Delta Agricultural Diversion Evaluation Summary Report, 1993 - 1995

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Technical Report 61
June 1998

Interagency Ecological Program for the San Francisco Bay/Delta Estuary

A Cooperative Program of:

California Department of Water Resources
State Water Resources Control Board
U.S. Bureau of Reclamation
U.S. Army Corps of Engineers
California Department of Fish and Game
U.S. Fish and Wildlife Service
U.S. Geological Survey
U.S. Environmental Protection Agency
National Marine Fisheries Service

Acknowledgements

This report represents an interagency effort by many people. Leo Winternitz (DWR) directed the study from 1992 through 1996. Members of the Interagency Ecological Program Delta Agricultural/Municipal Diversion Evaluation Project Work Team provided project guidance in 1994 and 1995, and reviewed drafts of all reports. Paul Raquel (DFG) and his staff, Spencer Kawasaki, Suzanne DeLeon, and Bill Harrell provided technical advice and services in developing and producing the sampling gear, and in study design and field sampling.

Lead Investigators were Stephani Spaar (DWR) in 1993, Stephani Spaar and Tracy Woods (DWR) in 1994, and Tracy Woods in 1995. Katie Wadsworth (DWR), Suzanne DeLeon (DFG) and Tracy Woods acted as field project leaders between 1993 and 1995. Field crewpersons included Angela Colagross-Schouten, Marci Booth, Teresa MacColl, Lauren Buffaloe, Debbie McEwan, Pam Casselman, and Rory Fagan (all of DWR) and Bill Harrell of DFG and later DWR. Ron Lundsford, Pam Casselman, Eric Santos and Lloyd Brenn of DWR, and Bob Farrell, and Mike Silva of DFG conducted channel sampling. Dr. Johnson Wang provided expertise in the processing and identification of fish eggs, larvae, and juvenile fish.

Lizette Cook completed a re-analysis of the compiled data and substantially revised the body and tables of the report based on this re-analysis. The authors thank Kevan Urquhart (DFG), Larry Brown (USBR), Stephani Spaar (DWR), Erin Sauls (USFWS), Jerry Morinaka (DFG), Spencer Kawasaki (DFG), Matt Nobriga (DWR), and Paul Raquel (DFG) for their comments on earlier drafts of this report.

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Introduction

Approximately 2,200 agricultural diversions with maximum flow rates of up to 250 cubic feet per second (cfs) occur within the Sacramento-San Joaquin Delta (Raquel pers. comm.). Diversions are active mostly during the agricultural season, generally occurring from late March or early April through September when water is needed for spring and summer crops (Brown 1982).

The length of the season, however, varies from year to year depending on rainfall and crop type. Diversions may also occur at other times of the year. For example, during fall and early winter, water may be diverted to leach salts from soils, break down post-harvest corn stubble, and flood land to attract waterfowl. During winter, water may also be diverted for winter wheat, and in drought years, for perennial crops including orchards and vineyards.

During the agricultural season, in-delta diversions may collectively transfer water at an estimated mean monthly rate of 2,000 to 5,000 cfs from delta channels (Brown 1982). These diversions are located in some sections of rivers and waterways used by migratory and resident fish, including endangered and threatened species such as winter-run chinook salmon (*Oncorhynchus tshawytscha*) and delta smelt (*Hypomesus transpacificus*).

Major crop irrigation coincides with the season when most fish are migrating and/or reproducing, and, therefore, when large numbers of larval, juvenile and adult fish are present in delta channels. Most agricultural diversions are not screened and losses due to entrainment may be a significant cause of the decline in abundance of some Delta fish. Potential factors influencing the rate and magnitude of fish entrainment in agricultural diversions are presented in Table 1.

Most small diversion intakes are situated two to three feet above the river bottom (Allen 1975). Species and/or life stages of species that tend to orient themselves near the bottom of the channel are potentially more susceptible to entrainment in these diversions than midwater or surface-oriented species. However, benthic species (e.g., sculpins (Cottidae) and gobies (Gobiidae) may not be highly susceptible to entrainment if they use the boundary layer as a velocity refuge or can hold on to the substrate with specialized body parts (Urquhart pers. comm.).

In other species, where vertical distribution may vary both temporally and spatially, susceptibility to entrainment may also vary. Young salmon in the Sacramento River system, for example, may occur near the surface (Hatton 1940; Hallock and Van Woert 1959; Sasaki 1966) but have been reported to migrate at greater depths as the season progresses and as they move down the estuary (Gritz and Stevens 1971). Within the delta, the distribution of young salmon in the water column may also vary at night (Wickwire and Stevens 1971).

Concerns about agricultural diversion impacts to delta fish populations prompted fish screening requirements under three sections of the California Department of Fish and Game (DFG) Code Division 6, Part 1, Chapter 3, Articles 3, 4 and 5 comprised of DFG Code Section 5930 B 6100. Covered in the code are requirements for diversions over 250 cfs (Section 5980), diversions under 250 cfs (Section 6020) and diversions installed after January 1, 1972 (Section 6100).

In 1992, the Interagency Ecological Program for the Sacramento-San Joaquin Estuary (IEP) initiated The Delta Agricultural Diversion Evaluation to investigate the effects of in-delta diversions on resident and anadromous fish. Portions of the evaluation were required under the U.S. Army Corps of Engineers permit (No. 199101051, effective March 30, 1992) for the Southern Delta Temporary Barriers

Project and the Delta Smelt Study Plan (Sweetnam and Stevens 1991). Overall, the study goal was to obtain information about fish entrainment in delta agricultural diversions that could assist in the evaluation of projects designed to reduce entrainment.

Such projects could include plans to consolidate and/or screen agricultural diversions or to modify water use patterns of in-delta agricultural diversions. Study objectives were: (1) to develop reliable means of estimating fish entrainment; (2) to evaluate entrainment losses of resident and migratory fish species at several agricultural diversion sites; and (3) to determine the susceptibility of fish species to entrainment relative to their abundance and life stages in adjacent delta channels.

A pilot study for the Delta Agricultural Diversion Evaluation was conducted by the California Department of Water Resources (DWR) in 1992 (Spaar 1994). This report presents the results obtained from the program during the years 1993, 1994 and 1995.

Methods

Description of Diversion Sites

Sampling focused on the collection of eggs, larvae, juvenile and adult fish. The number of diversions sampled varied across years. Five sites (1, 2, 2B, 4, and 10) in the south and west delta were sampled in 1993 (Figure 1). Four of those (Sites 1, 2, 4 and 10) were sampled in 1994 and three (Sites 1, 2, and 4) in 1995. Sites were numbered sequentially from 1 through 4.

Site 10 was numbered arbitrarily so as to leave site numbers available for possible additional study locations in the south delta. Site 2B was originally an alternate site for Site 2. Site 3 was included in the pilot study of 1992 (Spaar 1994) but was then dropped from the program.

Site 1 was located in the west delta on Twitchell Island (Reclamation District 1601). The diversion consisted of a 16-inch siphon that draws water from the San Joaquin River. The diversion is not normally active during the irrigation season, but was operated intermittently for purposes of this study, except in 1994, when the farmer used some of the diverted water to irrigate about 350 acres of corn for a few days (Beck pers. comm.). A propeller flowmeter (Ketema McCrometer model M0300) with flow indicator (in cfs) and totalizer (in acre-feet (af)) was installed on the siphon in 1993 to record velocity and sample volume measurements. The maximum flow capacity from this diversion was approximately 22 cfs but actual flows were typically less than this, varying over time.

Sites 2 and 2B were located in the south delta on the eastern side of Bacon Island (Reclamation District 2028). During the study, these two siphons diverted water from the Middle River into a ditch to irrigate about 350 to 380 acres of potatoes, as well as several acres of corn and sunflower (Campbell pers. comm.).

From April through October, a 16-inch siphon (Site 2) diverted water continuously 24 hours a day. A 14-inch siphon (Site 2B) diverted additional water when needed or when the larger siphon needed repairs. Diversions, therefore, were not continuous at this site. Maximum flow capacity for the 16- and 14-inch siphons was approximately 22 and 17 cfs, respectively, though actual flows were variable and typically lower. Propeller flowmeters (Ketema McCrometer model M0300) were installed in both siphons on May 4, 1992.

Site 4 was located in the south delta, within the Naglee Burk Irrigation District, south of Fabian Tract on Old River. A 30 horsepower pump diverted water from Old River through a 20-inch intake pipe at up to 20 cfs into a concrete distribution box. The box distributed water to the south or east to alfalfa and corn fields. During this study, water was diverted intermittently from May through August; however, the pump was frequently shut down for periods of several days. A flowmeter (Ketema McCrometer model M0300) was installed on the discharge line on September 4, 1992.

Site 10 was located in the east delta on Bouldin Island (Reclamation District 756). The two 24-inch siphons diverted water intermittently off the South Fork of the Mokelumne River to corn and wheat fields. During sampling from June through August 1993, a flowmeter (Marsh-McBirney, Inc. model 2000) was placed directly in the water flow at the mouth of the sampling net.

This site was intended primarily as a sampling site for concurrent efforts by DFG—also to evaluate diversion impacts on delta fish. It was sampled a total of 6 days in the latter portion of the season by DWR and DFG personnel. Because the sample size is small and temporal comparisons could not be made with other sites, data from Site 10 is presented separately in Appendix A. More substantial data from this site (and others) is reported elsewhere (DeLeón 1994; Griffin 1993).

Description of Channel Sites

Three delta channel sites, located in the vicinity of diversion Sites 1, 2, and 4, were also sampled. The sites were coded after DFG Egg and Larval Survey sampling stations. They included Site 49 located on the San Joaquin River at Oulton point adjacent to the Twitchell Island diversion (Site 1), Site 932 on Middle River near the Bacon Island diversions (Sites 2 and 2B), and Site 93 on Old River near the Naglee Burk diversion (Site 4) (Figure 1).

Categorization of Fish by Length

A length criterion was developed to compare entrainment susceptibility between fish. Delta smelt, one of the primary species of special concern for this study, was used as a model to distinguish fish able to pass through a certain net mesh size from those unable to. By 30 mm TL delta smelt are in juvenile stages (ie. when young take on the appearance of the adult) (Wang 1986)). Thirty mm Delta smelt are retained by a 3 mm mesh net (Young and Cech 1994).

From these observations it was determined, for purposes of this study, that fish measuring 30 mm TL and above would be classified as later-life stage fish and those under 30 mm TL would be classified as early-life stage fish. Note, however, that because different species exhibit substantial size variability and morphology at different life stages, not all life stages of some species can accurately be classified under the conditions of these length criteria.

Diversion Sampling for Early-life Stage Fish using an Egg and Larval Net

A 2.4 m egg and larval net made of 505 micron nylon mesh with a 0.3 m2 opening was used to collect early-life stage fish. At all diversion sites, the net was mounted on a plastic pipe frame and staked in the ditch a few feet downstream of the area of turbulent flow. Therefore, only a portion of the total volume of water diverted was sampled. It was assumed that early-life stage fish were uniformly distributed in the water column. A flowmeter (General Oceanics model 2030) was mounted in the mouth of the net to estimate the volume of water sampled in cubic meters. These measurements were later converted to acre-feet.

Water temperature (in degrees Fahrenheit) and electrical conductivity (in microSiemens per cm) were recorded with each sample. Fish were collected in a 0.95 liter collecting jar, screened with 470 micron wire mesh attached to the cod end of the net. Sampling periods were approximately five to ten minutes depending on debris load. Total sampling effort varied across sites and years (Table 2). After collection, the samples were transferred to 0.95 liter storage jars.

A solution of 5 percent formalin was used to preserve the specimens for later identification by an independent contract laboratory. Rose bengal dye was added to increase specimen visibility. Eggs and larvae were counted and identified to species. Striped bass eggs were recorded as dead, in morula, or in early- or late-embryonic stages. Larval fish were identified to species, though in some cases, they were only identified to genus or family. Larvae were measured to the nearest tenth of a millimeter total length (TL). Delta smelt and striped bass measurements were also recorded in standard length (SL).

Sampling days were planned for approximately two days per week but varied substantially over time, infrequently approximating this schedule except during several periods at Site 2. At all sites, but particularly at Sites 1 and 4, total sampling effort was frequently less than one 10-minute sample per week. All diversion sites were sampled for eggs and early- and later-life stage fish in 1993.

Sampling effort across years varied substantially and was comparable only at Site 2. Sampling at Site 1 for eggs and early-life stage fish was limited in 1993 and 1994 due to persistent silt loading within the diversion causing destruction of eggs and early-life stage fish. For this reason sampling was discontinued after May 12, 1994. Sampling at Site 2B did not occur in 1994 or 1995 because that siphon was not operated in those years. Sampling for early-life stage fish was not conducted at Site 4 in 1994 or 1995.

Diversion Sampling using a Fyke Net

A 7-m fyke net made of 3.2 mm nylon mesh was used to collect later-life stage fish at Sites 1 and 2. This net also collected many early-life stage fish. Sampling frequency varied from one to two days per week to once per month. A wooden live box was attached to the end of the net. The mouth of the fyke net was attached as close to the mouth of the diversion as possible in an effort to sample 100 percent of the outfall. At Site 2, 100 percent of the outfall was passed through the fyke net.

At Site 1, it was not possible to capture the entire outfall due to the architecture of the diversion. Furthermore, the live boxes at both Sites 1 and 2 were too heavy to lift when full. Therefore, prior to lifting them, some of the water was drained out and during this time fish may have escaped. For these reasons, the actual proportion of the fish captured is unknown.

At Site 4 the 7-m net could not be used due to the unique size and shape of the outfall. Instead, a 4.9-m fyke net was used. This net was made of 3.2 mm mesh with 2.7 m flanked wings and a nylon 3.2 mm (one-eighth inch) mesh live box at its end. The net was positioned as close as possible to the mouth of the outfall to sample most of the flow. Sandbags also were placed along the bottom edges of its frame and wings to discourage fish from escaping from the net. The distance of the net from the mouth of the outflow varied and was never adequate to capture 100 percent of the outfall. The proportion of outfall sampled, therefore, is unknown.

The fyke nets were generally deployed for three to six hours during each sampling period. Occasionally, longer sampling periods were conducted (up to 24 hours) to provide data for comparing day and night catches. Fish were collected from the live boxes every one to two hours, transferred to 0.95 liter storage jars or 20 milliliter vials depending on the size of the fish, and preserved in 5 percent formalin.

Despite variations across sites, the sampling effort using the fyke net was substantially greater than the effort for sampling early-life stage fish in the diversions using the egg and larval net (Tables 2 and 3).

Simultaneous Channel and Diversion Sampling

On seven days in 1994, sampling was simultaneously conducted in the channels and at two nearby diversion sites. Sampling for early-life stage fish was conducted using an egg and larval net in both the channels and diversions. Sampling for later-life stage fish was conducted using a fyke net in the diversions and either a townet or a midwater trawl in the channels.

The townet consisted of a 4 m net made of 1.3 cm stretch nylon mesh. The midwater trawl was made of nine 1.5 m sections, which graduated in mesh size from 20.3 cm at its mouth to 1.3 cm at its cod end. The net measured 18 m with a 3.7 m2 mouth opening. Early-life stage fish were simultaneously sampled at Sites 2 and 932 on May 5, 1994. Later-life stage fish were simultaneously sampled at Sites 2 and 932 on July 7, 1994 and at Sites 1 and 49 on July 11, September 29,October 5 and October 17, 1994. No simultaneous sampling for early-life stage fish was conducted at Site 1 due to silt loads in the diversion. No simultaneous sampling of either early- or later-life stage fish was conducted at Site 4 due to placement of a temporary barrier within the channel that prevented boat access to the channel site.

Townet gear was used in the channel at Site 49 on July 11, 1994 and at Site 932 on July 7, 1994. Midwater trawl gear was used at Site 49 on the remaining days that simultaneous sampling was conducted (May 11, September 29, October 5 and October 17, 1994). Mesh sizes differed between gears used to capture later-life stage fish. For example, mesh size of the townet was 2.46 times larger than that of the fyke net. Mesh sizes of the midwater trawl nets were up to 6,344 times larger than that of the fyke net. These substantial differences must be considered when reviewing the capture results as catch efficiency and mean lengths of fish captured may vary significantly across gear types (Rozas and Minello 1997).

The water volume applied to the townet data was 0.596 af per tow. This is the amount estimated by the U.S. Fish and Wildlife Service (USFWS) for a 10 minute townet sample using a similarly sized net. Water volumes sampled by the midwater trawl were calculated using the formula totalmeter x area x k, where totalmeter equals the number of revolutions from a flowmeter (General Oceanics Model 2030) attached to the net, area equals the area of the mouth of the net (13.69m^2), and k is a constant (26873/999999) which converts flowmeter revolutions to distance in meters.

Regardless of tidal stage or net type, nets were deployed in oblique tows in the channels for either five or ten minutes. All fish collected were identified to species (where possible), counted, and measured to the nearest millimeter TL. Those fish that could not be identified in the field were preserved in five-percent formalin and sent to an independent contract laboratory for identification. Water velocity (in cfs), volume sampled (in af), temperature (in degrees Fahrenheit) and electrical conductivity (in microSiemens per cm) were also recorded at the time diversion and channel samples were collected.

Additional Channel Sampling

Channel sampling that was not simultaneous with diversion sampling was also conducted. This data is provided as a qualitative demonstration of how catch results can vary over time and space. Note that variation in catch results, however, is also gear dependent and gear efficiencies can vary substantially (Rozas and Minello 1997). Additional channel sampling was conducted at Sites 49, 93 and 932 for early-life stage fish each year between 1993 and 1995 using a 505 micron egg and larval net (Appendix B).

In 1993, Channel Sites 49 and 932 were sampled by midwater trawl for later-life stage fish on two days in late August, by townet on seven days during summer months, and by otter trawl on one day in late September (Appendix C).

Data Treatment

Net efficiencies within the diversions were not determined. Therefore, neither the fyke net nor the egg and larval net's effectiveness in collecting different sized fish from the diversions is known. Lack of knowledge about net efficiencies and the rate of net avoidance by fish both affected the ability to estimate total entrainment. For these reasons, only catch per unit effort (CPUE) (the number of fish captured per af of water sampled) is reported. Note that CPUE represents minimum capture rates. Due to inherent, but unquantified gear variability, combined with site-specific habitat differences, catch and CPUE reported from the diversions should only be compared within sites.

Efficiencies for the townets and midwater trawls used in the channels were also not determined. However, these channel sampling methods are known in general to have low efficiency and high variability (Rozas and Minello 1997). Therefore CPUE reported from the channel samples is only useful for indicating some of the species present in the channels and their relative abundance with respect to capture rates. Because of habitat variation across time and space, and behavioral variation among fish species and life stages, relative within sample abundances probably varied across time and location, and are, therefore, not comparable.

For each diversion site CPUE, calculated from samples collected during the day, were compared with those collected at night. If sampling began after sunset but before sunrise, the sample was termed a "night" sample. If sampling began between sunrise and sunset, the sample was termed a "day" sample.

The two groups were analyzed using a t-test for dependent samples to determine if there was a significant difference between CPUE. A p-value of less than or equal to 0.05 was chosen as the determining criteria. Note however that this analysis too was conducted under the assumption of low variability in gear efficiency.

Diversion Sampling for Early-life Stage Fish using an Egg and Larval Net

Data collected from Sites 1, 2B, and 4 were not analyzed because of small sample sizes and unequal effort across sites (Table 2), but are presented separately in Appendix D.

Total CPUE at Site 2 varied across years from 792.5 in 1993 to 144.6 in 1994 to 547.0 in 1995 (Tables 5 - 7). Catch per unit effort for individual species also varied (Tables 5 - 7). In 1993 threadfin shad and bigscale logperch were the two most abundant species captured. Prickly sculpin and shimofuri goby were the most abundant species captured in 1994. In 1995 threadfin shad and centrarchids were the most abundant fish captured. The total number of taxa recorded was 8 in 1993, 7 in 1994 and 5 in 1995. In 1993, five early-life stage delta smelt were recorded (Table 5). No early-life stage chinook salmon, longfin smelt or splittail were recorded.

Length frequency distributions were somewhat similar across years (Figure 2). Median standard lengths were 6 mm in 1993 and 1995 and 8 mm in 1994. Distributions in all years were skewed towards smaller sizes.

Diversion Sampling using a Fyke Net

More than ninety percent of fish captured at Sites 1, 2, and 4 during the study period were early-life stage size (Tables 8-10). As a result, catch per unit effort of later-life stage fish was substantially less overall than for early-life stage fish. At Sites 1 and 2, CPUE was also relatively more consistent across years (Tables 8-10). Less than 1 fish total was recorded per af of water sampled at any site each year. Total CPUE was highest at Site 1 in all years except in 1993. That year, CPUE at Site 1 was equal to that at Site 4. CPUE of all fish also appeared to vary somewhat across years and sites but small observed numbers of later life-stage fish, uncertain gear efficiencies, and spatial variability do not permit statistical comparisons.

The observed number of species of later-life stage fish varied across diversion sites. However, within sites, the total numbers of species remained relatively consistent between years (Tables 8 – 10). The total number of species captured was greatest at Site 1. At least 15 species were captured at Site 1 per year, compared to at least 7 at Site 2, and 5 each year at Site 4.

