The co-occurrence of delta smelt and prey in the summer

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Summary

Delta smelt (smelt) abundance has declined in recent years. The Fall Midwater Trawl (FMWT) index, the primary index used to track smelt abundance, reached its lowest level in 2004. Bennett found that smelt caught in the summer of 1999 were food-limited (Bennett 2005a). He suggested food-limitation or some other factor acting in the late summer could be controlling the FMWT abundance index.

We quantified food-limitation for smelt in the summer to associate it with the subsequent FMWT index. First, we divided the smelt range into areas shown in Figure 1. For each area for each year beginning in 1985, we estimated the relative abundance of smelt and the density of zooplankton that smelt prey on. The product of relative abundance and prey density in each area measures smelt-prey co-occurrence. Summing these products over all areas estimates co-occurrence for the year.

We hypothesized that this estimate of co-occurrence should be correlated with the subsequent FMWT index of abundance. We found a highly significant correlation (R^2=0.60, p=0.00009) between the FMWT and the co-occurrence of smelt and two of its primary prey (Bennett 2005a), the zooplankton *Eurytemora affinis* (Eurytemora) and *Pseudodiaptomus forbesi* (Pseudodipatomus). Figure 2 shows this correlation.

Recently, at a workshop reviewing the Pelagic Organism Decline Program, Baxter reported that smelt also feed on *Acartiella sinensis* (Acartiella) and *Tortanus species* (Tortanus) (Baxter 2005). We added the densities of these two species to those of Eurytemora and Pseudodiaptomus and multiplied these total densities by relative smelt abundance, area-by-area, and summed across all areas each year. The correlation of these annual co-occurrence estimates with subsequent FMWT index was not as good (R^2=0.60, p=0.00009). However, this correlation was strongly affected by data from 1994, a year of abnormally high Acartiella density in the lower Sacramento River. Omitting this year improves the correlation (R^2=0.67, p=0.00003). Figure 3 shows these correlations.

The primary area of co-occurrence is the lower Sacramento River, from just upstream of Threemile Slough to the confluence with the San Joaquin River. Over all 20 years analyzed, this area averaged about 60% of the total smelt-prey co-occurrence products. In this area the density of Pseudodiaptomus, the primary prey of smelt, has declined since 1989, when it was first routinely sampled. Densities are approaching zero. This would appear to be the major factor in the decline of delta smelt abundance.

Method

Delta smelt relative abundance

We used smelt catch data from the summer townet survey (STN) to estimate smelt abundance. This survey is carried out approximately every

two weeks, usually beginning in June. It was originally used to set the striped bass index. Therefore, until recent years, sampling only occurred until the average size of striped bass in two consecutive surveys bracketed the 1.5 inches, the size of young striped bass used for the index of young-of-the-year abundance. Other fish are caught in the survey, so it has also been used to estimate abundance of other fish, including juvenile smelt, in the summer. However, the sampling protocol resulted in July being the only month when samples were collected in all but one year since 1984. In some years, no samples were collected in June. In other years there were no samples in August. Therefore, we used samples from July for this analysis. In 1988 no samples were taken in July, so we eliminated that year from the analysis.

We used all catch data from surveys the occurred entirely or partly in July. In some years there was only one survey in July. In other years there were two or three.

Until recent years, there were no meter readings to estimate the volume of water passing through the net. The metadata information for the STN says meter readings were similar (within 10% of each other) in past studies, so no readings were routinely taken. Therefore, catch is a measure of catch per unit effort, or density.

We grouped the STN stations into the areas shown in Figure 1. We averaged the catch for all stations in an area for each survey. If there was more than one survey in July of a year, we averaged the area averages over the surveys to obtain an average catch of smelt for each area for July of each year. The

average catch for each area was multiplied by the volume of the area. Volumes were taken from Miller (Miller 2005). These products estimate smelt relative abundance for each area for each year.

Prey densities

For prey densities we used data from long-term monthly zooplankton surveys conducted by the California Department of fish and Game. The Pelagic Organism Decline Program detected problems with this data set and spent a number of weeks correcting them. We used the corrected data.

We grouped the monthly zooplankton stations for July into the areas in Figure 1. We averaged the catch per unit effort (CPUE) values for each species over all stations in an area. We summed these average densities, first for Eurytemora and Pseudodiaptomus alone, then for Eurytemora, Pseudodiaptomus, Acartiella, and Tortanus. This gave us two estimates of prey for each area for each year, one estimate for the two zooplankton, Eurytemora and Pseudodiaptomus, historically thought to comprise most of the smelt prey, and one estimate including recently noted prey of smelt.

We did not attempt to account for the relative nutritional value of these four prey species, although this could be a useful addition to this analysis.

Co-occurrence products

We estimated co-occurrence for each year as the sum over all areas of the product of smelt abundance and prey density for each area. As suggested by Herbold (Herbold 2005), it is possible that below a certain prey density,

smelt cannot find prey; that is, there is a prey density greater than zero below which prey density might as well be zero. Herbold also suggested that there might be an upper limit to prey density; that is, there is a prey density above which smelt feeding rate does not increase. In previous analyses of co-occurrence we selected various minimum and maximum practical prey densities and found that we could improve the correlation between FMWT index and co-occurrence products by doing so. If data were available from laboratory studies of smelt to provide a basis for estimating practical minimum and maximum prey densities, the correlation of FMWT with co-occurrence might be improved.

Results

Co-occurrence products for each area and year for only Eurytemora and Pseudodiaptomus prey are in Table 1. The percentage of each year's total co-occurrence product is in Table 2. Each colored rectangle indicates an area whose co-occurrence product was at least 10% of the total for that year. Dark blue rectangles show the minimum number of areas whose co-occurrence products totaled at least 75% of the total for that year. This table shows that the lower Sacramento River is the most important area of co-occurrence for smelt and prey. Chipps Island and Suisun Bay are the next most important. Other areas are typically not important. In particular, areas near the export pumps are never important. It is possible that co-occurrence products were low near the export pumps because of entrainment, but Bennett stated recently that delta smelt were never prevalent in the southeastern Delta (Bennett 2005b).

Tables 3 and 4 show time trends in densities for all four prey species, Eurytemora, Pseudodiaptomus, Acartiella, and Tortanus. The same conclusions apply for these data as for the analysis with only the two primary prey species.

Figures 4 through 7 are the densities for prey species in the three most important areas of co-occurrence. All graphs have the same vertical scale. Pseudodiaptomus was introduced in 1986, and sampling did not begin for this species until 1989. Note the virtual disappearance of Eurytemora after 1987.

It is clear from these graphs that Pseudodiaptomus has been the primary prey for smelt in July. Figure 8 shows the trend in Pseudodiaptomus densities in the three most important areas of smelt-prey co-occurrence. Note the marked downward trend in the lower Sacramento River, the most important co-occurrence area. Also note the low densities in all three areas in recent years.

