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DRAFT

RELATIONSHIP BETWEEN AVERAGE LOCATION OF X-2 AND ANNUAL ABUNDANCE INDICES OF VARIOUS ESTUARINE ORGANISMS

prepared for

California Urban Water Agencies
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by

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NOTICE

This draft report was prepared as a technical document for reference use by California Urban Water Agencies and others in preparing their comments to the US Environmental Protection Agency on "Water Quality Standards for Surface Waters of the Sacramento River, San Joaquin River, and San Francisco Bay and Delta of the State of California, January 6, 1994." This draft technical report is not part of the CUWA formal comment to EPA.

PREFACE

This report was prepared for the California Urban Water Agencies (CUWA) as a part of a CUWA review of the Environmental Protection Agency's proposed "Water Quality Standards for Surface Waters of the Sacramento River, San Joaquin River, and San Francisco Bay and Delta of the State of California (40 CFR Part 131). CUWA commissioned this report as a part of its overall review and evaluation of this standard. This report addresses the following scientific questions:

1) Is there a consistent relationship between average calculated location of the surrogate for the imaginary 2-ppt isohaline (X-2) and abundance indices for selected estuarine organisms?

2) If not, is there an inconsistent relationship between average calculated X-2 location and abundance indices--what are some possible reasons for the inconsistencies?

3) Do abundance indices of selected estuarine organisms change in a consistent way in response to sequential changes in average calculated location of X-2 from year to year?

4) Is there evidence for discontinuities in the relationships between average calculated location of X-2 and abundance indices for selected estuarine organisms? If so, can such discontinuities help in understanding the nature of any relationship between abundance indices and estuarine functions?

5) Is there evidence in relationships among abundance indices themselves of bias related to sampling protocol or data analysis? If so, what types of bias might there be?

RELATIONSHIP BETWEEN AVERAGE LOCATION OF X-2 AND ANNUAL ABUNDANCE INDICES OF VARIOUS ESTUARINE ORGANISMS

BACKGROUND

The relationship between the location of a calculated surrogate for a theoretical 2 ppt isohaline ("X-2") and abundance indices for various estuarine organisms is indirect at best. As was pointed out repeatedly in testimony at the Bay\Delta Hearings, in background documents for the San Francisco Estuary Project, in primary source documents for EPA's proposed salinity standard and in EPA's proposal document itself, the location of X-2, which is a calculated theoretical average location for an "imaginary" 2 ppt isohaline (EPA, Proposal) is in turn a surrogate for an estuarine *process*. This process is fresh-salt mixing, which occurs over a very wide *area*, the "entrapment zone" (not a point or a line). This zone typically extends downstream for a distance of several miles from the theoretical location of the imaginary isohaline. It is the entrapment zone and the physical and biological processes which occur in it, not the average calculated X-2 location, that are thought to have some relationship to abundance indices of certain selected estuarine organisms. And it is the location of this zone with respect to certain geomorphic features of the estuary (shoals, tidal flats and marshes), not the average location of the calculated 2 ppt isohaline, which is thought to be important to the "health of the estuary." It is essential that this be born in mind when considering the nature of any possible relationship between the entrapment zone surrogate, average calculated X-2, and annual abundance indices generated by California Department of Fish and Game (CDFG) for selected estuarine organisms (see below). It is also essential to understand the forces which dictate the character of the entrapment zone in order to understand the nature of the relationship between this area and associated biota. Finally, it is very important to always bear in mind that the term "X-2", when used here, in the EPA Proposed Water Quality Standard, in EPA's primary source documents, in statistical correlations upon which the proposed salinity standard purports to be based, or anywhere else, is a *theoretical average location of an imaginary 2 ppt isohaline calculated from river outflow data*. This parameter, as it has been and continues to be used, is *not real and cannot be directly measured.*

The results and recommendations of the Bay/Delta Estuary Workshop, convened in 1992 in order to study the relationships between river outflow and certain bay and estuary resources and processes, is heavily relied upon by EPA as justification for the proposed salinity standard. Schubel (Facilitator) and other participants in the Workshop go to some pains to emphasize that potential cause-and-effect relationships between parameters they considered and estuarine biota were not part of their analysis. This was mostly because of the very complex interactions of a large number of physical and biological factors and processes, one of which is salinity, in estuaries in general and the San Francisco Bay / Sacramento-San Joaquin Delta (Bay/Delta)estuary in particular. For this reason, the workshop participants chose to use simple statistical relationships (correlations) as an approach which "lumps together" (Schubel, 1993) a variety of these factors.

As mentioned above, the "entrapment zone" is an area in estuaries where fresh and salt water mix. In general, a denser layer of salt water extends landward, subtending a less dense layer of fresh water with a net seaward movement. Naturally, both water masses are shifted back and forth and partially mixed, both vertically and horizontally, in response to tidal forces. Primarily because of the differing densities of the fresh and salt water masses and their net relative movement, the entrapment zone, as it is moved about by tidal forces, tends to be an area of higher turbulent mixing and re-suspension of sediments into the water column and an area where many important estuarine processes, including biological processes, are concentrated. Workshop participants (and the EPA) felt that the entrapment zone and its attendant physical and biological processes were worthy of special attention, especially for fresh water sensitive estuarine species.

In order to investigate the relationship between river outflow and the entrapment zone, workshop participants selected certain estuarine species for their affinities for fresh water (at least at some point in their life cycles). Workshop participants felt that the imaginary 2 ppt isohaline (average calculated "X-2"; about 6% sea water), would be a suitable surrogate for the *upstream limit* of the entrapment zone, and might therefore be a suitable surrogate for the upstream limit of those estuarine processes which are "fresh water sensitive". They also considered average location of X-2 a surrogate for outflow, which is logical since X-2 is calculated from river outflow data. For these reasons, they contemplated statistical correlations in "the simplest generalized linear models" (Jassby 1992a) between the average location of X-2 and various abundance indices for fresh water sensitive organisms and primary productivity.

The abundance indices used by Jassby and very heavily relied upon by EPA in their justification of a need for a salinity standard were generated by California Department of Fish and Game from data collected during fall midwater trawl sampling and from the San Francisco Estuary Project. The manner in which these annual abundance indices were generated has come under scrutiny as part of this CUAA review of supportive information for the proposed EPA standard. This scrutiny has revealed a number of very serious and fundamental errors and omissions in the data analysis procedures used to derive annual abundance indices, especially those generated from fall midwater trawl data, which profoundly influence the indices themselves and the interpretations to which they have been subjected by both the San Francisco Estuary Project Workshop and EPA *including trends relative to average calculated location of X-2*. Several of these fundamental errors and omissions are discussed in companion technical reports by Fox (Reference ----) and R-2 Resources (Reference ----). In spite of these shortcomings and the serious doubt cast on the reliability of the indices and the interpretations by the Workshop and

EPA, it was felt that a thoughtful consideration of the "relationships" appealed to by Jassby and EPA would be a valuable exercise. Obviously, the sampling data, especially the fall midwater trawl data must be completely re-analyzed and annual abundance indices re-computed before they can be invoked in any serious way in support of EPA's proposed standard or any other important water management proposal. This re-analysis should assume a high priority and be completed in advance of promulgation of the Final Rule.