One chinook salmon was recorded at Site 1 in 1994 and 1995 (Tables 9–10). Lengths were 90 and 105 mm TL respectively (Figure 3). At Site 1, four later-life stage delta smelt measuring 30 to 36 mm TL were recorded in 1994 (Table 9 and Figure 3). In 1995 one splittail measuring 52 mm TL was recorded at Site 2 (Table 10 and Figure 4). Catch per unit effort of later-life stage striped bass ranged from 0.02 to 0.04 at Site 1, and 0 to 0.1 at Sites 2 and 4 (Tables 8–10).

Later-life stage fish observed in relatively higher densities at Site 1 were mosquitofish (CPUE = 0.15) and inland silversides (0.08) in 1993 (Table 8), yellowfin gobies and shimofuri gobies (CPUE = 0.15 and 0.12 respectively) in 1994 (Table 9) and threadfin shad (CPUE = 0.09) in 1995 (Table 10). At Site 2, these were yellowfin gobies (CPUE = 0.07) in 1993 (Table 8), white catfish and shimofuri gobies (CPUE = 0.04 and 0.04 respectively) in 1994 (Table 9) and bluegill (CPUE = 0.05) in 1995 (Table 10). At Site 4, highest observed densities were of threadfin shad and white catfish (CPUE = 0.31 and 0.17 respectively) in 1993 (Table 8), prickly sculpins and white catfish (CPUE = 0.02 and 0.02 respectively) in 1994 (Table 9) and white catfish (CPUE = 0.17) in 1995 (Table 10).

Sixteen fish were recorded at Site 2B in 1993. Fourteen were early-life stage fish, including shimofuri goby, yellowfin goby, striped bass, threadfin shad and centrarchids. The others were two later-life stage fish, a yellowfin goby and a shimofuri goby.

Length ranges of later-life stage fish within sites were somewhat similar between years (Figures 3–5). Length ranges at Site 1 were 30 to 390 mm TL in 1993, 30 to 330 mm TL in 1994 and 30 to 334 mm TL in 1995 (Figure 3). At Site 2, fish measured 30 to 347 mm TL in 1993, 30 to 335 mm TL in 1994 and 30 to 265 mm TL in 1995 (Figure 4). Length ranges at Site 4 were 30 to 170 mm TL in 1993, 31 to 250 mm TL in 1994, and 30 to 140 mm TL in 1995 (Figure 5).

Simultaneous Channel and Diversion Sampling

Species recorded from simultaneous sampling appeared to differ between the channel and diversion. At least seven species of early-life stage fish were collected in the channel (Site 932) compared to two in the diversion (Site 2) (Table 11). Prickly sculpin was most common (CPUE = 67.1) in the channel followed by shimofuri goby (CPUE = 65.2) and striped bass (CPUE = 28.0). Two delta smelt (CPUE = 1.0) were also collected in the channel. Two prickly sculpin and two bigscale logperch (CPUE = 12.0 each) were observed in the diversion. Median body lengths were similar (7 mm TL) for fish collected at both sites (Figure 6).

Length range, number of species and total number of later-life stage fish captured during simultaneous sampling differed between the channel (Site 932) and diversion (Site 2). Seven species measuring 24 to 89 mm TL were observed in channel samples (Table 12 and Fig.7). Striped bass was most common in the channel followed by catfish. Data was not available to calculate CPUE for channel samples.

Of the six species observed during simultaneous sampling at Sites 1 and 49 on July 11, 1994, five were observed in channel samples compared to four in the diversion (Figure 8). Threadfin shad had the highest relative capture rate in the diversion but were not captured with the townet in the channel. Fish collected with the townet measured 26 to 66 mm TL. Fish captured in the diversion measured 16 to 34 mm TL.

Species captured showed little overlap between the channel (Site 49) and the diversion (Site 1) when midwater trawl gear was used in the channel. Species observed in the diversion were not observed in the channel, with the exception of threadfin shad on September 29 and October 5, 1994 and striped bass on May 11, 1994 (Table 13). On September 29, October 5, and October 17, 1994, when capture of American and threadfin shad was relatively high in channel samples, observed entrainment of this species in the diversion was relatively low.

Species compositions at Site 49 appeared to vary seasonally (Table 13). For example, delta smelt, prickly sculpin, yellowfin goby and ictalurids were only captured in May. Chinook salmon and cyprinids were captured in the channel in May, September, and October. Threadfin and American shad and shimofuri gobies were only captured during September and October. Simultaneous sampling, however, only occurred on one day in May, July and September and on two days in October. Because of these small sample sizes, no valid conclusions can be drawn about seasonal variation of species composition in the diversion at Site 1.

During simultaneous sampling using the midwater trawl, the relative magnitude of catch per unit effort at Sites 1 and 49 varied across months. On May 11, 1994 CPUE was greater for all species captured in the diversion than in the channel (Table 13). On the other three days, CPUE was generally higher for fish captured in the channel.

There was little overlap in body length between fish captured in the channel (Site 49) by midwater trawl and those caught at diversion Site 1 (Figures 9-12). Fish caught in the diversion tended to be smaller. This is, however, most likely a consequence of the small mesh size used in the diversion.

On two days, measurements of fish caught in the channel were mistakenly recorded in fork length (Figures 9 and 12) indicating that the size overlap would have been less had total length been measured. Of the larger fish observed in the channel, four were chinook salmon, two were striped bass and one a carp. The larger fish observed in the diversion included one largemouth and three striped bass. One delta smelt (23 mm TL) was caught at Site 1 during simultaneous sampling on May 11, 1994 (Figure 9).

Day and Night Fish Density Comparisons

Catches of entrained early-life stage fish were not significantly different between day and night samples collected at Site 2 in 1994 and 1995 ($p \geq 0.05$) (Table 14). An insufficient number of paired samples ($n \leq 2$) from Site 1 in 1993 and 1994 precluded diurnal comparison of entrainment densities of early-life stage fish at that site.

In contrast, sampled densities of later-life stage fish were significantly greater at night than during the day at Site 2 in 1993 and 1995 ($p \leq 0.05$), and at Site 1 in 1994 ($p \leq 0.01$) (Table 14). Note however that under an assumption of high potential gear efficiency variability, these results could differ.

Seasonal Entrainment

Total species numbers were largest from May through August, when the vast majority of sampling effort occurred (Table 15). Sampling intensity was, however, also proportionately greater in those months. No sampling was conducted from February through March in any year. The period between November and January was only sampled from November 1993 through January 1994.

Discussion

Quantitative estimates of site specific fish entrainment were not accomplished largely because of insufficient sampling over the irrigation period, a result of staff and equipment limitations and lack of cooperation from diversion operators. In addition, most sampling occurred during daylight hours though diversions were continuously active for several days at a time. While generally higher fish densities collected at night from Sacramento-San Joaquin delta diversions have been observed elsewhere (e.g., Pickard et al. 1982), the small amount of nighttime sampling in this study precluded conclusions about daytime versus nighttime entrainment. Because of this, no point estimates of daily entrainment were obtained either.

The results of this study do, however, suggest that small-scale diversions within the Sacramento-San Joaquin delta can entrain a large diversity of fish species, at least from May through August, when young-of-year (YOY) of many species are present. Furthermore, the actual number of entrained fish can be large. Because the period of high YOY abundance overlaps with the principal agricultural season, substantial numbers of fish may be lost to irrigation operations each year.

The results also tend to suggest that small, unscreened diversions may entrain a greater number of smaller than larger fish. Similar results were also reported from this program's pilot study (Spaar 1994). Speculatively, fish in early-life stages may become entrained in higher densities than later-life stage fish for several reasons. Larval fish can potentially be more abundant in adjacent channels than older fish in areas of high spawning success. Additionally, the seasonal timing of active diversions often coincides with periods of high abundance of eggs and larvae in adjacent channels (Miller pers. comm.)

Early-life stage fish may also be more vulnerable to entrainment because of under developed swimming ability. For example, because young striped bass under 17 mm standard length are poor swimmers, they are likely entrained more often than larger striped bass (Allen 1975). Note, however, that because the sampling methods used in this study to collect larger fish were not entirely efficient, comparisons of the relative numbers of larger and smaller numbers of fish are not valid.

Catch Per Unit Effort calculations derived from this study tend to suggest that relatively higher numbers of bottom oriented fish and relatively lower densities of special status species like chinook salmon and delta smelt were entrained. The larger numbers of bottom oriented species observed in this study may reflect increased vulnerability during epibenthic foraging (Urquhart pers. comm.). The sampling regime of this study, however, was not sufficiently consistent to confidently identify relative densities of fish species entrained.

Because actual channel densities of fish are not known, it is impossible to separate density effects from behavioral and life stage effects contributing to entrainment vulnerability. The large numbers of threadfin shad entrained at times demonstrate the potential for entrainment of surface oriented species. Failure to observe many individuals of species such as salmon and delta smelt may therefore have been a consequence of small sample sizes, species distribution patterns during the sampling period, and/or species specific behavior.

The virtual lack of overlap in species observed between the channels and diversions from simultaneous sampling efforts suggest that results from midchannel sampling cannot be used to predict those species most likely to be entrained or the total number of fish lost to entrainment. This is most likely because habitats, and therefore species compositions, vary between mid channel and near shore locations. Mid-channel species and life-stages may therefore not be expected to occur as often in diversions. For example, American shad, a midchannel species, was regularly collected from the channels, but rarely from the diversions. The substantial differences in gear types and net mesh sizes used, however, could also account for part of the variation in species observed between channel and diversion sites.

It is not presently possible to identify the proportional effect of the impacts agricultural diversions have on resident and migratory delta fish. This is due mainly to our inability to quantify population sizes and demographics in an open and highly variable system like the Sacramento-San Joaquin delta. Because we lack this information, we cannot relate data from fish captured in diversions to population level effects on species in the system. Furthermore, because environmental variables, such as outflow and water quality, which affect fish distributions, change over time, and because fish behaviors are complex and variable, the ability to predict future impacts does not exist.

Near shore sampling with the goal of determining species presence could potentially be accomplished. Such efforts, however, should not occur simultaneously with diversion sampling as this could effect behavior of the fish and thereby entrainment. Because channel sampling is generally characterized by low and highly variable efficiencies (Rozas and Minello 1997), fish density comparisons between channels and diversions, as well as entrainment density estimation, based on channel sample observations, will be a challenge for future studies.

Through this study we have gained a broader understanding of the difficulties involved with assessing fish entrainment in agriculture diversions. A combination of variable study design and sampling methodology, and small sample sizes, brought about, in part, by uncontrollable confounding events, precluded achievement of one of this study's objectives - to evaluate entrainment losses of resident and migratory fish species at several agricultural diversion sites.

The difficulties associated with accomplishing the study's other objectives - to develop reliable means of estimating fish entrainment, and to determine the susceptibility of fish species to entrainment relative to their abundance and life stages in adjacent Delta channels - are also now better understood. Because channel habitat varies over time and space throughout the Delta, high spacio-temporal variability of channel species composition and densities must be assumed. The data in Appendix C indicates such variability within the channel sites included in this study. As a result, reliable extrapolation of entrainment measures from a sampled diversion to another site separated by time or location is not possible.

Fortunately, some of the difficulties encountered during this study can be reduced in future ones. To do so, a concise, detailed set of objectives must be prepared along with a thorough analysis of their attainability, followed by careful planning and implementation.

Recommendations

A sufficient body of information, required for the development of management plans for small agricultural diversions in the delta, was not produced by this study. Further procedures and evaluations are suggested which should provide the basis for better decision making. Recommendations include altering study objectives to produce a higher expectation of accomplishment, continuing discussion between knowledgeable persons, and creating well planned studies to address specific questions. Recommendations are as follows.

- Omit the goal of extrapolating species likely to be entrained, and total entrainment estimates of fish, from sampled to unsampled diversions unless studies involve statistically determined adequate sample sizes of diversions across all water year types. This would be a lengthy project, involving many years and considerable expense.
- Conduct a thorough literature review including studies from other geographic regions.
- Plan a forum for discussion within a Project Work Team or a special colloquium about:
  (1) relationships of sampling results between channels and diversions.
  (2) methods for sampling channels and diversions that would increase data reliability.
  (3) methods for simultaneously sampling channels and diversions.
  (4) possible means of modeling entrainment losses at unsampled diversions based on results from sampled diversions separated by space and/or time.
- Continue studies to assess the relative magnitudes of entrainment at unscreened agricultural diversions and the patterns of daily, seasonal, and annual loss of fish.
  (1) Identify clear obtainable study objectives and focus, define and outline questions in scientific form.
  (2) Define adequate study designs and methodology prior to initiating field investigations. Data should be subjected to statistical analysis.
  (3) Previous studies within the Sacramento-San Joaquin delta (e.g., Spaar 1994, Wadsworth 1998), designed to evaluate fish entrainment in agricultural diversions have been conducted on limited geographical scales. Consequently the present body of information is inadequate for planning and management purposes. Studies should be conducted over a broader geographical region. This would provide more reliable data about species vulnerability to entrainment overall and better identify factors associated with entrainment. Study sites should be chosen where factors limiting appropriate study design and methodology are minimized.
    - Locate study sites where diversions have operational frequency sufficient to enable at least eight sampling days per month from April through August.
    - Ensure that communication and cooperation with site managers is established and maintained, permitting ready site access and notice of diversion operation.
    - Ensure adequate staff and equipment allocation to meet sampling protocol including minimum sample size requirements.
- Design and conduct additional studies that would qualitatively assess potential differences in the magnitude of entrainment of total numbers, life stages and species between screened and unscreened diversions. Studies should include delta

diversions where side by side intakes serve as experimental and control treatments. Data from both screened and unscreened intakes allow numerical estimation of the types, sizes and abundances of fish excluded from diversions by screens and how these differ across seasons. See Appendix E for results of an earlier study of fish entrained by a screened versus an unscreened agricultural diversion. Such studies also serve as further means of evaluating the effectiveness of screens installed on intakes for mitigation purposes. Limitations would still include the inability to extrapolate results between years or across sites. Calculated estimates could, however, indicate trends in annual entrainment and identify specific sites where mitigation efforts to reduce or avoid entrainment would be most beneficial. Features of such a study should include the following:

(1) Site locations should be chosen where the occurrence and relative abundance of fish in adjacent channels in known to be great. This is important because fish entrainment, theoretically, is, at least in part, a function of channel density.

(2) Residence times of species of concern should coincide with the primary irrigation season.

(3) Diversions should have high operation frequency.

(4) Diversions should be active throughout the primary irrigation season.

(5) Sites should have at least two side by side diversions.

(6) Sites must be accessible for sampling.

(7) Sites must have a source of power on site or the installation of power must be possible.

(8) Intake screening should be feasible.

(9) At least one diversion at a site should be screened and at least one left unscreened.

(10) Sampling should be conducted at least twice per week, if not more often.

(11) Sampling should include equally weighted random sampling during day, night and crepuscular periods.

(12) Sampling methods should ensure that 100 percent of the diversion outfall is strained during each sampling period.

(13) Samples should be collected at each site during those months in which agricultural diversions are potentially operating.

(14) Sampling should be conducted over at least a three-year period at each site.

(15) Data from existing delta channel surveys (e.g., DFG's Global Positioning System data (related to the delta agricultural diversion inventory), resident fishes survey, midwater trawl survey, townet survey, and egg and larval survey, USFWS's salmon trawling and beach seine survey, and DWR's egg and larval survey) can be used to determine fish occurrence to the extent that the data is useful.

- A companion laboratory study should be designed to compliment field work by addressing questions difficult to investigate in the field. Such a laboratory study should examine:

(1) density effects on entrainment.

(2) species and life-stages most vulnerable to loss through impingement on diversion screens.

References

Allen, D. H. 1975. Loss of striped bass (*Morone saxatilis*) eggs and young through small, agricultural diversions in the Sacramento-San Joaquin Delta. California Department of Fish and Game, Anadromous Fisheries Branch Administrative Report No. 75-3.

Brown, R. L. 1982. Screening agricultural diversions in the Sacramento-San Joaquin Delta. Available from the California Department of Water Resources, Environmental Services Office, 3251 S Street, Sacramento, California 95618.

DeLeón, S. 1994. Striped Bass Stamp Fund agricultural diversions quarterly report, May - July, 1994. Available from the Department of Fish and Game, Bay-Delta Division, 4001 North Wilson Way, Stockton, California 95205.

Griffin, S. 1993. Monitoring of an unscreened agricultural diversion on the San JoaquinRiver at McMullin Tract, Public Notice No. 199200393, San Joaquin County, California, May-July 1993. Available from the Department of Fish and Game, Bay-Delta Division, 4001 North Wilson Way, Stockton, California 95205.

Gritz, W. J., Stevens, D. E. 1971. Distribution of young king salmon (*Oncorhynchus tshawytscha*) in the Sacramento River near Pittsburg. California Department of Fish and Game, Anadromous Fisheries Branch, 1416 9th Street, Sacramento, California 95616.

Hallock, R. J., Van Woert, W. F. 1959. A survey of anadromous fish losses in irrigation diversions from the Sacramento and San Joaquin Rivers. California Fish and Game Bulletin 45(4): 227-293.

Hatton, S. R. 1940, Progress report on Central Valley fisheries investigation. California Fish and Game Bulletin 26(4): 334-372.

Pickard, A., Baracco, A., Kano, R. 1992. Occurrence, abundance and size of fish at the Roaring River Slough intake, Suisun Marsh, California during the 1980-81 and the 1981-82 diversion seasons. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. Technical Report 3 (FF/bio-4ATR/82-82).

Rozas, L. P., Minello, T. J. 1997. Estimating densities of small fishes and decapod crustaceans in shallow estuarine habitats: a review of sampling design with focus on gear selection. Estuaries 20(1): 199-213.

Sasaki, S. 1966. Distribution and food habits of king salmon, *Onchorhynchus tshawytscha*, and steelhead rainbow trout, *Salmo gairdnerii*, in the Sacramento-San Joaquin Delta, pp. 108-114. In: Jerry L. Turner and D. W. Kelley (editors) Ecological Studies of the Sacramento-San Joaquin Delta, Part II. California Department of Fish and Game Bulletin 136: 1-168.

Spaar, S. A. 1994. Delta agricultural diversion evaluation - 1992 pilot study. Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary Technical Report 37.

Sweetnam, D. A., Stevens, D. E. 1991. Delta smelt study plan. Available from the California Department of Fish and Game, Bay-Delta Division, 4001 North Wilson Way, Stockton, California 95205.

Wadsworth, K. 1998. 1993 and 1994 Lakos Screen Evaluation. Available from the California Department of Water Resources, Environmental Services Office, 3251 S Street, Sacramento, California 95618.

Wang, J. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: a guide to the early life histories. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. Technical Report 9.

Wickwire, R. H., Stevens, D. E. 1971. Migration and distribution of young king salmon, *Oncorhynchus tshawytscha*, in the Sacramento River near Collinsville. Administrative Report No. 71-4. Available from the California Department of Fish and Game, Anadromous Fisheries Branch, 1416 9th Street, Sacramento, California 95616.

Young, P. S., Cech, J. J. 1994. Delta smelt (*Hypomesus transpacificus*) morphometry and its use for calculating screen mesh size and vertical bar interval. Available from the Department of Water Resources, Environmental Services Office, 3251 S Street, Sacramento, California 95618.

Personal Communications

Beck, Ron. Farmer, Twitchell Island. Conversations in 1994.

Campbell, Mark. Farmer, Bacon Island. Conversations in 1993 – 1995.

Miller, Lee. Senior Biologist, California Department of Fish and Game, Bay-Delta Division. Conversation on November 7, 1997.

Raquel, Paul. Fisheries Biologist, California Department of Fish and Game, Inland Fisheries Division. Conversations in 1996 and 1997.

Urquhart, Kevin. Senior Fisheries Biologist, California Department of Fish and Game, Bay-Delta Division. Conversation on January 7, 1998.

Tables 1-15

Table 1. Potential Factors Influencing the Rate and Magnitude of Fish Entrained in Unscreened Agricultural Diversions

Biological Factors

Life stage of the fish
Seasonal occurrence of fish in the source channel
Abundance of fish within the source channel
Distribution of fish within the source channel
Feeding behavior of the different fish species
Spawning behavior of the different fish species

Diversion Specific Factors

Seasonal timing of diversion operations
Frequency of diversion operations
Duration of diversion operations
Flow rate through diversion
Total volume of water diverted
Orientation of diversion in the channel
Depth of diversion in the channel

Environmental Factors

Time of day
Tidal change and current velocity
Turbulence
Channel bottom configuration
Turbidity
Type of local aquatic habitat (e.g. vegetated or unvegetated)

Adapted from Spaar 1994

Table 2. Summary of Diversion Sampling for Early-life Stage Fish Using an Egg and Larval Net, 1993-1995

	Site 1 Twitchell Island	Site 2B Bacon Island, 14" siphon	Site 2 Bacon Island, 16" siphon	Site 4 Naglee Burk
1993				
Sampling period	6/28 - 7/14	7/13 - 7/27	5/4 - 7/9	5/24 - 6/23
Number of days sampled	2	2	22	6
Total number of samples	2	7	100	9
Acre-feet sampled	0.019	0.043	1.045	0.232
1994				
Sampling period	1/19 - 5/12	N/A	4/26 - 7/8	N/A
Number of days sampled	5		21	
Total number of samples	6		78	
Acre-feet sampled	0.072		1.121	
1995				
Sampling period	N/A	N/A	5/30 - 7/11	N/A
Number of days sampled			11	
Total number of samples			20	
Acre-feet sampled			0.040	

N/A = site not sampled.

