Estimating the population of delta smelt using the Spring Kodiak trawl data

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Summary

Beginning in 2002, sampling for adult delta smelt (smelt) has been carried out each month, beginning in January, using what is termed the "Spring Kodiak trawl." Of all methods used to sample routinely for delta smelt, the Kodiak trawl is the most efficient. It samples for adult smelt throughout their range with relatively efficient gear. Results from that trawl would, therefore, provide a reasonable basis for estimating the population of spawning adult smelt, a critical need in studies of the smelt's declining abundance.

I assumed that the Kodiak trawl was 100% efficient. The Kodiak net is pulled by two boats, so some herding of delta smelt would be expected. This herding phenomenon would tend to make the trawl efficiency greater than 100%. On the other hand, Hanson (Hanson 2005) reports that when a number of salmon smolts were dumped into the water at the mouth of the Kodiak net, only 90% were recovered. This phenomenon would tend to make the trawl less than 100% efficient. Pending more specific data on Kodiak trawl efficiency, an assumption of 100% efficiency seems reasonable

The population of smelt estimated by these methods ranged from about 300,000 in 2005 to about 800,000 in 2002.

Except in 2002, populations trended downward each succeeding month, reflecting the continual mortality of delta smelt. Exponential mortality rates computed for the monthly population estimates averaged -0.025/day and ranged from -0.009/day to -0.062/day.

In the four years of Kodiak trawls for adults (2002-2005) sampling occurred in 17 months, starting with January of each year except 2003. In nine of those months, supplemental sampling also occurred in the manmade part of the Sacramento Ship Channel, above Cache Slough. A surprisingly large percentage of smelt, ranging up to almost 100%, was found there, especially in April and May. The percentage in the Ship Channel tended to increase with each succeeding month. This suggests that the Ship Channel should be included in the routine sampling stations for the Kodiak trawl.

Background

Delta smelt (*Hypomesus transpacificus*) reside in the Bay-Delta system. Depending on the time of year, they range from San Pablo Bay to well up into the Sacramento-San Joaquin Delta. Most smelt (about 95%) live only one year (Bennett 2005). Delta smelt abundance declined in the early 1980s, and the species was listed as threatened under both the California and federal Endangered Species Acts.

Delta smelt are entrained at the pumping plants of the State Water Project (Banks Pumping Plant) and the federal Central Valley Project (Tracy Pumping Plant) in the southeastern Delta. Exports are curtailed to limit entrainment,

making delta smelt the most important fish in California with respect to water project operations.

Despite its importance, no generally accepted estimates of the size of the population have been made. Stevens (Stevens 1990) estimated the population at 280,000. Bennett estimated the population of various life stages assuming gear efficiency of 100%, but did not claim that these results were accurate (Bennett 2005). Miller, using data from the fall midwater trawl and correcting for the relative inefficiency of that gear, estimated the adult population at the end of March for the years 1996-1999 at 200,000 to 800,000 and commented that the actual population could be as much as 50 percent greater (Miller 2000). However, Miller's methods and the resulting estimates drew considerable criticism and have not been generally accepted.

Method

The Kodiak Spring Trawl samples at fixed stations (Figure 1) in the Bay-Delta system once per month beginning in January (February in 2003) and continuing each month until at least March and, in recent years, May (CDFG 2005). In addition, supplemental surveys were made in some months in areas with higher densities of delta smelt. Some of these supplemental stations were not sampled in the routine monthly surveys. Stations in the manmade part of the Sacramento Ship Channel were not sampled in routine surveys but were often included in supplemental surveys.

On the Spring Kodiak survey web site (CDFG 2005) there is a brief description of the manner in which the Spring Kodiak surveys are conducted, but the description is not consistent with the way surveys were conducted in all years. No detailed plan for the surveys is included on the web site. Such a plan would be convenient for those who are using data from the surveys.

In some months, the routine survey was followed within a week to 10 days by a supplemental survey that sampled stations where delta smelt were thought to be. For each such month, I combined the catch data from the routine survey with all the data from the supplemental survey immediately following the routine survey. Table 1 shows the dates of the routine and supplemental surveys for each year. This table also shows which routine and supplemental surveys were combined.

For each combined survey I segregated the stations into the areas in Figure 2. The correspondence of stations to areas is shown in the Appendix. CPUEs were averaged over each area for each survey.

