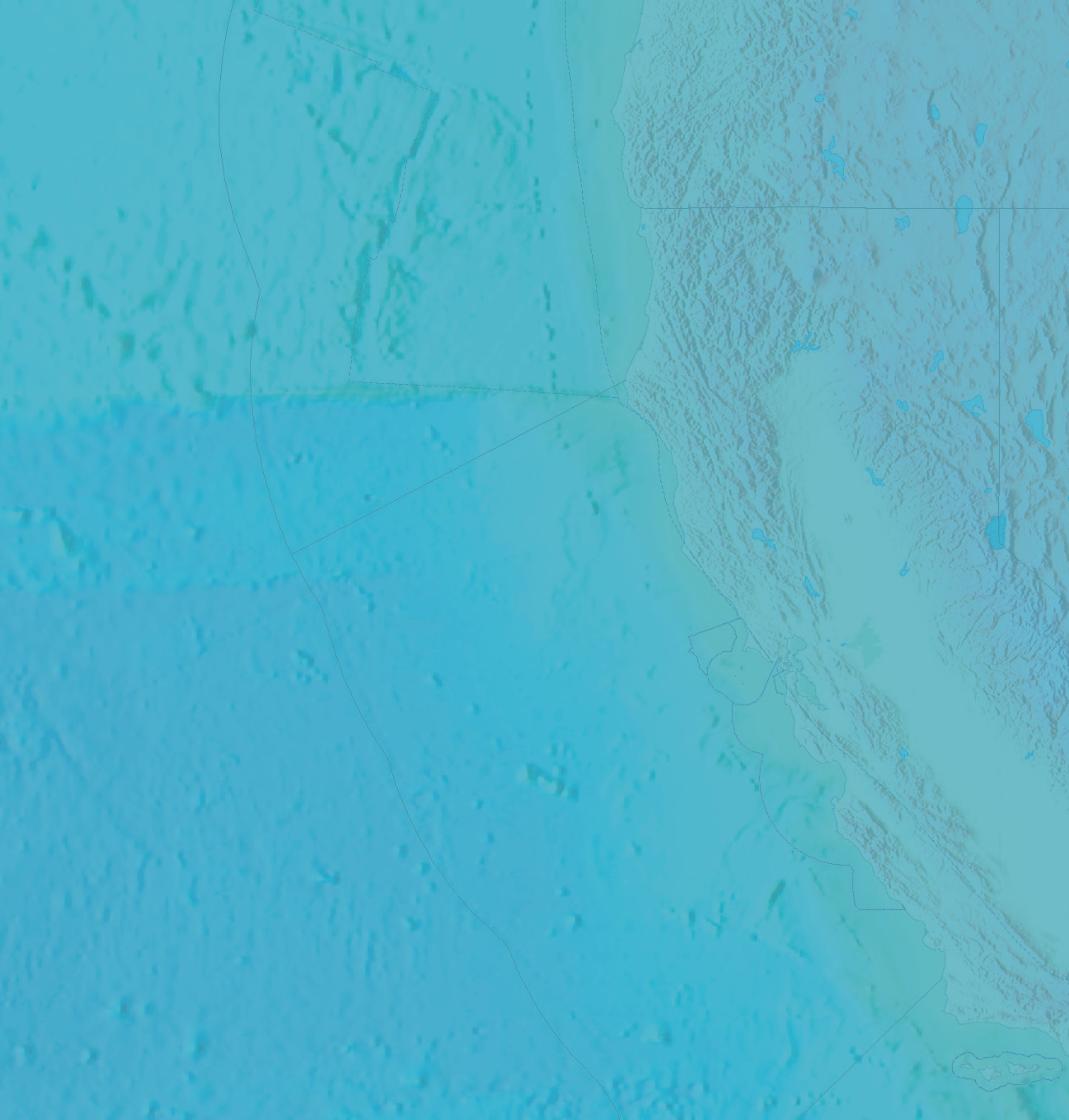
A Possible Approach for Integrating Delta Aquatic Species Survey Data

OCTOBER 2006



Cover Map Graphic from DFG Website: http://www.delta.dfg.ca.gov

Cover Photographs of 20-mm Survey Sampling from IEP Long-Term Fish Monitoring Program Element Review (2004)

Jones & Stokes. 2006. *A possible approach for integrating Delta aquatic species survey data.* Sacramento, CA.

Jones & Stokes

Memorandum

Date: October 2006

To: Bay-Delta Scientists and Resource Managers

From: Jones & Stokes staff
Contact: Russ Brown, Ph.D.
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Subject: **Improved Delta Habitat and Fish Impact Assessments**

Jones & Stokes staff has participated in impact assessments and evaluations for many water projects and habitat restoration efforts over the past 20 years. The habitat and fish evaluations for each of these proposed projects require a comprehensive description of the historical and existing habitat conditions and an accurate understanding of the dominant relationships between various habitat factors and fish distribution and abundance. Most of our impact assessments (CEQA and NEPA documents) begin with reiterating the somewhat limited information about the life history, required habitat conditions (salinity and temperature), and the measured patterns of abundance and distribution for each fish of interest. The established relationships between habitat and fish responses then are described to introduce impact assessment calculations or more qualitative conclusions about likely impacts.

This report suggests a general approach to impact assessment that would be based on assessment models for each fish population in the Bay-Delta ecosystem, including fish in the tributary streams of the Sacramento–San Joaquin Basins. This assessment approach could begin with summary reports about the methods and results of each of the major IEP fish surveys. The results from each survey could be integrated to provide a consistent description of the habitat conditions and the abundance and distribution patterns for the fish populations in the Bay-Delta. The summary reports for the major IEP surveys could complement the ongoing IEP POD studies and contribute to the CALFED Science goals of coordinating with IEP scientists and communicating improved scientific understanding of the Bay-Delta habitat and ecosystem.

The IEP fish survey summary reports could provide the basis for a common description of existing conditions that could be used for all subsequent Bay-Delta impact assessments. The extensive environmental information needed for reliable impact assessments can be thought of as an "electronic encyclopedia" about what has been observed in the Bay-Delta ecosystem. An assessment model for each fish population would provide the foundation for more accurately evaluating the likely effects of potential projects to restore habitats or modify our water management facilities and operating criteria.

Please read this report and respond with your ideas about how to refine our evaluation of the existing fish survey information and how to develop better methods for habitat and fish impact assessments.

Contents

Tables and Figures

Acronyms and Abbreviations

Bay	San Francisco Bay
CBDA	California Bay-Delta Authority
cfs	cubic feet per second
CVP	Central Valley Project
Delta	Sacramento–San Joaquin River Delta
DFG	California Department of Fish and Game
EC	salinity (electrical conductivity)
FMWT	Fall Midwater Trawl
IEP	Interagency Ecological Program
msl	mean sea level
NOAA Fisheries	National Marine Fisheries Service
POD	pelagic organism decline
QWEST	net flow on the San Joaquin River at Jersey Point
SWP	State Water Project
µS/cm	microSiemens per centimeter

A Possible Approach for Integrating Delta Aquatic Species Survey Data

Introduction

Ecological evaluations of San Francisco Bay (Bay) and the Sacramento–San Joaquin River Delta (Delta) rely on the sampling and measurement surveys conducted by dedicated staff scientists of the Interagency Ecological Program (IEP) agencies and associated university research faculty and students. The scientific methods employed by these agency and research scientists identify hypotheses about the observed ecological conditions and relationships among physical, chemical, and biological variables within this interactive and dynamic natural ecosystem. Evidence from all historical fish and aquatic organism surveys as well as other available sources of information, together with the existing understanding of species life-stage and movement patterns, is employed in this quest for accurate knowledge and understanding to provide management guidance to the resource protection and water management agencies. These scientific findings are often communicated to interested public and political representatives as part of the general discussions of appropriate and effective management and protection of California's environmental and water resources.

The potential causes of observed variations in the abundance of some pelagic fish species are being investigated intensively, and the major factors that can be linked to changes in the reproduction and survival of these species certainly will be controlled, if possible. Management adjustments from both the water project agencies and the fish protection agencies may be required. For example, sampling programs might be adjusted to reduce the uncertainty related to tracking the distribution and abundance of all life stages of these species in the Delta.

The California Bay-Delta Authority (CBDA) sponsored a technical panel of fish scientists and a workshop on November 14 and 15, 2005, to review the initial efforts and plans of the IEP Pelagic Organism Decline (POD) work-team. One of the panel's recommendations was that the recent decline in the fall midwater trawl (FMWT) indices should be investigated as part of the overall trends and variations in the pelagic organism populations in the Bay-Delta. This report illustrates how more data from several existing IEP fish surveys could be compared and integrated to derive more comprehensive information about the relative abundance and distribution of pelagic organisms in the Bay-Delta, as well as aid the search for major factors that may influence these fish abundance and distribution patterns.

The suggested approach begins with the integration of all available historical survey data to identify the abundance and distribution patterns of all major pelagic organisms in the Bay and Delta. The sampling characteristics for each major survey (FMWT, Bay Study, Chipps Island trawl, 20-mm survey, summer townet, winter Kodiak, and Central Valley Project [CVP] and State Water Project [SWP] salvage) could be compared, and results from each survey could be combined with our knowledge of the life-history and movement patterns for each species to provide an annual integrated description of the abundance and distribution of each species within the Bay-Delta habitats. The basic survey data could be made more easily available and distributed to support more detailed analyses and evaluations by interested scientists and resource managers.

Several targeted actions that could be taken to study and protect the current population of delta smelt are suggested. For example, because the peak abundance of adult delta smelt in the Chipps Island trawl has been observed in January or February of several recent years, Chipps Island trawls could be conducted daily from January through March to better track the relative abundance of delta smelt. These integrated evaluations and initial protective actions will strengthen the ongoing IEP POD work-team efforts to evaluate potential causes for recent low FMWT index values.

Fall Midwater Trawl Monthly Catch and Annual Indices

The FMWT began in 1967 as one of the original (the summer townet was established in 1959) annual fish surveys established to determine the relative abundance and distribution of juvenile striped bass in the Delta and Suisun Bay. The FMWT survey has used generally consistent methods at about 100 stations to catch fish in September, October, November, and December of almost every year (missing 1974 and 1979). An index value (very similar to the total catch of fish in the 400 samples for each year) generally has been used to track the abundance of striped bass, delta smelt, American shad, and longfin smelt. Many other fish are caught, but these four "index fish" have established abundance indices that are calculated and compared for trends by the California Department of Fish and Game (DFG).

The basic sampling variability is quite large for rare fish such as delta smelt and longfin smelt. Therefore, the sampling statistics for this survey program could be considered more fully in the interpretation of the annual catch (i.e., indices). Appendix A demonstrates the high variability expected for random distributions of rare fish. Sampling variability may be much higher for clumped or patchy (i.e., schooling) fish, such as northern anchovy and threadfin shad.

The FMWT sampling variability can be illustrated by comparing the four monthly catch values that are used to calculate the annual index. The populations of each pelagic fish species during the fall are assumed to be relatively constant, although there may be movement of some species (into or out of the FMWT sampling areas), and there is an expected mortality for all fish species (of perhaps 5–10% per month). Nevertheless, the observed variability in the monthly FMWT catch is quite high for all species. Combining the four monthly catch values would reduce the uncertainty in the actual fish abundance, but the variability remains large for rare fish.

For example, Figure 1 shows the monthly FMWT catch of delta smelt for 1967–2005. The range of monthly catches within any particular year is quite high. Almost every year has at least one month with a very low catch (i.e., fewer than 25 fish). Several years have a high monthly catch value (i.e., more than 200 fish). While some monthly catch values are similar within a year, the difference between the highest and lowest monthly catch values is more than 100 fish in almost all years, and more than 200 fish in the four recent years with high index values (1998–2001). Some fluctuations in the annual index values may be the result of sampling variability and may not reflect changes in abundance.

The historical range of variation in the monthly catch and the annual catch (index value) could be considered more fully in the interpretation of the recent changes in the index values. Sampling variability may limit the ability to determine whether the recent abundance index values are actually lower than previous periods of low delta smelt abundance. Because of the high sampling variability, the annual index values may reflect random fluctuations in FMWT sampling success, rather than a reliable measure of the population abundance.

Figure 2a shows the cumulative probability of the monthly catch of delta smelt for the entire 1967–2004 FMWT survey period. There was a 10% chance of a monthly catch of fewer than 15 fish, a 33% chance of fewer than 50 fish, a 66% chance of fewer than 100 fish, and a 10% chance of more than 300 fish.

Figure 2b indicates that the distribution (probability) of FMWT monthly catch of delta smelt has not shifted greatly from the first half of the record (1967–1980) to the second half of the record (1981–2004). Determining whether the population has actually shifted in the recent four years (since 2001) may not be statistically possible with this large monthly variability.

Recommendation (1)

A consistent evaluation of all available fish data is needed to guide management decisions and actions. The reliance on a few annual summary index values could be replaced by a more thorough evaluation of the integrated data obtained each year from the FMWT and other Delta fish surveys.

In particular, the Bay Study, winter Kodiak trawls, spring 20-mm surveys, summer townet surveys, and FMWT data could be combined to provide an annual population assessment for delta smelt and other pelagic fish. The daily results from the Chipps Island trawl and the CVP and SWP salvage data also could be included in the annual assessments. These integrated assessments would provide a general description of the abundance and distribution patterns for delta smelt and other fish, and could be used to determine trends or shifts in recent years. Statistical methods could be employed to quantify the expected sampling variability for each survey, for an assumed abundance and distribution of each fish population.

The integrated assessment could include variations in general environmental factors (e.g., Delta outflow, temperature) or other biological factors (e.g., abundance of competing pelagic species, zooplankton, and jellyfish) that may help to interpret some of the observed variations in pelagic fish. The ongoing POD investigations by IEP scientists can contribute greatly to this overall assessment of fish abundance and distribution patterns, as well as the identification of major environmental factors influencing these pelagic fish patterns.

Sampling the Salinity Habitat of Pelagic Fish

The salinity habitat range is likely an important factor governing the distribution of estuarine pelagic fish species. An attempt could be made to distinguish between the sampled range of habitat conditions and the suitable range of habitat conditions for each species. The relative catch of delta smelt throughout the entire range of FMWT salinity samples has been evaluated as an example of the recommended approach.

Figure 3 shows the overall cumulative distribution of FMWT samples (trawls) and delta smelt catch as a function of salinity (electrical conductivity [EC]) for 1967–2004. Samples were collected from salinities less than 200 microSiemens per centimeter (µS/cm) to more than 40,000 µS/cm. About 30% of the samples were collected at salinities of less than 1,000 µS/cm, and 50% were collected at salinities of less than 10,000 µS/cm. In contrast, the majority of delta smelt catch was confined to samples of less than 10,000 µS/cm.

Figure 3 also indicates the probability of delta smelt catch (i.e., probability of catching at least one delta smelt in a trawl) for stations within each 500 µS/cm increment of salinity. The probability of catch is greater than 0.25 (25%) between 1,000 µS/cm and 10,000 µS/cm. The maximum probability is about 0.5 (50%) between 2,000 µS/cm and 6,500 µS/cm, which means that 50% of the trawls in that salinity range catch delta smelt. The highest expected average catch per sample is between two and five fish, within the salinity range of 2,000 µS/cm to 6,500 µS/cm. Because half of the trawls do not catch delta smelt, trawls that do catch delta smelt must average four to ten fish to result in the average of two to five fish per trawl. Approximately half of the FMWT stations are within the delta smelt preferred salinity range.

The average catch or density (catch/volume) of fish in the samples from within this suitable salinity habitat zone might be a more informative index of abundance than the average density for the entire survey. The fraction of the stations within the suitable habitat zone is a sampling survey characteristic that could be tracked separately. More information about the distribution of fish within the suitable habitat zone can be obtained by analyzing the distribution of catch from the individual monthly samples. The fish are not likely to be uniformly distributed when the probability of catch is relatively low. They are more likely to be randomly distributed or patchy, caused by schooling behavior or food (e.g., zooplankton) patchiness. Estimates of abundance require an estimate of this distribution pattern, as well as the sampling efficiency and the volume of water within the suitable salinity habitat zone.

Table 1 shows the FMWT catch and station information for the 2005 monthly survey results. The catch, the number of stations with catch, and the fraction of the catch that was upstream of Martinez (i.e., Suisun Bay and Delta) provide some of the recommended distribution and sampling variability information. For example, the northern anchovy monthly catch values were 335 at 26 stations in September, 2,676 at 22 stations in October, 93 at seven stations in November, and 1,156 at 19 stations in December. The catch value in November was low because 18 stations in San Pablo Bay were not sampled (equipment problems). The total catch of northern anchovy was 4,260 in 74 trawls, which was an average of 58 fish/trawl for trawls with northern anchovy. Northern anchovy is known to be a schooling fish. Only 4% of the northern anchovy catch was from stations upstream of Martinez. Northern anchovy is known to have a relatively high suitable salinity-habitat zone.

As another example, Table 1 indicates that American shad were much more widely distributed than northern anchovy. The 2005 American shad catch values were 488 at 55 stations in September, 536 at 59 stations in October, 174 at 44 stations in November, and 196 at 61 stations in December. The total catch was 1,395 in 219 trawls (50% of the 443 trawls in 2005), which is an average of six fish/trawl for trawls with American shad. For American shad, 86% of the catch was upstream of Martinez.

Table 1 also shows the delta smelt monthly catch values for 2005. There were four delta smelt at four stations in September, ten at six stations in October, seven at six stations in November, and 16 at 11 stations in December. The annual catch was 37 fish in 27 trawls, which is less than 1.5 fish/trawl for trawls with delta smelt. All of the delta smelt were caught upstream of Martinez.

Recommendation (2)

The suitable salinity–habitat zone for each major fish species found in the Bay Study and FMWT survey could be identified. The survey summaries could separately report the catch, the portion of samples within the suitable salinity–habitat zone, and the catch per station within the suitable salinity-habitat zone for each species. Adjustments in the sampling station locations could be considered if it is determined that there are not enough sampling stations within the suitable salinity–habitat zones for species of interest. Reporting the catch per station within the suitable salinity-habitat zone would allow information from historical sampling locations to be compared to results from modified sampling locations.

Table 1. Summary of Fall Midwater Trawl Catch from September to December 2005

Common Name	Sept Total Monthly Catch	Sept Number of Stations with Catch	Oct Total Monthly Catch	Oct Number of Stations with Catch	Nov Total Monthly Catch	Nov Number of Stations with Catch	Dec Total Monthly Catch	Dec Number of Stations with Catch	Total Catch Sept to December	Sept to December Trawls with Catch	Percent of Annual Abundance	Percent of Catch Upstream of Martinez
Bat ray					2	2	1	1	3	3	0.03%	33%
Maeotias (Black Sea jellyfish)	680	21	443	17	718	18	3	2	1844	58	16.07%	100%
Siberian prawn	16	3	31	5	4	4	1	1	52	13	0.45%	100%
Polyorchis (native jellyfish)							674	28	674	28	5.87%	22%
Comb jelly or sea gooseberry							172	25	172	25	1.50%	42%
Northern anchovy	335	26	2676	22	93	7	1156	19	4260	74	37.13%	4%
Plainfin midshipman							6	3	6	3	0.05%	17%
Pacific herring	91	10	62	16	6	4	5	5	164	35	1.43%	63%
American shad	488	55	536	59	174	44	197	61	1395	219	12.16%	86%
Threadfin shad	210	19	792	18	703	25	464	61	2169	123	18.90%	97%
Crangon shrimp	59	8	2	2	2	1	123	11	186	22	1.62%	45%
Palaemon shrimp							4	2	4	2	0.03%	25%
Delta smelt	4	4	10	6	7	6	16	11	37	27	0.32%	100%
Longfin smelt	1	1	5	3	11	8	144	44	161	56	1.40%	75%
Pacific staghorn sculpin			1	1			1	1	2	2	0.02%	0%
Starry flounder	1	1	1	1			1	1	3	3	0.03%	0%
Young-of-year striped bass	41	17	14	9	21	11	32	22	108	59	0.94%	95%
Age 1 striped bass	7	5	4	3	3	3	6	5	20	16	0.17%	64%
Age 2 striped bass	5	4	4	3			6	4	15	11	0.13%	53%

Common Name	Sept Total Monthly Catch	Sept Number of Stations with Catch	Oct Total Monthly Catch	Oct Number of Stations with Catch	Nov Total Monthly Catch	Nov Number of Stations with Catch	Dec Total Monthly Catch	Dec Number of Stations with Catch	Total Catch Sept to December	Sept to December Trawls with Catch	Percent of Annual Abundance	Percent of Catch Upstream of Martinez
Topsmelt	3	2	90	14	2	2	51	9	146	27	1.27%	3%
Channel catfish	2	2					1	1	3	3	0.03%	100%
White croaker							6	3	6	3	0.05%	16%
Yellowfin goby			2	2	1	1	3	2	6	5	0.05%	100%
Bluegill							2	2	2	2	0.02%	100%
Golden shiner							1	1	1	1	0.01%	100%
Jacksmelt	1	1	2	2			1	1	4	4	0.03%	25%
English sole							1	1	1	1	0.01%	0%
Chinook salmon					1	1	19	16	20	17	0.17%	100%
Shimo furi goby	1	1	1	1			1	1	3	3	0.03%	66%
White catfish					4	1			4	1	0.03%	100%
Splittail	1	1							1	1	0.01%	0%
Inland silverside	1	1							1	1	0.01%	100%
Redear sunfish					1	1			1	1	0.01%	100%
Total Catch or Trawls	1,947	116	4,676	114	1,753	98	3,098	115	11,474	443	100%	81%
Catch without jellyfish	1,267		4,233		1,035		2,249		8,784		76%	

Delta Smelt Abundance Patterns in Central Valley Project and State Water Project Salvage and Chipps Island Trawls

The CVP Tracy and SWP Skinner fish salvage facilities provide louver screening (separation) of fish longer than 20 mm from the water being pumped from the Delta. However, because these pumps are located at the southwest corner of the Delta channel network, the density of fish that are screened and counted and salvaged (returned to the Delta near Antioch) may be lower than fish densities in other Delta locations with more suitable habitat conditions (e.g., confluence or X2 zone and Suisun Marsh/Bay).

Compensating for the south Delta location factor are two important sampling considerations—(1) the dual salvage facilities with similar pumping volumes (4,400 cubic feet per second [cfs] capacity at CVP and 6,680 cfs capacity at SWP) and (2) the large sampling volumes (i.e., fish are counted in about 1/12 of the water being screened and pumped). The salvage records provide replicate daily samples of the south Delta fish densities, with maximum daily sample volumes of 500 to 1,000 acre-feet. Even without adjusting for the louver efficiency and predation losses that may be associated with the salvage facilities, the daily catch and density estimates are an excellent record for understanding and evaluating delta smelt and other pelagic fish abundance patterns.

The Chipps Island trawl was established to track Chinook salmon abundance and out-migration patterns from the Delta toward Suisun Bay. The Chipps Island trawl was initially deployed in the spring months of April, May, and June. However, interest in other races of Chinook salmon (winter-run and spring-run) led to an expanded sampling schedule that started in December and continued into the summer, beginning in 1994. The Chipps Island trawl now operates in almost all months, although trawling is conducted only every 3 days during the fall. Because several 20-minute trawls are made during daylight hours, the daily sample volume is 150–200 acre-feet. This is a considerable sample volume and provides a reasonable estimate of the density (and abundance) of fish that are caught at this location (pelagic species). Efficiency of the trawl for fish other than Chinook salmon remains uncertain. The net size was increased slightly in 1997 (Pat Brandes pers. comm.) to reduce the number of delta smelt caught in the Chipps Island trawl, suggesting this is a very good place to catch delta smelt. The observed patterns of daily delta smelt density near Chipps Island provide another important record of relative seasonal and annual abundance in the Delta. The Chipps Island trawl data for other fish species may also be useful for the overall assessment of pelagic fish in the Delta.

Seasonal Density Patterns of Delta Smelt for 1994–2005

Review of the CVP and SWP salvage records together with the Chipps Island trawl results (not adjusted for net efficiency) can provide a fascinating overview of the natural fluctuations and variations in timing and magnitude of delta smelt adult migration and spawning and juvenile abundance in the Delta. The seasonal patterns of delta smelt density (catch/volume) at Chipps Island and in the CVP and SWP salvage are shown in Figures 4–9 for 1994–2005. The Delta outflow is shown for comparison. These 12 years include the period of unusually high abundance in the FMWT survey, as well as the recent four years of lower FMWT abundance.

The seasonal salvage density patterns reflect the basic features of the delta smelt life history. Adults apparently disperse from the confluence near Chipps Island into the Delta freshwater sloughs and channels, showing up in the CVP and SWP salvage records during the December–March period. Delta smelt generally spawn in March and April, so juveniles longer than 20 mm begin showing up in the salvage at relatively high densities in late May and early June of most years. Salvage of delta smelt generally is greatly reduced in late June or July, perhaps because the ideal spawning temperature is <20˚C, or because the juveniles move toward the estuary habitat near the confluence and Chipps Island, or because they are rapidly entrained in the exports. A review of these recent years of salvage patterns may suggest that the movement of adults into the south Delta channels occurs immediately after the first large outflow event (i.e., greater than 25,000 cfs after December 1). Fewer adults and juveniles are observed in the CVP and SWP salvage in extremely wet years, such as 1998, 2005, and 2006.

The seasonal density at Chipps Island generally also follows this simple life-history pattern. The lowest density of delta smelt generally occurs in April and May; adults may have dispersed to spawn and juveniles may not yet have arrived at their preferred rearing area at the upstream edge of the estuary salinity gradient near Chipps Island. The density appears to increase in June and July as juveniles arrive. The Chipps Island density may decrease from natural mortality or increase from downstream movement of juveniles into September (when the first FMWT survey is conducted). Chipps Island sampling has not been as intensive during these summer months, following the peak Chinook salmon migration period. The Chipps Island density appears to reach a maximum sometime between December and February, as more of the adults migrate into the confluence area. The Chipps Island density appears to decrease during the period that the adults are salvaged at the pumps, suggesting that the population has dispersed from the Chipps Island area to spawn. The density remaining near Chipps Island is generally greater than the peak adult salvage density. Possible relationships between Delta outflow or Chipps Island salinity and delta smelt density could be explored to increase our understanding of the observed density patterns in the Chipps Island trawls.

Comparison of the CVP and SWP salvage densities with the CVP and SWP pumping patterns for these same years (1994–2005) is shown in Figures 10–15. The delta smelt densities are often very similar at the two salvage facilities.

Further analysis of these replicate records of delta smelt density patterns could be made to better understand the variations in density caused by different sources of water (i.e., San Joaquin River inflows often provide a majority of the water pumped at the CVP and do not have delta smelt juveniles). The relative predation losses at the two facilities might also be examined. Similar analyses of the Chipps Island and salvage records could be conducted for other relatively abundant pelagic fish.

An annual abundance index might be estimated from the peak monthly occurrence of delta smelt in the Chipps Island trawl data. The monthly average delta smelt occurrence (fish/day) for 1994–2005 is shown in Table 2. The Chipps Island trawl abundance records indicate very high peak monthly occurrence of delta smelt in 1994 and 1996. This is similar to the FMWT index values that were high in the fall of 1993 and 1995. The most recent decline in annual Chipps Island abundance occurred from 1999 (98/day) to 2000 (32/day) to 2001 (5/day), 2 years ahead of the reported delta smelt FMWT decline between 2001 and 2002. The Chipps Island trawl abundance of delta smelt does appear to be relatively low in the four recent years (2002–2005). However, we do not have Chipps Island trawl data for the winter months of peak abundance prior to 1994. The occurrence of delta smelt in the Chipps Island trawls in the four recent years has been lower than for 1994–2001, but this cannot be identified as unusually low relative to historical fluctuations in the delta smelt catch values because the period of record for this survey is relatively short (12 years).

Recommendation (3)

The daily CVP and SWP salvage densities and the Chipps Island trawl densities could be combined to provide a more complete record of delta smelt and other pelagic fish abundance and distribution in the Delta since 1994 (13 years). The results from these two sampling programs could be integrated with other IEP sampling programs to provide an annual integrated description of the life-stage abundance and distribution patterns of delta smelt and other Delta fish species. The relationship between FMWT catch for stations in the vicinity of Chipps Island could be identified for 1994–2005 and an integrated annual abundance index developed as a more informative measure of likely adult delta smelt abundance within the suitable habitat zone for pre-spawning adults.

Table 2. Monthly Average of the Daily Catch of Delta Smelt in the Chipps Island Trawl

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Max of Oct–Jan Daily Catch Index of Annual Abundance	Previous FMWT Index
1990							1	0	4					
1991							1	0	0					
1992							2	1	1					
1993							2	2	3	2				
1994		177	12	73	63	36	3	1	352				177	1,078
1995	16	19	62	28	14	15	8	5	20	27	122	230	62	102
1996	264	258	200	254	26	102	99	79	118	142	114		264	899
1997	90	37	45	1	1	6	1	4	13	11	10	11	90	127
1998	7	10	51	18	3	11	10	5	15			32	51	303
1999	53	37	41	62	23	32	28	19	23	86	63	34	62	420
2000	32	41	98	86	13	14	7	5	35	100	77	59	98	864
2001	11	32	29	32	33	8	1	4	33	5	3	1	32	756
2002	0	5	5	4	5	2	1	1	2	1			5	603
2003	1	2	7	10	18	2	1	2	2	3	2	1	10	139
2004	0	0	1	2	1	2	2	0	1	1	2	1	2	210
2005	0	9	7	4	3	4	3	4	6	12	3	2	9	74

Note: There may have been a change in the net size in 1997 to reduce the take of delta smelt. The Chipps Island trawl appears to provide an important seasonal pattern of delta smelt density (i.e., abundance) that could be integrated with other Delta survey efforts to provide a comprehensive assessment of delta smelt abundance and distribution.

Delta Smelt Length-Frequency Diagrams for the 20-mm Surveys

The 20-mm surveys were initiated in 1995 to track the early life stages of delta smelt in the Delta and Suisun Bay. A total of 48 stations are towed with a 1.6 mm mesh net every 2 weeks from late March to early July (Figure 16). DFG has calculated index values, but these have not been published or discussed. The sum of the geometric mean density (catch/10,000 m^3) from the four surveys bracketing the mean size of 20 mm is apparently used for the index. The total catch from each survey also provides a straightforward measure of abundance, if the habitat areas represented by the stations are assumed to be similar.

The DFG website provides a very informative summary of the entire 20-mm survey for each year with a series of length-frequency (length-count) panels for each survey. The total catch from each survey and the average length of delta smelt caught in each survey are given. Figures 17–28 show the delta smelt length-count distributions for the 11 years of 20-mm surveys, 1995–2006. A thorough review of these data may reveal information about spawning period, growth rate, mortality rate, and catch efficiency. The 20-mm survey results for each year are similar for the entire 12-year period of record, with no apparent trends or changes in recent years. Table 3 provides a summary of the survey starting dates, total delta smelt catch, and average delta smelt length for these 11 years. The DFG website can be used to find similar summaries for other fish species caught in the 20-mm surveys.