Table 3. Summary of Diversion Sampling Using a Fyke Net, 1993-1995

	Site 1 Twitchell Island	Site 2 Bacon Island, 16" siphon	Site 4 Naglee Burk
1993			
Sampling period	6/11/93 - 1/19/94	4/28 - 10/14	5/24 - 8/31
Number of days sampled	28	47	11
Total number of samples	122	228	38
Acre-feet sampled	143.16	257.30	191.10
1994			
Sampling period	4/27 - 10/17	4/26 - 8/2	6/1 - 8/30
Number of days sampled	28	31	11
Total number of samples	130	191	36
Acre-feet sampled	136.79	167.02	171.07
1995			
Sampling period	6/5 - 8/31	5/30 - 8/29	8/2 - 8/29
Number of days sampled	21	25	8
Total number of samples	44	51	12
Acre-feet sampled	202.53	199.81	130.22

Table 4. Summary of Simultaneous Diversion and Channel Sampling, 1994

Channel Gear/ Diversion Gear Channel Site/ Diversion Site	Sample Date	Sample Time	No. Channel Samples	No. Diversion Samples	Volume Sampled Channel (AF)	Volume Sampled Diversions (AF)
Egg and Larva Net/Egg and Larval Net						
Site 932 -Middle River/ Site 2 - Bacon Island	5/5	0500-1030	12	12	2.07	2.57
Townet/ Fyke Net						
Site 49 – San Joaquin River/ Site 1 - Twitchell Island	7/11	1630-2230	7	7	4.17	7.06
Site 932 - Middle River/ Site 2 - Bacon Island	7/7	1845-2345	9	9	5.36	7.27
Midwater Trawl/Fyke Net						
Site 49 - San Joaquin River/ Site 1 - Twitchell Island	5/11	1630-2230	8	8	42.61	3.77
Site 49 - San Joaquin River/ Site 1 - Twitchell Island	9/29	1504-2204	8	7	60.75	5.78
Site 49 - San Joaquin River/ Site 1 - Twitchell Island	10/5	0305-0805	6	6	52.36	6.03
Site 49 - San Joaquin River/ Site 1 - Twitchell Island	10/17	1417-2003	7	7	54.28	6.74

AF = acre-feet

Table 5. Catch and Catch Per Unit Effort of Early-life Stage Fish at Diversion Site 2 (Bacon Island 16-Inch Siphon) Using an Egg and Larval Net,1993

Species	Catch	CPUE
Delta smelt	5	5.0
Threadfin shad	479	458.4
Bigscale logperch	220	210.5
Shimofuri goby	38	36.4
Striped bass	54	51.7
Prickly sculpin	14	13.4
Centrarchidae	19	18.2
Cyprinidae	3	2.9
Total	**832**	**796.5**

CPUE = catch per unit effort = catch per acre-foot of water sampled.

Table 6 . Catch and Catch Per Unit Effort of Early-life Stage fish at Diversion Site 2 (Bacon Island 16-inch Siphon) Using an Egg and Larval Net, 1994

Species	**Catch**	**CPUE**
Striped bass	9	8.0
Yellowfin goby	0	0
Bigscale logperch	13	11.6
Prickly sculpin	78	69.6
Threadfin shad	19	17.0
Shimofuri goby	35	31.2
Centrarchidae	6	5.4
Cyprinidae	2	1.8
Total	**162**	**144.6**

CPUE = catch per unit effort = catch per acre-foot of water sampled.

Table 7. Catch and Catch Per Unit Effort of Early-life Stage Fish at Diversion Site 2 (Bacon Island 16-inch Siphon) Using an Egg and Larval Net, 1995

Species	Catch	CPUE
Threadfin shad	12	300.0
Bigscale logperch	1	25.0
Centrarchidae	7	175.0
Cyprinidae	1	25.0
Ictaluridae	1	25.0
Total	**22**	**550.0**

CPUE = catch per unit effort = catch per acre-foot of water sampled.

Table 8. Catch and Catch Per Unit Effort of Fish Captured in Diversions Using a Fyke Net, 1993

	Site 1 Twitchell Island				Site 2 Bacon Island				Site 4 Naglee Burk			
	Early-life Stage Fish		Later-life Stage Fish		Early-life Stage Fish		Later-life Stage Fish		Early-life Stage Fish		Later-life Stage Fish	
Species	Catch	CPUE	Catch	CPUE	Catch	CPUE	Catch	CPUE	Catch	CPUE	Catch	CPUE
Delta smelt	1	0.01	0	0.00	3	0.01	2	0.01	0	0.00	0	0.00
Striped bass	70	0.49	3	0.02	1787	6.94	0	0.00	1	0.01	1	0.01
American shad	0	0.00	3	0.02	0	0.00	0	0.00	0	0.00	0	0.00
Threadfin shad	331	2.31	7	0.05	1262	4.90	0	0.00	3842	20.10	60	0.31
Inland silverside	115	0.80	11	0.08	0	0.00	0	0.00	1	0.01	0	0.00
Prickly sculpin	0	0.00	2	0.01	76	0.30	0	0.00	0	0.00	0	0.00
Bigscale logperch	1	0.01	5	0.03	114	0.44	0	0.00	0	0.00	0	0.00
Yellowfin goby	4	0.03	8	0.06	465	1.81	19	0.07	3	0.02	0	0.00
Shimofuri goby	6	0.04	6	0.04	436	1.69	2	0.01	6	0.03	0	0.00
Carp	1	0.01	1	0.01	3	0.01	0	0.00	0	0.00	0	0.00
Golden shiner	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00
Largemouth bass	3	0.02	3	0.00	8	0.03	1	0.01	0	0.00	0	0.00
Blue gill	2	0.01	1	0.00	3	0.01	4	0.02	14	0.07	0	0.00
Black crappie	0	0.00	2	0.00	2	0.01	0	0.00	1	0.01	0	0.00
unk centrarchids	3	0.02	0	0.00	7	0.03	0	0.00	0	0.00	0	0.00
White catfish	0	0.00	0	0.00	0	0.00	7	0.03	3	0.02	33	0.17
Channel catfish	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00
Brown bullhead	0	0.00	0	0.00	6	0.02	0	0.00	0	0.00	0	0.00
unk ictalurids	0	0.00	0	0.00	6	0.02	0	0.00	3	0.02	2	0.01
Mosquitofish	7	0.05	21	0.15	0	0.00	0	0.00	5	0.03	2	0.01
Threespine stcklbck	0	0.00	1	0.10	0	0.00	0	0.00	0	0.00	0	0.00
unidentified fish	0	0.00	0	0.00	7	0.03	1	0.01	1	0.01	0	0.00
Total	544	3.80	75	0.58	4186	16.27	36	0.14	3880	20.30	98	0.51

Table 9. Catch and Catch Per Unit Effort of Fish Captured in Diversions Using a Fyke Net, 1994

	Site 1 Twitchell Island				Site 2 Bacon Island				Site 4 Naglee Burk			
	Early-life Stage Fish		Later-life Stage Fish		Early-life Stage Fish		Later-life Stage Fish		Early-life Stage Fish		Later-life Stage Fish	
Species	**Catch**	**CPUE**	**Catch**	**CPUE**	**Catch**	**CPUE**	**Catch**	**CPUE**	**Catch**	**CPUE**	**Catch**	**CPUE**
Chinook salmon	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00
Delta smelt	14	0.10	4	0.03	0	0.00	0	0.00	0	0.00	0	0.00
Striped bass	778	5.69	5	0.04	159	0.95	0	0.00	2	0.01	0	0.00
Threadfin shad	46	0.34	7	0.05	84	0.50	0	0.00	48	0.28	0	0.00
Inland silverside	0	0.00	3	0.02	0	0.00	0	0.00	0	0.00	0	0.00
Prickly sculpin	34	0.25	12	0.09	29	0.17	4	0.02	1	0.01	4	0.02
Bigscale logperch	15	0.11	2	0.01	7	0.04	0	0.00	0	0.00	0	0.00
Yellowfin goby	186	1.36	20	0.15	16	0.10	1	0.01	0	0.00	0	0.00
Shimofuri goby	17	0.12	16	0.12	184	1.10	6	0.04	6	0.04	2	0.01
Carp	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00
Largemouth bass	3	0.02	3	0.02	3	0.02	0	0.00	0	0.00	0	0.00
Blue gill	0	0.00	0	0.00	10	0.06	3	0.02	0	0.00	1	0.01
Black crappie	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00
unk centrarchids	0	0.00	0	0.00	0	0.00	0	0.00	1	0.01	0	0.00
White catfish	0	0.00	1	0.01	0	0.00	6	0.04	0	0.00	4	0.02
Channel catfish	0	0.00	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00
Brown bullhead	1	0.01	1	0.01	5	0.03	1	0.01	0	0.00	0	0.00
unk ictalurids	1	0.01	0	0.00	4	0.02	1	0.01	9	0.05	0	0.00
Mosquitofish	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00
Threespine stcklbck	0	0.00	7	0.05	0	0.00	0	0.00	0	0.00	0	0.00
Wakasagi	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00
Staghorn sculpin	0	0.00	0	0.00	1	0.01	2	0.01	0	0.00	1	0.01
Tule perch	5	0.04	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00
unidentified fish	1	0.01	0	0.00	5	0.03	0	0.00	1	0.01	0	0.00
Total	1101	8.05	84	0.61	510	3.05	25	0.15	68	0.40	12	0.07

Table 10. Catch and Catch Per Unit Effort of Fish Captured in Diversions Using a Fyke Net, 1995

	Site 1 Twitchell Island				Site 2 Bacon Island				Site 4 Naglee Burk			
	Early-life Stage Fish		Later-life Stage Fish		Early-life Stage Fish		Later-life Stage Fish		Early-life Stage Fish		Later-life Stage Fish	
Species	**Catch**	**CPUE**	**Catch**	**CPUE**	**Catch**	**CPUE**	**Catch**	**CPUE**	**Catch**	**CPUE**	**Catch**	**CPUE**
Chinook salmon	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00
Striped bass	62	0.31	5	0.02	4	0.02	2	0.01	0	0.00	0	0.00
Splittail	0	0.00	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00
Sacramento sucker	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00
American shad	0	0.00	3	0.01	0	0.00	0	0.00	0	0.00	0	0.00
Threadfin shad	1345	6.64	18	0.09	62	0.31	0	0.00	0	0.00	0	0.00
Inland silverside	13	0.06	6	0.03	0	0.00	0	0.00	0	0.00	0	0.00
Prickly sculpin	2	0.01	4	0.02	0	0.00	0	0.00	0	0.00	1	0.01
Bigscale logperch	6	0.03	8	0.04	1	0.01	0	0.00	0	0.00	0	0.00
Yellowfin goby	21	0.10	15	0.07	3	0.01	0	0.00	0	0.00	0	0.00
Shimofuri goby	9	0.04	6	0.03	0	0.00	0	0.00	0	0.00	1	0.01
Largemouth bass	0	0.00	9	0.04	4	0.02	6	0.03	0	0.00	0	0.00
Blue gill	21	0.10	2	0.01	25	0.12	10	0.05	2	0.02	2	0.01
Black crappie	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Red sunfish	0	0.00	1	0.01	0	0.00	1	0.01	0	0.00	0	0.00
unk centrarchids	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00
White catfish	58	0.29	2	0.01	51	0.26	5	0.02	14	0.11	22	0.17
Channel catfish	2	0.01	0	0.00	0	0.00	0	0.00	7	0.05	7	0.05
Brown bullhead	0	0.00	0	0.00	83	0.42	0	0.00	1	0.01	1	0.01
unk ictalurids	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Mosquitofish	23	0.11	0	0.00	1	0.01	1	0.01	0	0.00	0	0.00
Riffle sculpin	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00
Threespine stcklbck	3	0.01	14	0.07	0	0.00	0	0.00	0	0.00	0	0.00
Wakasagi	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Staghorn sculpin	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Tule perch	1	0.01	1	0.01	0	0.00	1	0.01	0	0.00	0	0.00
Pac brook lamprey	1	0.01	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00
unidentified fish	1	0.01	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00
Total	1568	7.74	99	0.49	235	1.18	27	0.14	24	0.18	34	0.26

Table 11. Summary of Catch and Catch Per Unit Effort during Simultaneous Channel and Diversion Sampling for Early-life Stage Fish at Channel Site 932 (Middle River) and Diversion Site 2 (Bacon Island), 1994

		Channel Site 932 Middle River		Diversion Site 2 Bacon Island	
Date/Gear	**Species**	**Catch**	**CPUE**	**Catch**	**CPUE**
5/5/94	Shimofuri goby	135	65.2	0	0.0
Egg and Net	Delta smelt	2	1.0	0	0.0
Larval Net	Bigscale logperch	2	1.0	2	12.0
	Prickly sculpin	139	67.1	2	12.0
	Threadfin shad	2	1.0	0	0.0
	Striped bass	58	28.0	0	0.0
	Centrarchidae	2	1.0	0	0.0

CPUE = catch per unit effort = catch per acre-foot of water sampled.

Table 12. Summary of Catch and Catch Per Unit Effort during Simultaneous Channel and Diversion Sampling Using a Townet and Fyke Net at Channel Site 932 (Middle River) and Diversion Site 2 (Bacon Island), 1994

		Channel Site 932 Middle River (Townet)		Diversion Site 2 Bacon Island (Fyke Net)	
Date	**Species**	**Catch**	**CPUE**	**Catch**	**CPUE**
7/7/94	Centrarchidae	0	N/A	3	0.4
	American shad	16	N/A	0	0
	Threadfin shad	5	N/A	18	2.5
	Striped bass	114	N/A	0	0
	Yellowfin goby	19	N/A	0	0
	Inland silverside	16	N/A	0	0
	Ictaluridae	46	N/A	3	0.4
	Shimofuri goby	0	N/A	10	1.4

CPUE = catch per unit effort = catch per acre-foot of water sampled.

N/A = Not Available.

Ictalurid species = channel catfish and white catfish.

Table 13. Summary of Catch during Simultaneous Channel and Diversion Sampling Using a Townet, Midwater Trawl, and Fyke Net at Channel Site 49 (San Joaquin River) and Diversion Site 1 (Twitchell Island) between May and October, 1994

		Channel Site 49		Diversion Site 1	
Date/Gear	Species	Catch	CPUE	Catch	CPUE
7/11/94	American shad	2	N/A	0	0
Townet (Channel)	Striped bass	7	N/A	3	0.422
Fyke Net (Diversion)	Splittail	1	N/A	0	0
	Yellowfin goby	1	N/A	1	0.14
	Inland silverside	6	N/A	1	0.14
	Threadfin shad	0	N/A	12	1.70
5/11/94	Striped bass	2	0.05	5	1.33
Midwater	Chinook salmon	2	0.05	0	0
Trawl (Channel)	Ictaluridae	3	0.07	0	0
Fyke Net (Diversion)	Cyprinidae	1	0.02	0	0
	Delta smelt	0	0	1	0.26
	Prickly sculpin	0	0	6	1.59
	Yellowfin goby	0	0	6	1.59
9/29/94	American shad	114	1.88	0	0
Midwater	Threadfin shad	70	1.15	1	0.13
Trawl (Channel)	Inland silverside	1	0.02	0	0
Fyke Net (Diversion)	Striped bass	7	0.12	0	0
	Centrarchidae	0	0	1	0.13
	Shimofuri goby	0	0	6	0.78
10/5/94	American shad	67	1.28	0	0
Midwater	Threadfin shad	80	1.53	1	0.17
Trawl (Channel)	Striped bass	19	0.36	0	0
Fyke Net (Diversion)	Chinook salmon	2	0.04	0	0
	Threespine stickleback	0	0	3	0.50
	Shimofuri goby	0	0	4	0.66
10/17/94	American shad	61	1.12	0	0
Midwater	Threadfin shad	38	0.70	0	0
Trawl (Channel)	Shimofuri goby	0	0	5	0.74
Fyke Net (Diversion)	Striped bass	0	0	4	0.59
	Inland silverside	0	0	1	0.15
	Cyprinidae	0	0	1	0.15

CPUE = catch per unit effort = catch per acre-foot of water sampled.
N/A = Not Available.

Table 14. Paired Comparisons of Fish Catch Per Unit Effort from Diversions, Day versus Night, 1993, 1994, 1995

	1993		1994		1995	
Early-Life Stage Fish	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
Site 2 Bacon Island, 16"	N/A		110.58 (7)	187.18 (7)	242.09 (9)	203.45 (9)
Site 1 Twitchell Island	—	—	N/A			
Later-Life Stage Fish	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
Site 2 Bacon Island, 16"	10.53 (21)*	29.38 (21)*	3.19 (11)	5.96 (11)	0.41 (12)*	1.91 (12)*
Site 1 Twitchell Island	2.28 (10)	14.22 (10)	5.16 (27)**	12.68 (27)**	6.17 (9)	10.07 (9)

Values shown are the mean catch per unit effort for all species combined used in the t test for dependent samples of day vs. night catch. Catch per unit effort is the total number of fish captured per acre foot of water sampled. The figure in parentheses equals the number of paired samples. Results considered significant at $p \leq 0.05$.

no asterisk	$p > 0.05$
*	$p \leq 0.05$
**	$p \geq 0.01$

N/A = site not sampled or all samples were collected during the day.

– = insufficient number of paired samples ($n \leq 2$).

Table 15. Annual Entrainment of Fish by Species in Agricultural Diversions, 1993, 1994, and 1995

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chinook salmon					4	5						
Delta smelt				4	3,4	3,4						
Wakasagi					4							
Splittail						5						
Striped bass					3,4	3,4,5	3,4,5	3,4,5		4		
Cyprinidae					3,4	3,4,5	3			3		
Sacramento sucker							5					
Centrarchidae	4			4	3,4	3,4,5	3,5	3,5	3,4	3		
Tule perch					4	4		5				
Bigscale logperch				4	3,4	3,4,5	3,5	3,5	4			
Pacific lamprey						5						
Prickly sculpin					3	3,5	3	3,5				
Pacific staghorn sculpin				4	4	4						
Riffle sculpin						5						
Threespine stickleback						4,5	5	4,5		3,4		
Yellowfin goby					3,4	3,4,5	3,4,5	3,5	3	3	3	
Shimofuri goby	4				3,4	3,4	3,4,5	3,5	3			3
Chameleon goby					4			4	4	4		
Ictaluridae					3,4,5	3,4,5	3,4,5	3,4,5	3,4			
American shad							3,5		3			
Threadfin shad					3,4	3,4,5	3,4,5	3,4,5	4	3,4	3	
Inland silverside							3,4,5	3,4,5		4		
Mosquitofish						5	3,5	3,5		3	3	3
Starry flounder							5	5				

3 = 1993, 4 = 1994, 5 = 1995

Number of days per month that sampling was conducted

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						Month						
1993	0	0	0	3	14	11	12	9	4	3	3	3
1994	1	0	0	3	15	11	3	7	2	2	0	0
1995	0	0	0	0	2	11	17	19	0	0	0	0