The data sets from Jassby (1992b; contained in Schubel, 1993) exhibit a great deal of "scatter" or variation in the relationship between average location of X-2 and abundance indices of the selected estuarine species. Jassby (and EPA) have assumed a continuous function relationship between the average location of X-2, and found "no well-defined break point that can be reliably identified *statistically* in the composite relationship of these components" (average X-2 location and abundance indices) (Schubel, 1993; emphasis added). However, a visual inspection of the graphic representations of the data reveals obvious discontinuities, which show some consistency across species:

- Sudden "stepwise" shifts in abundance index as a function of average X-2 location with intervening "plateaus" in the relationship;
- Sudden changes in the slope of the function, sometimes accompanied by a shift;
- Sudden and large changes in the variability of abundance index as a function of average X-2 location.

This means that the rules governing simple regression analysis may have been violated, possibly invalidating conclusions or warranting thoughtful re-interpretation. Jassby (1992a) points the way toward re-analysis: "These [simplest generalized linear] models no doubt can be refined for other purposes, such as...determining standards."

Following Jassby's lead, the abundance indices generated by CDFG from historical data sets for the list of species analyzed by the Workshop and being relied upon by EPA to justify its proposed salinity standard were scrutinized in light of the historical data on average X-2 location. This scrutiny was undertaken to see if refinements to Jassby's simple linear models might lead to refinements in interpretations of the data which could be justified on the basis of general physical and ecological principles.

For the most part, changes in the behavior of the uncorrected annual abundance indices tend to gravitate toward a relatively narrow region of average calculated X-2 location. This suggests a relatively consistent discontinuity in the relationship between calculated X-2 location at a certain point in the system, and certain physical and/or biological mechanisms operating on one side of a transition zone which do not operate, at least not in the same way, on the other side.

The implication is that *if* there is a causal relationship between the entrapment zone and associated fresh water sensitive species, and if the median calculated position of X-2 were "located" comfortably anywhere within the region exhibiting abundance indices suggestive of reasonably robust populations of these organisms, a wide variety of estuarine values would be substantially protected.

To this end, a variety of analyses were performed on the data. These include:

- Formal cluster analyses and statistical tests to determine how clusters differ from each other, especially adjacent clusters, both quantitatively (differences in means) and qualitatively (differences in variances; differences in internal regressions);

- Co-abundance analysis to determine whether uncorrected abundance indices for different species selected by EPA in support of their proposed salinity standard behave similarly with respect to average calculated location of X-2;

- Abundance versus primary productivity (and calculated riverine particulate organic carbon) analysis to shed light on possible trophic relationships among uncorrected abundance indices and average calculated location of X-2;

- Vector analysis, to determine how uncorrected abundance indices for individual species respond to sequential changes in average calculated location of X-2 from one year to the next.

CLUSTER ANALYSES

Formal cluster analyses are the subject of a companion Technical Report by Fox (Reference ---). In general, these analyses indicate that apparent discontinuities in mean abundance indices are statistically significant for eight of the nine species chosen by EPA to support their proposed salinity standard. These analyses also showed statistically significant discontinuities in the variance for eight of the nine species, even when data were logged to account for a "percent change" phenomenon often seen in biological data, and statistically significant changes in the slopes of the relationships for six of the nine species. Finally, these analyses indicate that the apparent discontinuities in the uncorrected annual abundance indices generally occur in a geographic area within a few kilometers upstream or downstream of Chipps Island.

These analyses do not *prove* beyond a traditional statistical doubt the existence of a consistent, discrete discontinuity in the uncorrected aggregate annual abundance index data for several estuarine organisms relative to the location of calculated X-2. On the other hand, the data are strongly *suggestive* of such a discontinuity, and the same statistical tests do not favor a continuous function over a discontinuous one. In strict *statistical* terms, it is a standoff. When statistics fail to help with a choice between alternative interpretations, analysts are forced to appeal to reason and what is known (in this case) about the biology of the organisms of interest: "biological good sense." In consideration of the dynamics of the system and the physical attributes of the setting, it is difficult to conclude that there would *not* be a threshold or abrupt discontinuity in the relationship between the biology and a location of the entrapment zone, with the 2-ppt isohaline approximating its upstream end, over the majority of Suisun Bay, Grizzly Bay, Honker Bay and their associated shoals tidal flats and marshes.

Data for several individual species show rather obvious changes in the behavior of the functions in the general vicinity of Chipps Island or immediately downstream. The nature of these changes differs, depending on the species being considered. This is to be expected, however, since each individual species differs both qualitatively and quantitatively in its environmental needs and in its response to environmental perturbations, whether positive or negative. These conclusions are consistent with those of the SFEP Workshop and biological documentation which led up to it.

CO-ABUNDANCE ANALYSIS

The sudden increases in variability in abundance index data for a variety of estuarine species with average location of X-2 anywhere downstream of Chipps Island (about 72 km) warrants particular consideration. This characteristic of the data suggests, as indicated above, that as long as the average X-2 location is downstream of the threshold location, the abundance index *may or may not* exhibit a high value, whereas if average X-2 is upstream of the threshold location, a high abundance index value should not be expected. This indicates that average X-2 downstream of the threshold location is a *necessary but not sufficient condition* for a high abundance index value. In other words, there is an "opportunity" for a high abundance index value, but *other factors* determine whether or not that opportunity is realized.

The justification of the EPA proposed salinity standard is based on the expectation that if the average calculated X-2 location can be favorably positioned (by flow manipulation), most or all of the estuarine species with abundance indices which appear to be sensitive to location of X-2, bearing in mind that it is a calculated surrogate for an imaginary isohaline, will again begin to exhibit high abundance indices. This expectation is in turn based on correlations between uncorrected historical abundance indices and average calculated location of X-2. But the high variability of abundance indices for most species with average X-2 located downstream of the apparent threshold location raises the question of co-abundance of species under seemingly favorable historical average X-2 location conditions. Indeed, if many of the sensitive species often appear to be co-abundant (high abundance indices in the same years), and if those years correspond to years of "favorable" average location of X-2, a case could be made that populations of those organisms were responding to the independent variable (average calculated X-2 location) and that this parameter is a reasonable surrogate for beneficial conditions it the part of the estuary under its influence. On the other hand, if sensitive organisms are rarely co-abundant, factors other than average location of X-2 must be dominating the abundance indices, and manipulation of average location of X-2, or the parameter for which it is a surrogate (salinity) would generally be fruitless, at least as far as realization of biological benefits is concerned. This would make salinity an inferior candidate for use in a water quality standard.