The catch of delta smelt varies moderately from one 20-mm survey to the next. Once juveniles begin to show up in the 20-mm tows, the abundance may increase with new recruits or decline with mortality, but the overall population length-frequency distribution is expected to slowly change with time. However, because of sampling variability, some surveys are much more successful in capturing a representative length-frequency distribution. This emphasizes the need to integrate all available information from each IEP fish survey and provide an interpretation of the combined results that includes ample consideration of the basic fish sampling difficulties that cause high catch variability.

Following the example of the FMWT survey index, a 20-mm index can be estimated by summing the catch in four surveys when the average length increases from 20 mm to 30 mm, generally between late May and early July of most years. The catch generally increases during this same period. Table 3 indicates the four surveys selected for the example annual index of 20-mm delta smelt catch. The annual values have fluctuated from about 300 (in 1995) to about 2,000 (in 1996 and 2000). The 20-mm index catch for delta smelt was about 500 in four recent years (2002–2005), but was 893 in 2006. Similar values of about 500 were found in 1995 and 1998. Compared to other surveys (e.g., FMWT), the 20-mm catch of delta smelt appears to be more nearly constant over the 12 years of 1995–2006.

Recommendation (4)

Investigate the sampling variability of the 20-mm survey using methods similar to those proposed for the FMWT samples. Evaluate the seasonal length-frequency changes to identify population parameters (e.g., spawning periods, growth rates), as well as estimate the likely delta smelt population for the 1995–2006 period. Integrate these early life-history records with other sampling surveys to provide an annual pattern of abundance and distribution for each of the recent years. These integrated sampling results could provide the basis for a life-history model of delta smelt.

Table 3. Summary of 20-mm Survey Results for Delta Smelt for 1995–2006 (* indicates the surveys used to calculate the "4-survey" annual index)

Survey	Beginning Date	Total Catch	Mean Length	Survey	Beginning Date	Total Catch	Mean Length
1995				**1996**			
1	24-Apr	11	14	1	10-Apr	79	8
2	8-May	28	17	2	24-Apr	164	12
3	22-May	94	19	3	9-May	900	15
4*	5-Jun	51	22	4*	21-May	728	19
5*	19-Jun	46	22	5*	8-Jun	630	20
6*	3-Jul	111	30	6*	24-Jun	385	27
7*	17-Jul	129	31	7*	8-Jul	303	30
8	31-Jul	126	38	8	22-Jul	218	34
Index		337		Index		2,046	
1997				**1998**			
1	31-Mar	6	8	1	6-Apr	5	12
2	14-Apr	24	12	2	21-Apr	13	10
3	28-Apr	122	12	3	4-May	109	15
4	12-May	214	14	4*	18-May	60	18
5*	27-May	860	19	5*	1-Jun	158	24
6*	9-Jun	352	24	6*	15-Jun	108	27
7*	24-Jun	179	32	7*	28-Jun	82	33
8*	8-Jul	42	37	8	13-Jul	51	40
9	22-Jul	40	41	9	27-Jul	73	44
Index		1,433		Index		408	
1999				**2000**			
1	12-Apr	86	11	1	20-Mar	28	6
2	26-Apr	148	13	2	3-Apr	96	12
3	10-May	233	16	3	17-Apr	69	11
4*	23-May	374	19	4	1-May	148	13
5*	7-Jun	415	21	5*	15-May	259	14
6*	21-Jun	469	24	6*	29-May	289	19
7*	6-Jul	333	26	7*	12-Jun	1212	22
8	19-Jul	164	35	8*	26-Jun	336	26
Index		1,591		Index		2,096	

Survey	Beginning Date	Total Catch	Mean Length	Survey	Beginning Date	Total Catch	Mean Length
2001				**2002**			
1	19-Mar	3	7	1	2-Apr	28	8
2	2-Apr	15	10	2	15-Apr	111	11
3	16-Apr	12	11	3	29-Apr	40	14
4	30-Apr	85	11	4*	13-May	143	20
5*	14-May	173	13	5*	28-May	50	25
6*	29-May	200	22	6*	10-Jun	83	25
7*	11-Jun	422	27	7*	24-Jun	151	38
8*	25-Jun	94	30				
Index		889		Index		427	

2003				**2004**			
1	24-Mar	27	6	1	29-Mar	6	10
2	7-Apr	28	11	2	12-Apr	18	10
3	21-Apr	27	11	3	26-Apr	20	11
4	5-May	29	13	4	10-May	189	16
5*	19-May	71	17	5*	24-May	210	23
6*	2-Jun	132	20	6*	7-Jun	119	27
7*	16-Jun	206	24	7*	21-Jun	45	32
8*	30-Jun	90	30	8*	6-Jul	42	37
Index		499		Index		416	

2005				**2006**			
1	14-Mar	3	7	1	NA		
2	28-Mar	5	9	2	NA		
3	11-Apr	3	12	3	17-Apr	49	11
4	25-Apr	68	14	4	1-May	22	14
5	9-May	177	16	5*	15-May	254	17
6*	23-May	214	20	6*	30-May	364	20
7*	6-Jun	92	25	7*	12-June	240	25
8*	20-Jun	151	33	8*	26-June	35	29
9*	5-Jul	71	37	9	NA		
Index		528		Index		893	

Annual Estimates of Pelagic Fish Abundance from the Summer Townet Survey

The summer townet survey was initiated in 1959 with 31 stations located upstream of the Napa River. The original purpose was to predict recruitment to the adult striped bass stock, but the townet survey results have proven valuable in gaging the environmental health of the estuary. A similar index for delta smelt was useful in determining its status as a threatened species. Three tows are made at each station, sampling about 1.5 acre-feet at each station with a 0.5-inch mesh net every other week for six surveys, scheduled about the time that striped bass fry length increases to between 1 and 2 inches (mid June through August).

The annual catch results from the summer townet survey indicate that striped bass and delta smelt have been the two most abundant fish. The abundance of both in the last 20 years is lower than the catch in the first 25 years. The townet index values for striped bass and delta smelt correspond to about 1% of the total catch of these two fish. Many other fish are also collected.

Table 4 gives the total catch of all fish in the summer townet survey from 1959 to 2005 (missing 1966–1968 data). A total of about 500,000 fish have been collected (average of 11,500 each year). Table 4 indicates that striped bass has been the dominant species collected in the summer townet, with 73% of the total catch. Delta smelt has been the second most abundant fish in the summer townet, with about 11% of the catch. Northern anchovy and threadfin shad have each made up about 5% of the catch. White catfish and longfin smelt have each made up about 3% of the catch. Yellowfin goby and American shad have each made up about 1.5% of the catch. The catch of several additional species has been more than 500 fish (0.1% of the catch). All other fish are rare, making up collectively less than 0.5% of the total catch.

DFG has reported the results of the 2006 summer townet indices for striped bass and delta smelt:

> The 2006 Summer Townet Survey index for striped bass is 0.5 (on August 18). This is the lowest index of record. Early information from the Summer Townet Survey indicated a stronger year class, but protracted spawning and the apparent mortality to several of the cohorts led to the low index. The 2006 Summer Townet Survey index for delta smelt is 0.4 (on July 7). Additional sampling outside of the historical sampling area indicates that this index may be biased low due to fish outside the sampling area.

These index values appear very low. However, the index values are only a small fraction (about 1%) of the total catch during the six townet surveys each year. Reporting the total catch of fish from the six summer townet surveys each year might be more useful for indicating the relative abundance of striped bass, delta smelt, and other fish in the Delta.

Figure 29 shows the annual summer townet catch from 1959 to 2005. The total catch was dominated by striped bass in the 1960s and 1970s. A few years had catches of more than 25,000 striped bass. The annual catch of striped bass declined to less than 5,000 fish since 1974 (31 years ago). The annual catch of striped bass has been less than 1,000 fish in eight of the past 17 years since 1989, with annual catches ranging from less than 200 to more than 4,000 fish. There does not seem to be any unusual further decline in recent years (since 2001). The abundance of striped bass remains low, with an average catch of about 830 fish in the last ten years, an average of 1,585 for the past 20 years, and an average of 7,500 for the entire survey period. The 2006 striped bass townet index of 0.5 corresponds to a likely catch of about 100 striped bass.

Figure 29 also shows the delta smelt catch was higher in the 1960s and early 1970s. A few years had catches of about 4,000 delta smelt. The annual catch of delta smelt declined to less than about 1,000 fish since 1983 (23 years ago). The annual catch of delta smelt has been less than 200 fish in eight of the past 22 years since 1984, with annual catches ranging from less than 200 to more than 1,000 fish. The catch values have declined from the recent peak of about 800 in 1999 and 2000, to the low catch of less than 200 in 2004 and 2005. The abundance of delta smelt remains low compared with the catch from the 1960 and 1970s, with an average catch of about 450 fish in the last ten years, an average of 420 in the past 20 years, and an average of 1,235 for the entire survey period. The 2006 delta smelt townet index of 0.4 corresponds to a likely catch of about 40 delta smelt.

There are several other fish species with an annual catch of more than 100 fish. White catfish and threadfin shad have been relatively abundant in the past eight years. The townet catches relatively small fish (less than 2 inches) and shows a more diverse collection of fish in recent years, no longer dominated almost exclusively by young-of-the-year striped bass.

Recommendation (5)

Investigate the sampling variability and abundance of all pelagic fish in the summer townet. Combine the summer townet data with the 20-mm and FMWT data to provide a more integrated picture of the life-stage development and abundance for each pelagic fish. Compare the townet results with the CVP and SWP salvage records and the Chipps Island Trawl data. Replace the indices for delta smelt and striped bass with the total catch of all the fish from the townet and other IEP fish surveys.

Table 4. Annual Catch of Fish Species in Summer Townet Survey 1959–2005

Year	Striped Bass	Delta Smelt	Northern Anchovy	Threadfin Shad	White Catfish	Longfin Smelt	Yellowfin Goby	American Shad	Catfish (Unid)	Channel Catfish	Smelt (Unid)	Inland Silverside	Pacific Herring	Chameleon Goby	Tridentiger	Threespine Stickleback	Splittail	Shokihaze Goby	Gobies (Unid)	Starry Flounder	Topsmelt	Plainfin Midshipman	Shimofuri Goby	Carp	Jacksmelt	Chinook Salmon
1959	3,398	1,803	2,394			89	32		1		184	170	42			5	1			1						3
1960	6,436	1,748	402			76	9	1	24		2	8	55			1	3			4					7	2
1961	10,759	2,236	176		2	220	32		378		1		177			3	32			3		3		1		12
1962	22,770	2,938	64	5	108	925	1	28	442				108			2	1			2	1	3		1	8	7
1963	29,018	302	91	112	1,231	14	27	115	18				7			19	50			22	2	2		3		6
1964	21,864	4,019	109	34	383	570	104	151	5				45			1				14		11		2		4
1965	26,446	1,095	28	79	31	601	8	654	342		32		46			4	11			1				3		3
1966																										
1967																										
1968																										
1969	19,494	317	21	379	839	695	17	82	2,607	4	4		42			20	33		2	23	2	4		55		
1970	18,758	3,227	263	555	564	447	38	40	796		3		93			6				5	11	10				5
1971	26,974	2,419	193	560	2,458	1,221		120	16	35	478		1			59	9			5		1				3
1972	17,865	3,703	600	252	537	542	70	109		12	43		12			10	5			3	9	9		23		6
1973	15,435	1,580	623	160	650	304	12	108	481	1	798		112			10	1		1	17	25	14		15		9
1974	15,059	1,323	273	49	635	1,612	4	308			91		36			14	17			11	1	5				2
1975	20,017	1,885	60	110	963	46	40	720		2	1		6			19	3		2			5		1		4
1976	3,532	4,002	751	397	18	23	9	155					22			8	3			2	30	4				2
1977	2,968	4,328	920	1,447	29	200		316			192	40	165			63	4			1	12					6
1978	10,823	3,938	2,059	518	101	32	392	1,131	2	9		94	13			61	45			36	5	2		2		20
1979	3,146	953	507	508	207	496	81	213		16		34	2			8	3				18	3				17
1980	3,300	1,067	419	437	285	686	300	92	1	14		23	14			20	5			43	19	7			2	1
1981	3,172	1,255	1,480	387	14	173	35	102	16	3		49	23			3	1			1	5	3			5	2
1982	10,448	1,307	694	354	6	1,252	108	320	7	1		57	313			91	117			8	1	2				10
1983	3,722	312	1,217	428	10	33	26	585	2	1		96	51			248	9			1		2			11	2
1984	1,943	73	1,794	1,524	9	1	20	49			2	292	55			46	11								51	2

Year	Striped Bass	Delta Smelt	Northern Anchovy	Threadfin Shad	White Catfish	Longfin Smelt	Yellowfin Goby	American Shad	Catfish (Unid)	Channel Catfish	Smelt (Unid)	Inland Silverside	Pacific Herring	Chameleon Goby	Tridentiger	Threespine Stickleback	Splittail	Shokihaze Goby	Gobies (Unid)	Starry Flounder	Topsmelt	Plainfin Midshipman	Shimofuri Goby	Carp	Jacksmelt	Chinook Salmon
1985	1,095	67	2,426	264	23	27	40	39	1	9		47	3			25	1					1			12	
1986	5,474	355	1,599	207	68	40	168	62	1	3	1	77	11			37	34			104	5			1	36	
1987	1,989	201	3,102	216	52	166	71	5				19	22			10	1			2	12					1
1988	1,314	194	280	109	21	40	3	80		21		63	29			13	11		5	3	57	9				1
1989	735	147	175	102	49	68	704	12		1		18	2	314		9	8		197	1	22	1		1		1
1990	1,048	123	268	12	123	3	689	29		21	3	7	9	944		11	1		52	5	9	58		20		
1991	866	446	277	292	20	10	9	60		8		26	22	9		9	18		100	3	66	5		16		1
1992	1,770	158	2,181	456	24	10	3	80	1	25	2	63	44	6		38	4		24		2	1		1	1	3
1993	4,236	661	244	240	185	35	842	163	4	29	1	31		3		33	5			4						4
1994	1,597	1,073	329	24	46	17	61	46		2		41	12	34		2	2		4	7		19			2	2
1995	4,395	562	436	436	491	562	627	378	138	150		27	10			26	64		3	1	4	12	6	1		
1996	323	589	55	341	42	166	83	136		1		36				10	2		1	3		9	1		1	1
1997	341	228	373	929	33	24	13	24		2		126	1			20	1		6	1	16	2	20			
1998	1,418	406	1,386	920	477	188	123	372		62		140	2			89	85			15	1		34	8	1	1
1999	646	883	66	498	544	571	354	17	2	2	1	59				8	37				1	3	26	1	1	1
2000	1,801	792	47	515	1,306	1,106	2,438	107		746		94	2			2	12			1		28	34	2	2	
2001	1,040	492	73	2,403	338	57	31	62		238		17			246	2	2	120	163			1	2			1
2002	307	464	60	8,385	195	442	18	5		93		24	82		400	12	2	166	6	3	9	8	59		1	
2003	1,773	338	64	767	712	90	79	361		335		123	23		50	26	29	64		8	2	4	12			3
2004	194	189	18	694	174	127	22	9		48		19	9		533	9	3	132		1	1	13	13		11	1
2005	471	120	17	149	420	43	27	100		63	1	42			50	15	7	152		2		6	17	1		
Total	330,180	54,318	28,614	26,254	14,423	14,050	7,770	7,546	5,285	1,957	1,840	1,962	1,390	1,310	1,279	1,127	693	634	566	367	348	270	224	158	152	149
Percent	65.56	10.79	5.68	5.21	2.86	2.79	1.54	1.50	1.05	0.39	0.37	0.39	0.34	0.26	0.25	0.22	0.14	0.13	0.11	0.07	0.07	0.05	0.04	0.03	0.03	0.03

Integrated Annual Estimates of Pelagic Fish Abundance

The many fish sampling programs that are conducted in the estuary each year by hard-working and dedicated agency scientists deserve to be more fully evaluated and integrated into a collective understanding of the life history, distribution, and abundance of each fish species in the Bay-Delta ecosystem. The first step in this approach would be to conduct a comprehensive review and summary analysis of each sampling program. The only such document prepared recently was the IEP technical report 63, "Report on the 1980–1995 Fish, Shrimp, and Crab Sampling in the San Francisco Estuary, California," authored by Baxter et al. in 1999. This report provides many excellent summaries of catch data for the five different sampling surveys in this Bay Study program (midwater trawl, bottom otter-trawl, plankton net, beach seine, and ringnet for shrimp). General summaries of catch by month and by location (major bays) for the trawls provide good confirmation of the life-history description for each species.

The Bay Study summary report includes basic life-history descriptions for each fish and shows graphs of which bays and during which months most of the fish were caught. Figures 29 and 30 show the annual midwater trawl catch of longfin smelt, delta smelt, striped bass juveniles, and Chinook salmon juveniles. Annual catch of longfin smelt is generally higher in the otter trawls. The annual catch of striped bass has been lower recently than during the 1980s. The Chinook salmon catch has always been quite small but has increased since the 1980s. Several stations were added to the Bay Study in 1991, but the original stations are used by DFG in their calculated abundance indices. The delta smelt catch in the Bay Study midwater trawl has actually increased since 2001, with most fish found upstream of Chipps Island at the stations added in 1991.

The difficulty of identifying simple annual factors to explain the variations in pelagic fish abundance is illustrated with Figures 31–33, which show the monthly and annual FMWT catch for several of the most abundant pelagic fish. Of these species, only the striped bass juvenile catch has shown a consistent decline from the early years to the recent years. Each of the other species shows a great deal of variability between years, with high abundance values that are five or ten times greater than the low abundance values, but with no dramatic or unusual decline in recent years. The annual index values fluctuate among the fish species, with no consistent period of joint decline. American shad are currently one of the most abundant fish caught in the FMWT, although American shad were relatively low in 1999–2001. Delta smelt were unusually high in 1999–2001. Their current levels are similar to other periods of relatively low abundance. Threadfin shad are currently one of the most abundant fish caught in the FMWT and were exceptionally high in 1997–2001. For every delta smelt caught, about five–ten threadfin shad are caught. Longfin smelt and Sacramento splittail both generally have much higher FMWT abundances following wet years (high runoff). The range of catch for both species is quite high. The abundance in recent years appears normal for comparatively dry years, relative to the historical range.

More substantial efforts could be made to combine the results from each IEP fish sampling program each year. The sampling programs provide complementary information about life stages and distribution of each estuary fish species. Using a single index value from each survey for each year for a few selected fish species does not provide sufficient information for increasing our basic understanding of these fish. Statistical evaluations (no matter how sophisticated) of these annual time-series values are not likely to yield much new information or understanding about the causes for year-to-year fluctuations in fish abundance. A more comprehensive evaluation and integration of the data from all surveys would provide a more informative description of the status of pelagic fish in the Bay-Delta estuary.

Summary reports for each fish survey could combine the available life-history information about each species to describe the distribution and movement patterns for these estuary fish. The basic sampling patterns and statistical characteristics of the survey methods could be described. The relationships (competition, predation) between the coexisting pelagic fish species could be given appropriate attention. These summary reports are likely to describe a dynamic, interacting ecosystem with many species, each of which has many more internal constraints and feedback controls than the few external factors that we may influence and manage. These summary reports may allow us to focus our attention on clearly identified and confirmed changes that may be reversed or mitigated with our targeted investigations and management interventions.

Recommendation (6)
A summary and analysis of the Bay Study surveys for the 25-year period 1980–2005 could be prepared. Similar analysis of each of the other IEP surveys also could be prepared as a supplement to the 2006–2007 POD investigations, following the example provided in the 1980–1995 Bay-Study summary report. These fish surveys include: striped bass egg and larvae, FMWT survey, summer townet, winter Kodiak trawl, 20-mm survey, Chipps Island trawl, Delta beach seines, CVP and SWP salvage, and the Suisun Marsh survey. The great wealth of information contained in these surveys has not been thoroughly investigated.

Possible Delta Management Actions

In addition to providing the summary documents and integrated evaluations of the IEP fish surveys, several targeted actions can be taken to protect the current population of delta smelt and other species of concern. Other actions may be identified and considered for implementation by agency scientists and resource managers. Below are some initial actions for managers to consider for 2007 and subsequent years.

- Consider opening the Delta Cross Channel (DCC) during March, April, and May to increase the net flow on the San Joaquin River at Jersey Point (QWEST) to improve the movement of juvenile delta smelt that spawn in the south Delta channels toward the confluence. This action may have a negative effect on migrating juvenile Chinook salmon, but the positive effects on delta smelt may be viewed as more important (i.e., ecologically valuable). Results from the 20-mm survey may help to schedule the DCC opening to maximize the benefits.

- Improve the salvage success for delta smelt adults at CVP and SWP salvage facilities in January, February, and March (an average of more than 1,000 adult delta smelt each month at each facility have been counted in recent years). Provide 24-hour separation of delta smelt into special-purpose holding tanks. Many delta smelt might be salvaged and released successfully using a barge to distribute adults into Suisun Marsh, Cache Slough channels, and other suspected spawning areas.
- Conduct more intensive FMWT surveys, with five (replicate) tows at stations within the suitable salinity habitat (upstream of Martinez) for delta smelt. Consider extending the FMWT to January and February to provide a more accurate estimate of adult abundance.
- Conduct daily Chipps Island trawls (rather than every 3 days) in January, February, and March to provide improved estimates of delta smelt densities near Chipps Island.
- Install a fabric-screen ("Gunderboom") facility in front of the two existing power-plant cooling water intakes near Antioch and Pittsburg to reduce the entrainment loss of delta smelt from this suitable salinity-habitat zone. Conduct sampling to measure the number of fish approaching the intakes prior to installation of the device.
- Design and install a submerged rock levee along the south shore of Clifton Court Forebay (CCF) to provide a "salvage corridor" to reduce the influence of predation on small fish such as delta smelt and juvenile Chinook salmon. The channel would be about 250 feet wide and would direct the majority of inflow from the CCF gates to the Skinner Fish Salvage Facility. This 2.25-mile (12,000-foot) "breakwater" levee could made of 4- to 6-inch-diameter rocks and would reduce the travel time for water entering the CCF from more than 2.5 days to less than 2 hours (when pumping at 5,000 cfs). A series of removable wall sections could be included near the CCF gates to allow the channel to be switched "on and off" for experimental comparisons of salvage with and without the corridor. The rock levee would allow the normal CCF operations for storage and release of water to continue.

  The basic design might be a sediment levee foundation with a top width of 20 feet at elevation –5 feet mean sea level (msl). The sediment for these foundation levees might be dredged from the 250-foot-wide corridor along the south shore. A 20-foot-wide-by-10-foot-high 1:1 slope rock pyramid would be placed on top of the sediment foundation, extending to +5 feet msl. The size of the rock could be investigated during the final design to ensure that the rock levee excludes most fish from moving through the rock barrier. About 50,000 cubic yards of rocks would be needed to construct this "salvage corridor" rock levee to reduce predation losses.

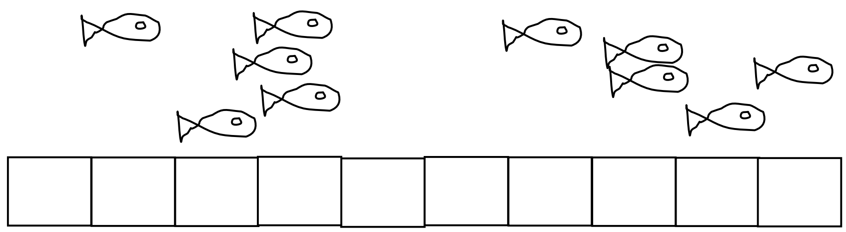
Appendix A
Chance of Catching Randomly Distributed Fish

Catching fish in San Francisco Bay and Sacramento–San Joaquin River Delta channels is a difficult enterprise. Towing nets behind boats without catching them on the bottom or sides of the channels and actually moving through the location of fish are major accomplishments. If the fish are scarce (e.g., delta smelt) the chance of catching one or more in a sample is relatively low. This appendix describes some of the sampling characteristics related to the chance of catching fish in a given net sample of water.

The probability of catching fish depends on the number of fish within the habitat volume (i.e., fish density) and the fraction of the habitat volume sampled with a towed net. The catch probability is also affected by the fact that fish size and swimming abilities may allow them to avoid the net (sampling efficiency). This appendix does not consider the efficiency of the various nets used in the Interagency Ecological Program (IEP) sampling surveys. The sampling efficiency is assumed to be 100% of the fish in the sample volume. Fish distribution could be even, random, clumped, or something in between. If fish sampling gives catch results that are variable, there is likely some degree of randomness. If fish school or aggregate together, the sampling variability will be even greater.

To illustrate the method of calculating the chance of catching randomly distributed fish, we will use the example of ten fish (named A–J) that are randomly distributed in ten bins. One bin represents the sample volume (i.e., 1/10 of the total volume is sampled). The probabilities of catching different numbers of fish are listed below. These probabilities are determined by imagining that each of the ten fish is tossed randomly into one of the ten bins. The order that the fish are tossed does not matter. We are only interested in how many fish are likely to fall in the one bin that represents the sample volume.

The methods for these examples can be generalized for other scenarios of randomly distributed fish. The probability of catching a certain number of fish can be calculated from the total number of fish (N), the sample volume (S), and the total volume (V).



Chance of Catching Zero Fish (P_0)

$P_0 = [(V - S)/ V]^N = (9/10)^{10}$

Where:

$[(V - S)/ V]$ = the chance of not catching a fish as it falls into a bin. As fish A–J fall into the ten bins, the chance that each one of them will fall into a bin other than the sample bin is 9/10. The chance that all of them will miss the sample bin is $(9/10)^{10} = 0.35$.

Chance of Catching Fish A and No Other Fish (P_a)

$P_a = (S / V) * [(V - S)/ V]^{(N-1)} = 1/10 * (9/10)^9$

Where:

(S / V) = the chance of catching fish A. If fish A randomly falls into one of ten bins, there is a 1/10 chance that fish A will fall into the sample bin.

$[(V - S)/ V]^{(N-1)}$ = the chance of not catching the other nine fish (B–J). As fish B–J fall into the ten bins, the chance that each one of them will fall into a bin other than the sample bin in 9/10. The chance that all of them will miss the sample bin is $(9/10)^9$.

Chance of Catching One and Only One Fish (P_1)

This is the same as the previous example except that any one of fish A–J can be caught.

$P_1 = P_a * C_1 = P_a * 10$

Where:

C_1 = the number of ways to get one fish. In this case, there are ten ways to get one fish because the one fish caught could be any one of fish A–J.

Chance of Catching Two and Only Two Fish (P_2)

The chance of catching fish A and B, and no other fish (P_{ab}) is:

$P_{ab} = (S / V)^2 * [(V – S)/ V]^{(N-2)} = (1/10) * (1/10) * (9/10)^8$

The chance that two and only two of the ten fish will end up in the sample bin is equal to P_{ab} times the number of ways to get a combination of two fish (C_2), where:

$C_2 = [N * (N-1)] / 2 = (10 * 9) / 2$

Where:

[N ∗ (N-1)] equals the number of combinations of two fish, assuming that the order is important (i.e., that catching fish A then fish B [AB] is different from catching B then A [BA]). Because the order of the fish is not important, it is necessary to divide by 2, where the 2 represents the number of ways that two things can be ordered or arranged.

Chance of Catching Three and Only Three Fish (P_3)

The chance of catching fish A, B, and C and no other fish (P_{abc}) is:

$P_{abc} = (S / V)^3 * [(V – S)/ V]^{(N-3)} = (1/10) * (1/10) * (1/10) * (9/10)^8$

The chance that three and only three of the ten fish will end up in the sample bin is equal to P_{abc} times the number of ways to get a combination of three fish (C_3), where:

$C_3 = [N * (N-1) * (N-2)] / (3*2) = (10*9*8) / 6$

Where:

[N ∗ (N-1) ∗ (N-2)] equals the number of combinations of three fish, assuming that the order is important (i.e., that ABC is different from BAC). Because the order of the fish is not important, it is necessary to divide by 6, where 6 represents the number of ways that three things can be ordered or arranged.

Chance of Catching X and Only X Fish (P_X)

The general equation for the probability of catching X fish is:

$$P_X = (S / V)^X * [(V - S)/ V]^{(N-X)} * [N!/(N-X)!]/X!$$

Where "!" denotes the factorial of a number (i.e., X ∗ (X-1) ∗ (X-2) ∗…1).

Example Results

Let us try some examples for sampling from 100 bins with 100 fish randomly distributed. The results may surprise you. Using the equations described above, we can determine the chance of finding 0, one, two, three, four, and five fish in a bin.