The densities of both Acartiella and Tortanus are much lower than those of Pseudodiaptomus through the year 1999 or 2000, except in 1994 when Acartiella densities were comparable to those of Pseudodiaptomus. With the low densities of Pseudodiaptomus in recent years, the densities of Acartiella and Tortanus have become relatively more important. Even so, total prey density, shown in Figure 9, has declined in all three important co-occurrence areas, especially in recent years.

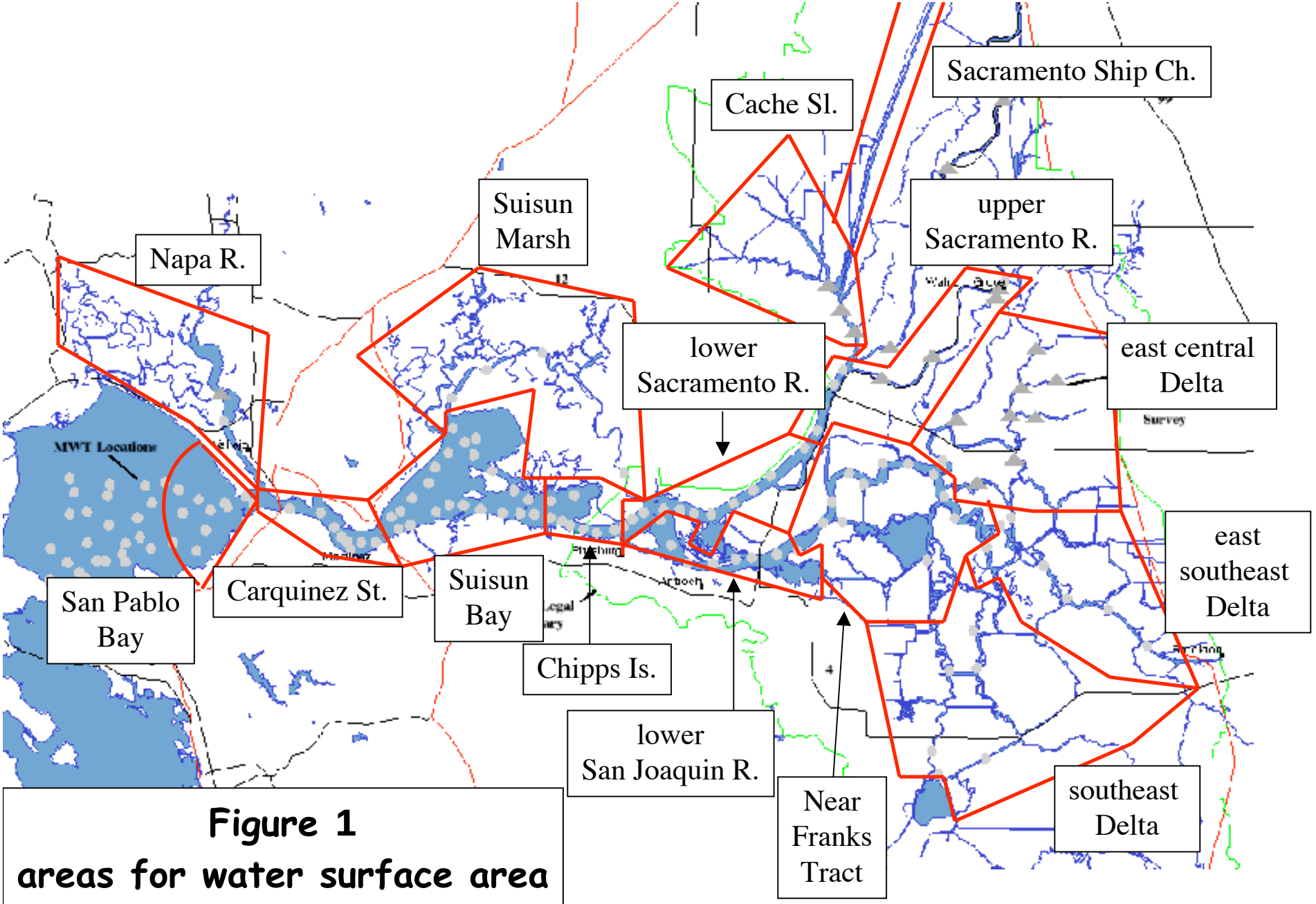


Figure 1
areas for water surface area & volume estimates

Figure 2
delta smelt fall midwater trawl abundance index vs.
July co-occurrence of smelt and prey
(Pseudodiaptomus and Eurytemora)