The Kodiak trawl fishes on the surface with a net that is 6 feet deep. Therefore, no samples are taken from greater depths. Bennett (Bennett 2005) shows some data indicating that older juvenile smelt are distributed throughout the water column at depths of 30 to 35 feet. These data suggest that density declines with depth but that there are more smelt below six feet depth than above. Others have suggested based on sampling experience that most adult smelt are near the surface (Baxter 2005). I assumed that densities estimated for the upper six feet from the Kodiak Trawl also

applied to depths from six to 12 feet and that no smelt resided below a depth of 12 feet. Obviously, the distribution of adult smelt in the water column deserves more study.

The assumption that all adult smelt reside in the upper 12 feet of the water column required an estimate of the volume of water in the upper 12 feet. Development of these estimates is described elsewhere (Miller 2005).

To estimate the population of delta smelt I multiplied the average CPUE for each area by the volume of that area in the upper 12 feet of the water column.

Results

The resulting estimates are shown in Figure 3 and Table 2. Note that sampling was not carried out in April and May of 2002 and January of 2003.

According to Bennett, spawning can occur from late February to June (Bennett 2005). Most smelt die after spawning, so the February population is probably the best estimate of the population of spawning adults.

These population estimates are the sum of estimates for each of the areas. Therefore, they describe the distribution of adult smelt in the Bay-Delta system. In nine of the total months sampled, the supplemental trawl included stations in the Sacramento Ship Channel, which is not sampled in the routine surveys. For those nine months Figure 3 also shows the percentage of delta

smelt in the Sacramento Ship Channel. Note that this percentage is as high as 80% and tends to increase with each month. This suggests that delta smelt are either surviving better in the Ship Channel, migrating there from elsewhere, or spawning later there.

If smelt reside in substantial numbers in the Ship Channel in the summer and fall, these data suggest that the summer townet and fall midwater trawl abundance estimates might not be sampling where a significant fraction of the delta smelt reside. It also suggests that the Ship Channel should be included in the routine stations sampled in the Spring Kodiak survey.

Population estimates for 2002-2005 appear to decline exponentially except for the relatively high population estimate for February of 2002 that is not consistent with an exponential decline. The exponential mortality rate can be estimated for each pair of monthly data from the same year's survey. The population in any month relative to the population of the previous month is given by the equation,

$$P_2 = P_1 * e^{-bt},$$

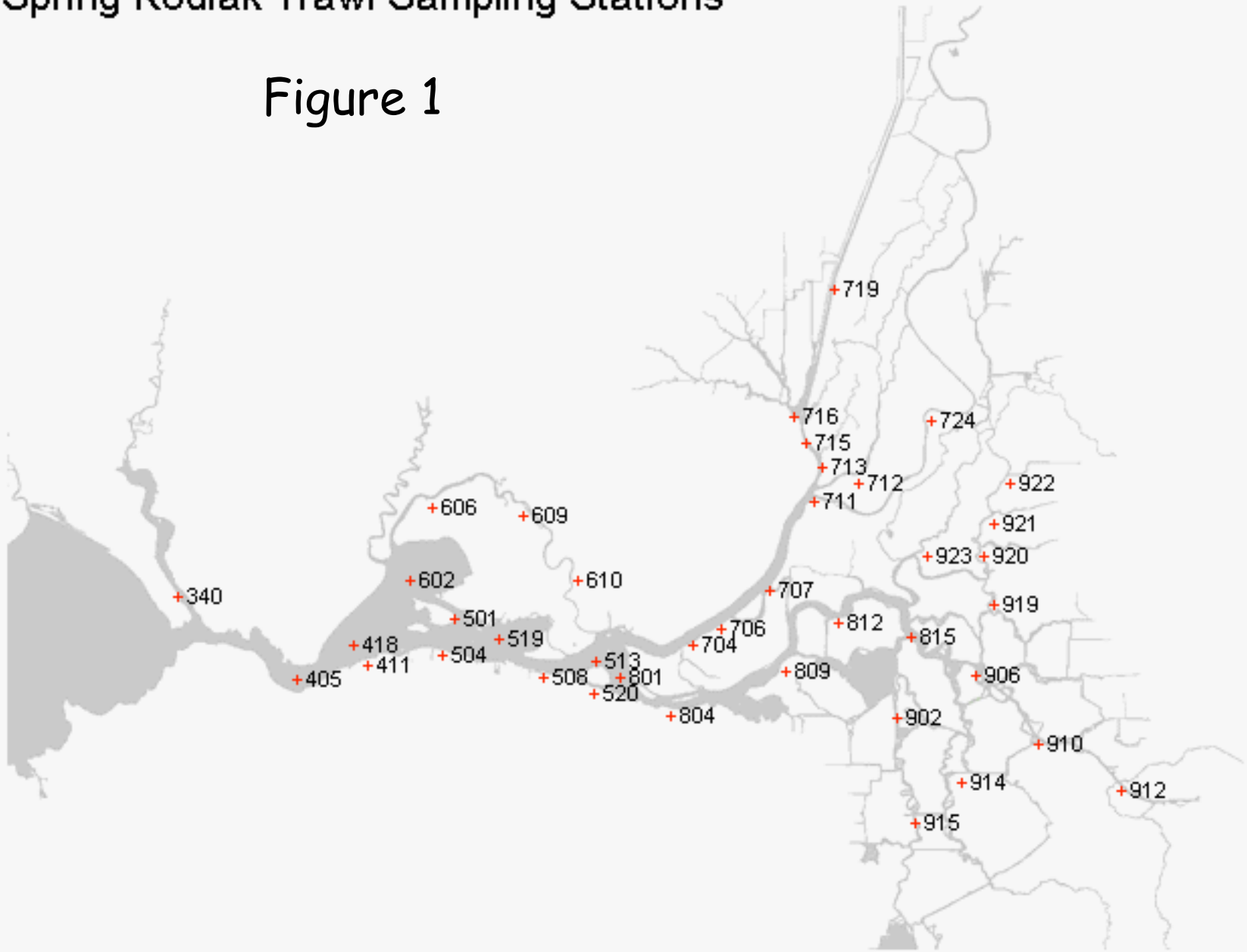
where P_2 is the population in the second of two consecutive months, P_1 is the population in the first of the two months, b is the exponential mortality rate, and t is the time between months. Table 3 shows exponential mortality rates for 2003-2005, estimated from monthly populations excluding smelt in the Ship Channel because it was not sampled each month.