Figures 1-12

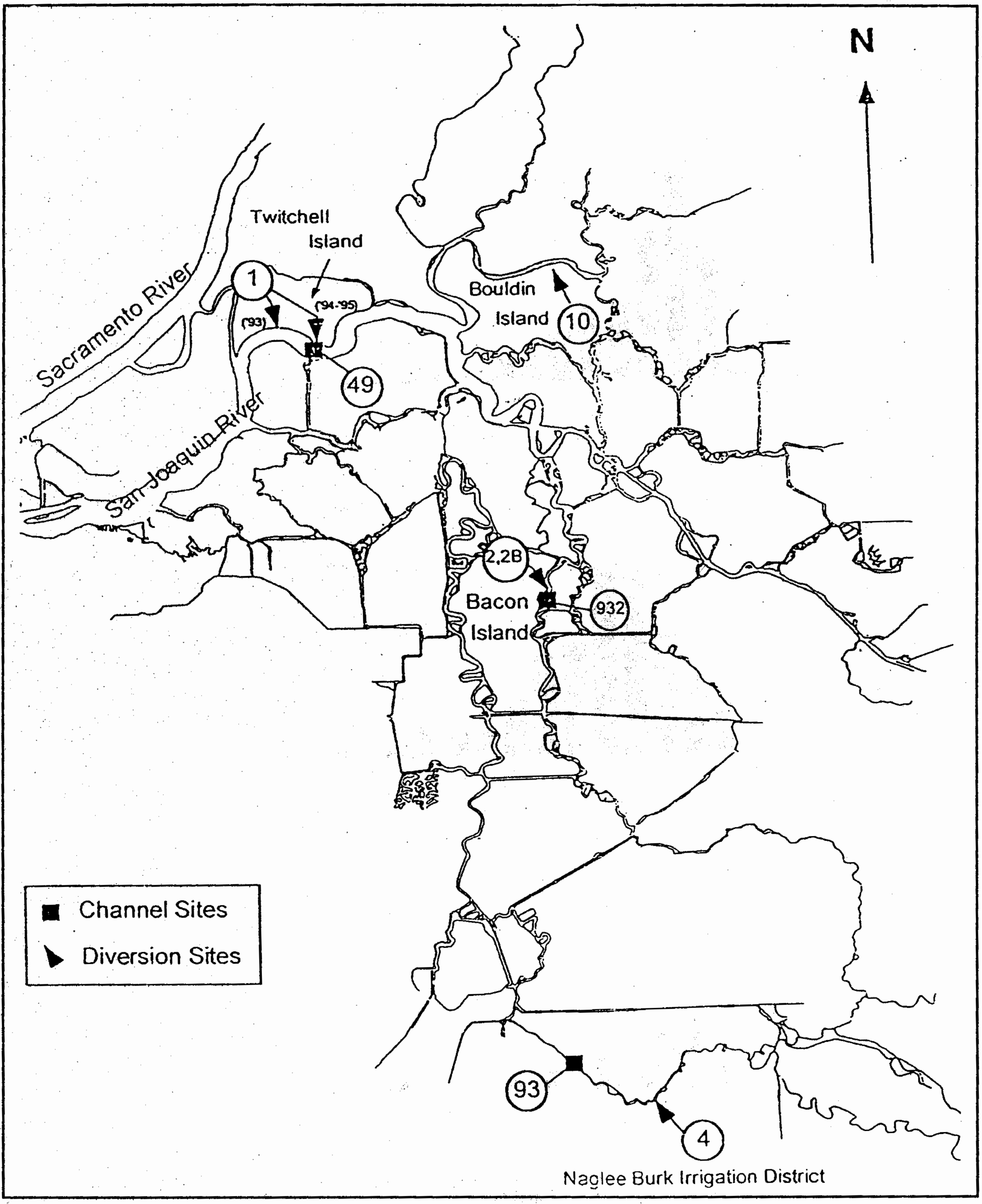

Figure 1
Channel and Diversion Sampling Sites, 1993-1995

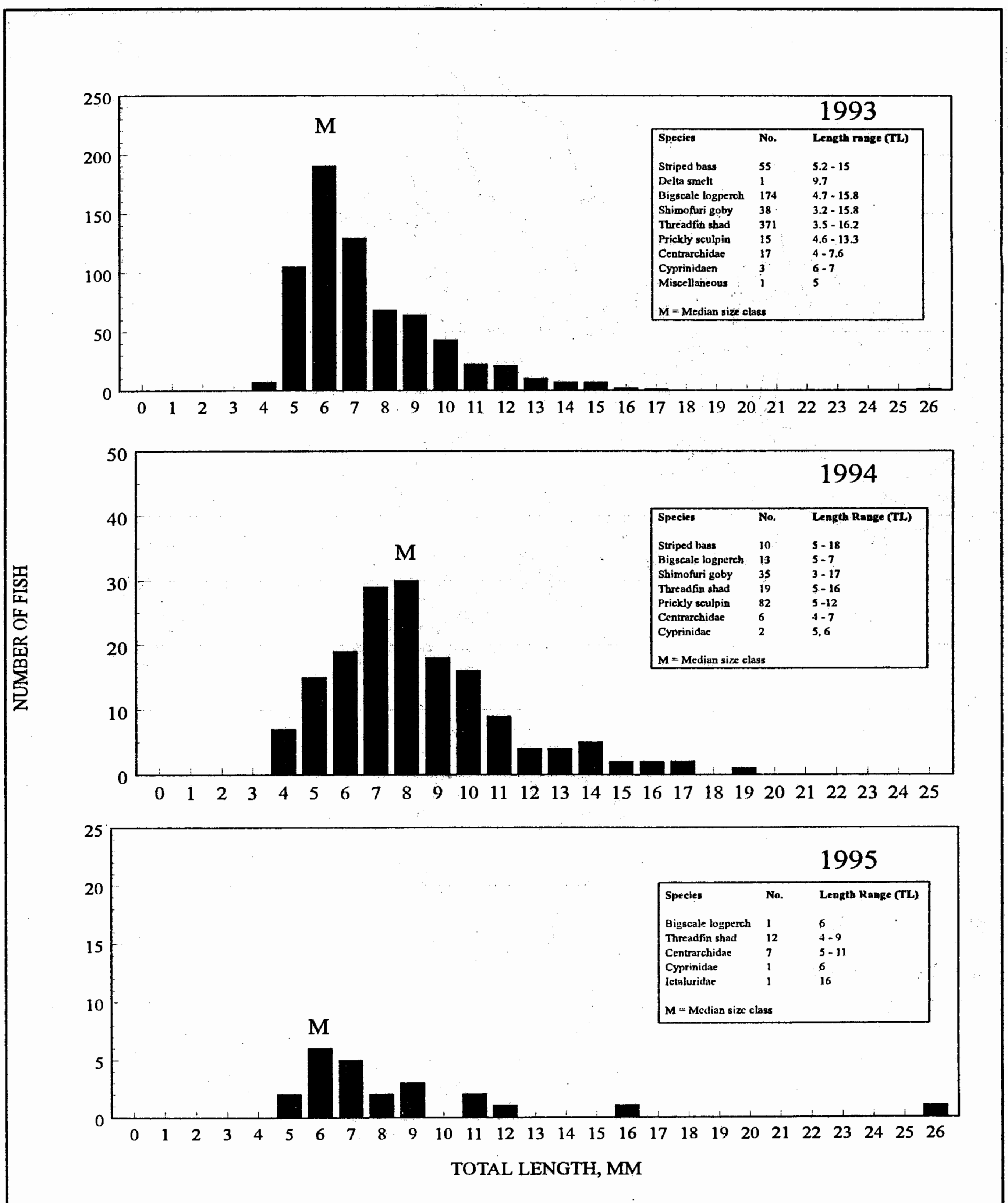

Figure 2
Length-Frequency Distributions of Early-life Stage Fish Collected at Diversion Site 2 (Bacon Island) Using an Egg and Larval Net, 1993-1995

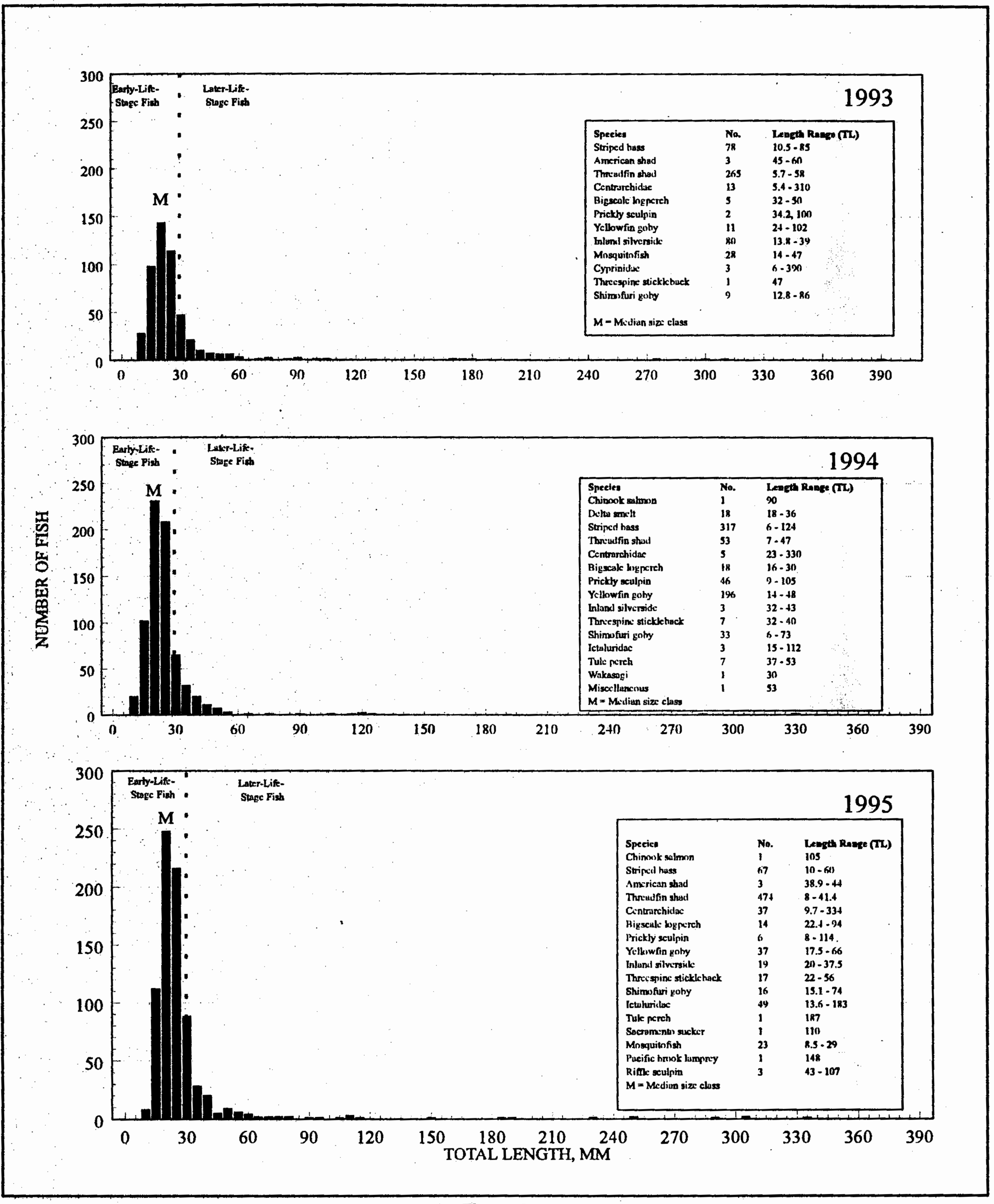

Figure 3
Length-Frequency Distributions of Fish Collected at Diversion Site 1 (Twitchell Island) Using a Fyke Net, 1993-1995

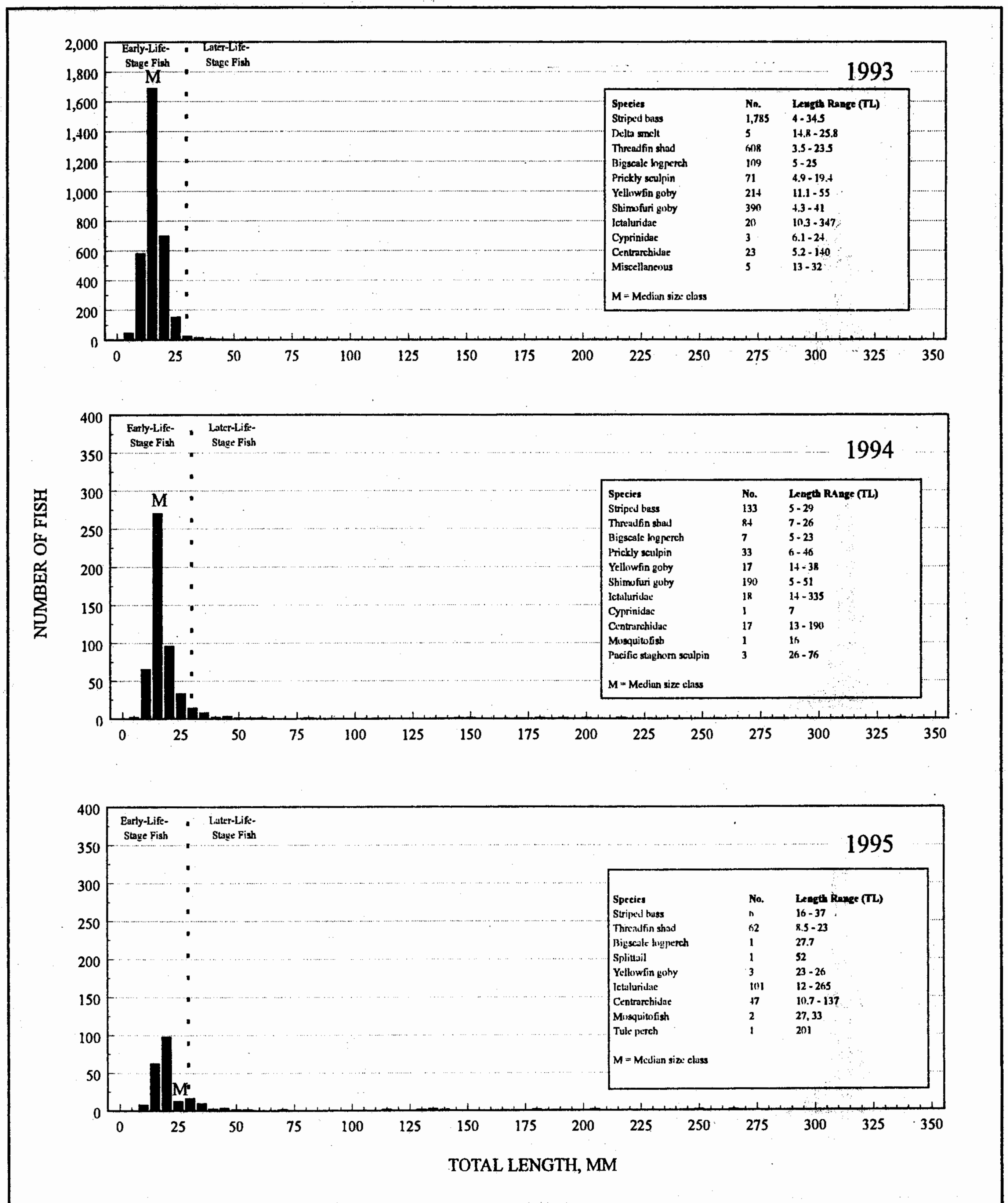

Figure 4
Length-Frequency Distributions of Fish Collected at Diversion Site 2 (Bacon Island) Using a Fyke Net, 1993-1995

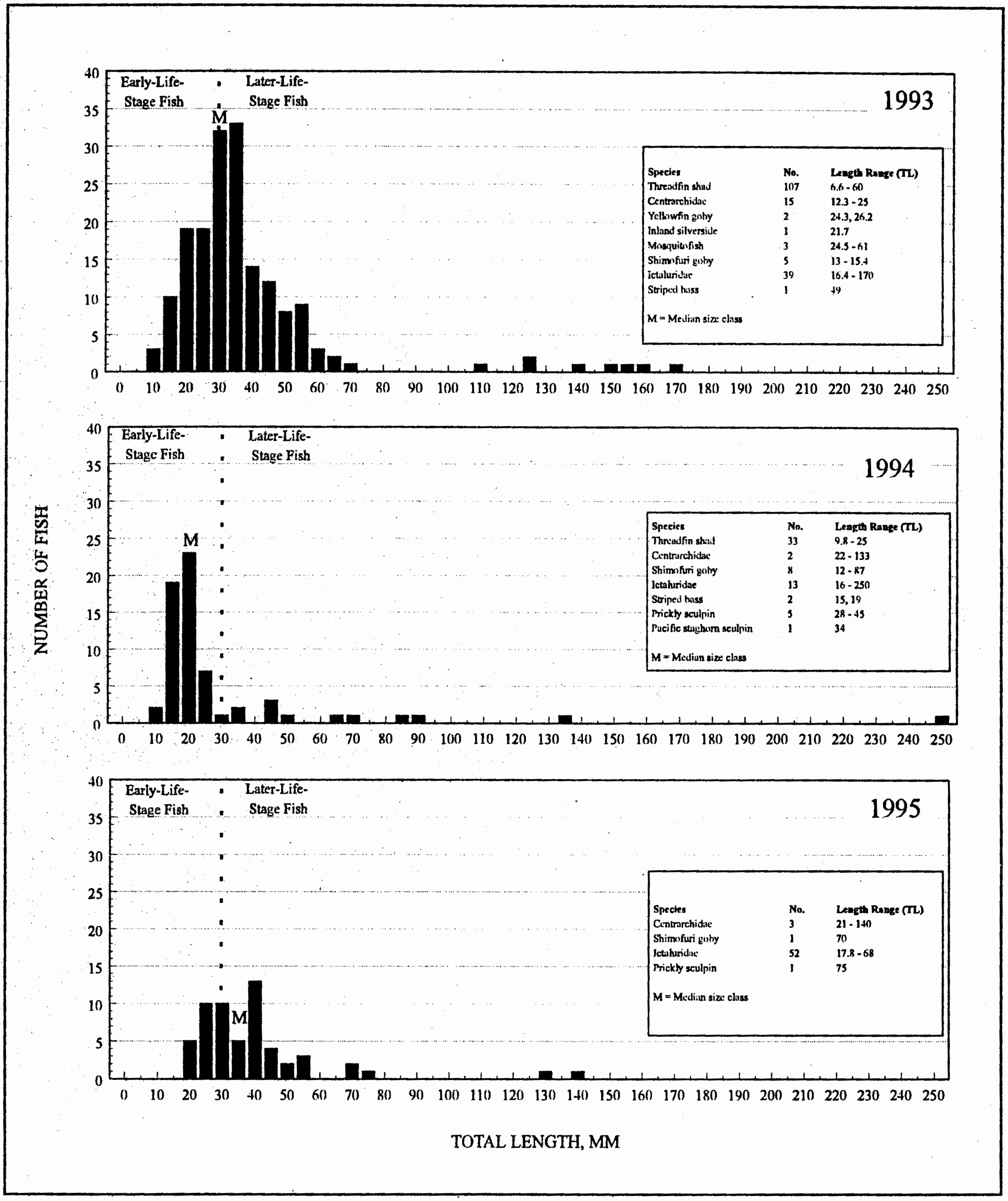

Figure 5
Length-Frequency Distribution of Fish Collected at Diversion Site 4 (Naglee Burk)
Using a Fyke Net, 1993-1995

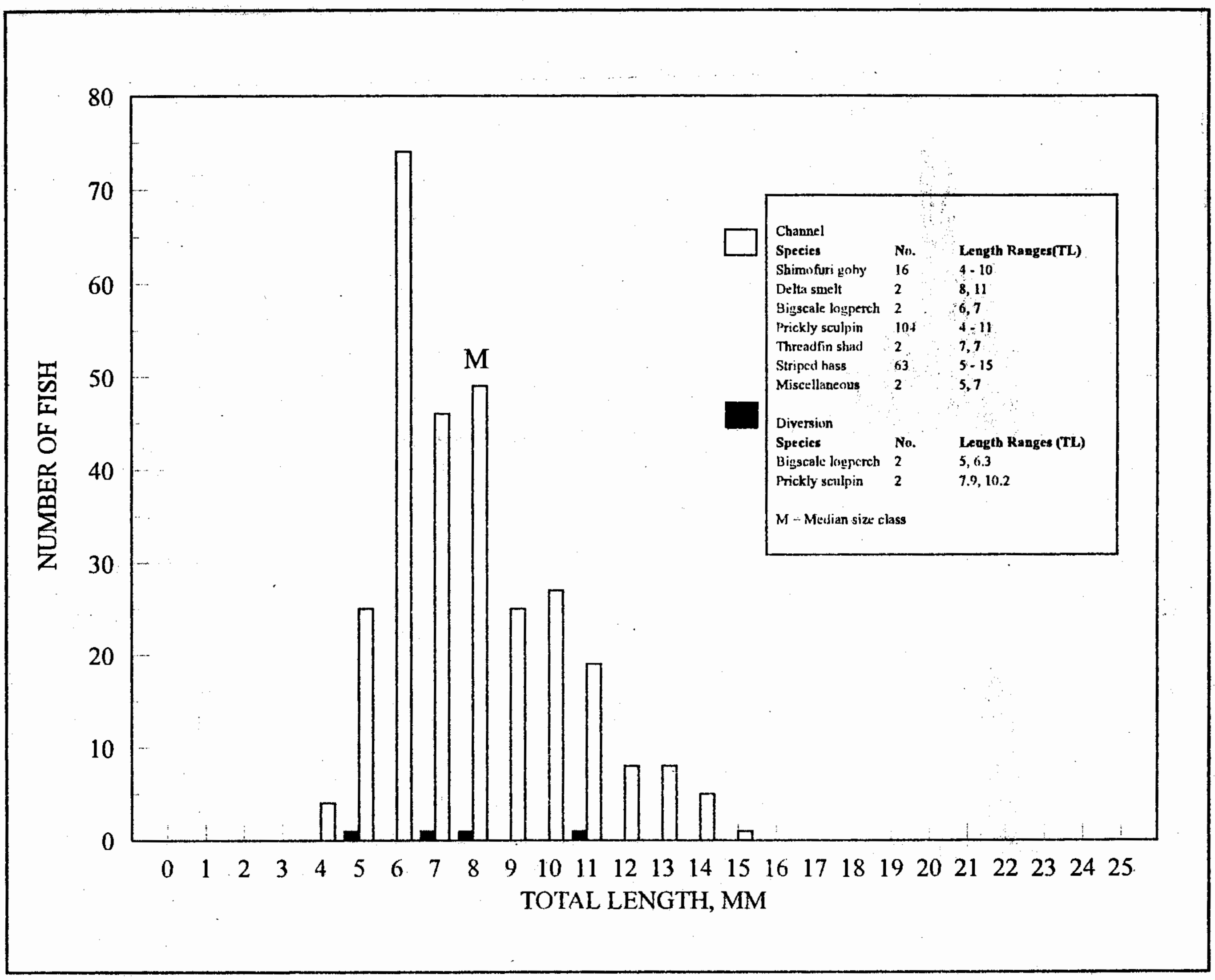

Figure 6
Length-Frequency Distributions of Early-life Stage Fish Collected during Simultaneous Sampling at Diversion Site 2 (Bacon Island) and Channel Site 932 (Middle River), May 5, 1994