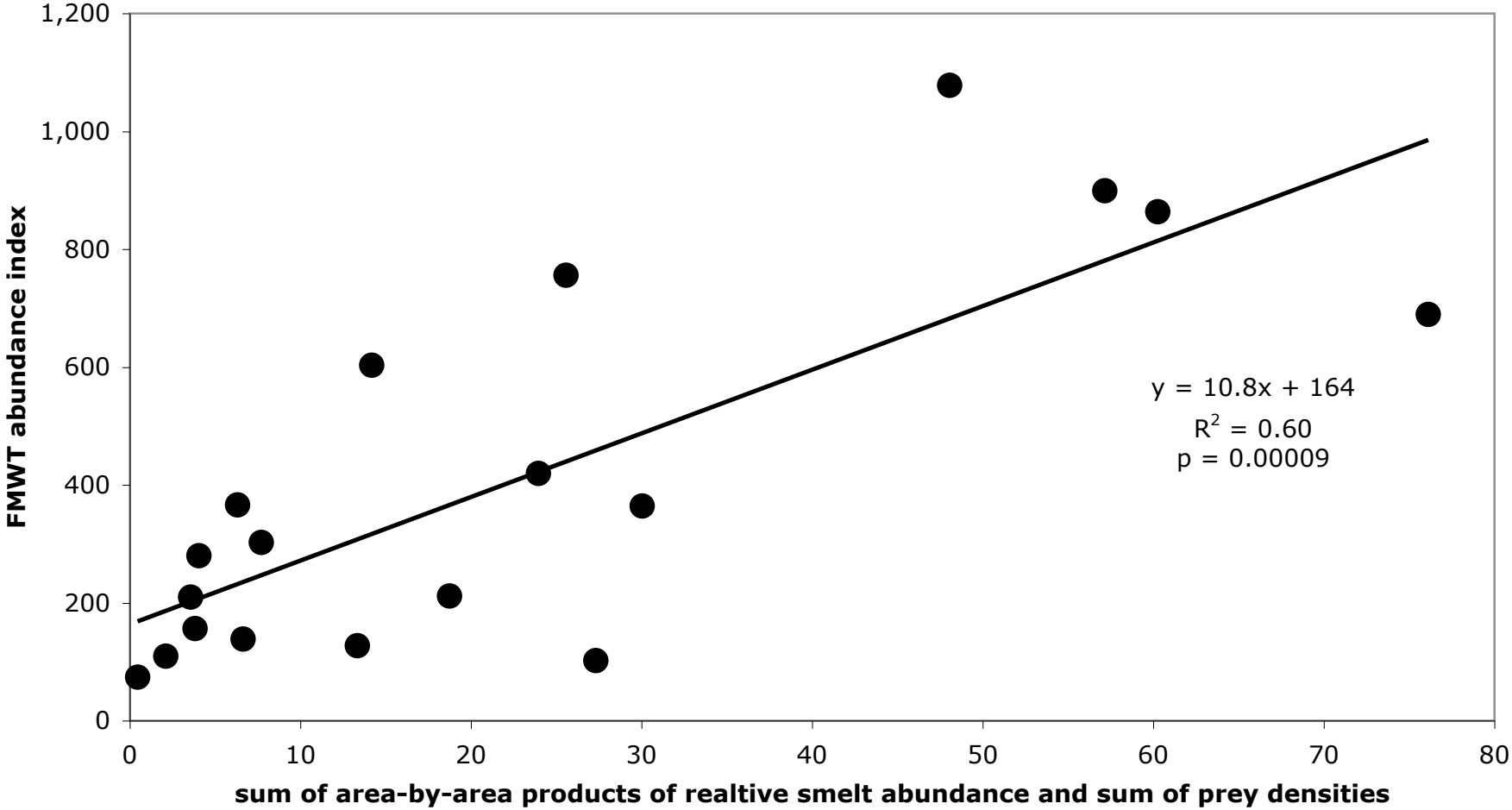
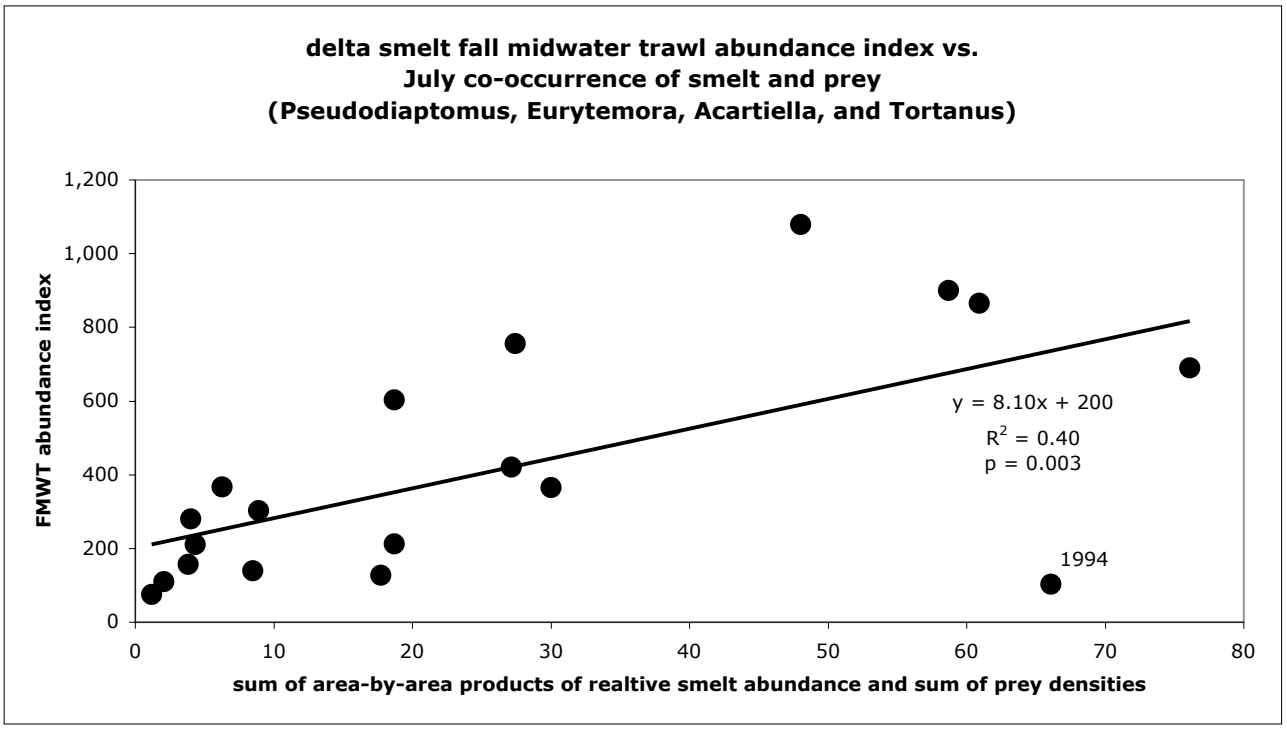


Figure 3
delta smelt-prey co-occurrence in July for all four prey species
with and without 1994 data



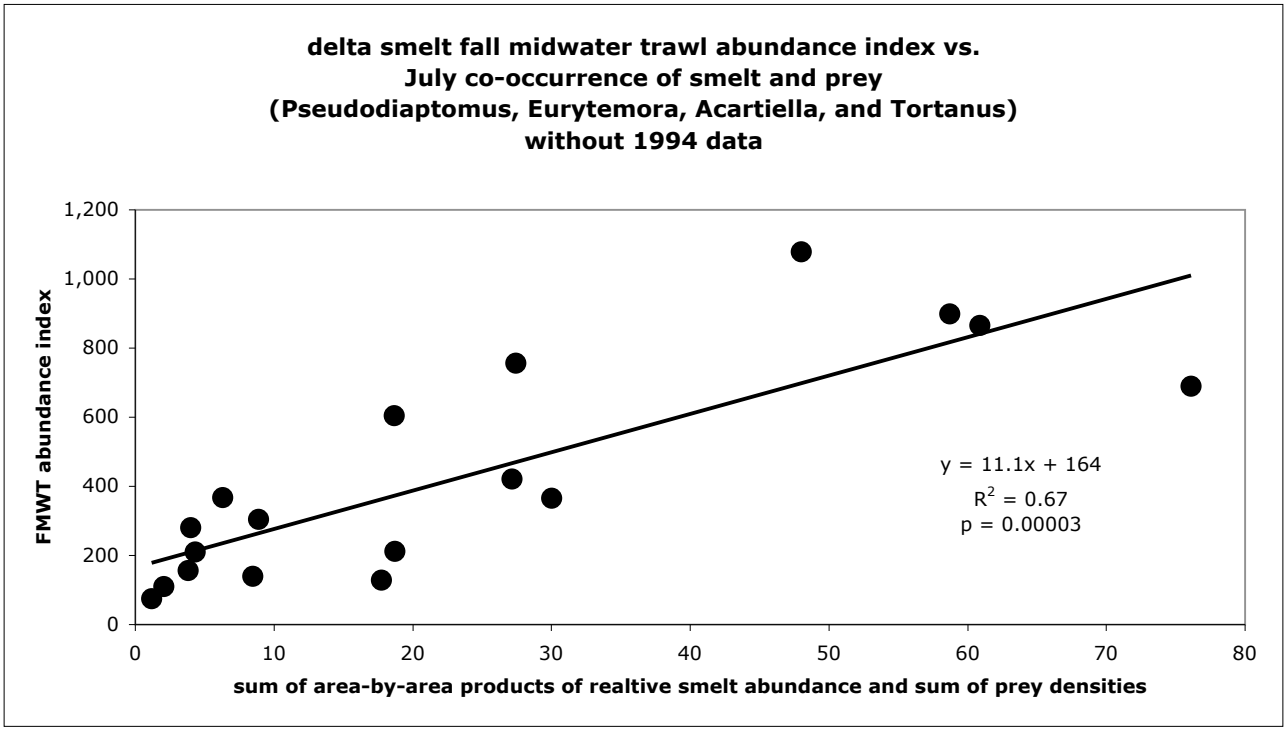


Figure 4
Densities of Eurytemora in areas of high co-occurrence of delta smelt and prey