Appendix
Kodiak stations and areas

kodiak stations	areas
340	Napa River
405	Carquinez Strait
411	Suisun Bay
418	Suisun Bay
501	Suisun Bay
504	Chipps Island
508	Chipps Island
513	lower Sacramento River
519	Chipps Island
520	lower San Joaquin River
602	Suisun Bay
606	Suisun Marsh
609	Suisun Marsh
610	Suisun Marsh
704	lower Sacramento River
706	lower Sacramento River
707	lower Sacramento River
711	upper Sacramento river
712	Cache Slough
713	Cache Slough
715	Cache Slough
716	Cache Slough
719	Sacramento Ship Channel
724	upper Sacramento River
725	upper Sacramento River
799	Sacramento Ship Channel
801	lower San Joaquin River
804	lower San Joaquin River
809	near Franks Tract
812	near Franks Tract
815	near Franks Tract
902	near Franks Tract
906	east southeast Delta
910	east southeast Delta
914	southeast Delta
915	southeast Delta
919	east central Delta
920	east central Delta
921	east central Delta
922	east central Delta
923	east central Delta
999	near Franks Tract or E SE Delta

Spring Kodiak Trawl Sampling Stations

Figure 1



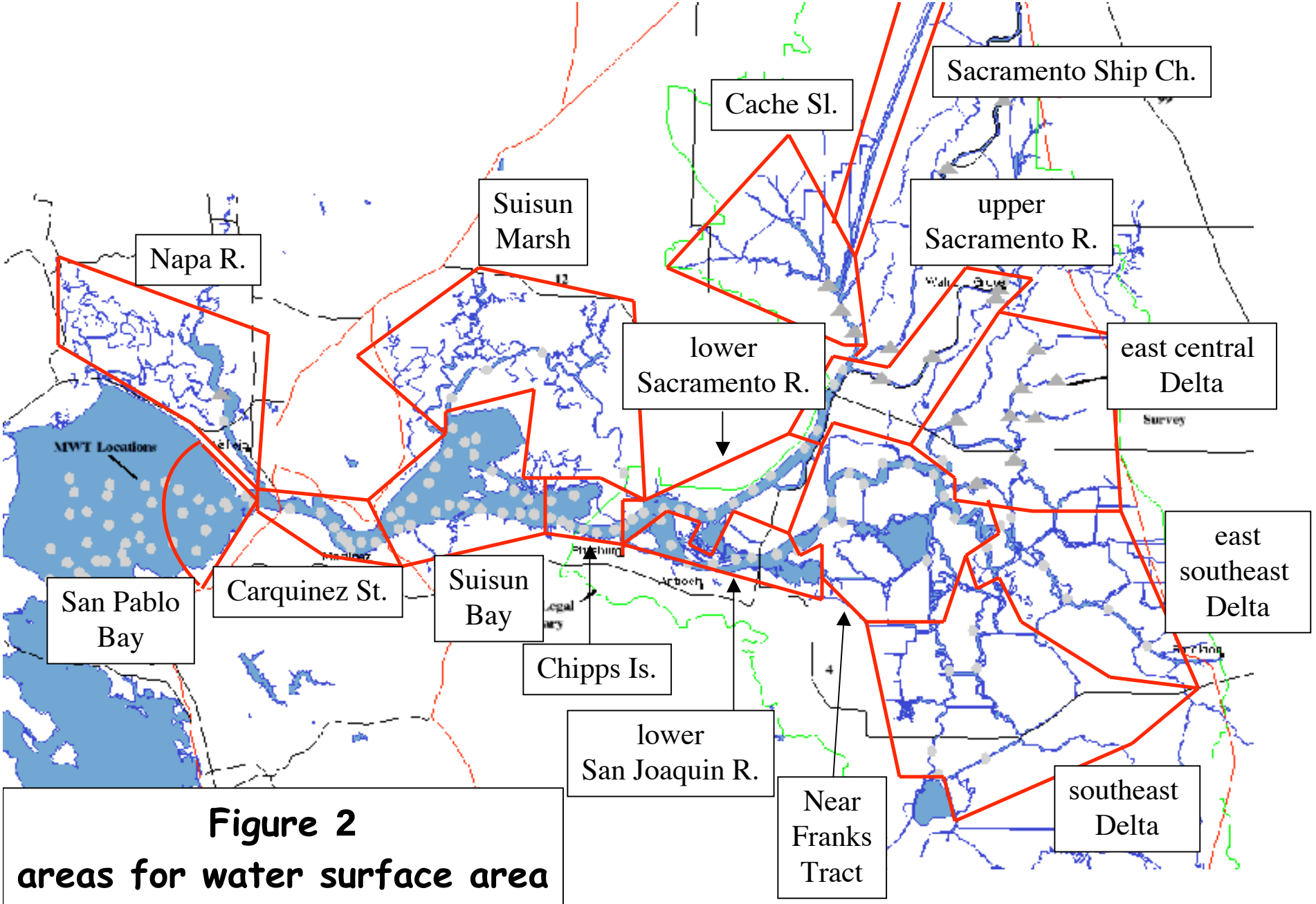
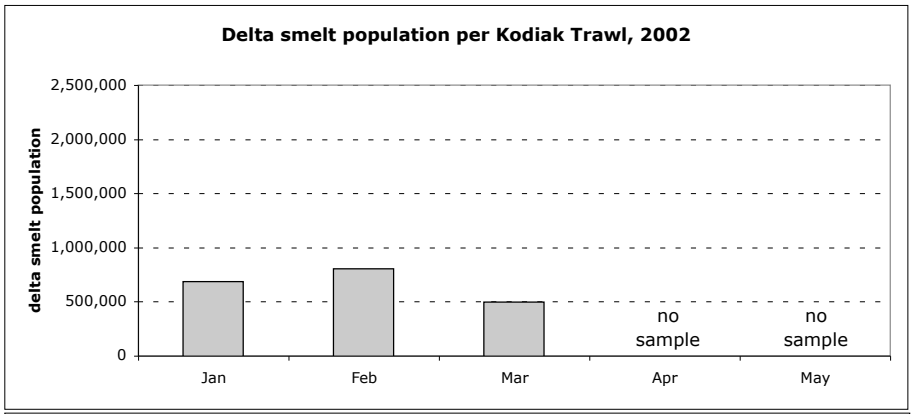
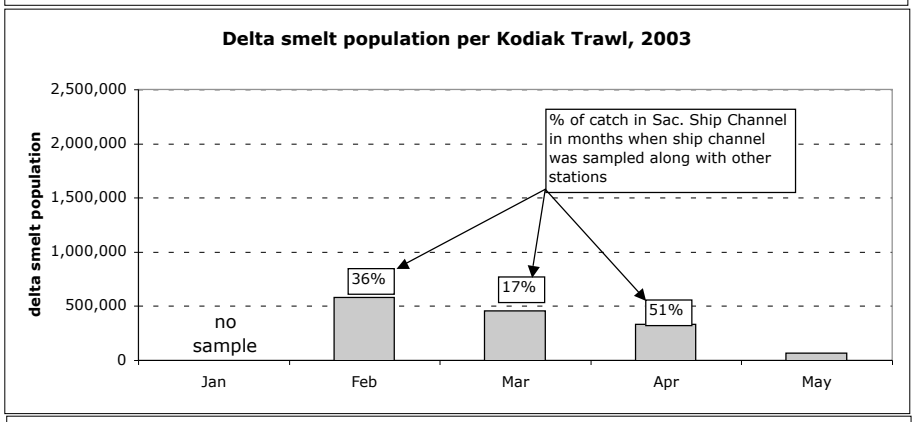
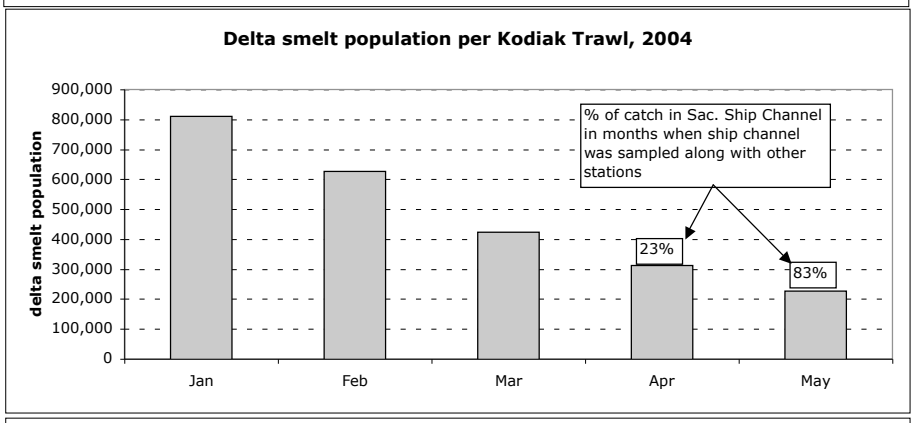