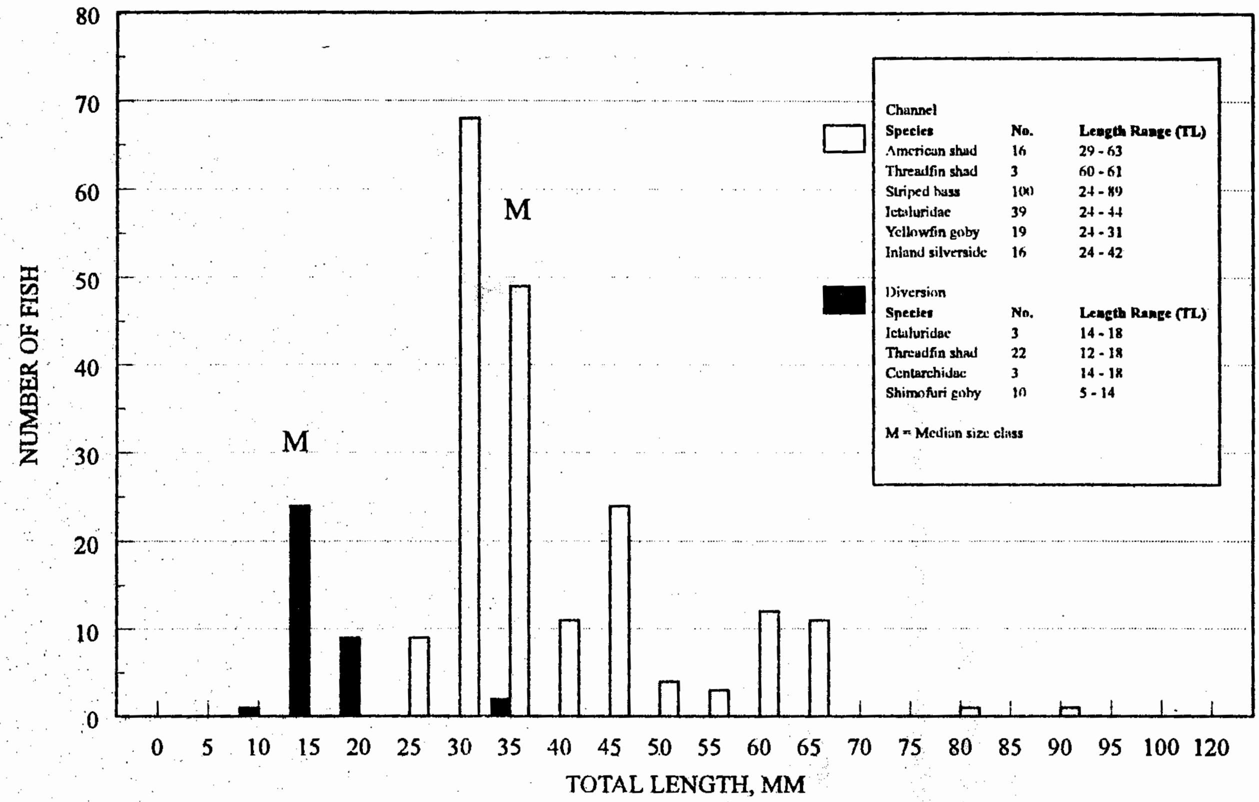

Figure 7
Length-Frequency Distributions of Fish Collected during Simultaneous Sampling at Diversion Site 2 (Bacon Island) and Channel Site 932 (Middle River) Using a Fyke Net, July 7, 1994

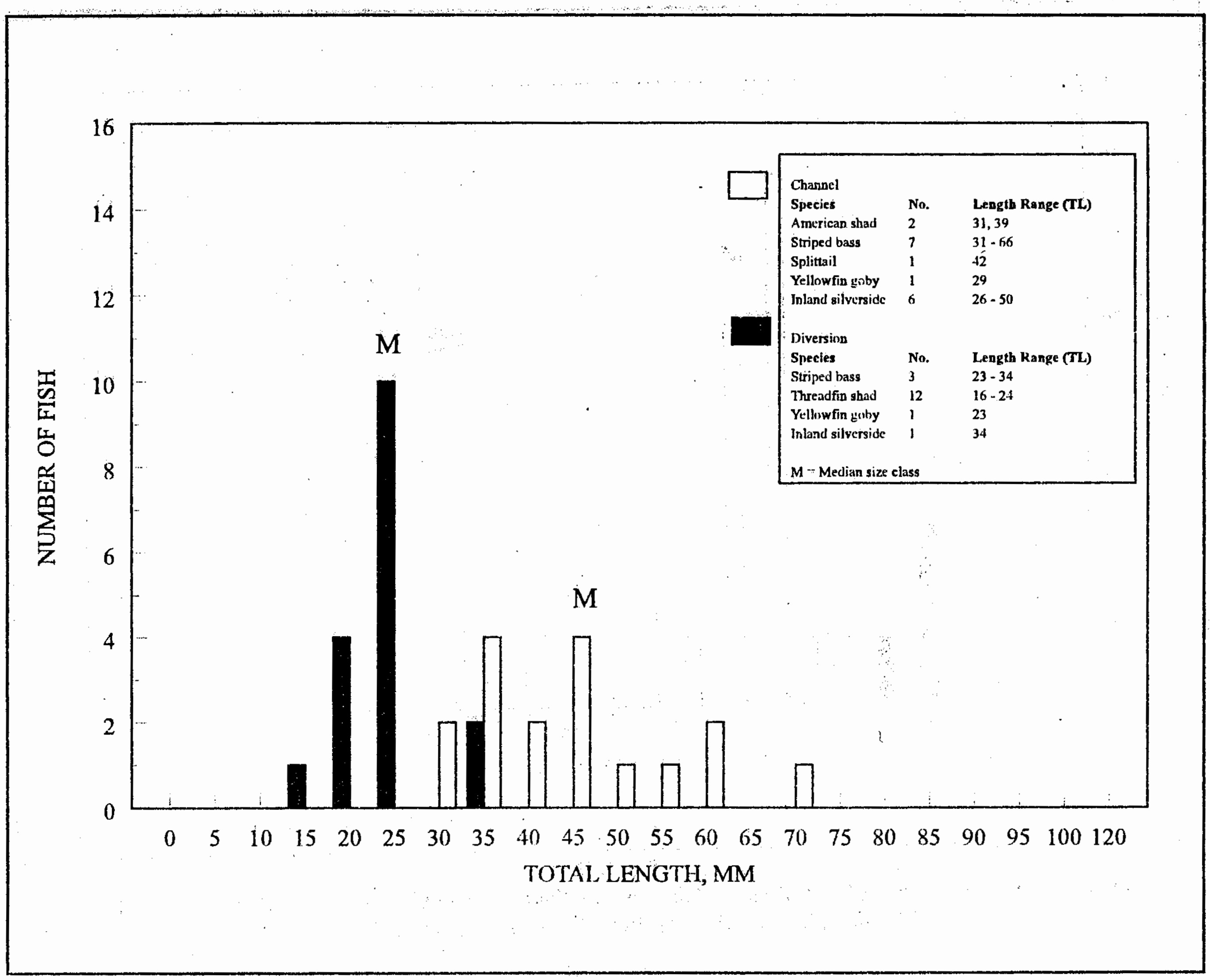

Figure 8
Length-Frequency Distributions of Fish Collected during Simultaneous Sampling at Diversion Site 1 (Twitchell Island) and Channel Site 49 (San Joaquin River at Oulton Point) Using a Fyke Net, July 11, 1994

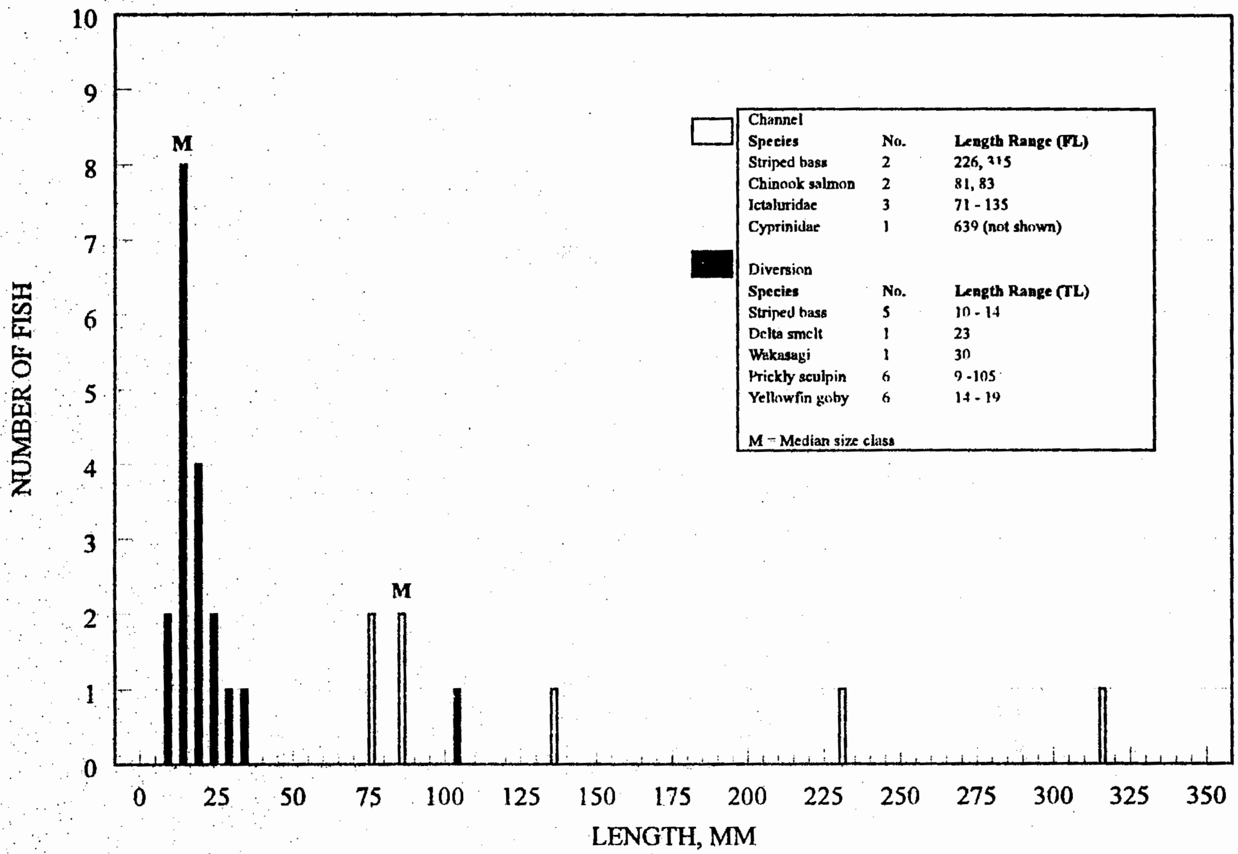

Figure 9
Length-Frequency Distributions of Fish Collected during Simultaneous Samping at Diversion Site 1 (Twitchell Island) and Channel 49 (San Joaquin River at Oulton Point) Using a Fyke Net, May 11, 1994

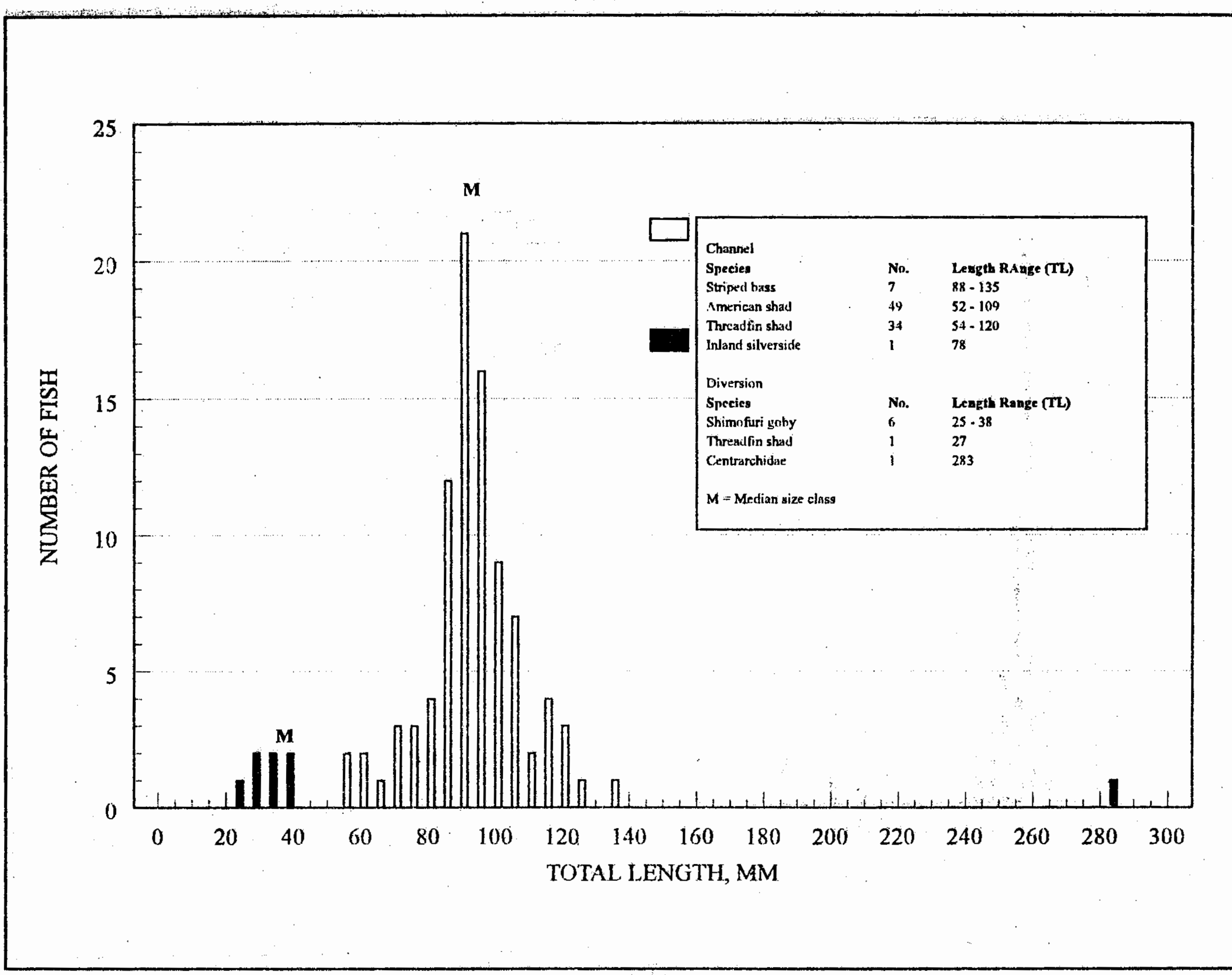

Figure 10
Length-Frequency Distributions of Fish Collected during Simultaneous Sampling at Diversion Site 1 (Twtichell Island)

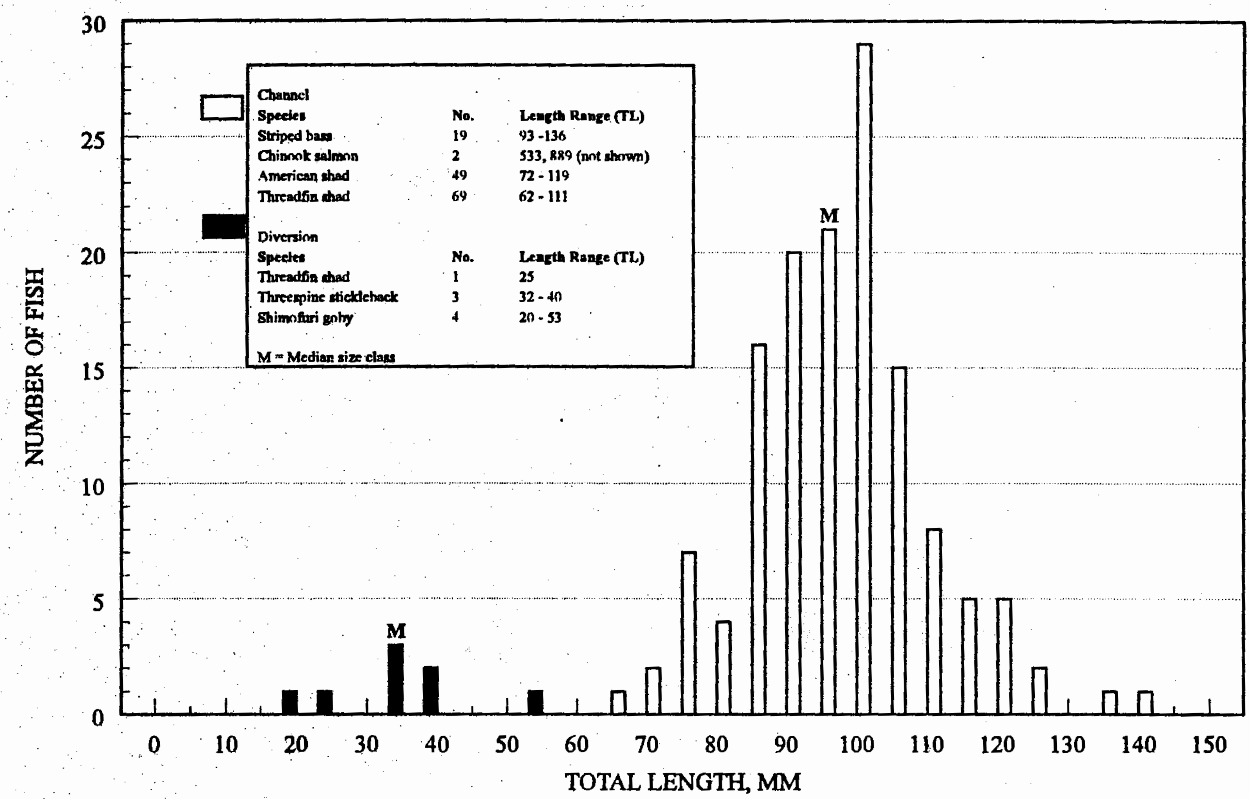

Figure 11
Length-Frequency Distributions of Fish Collected during Simultaneous Sampling at Diversion Site 1 (Twitchell Island) and Channel Site 49 (San Joaquin River at Oulton Point) Using a Fyke Net, October 5, 1994

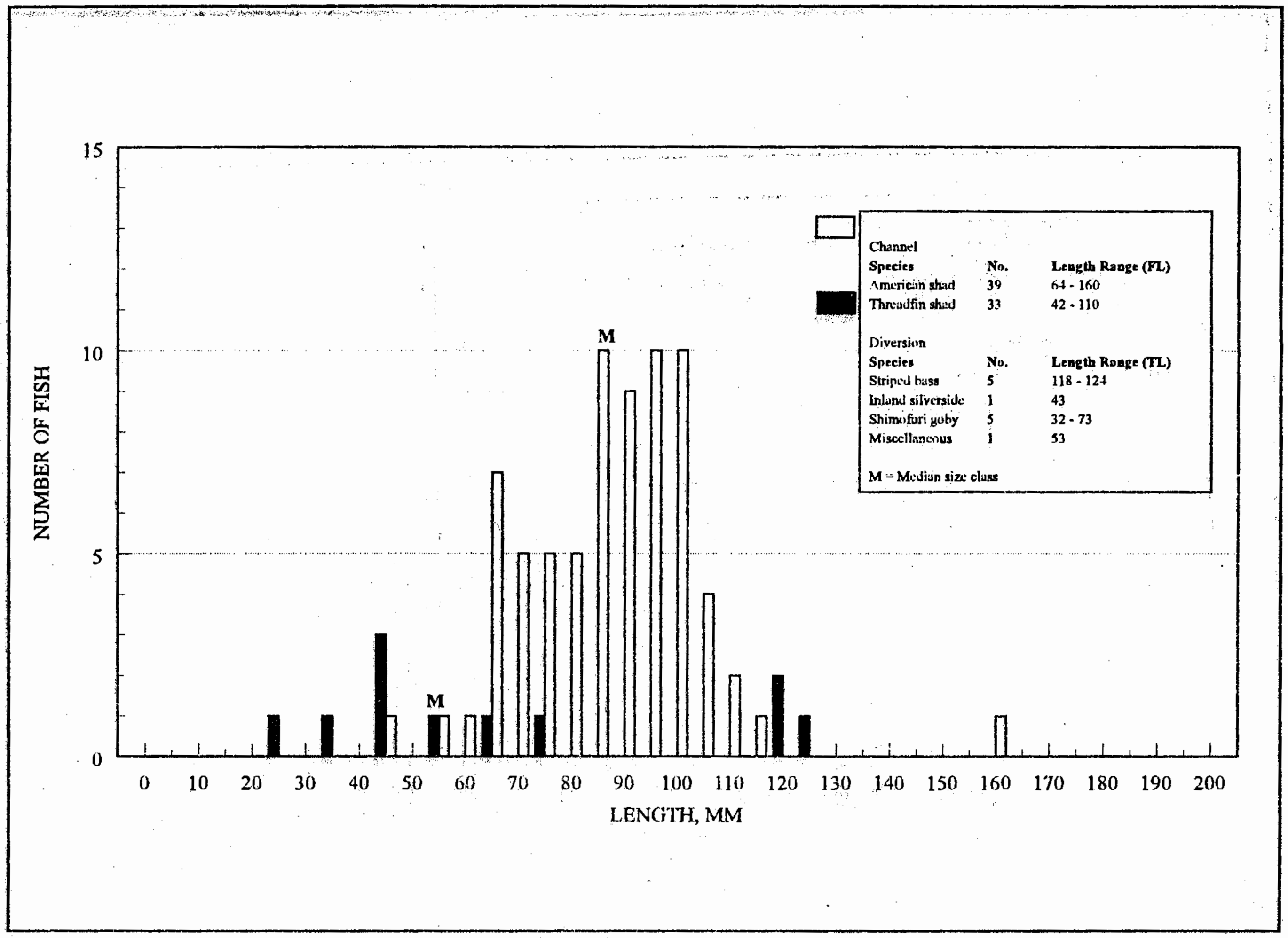

Figure 12
Length-Frequency Distributions of Fish Collected during Simultaneous Sampling at Diversion Site 1 (Twitchell Island) and Channel Site 49 (San Joaquin River at Oulton Point) Using a Fyke Net, October 17, 1994

Appendices A-E

APPENDIX A

Data about fish collected at the agricultural diversion on Bouldin Island (Site 10) by Department of Water Resources staff on 6 days between June 21 and August 20, 1993. Site 10 was a data collection site of the California Department of Fish and Game and the resulting data is presented in the Striped Bass Stamp Fund Agricultural Diversions Quarterly Report (DeLeon 1994) and in Monitoring of an Unscreened Agricultural Diversion on the San Joaquin River at McMullin Tract (Griffin 1993). Department of Water Resources personnel sampled the site to enable comparison of species composition and abundance with the sites included as part of the Interagency Ecological Program's Delta Agricultural Diversion Evaluation but were unable to sample frequently enough to collect a sufficient data set.