To test this hypothesis, abundance index data for fresh water sensitive species were analyzed for co-abundance. Figure 1 displays plots of the abundance indices of three indigenous estuarine fishes which have garnered the most interest in terms of sensitivity to fresh water and the average location of X-2: delta smelt, longfin smelt and splittail. The abundance of each has been plotted against the abundance the other two in all three possible combinations. Each point represents the annual abundance index of two of these fish in any particular year. It can be seen that, according to the annual abundance indices, none of these fish tends to be co-abundant with any of the others. These data tell us that, for whatever reason, an abundance index for any of these fish is almost *never* high when the index for another fish is high, in spite of the average location of X-2 or any other factor or combination of factors. This is a very important finding, because it casts serious doubt on EPA's rationale used as justification for salinity as a water quality standard.

On the surface of it, this behavior of the abundance indices is inconsistent with the idea that they are reflective of the "health of the estuary" and that if only the salinity conditions in Suisun Bay were right, they would rise to levels indicative of robust populations of all these species. There are several possible interpretations for these relationships in the data. These include:

- There is density-dependent competition among these species in years with otherwise favorable estuarine conditions (*e.g.* average location of X-2 or some other factor);

- There is a sampling artifact related primarily to transient estuarine conditions (*i.e.* tidal stage and phase, current strength and direction possibly modulated by meteorology, etc.) and habitat partitioning and differential species distribution at the time and place of sampling;

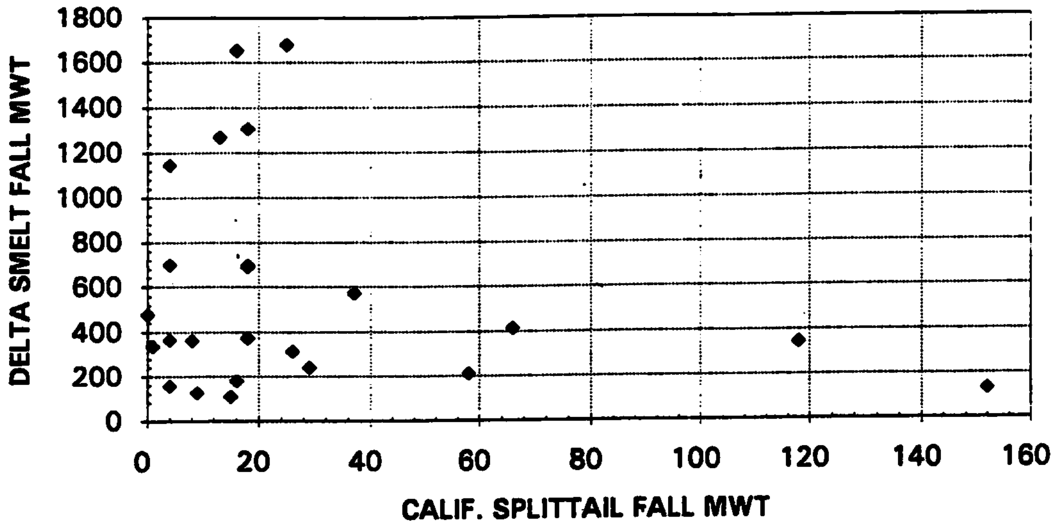
- There is a data analysis artifact related primarily to the "multiplier effect" in generation of abundance indices from actual catch data, particularly with regard to tidal stage during the time of sampling;

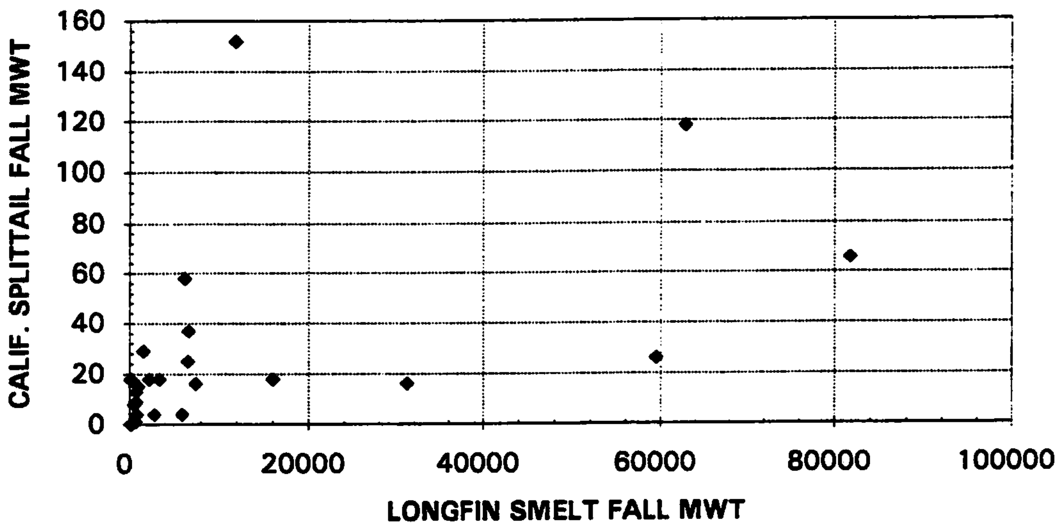
- There is a data analysis artifact relating to the year class making up the catch from which abundance indices are calculated (except for delta smelt);

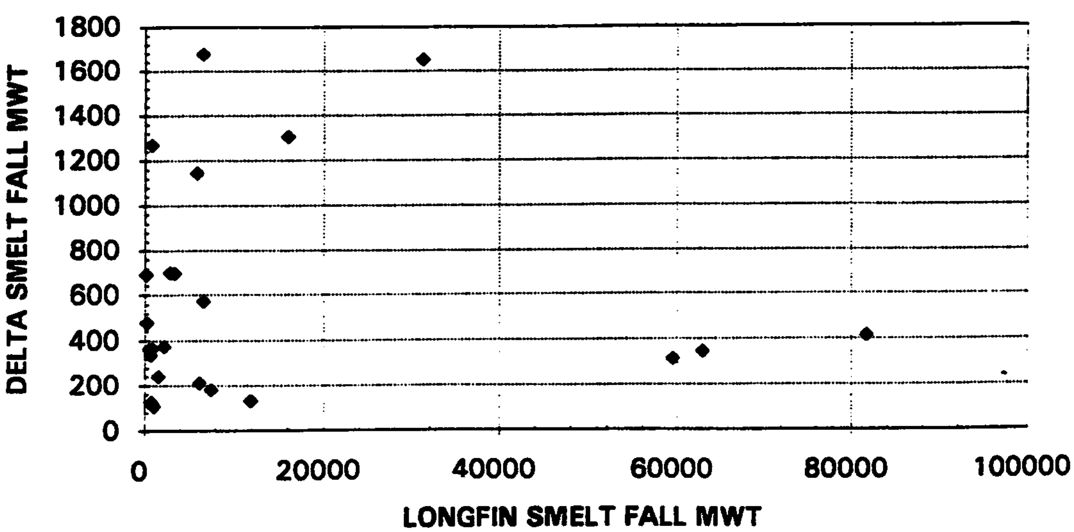
- There is a data analysis artifact relating to the use of data which was not corrected for water column depth at the time and place of sampling and differential vertical distribution of species in the water column.