Figure 2
areas for water surface area & volume estimates

Figure 3
Population of adult delta smelt in the upper 12 feet of water







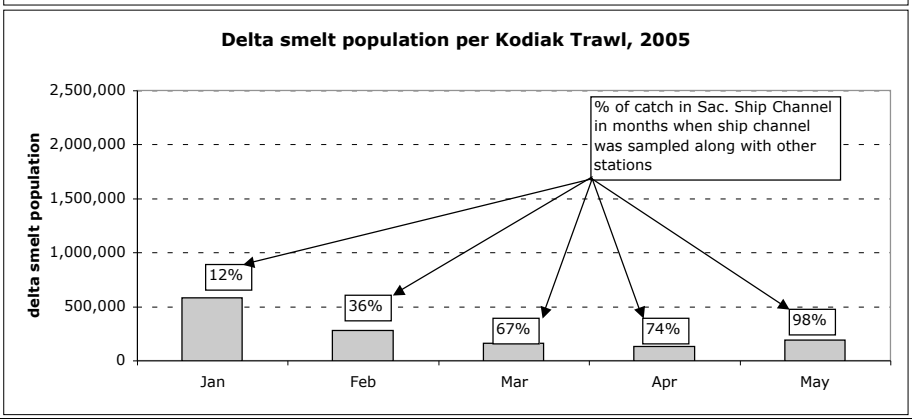


Table 1

Dates of routine and supplemental surveys and surveys combined for each month

January-early March

2002	routine survey dates	supplemental survey dates	combined survey
1-Jan			
2-Jan			
3-Jan			
4-Jan			
5-Jan			
6-Jan			
7-Jan	x		Jan
8-Jan	x		
9-Jan	x		
10-Jan	x		
11-Jan			
12-Jan			
13-Jan			
14-Jan			
15-Jan			
16-Jan			
17-Jan			
18-Jan			
19-Jan			
20-Jan			
21-Jan			
22-Jan			
23-Jan			
24-Jan			
25-Jan			
26-Jan			
27-Jan			
28-Jan			
29-Jan			
30-Jan			
31-Jan			
1-Feb			
2-Feb			
3-Feb			
4-Feb	x		Feb
5-Feb	x		
6-Feb	x		
7-Feb	x		
8-Feb			
9-Feb			
10-Feb			
11-Feb			
12-Feb			
13-Feb			
14-Feb			
15-Feb			
16-Feb			
17-Feb			
18-Feb			
19-Feb			
20-Feb			
21-Feb			
22-Feb			
23-Feb			
24-Feb			
25-Feb			
26-Feb			
27-Feb			
28-Feb			
1-Mar			
2-Mar			
3-Mar			
4-Mar	x		Mar
5-Mar	x		
6-Mar	x		
7-Mar	x		