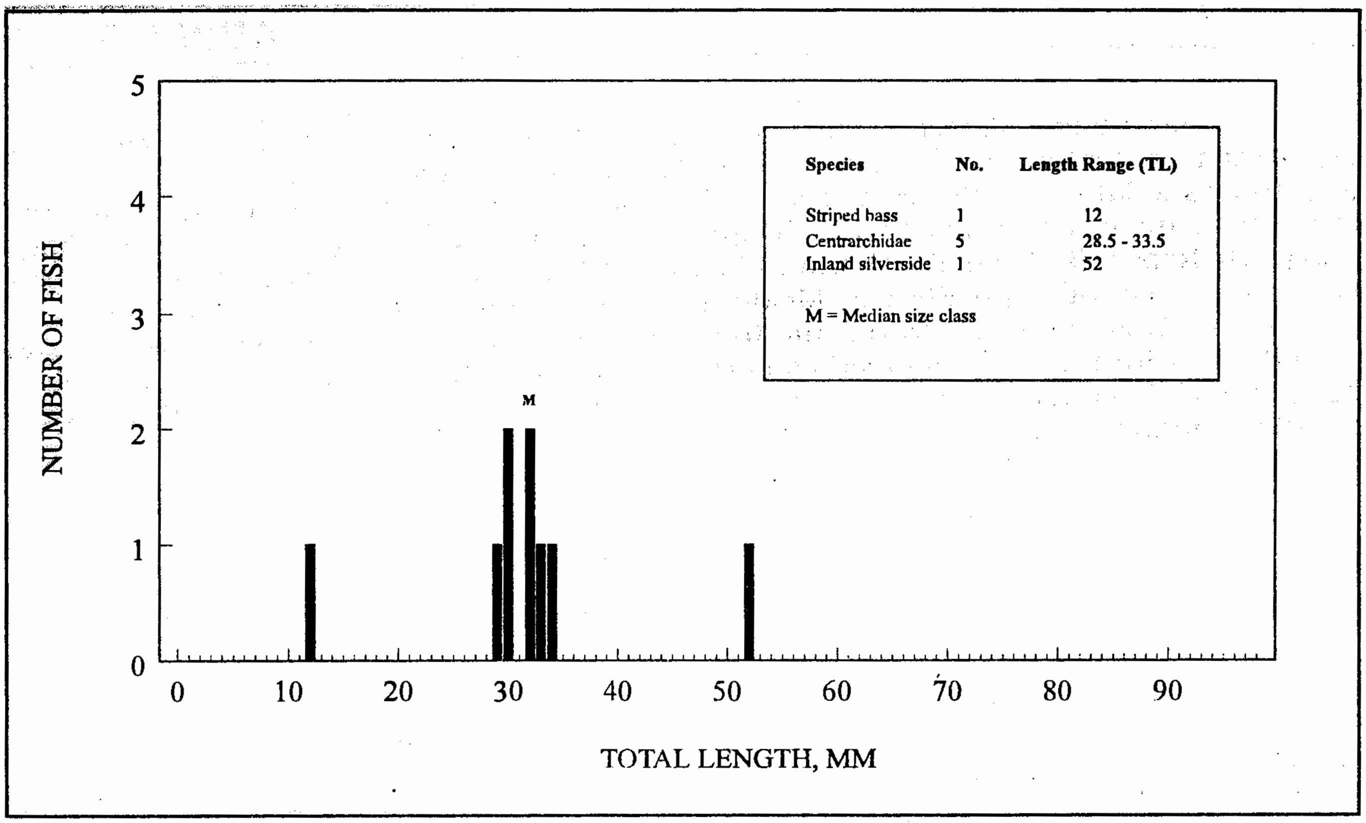

Figure A-1
Length-Frequency Distributions of All Fish Collected at Diversion Site 10 (Bouldin Island), June 21 through August 20, 1993

APPENDIX B

Data about early-life stage fish captured in 505-micron mesh egg and larval nets in the years 1993 through 1995 at channel sites 49, 93, and 932 (near study Sites 1 (Twitchell Island), 4 (Naglee Burk) and 2 (Bacon Island's 16 inch siphon)), respectively. Data is included to provide additional qualitative information about relative numbers and total catches of species and how these may vary across time and space.

Table B - 1. Summary of Channel Sampling for Early-life Stage Fish Using a 505 Micron Mesh Egg and Larval Fish Net, 1993-1995

	1993	1994	1995
Site 49 - San Joaquin River at Oulton Point			
Sampling period	June 1 - July 15	February 11 - July 5	February 15 - July 10
Number of days sampled	20	42	20
Total Number of samples	20	42	20
Number of acre-feet sampled	1.35	5.35	3.82
Site 93 - Old River, downstream of Naglee Burk			
Sampling period	February 27 - July 5	February 11 - July 5	February 15 - June 1
Number of days sampled	33	46	22
Total Number of samples	33	46	22
Number of acre-feet sampled	4.26	7.52	4.36
Site 932 - Middle River at Bacon Island			
Sampling period	February 27 - July 15	February 11 - July 5	February 15 - June 1
Number of days sampled	35	43	17
Total Number of samples	35	43	17
Number of acre-feet sampled	3.69	6.54	3.44

Table B - 2. Catch of Striped Bass Eggs and Early-life Stage Fish at Site 49 (San Joaquin River at Oulton Point) Using a 505 Micron Mesh Egg and Larval Fish Net, 1993 - 1995

	1993		1994		1995	
Striped Bass Eggs	**Catch**	**CPUE**	**Catch**	**CPUE**	**Catch**	**CPUE**
Morula	10	7.4	189	35.3	5	1.3
Early embryo	8	5.9	64	12.0	0	0
Late embryo	0	0	71	13.3	5	1.3
Dead	1	0.7	17	3.2	30	7.8
TOTAL	19	14.0	341	63.8	40	10.4

	1993		1994		1995	
Early-Life Stage Fish (Species)	**Catch**	**CPUE**	**Catch**	**CPUE**	**Catch**	**CPUE**
Striped bass	125	92.6	135	25.2	147	38.5
Longfin smelt	0	0	10	1.9	0	0
Delta smelt	2	1.5	102	19.1	6	1.6
Splittail	0	0	0	0	4	1.0
Yellowfin goby	0	0	1	0.2	0	0
Shimofuri goby	4	3.0	190	35.5	0	0
Threadfin shad	70	51.8	19	3.6	33	8.6
Prickly sculpin	8	5.9	992	185.4	962	251.8
Sacramento sucker	1	0.7	0	0	1	0.3
Bigscale logperch	0	0	7	1.3	35	9.2
Centrarchidae	0	0	11	2.1	30	7.8
Other	3	2.2	0	0	15	3.9
TOTAL	213	157.7	1,467	274.3	1,233	322.7

CPUE = catch per unit effort = catch per acre-foot of water sampled.

Table B - 3. Catch of Striped Bass Eggs and Early-life Stage Fish at Site 93 (Old River Downstream of Naglee Burk) Using a 505 Micron Mesh Egg and Larval Fish Net, 1993 - 1995

	1993		1994		1995	
Striped Bass Eggs	**Catch**	**CPUE**	**Catch**	**CPUE**	**Catch**	**CPUE**
Morula	0	0	115	15.3	0	0
Early embryo	0	0	1	0.1	0	0
Late embryo	0	0	2	0.3	0	0
Dead	0	0	20	2.7	0	0
TOTAL	0	0	138	18.4	0	0

	1993		1994		1995	
Early-Life Stage Fish (Species)	**Catch**	**CPUE**	**Catch**	**CPUE**	**Catch**	**CPUE**
Chinook salmon	0	0	0	0	1	0.2
Striped bass	80	18.8	23	3.1	0	0
Longfin smelt	0	0	1	0.1	0	0
Delta smelt	0	0	4	0.5	1	0.2
Splittail	1	0.2	0	0	24	5.5
Shimofuri goby	696	163.4	3,770	501.3	0	0
Threadfin shad	664	155.9	161	21.4	39	8.9
Prickly sculpin	920	216.0	1,876	249.5	185	42.4
Sacramento sucker	1	0.2	1	0.1	2	0.5
Bigscale logperch	28	6.6	11	1.5	7	1.6
Cyprinidae	0	0	6	0.8	0	0
Centrarchidae	30	7.0	3	0.4	82	18.8
Other	14	3.3	2	0.3	321	73.6
TOTAL	2,434	571.4	5,858	779.0	662	151.7

CPUE = catch per unit effort = catch per acre-foot of water sampled.

Table B - 4. Catch of Early-life Stage Fish at Site 932 (Middle River at Bacon Island) Using a 505 Micron Mesh Egg and Larval Fish Net, 1993 - 1995

Early-Life Stage Fish (Species)	1993 Catch	1993 CPUE	1994 Catch	1994 CPUE	1995 Catch	1995 CPUE
Striped bass	97	26.3	108	16.5	0	0
Longfin smelt	0	0	4	0.6	2	0.6
Delta smelt	4	1.1	12	1.8	0	0
Splittail	0	0	0	0	2	0.6
Yellowfin goby	0	0	1	0.2	0	0
Shimofuri goby	166	45.0	958	146.5	0	0
Threadfin shad	78	21.1	179	27.4	11	3.2
Prickly sculpin	1,752	474.8	2,898	443.1	494	143.6
Sacramento sucker	0	0	0	0	0	0
Bigscale logperch	25	6.8	12	1.8	16	4.6
Centrarchidae	22	6.0	29	4.4	23	6.7
Other	3	0.8	2	0.3	53	15.4
TOTAL	2,147	581.9	4,203	642.6	601	174.7

CPUE = catch per unit effort = catch per acre-foot of water sampled.

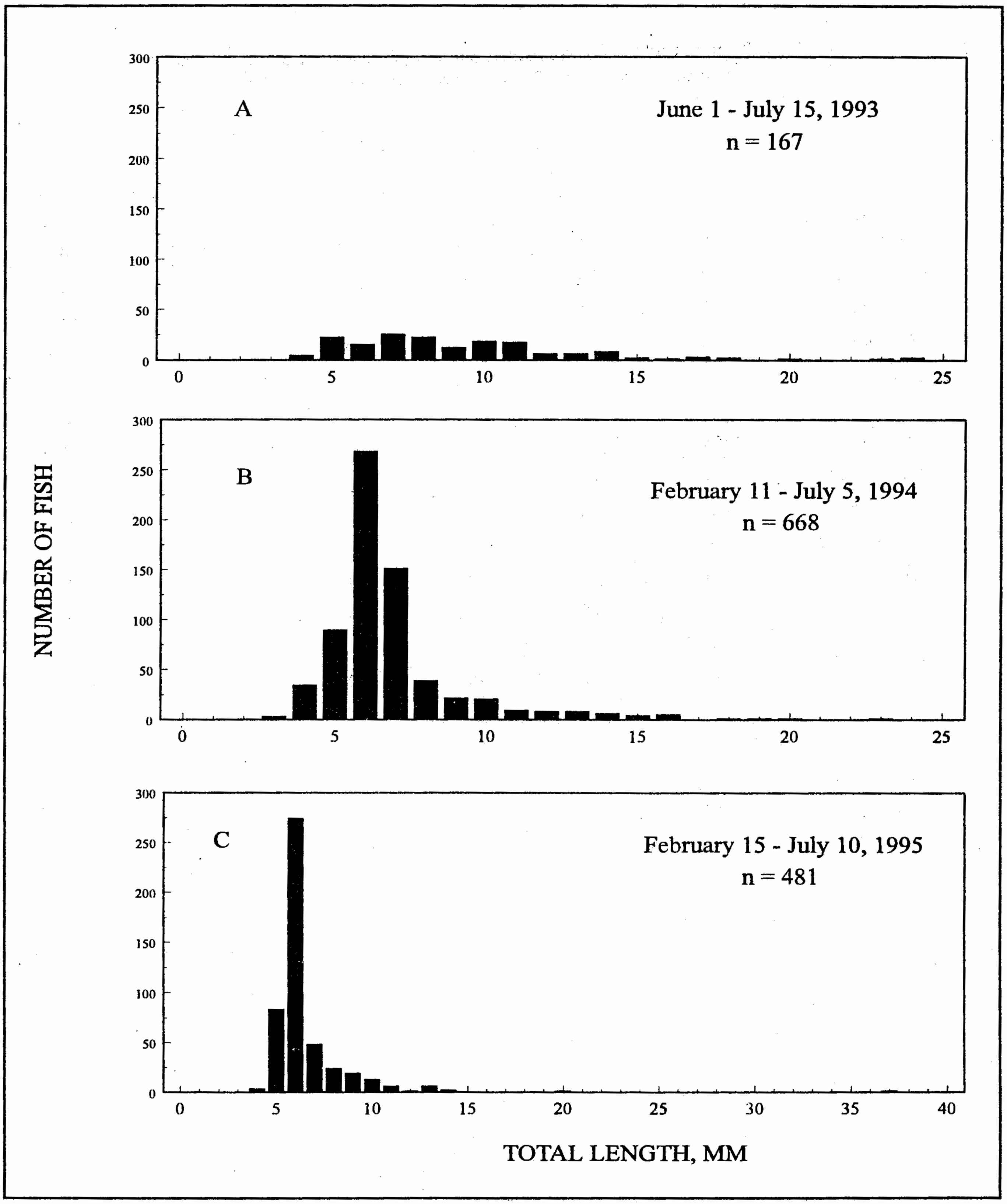

Figure B-1
Length-Frequency Distributions of Early-life Stage Fish Collected at Channel 49 (San Joaquin River) Using a 505 Micron Mesh Egg and Larval Fish Net, 1993-1995

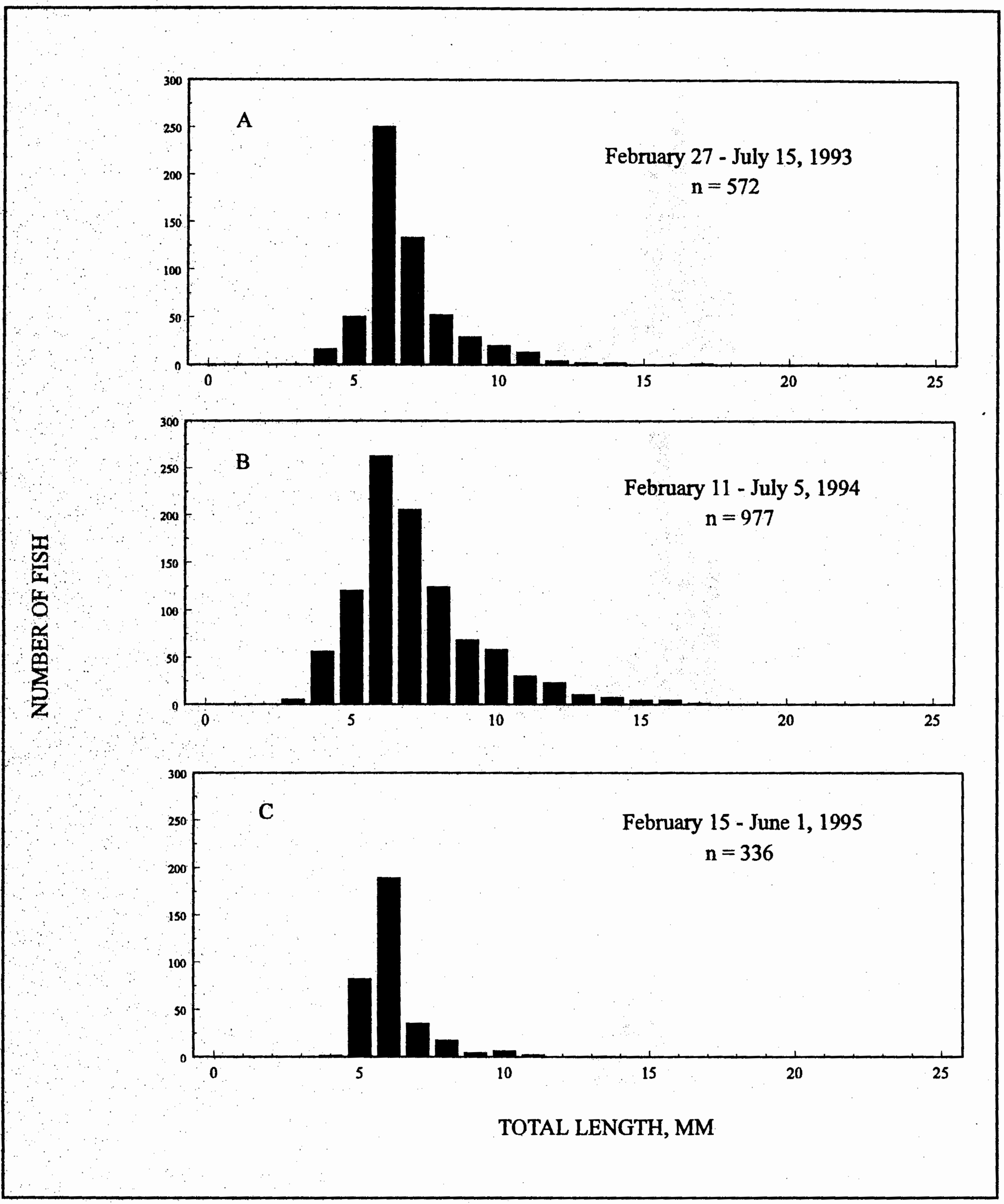

Figure B-2
Length-Frequency Distributions of Early-life Stage Fish Collected at Channel Site 932 (Middle River) Using a 505 Micron Mesh Egg and Larval Fish Net, 1993-1995

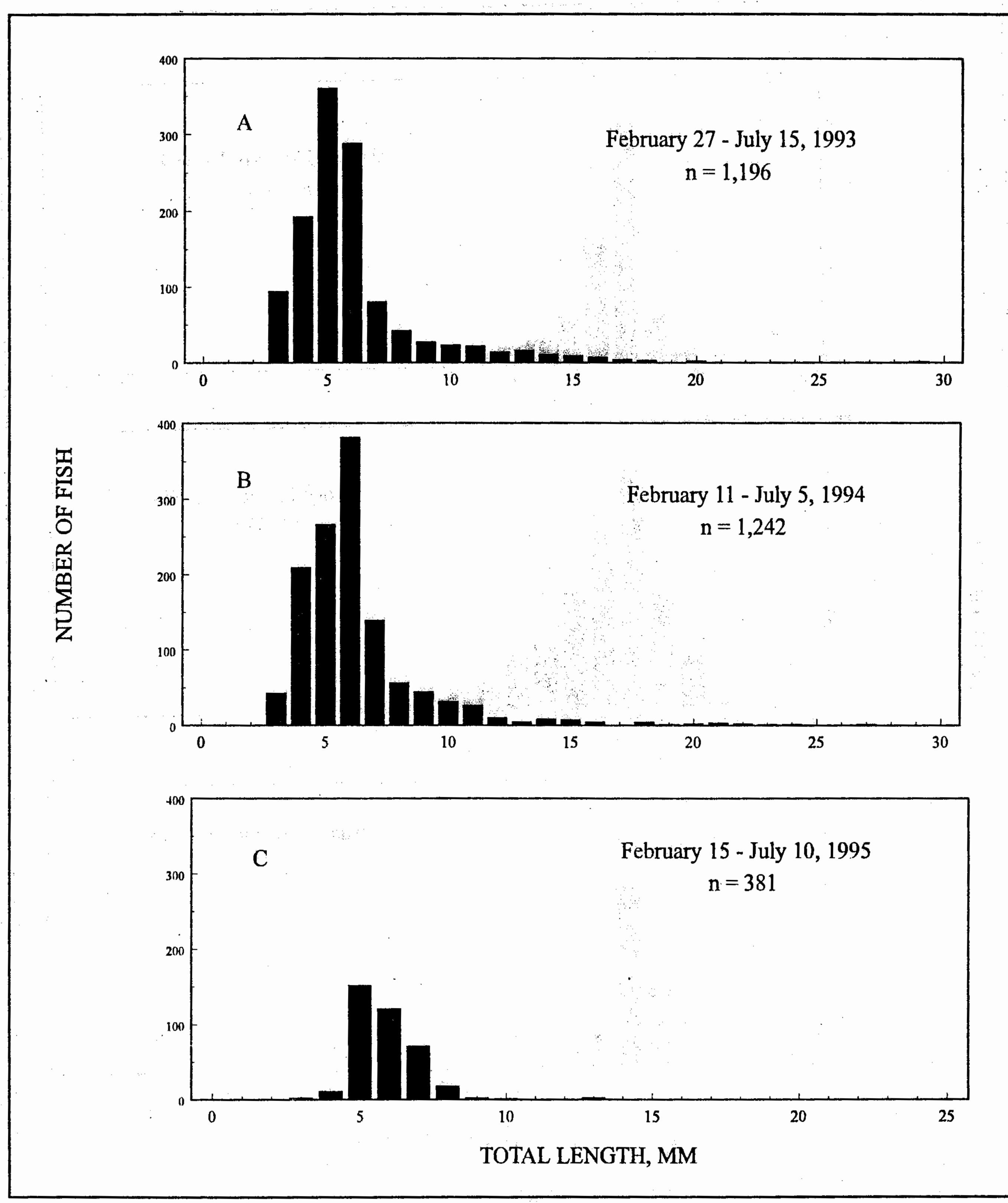

Figure B-3
Length-Frequency Distributions of Early-life Stage Fish Collected at Channel Site 93 (Old River) Using a 505 Micron Mesh Egg and Larval Fish Net, 1993-1995

APPENDIX C

Data about later-life stage fish captured in channels in 1993 at Sites 49 and 932 near diversion Sites 1 and 2, respectively. Sampling was conducted using midwater trawls, townets and otter trawls. Sampling effort was limited but the data are included to provide additional qualitative information about the relative number and total catch of species and how they may vary across sites. Gear efficiencies in channels can be low and highly variable. Gear type may also account for a portion of the variance between catches using different gear.