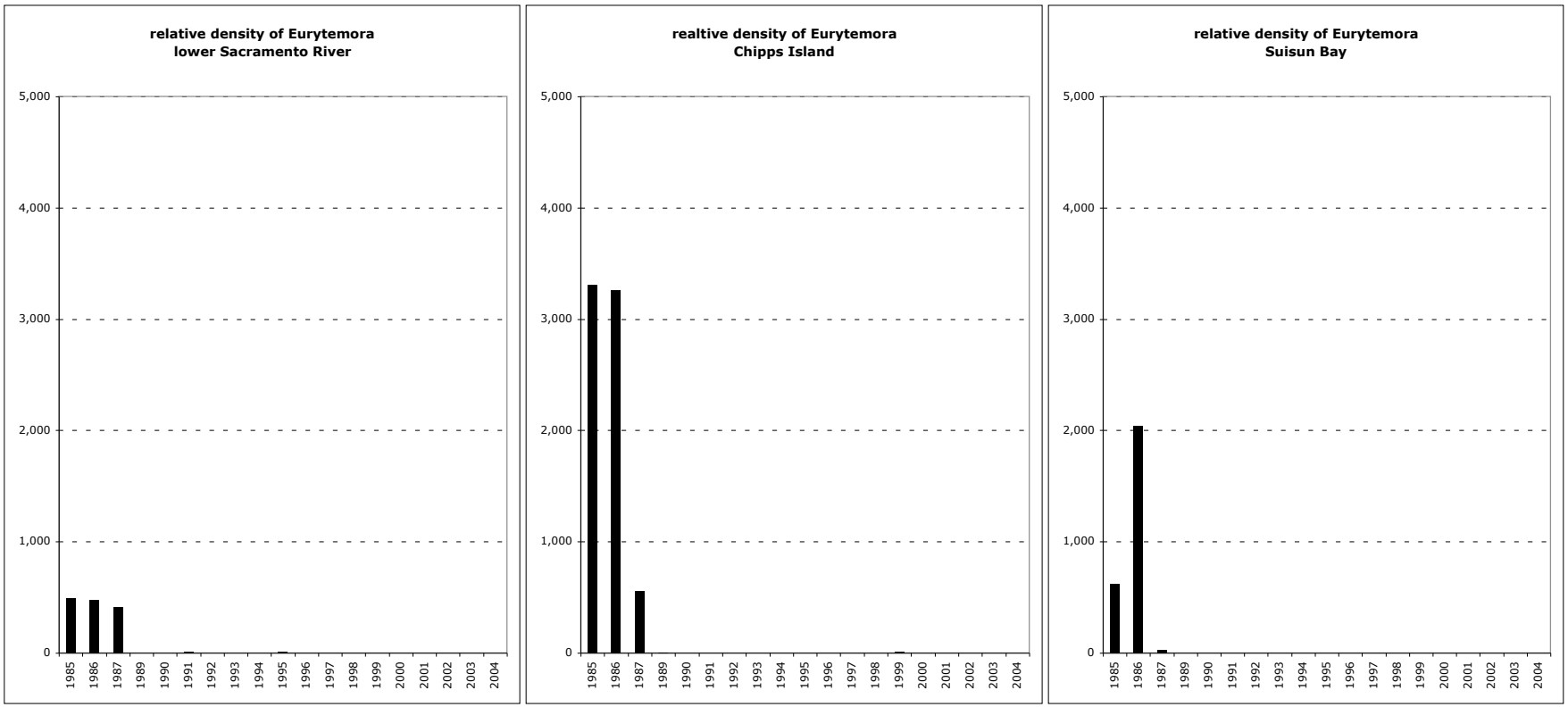


Figure 5
Densities of Pseudodiaptomus in areas of high co-occurrence of delta smelt and prey

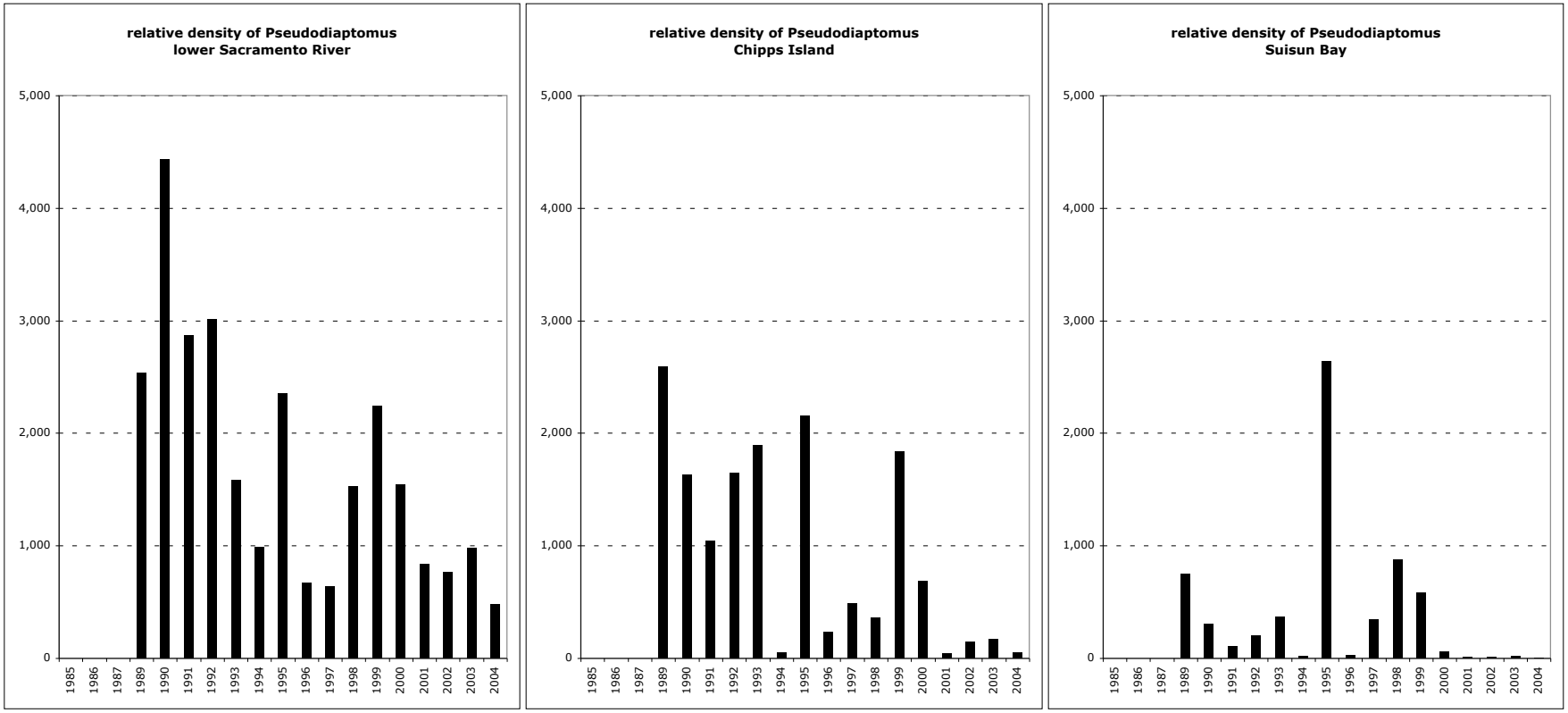


Figure 6
Densities of Acartiella in areas of high co-occurrence of delta smelt and prey