2003	routine survey dates	supplemental survey dates	combined survey
1-Jan			
2-Jan			
3-Jan			
4-Jan			
5-Jan			
6-Jan			
7-Jan			
8-Jan			
9-Jan			
10-Jan			
11-Jan			
12-Jan			
13-Jan			
14-Jan			
15-Jan			
16-Jan			
17-Jan			
18-Jan			
19-Jan			
20-Jan			
21-Jan			
22-Jan			
23-Jan			
24-Jan			
25-Jan			
26-Jan			
27-Jan			
28-Jan			
29-Jan			
30-Jan			
31-Jan			
1-Feb			
2-Feb			
3-Feb			
4-Feb			
5-Feb			
6-Feb			
7-Feb			
8-Feb			
9-Feb			
10-Feb			
11-Feb			
12-Feb			
13-Feb			
14-Feb			
15-Feb			
16-Feb			
17-Feb			
18-Feb	x		Feb
19-Feb	x		
20-Feb	x		
21-Feb	x		
22-Feb			
23-Feb			
24-Feb			
25-Feb			
26-Feb			
27-Feb			
28-Feb			
1-Mar			
2-Mar			
3-Mar		x	Feb
4-Mar		x	
5-Mar			
6-Mar			
7-Mar			

2004	routine survey dates	supplemental survey dates	combined survey
1-Jan			
2-Jan			
3-Jan			
4-Jan			
5-Jan			
6-Jan			
7-Jan			
8-Jan			
9-Jan			
10-Jan			
11-Jan			
12-Jan	x		Jan
13-Jan	x		
14-Jan	x		
15-Jan	x		
16-Jan			
17-Jan			
18-Jan			
19-Jan			
20-Jan			
21-Jan			
22-Jan			
23-Jan			
24-Jan			
25-Jan			
26-Jan		x	Jan
27-Jan		x	
28-Jan			
29-Jan			
30-Jan			
31-Jan			
1-Feb			
2-Feb			
3-Feb			
4-Feb			
5-Feb			
6-Feb			
7-Feb			
8-Feb			
9-Feb	x		Feb
10-Feb	x		
11-Feb	x		
12-Feb	x		
13-Feb	x		
14-Feb	x		
15-Feb	x		
16-Feb	x		
17-Feb	x		
18-Feb			
19-Feb			
20-Feb			
21-Feb			
22-Feb			
23-Feb		x	Feb
24-Feb		x	
25-Feb			
26-Feb			
27-Feb			
28-Feb			
29-Feb			
1-Mar			
2-Mar			
3-Mar			
4-Mar			
5-Mar			
6-Mar			
7-Mar			

2005	routine survey dates	supplemental survey dates	combined survey
1-Jan			
2-Jan			
3-Jan			
4-Jan			
5-Jan			
6-Jan			
7-Jan			
8-Jan			
9-Jan			
10-Jan			
11-Jan			
12-Jan			
13-Jan			
14-Jan			
15-Jan			
16-Jan			
17-Jan			
18-Jan			
19-Jan			
20-Jan			
21-Jan			
22-Jan			
23-Jan			
24-Jan	x		Jan
25-Jan	x		
26-Jan	x		
27-Jan	x		
28-Jan	x		
29-Jan			
30-Jan			
31-Jan			
1-Feb			
2-Feb			
3-Feb			
4-Feb			
5-Feb			
6-Feb			
7-Feb			
8-Feb		x	Jan
9-Feb		x	
10-Feb		x	
11-Feb			
12-Feb			
13-Feb			
14-Feb			
15-Feb			
16-Feb			
17-Feb			
18-Feb			
19-Feb			
20-Feb			
21-Feb			
22-Feb	x		Feb
23-Feb	x		
24-Feb	x		
25-Feb	x		
26-Feb			
27-Feb			
28-Feb			
1-Mar			
2-Mar			
3-Mar			
4-Mar			
5-Mar			
6-Mar			
7-Mar		x	Feb