0 fish = $0.99^{100} = 0.3660$

1 fish = $0.99^{99} = 0.3697$

2 fish = $100*99/2 * 0.01^{2} * 0.99^{98} = 0.18486$

3 fish = 0.0610

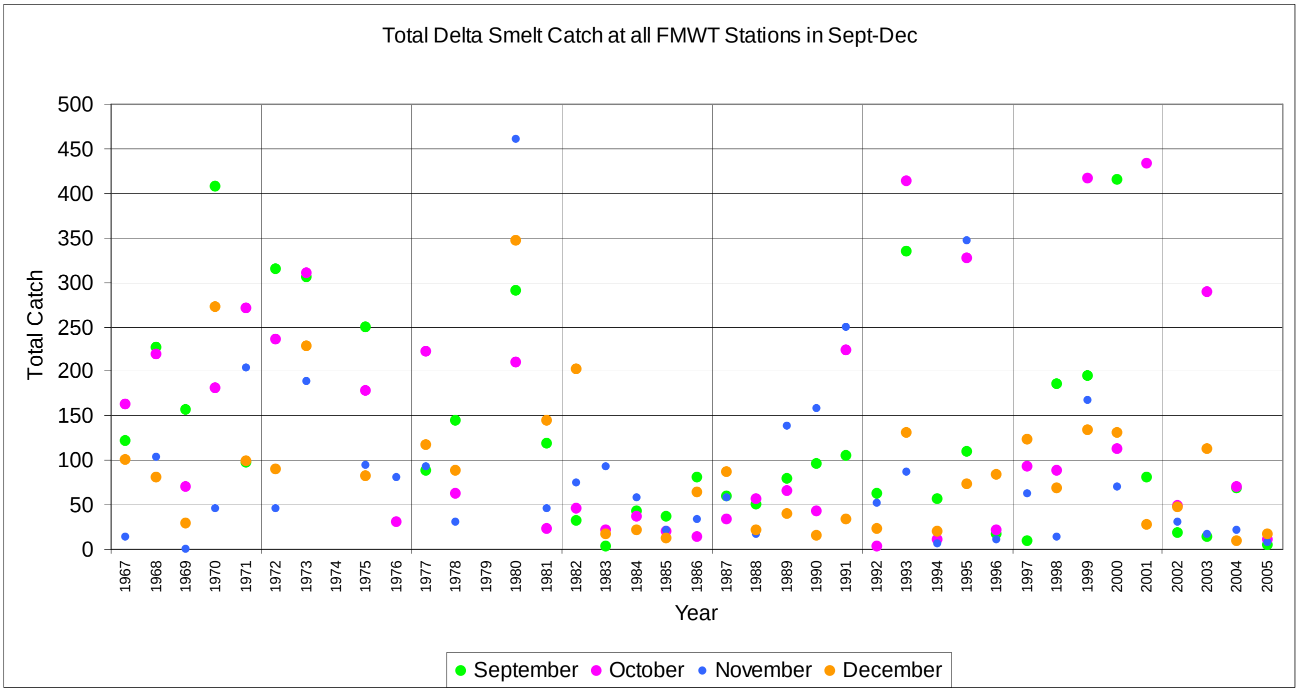
4 fish = 0.0149

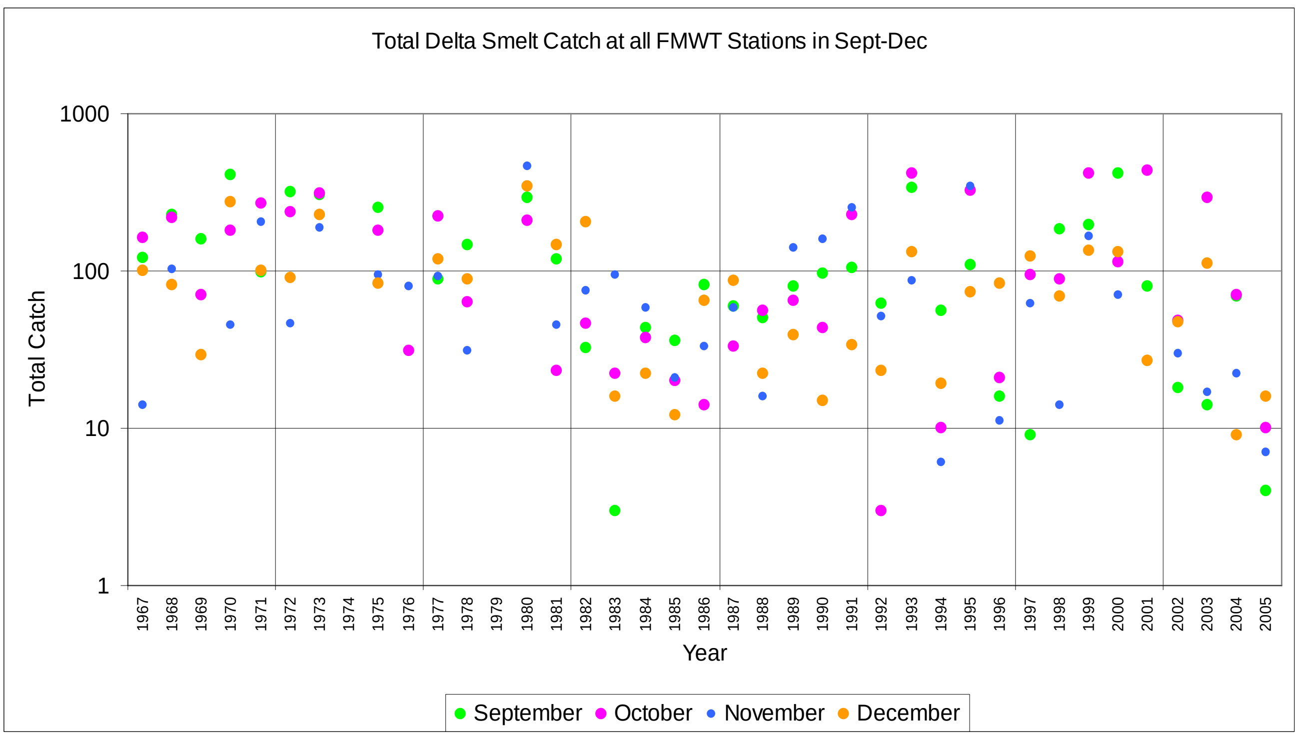
5 fish = 0.0029

With a random distribution, the results are not certain, but we would expect 36 empty bins, 36 bins with one fish, 18 bins with two fish, six bins with three fish, and one bin with four fish. Sampling random distributions is much different from sampling uniform distributions, where we would always get one fish per bin.

The sampling variability settles down as the number of fish or the sample size increases. For 1000 fish distributed within 100 bins, the chance of 0 fish is reduced to 0.00004. The chance of four fish is 0.02; five fish is 0.04; six fish is 0.06; seven fish is 0.09, eight fish is 0.11; nine fish is 0.12 and ten fish is 0.13; more than ten fish is 0.42.

The recommendation from this sampling exercise is that the distribution of catch, as well as the total number of fish caught per survey could be examined as part of the routine analysis of the FMWT, 20-mm surveys, and other IEP sampling programs. The individual sample results will tell us much more about the abundance and distribution of the relatively scarce fish in the Delta than the single annual index value. Because delta smelt are caught in only about half of the samples within the suitable salinity range, they may have an abundance that is slightly less than one fish (or group of fish) per sample volume. How many delta smelt would that represent within the entire Delta?





The top graph uses a linear scale, and the bottom plot uses a logarithmic scale. The variation in catch between monthly surveys each year is quite high. The annual index is equal to the sum of the catch for the four months and varies between about 100 and 1,000 (see Figure 34).

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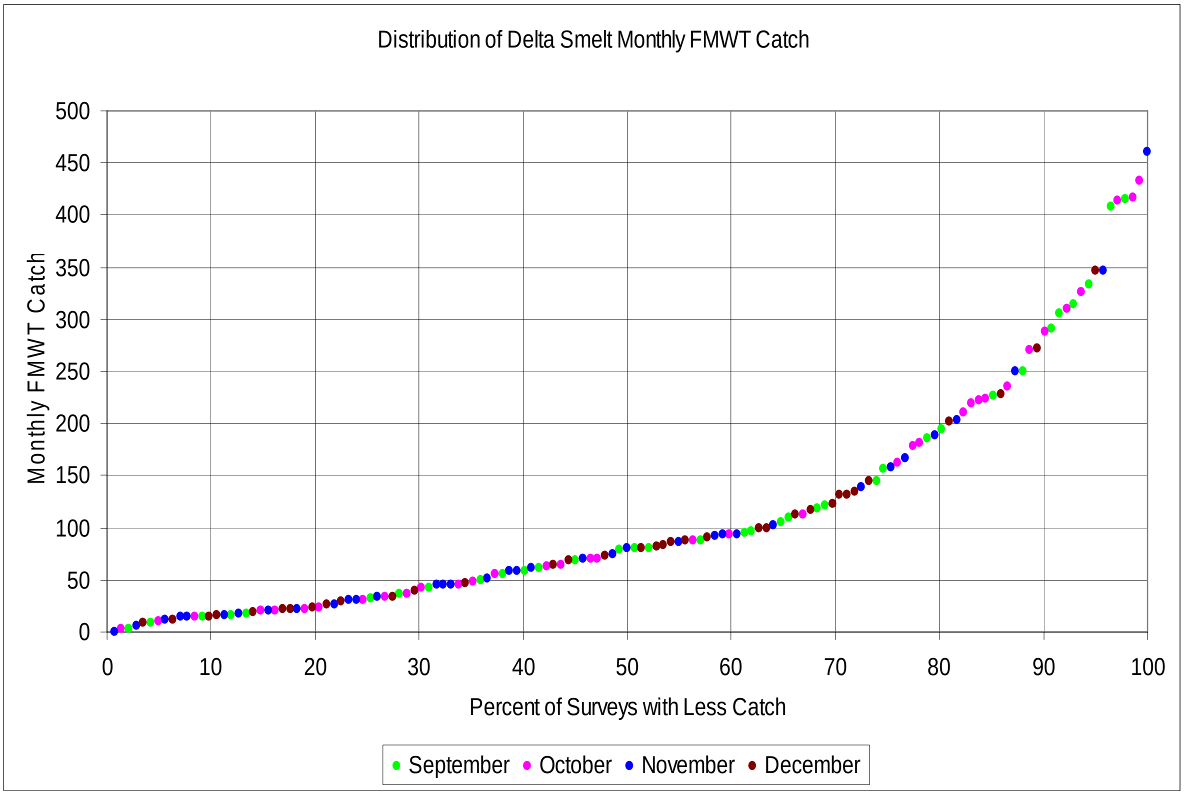
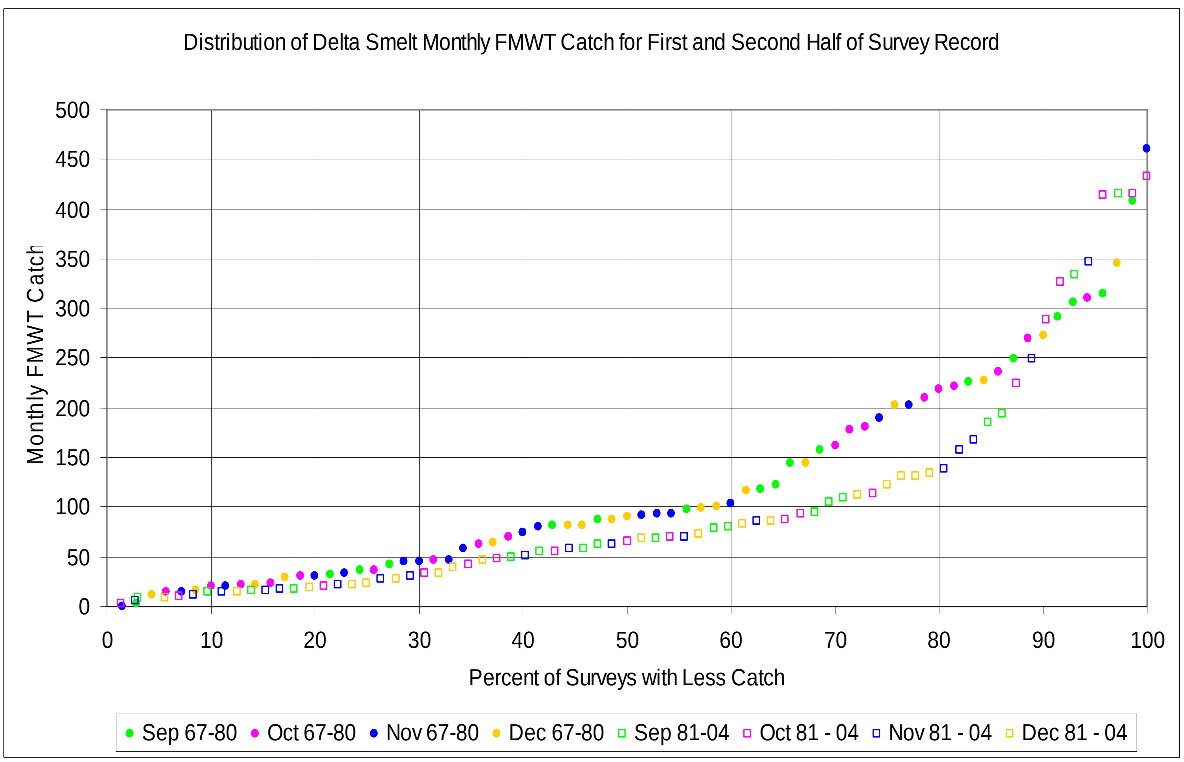
Figure 1

FMWT Monthly Delta Smelt Catch for 1967–2005





The bottom graph shows the cumulative distribution for the first half of the period of record and the second half. The probability of catching fewer than 50 fish was 30% in the first half and 40% in the second half. During both periods, there was a 10% chance of catching more than 300 fish in a monthly survey of 100 stations.

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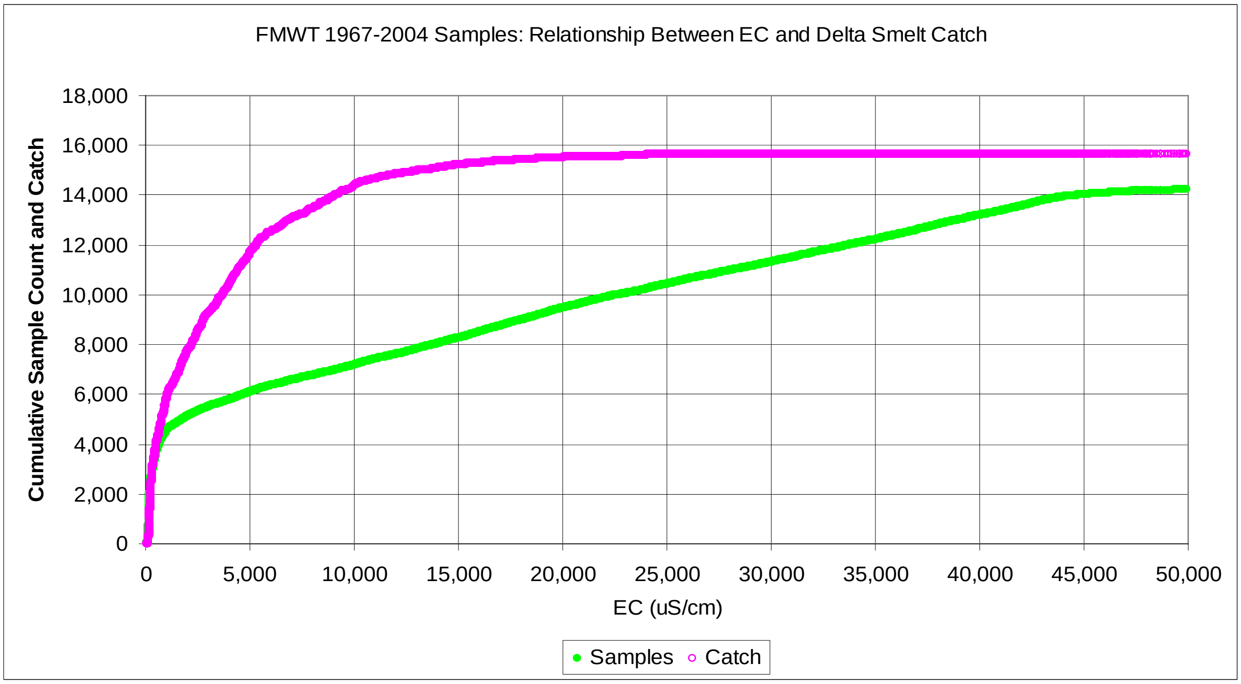
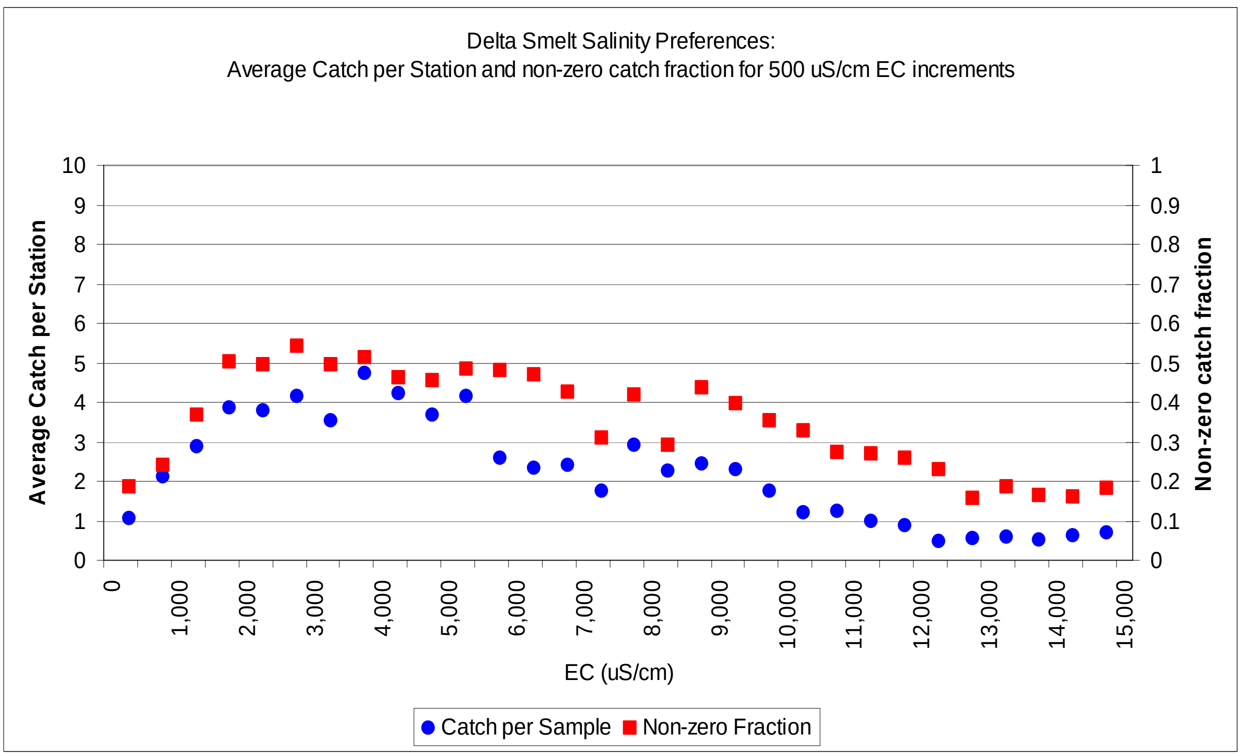
Figure 2

Cumulative Distribution of FMWT Monthly Delta Smelt Catch for 1967–2004





The bottom graph indicates that the greatest chance (50%) of catching delta smelt is salinity between 2,000 µS/cm and 6,000 µS/cm. In this range of salinity the average catch per sample is 2–5 fish/sample, or about 4–10 fish in samples with a catch.

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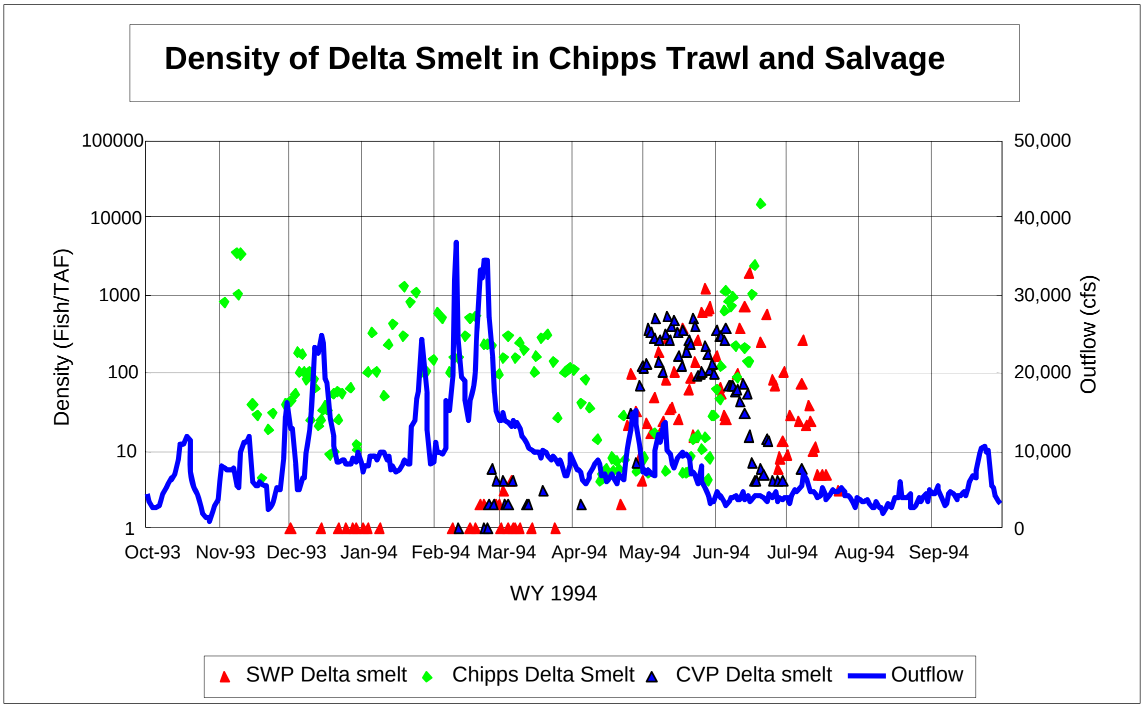
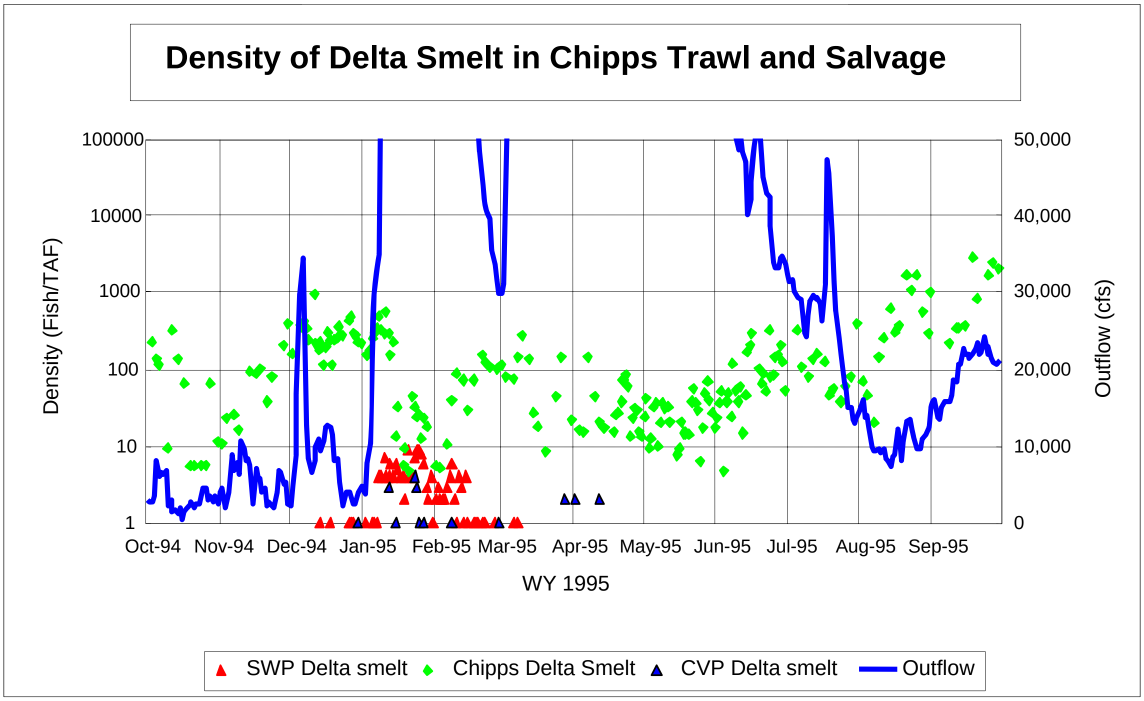
Figure 3

Comparison of Salinity Range Sampled with FMWT Surveys and Salinity Range with Delta Smelt Catch for 1967–2004 Surveys





Low salvage of adults in 1994 still was followed by high densities of juveniles. Adult densities are much higher at Chipps Island than in the salvage. Juvenile densities are highest in the salvage in May and June, and show up in June at Chipps Island (no Chipps Island trawls in the summer of 1994). There are few adults or juveniles salvaged in 1995, perhaps because of the relatively high outflow.

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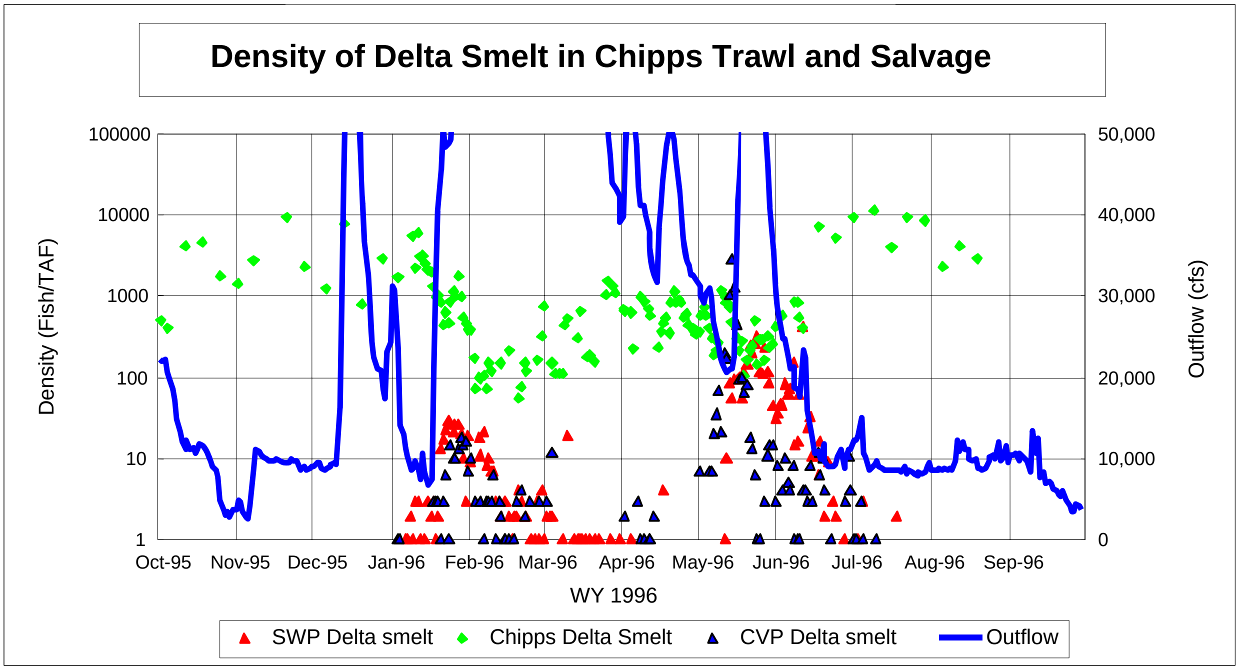
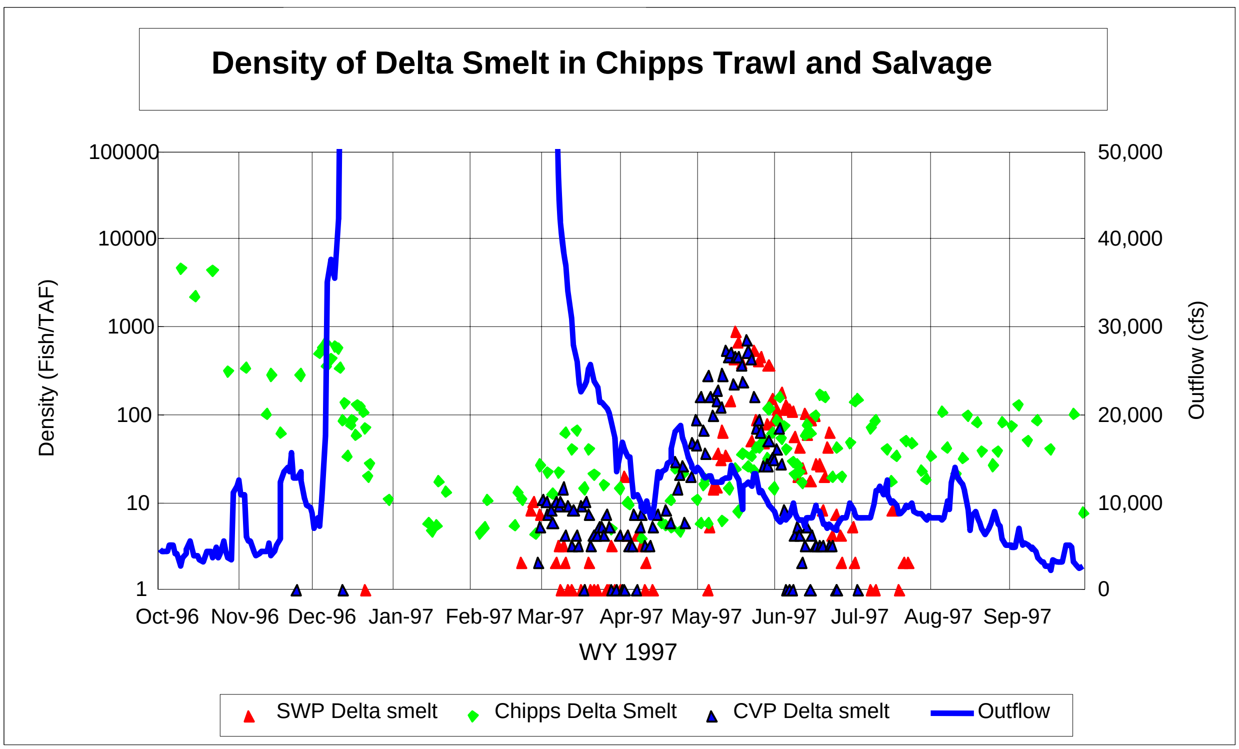
Figure 4

Comparison of Delta Smelt Density (fish/taf) in Chipps Island Trawl and the CVP and SWP Salvage for Water Years 1994 and 1995





Chipps Island densities were high in November–January and then decreased in February, as adults showed up at the salvage facilities. Juvenile densities were highest in salvage in May and June, and showed up in June and July at Chipps Island, as the juveniles migrated toward the confluence and 2 ppt salinity. Fewer juveniles showed up at Chipps Island in the summer of 1997.