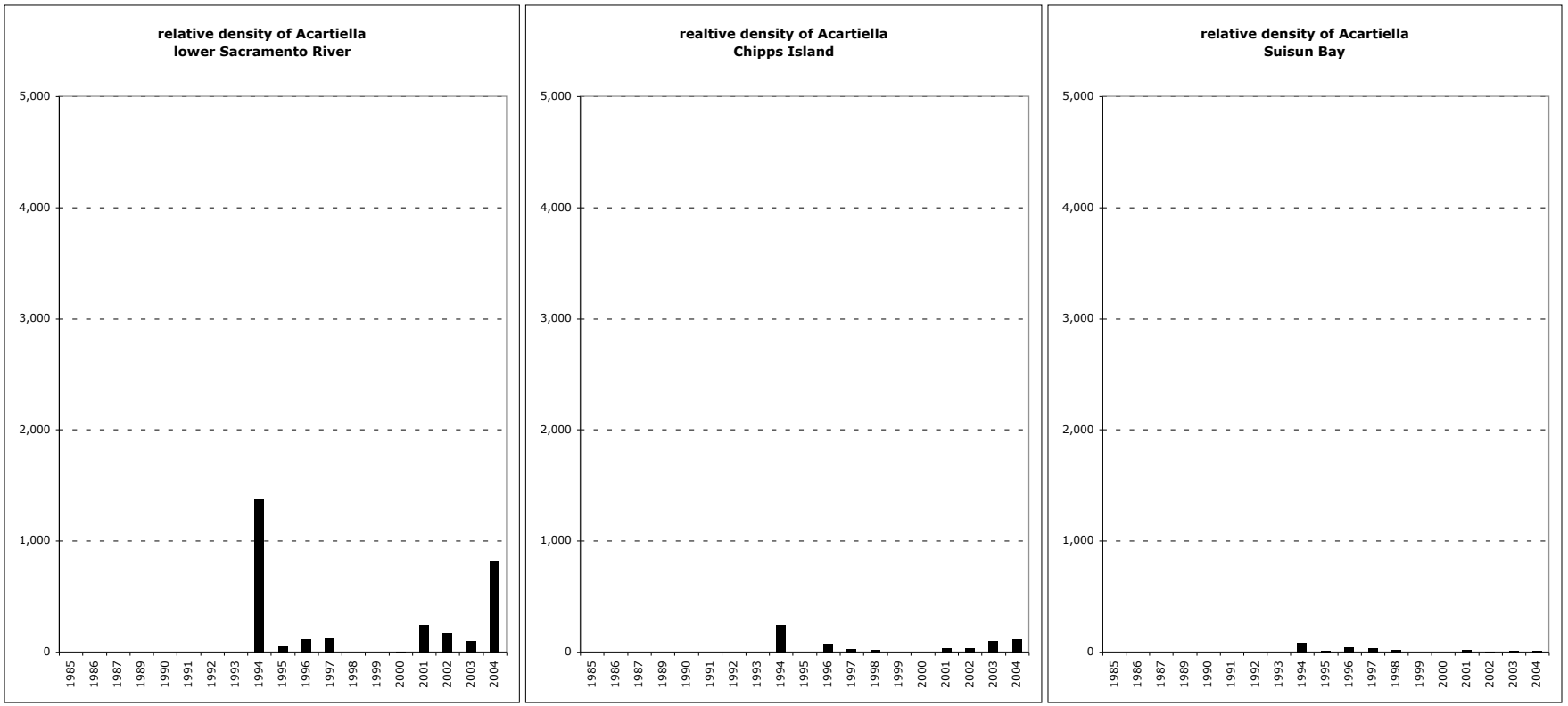


Figure 7
Densities of Tortanus in areas of high co-occurrence of delta smelt and prey