early March-May

2002	routine survey dates	supplemental survey dates	combined survey
8-Mar			
9-Mar			
10-Mar			
11-Mar			
12-Mar			
13-Mar			
14-Mar			
15-Mar			
16-Mar			
17-Mar			
18-Mar			
19-Mar			
20-Mar			
21-Mar			
22-Mar			
23-Mar			
24-Mar			
25-Mar			
26-Mar			
27-Mar			
28-Mar			
29-Mar			
30-Mar			
31-Mar			
1-Apr			
2-Apr			
3-Apr			
4-Apr			
5-Apr			
6-Apr			
7-Apr			
8-Apr			
9-Apr			
10-Apr			
11-Apr			
12-Apr			
13-Apr			
14-Apr			
15-Apr			
16-Apr			
17-Apr			
18-Apr			
19-Apr			
20-Apr			
21-Apr			
22-Apr			
23-Apr			
24-Apr			
25-Apr			
26-Apr			
27-Apr			
28-Apr			
29-Apr			
30-Apr			
1-May			
2-May			
3-May			
4-May			
5-May			
6-May			
7-May			
8-May			
9-May			
10-May			
11-May			
12-May			
13-May			
14-May			
15-May			
16-May			
17-May			
18-May			
19-May			
20-May			
21-May			
22-May			

2003	routine survey dates	supplemental survey dates	combined survey
8-Mar			
9-Mar			
10-Mar			
11-Mar			
12-Mar			
13-Mar			
14-Mar			
15-Mar			
16-Mar			
17-Mar	x		Mar
18-Mar	x		
19-Mar	x		
20-Mar	x		
21-Mar			
22-Mar			
23-Mar			
24-Mar			
25-Mar			
26-Mar			
27-Mar			
28-Mar			
29-Mar			
30-Mar			
31-Mar			
1-Apr			
2-Apr		x	Mar
3-Apr		x	
4-Apr		x	
5-Apr			
6-Apr			
7-Apr			
8-Apr			
9-Apr			
10-Apr			
11-Apr			
12-Apr			
13-Apr			
14-Apr	x		Apr
15-Apr	x		
16-Apr	x		
17-Apr	x		
18-Apr			
19-Apr			
20-Apr			
21-Apr			
22-Apr			
23-Apr			
24-Apr			
25-Apr			
26-Apr			
27-Apr			
28-Apr		x	Apr
29-Apr		x	
30-Apr		x	
1-May		x	
2-May		x	
3-May			
4-May			
5-May			
6-May			
7-May			
8-May			
9-May			
10-May			
11-May			
12-May			
13-May	x		May
14-May	x		
15-May	x		
16-May	x		
17-May			
18-May			
19-May			
20-May			
21-May			
22-May			

2004	routine survey dates	supplemental survey dates	combined survey
7-Mar			
8-Mar	x		Mar
9-Mar	x		
10-Mar	x		
11-Mar	x		
12-Mar	x		
13-Mar			
14-Mar			
15-Mar			
16-Mar			
17-Mar			
18-Mar			
19-Mar			
20-Mar			
21-Mar			
22-Mar		x	Mar
23-Mar		x	
24-Mar			
25-Mar			
26-Mar			
27-Mar			
28-Mar			
29-Mar			
30-Mar			
31-Mar			
1-Apr			
2-Apr			
3-Apr			
4-Apr			
5-Apr	x		Apr
6-Apr	x		
7-Apr	x		
8-Apr	x		
9-Apr			
10-Apr			
11-Apr			
12-Apr			
13-Apr			
14-Apr			
15-Apr			
16-Apr			
17-Apr			
18-Apr			
19-Apr			
20-Apr		x	Apr
21-Apr		x	
22-Apr			
23-Apr			
24-Apr			
25-Apr			
26-Apr			
27-Apr			
28-Apr			
29-Apr			
30-Apr			
1-May			
2-May			
3-May	x		May
4-May	x		
5-May	x		
6-May	x		
7-May	x		
8-May			
9-May			
10-May			
11-May			
12-May			
13-May			
14-May			
15-May			
16-May			
17-May			
18-May			
19-May			
20-May			
21-May	x		May
22-May			

2005	routine survey dates	supplemental survey dates	combined survey
8-Mar			
9-Mar			
10-Mar			
11-Mar			
12-Mar			
13-Mar			
14-Mar			
15-Mar			
16-Mar			
17-Mar			
18-Mar			
19-Mar			
20-Mar			
21-Mar			
22-Mar	x		Mar
23-Mar	x		
24-Mar	x		
25-Mar	x		
26-Mar			
27-Mar			
28-Mar			
29-Mar			
30-Mar			
31-Mar			
1-Apr			
2-Apr			
3-Apr			
4-Apr		x	Mar
5-Apr		x	
6-Apr			
7-Apr			
8-Apr			
9-Apr			
10-Apr			
11-Apr			
12-Apr			
13-Apr			
14-Apr			
15-Apr			
16-Apr			
17-Apr			
18-Apr	x		Apr
19-Apr	x		
20-Apr	x		
21-Apr	x		
22-Apr			
23-Apr			
24-Apr			
25-Apr			
26-Apr			
27-Apr			
28-Apr			
29-Apr			
30-Apr			
1-May			
2-May			
3-May		x	Apr
4-May			
5-May			
6-May			
7-May			
8-May			
9-May			
10-May			
11-May			
12-May			
13-May			
14-May			
15-May			
16-May		x	May
17-May		x	
18-May			
19-May			
20-May			
21-May			
22-May			