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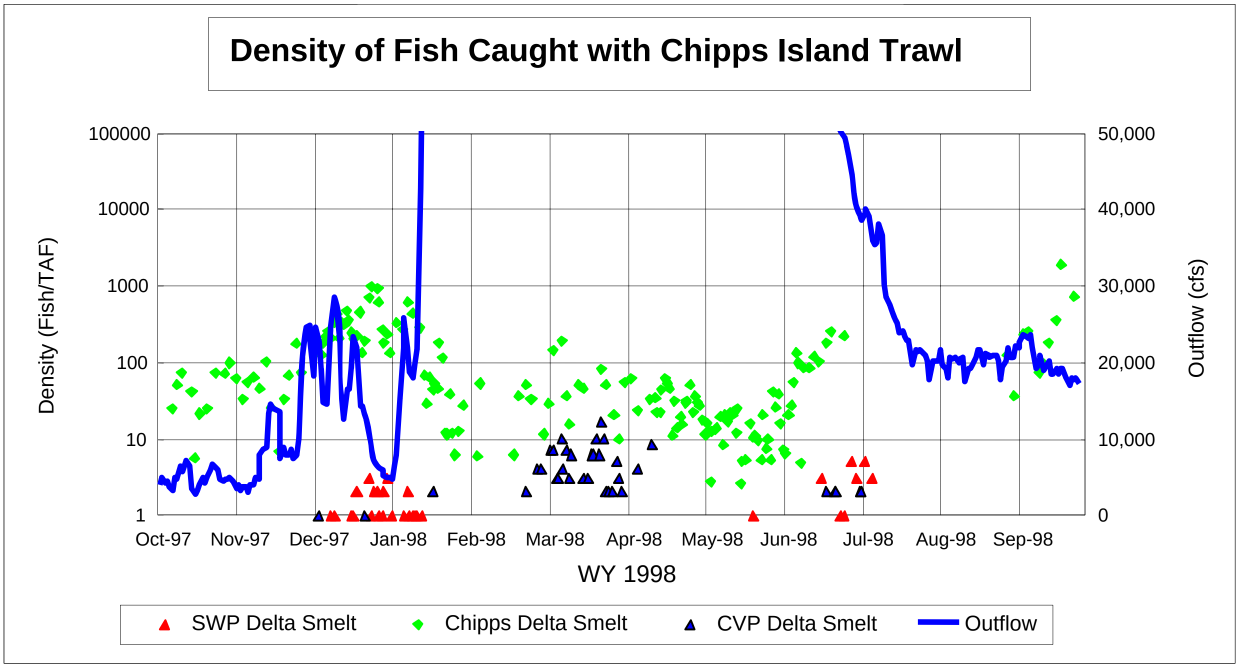
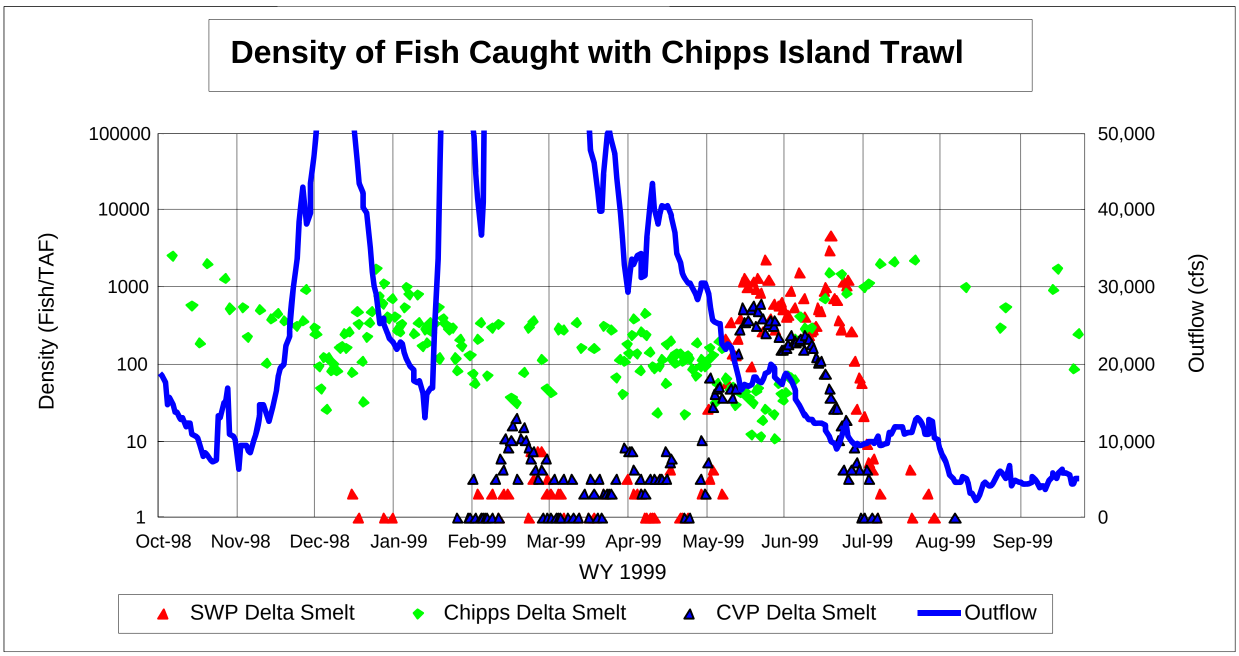
Figure 5

Comparison of Delta Smelt Density (fish/taf) in Chipps Island Trawl and the CVP and SWP Salvage Density (fish/taf) for Water Years 1996 and 1997





Salvage in 1998 was low presumably because of the high flow conditions. Adult densities at Chipps Island were highest in December and January of both years. Juvenile salvage densities were highest in May and June, and juveniles showed up in June and July at Chipps Island. Trawls have not been as frequent during summer and fall periods of lower Chinook density.

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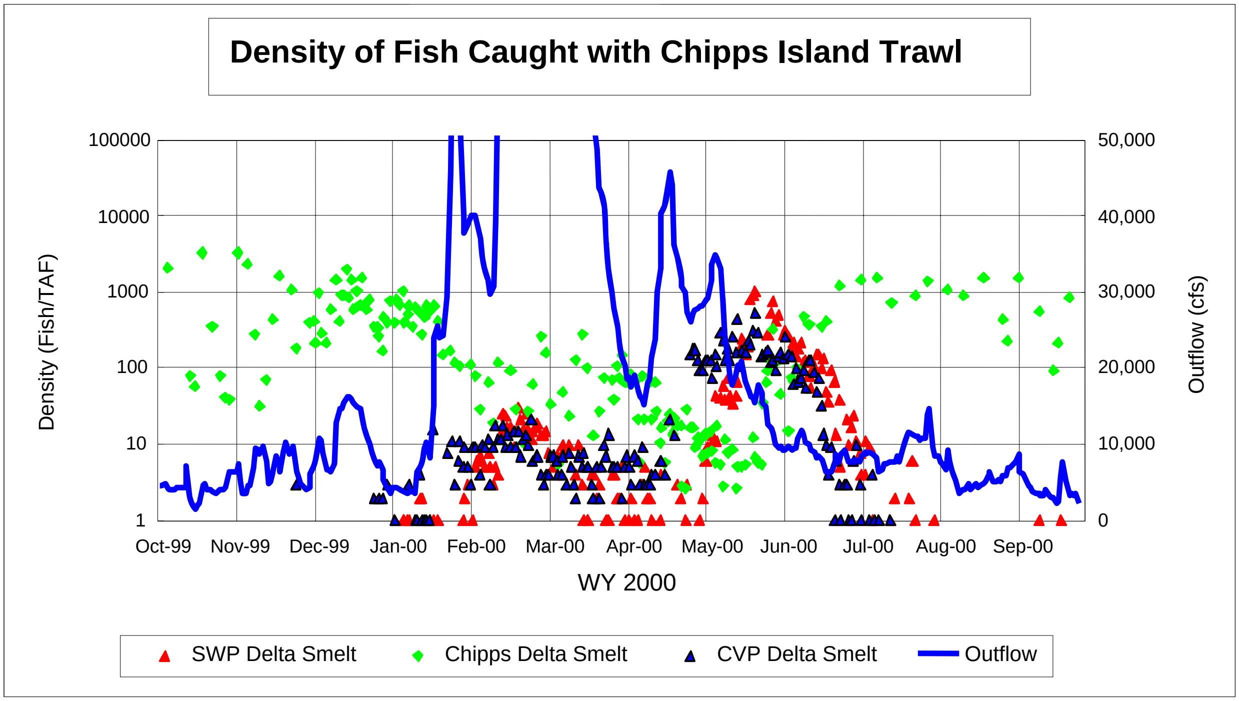
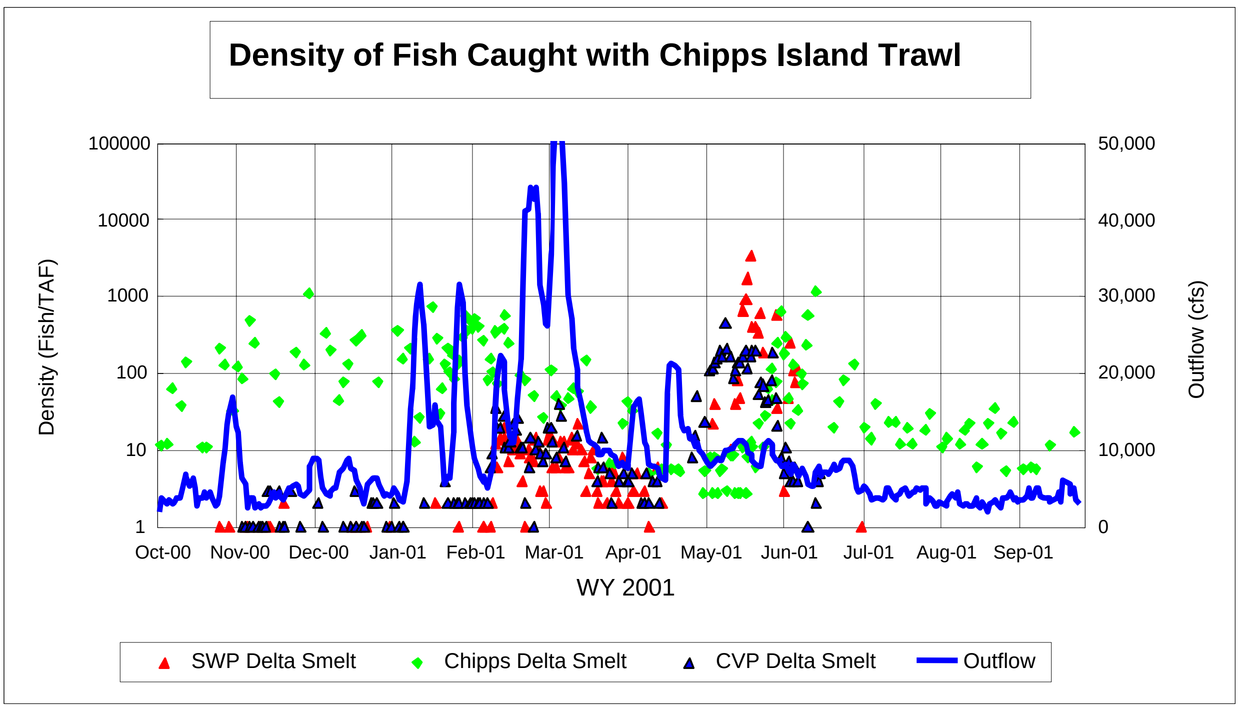
Figure 6

Comparison of Delta Smelt Density (fish/taf) in Chipps Island Trawl and the CVP and SWP Salvage Density (fish/taf) for Water Years 1998 and 1999





Adult densities appear to be higher at Chipps Island than in salvage. Adults showed up at salvage in February and March. Juvenile densities were highest in salvage in May, and then juveniles showed up in June at Chipps Island as they migrated toward confluence and 2 ppt salinity. Juvenile salvage in May 2001 was similar to salvage in May 2000, but June 2001 salvage and Chipps densities in the summer and fall of 2001 were lower than in 2000.

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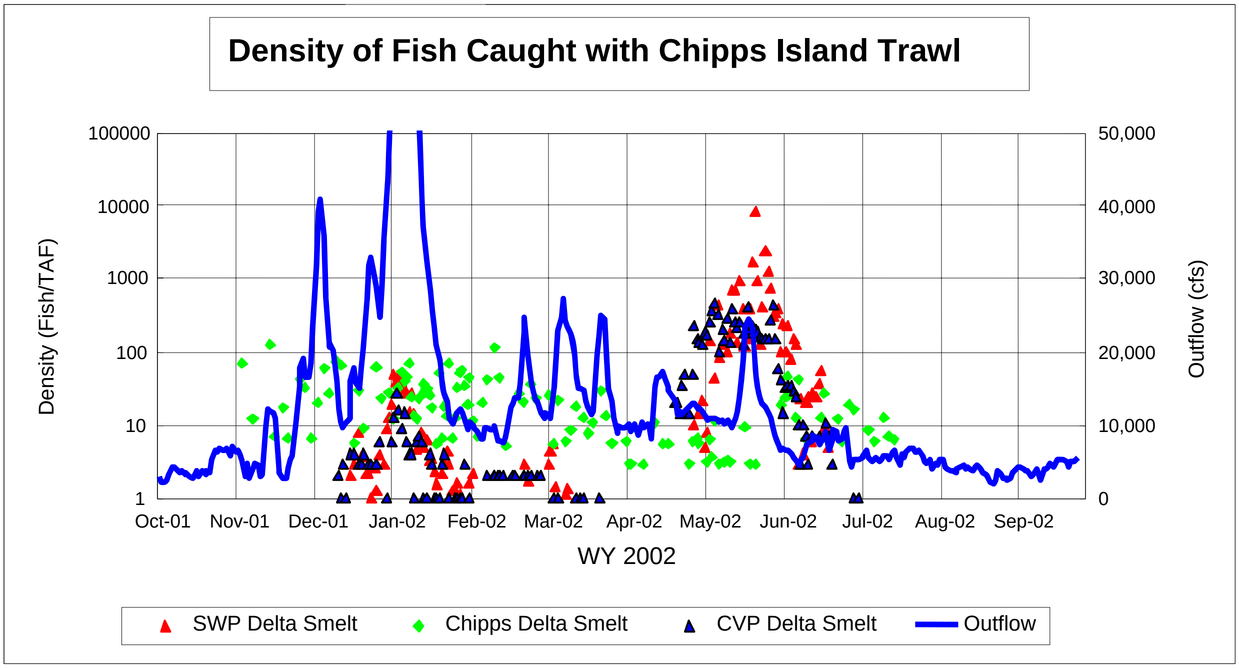
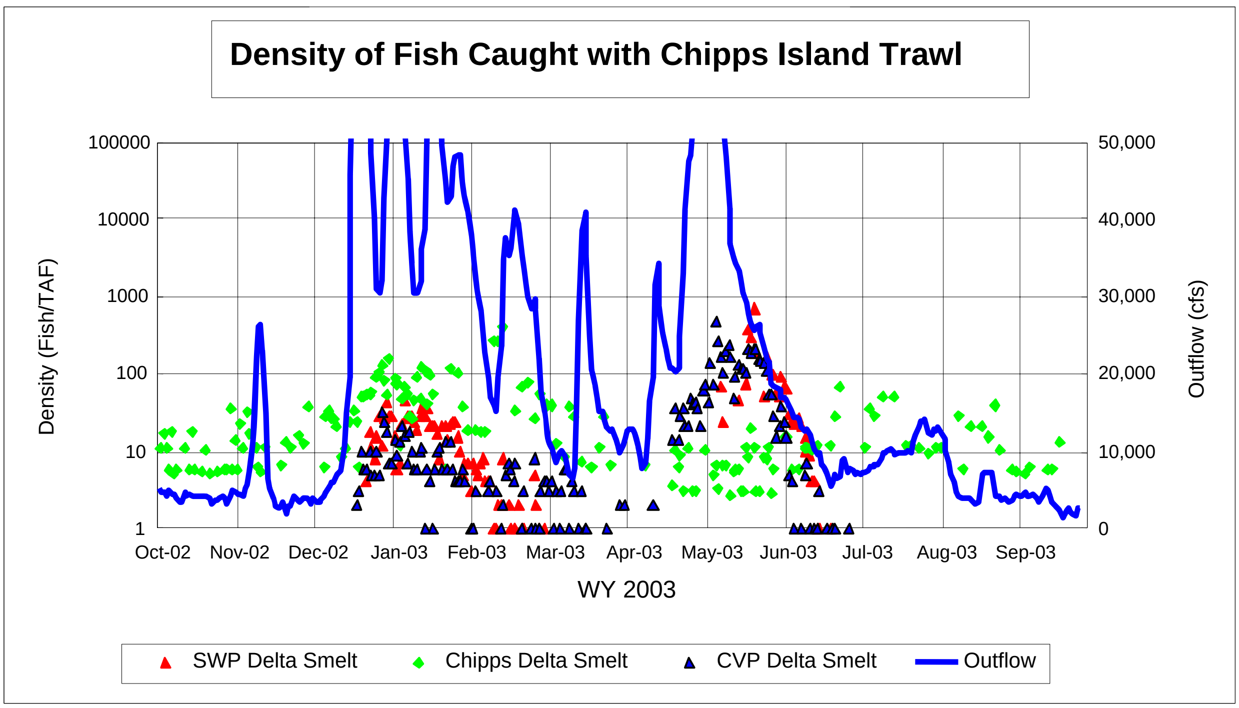
Figure 7

Comparison of Delta Smelt Density (fish/taf) in Chipps Island Trawl and the CVP and SWP Salvage Density (fish/taf) for Water Years 2000 and 2001





Adult densities in 2002 and 2003 were lower than in previous years. Adults showed up in salvage in December and January, concurrently with higher outflow, which may trigger dispersion to spawning areas. Juvenile densities were highest in salvage in May of both years, but juveniles showed up in June and July at Chipps Island. Fewer trawls were conducted in the summer of 2002.

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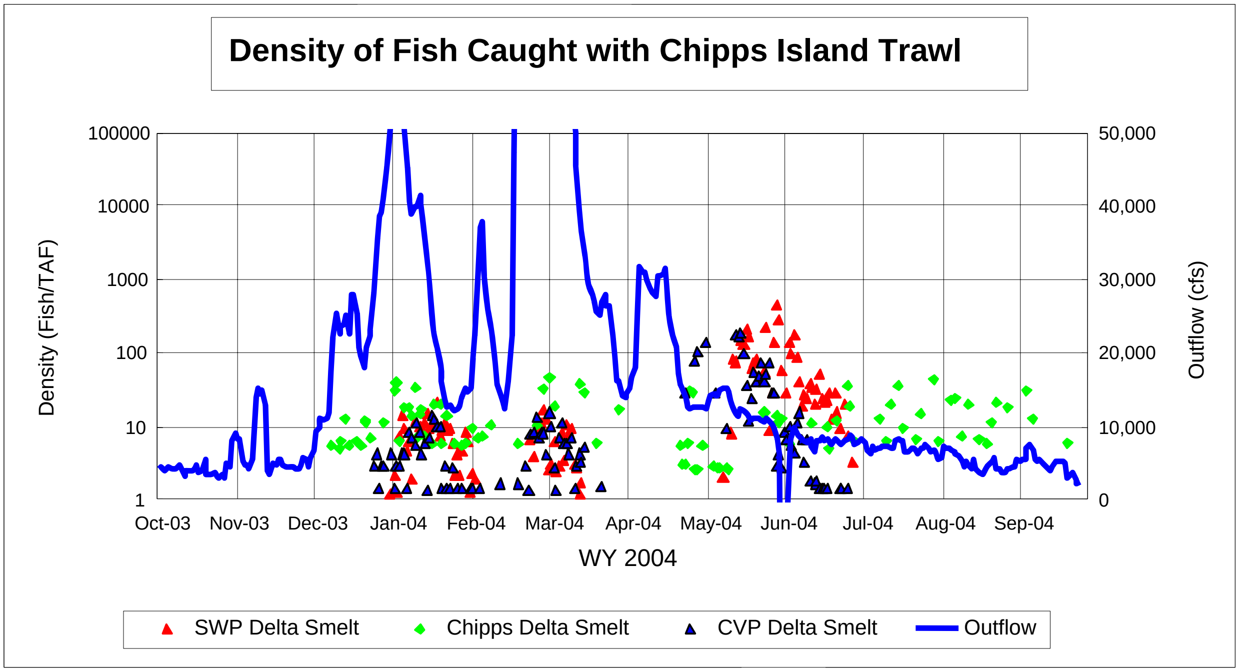
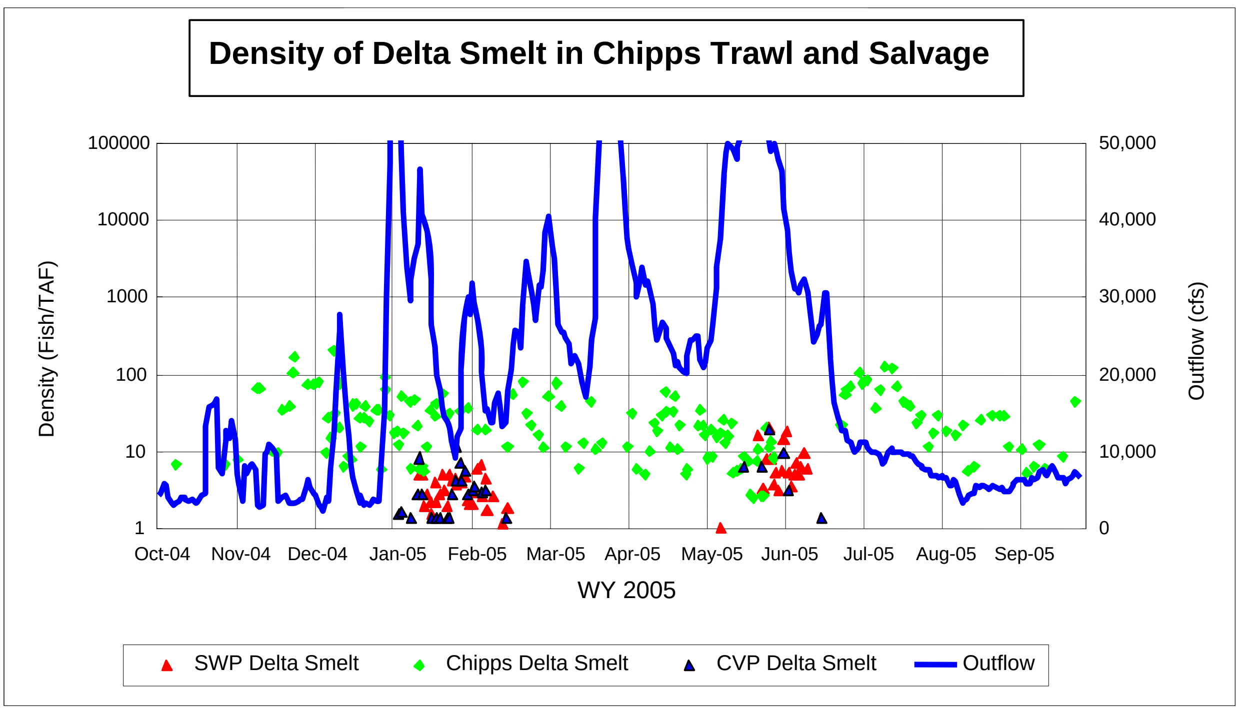
Figure 8

Comparison of Delta Smelt density (fish/taf) in Chipps Island Trawl and the CVP and SWP Salvage Density (fish/taf) for Water Years 2002 and 2003





Chipps Island densities in the winters of 2003 and 2004 were low. Adults showed up at salvage in January and March of 2004, and only in January and early February of 2005. Juvenile salvage densities in 2004 were highest in May and June, but were at low levels at Chipps Island during the summer. Few adults were salvaged in 2005, and the juvenile densities in late May were very low, perhaps because of high spring outflows. Only moderate juvenile densities were measured at Chipps in the summer and fall of 2005.

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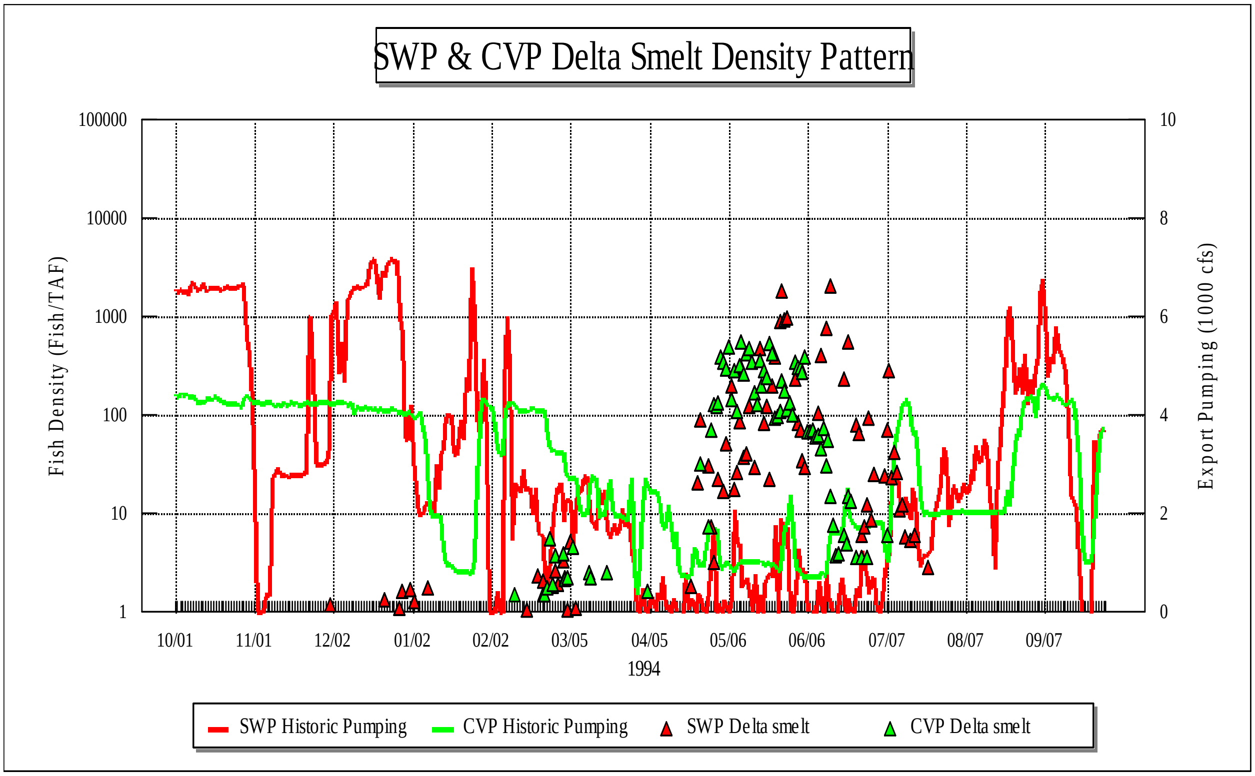
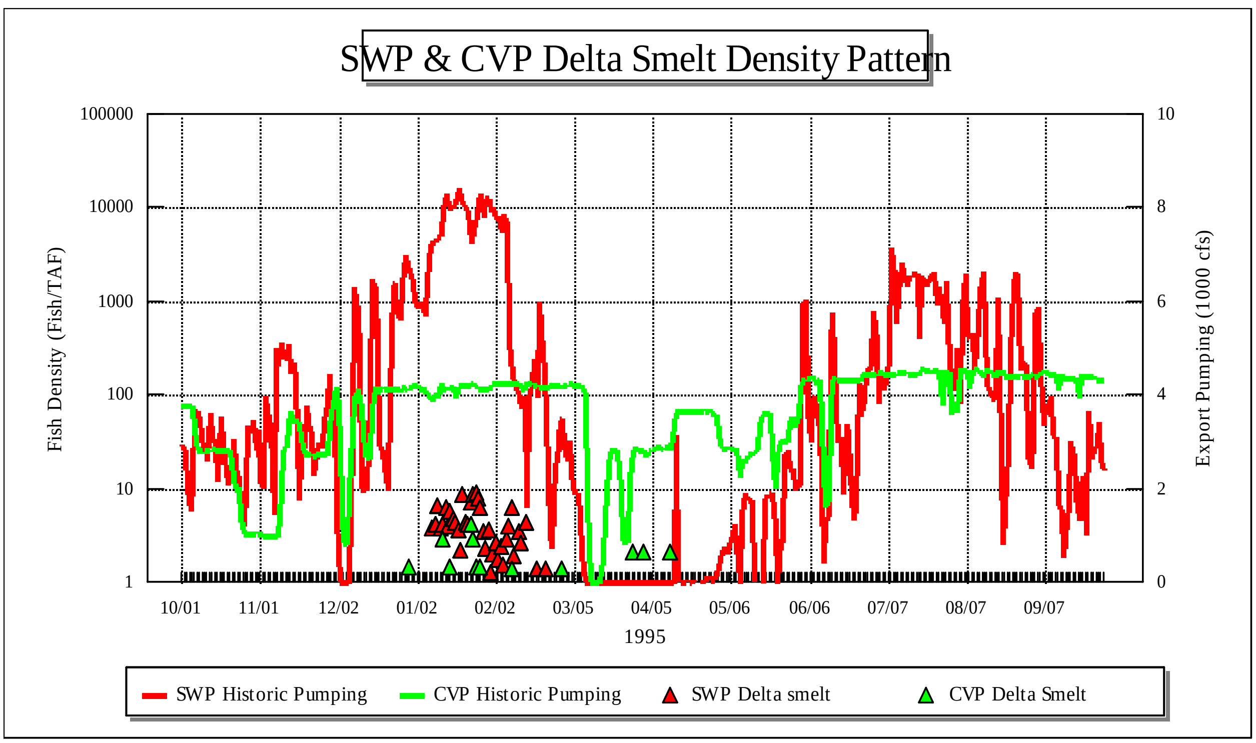
Figure 9

Comparison of Delta Smelt Density (fish/taf) in Chipps Island Trawl and the CVP and SWP Salvage Density (fish/taf) for Water Years 2004 and 2005





Very few adult delta smelt were salvaged in 1994 (no high outflow), with normal densities in the spring although pumping was very low. Some adults were salvaged in January and February 1995, but no juveniles were salvaged in spring, perhaps because of very high outflows until August.