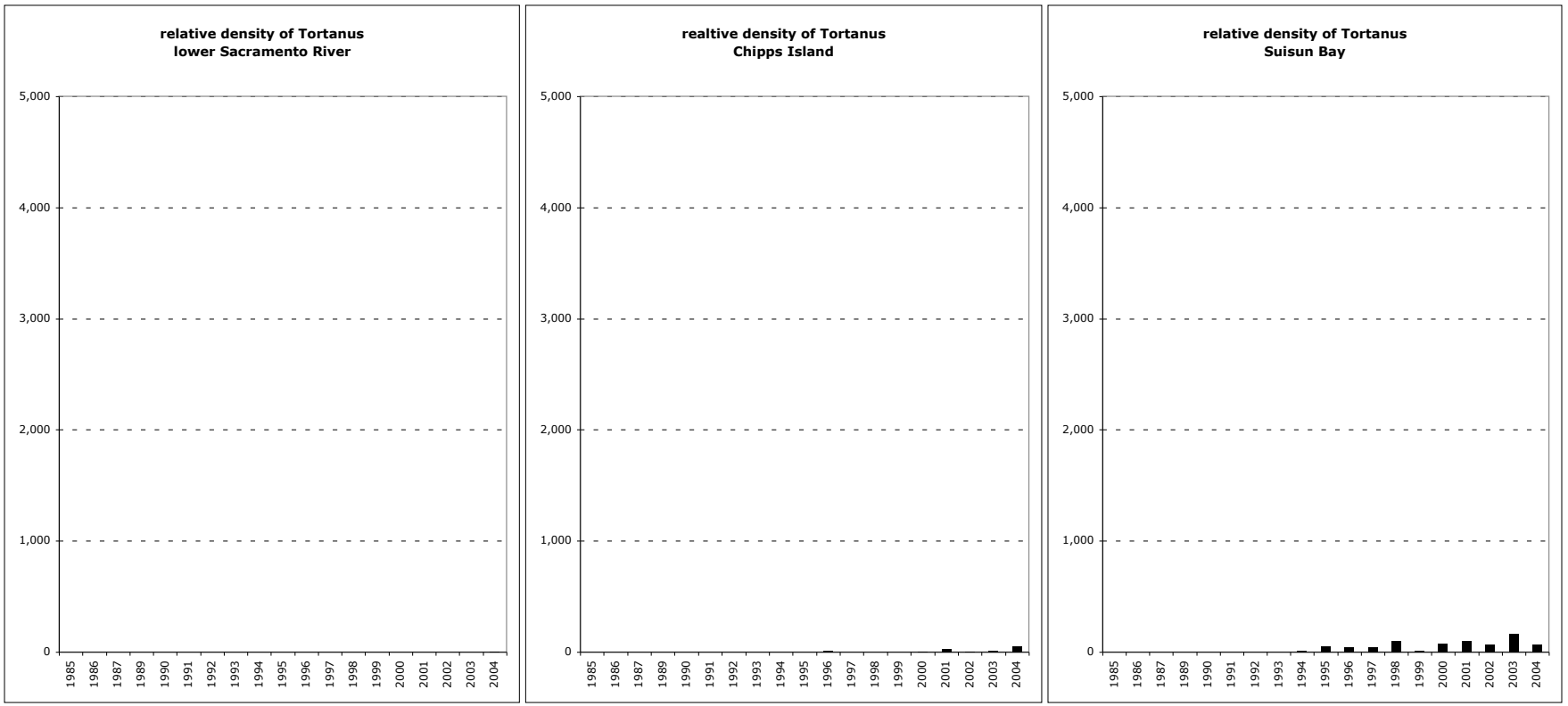


Figure 8
Trends in Pseudodiaptomus densities in areas of high delta smelt-prey co-occurence

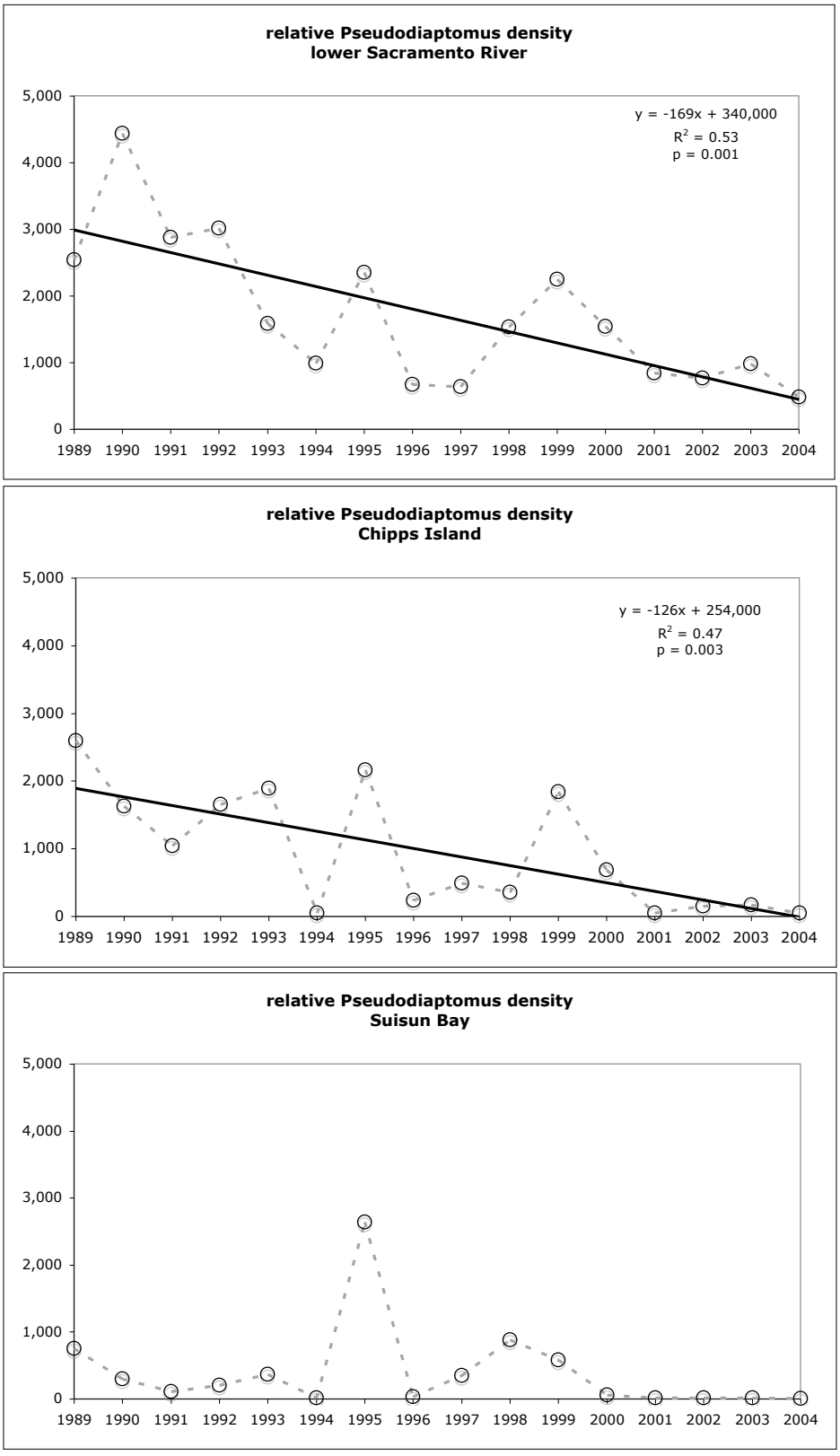
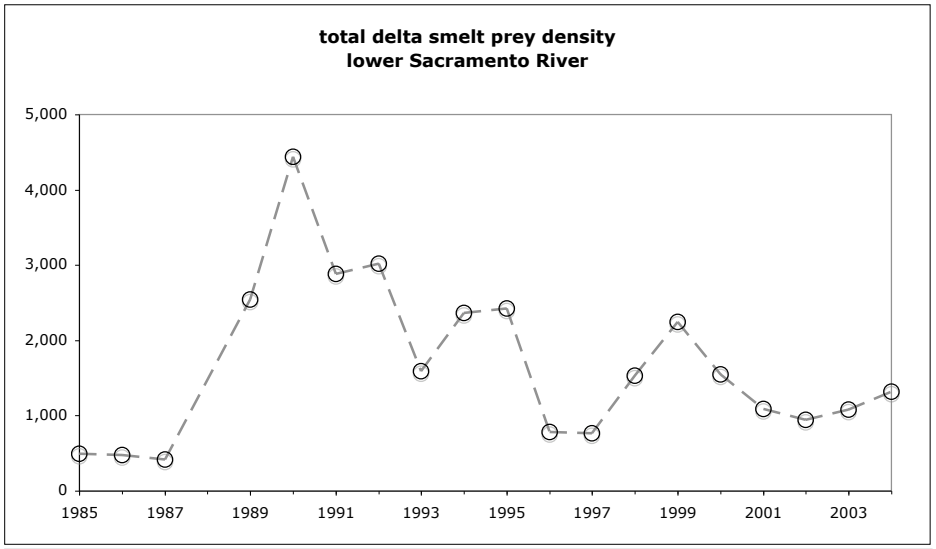
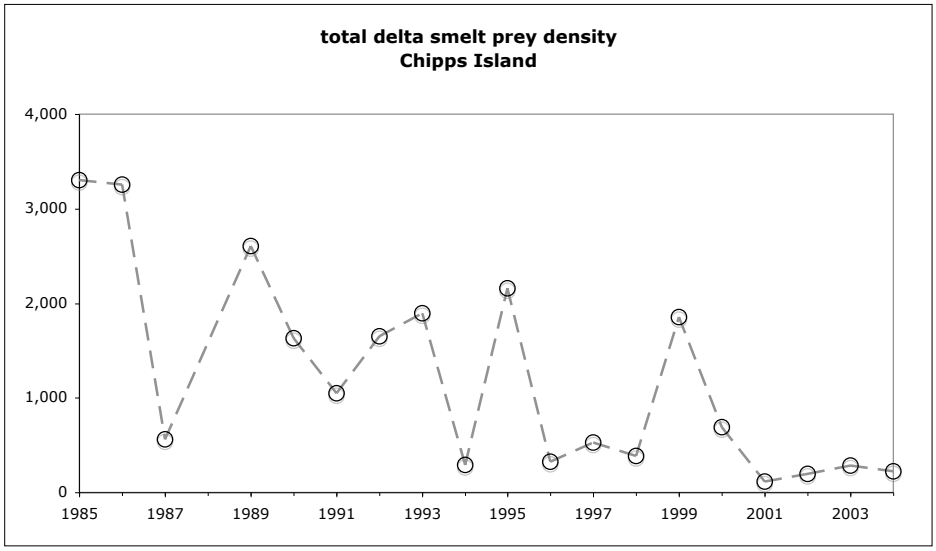