Table C - 1. Catch and Catch Per Unit Effort of Later-life Stage Fish (≥ 30 MM TL) at Channel Sites 49 (San Joaquin River At Oulton Point) and 932 (Middle River At Bacon Island) Using a Midwater Trawl, 1993

Summary of Sampling

	Site 49 San Joaquin River at Oulton Point	Site 932 Middle River at Bacon Island
Sampling period	August 23 & September 27	August 24 & September 28
Number of days sampled	2	2
Total number of trawls	26	20
Total number of acre-feet sampled	166.28	129.54

Later-life Stage Fish Collected

Species	Catch	CPUE	Catch	CPUE
Striped bass	175	1.05	106	0.82
Delta smelt	1	0.01	0	0.0
American shad	279	1.68	209	1.61
Threadfin shad	89	0.53	223	1.72
Inland silverside	8	0.05	1	0.01
Yellowfin goby	1	0.01	0	0.0
Cyprinidae	0	0.0	1	0.01
Ictaluridae	0	0.0	31	0.24
Bigscale Logperch	0	0.0	5	0.04
Shimofuri goby	0	0.0	3	0.02
Cetrarchidae	0	0.0	28	0.22
TOTAL	553	3.3	607	4.7

CPUE = catch per unit effort = catch per acre-foot of water sampled.

Table C - 2. Catch and Catch Per Unit Effort of Later-life Stage Fish (≥ 30 MM TL) at Channel Sites 49 (San Joaquin River at Oulton Point) and 932 (Middle River At Bacon Island) Using a Townet, 1993

Summary of Sampling

	Site 49 San Joaquin River at Oulton Point	Site 932 Middle River at Bacon Island
Sampling period	June 2 - July 8	May 25 - July 8
Number of days sampled	7	7
Total number of tows	7	7
Total number of acre-feet sampled	N/A	N/A

Later-life Stage Fish Collected

Species	Catch	CPUE	Catch	CPUE
Striped bass	2	N/A	16	N/A

N/A = Not enough information available to calculate the volume sampled.

CPUE = catch per unit effort = catch per volume of water sampled.

APPENDIX D

Catch and length frequency data for early-life stage fish captured at Sites 1 (Twitchell Island), 2B (Bacon Island's 14-inch simphon), and 4 (Naglee burk) in 1993 and 1994 as part of the Interagency Ecological Program's Delta Agricultural Diversion Evaluation.

Table D-1. Catch and Catch Per Unit Effort of Early-life-Stage Fish at Site 1 (Twitchell Island), Site 2B (Bacon Island 14-Inch Siphon) and Site 4 (Naglee Burk) Using an Egg and Larval Net, 1993

	Site 1 Twitchell Island		Site 2B Bacon Island, 14" siphon		Site 4 Naglee Burk	
Species	**Catch**	**CPUE**	**Catch**	**CPUE**	**Catch**	**CPUE**
Delta smelt	0	0	0	0	0	0
Threadfin shad	7	368.4	12	279.1	114	491.4
Bigscale logperch	1	52.6	1	23.2	0	0
Shimofuri goby	0	0	1	23.2	60	258.6
Striped bass	0	0	1	23.2	1	4.3
Prickly sculpin	0	0	0	0	0	0
Centrarchidae	0	0	0	0	8	34.5
Cyprinidae	0	0	0	0	2	8.6
TOTAL	8	421.0	15	348.7	185	797.4

CPUE = catch per unit effort = catch per acre-foot of water sampled.

Table D-2. Catch and Catch Per Unit Effort of Striped Bass Eggs and Early-life Stage Fish at Site 1 (Twitchell Island) Using an Egg and Larval Net, 1994

Striped Bass Eggs	**Catch**	**CPUE**
Morula	3	41.7
Early embryo	4	55.6
Late embryo	5	69.4
Dead	1	13.9
TOTAL	13	180.6

Early-Life-Stage Fish (Species)		
Striped bass	5	69.4
Yellowfin goby	2	27.8
Bigscale logperch	1	13.9
Prickly sculpin	8	111.1
Threadfin shad	0	0
Shimofuri goby	0	0
Centrarchidae	1	13.9
Cyprinidae	0	0
TOTAL	17	236.1

CPUE = catch per unit effort = catch per acre-foot of water sampled.

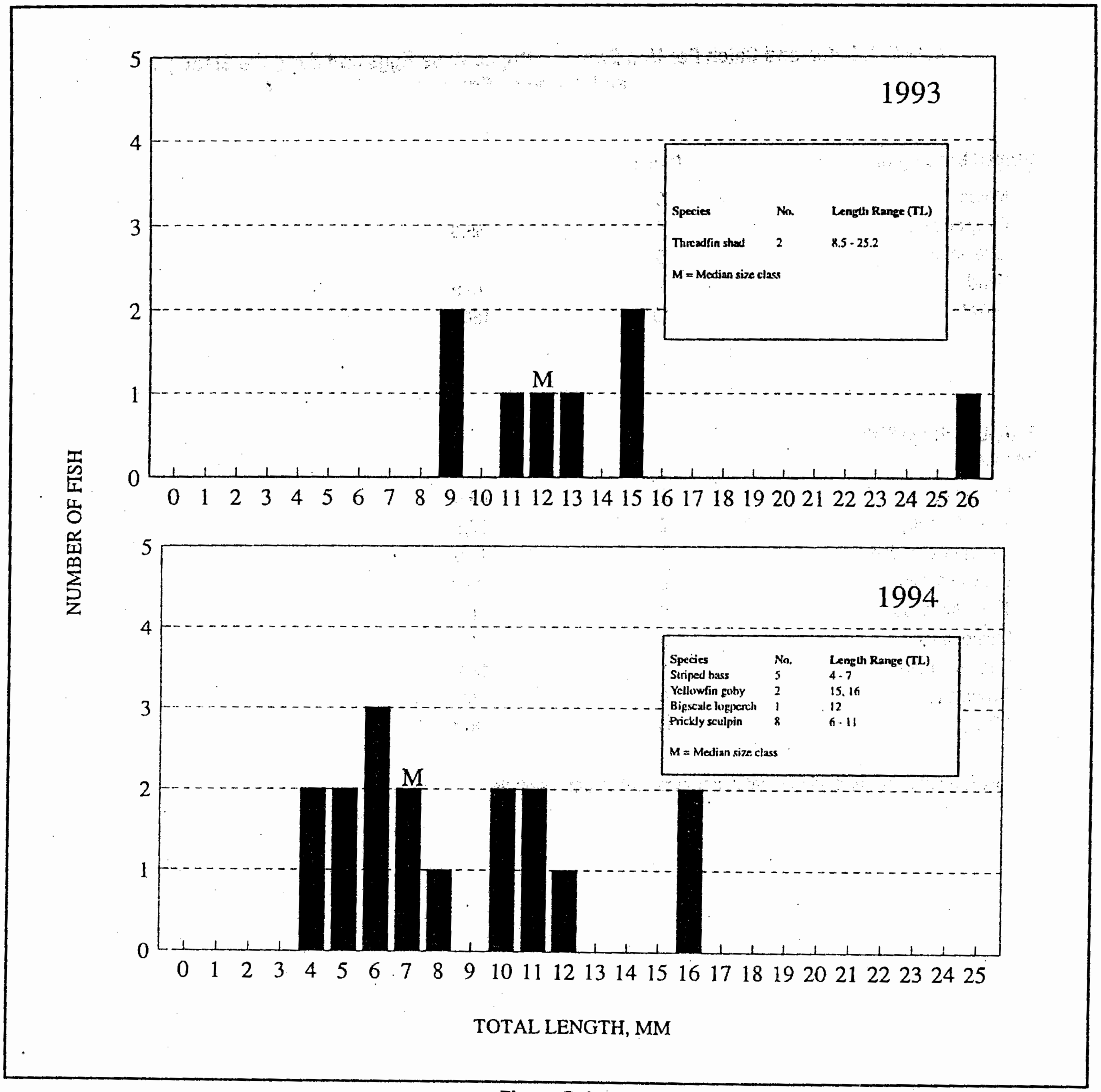

Figure D-1
Length-Frequency Distributions of Early-life Stage Fish Collected at Site 1 (Twitchell Island) Using an Egg and Larval Net, 1993-1994

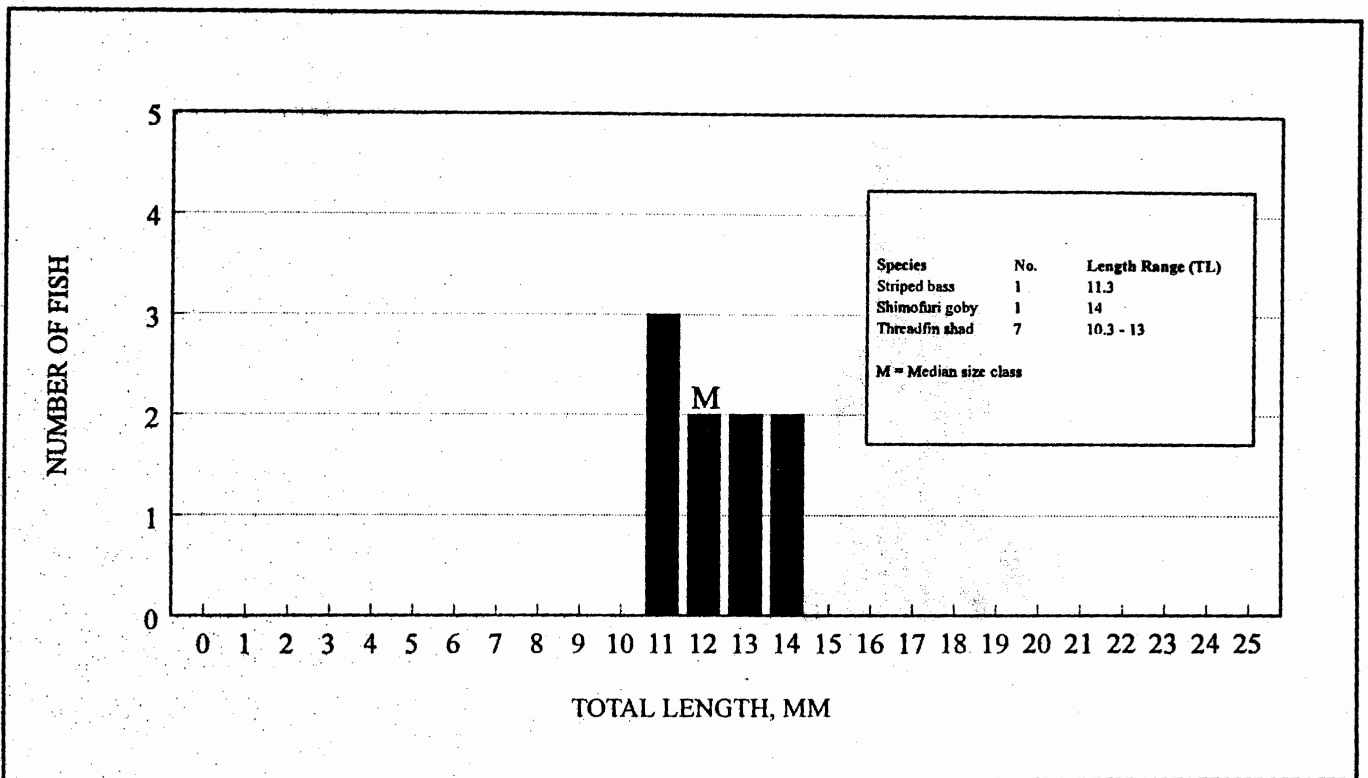

Figure D-2
Length-Frequency Distributions of Early-Life Stage Fish Collected at Site 2B (Bacon Island 14-inch Siphon) Using an Egg and Larval Net, 1993

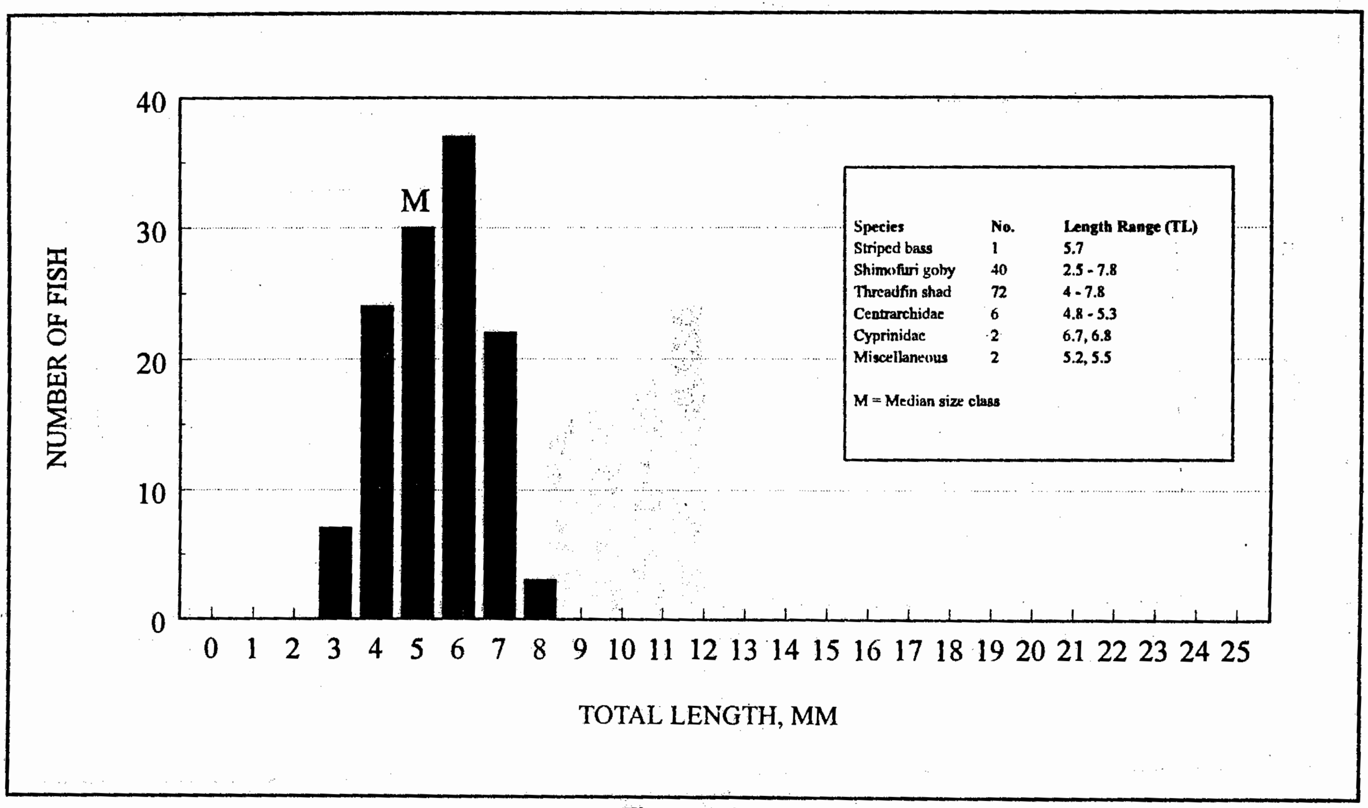

Figure D-3
Length-Frequency Distributions of Early-life Stage Fish Collected at Naglee Burk Using an Egg and Larval Net, 1993

APPENDIX E

1993 and 1994 Lakos Screen Evaluation

A Lakos-Plum Creek self cleaning, rotating, cylindrical fish screen was tested for its effectiveness at reducing fish entrainment in an agricultural diversion during 1993 and 1994. The diversion was located on Bacon Island adjacent to Middle River in the southern Sacramento-San Joaquin Delta. Overall study results showed:

- In 1993 and 1994, the density of fish collected under screened conditions was significantly less than the density of fish collected under unscreened conditions, with P.05 (n=30) and P.05 (n=54), respectively.
- Screen efficiency varied depending on the species of fish and life stage. In general, from spring through summer as fish grew in length, screen efficiency improved, as indicated by a decrease in entrainment.
- The self-cleaning Lakos-Plum Creek screen (2.3 mm square mesh, 0.045 mm wire diameter, 68.72 percent open area) was highly effective at reducing entrainment of fish over 20 mm TL.
- For the Lakos screen to be considered effective, it has to reduce fish loss and provide reliable operation. The screen significantly reduced entrainment; however, operational problems occurred with the siphon and spray bar system. Mortality resulting from impingement was not measured.

1993 AND 1994 LAKOS SCREEN EVALUATION

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May 1996

Introduction

In 1992, the Department of Water Resources (DWR) and Department of Fish and Game (DFG) implemented the Delta Agricultural Diversion Evaluation to develop reliable estimates of fish entrainment to agricultural diversions in the delta during the irrigation season, April through August. One component of the study was to test the effectiveness of a Lakos-Plum Creek self-cleaning fish screen on a 16-inch siphon at Bacon Island.

The 1993 and 1994 agricultural diversion screen tests took place in the central delta on the eastern side of Bacon Island, adjacent to Middle River (Figure 1). The Lakos-Plum Creek design (Model No. 3424-95512) had four self-cleaning, rotating, cylindrical screens constructed of 0.045 mm diameter phosphor bronze wire with 2.3 mm square mesh and 68.72 percent open area. The study was designed to determine the overall effectiveness of the Lakos screen design at reducing entrainment of fish into a small (less than 20 cfs) agricultural diversion. Another purpose of the study was to determine the feasibility of screening other similar agricultural diversions in the delta with the Lakos screen design.

Site Preparation

Before the screen could be installed and operated on Bacon Island, permission was obtained from the land owner. Electrical power was brought to the site and extensions and other special adjustments were made to the siphon. The screen backwash pump and electricity outlet box were enclosed with a chain link fence for safety and security reasons. The final cost of the Lakos fish screen at Bacon Island was $30,176.26, or approximately $2,011.75 per cfs when the siphon was operated at maximum capacity of 15 cfs.

Sampling Procedures

Sampling for juvenile and adult fish was conducted with and without the screen operating approximately once a week from June 3 through September 1, 1993, and April 26 through August 2, 1994. Sampling without the screen in place was achieved by raising the screen with the hand-winch until it was out of the water, and away from the diversion intake, and turning off the backwash pump. Conversely, screening the diversion was achieved by manually lowering the cylindrical drums with a hand-winch until the screen was in place over the intake, and then turning on the backwash pump for self-cleaning.

The screen test consisted of a paired sample of one hour under screened conditions and one hour under unscreened conditions. The order of screened to unscreened or unscreened to screened conditions was determined randomly. Most sampling was conducted during daylight hours for periods of four to eight hours. Night samples were collected through the tidal cycle over 24-hour sample periods one time during each of the sampling seasons. A total of 35 paired samples were collected in 1993 and a total of 54 paired samples were collected in 1994.