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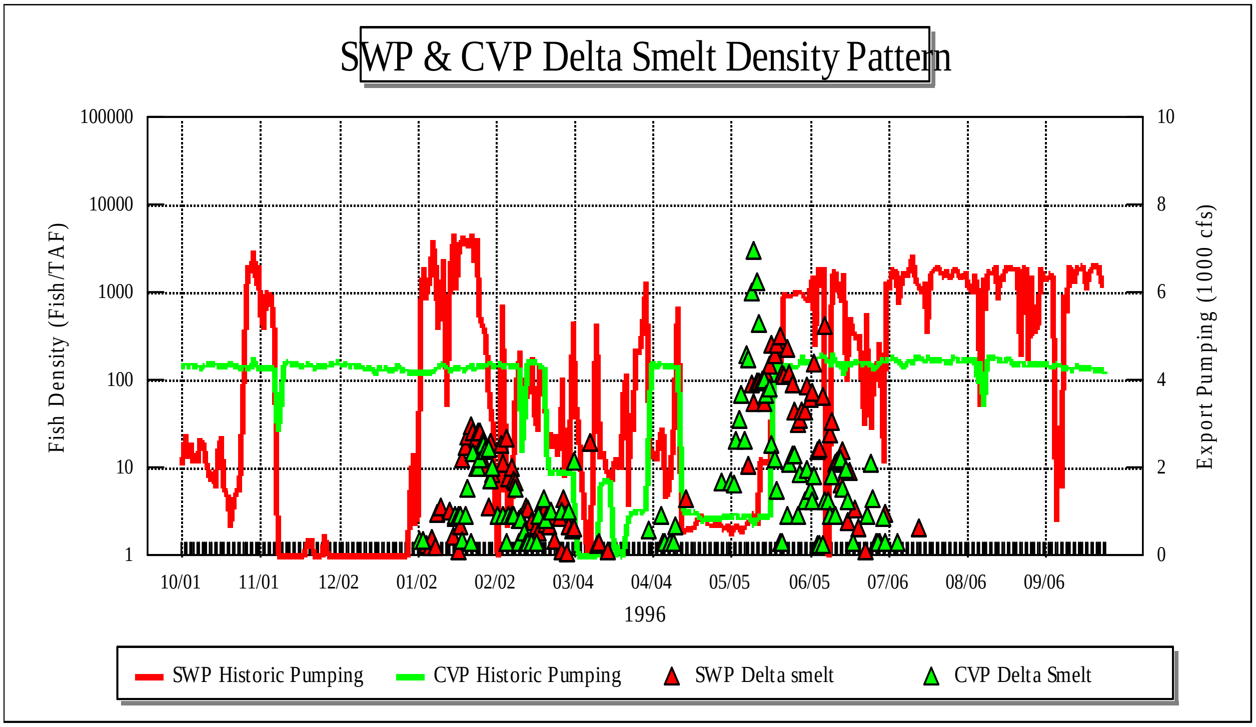
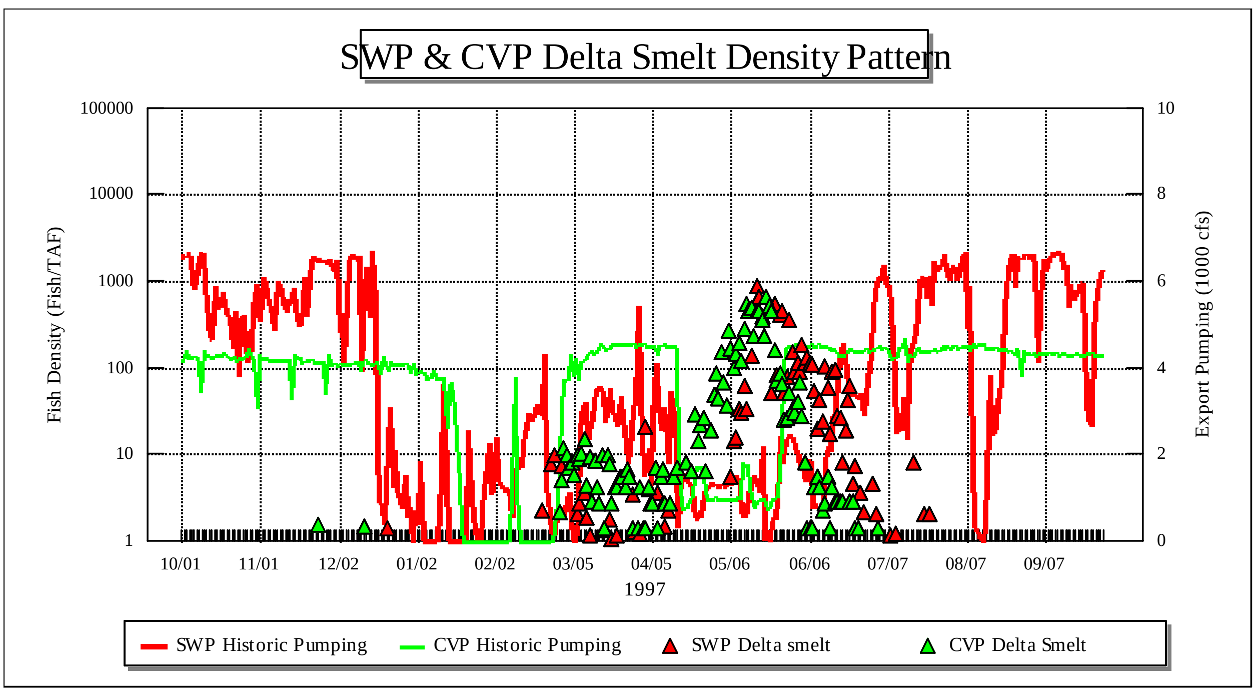
Figure 10

Delta Smelt SWP and CVP Salvage Density for Water Years 1994 and 1995





Adults showed up in January and February of 1996, with peak of juveniles in May and June of 1996. Adults in 1997 were delayed until March, but peak juveniles were still in May and June of 1997.

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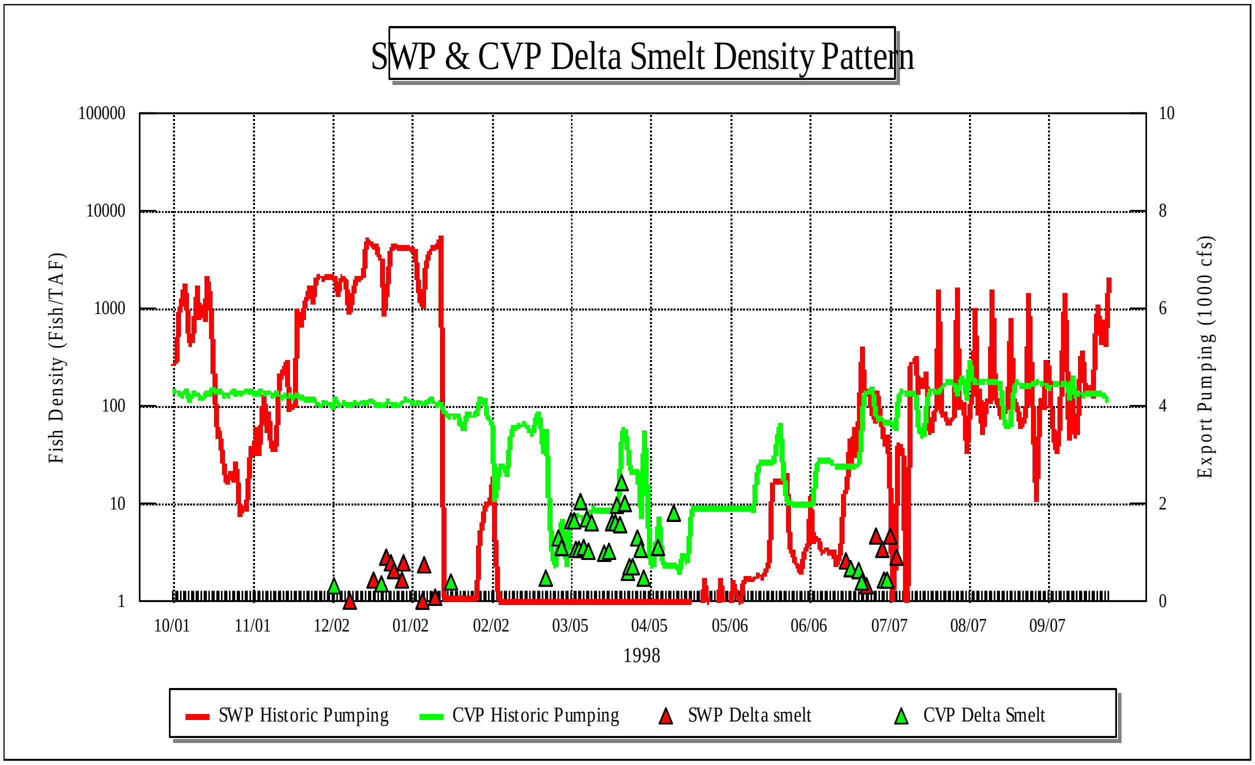
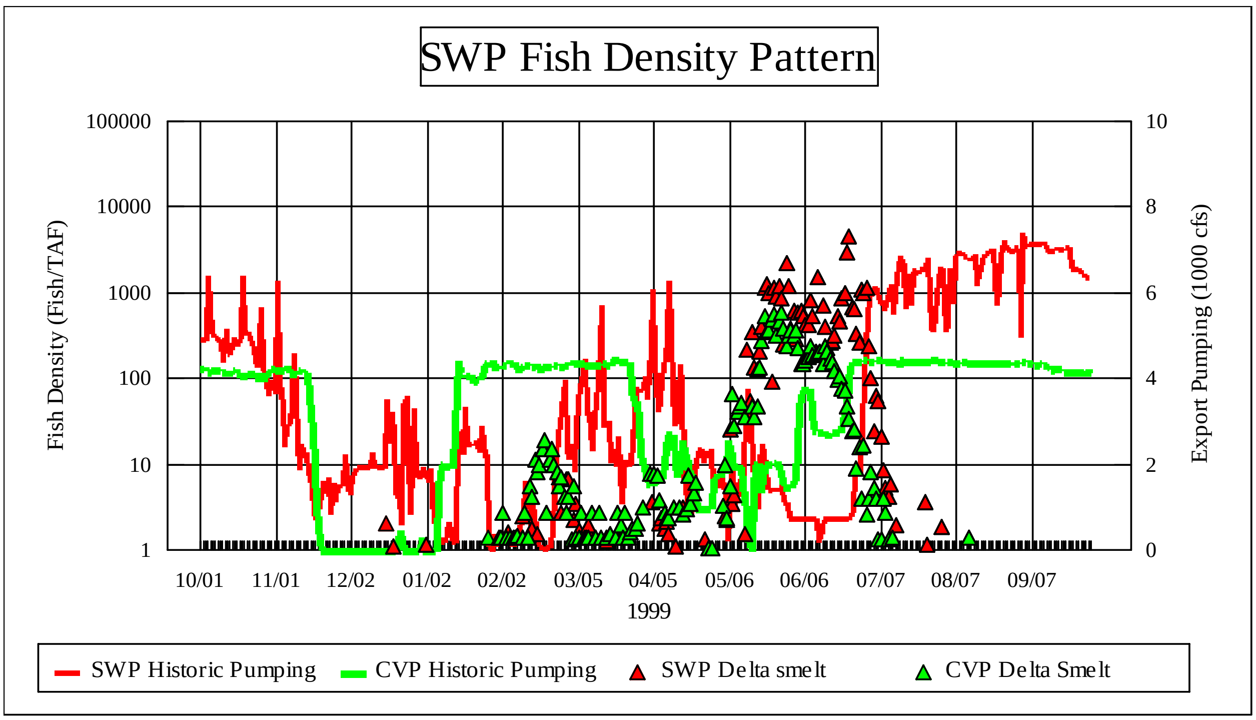
Figure 11

Delta Smelt SWP and CVP Salvage Density for Water Years 1996 and 1997

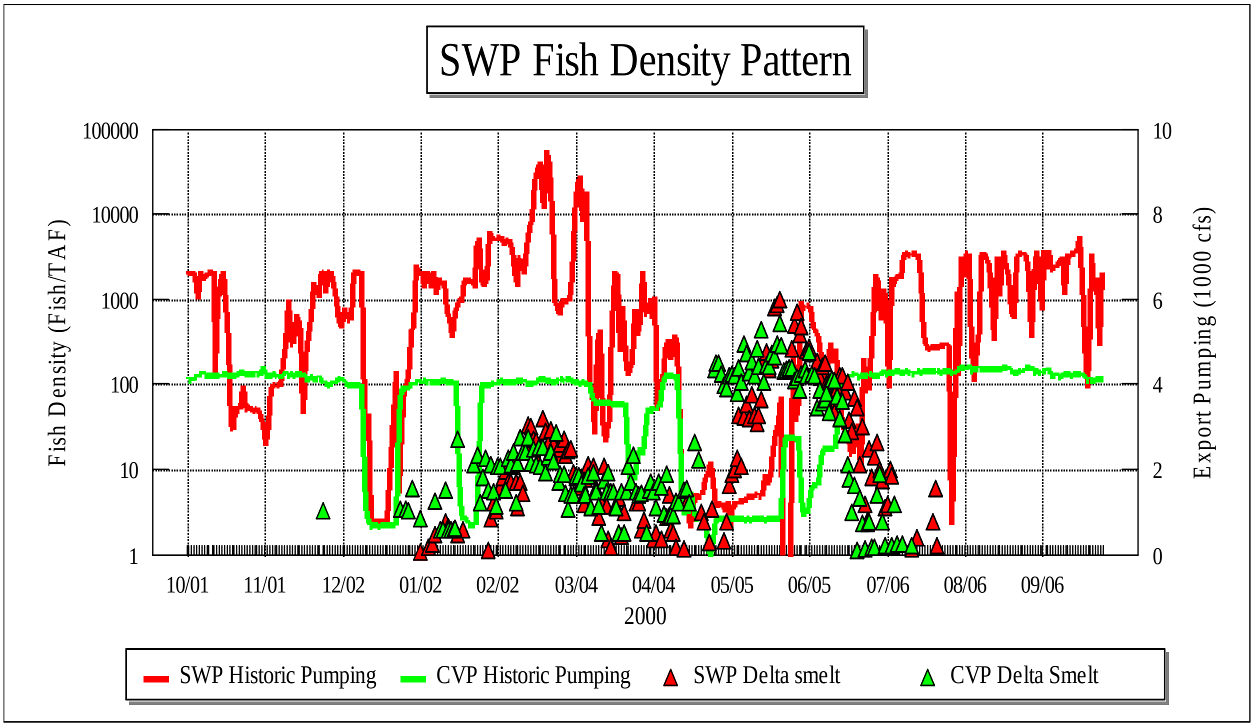


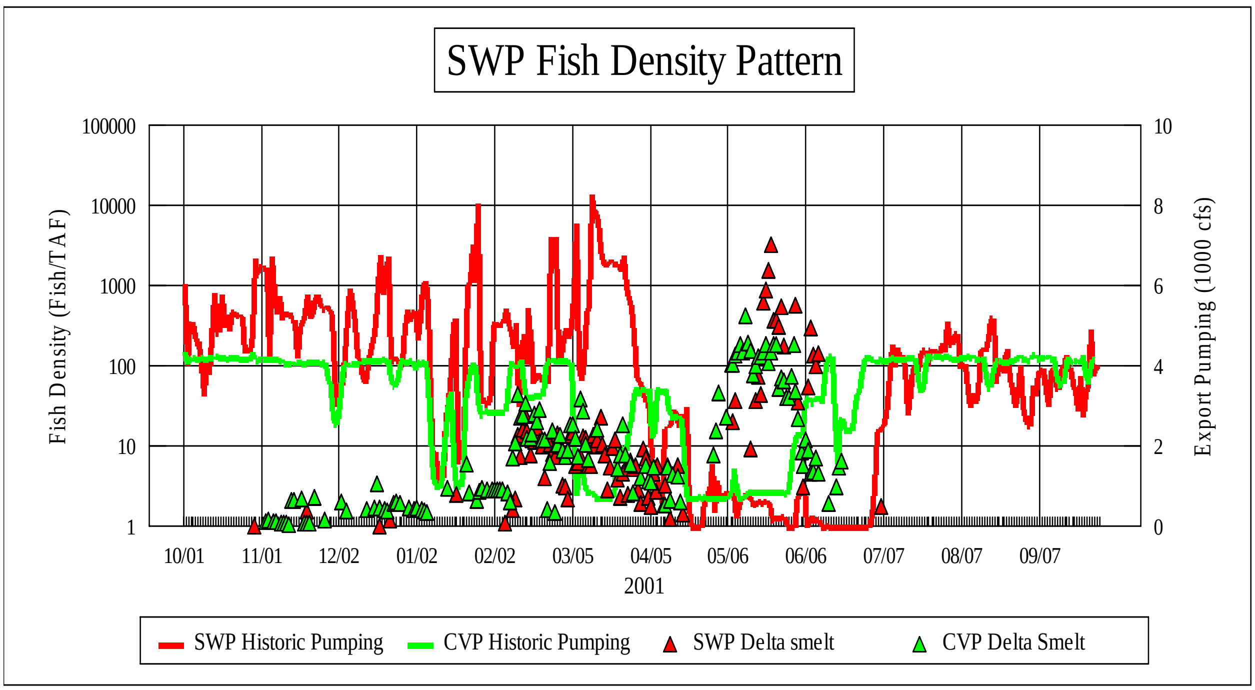


High Delta outflows in 1998 may have limited adult abundance in the south Delta, but there was no SWP pumping during months with traditional high salvage of adults and juveniles. CVP and SWP densities were similar for both adults in February and March and juveniles in May and June of 1999.

Figure 12

Delta Smelt SWP and CVP Salvage Density for Water Years 1998 and 1999





CVP and SWP densities were similar for both adults in February and March and juveniles in May and June of both years. Adult densities were about 10/taf for a month—February of 2000 and mid-February to mid-March of 2001. Juvenile densities were highest in May of both years, but lower at the CVP in June of 2001. There was no SWP salvage in June because there was no pumping.

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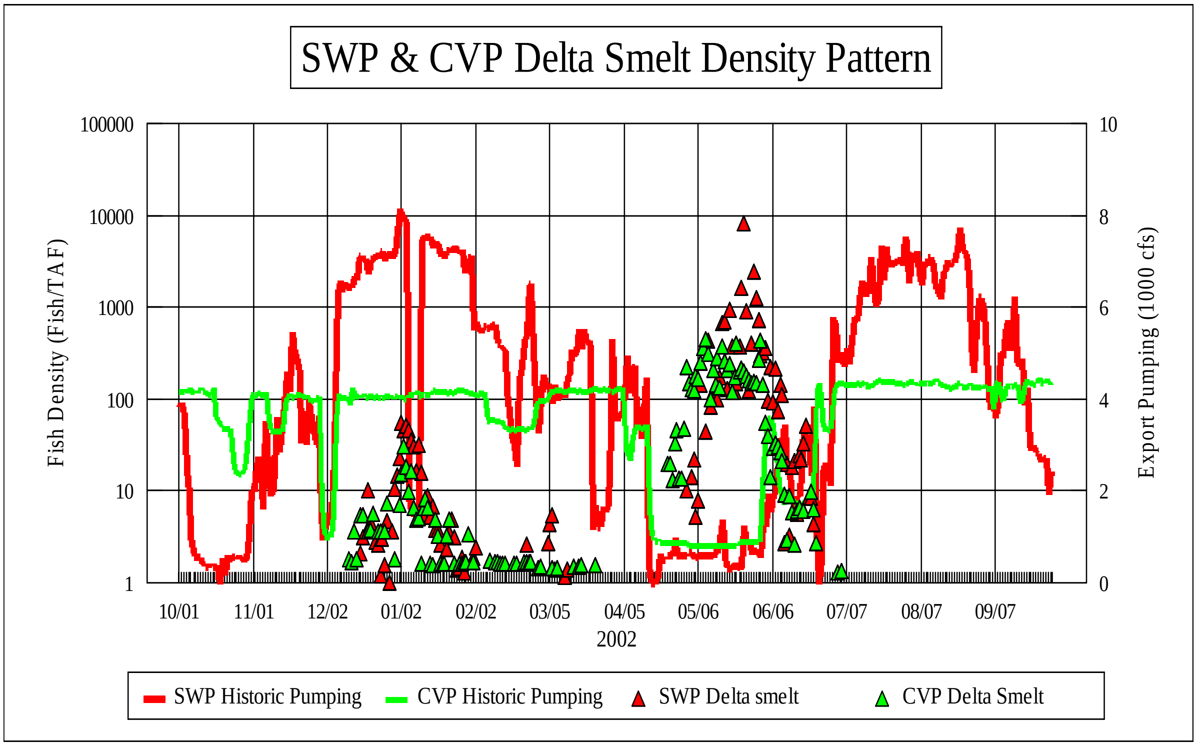
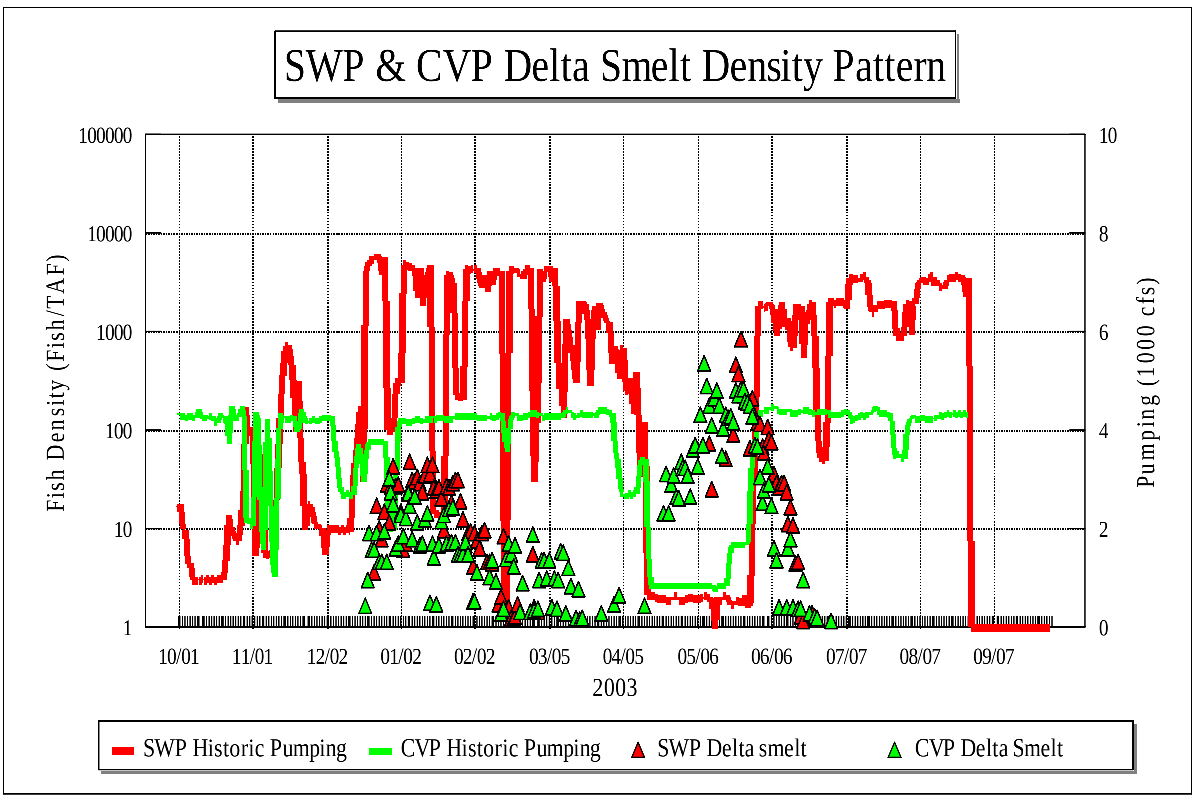
Figure 13

Delta Smelt SWP and CVP Salvage Density for Water Years 2000 and 2001





CVP and SWP densities were similar for both adults in February and March and juveniles in May and June. Adults were salvaged for a shorter period in 2002, while juvenile densities were highest in May of both years. The juveniles declined rapidly in early June of both years, although pumping was much higher in 2003, suggesting movement of juveniles out of the south Delta.

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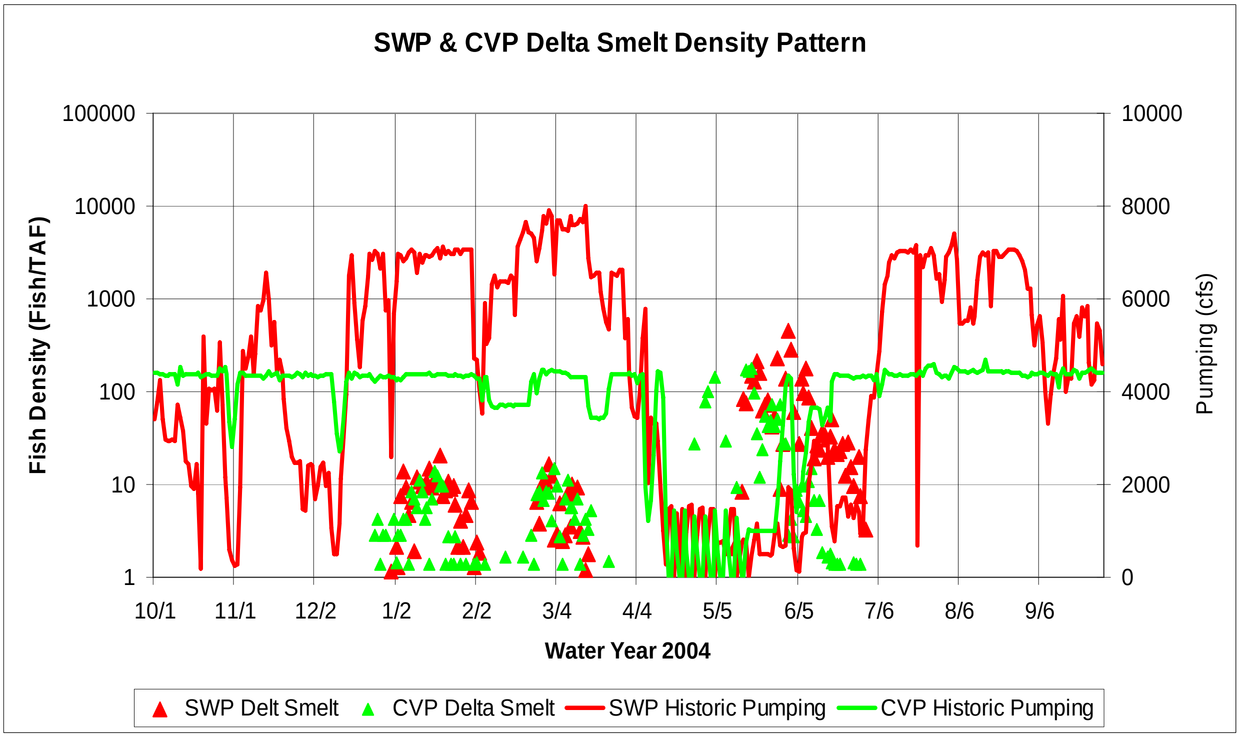
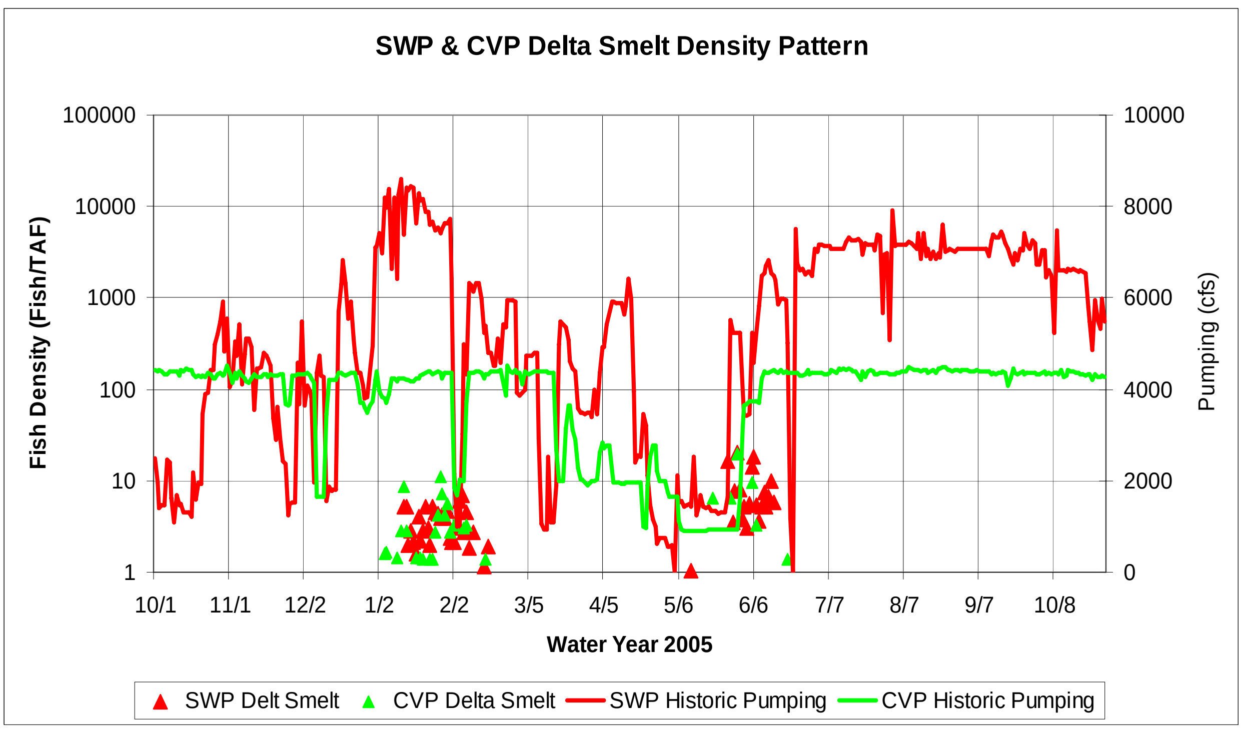
Figure 14

Delta Smelt SWP and CVP Salvage Density for Water Years 2002 and 2003





CVP and SWP densities were similar for adults in January–March and juveniles in May–June of 2004. Delta smelt adult and juvenile densities were very low in 2005, similar to 1995 and 1998, which were previous high spring outflow years.

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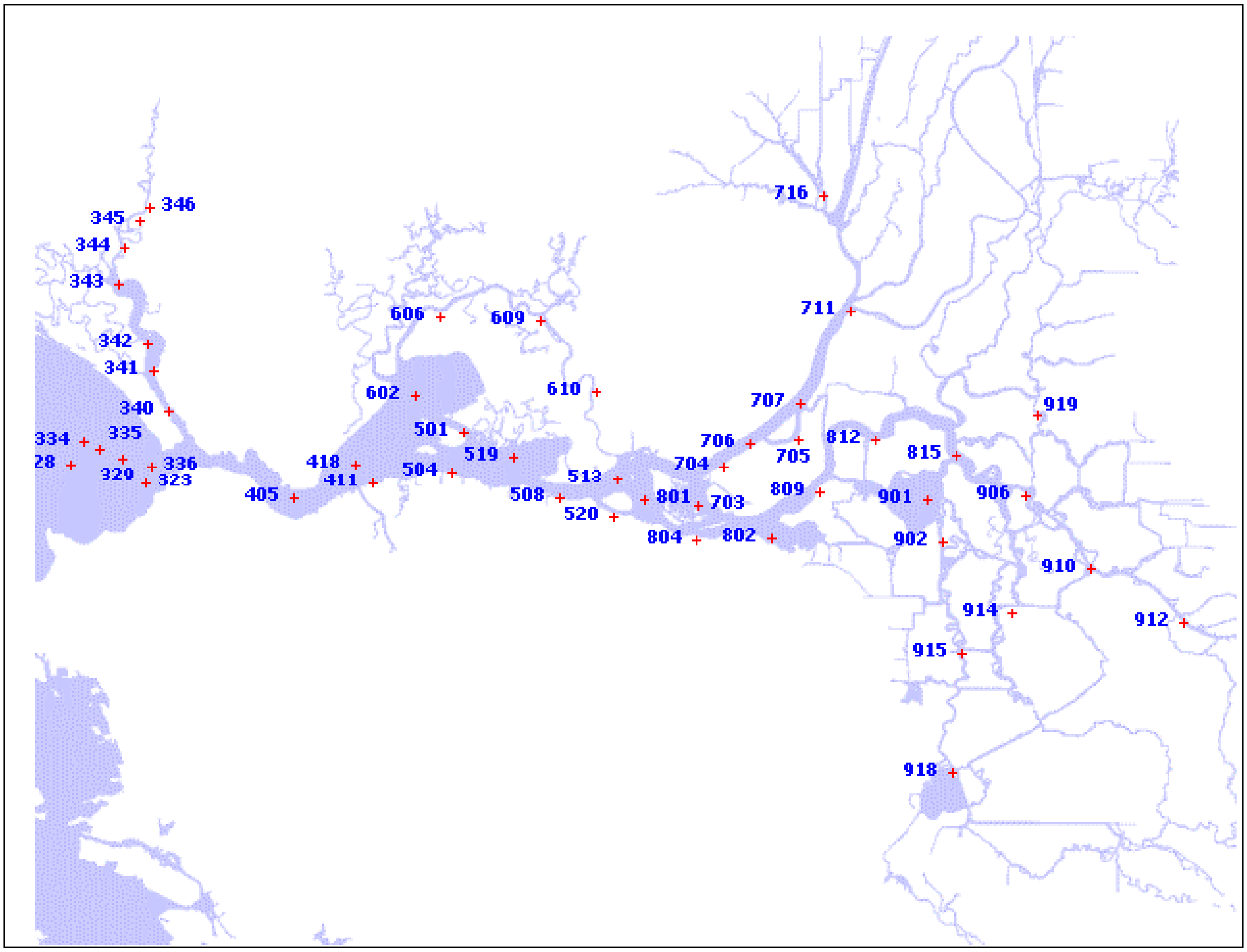
Figure 15

Delta Smelt SWP and CVP Salvage Density for Water Years 2004 and 2005



These stations are similar to the FMWT stations. Juvenile delta smelt are not usually found at high salinity stations, so sampling effort is generally confined to low salinity stations (EC of less than 10,000 µS/cm). The 20-mm survey data are displayed on the DFG website with bubble plots that show the relative catch at each station and length frequency diagrams for each year. Relative abundance indices for each year of 20-mm survey data are calculated in Table 2. There are few delta smelt caught in the first surveys because there are very few juveniles large enough to be caught in March and April. May and June surveys generally have the highest catch.