FIGURE 1

SACRAMENTO / SAN JOAQUIN / BAY DELTA
ANNUAL ABUNDANCE INDICES







- There are other data analysis artifacts which violate fundamental statistical rules for aggregation of sampling data such as summing catch data from repeated sampling of the same population when generating an abundance index, relying on means of highly skewed data as measures of central tendency, eliminating "outliers" without rigorous justification (especially when done inconsistently), etc.

None of these possible interpretations is mutually exclusive with respect to the others. Each is discussed briefly below.

Density dependent competition

This potential explanation is relatively straightforward, and is consistent with the concept that the average location of X-2 is a necessary but not sufficient condition for a population response of any individual species. The logic is that gross conditions in the estuary are not good enough in all years for "sensitive" species to flourish, but when they are, only one species can dominate. This could occur if, for example, food supplies or primary productivity were limiting for various species at this trophic level. "Micro" conditions would determine *which* species would dominate, but in all or nearly all cases an expansion of the population of one species would be at the expense of the others. This explanation assumes that the abundance indices accurately reflect actual populations of individual species (very little in the way of sampling artifact or "false positives"). Since habitat partitioning is known to occur among these species, including differential depth and salinity preferences during the time of sampling, density dependent competition, at least by itself, is probably not the most likely explanation for the behavior of the data.

Transient conditions sampling artifact

This potential explanation takes into account the profound effect of tides and currents and modulating effects of other factors such as prevailing wind direction and velocity on conditions within the water column. It is known that the sampling programs which have yielded the data from which the abundance indices were calculated were conducted according to a regular monthly schedule within the sampling period. We have learned, however, that the sampling protocol was *at least* inconsistent with regard to lunar tidal cycles and most likely did not take them into account in most years. Data analysis *never* took lunar tidal cycles into account. This is very important for three reasons:

- The tidal cycle is *by far* the single most important factor modulating the physical "workings" of this (or almost any) estuary;

- Estuarine species react very strongly to those physical estuarine processes modulated strongly by tidal influence;

- There is a relatively large, orderly shift in the timing of tidal phase and resulting current strengths and directions among successive years, but only a very small shift among successive months within a particular year.

Thus, if the sampling program is consistent with the calendar from year to year, it will be out of sync with respect to the important tidal and resulting current cycles from year to year. This generally results in serious and regularly recurring bias in sampling data, including biological data (Hutchinson and Sklar 1993; Burau 1994).

The nature of the shift in tidal and current cycles among successive years is such that a strong bias in the biological data used to generate annual abundance indices presented by Jassby and relied upon heavily by EPA is virtually certain. Peak spring tides and correspondingly strong currents, which are characterized by large differences between tidal extremes (high-high to low-low) and often small differences between intermediate tides (low-high to high-low), occur within a day or two of a new moon. Spring tides exert very powerful influences on mixing and net movements of water bodies of differing densities, especially if differences between low-high and high-low tides are small, as is often the case in the San Francisco Estuary. Neap tides, which are characterized by a more regular and less extreme pattern of tidal excursion, and therefore more moderate currents, occur within a few days of a full moon. These tides exert lesser influences on estuarine dynamics related to turbulent mixing, including current vectors, but produce peaks in salinity stratification and gravitational mixing.

On successive years, there is a recessional shift of approximately 11 days in the calendar occurrence of spring tides. This means, if the sampling schedule follows the calendar (which it does), sampling corresponds within a few days of the same part of the tidal cycle every third year, but closely corresponds (within one or two days) only every eighth year. Daily timing of tidal excursions is also an important variable. Although peak spring tides for a particular month occur at *about* the same time of day each year, they are offset by 11 days in successive years. Ebb, flood and slack current conditions also change their relationship to the timing of tidal stage (height) over the course of the 28 or 29 day lunar tidal cycle. Therefore, on any particular day of the month, not only are tidal excursions and resulting currents greatly different, but the timing of tidal excursions and resulting ebb, flood and slack conditions is offset by at least several hours. This means that sampling at a station or group of stations might be conducted (for example) consistently on flood conditions in one year but might very well occur consistently on slack or ebb conditions the next. Data collected in this manner *cannot* be considered comparable among years.

Since the data used to generate abundance indices upon which EPA has placed great reliance were *never* segregated for analysis according to the tidal and current conditions under which they were gathered, and since these conditions constitute a very influential but uncontrolled independent variable, we are actually looking at a data set with a *maximum* sample size of 4 to 9 (out of 27 years, disregarding a few missing years), depending on how closely an analyst might wish to have tidal and current conditions correspond to the sampling schedule. This is an insufficient sample size to reliably characterize abundance indices in terms of average location of X-2, especially considering its theoretical nature, or any other outflow-related variable. It is quite likely that these discrepancies in sampling are responsible for a large proportion of the variability in abundance indices of many of the organisms EPA uses to justify the need for the proposed salinity standard, along with the data analysis flaws documented in part in the accompanying Technical Report by Fox (Reference ----). This is especially true since different species, or different life stages of the same species, have significantly different salinity and other physical habitat preferences. This does not mean that the raw data are not good, or that salinity is not an important factor in both distribution and abundance of estuarine organisms. It means that the raw data need to be re-analyzed with tidal condition taken fully into account.

"Multiplier effect" sampling artifact

Sampling stations were divided into convenient "zones" for the generation of abundance index calculation. For each zone, the mean catch data for a particular species is multiplied by a factor reflecting the surface area (and volume of water) to adjust the catch for the size of the zone being sampled. ***But, the multiplier was never adjusted to reflect the area and volume of water at the time of sampling.*** This failure to adjust the multiplier leads to a very obvious and significant bias in the calculated abundance index, which shifts in an orderly way from year to year, but does not shift significantly within a year, given the sampling protocol.

The procedure used to calculate abundance indices must also assume that organisms being sampled are evenly distributed throughout the zone (there is no physical habitat segregation going on) and/or that the sampling stations accurately and evenly represent all habitat types, including those determined by transient conditions (tide, current, wind, etc., *see above*), or that any bias is consistent from year to year. Since no consideration was given to the matter of transient conditions in the sampling scheme or the analysis of data, this assumption was clearly violated. If *any* habitat segregation occurs with regard to transient conditions, which is certainly the case (as acknowledged by EPA and supported by primary source documents in discussions of the importance of the entrapment zone), the "multiplier effect" will magnify the transient conditions sampling artifact. One must add inundation (*e.g.* of mud flats) to the list of transient conditions at this point. This effect will add an additional bias to the extent that sampling stations do not evenly represent all physical habitat conditions which are not subject to transient conditions, such as bottom type, depth, vegetation, channel configuration, etc.