A fyke-type net constructed of one-eighth-inch mesh with live-box attached to the cod end was placed directly over the diversion outfall to sample one hundred percent of the diverted water during each test. Fish were identified to species, counted, and total length measured to the nearest mm. A flow meter (propeller type, Ketma McCrometer model MO300) installed in the diversion pipe measured diversion flow in cubic feet per second and total water volume diverted in acre-feet. Flowmeter readings were used to compute water volume sampled and fish densities entrained during each sample period.

Statistical evaluation of the data included the Wilcoxon signed ranks test, a nonparametric test based on the differences in paired observations, to determine the probability of a significant difference at the 0.05 level or 95 percent confidence (P=0.05) between the density of fish collected under screened and unscreened conditions. The Wilcoxon signed ranks test was also applied to individual species to determine if screening efficiency varied with species.

1993 Results Of Lakos Screen Study

Twelve species representing eight families were collected during screened and unscreened diversion sampling. All fish observed were introduced species. Striped bass were the most numerous, followed by threadfin shad, shimofuri goby, and yellowfin goby. No threatened or endangered species or species of special concern such as, delta smelt, winter-run chinook salmon, longfin smelt, or splittail, were collected during the 1993 screen test.

A total of 1,559 fish representing the twelve species was entrained in the diversion during the 15 days of 1993 screen testing. Of the 1,559 fish, 140 fish were collected with the screen in operation and 1,419 fish were collected without the screen in operation. For all species combined, the average number of fish entrained per acre-foot using the screen was 3.2, ranging between 0.0 and 20.6, while the average number of fish entrained per acre-foot without using the screen was 26.1, ranging from 0.0 to 184.8. Fish collected under screened conditions ranged in size from 4.5 - 51.0 mm total length (TL) (mean size 11.7 mm TL), while fish caught without the screen ranged in size from 3.5 - 347.0 mm TL (mean size 14.9 mm TL). Testing the two population means showed that the mean length of fish collected with the screen was significantly less (P.05) than the mean length of fish collected without the screen.

Results of the Wilcoxon signed ranks test indicate that the density of fish collected under screened conditions was significantly less (P.05, n=30) than the density of fish collected under unscreened conditions, with P-level equal to 0.001 (Table 1). In other words, the Lakos screen effectively reduced entrainment with greater than 95 percent certainty.

Separating out densities by species and applying the Wilcoxon signed ranks test showed that the Lakos screen significantly reduced entrainment of striped bass (mean length 15 mm TL), shimofuri goby (mean length 12 mm TL), bigscale logperch mean length 14 mm TL), and threadfin shad (mean length 11 mm TL)(Table 1). The screen did not significantly (P0.05) reduce entrainment of prickly sculpin (mean length 11 mm TL) and yellowfin goby (22 mm TL)(Table 1). An insufficient number of paired samples (n) to test with nonzero differences occurred for the following species: largemouth bass, white catfish, brown bullhead, fathead minnow, carp, and bluegill (Table 1).

While sampling with the screen, the average diversion flow rate was 11.6 cfs (range 8.2 to 13.3 cfs). Without the screen in operation, the average sampling diversion flow rate was 12.7 cfs (range 8.2 to 14.8 cfs). The average reduction in diversion flow was 8 percent with the screen in place relative to the average non-screen diversion flow.

1994 Results Of Lakos Screen Study

Similar to 1993, twelve species were entrained in the diversion during the 17 days of 1994 screen testing, with ten of the species remaining consistent between years. Staghorn sculpin and black crappie, entrained in 1994, were not seen in 1993.

Of the 357 fish collected in 1994, 68 fish were collected with the screen operating and 289 fish were collected without the screen. Striped bass were the most numerous, followed by shimofuri goby, threadfin shad, and prickly sculpin. No threatened or endangered or species of concern were collected during the 1994 screen test.

For all species combined, the average number of fish entrained per acre-foot with the screen was 0.10, with a range from 0.0 to 21.95, while the average number of fish entrained per acre-foot without the screen was 4.68, with a range from 0.0 to 35.11. Fish collected under screened conditions ranged in size from 7.5 - 29.0 mm TL (mean size 13.7 mm TL) while fish collected without the screen ranged in size from 4.7 - 335.0 mm TL (mean size 18.1 mm TL). The mean length of fish collected with the screen was significantly less (P.05) than the mean length of fish caught without the screen.

Wilcoxon signed ranks test results show that the density of fish collected under screened conditions was significantly less (P.05, n=37) than the density of fish collected under unscreened conditions (Table 1). Separating out densities by species and applying the Wilcoxon signed ranks test showed that the Lakos screen significantly reduced (P.05) entrainment of shimofuri goby (mean length 14 mm TL) and striped bass (mean length 14 mm TL) (Table 1). The screen did not significantly reduce (P0.05) entrainment of prickly sculpin (mean length 12 mm TL) and threadfin shad (mean length 14 mm TL) (Table 1). An insufficient number of paired samples (n) to test with nonzero differences occurred for the following species: bigscale logperch, yellowfin goby, staghorn sculpin, black crappie, carp, largemouth bass, white catfish, and bluegill (Table 1).

While sampling with the screen, the average diversion flow rate was 9.7 cfs (range 3.5 to 12.4 cfs). Without the screen in operation, the average diversion sampling flow rate was 10.5 cfs (range 3.1 to 13.7 cfs). The average reduction in diversion flow was 7 percent with the screen in place relative to the average non-screen diversion flow.

Discussion

The Lakos-Plum Creek Self-Cleaning Fish Screen reduced entrainment of fish into the 16-inch diversion on Bacon Island. However, screen efficiency varied depending on the species of fish and life stage. In general, from spring through summer in 1993 and 1994, screen efficiency improved and entrainment decreased as fish grew in length.

In 1993, the 140 fish collected under screened conditions were less than or equal to 20.0 mm TL, except for one yellowfin goby that measured 51.0 mm TL (Figure 2). Most likely, the larger yellowfin goby was entrained before the screen was lowered into place, and became stuck in the siphon or net, then later appeared in the live-box. In 1994, the 68 fish collected under screened conditions were 29.0 mm TL and smaller (Figure 3). Overall, the Lakos screen was highly effective at reducing entrainment of fish over 20.0 mm TL (Figure 2 and 3).

Although impingement mortality was not measured, past studies have indicated that approach velocities of 0.2 feet per second or lower, and sweeping velocities no greater than 0.37 feet per second, are required to prevent impingement and increased mortality of more sensitive species and life stages. Past test results were based on the swimming ability and impingement of larval and juvenile American shad and striped bass.

Average velocity through the Lakos screen was estimated to be 0.21 feet per second at the maximum diversion flow of 15 cfs. However, the diversion flow was generally less than 15 cfs during the 1993 and 1994 screen test, which would reduce the screen velocity. No measurements were taken of channel velocities sweeping past the test screen during 1993 and 1994 testing.

If fish avoid entrainment, the assumption is that fish survive. However, the possibility of impingement exists, along with the potential impacts of the backwash spray. If the backwash system results in physical injury to the fish, acute or delayed mortality may occur due to injuries or increased vulnerability to predation. Vulnerability to predation could also increase if the fish becomes too disoriented to escape or evade predators.

Flow alterations were noted by the farmer. Flow rate declined by as much as 1.5 cfs when the screen was in position on the end of the diversion pipe. Although the increase and decrease in flow due to operation of the screen did not appear to impact production or growth of potatoes, corn, and sunflowers grown on the island, it is important to note that the screen operation does impact diversion flow.

Operational problems occurred when the siphon lost prime several times from a leak in the backwash system, resulting in no screen sampling during July 1994. Also, fresh water sponge growths periodically blocked the spray jets so that the self-cleaning backwash system did not work properly. The jets needed to be unplugged manually two separate times in 1994. These features of the siphon and screen, in particular, would need to be addressed for maintenance criteria and reliability before the screen could be used on a widespread basis in the Delta.

Recommendations And Conclusions

The feasibility of test screening other small diversions in the Delta is questionable. Accessibility to properties and diversions, as well as obtaining permission from individual land owners to install and monitor screens is necessary. After electricity is brought to the site for operation of the screen, appropriate safety and security measures are also required. Finally, due to the problems that arose during the testing of the screen, a routine maintenance program is needed to ensure that a screen is working properly and meets current screen approach velocity criteria.

Table E-1. Paired Comparisons of Fish Densities Collected under Screened and Unscreened Conditions

Species	1993 Screen Test	1994 Screen Test
Striped Bass	P=0.000, n=24	P=0.005, n=22
Shimofuri Goby	P=0.000, n=24	P=0.000, n=33
Yellowfin Goby	P=0.463, n=6	* n=3
Prickly Sculpin	P=0.075, n=6	P=0.207, n=8
Bigscale Logperch	P=0.012, n=8	* n=3
Threadfin Shad	P=0.002, n=24	P=0.328, n=11
Largemouth Bass	* n=3	* n=2
White Catfish	* n=2	* n=3
Brown Bullhead	* n=3	* n=0
Fathead Minnow	* n=1	* n=0
Carp	* n=1	* n=1
Staghorn Sculpin	* n=0	* n=3
Black Crappie	* n=0	* n=1
Bluegill	* n=2	* n=1
All Species Combined	P=0.001, n=30	P=0.001, n=37

Values shown are the significance levels from the Wilcoxon Signed Ranks Test. An asterisk indicates zero catch during paired sampling or an insufficient number of paired samples (n) to test with nonzero differences.

Ho: The density of fish collected under screened conditions is not significantly less than the density of fish collected under unscreened conditions.

Ha: The density of fish collected under screened conditions is significantly less than the density of fish collected under unscreened conditions at a confidence level of 95% (P.05).

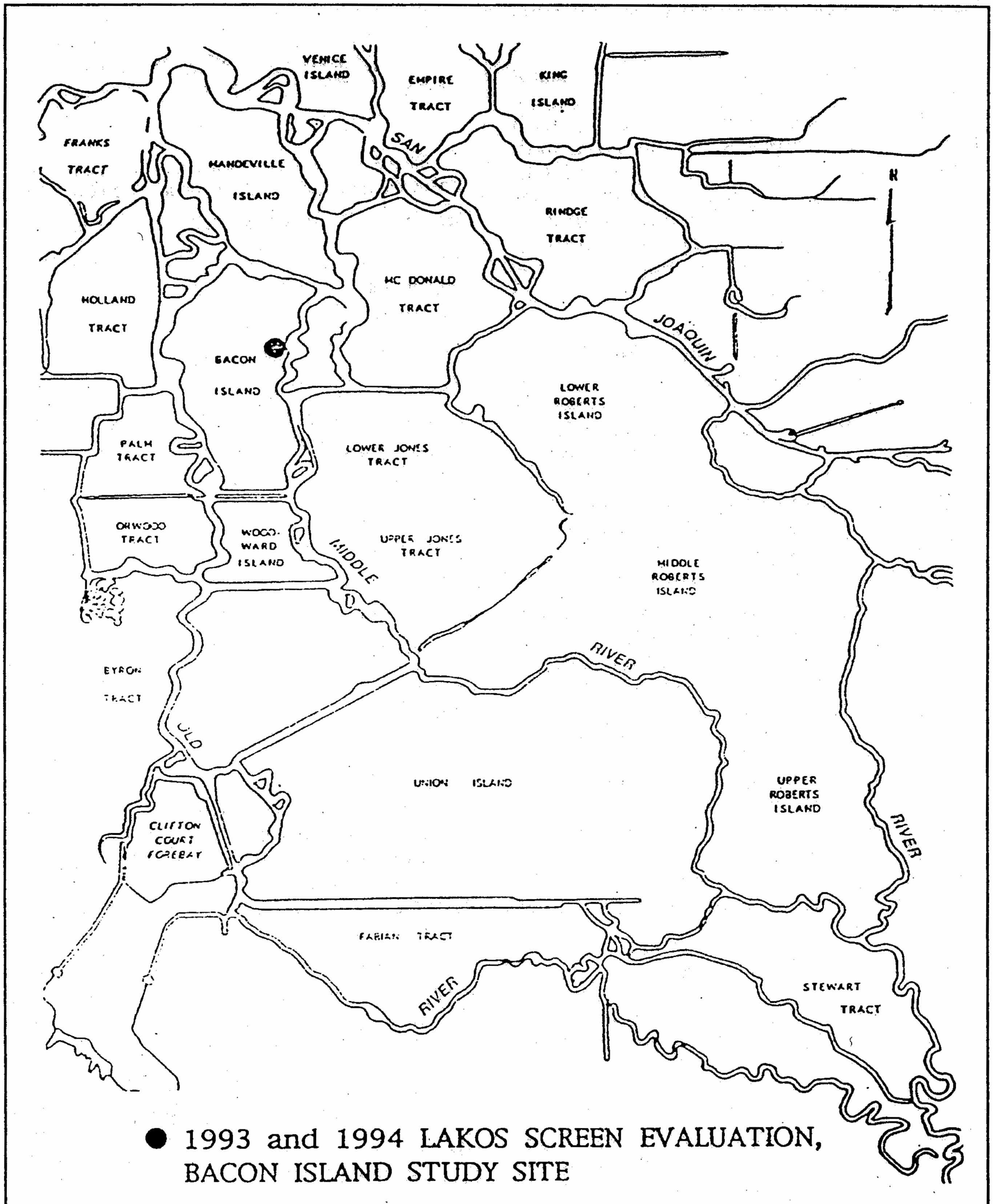

Figure E-1
Location of the 1993 and 1994 Lakos Screen Study Site, Bacon Island

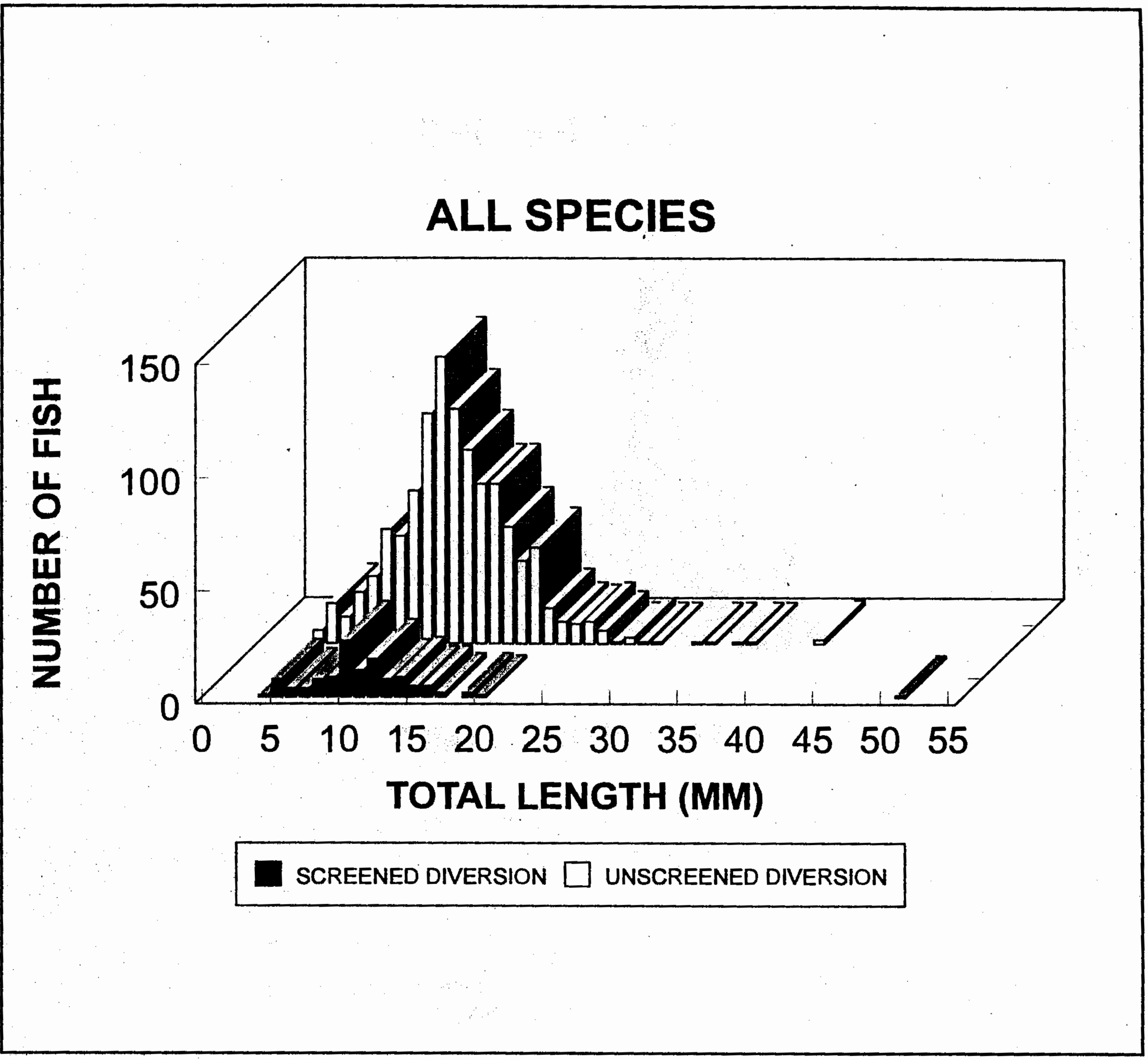

Figure E-2
Length-Frequency Distribution of 5-55 mm TL Fish under Screened and Unscreened Conditions at Bacon Island Study Site, 1993

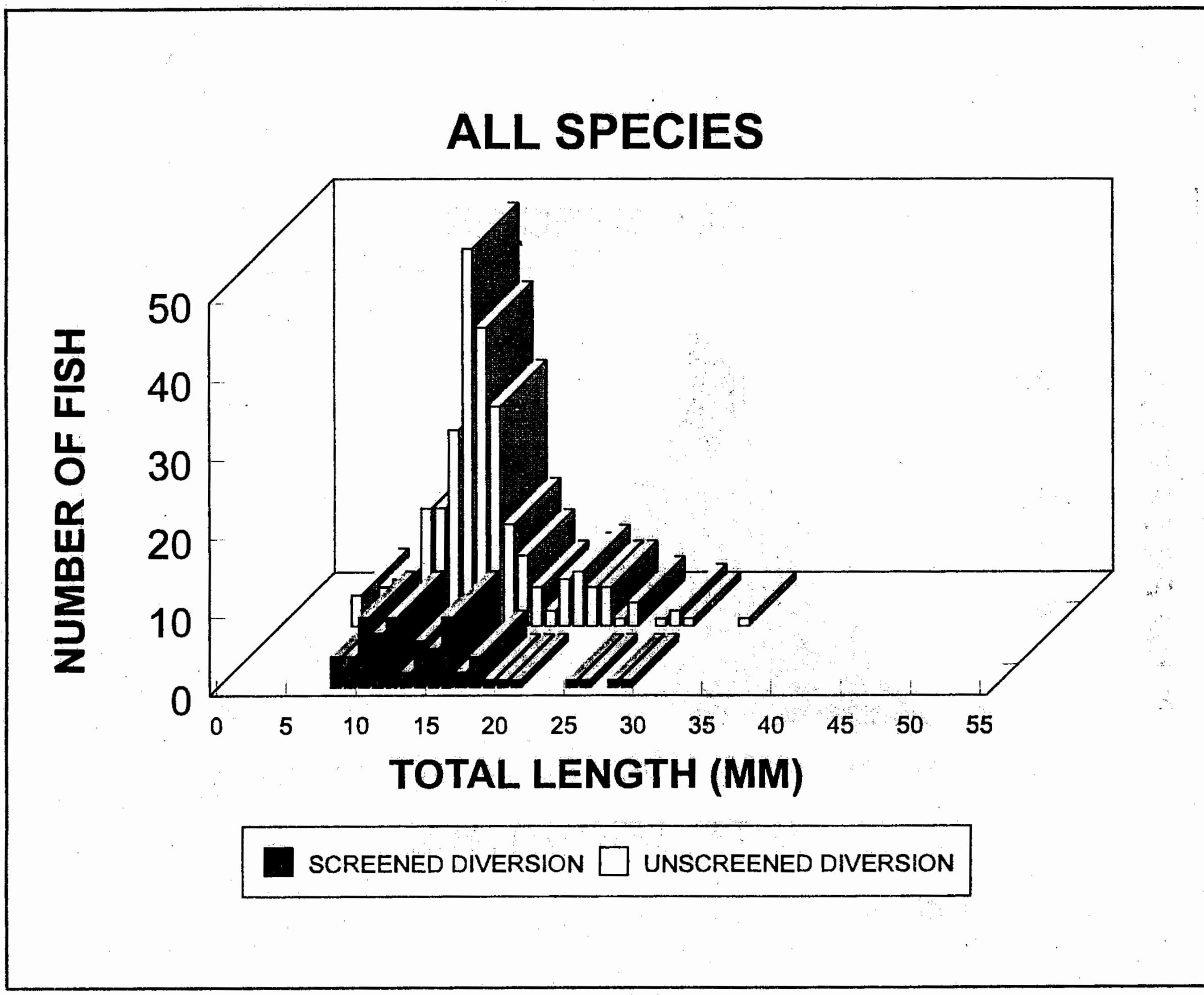

Figure E-3
Length-Frequency Distribution of 5-55 mm TL Fish under Screened and Unscreened Conditions at the Bacon Island Study Site, 1994