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Figure 16

Map of 20-mm Survey Sampling Stations

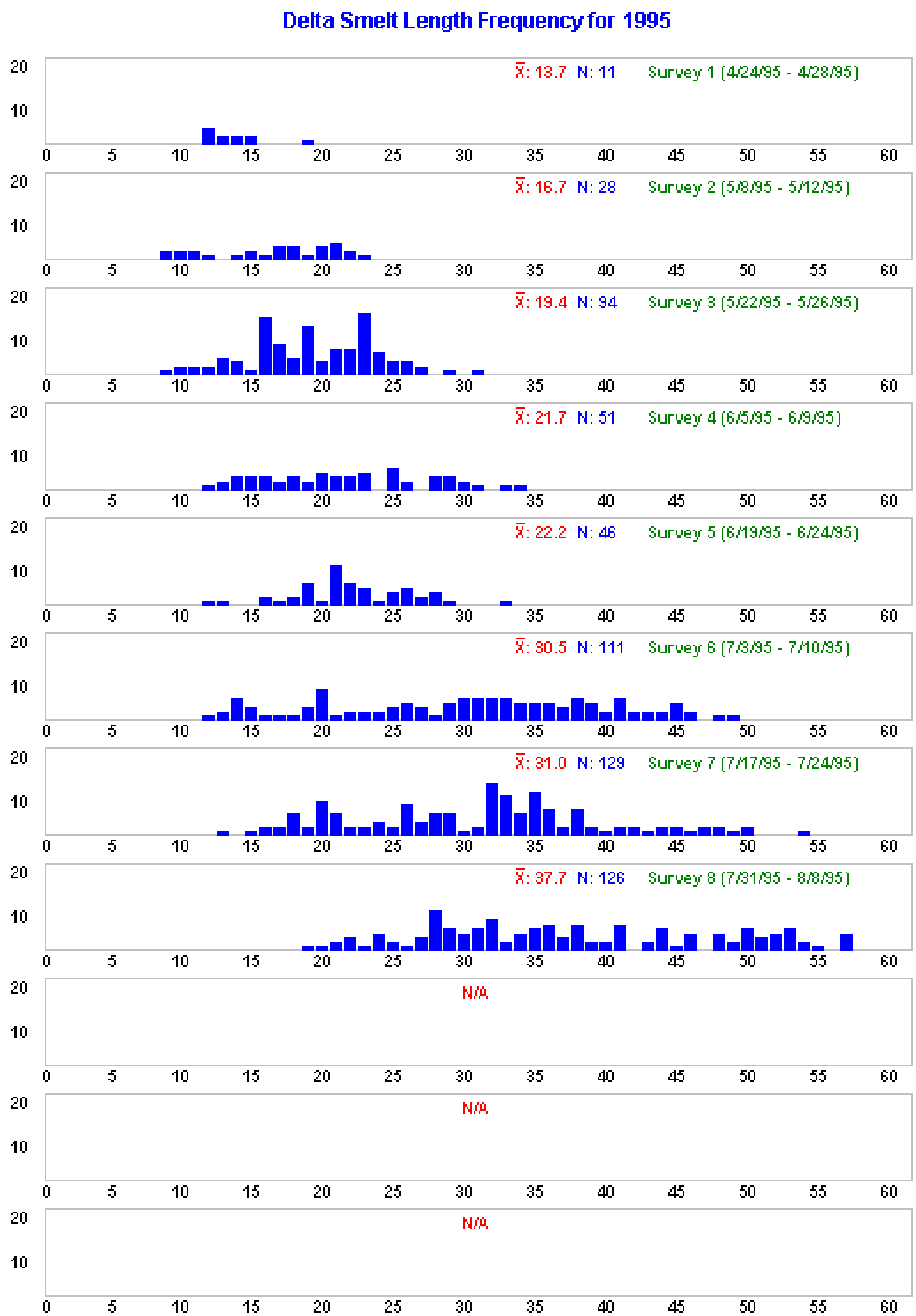

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Figure 17

Delta Smelt Length-Frequency Diagrams for 20-mm Surveys during 1995

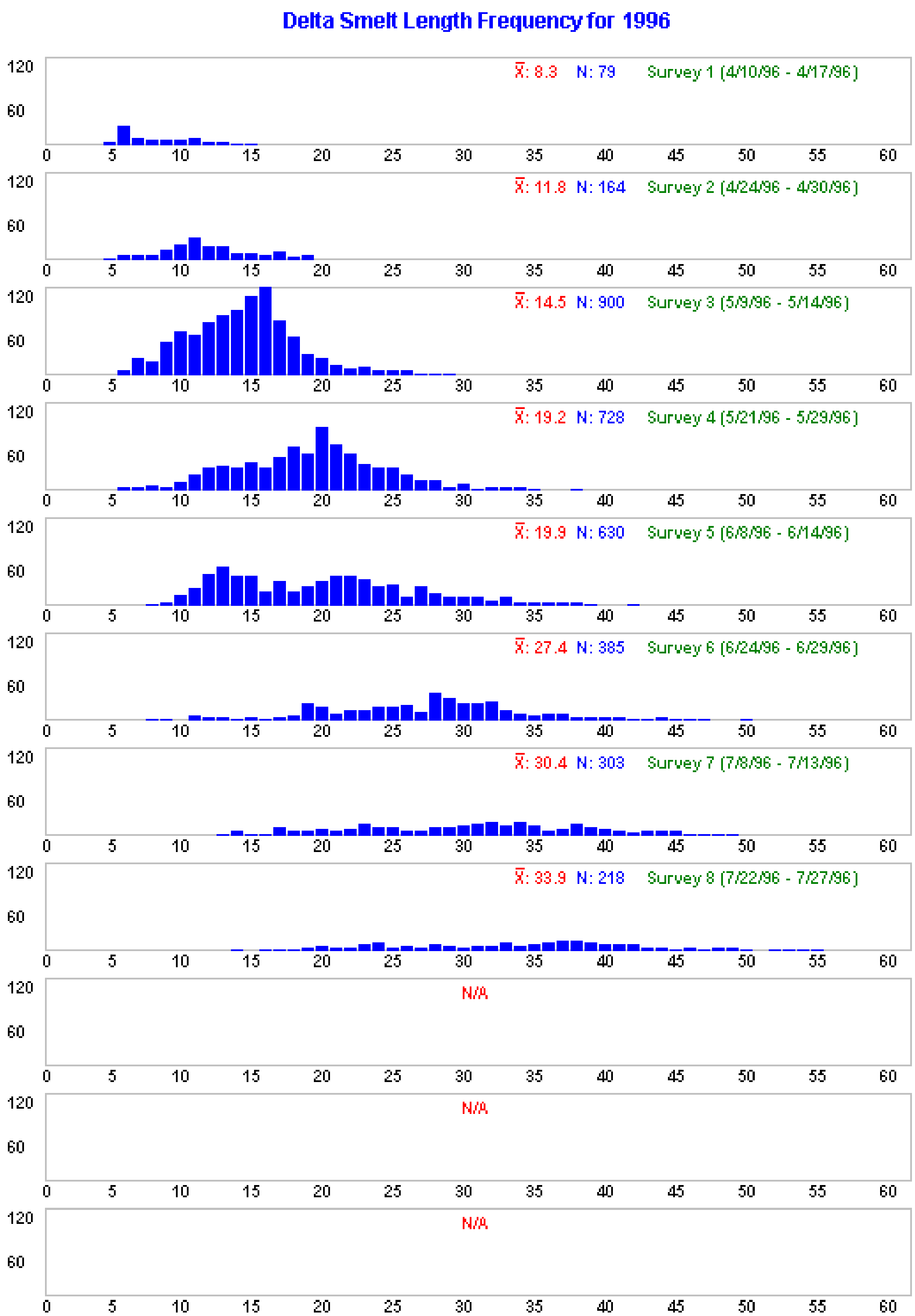

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Figure 18

Delta Smelt Length-Frequency Diagrams for 20-mm Surveys during 1996

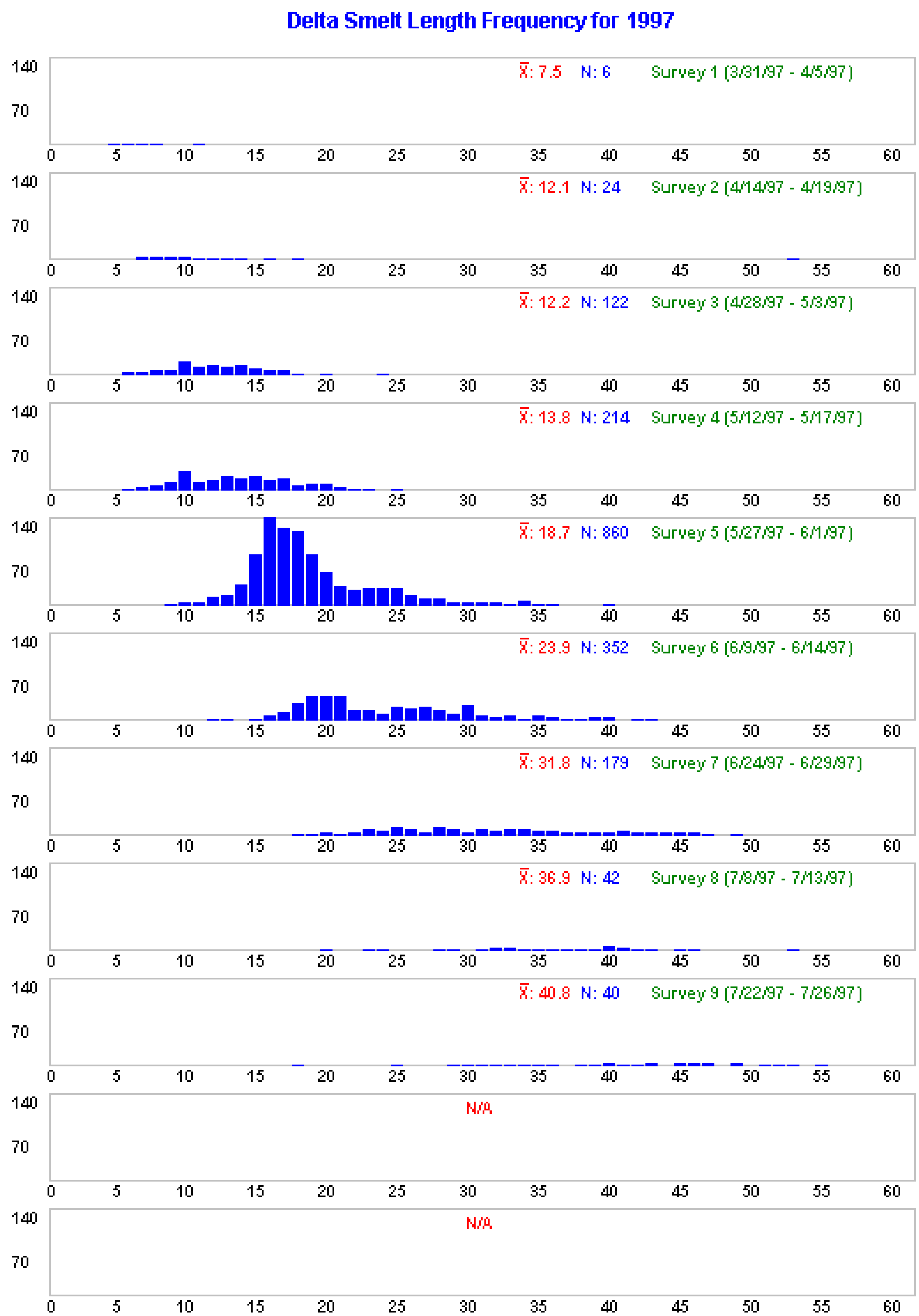

Figure 19

Delta Smelt Length-Frequency Diagrams for 20-mm Surveys during 1997

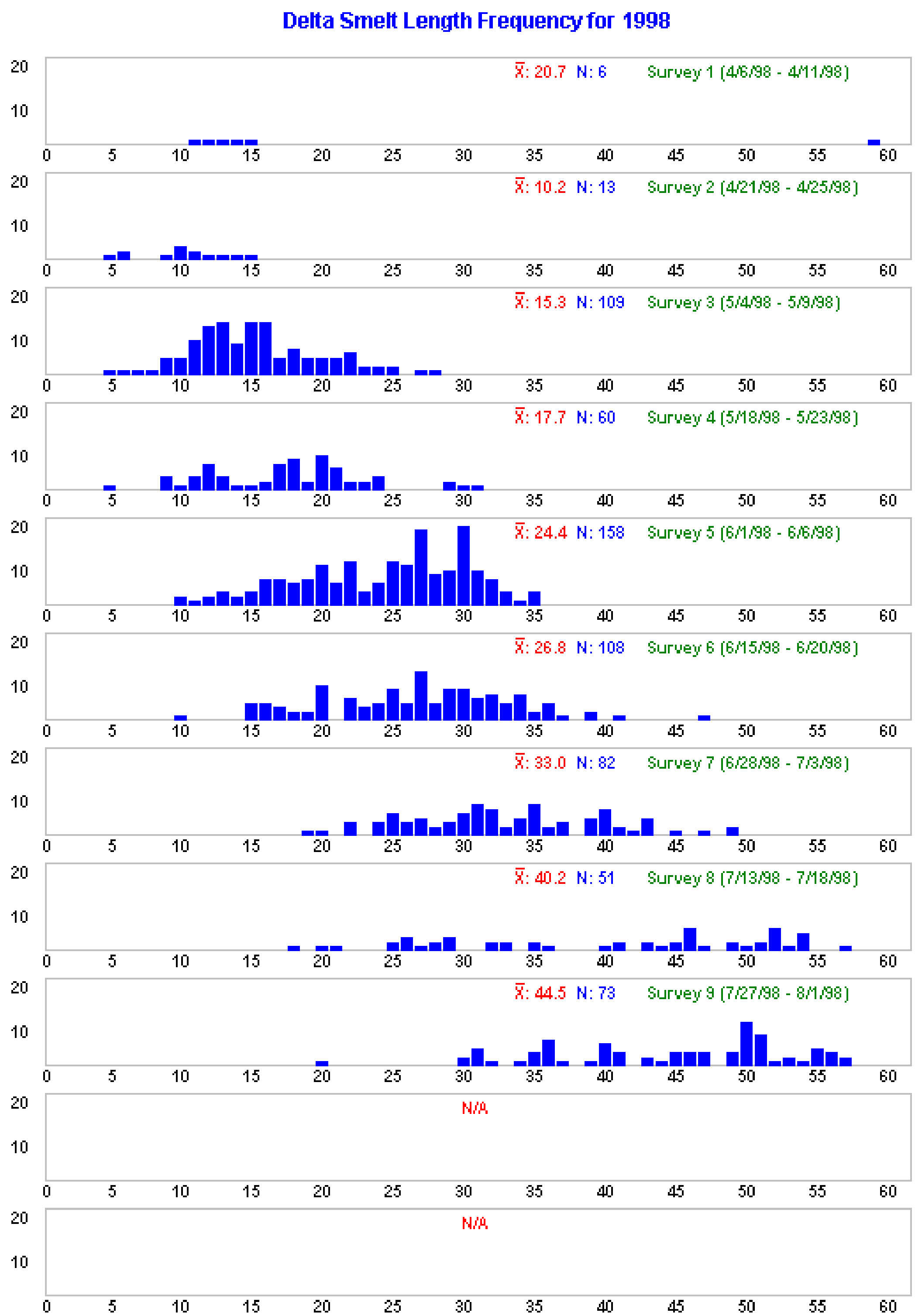

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Figure 20

Delta Smelt Length-Frequency Diagram for 20-mm Surveys during 1998

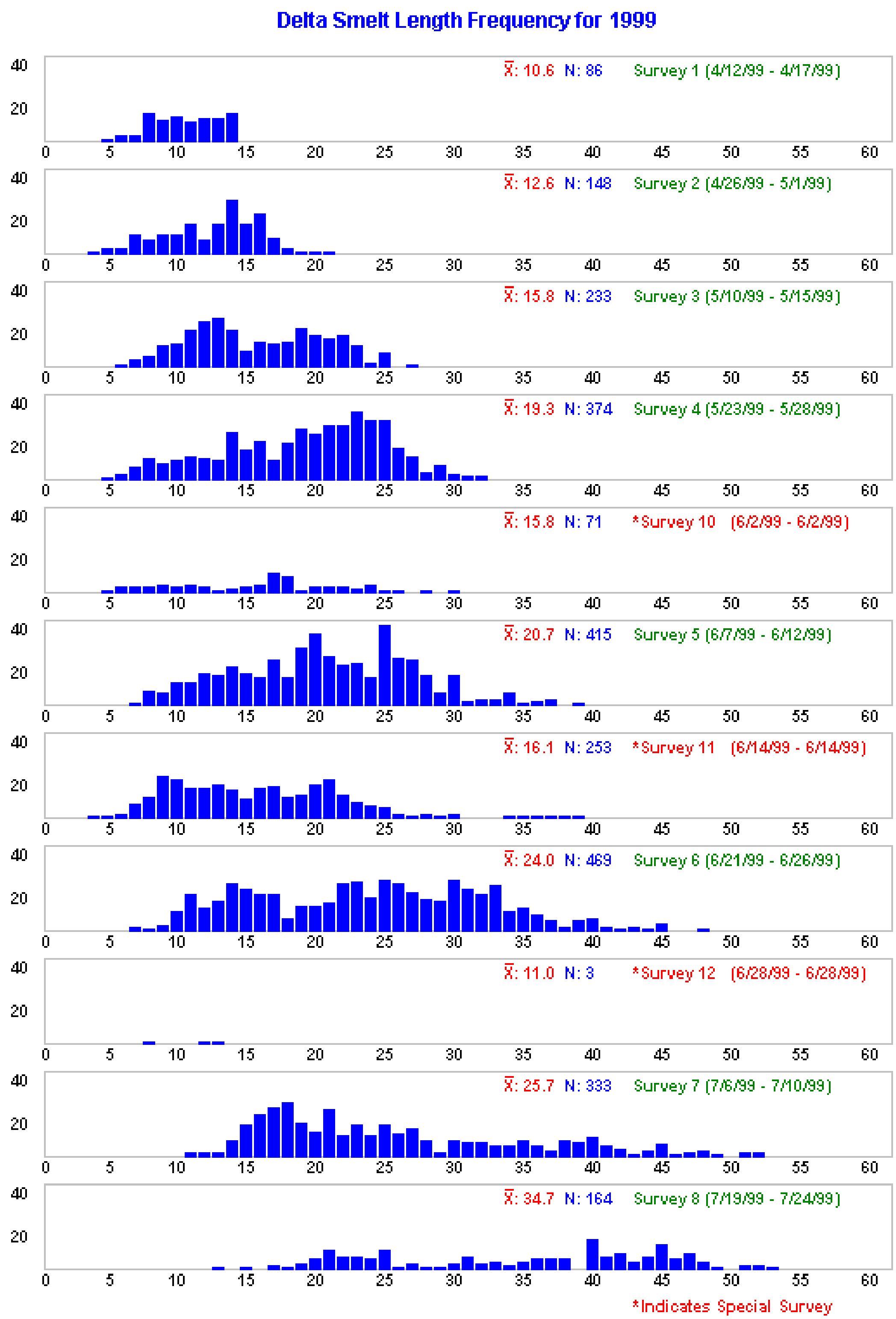

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Figure 21

Delta Smelt Length-Frequency Diagram for 20-mm Surveys during 1999

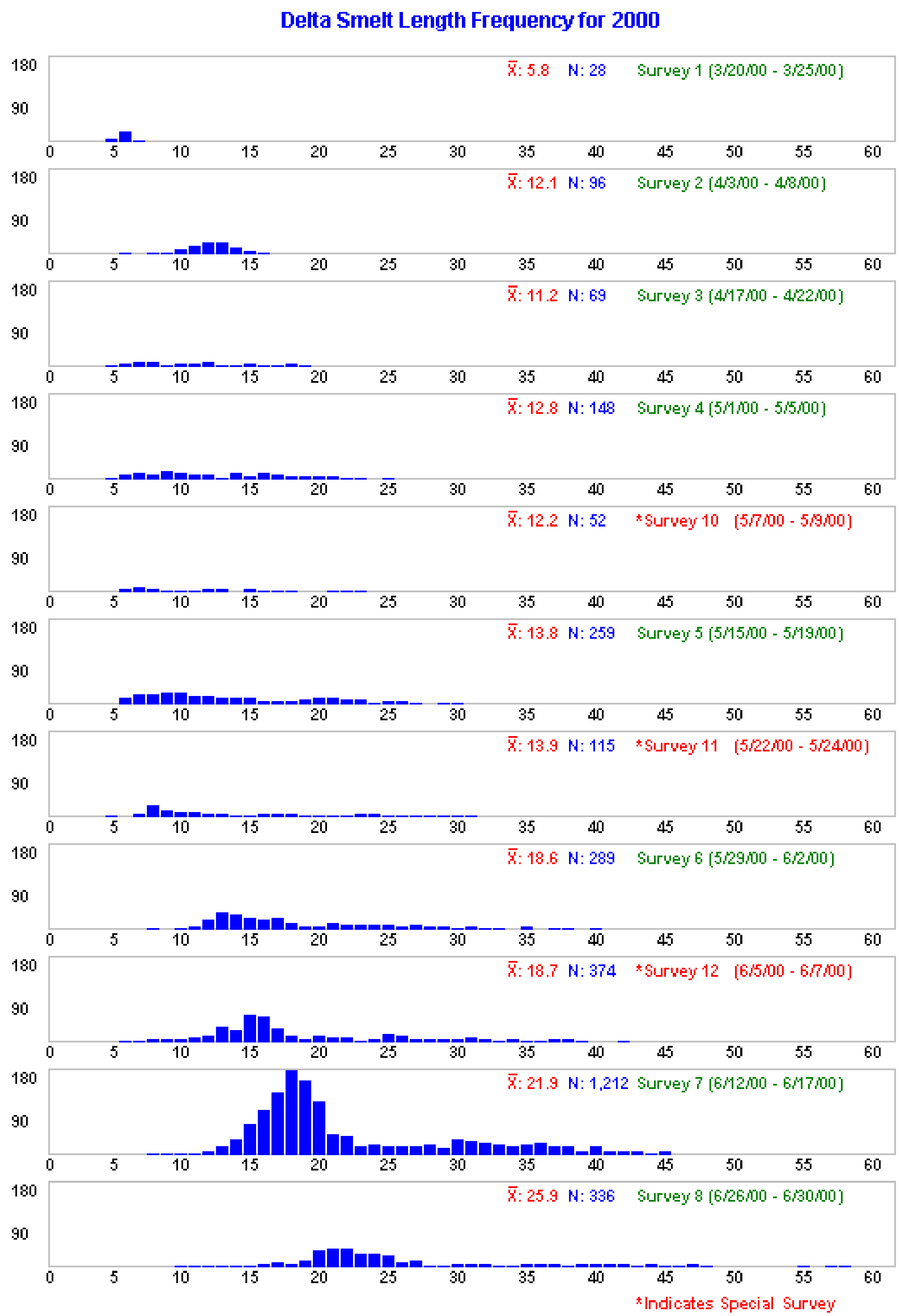

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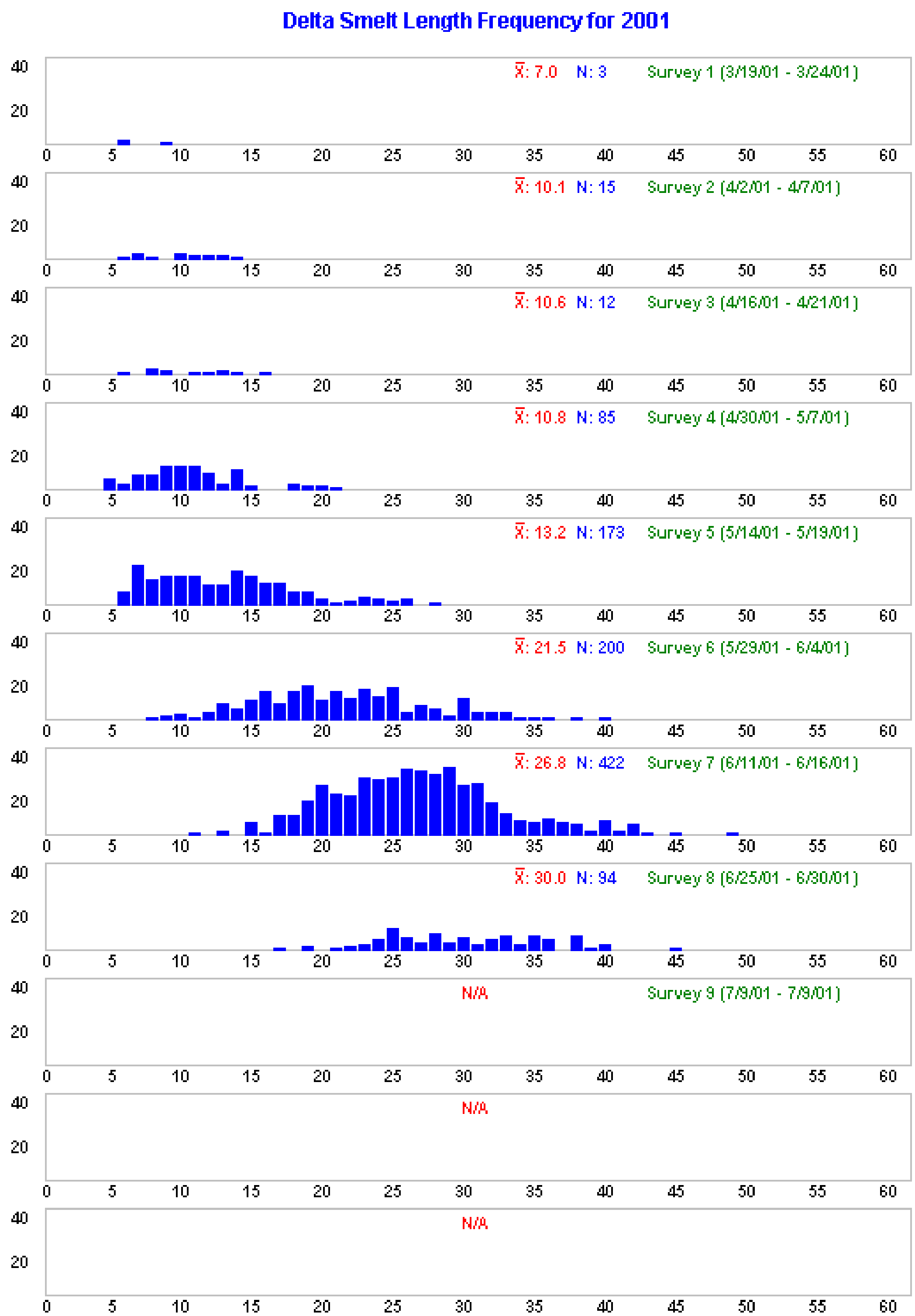
Figure 22

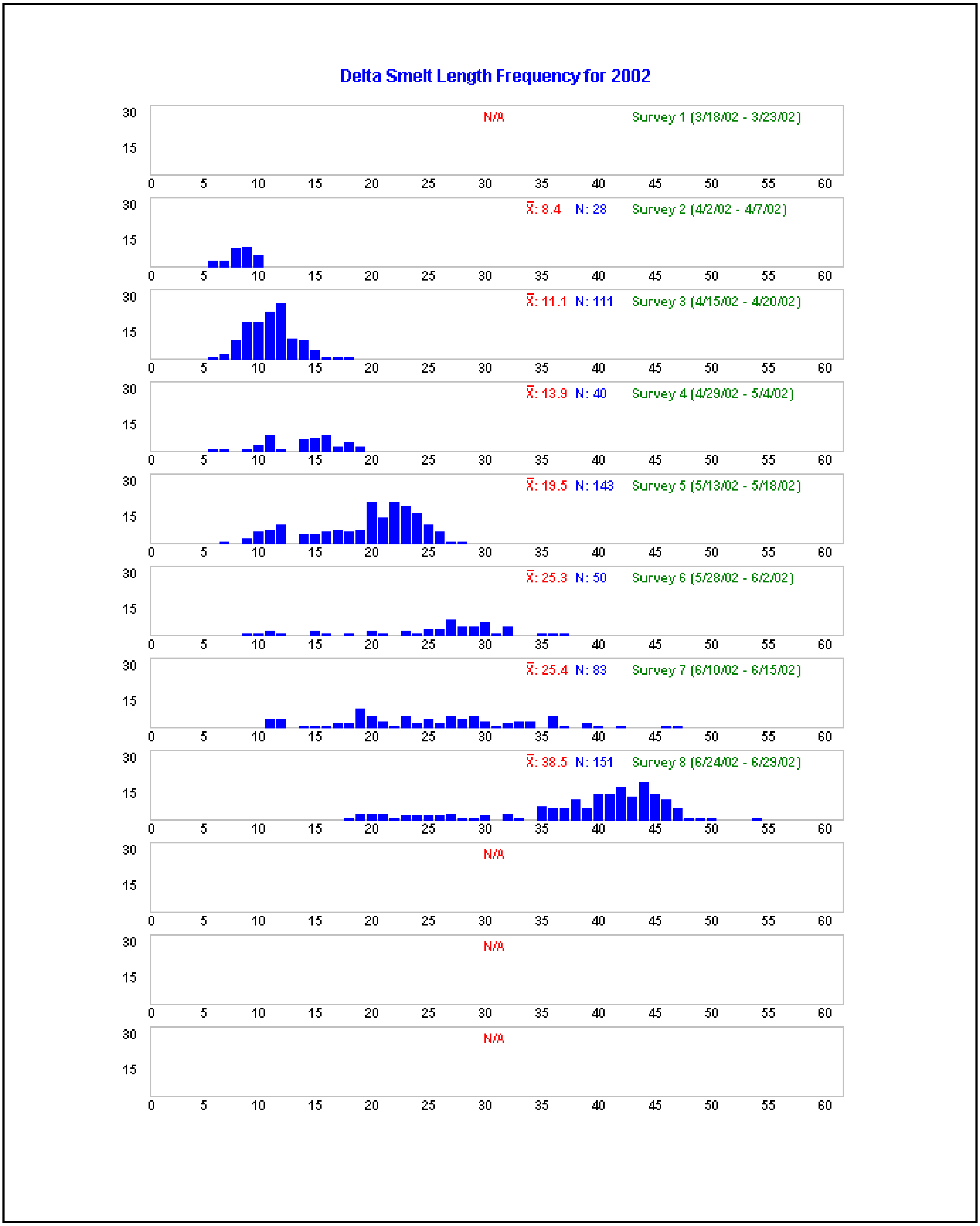
Delta Smelt Length-Frequency Diagrams for 20-mm Surveys during 2000