Figure 9
total delta smelt prey density in most important areas of delta smelt-prey co-occurrence





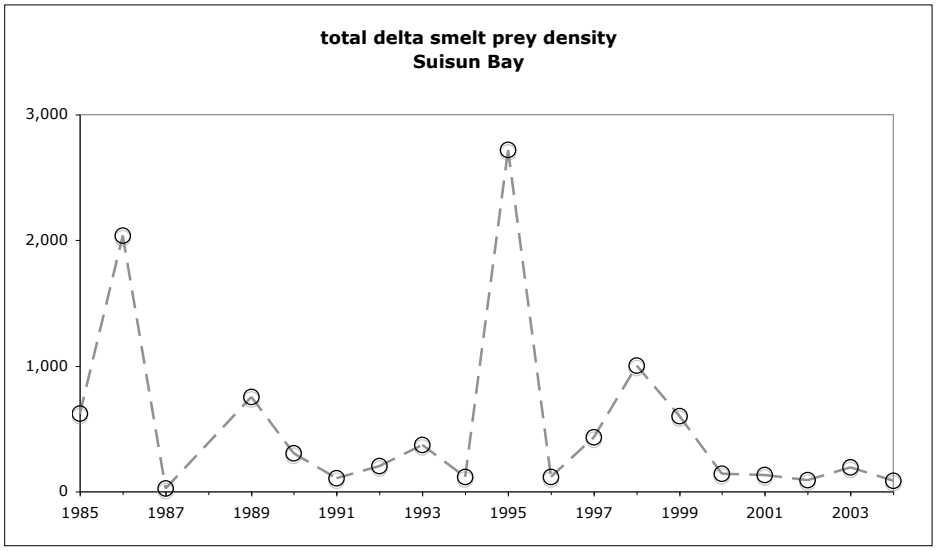


Table 1

Co-occurrence products = (relative delta smelt abundance)*(sum of densities of prey)

prey = Eurytemora, Pseudodiaptomus, Acartiella, Tortanus

colored areas each have at least 10% of that year's co-occurrence product

darker blue areas total at least 75% of that year's co-occurrence product

year	San Pablo Bay	Napa River	Carquinez St.	Suisun Bay	Suisun Marsh	Chipps Is.	Lower Sac. R.	Lower SJR	nr Franks Tract	SE Delta	E-SE Delta	total
1985	0	0	0	0	0	968,245	1,100,430	26,027	0	0	0	2,094,702
1986	0	0	0	3,970,442	178,099	5,999,813	8,401,327	178,540	0	0	0	18,728,221
1987	0	0	0	0	19,107	0	3,932,286	71,259	11,957	0	0	4,034,608
1989	0	0	0	199,955	696,083	0	5,370,755	0	0	32,080	0	6,298,872
1990	0	0	0	268,307	327,691	1,091,607	24,864,384	3,115,131	300,339	0	61,207	30,028,667
1991	0	0	0	38,127	113,651	241,388	72,852,008	2,059,998	813,567	0	0	76,118,738
1992	0	0	0	36,161	0	623,223	2,818,812	355,709	0	0	0	3,833,906
1993	0	0	40,531	11,319,088	211,376	6,263,608	22,646,466	7,569,210	0	0	0	48,050,278
1994	0	0	0	896,340	142,768	697,702	64,284,990	0	0	0	78,971	66,100,771
1995	0	0	0	56,264,749	154,203	1,989,654	302,059	0	0	0	0	58,710,666
1996	0	0	0	3,655,908	594,951	2,605,587	7,254,200	3,635,993	0	0	0	17,746,639
1997	0	0	0	1,075,131	0	1,850,162	5,569,547	428,963	0	0	0	8,923,803
1998	0	0	637,578	23,405,319	2,349,285	144,379	476,470	148,766	0	0	0	27,161,797
1999	32,459	0	0	23,686,370	1,167,958	15,757,587	18,446,826	1,322,466	488,115	0	0	60,901,780
2000	0	0	0	3,211,052	3,067,114	2,200,592	17,948,120	1,025,135	0	0	0	27,452,014
2001	0	0	0	475,072	6,701	49,060	18,155,215	0	0	0	0	18,686,047
2002	0	0	0	477,678	0	187,581	7,138,773	675,030	0	0	0	8,479,062
2003	0	0	0	68,586	43,678	1,119,740	2,894,094	219,885	0	0	0	4,345,984
2004	0	0	0	68,080	0	207,834	817,926	96,884	0	0	0	1,190,724