Year class data analysis artifact

Delta smelt generally typically exhibit a one year life cycle, with only a few individuals surviving as two-year-olds; there can be no differential age class vulnerability to sampling, since essentially only one cohort is present during the sampling period. Longfin smelt have a two year life cycle, however, and splittail may live for 5-6 years. It is likely that gear is not sampling all age classes of these two species with equal efficiency, thus biasing abundance indices calculated from total catch. For example, there is an obvious differential in vulnerability to sampling between age classes in the Bay Study longfin smelt data, with adults being much more vulnerable to sampling than juveniles in both the Bay Study fall midwater trawl and in the otter trawl sampling. This is demonstrated by comparing yearling (one-plus) abundance indices in any one year with young-of-the-year indices from the previous year. In most cases, cohort size, as indicated from the abundance indices alone, increases from one year to the next. In other words, the apparent adult population is greater than the juvenile population the year before (sometimes as much as 300-400%), which is clearly impossible. The problem is that these segregated data (Bay Study data) were not the data used by Jassby and EPA to generate correlations with average location of X-2. If they were, the year class artifact could be sorted out. Instead, a larger data set (more years) was used, with only the *total catch* (juveniles plus adults) going into the calculation of the abundance index. For this reason, it is impossible to tell whether a salinity effect, if there was one, operated on juveniles, adults, or both. Since some habitat partitioning is obviously occurring between year classes, it is likely that any actual effect is operating differentially, but it is not possible to distinguish the direction. Therefore, it is also impossible to determine which year's abundance index to compare with which year's average X-2 location. Likewise, it is impossible to know whether to compare a given year's longfin smelt abundance index with that of delta smelt from the same year or the previous year. The problem is much more confusing with splittail, because six cohorts are present simultaneously and a very large bias is virtually certain.

Depth correction data analysis artifact

Tow net data are gathered by fishing a net over the entire range of depths in the water column at the sampling site by starting the tow at the bottom and slowly manipulating the net closer to the surface over the set duration of the tow. In this way, the total catch is integrated over the entire vertical distance from the bottom to the surface. Obviously, if such a technique is employed at a deep sampling station, the net spends much less time sampling near the surface than it would at a shallow station. It is known that target species are not evenly distributed vertically in the water column. Delta smelt, for example, are generally taken near the surface. Thus, even if these fish were evenly distributed horizontally, which they probably are not, a negative bias would exist at deep stations relative to shallow ones. Abundance indices for various zones along the estuary are calculated by essentially multiplying the average catch for the stations in that zone by a factor related to the size of the zone. Since the larger zones in wider parts of the system also have a greater proportion of shallow stations, failure to correct catch data for the time the net spends fishing in the part of the water column where the fish are introduces a double bias, both operating in the same direction. As far as can be determined, abundance data appealed to by EPA in support of their proposed salinity standard were not corrected for sampling station depth.

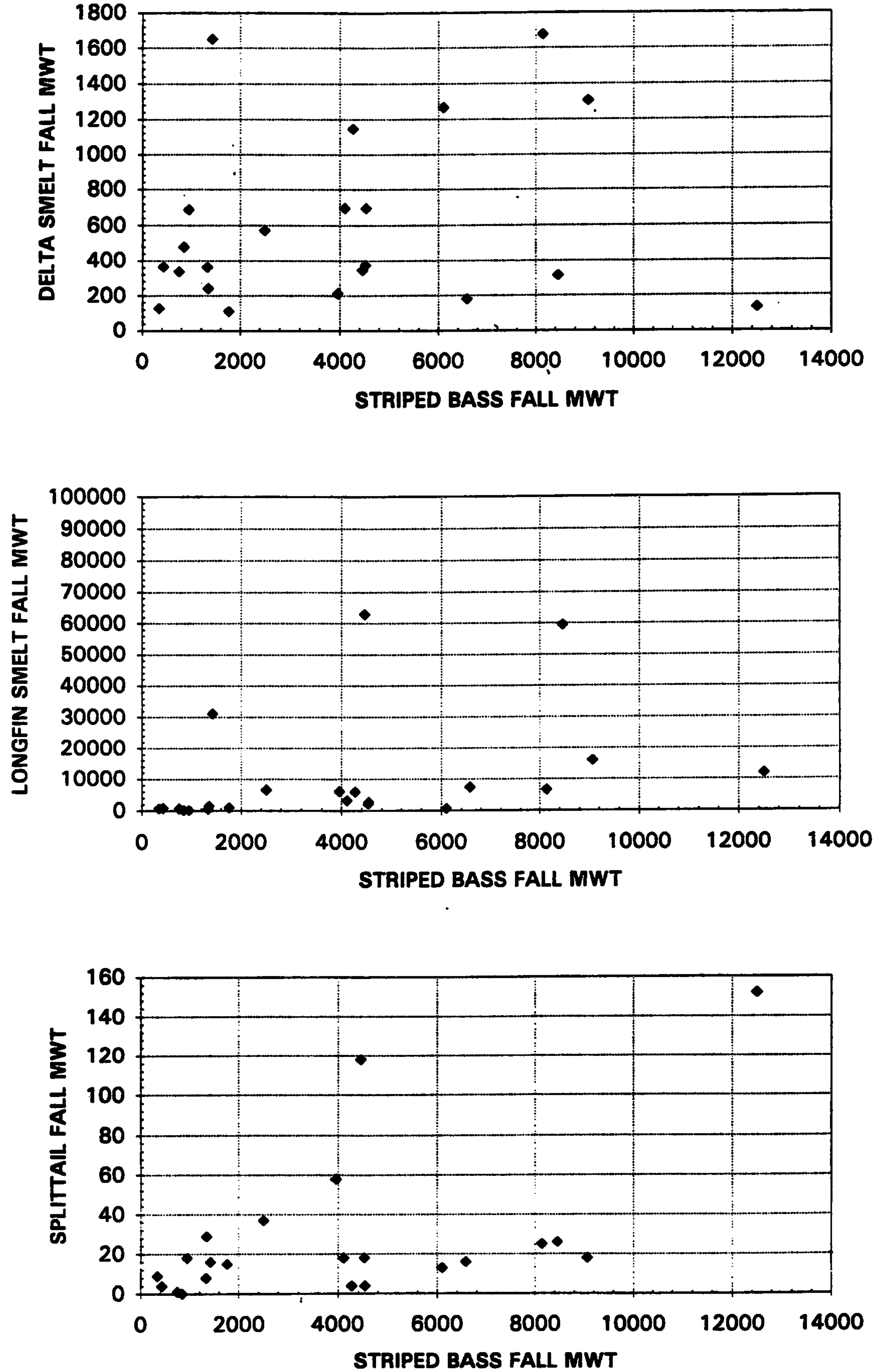
Combined effects

Obviously, the sampling and data analysis artifact biases probably have a profound effect on the abundance indices calculated from catch data. It is clear that the multipliers used to "correct" for sampling zone size were themselves *not* corrected for tidal stage (height) at the time of sampling. The density dependent competition factor is a difficult one to assess, given currently available information. If it is operating at all, it is probably not operating in all years. Naturally, this complicates interpretation. It is probable that the relative influence of density dependent competition, if it is operating, has increased in recent years due to the introduction of exotic species (especially herbivores), exacerbated by the drought. Finally, conceptual flaws and other errors in analysis of raw data by others in producing annual abundance indices relied upon by EPA are a profound source of bias which needs to be sorted out before intelligent use of these data can be made.