Jones & Stokes

Figure 23

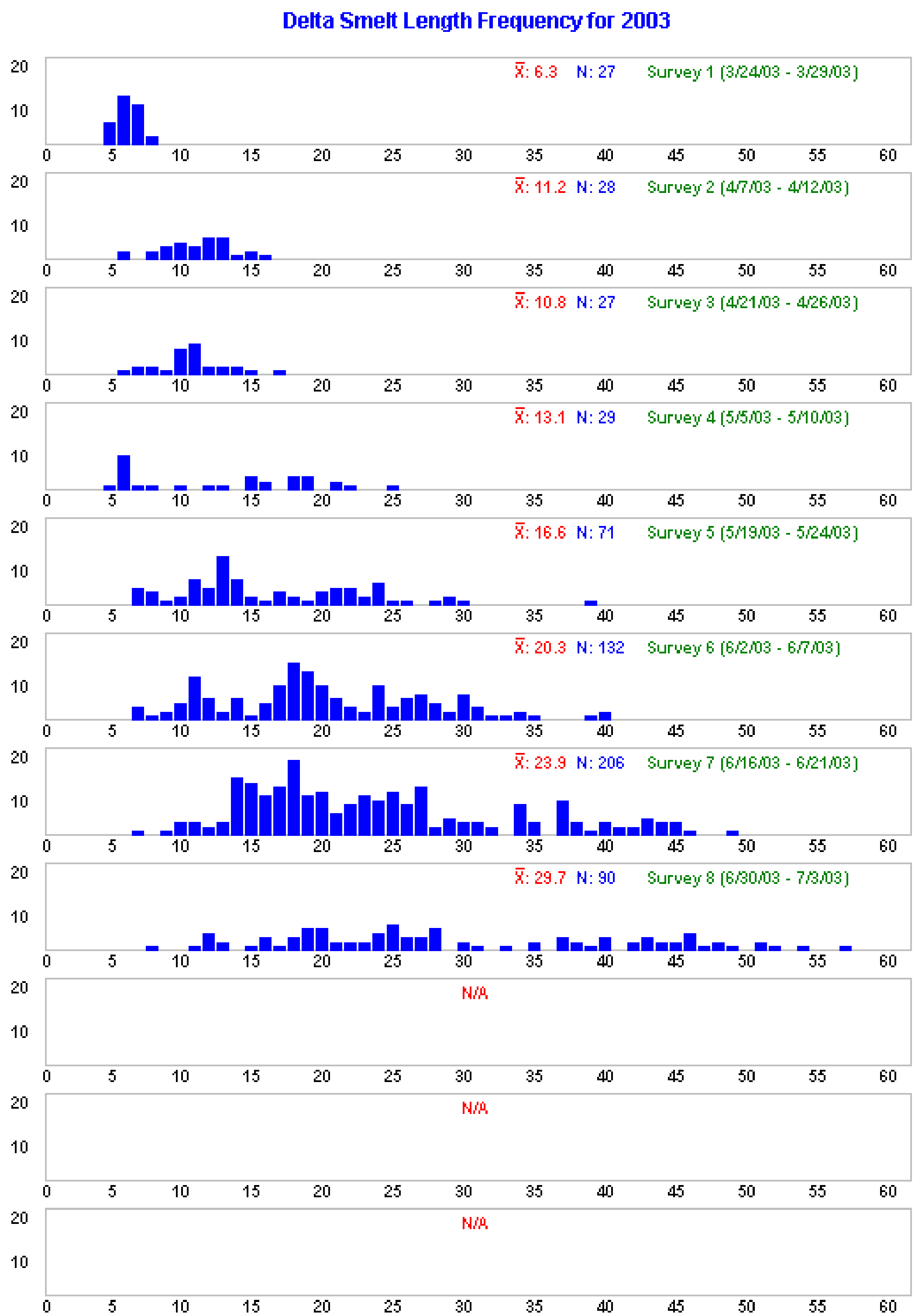
Delta Smelt Length-Frequency Diagrams for 20-mm Surveys during 2001



Jones & Stokes

Figure 24

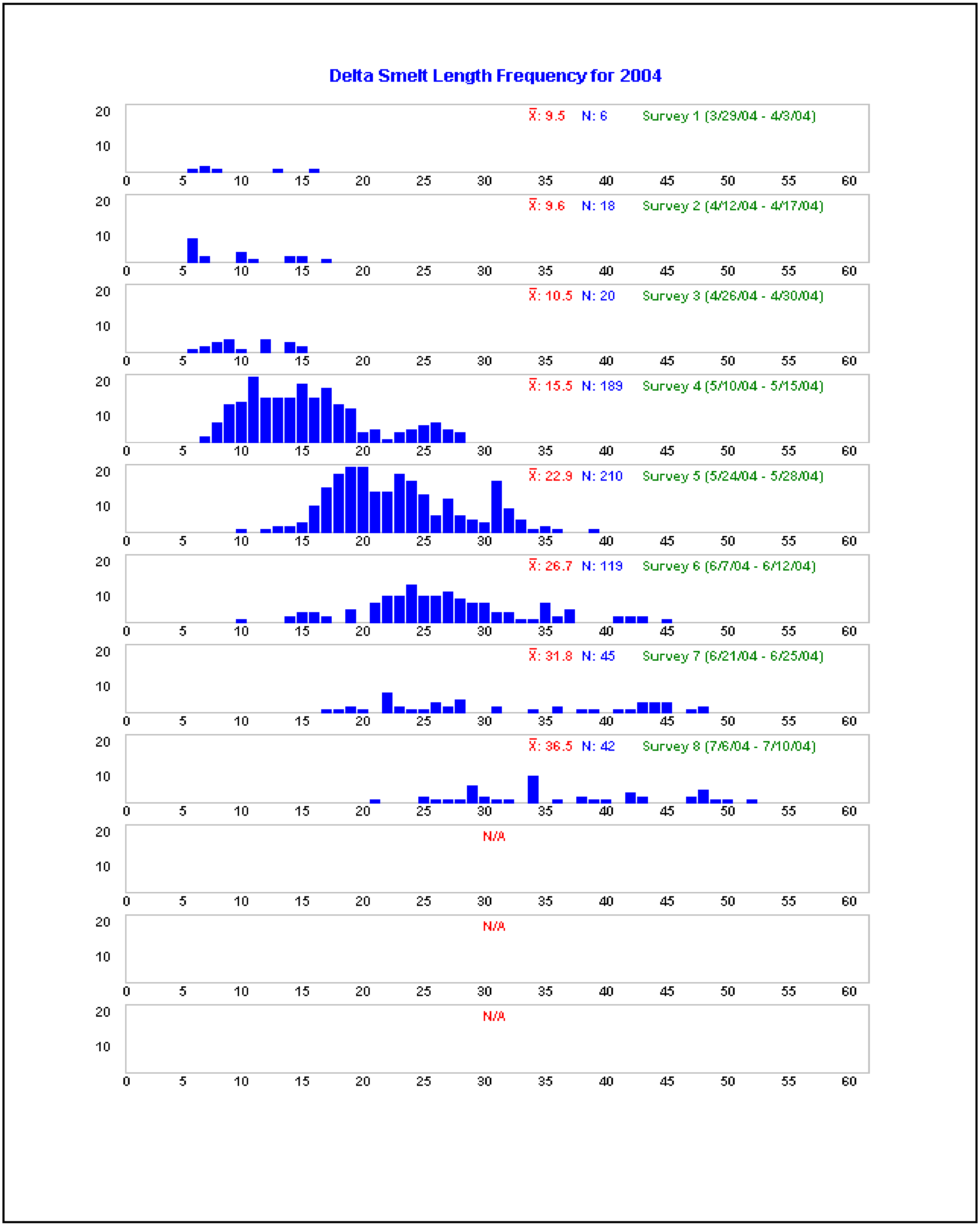
Delta Smelt Length-Frequency Diagrams for 20-mm Surveys during 2002



Jones & Stokes

Figure 25

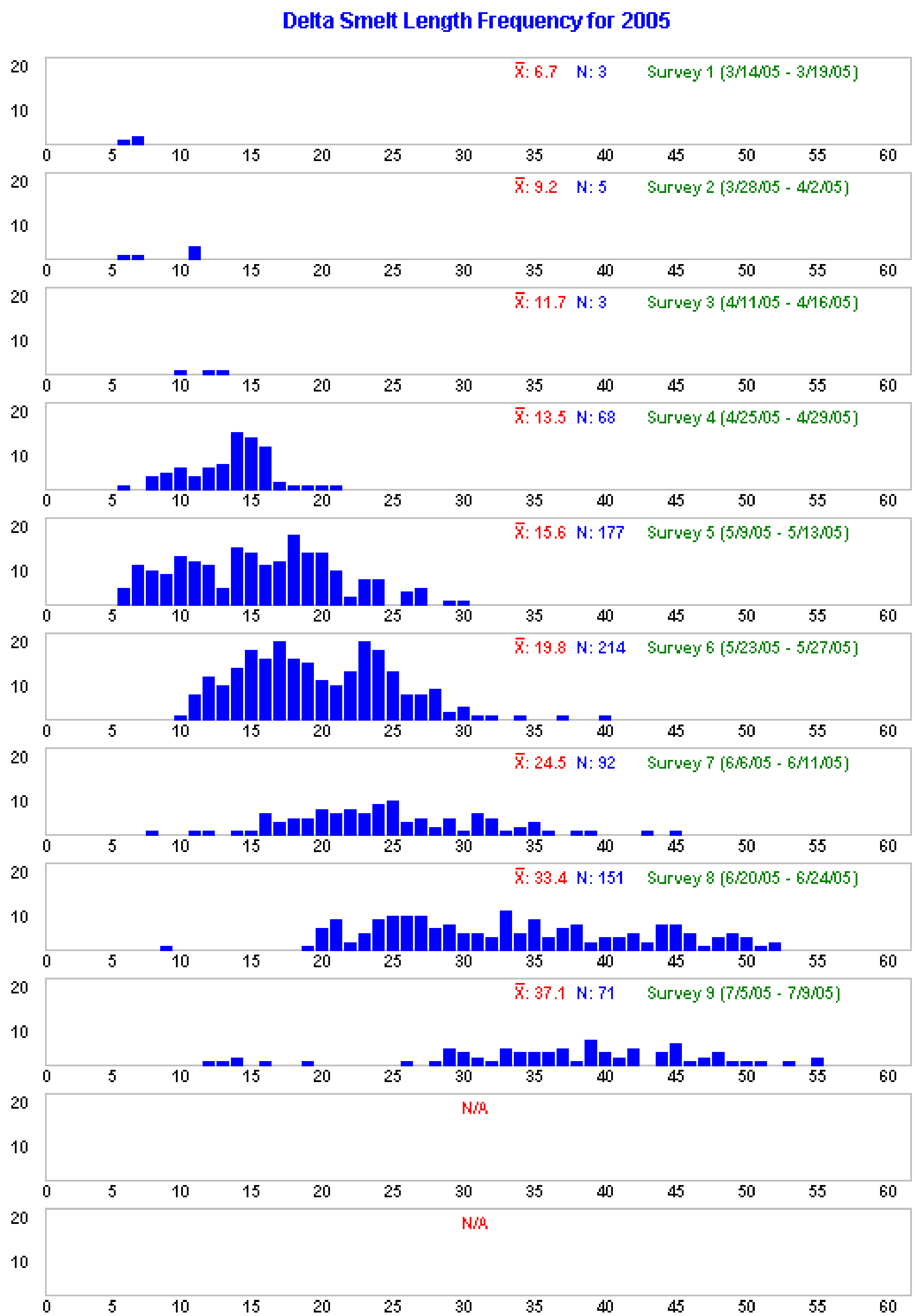
Delta Smelt Length-Frequency Diagrams for 20-mm Surveys during 2003



Jones & Stokes

Figure 26

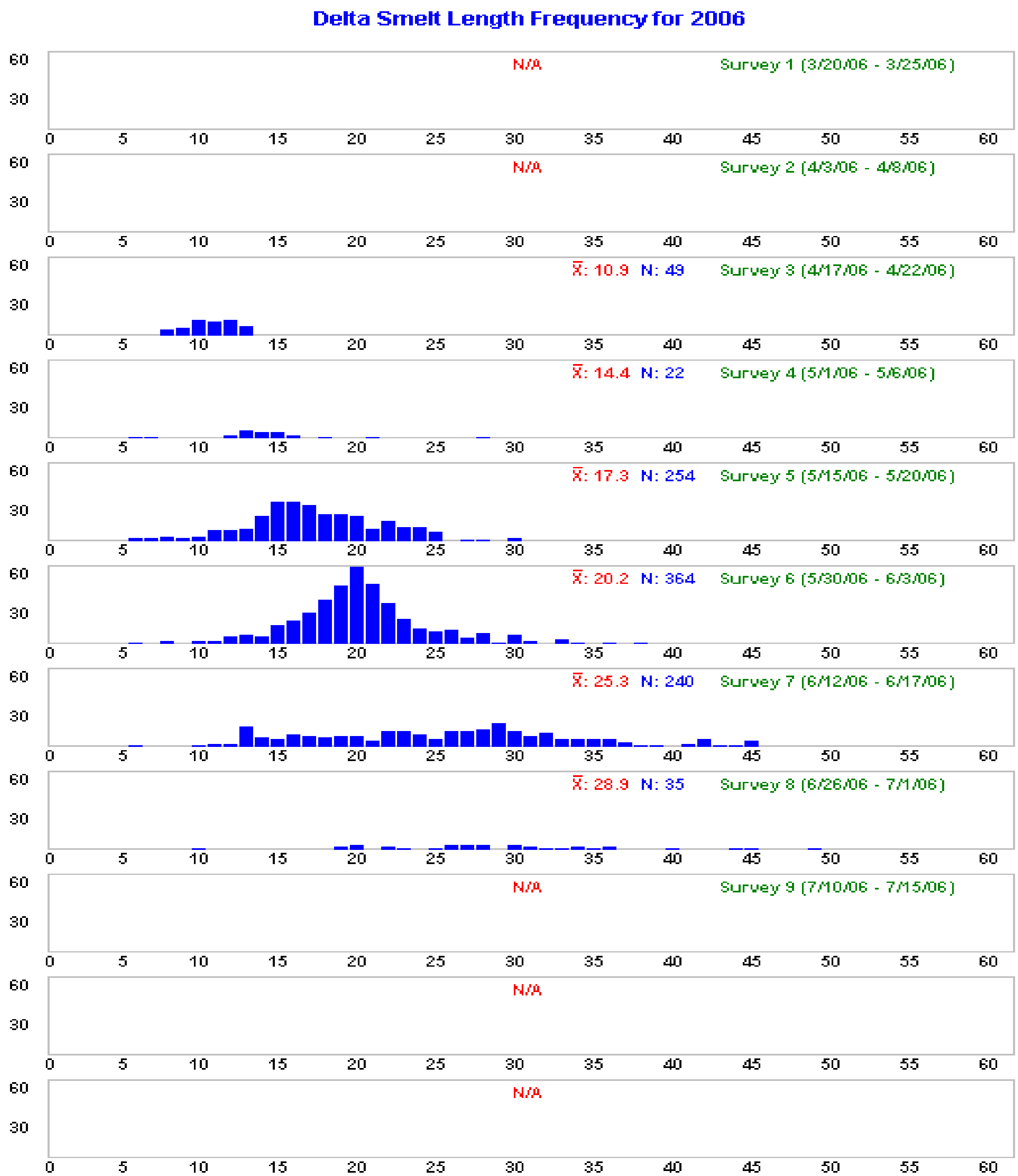
Delta Smelt Length-Frequency Diagrams for 20-mm Surveys during 2004



Jones & Stokes

Figure 27

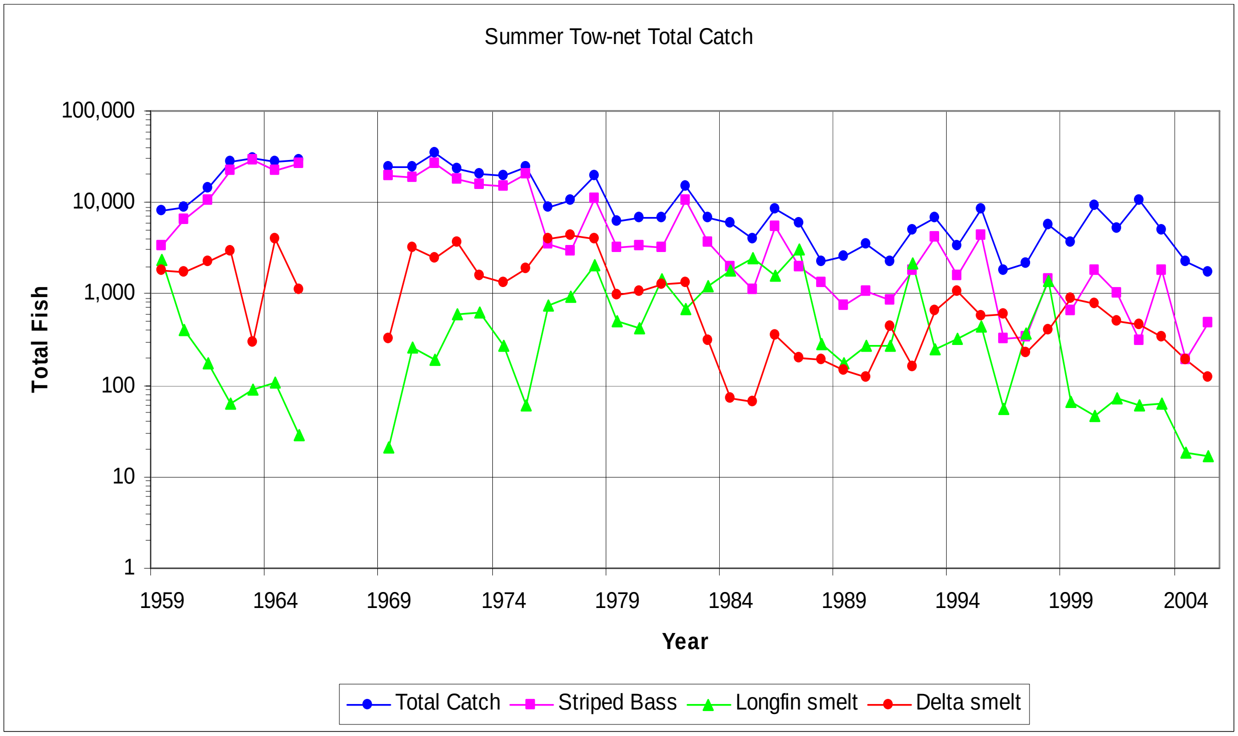
Delta Smelt Length-Frequency Diagrams for 20-mm Surveys during 2005

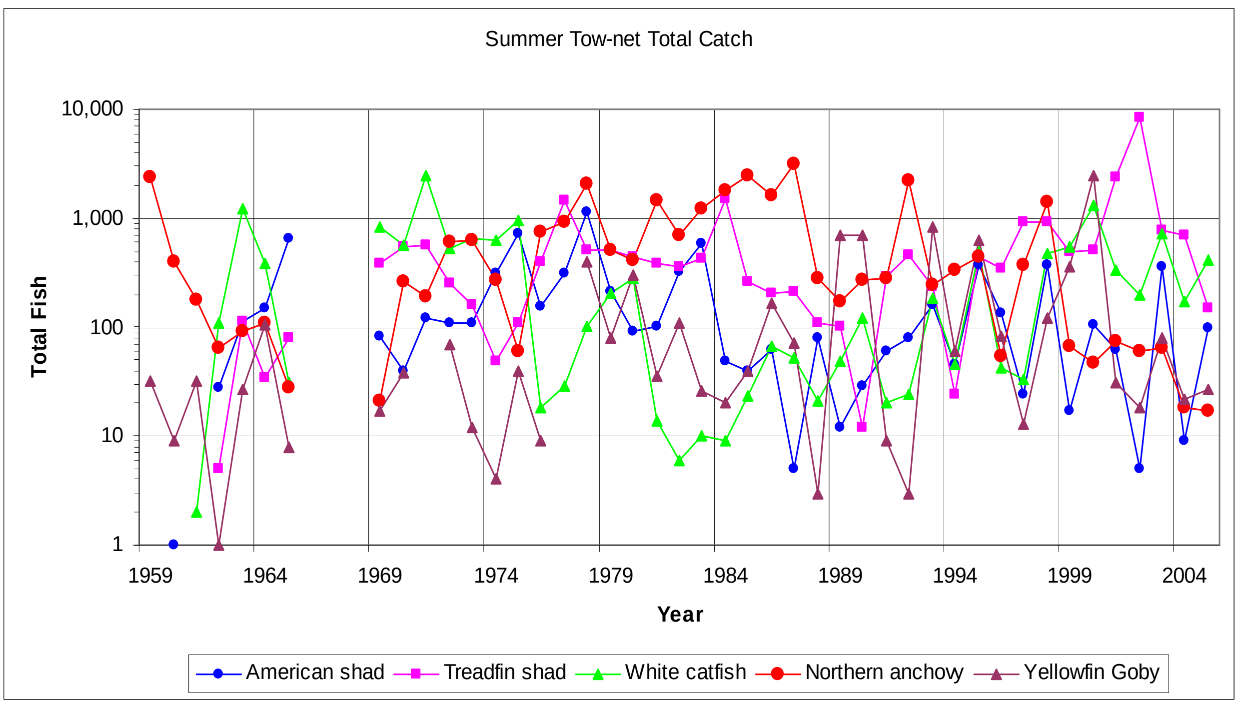


Jones & Stokes

Figure 28

Delta Smelt Length-Frequency Diagrams for 20-mm Surveys during 2006



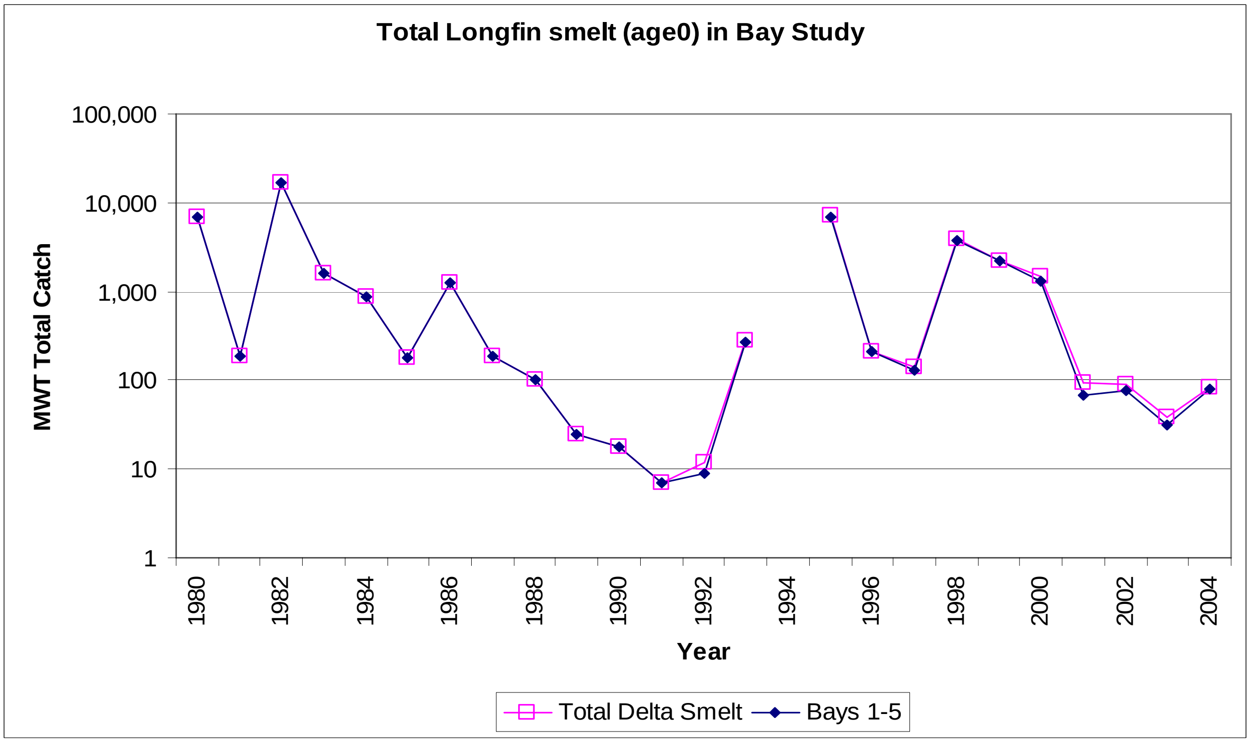


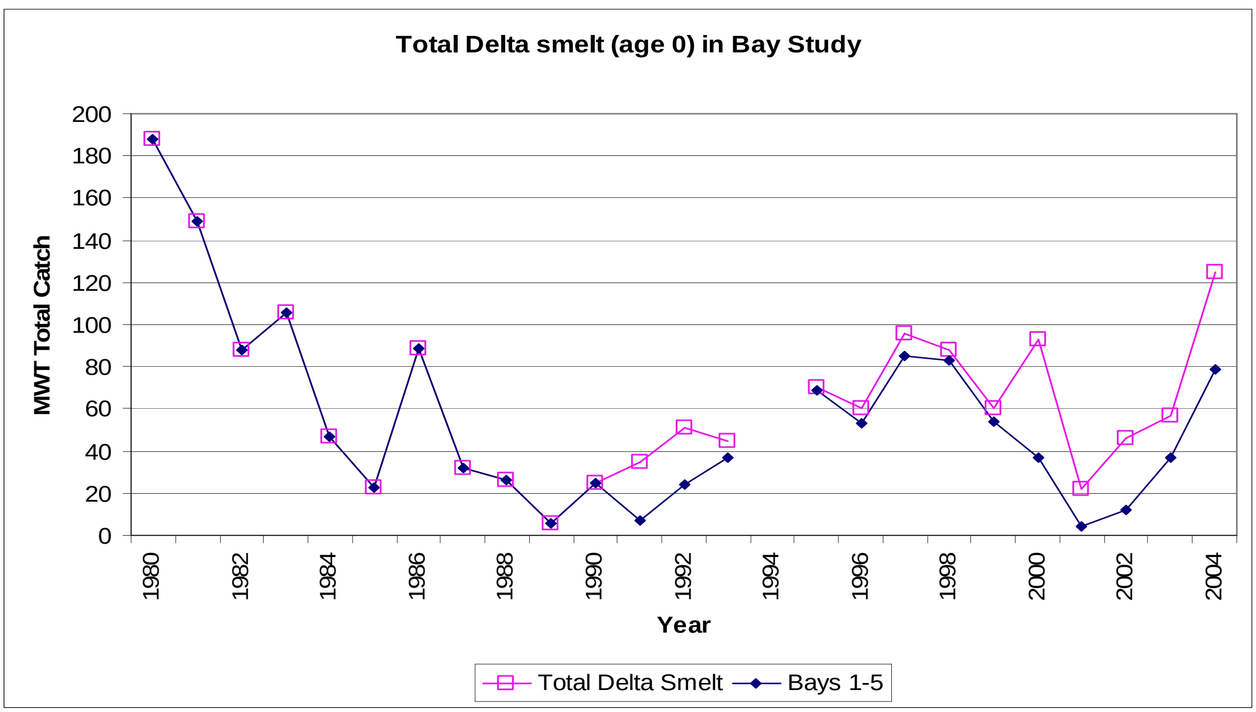
The summer townet catch was highest and dominated by striped bass in the 1960s and 1970s. Delta smelt was the second most abundance specie during these years. The total catch has remained between about 2,000 and 10,000 fish since 1983. Striped bass and delta smelt remain abundant, while threadfin shad and White catfish have also been relatively abundant fish in recent years.