Table 2

Percentage of co-occurrence products = (relative delta smelt abundance)*(sum of densities of prey)

prey = Eurytemora, Pseudodiaptomus, Acartiella, Tortanus

colored areas each have at least 10% of that year's co-occurrence product

darker blue areas total at least 75% of that year's co-occurrence product

year	San Pablo Bay	Napa River	Carquinez St.	Suisun Bay	Suisun Marsh	Chipps Is.	Lower Sac. R.	Lower SJR	nr Franks Tract	SE Delta	E-SE Delta	total
1985	0%	0%	0%	0%	0%	46%	53%	1%	0%	0%	0%	100%
1986	0%	0%	0%	21%	1%	32%	45%	1%	0%	0%	0%	100%
1987	0%	0%	0%	0%	0%	0%	97%	2%	0%	0%	0%	100%
1989	0%	0%	0%	3%	11%	0%	85%	0%	0%	1%	0%	100%
1990	0%	0%	0%	1%	1%	4%	83%	10%	1%	0%	0%	100%
1991	0%	0%	0%	0%	0%	0%	96%	3%	1%	0%	0%	100%
1992	0%	0%	0%	1%	0%	16%	74%	9%	0%	0%	0%	100%
1993	0%	0%	0%	24%	0%	13%	47%	16%	0%	0%	0%	100%
1994	0%	0%	0%	1%	0%	1%	97%	0%	0%	0%	0%	100%
1995	0%	0%	0%	96%	0%	3%	1%	0%	0%	0%	0%	100%
1996	0%	0%	0%	21%	3%	15%	41%	20%	0%	0%	0%	100%
1997	0%	0%	0%	12%	0%	21%	62%	5%	0%	0%	0%	100%
1998	0%	0%	2%	86%	9%	1%	2%	1%	0%	0%	0%	100%
1999	0%	0%	0%	39%	2%	26%	30%	2%	1%	0%	0%	100%
2000	0%	0%	0%	12%	11%	8%	65%	4%	0%	0%	0%	100%
2001	0%	0%	0%	3%	0%	0%	97%	0%	0%	0%	0%	100%
2002	0%	0%	0%	6%	0%	2%	84%	8%	0%	0%	0%	100%
2003	0%	0%	0%	2%	1%	26%	67%	5%	0%	0%	0%	100%
2004	0%	0%	0%	6%	0%	17%	69%	8%	0%	0%	0%	100%

Table 3

Co-occurrence products = (relative delta smelt abundance)*(sum of densities of prey)

prey = Eurytemora, Pseudodiaptomus

colored areas each have at least 10% of that year's co-occurrence prouduct

darker blue ares total at least 75% of that year's co-occurrence product

year	San Pablo Bay	Napa River	Carquinez St.	Suisun Bay	Suisun Marsh	Chipps Is.	Lower Sac. R.	Lower SJR	nr Franks Tract	SE Delta	E-SE Delta	total
1985	0	0	0	0	0	968,245	1,100,430	26,027	0	0	0	2,094,702
1986	0	0	0	3,970,442	178,099	5,999,813	8,401,327	178,540	0	0	0	18,728,221
1987	0	0	0	0	19,107	0	3,932,286	71,259	11,957	0	0	4,034,608
1989	0	0	0	199,955	696,083	0	5,370,755	0	0	32,080	0	6,298,872
1990	0	0	0	268,307	327,691	1,091,607	24,864,384	3,115,131	300,339	0	61,207	30,028,667
1991	0	0	0	38,127	113,651	241,388	72,852,008	2,059,998	813,567	0	0	76,118,738
1992	0	0	0	36,161	0	623,223	2,818,812	355,709	0	0	0	3,833,906
1993	0	0	40,531	11,319,088	211,376	6,263,608	22,646,466	7,569,210	0	0	0	48,050,278
1994	0	0	0	153,249	73,931	117,132	26,887,687	0	0	0	78,971	27,310,969
1995	0	0	0	54,709,307	154,203	1,989,654	294,808	0	0	0	0	57,147,972
1996	0	0	0	1,017,723	578,317	1,894,357	6,212,121	3,635,993	0	0	0	13,338,511
1997	0	0	0	868,345	0	1,735,572	4,671,473	428,963	0	0	0	7,704,353
1998	0	0	197,014	20,653,994	2,349,285	135,887	476,470	148,766	0	0	0	23,961,415
1999	0	0	0	23,064,932	1,167,958	15,757,587	18,446,826	1,322,466	488,115	0	0	60,247,883
2000	0	0	0	1,439,034	3,057,970	2,191,066	17,869,193	1,025,135	0	0	0	25,582,398
2001	0	0	0	55,226	5,272	20,070	14,080,580	0	0	0	0	14,161,147
2002	0	0	0	88,562	0	146,721	5,817,845	596,538	0	0	0	6,649,666
2003	0	0	0	7,044	36,843	678,630	2,632,949	207,669	0	0	0	3,563,135
2004	0	0	0	6,212	0	46,629	301,082	90,842	0	0	0	444,766

Table 4

Percentage of co-occurrence products = (relative delta smelt abundance)*(sum of densities of prey)

prey = Eurytemora, Pseudodiaptomus

colored areas each have at least 10% of that year's co-occurrence prouduct

darker blue ares total at least 75% of that year's co-occurrence product

	San Pablo Bay	Napa River	Carquinez St.	Suisun Bay	Suisun Marsh	Chipps Is.	Lower Sac. R.	Lower SJR	nr Franks Tract	SE Delta	E-SE Delta	sum
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1986	0%	0%	0%	21%	1%	32%	45%	1%	0%	0%	0%	100%
1987	0%	0%	0%	0%	0%	0%	97%	2%	0%	0%	0%	100%
1989	0%	0%	0%	3%	11%	0%	85%	0%	0%	1%	0%	100%
1990	0%	0%	0%	1%	1%	4%	83%	10%	1%	0%	0%	100%
1991	0%	0%	0%	0%	0%	0%	96%	3%	1%	0%	0%	100%
1992	0%	0%	0%	1%	0%	16%	74%	9%	0%	0%	0%	100%
1993	0%	0%	0%	24%	0%	13%	47%	16%	0%	0%	0%	100%
1994	0%	0%	0%	1%	0%	0%	98%	0%	0%	0%	0%	100%
1995	0%	0%	0%	96%	0%	3%	1%	0%	0%	0%	0%	100%
1996	0%	0%	0%	8%	4%	14%	47%	27%	0%	0%	0%	100%
1997	0%	0%	0%	11%	0%	23%	61%	6%	0%	0%	0%	100%
1998	0%	0%	1%	86%	10%	1%	2%	1%	0%	0%	0%	100%
1999	0%	0%	0%	38%	2%	26%	31%	2%	1%	0%	0%	100%
2000	0%	0%	0%	6%	12%	9%	70%	4%	0%	0%	0%	100%
2001	0%	0%	0%	0%	0%	0%	99%	0%	0%	0%	0%	100%
2002	0%	0%	0%	1%	0%	2%	87%	9%	0%	0%	0%	100%
2003	0%	0%	0%	0%	1%	19%	74%	6%	0%	0%	0%	100%
2004	0%	0%	0%	1%	0%	10%	68%	20%	0%	0%	0%	100%

References

Baxter 2005, Baxter, Randy, California Department of Fish and Game, comments at November, 2005 Pelagic Organism Decline Workshop

Bennett 2005a, Critical Assessment of the Delta Smelt Population in the San Francisco Estuary, William A. Bennett, San Francisco Estuary and Watershed Science, 2005

Bennett 2005b, Bennett, William A., University of California at Davis, comments at November, 2005 Pelagic Organism Decline Workshop

Herbold 2005, Herbold, Bruce, Federal Environmental Protection Agency, personal communication, 2005

Miller 2005, Estimating areas and volumes of water in the region, San Pablo Bay to Stockton and Walnut Grove, November, 2005