In spite of these serious difficulties, however, certain useful information relating to the relationship between the entrapment zone and the associated biological system are suggested by the data. Co-abundance data for other pairs of fresh water sensitive estuarine species support the lack of a broadly consistent relationship (across species in a given year) between abundance indices and average location of X-2. Plots for striped bass midwater trawl abundance indices and each of the three indigenous fishes discussed above (Figure 2) clearly show that there is no regular co-abundance relationship for this species and longfin smelt or splittail. Although longfin smelt or splittail abundance indices *may occasionally* be high in the same year that a striped bass abundance index is high (two years out of 22 data pairs for each species, but *different* years), there is clearly no pattern to these occurrences; co-abundance is the exception, not the rule. There is such a relationship (albeit with much scatter in the data) with delta smelt, however. This could mean either that populations of these two fish vary in accordance with the same or co-dependent environmental variables, or that sampling and/or data analysis artifacts are being expressed in similar ways. Until data are re-analyzed in light of biasing factors discussed above, it is impossible to discriminate between these possibilities. The different

FIGURE 2

SACRAMENTO / SAN JOAQUIN / BAY DELTA
ANNUAL ABUNDANCE INDICES



patterns exhibited by longfin smelt and splittail are most likely due to habitat partitioning with regard to salinity, combined with a significant multiplier artifact, but this cannot be firmly established until the data are re-analyzed.

When the analysis bridges two trophic levels, fish and one of their prominent food items, *Neomysis*, there is again a failure of any regular pattern of co-abundance to appear (Figure 3). This is not too surprising, however, since Neomysis sampling is conducted on a year round basis, and fall midwater trawl sampling is conducted only in September, October, November and December. Any co-abundance relationship which *might* occur could easily be masked by the incongruity of the data sets.

ABUNDANCE VERSUS PRODUCTIVITY ANALYSIS

A significantly different picture appears when abundance indices for each of these species is plotted against primary productivity plus riverine particulate organic carbon calculated from flow data (POC). *Neomysis*, the principal herbivore analyzed by Jassby and considered by EPA in support of its salinity standard, shows a definite increase in both the variability of its abundance index and the general value of the index when the primary productivity POC index reaches a value of 9-11. Both striped bass MWT and striped bass survival abundance indices show a sudden increase average abundance index value and increased variability in the index at about the same level of primary productivity and POC (Figure 4). The patterns of these plots are strongly suggestive of a threshold phenomenon; since young striped bass feed on *Neomysis*, this should not be too surprising. *Crangon*, longfin smelt and splittail plots (Figure 5) show a similar phenomenon, but with the apparent sudden break in the data shifted slightly to primary productivity and POC index values of about 11-13 (if the vertical axis were expanded for longfin smelt, or if the data were logged, the apparent threshold for this species would be more visually obvious). The *only* species which does not show an apparent data discontinuity for increased abundance, or increased variability in abundance, with increasing primary productivity and calculated riverine POC is delta smelt (Figure 6).

Taken together, these data suggest that a primary productivity and riverine POC index in the vicinity of 9-12 is associated with higher abundance indices of a wide variety of estuarine species. The question arises: "Does this apparent threshold in the primary productivity and POC index help in the interpretation of the optimum average location of the theoretical X-2?" The relationship between the primary productivity and POC index and average location of X-2 is one of the "tightest" correlations to come out of the Jassby analysis. However, since much of this index is dependent on a riverine particulate organic carbon value which is *calculated from river flow*, there is substantial auto-correlation when this value is used in association with location of X-2, *which is also calculated from river flow data*. Therefore, great care is called for in the interpretation of these data.