Jones & Stokes

Figure 29

Total Annual Catch for Summer Townet and Catch of the Most Abundant Species for 1959–2005



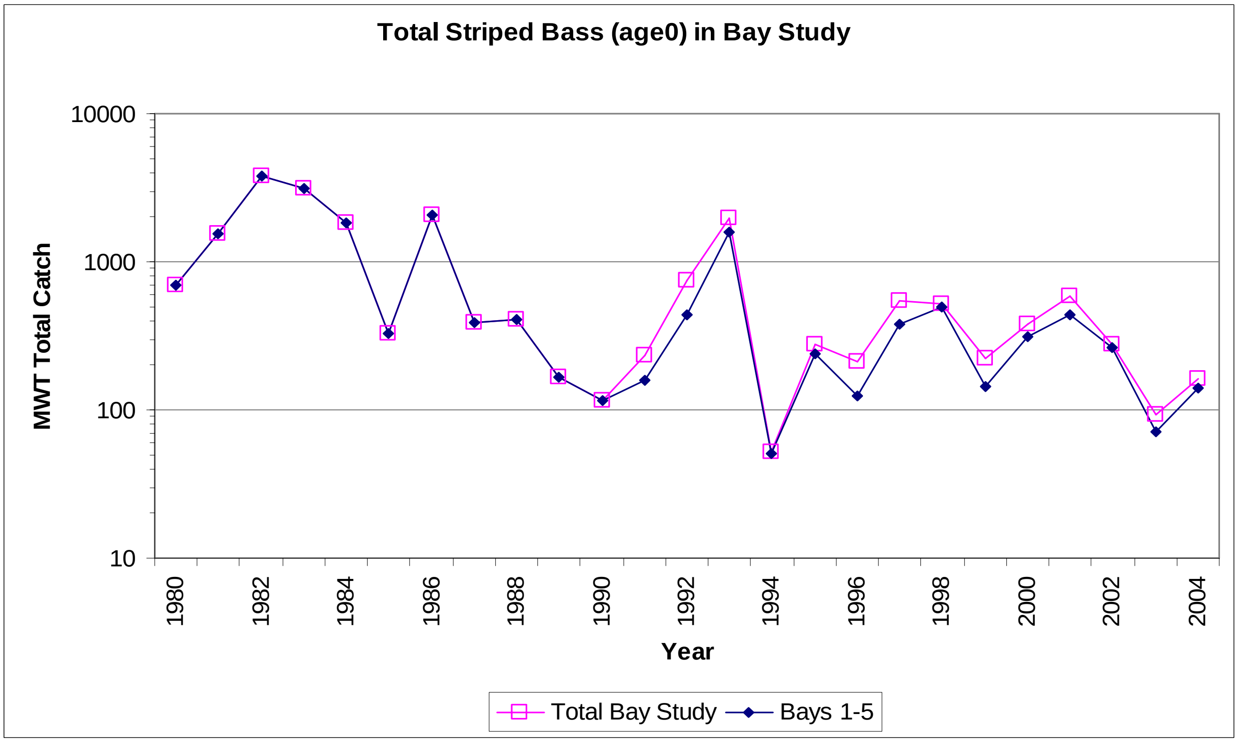


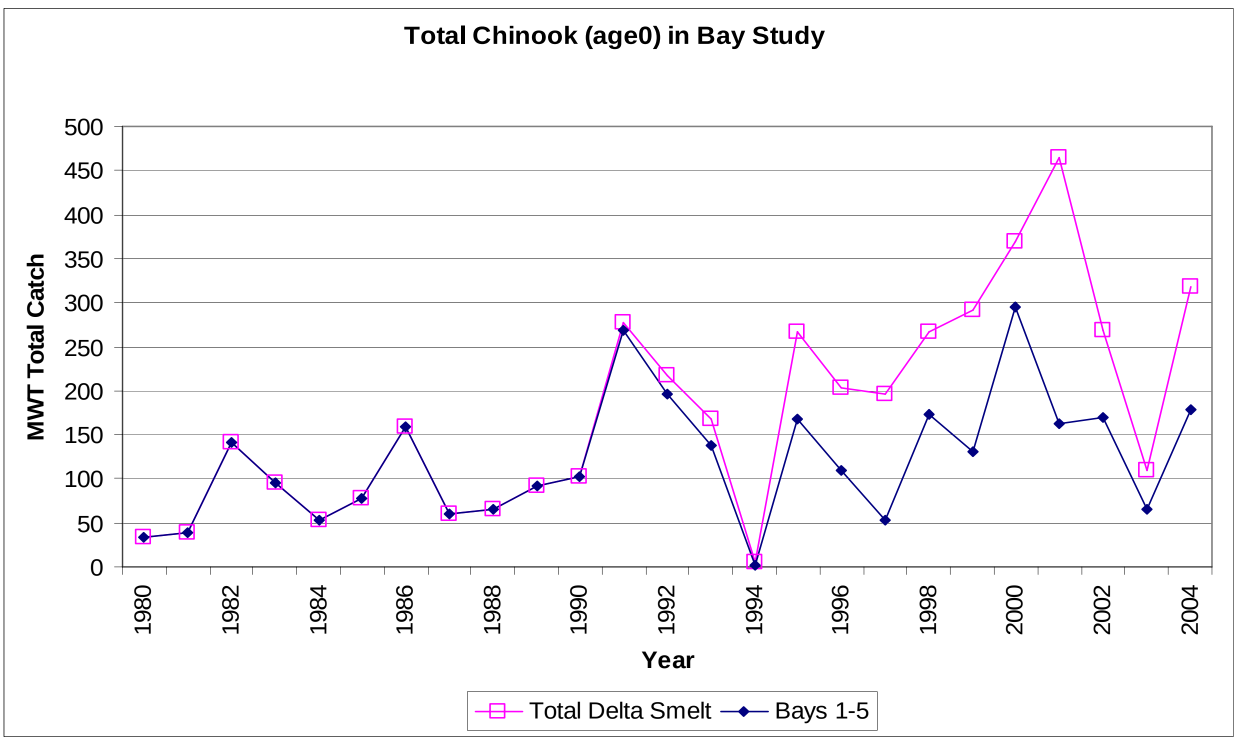
The catch of longfin smelt is higher in the otter trawl (not shown). Several stations were added in 1991, but the original stations are used in the DFG Bay Study Index. The delta smelt catch in the Bay Study has increased since 2001.

Jones & Stokes

Figure 30

Annual Catch of Longfin Smelt and Delta Smelt in the Bay Study Mid-Water Trawl for 1980–2004

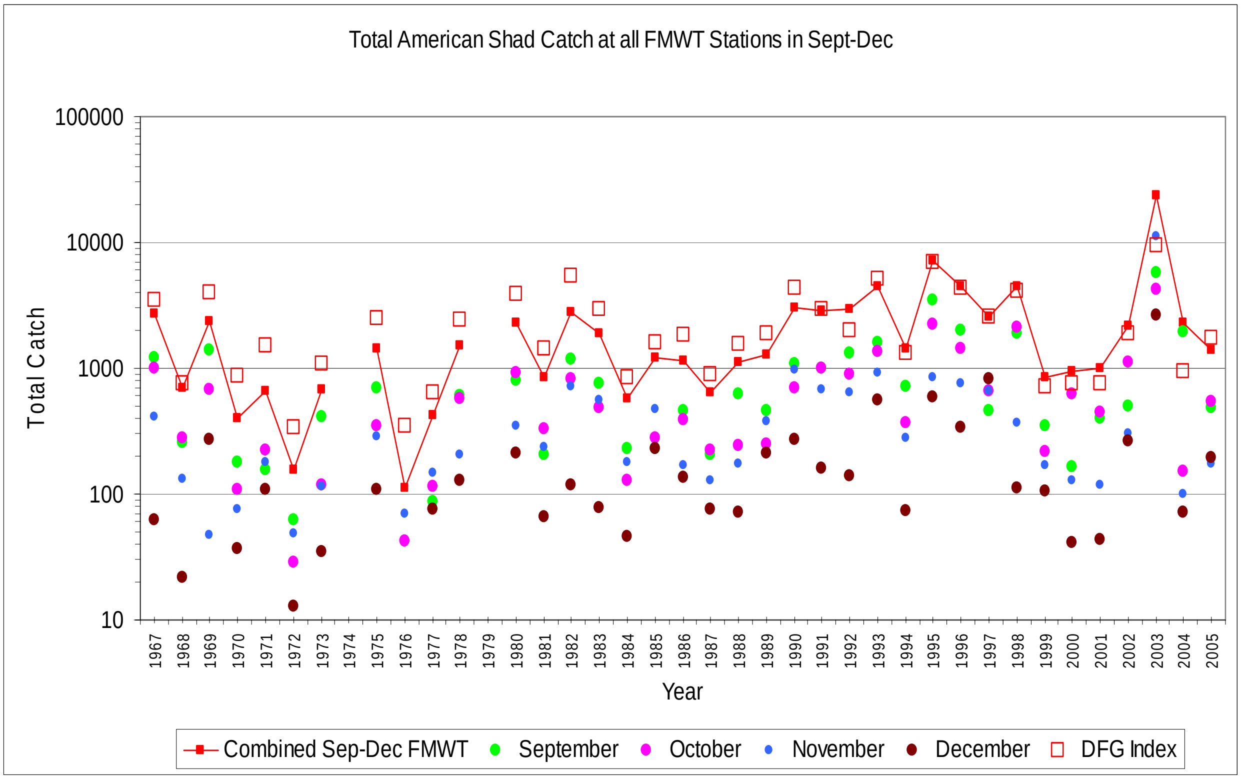


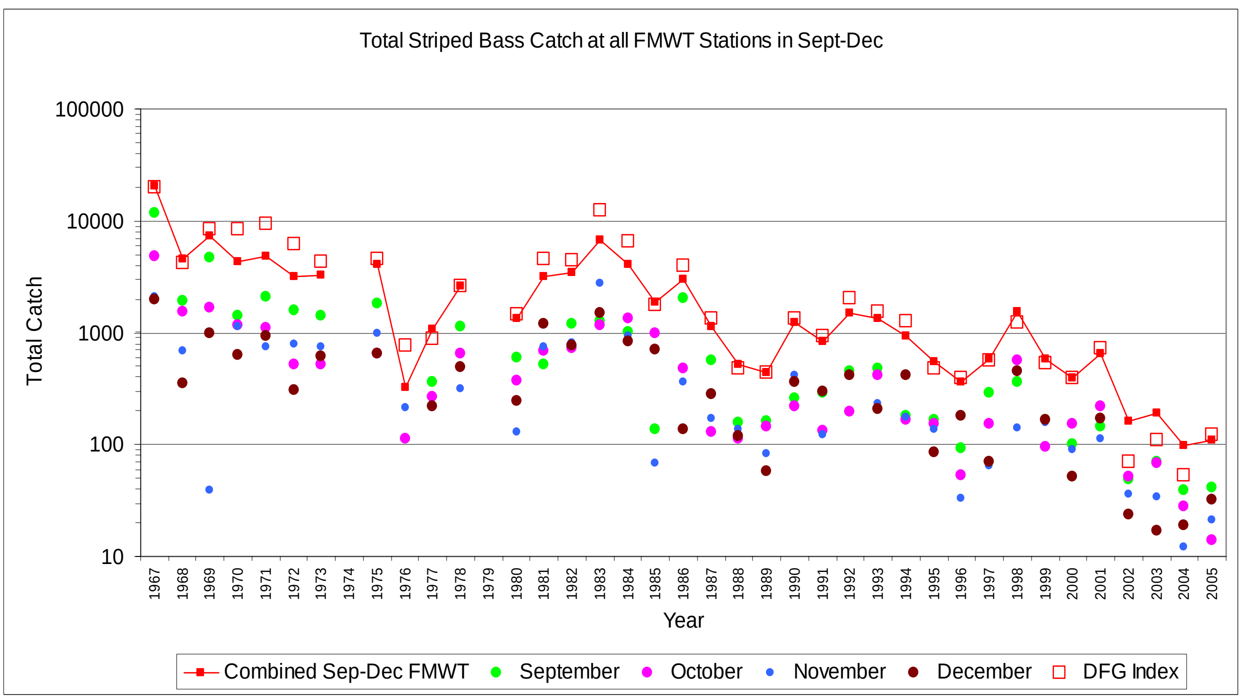


The recent striped bass catch has been lower than during the 1980s but has not declined as much as the FMWT striped bass index (See Figure 30). The Bay Study Chinook salmon catch is quite small but has increased since the 1980s.

Figure 31

Annual Catch of Juvenile Striped Bass and Chinook Salmon in the Bay Study Mid-Water Trawl for 1980–2004



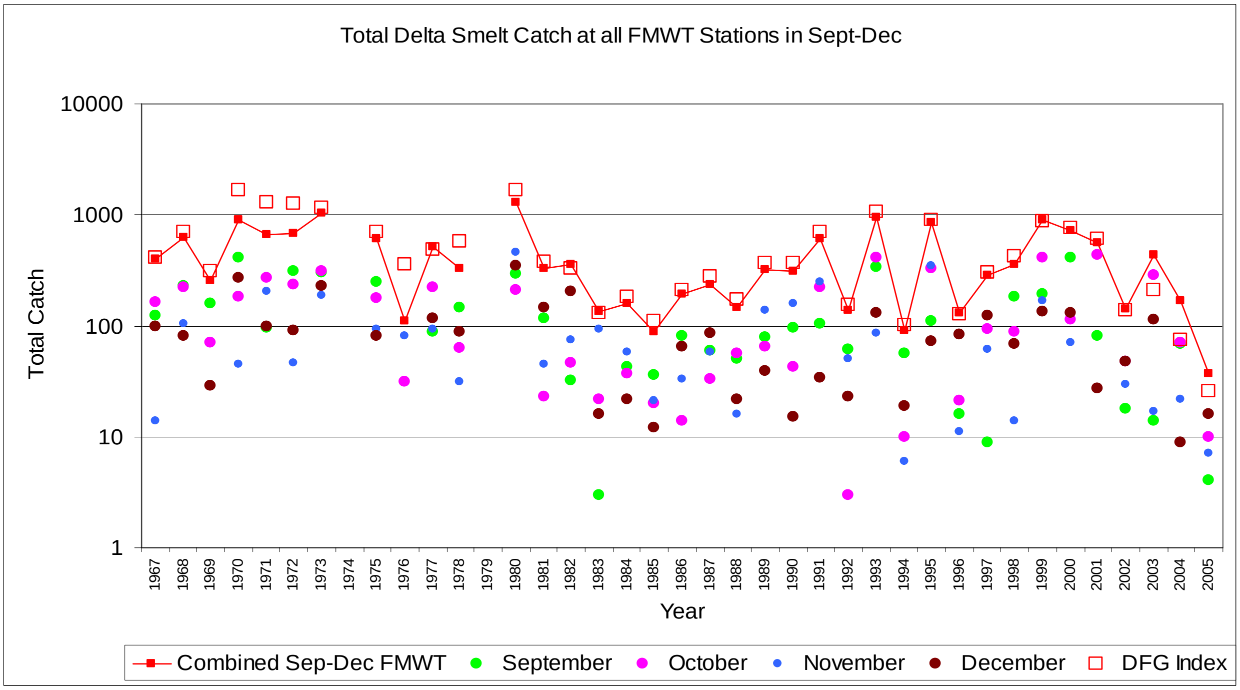


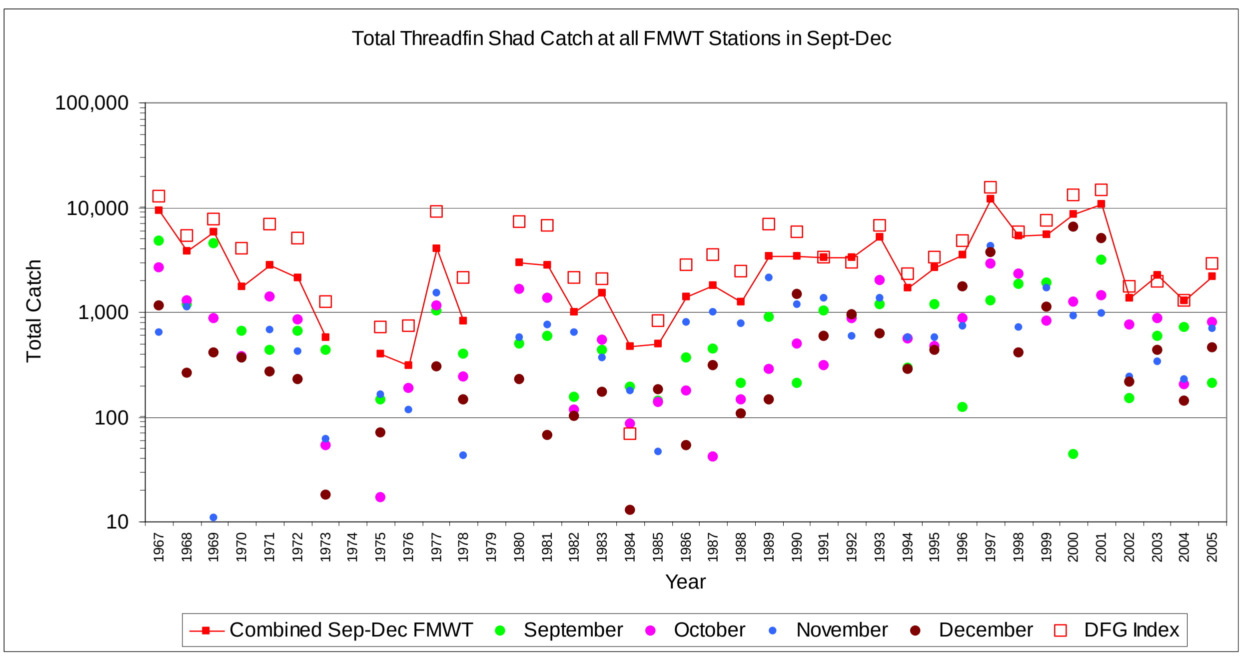
American shad have been one of the most abundant fish caught in the FMWT. American shad were relatively low in 1999–2001, and a record high in 2003. The striped bass catch has definitely declined since the late 1980s and has been the lower than most other historical values in recent years.

Jones & Stokes

Figure 32

Monthly and Annual FMWT Catch and DFG Index Values for American Shad and Striped Bass for 1967–2005



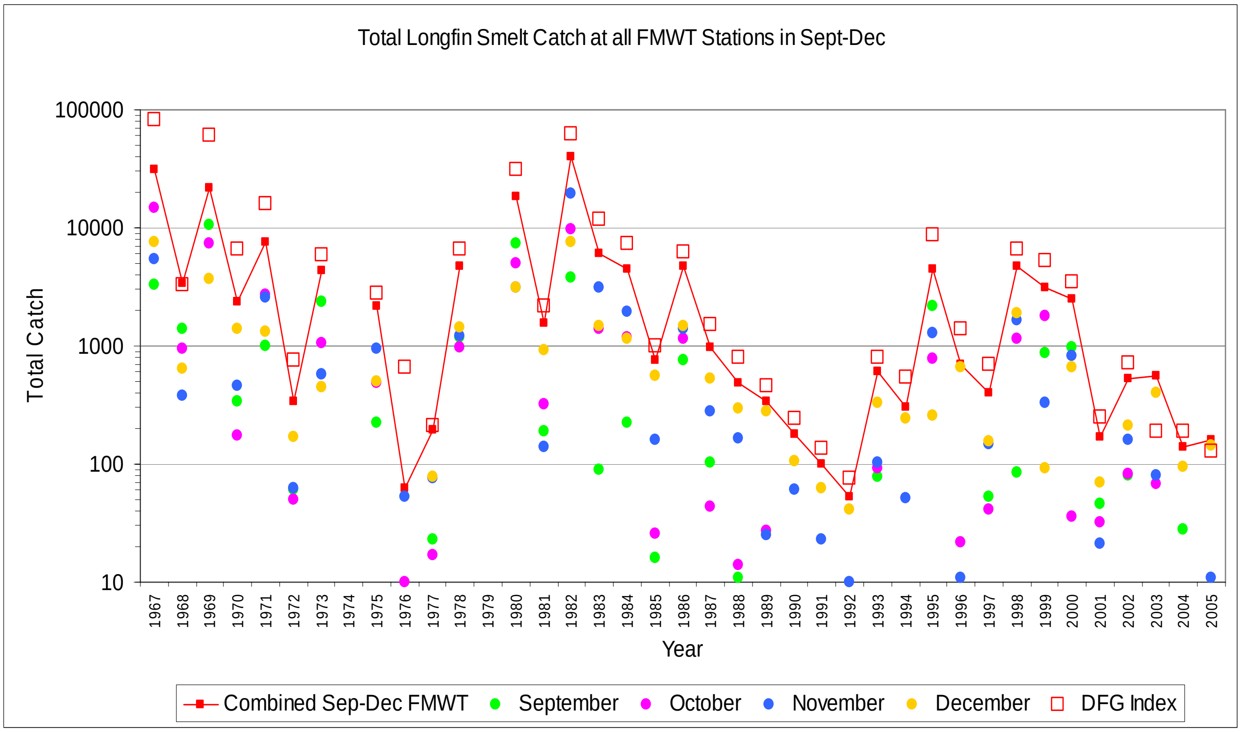


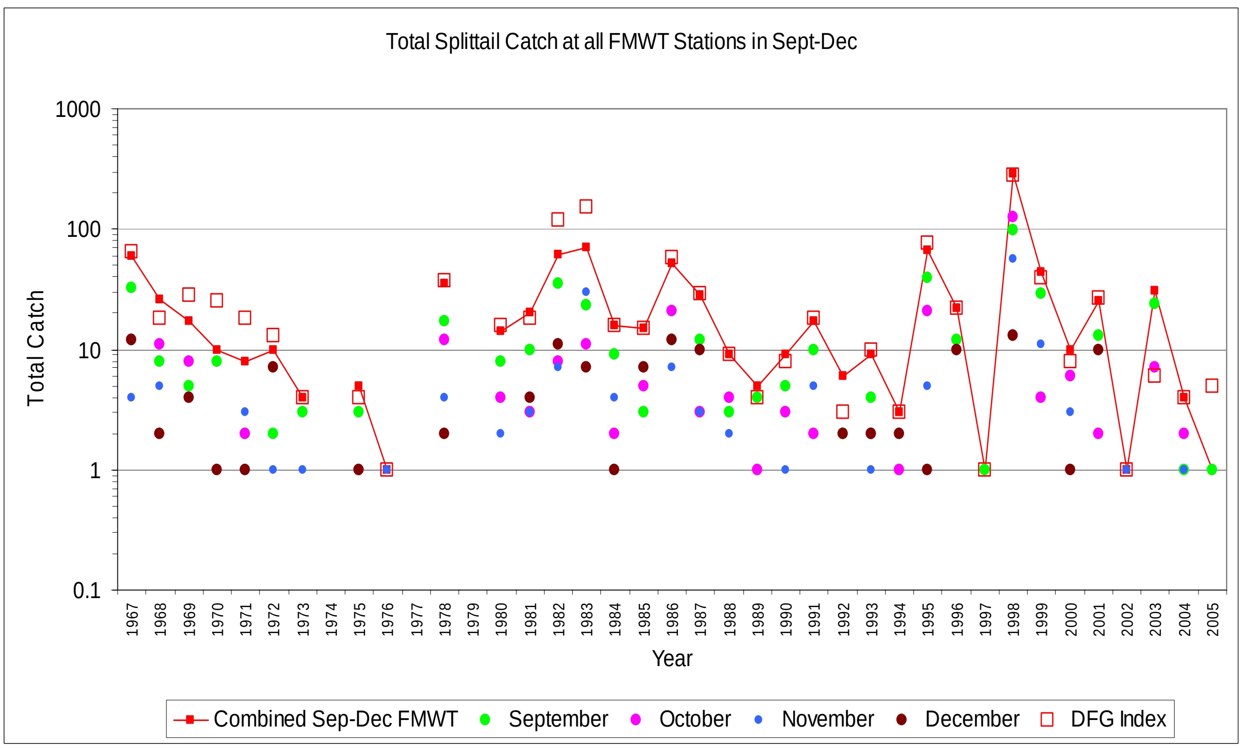
Delta smelt were relatively high in 1999–2001. Threadfin shad have been one of the most abundant fish caught in the FMWT, and were exceptionally high in 1997–2001. Threadfin shad abundance was comparatively lower in 2002–2005, but remained similar to many historical values.

Jones & Stokes

Figure 33

Monthly and Annual FMWT Catch and DFG Index Values for Delta Smelt and Threadfin Shad for 1967–2005



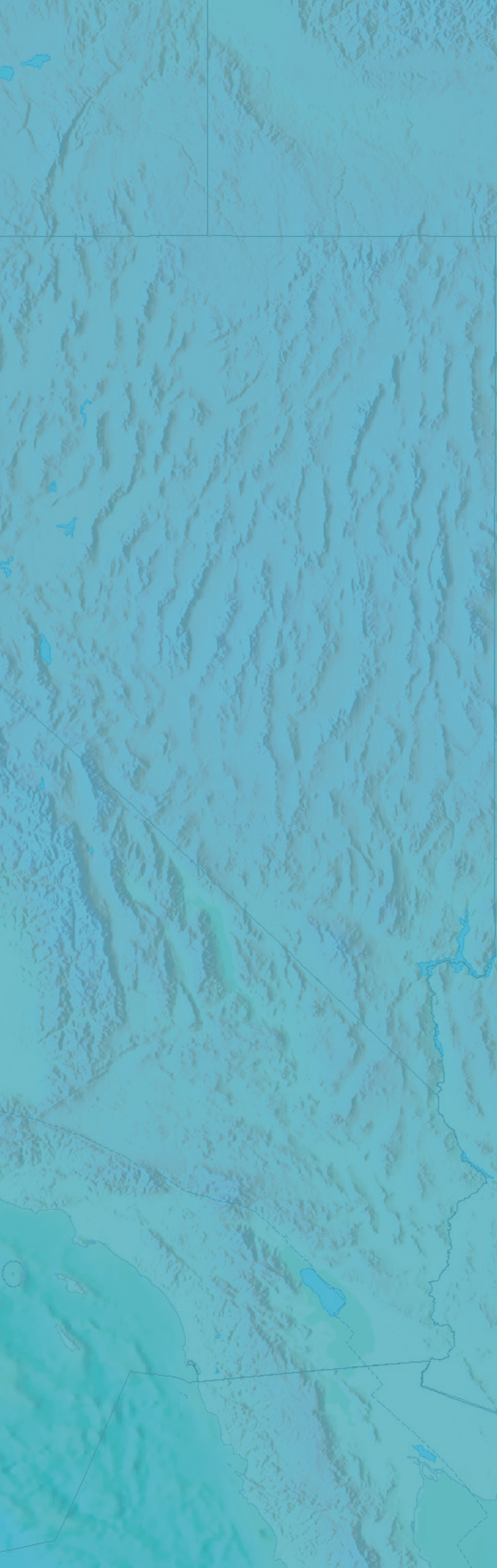


Both species have higher abundances following wet years (higher outflow). The range of annual catch values for longfin smelt is high (i.e., variable). Very few splittail are caught in the FMWT (millions are salvaged at the CVP and SWP pumps in wet years)

Jones & Stokes

Figure 34

Monthly and Annual FMWT Catch and DFG Index Values for Longfin Smelt and Sacramento Splittail for 1967–2005



A Delta Pelagic Poem

The fish aren't apparent, they swim out of sight;
We sample with townets, cast lines they may bite,
In hopes that we gather statistics profound
And analyze data with science that's sound.

A few fishes are here and some fishes are there,
And three or four fishes are found everywhere!
Gregarious fish may be swimming in schools,
But some are just loners with different rules.

Do they seem to be growing as nature intended,
Or is something amiss that demands to be mended?
Are the fish so disgruntled with their Delta home
That they seek more conducive environs to roam?

The numbers are in and they seem sort of tragic,
But do they apply to all species pelagic?
Some scientists find that the fish are just fine
While others assert they're no doubt in decline.

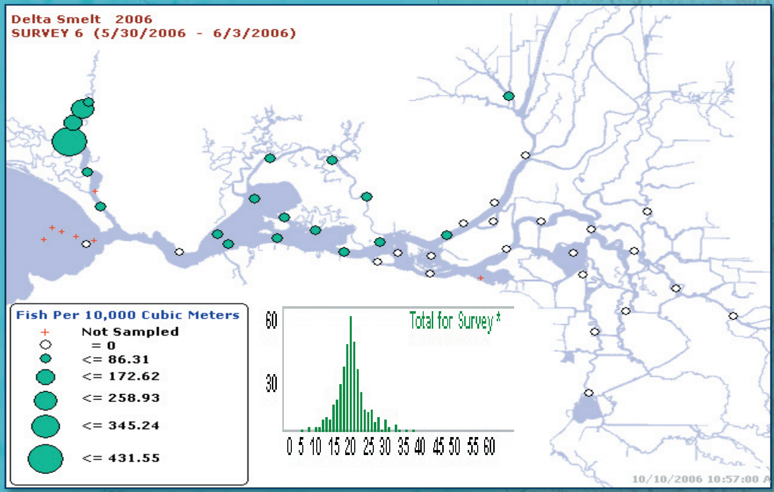
What numbers are normal, what numbers are odd?
Could man be the culprit behind this new POD?
Some fishes are natives—they've always been near,
While others have come from afar to live here.

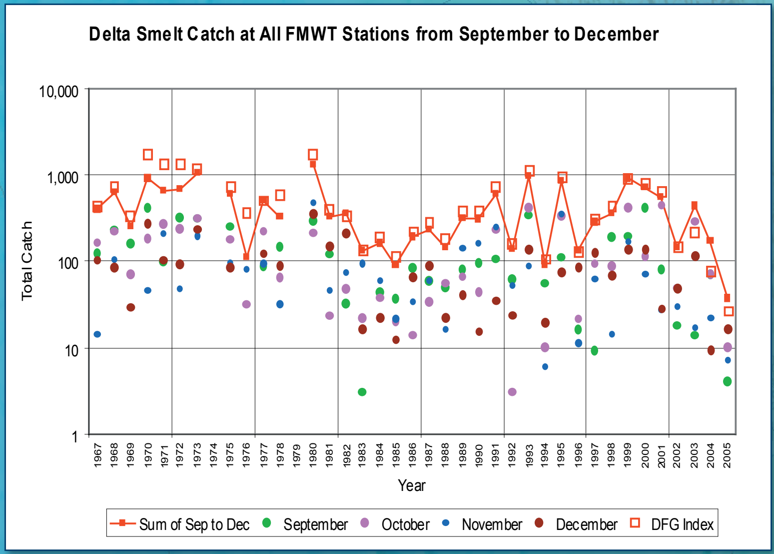
Fish once had the freedom to swim unopposed
From ocean to river in reaches not closed
By big pumps and dams and those many diversions
That disrupt and block fishes' normal dispersions.

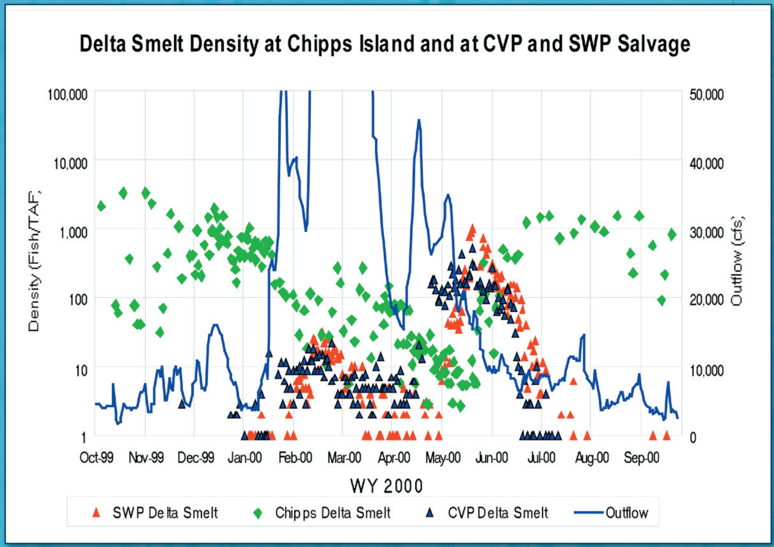
Restoration procedures defined in our plan
Show progress in mitigating the impacts of man;
On paper we've saved Delta fish without doubt—
Do fish see improvement they're happy about?

If one day our concepts and models converge
Our management could with new confidence surge,
We'd publish results of fish studies galore,
But, alas, at the moment they're fiction and lore.

We need to compare what each survey is finding
To build up our knowledge toward something that's binding.
By integrating more of what each of us studies
We'll share in solutions and stay best of buddies.







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