Table 2
Estimated number of adult delta smelt in the upper 12 feet of water

year	month	Napa River	Car-quinez Strait	Suisun Bay	Suisun Marsh	Chipps Island	lower Sac.	Cache Slough	upper Sac. River	lower San Joaquin River	near Franks Tract	east south east Delta	east central Delta	south-east Delta	Sac. Ship Channel	sum	sum w/o Sac. Ship Channel
2002	Jan	0	32,733	95,042	177,308	30,614	17,492	12,038	0	134,925	152,218	3,168	4,170	23,095	0	680,000	680,000
	Feb	**0**	**13,783**	**29,889**	**338,763**	**0**	**58,459**	**1,526**	**3,065**	**161,001**	**197,703**	**0**	**0**	**0**	**0**	**800,000**	**800,000**
	Mar	5,131	0	7,765	106,395	0	159,574	22,178	141,768	8,491	23,852	13,262	6,377	0	0	490,000	490,000
	Apr																0
	May																0
2003	Jan																0
	Feb	**0**	**0**	**133,157**	**22,204**	**44,166**	**26,496**	**95,405**	**0**	**14,389**	**26,937**	**6,942**	**0**	**3,716**	**208,215**	**580,000**	**370,000**
	Mar	0	0	151,124	10,115	40,695	83,850	60,514	12,107	192	9,747	0	10,623	0	77,923	460,000	380,000
	Apr	0	0	10,465	0	0	50,764	7,423	7,059	3,485	82,916	0	0	0	169,678	330,000	160,000
	May	0	0	20,467	0	13,974	6,559	16,272	0	5,691	0	0	1,434	0	0	60,000	60,000
2004	Jan	5,367	0	7,729	278,630	21,168	3,282	2,152	0	165,907	268,331	45,529	1,522	11,100	0	810,000	810,000
	Feb	**0**	**0**	**20,043**	**81,926**	**2,991**	**179,990**	**1,418**	**0**	**56,739**	**265,574**	**16,634**	**0**	**0**	**0**	**630,000**	**630,000**
	Mar	0	0	95,354	38,169	17,791	104,053	0	0	9,565	138,916	10,391	7,972	0	0	420,000	420,000
	Apr	0	0	0	0	7,280	108,544	3,525	3,009	21,096	95,568	0	0	0	73,277	310,000	240,000
	May	0	0	0	0	0	8,754	2,833	0	15,318	12,786	0	0	0	187,698	230,000	40,000
2005	Jan	0	0	140,021	84,055	36,069	175,852	21,404	0	0	52,240	2,293	2,665	0	68,148	580,000	510,000
	Feb	**16,516**	**0**	**16,992**	**72,169**	**6,552**	**37,788**	**23,189**	**0**	**2,912**	**0**	**0**	**0**	**0**	**100,007**	**280,000**	**180,000**
	Mar	0	0	7,805	6,646	8,710	20,282	7,200	1,950	0	0	0	0	0	108,169	160,000	50,000
	Apr	0	0	7,492	1,167	2,955	16,608	2,632	3,082	0	0	0	0	0	95,627	130,000	30,000
	May	0	0	0	0	0	0	3,505	0	0	0	0	0	0	187,164	190,000	0

Table 3
month-to-month exponential mortality rates for adult delta smelt

sum w/o Sac. Ship Channel	mid-date of Kodiak trawl	expon. mortality= LN(P2/P1)/(days)
682,802	8-Jan-02	
804,189	6-Feb-02	
494,792	6-Mar-02	-0.017
373,413	20-Feb-03	
378,967	18-Mar-03	
162,113	16-Apr-03	-0.029
64,397	14-May-03	-0.033
810,718	14-Jan-04	
625,316	13-Feb-04	-0.009
422,210	10-Mar-04	-0.015
239,022	6-Apr-04	-0.021
39,692	5-May-04	-0.062
514,599	26-Jan-05	
176,118	24-Feb-05	-0.037
52,593	24-Mar-05	-0.043
33,937	20-Apr-05	-0.016
3,505	16-May-05	

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