FIGURE 3

SACRAMENTO / SAN JOAQUIN / BAY DELTA
ANNUAL ABUNDANCE INDICES

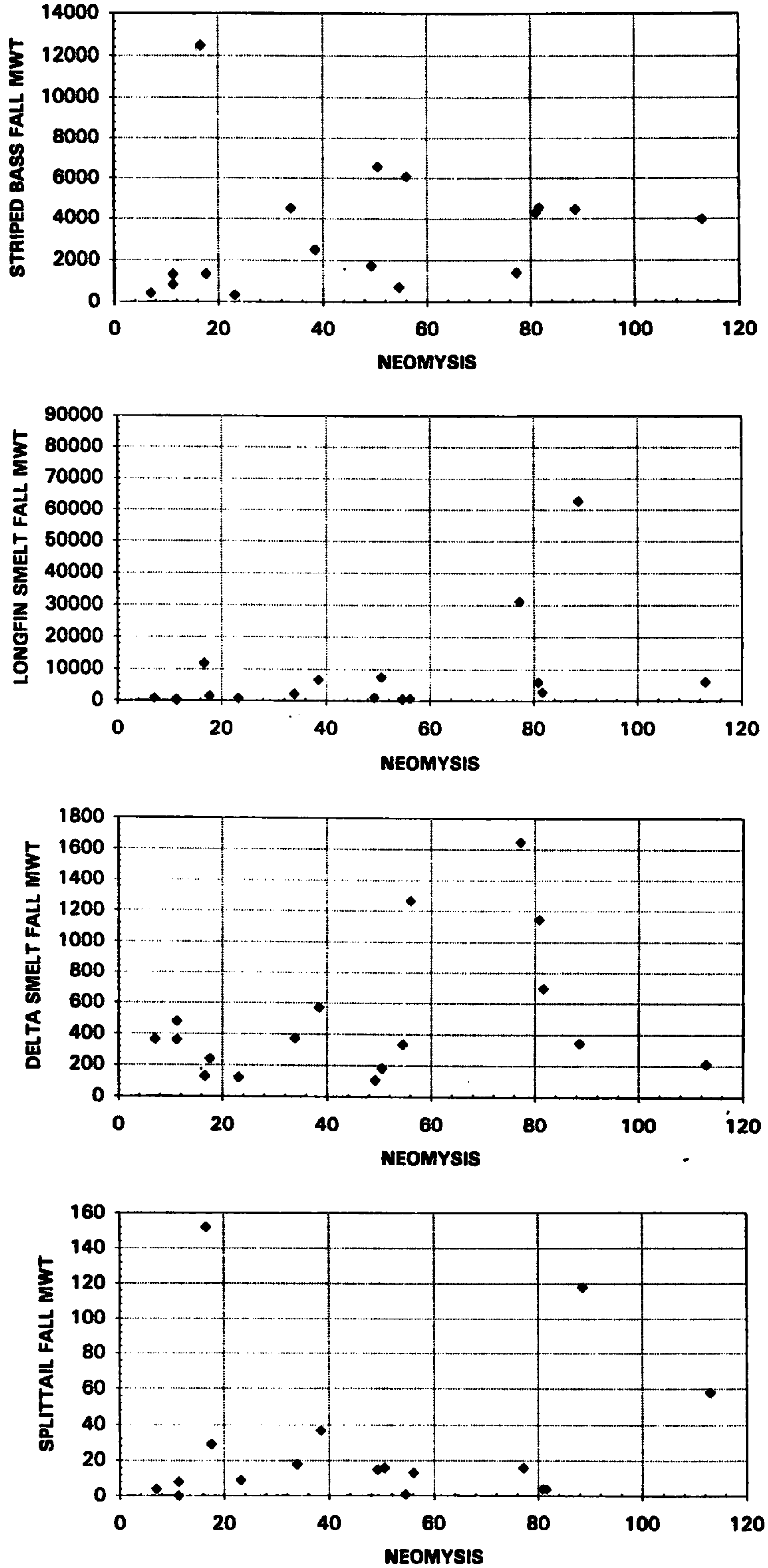


FIGURE 4

SACRAMENTO / SAN JOAQUIN / BAY DELTA
ANNUAL ABUNDANCE INDICES

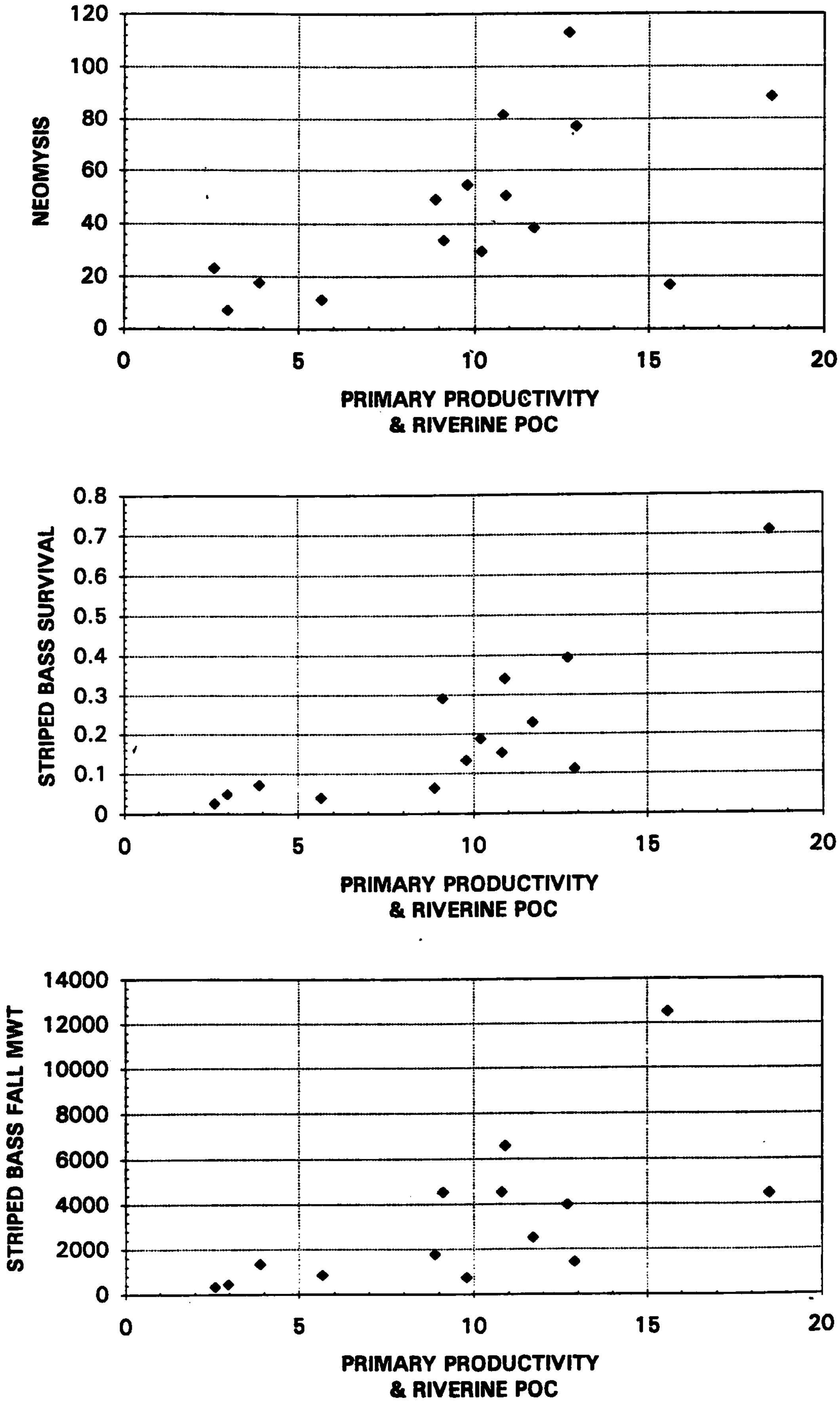


FIGURE 5

SACRAMENTO / SAN JOAQUIN / BAY DELTA ANNUAL ABUNDANCE INDICES

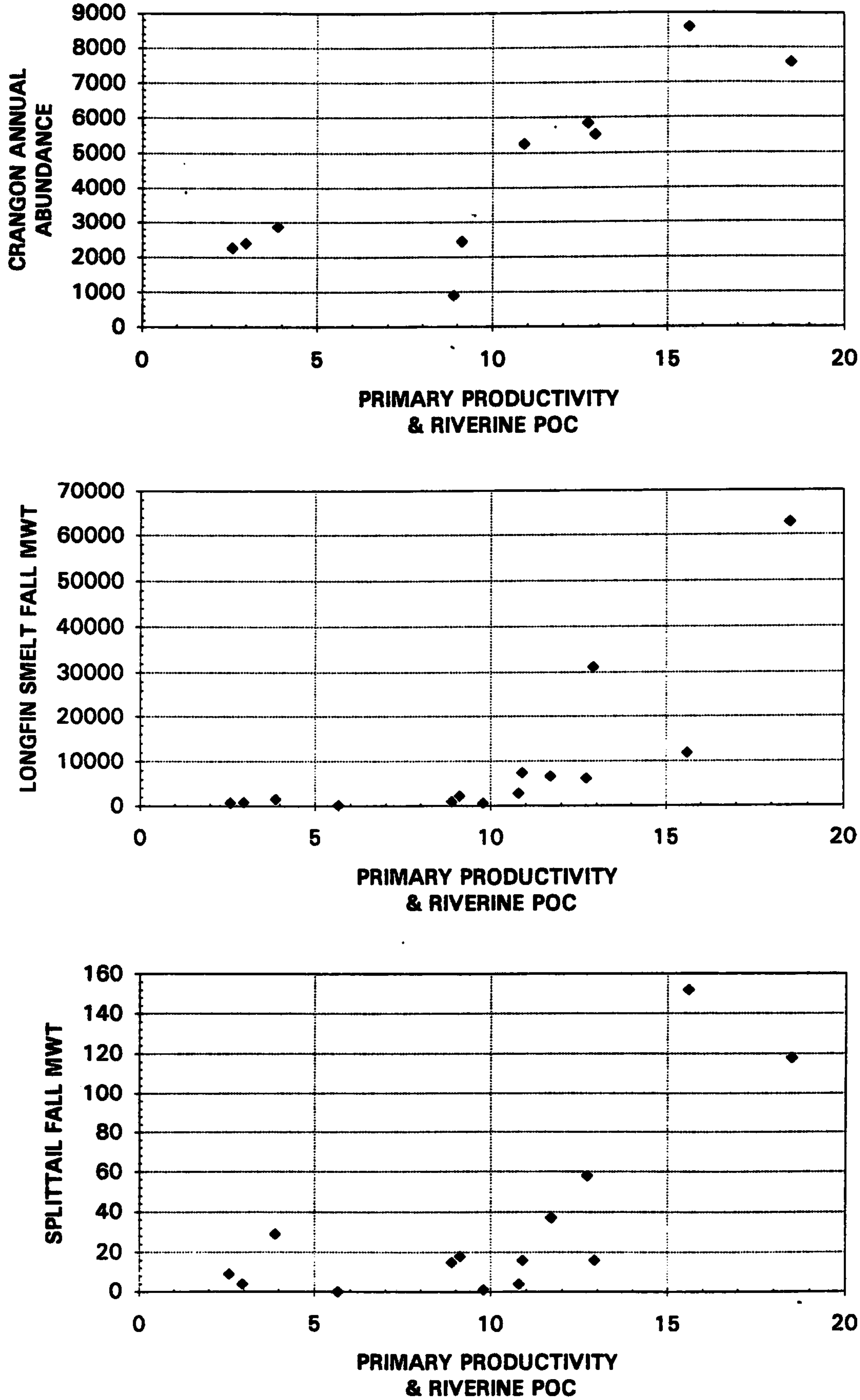
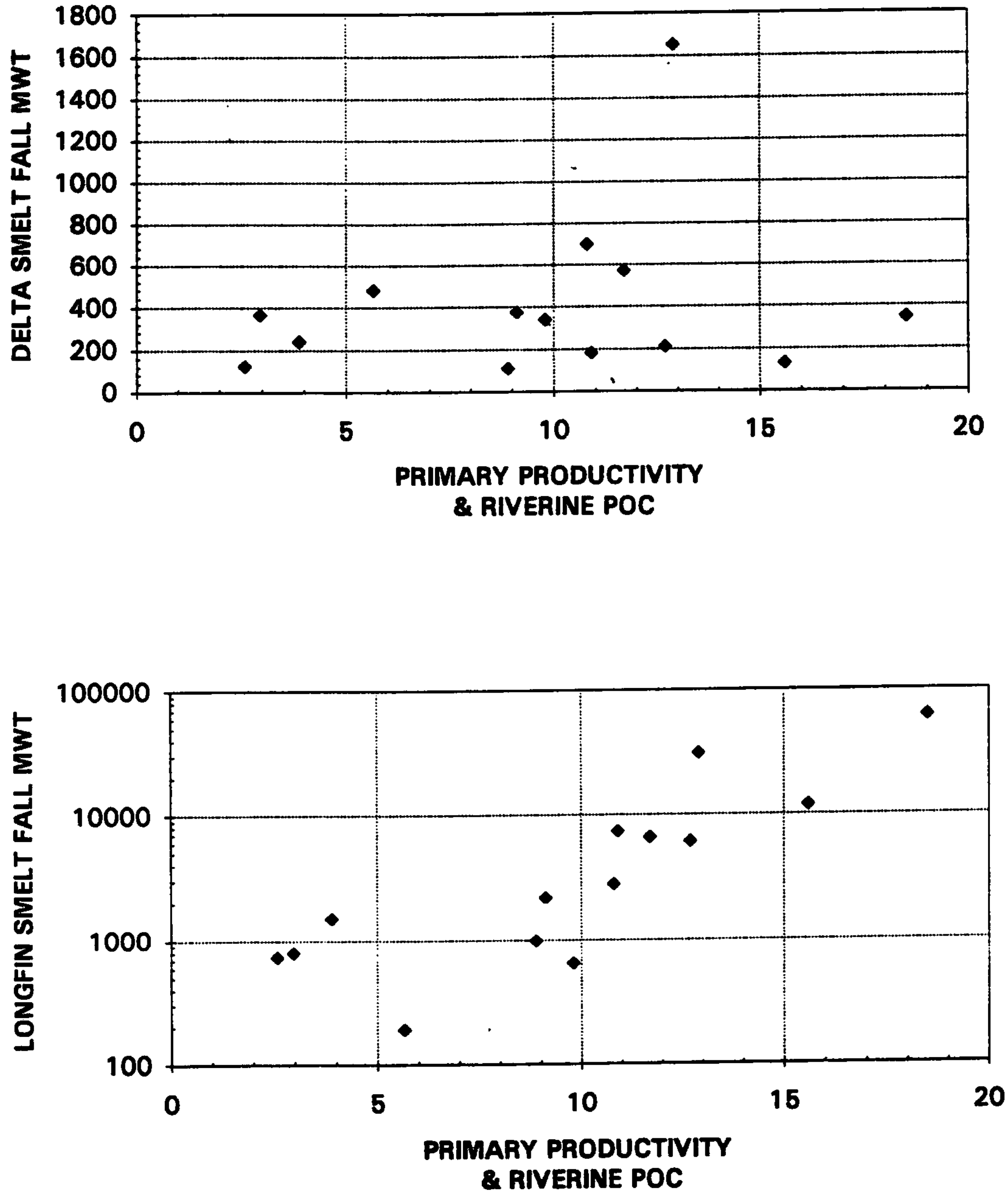


FIGURE 6

SACRAMENTO / SAN JOAQUIN / BAY DELTA
ANNUAL ABUNDANCE INDICES



If the apparent threshold relationships between the base of the food chain (primary productivity and riverine POC) and abundance indices for various estuarine organisms are real, which makes some biological good sense, then managing the location of average calculated X-2 for a primary productivity and riverine POC index in the vicinity of 9-12 goes some distance in managing the estuary for these organisms. The average location of X-2 which is consistently associated with a primary productivity and POC index in the desired range, which happens to be "comfortably within" a major cluster for these data, is 70-72 km. This location is just downstream of Chipps Island.

In spite of the tendency for auto-correlation, this is entirely consistent with the "remarkably congruent" evidence presented to the State Water Resources Control Board in the Bay-Delta Hearings on the functioning and benefits of the entrapment zone, especially as summarized by Fullerton (1991). This evidence, also appealed to by EPA in support of their proposed salinity standard, consistently focuses on primary productivity as the key to the benefits of the entrapment zone, with implications for many organisms at several higher trophic levels. As pointed out in the testimony, the entrapment zone is that large area *downstream of* the null zone (closely approximated by the imaginary 2 ppt isohaline or the calculated X-2) in which the antagonistic forces of gravity and turbulent upwelling tend to concentrate fine particulates and certain phytoplankton species. Testimony summarized by Fullerton recommended an average location of the surrogate calculated X-2 at Chipps Island. The Workshop, summarized by Schubel, also recommended an average location of X-2 at Chipps Island, placing the entrapment zone in the Suisun Bay, Grizzly Bay, Honker Bay complex.

VECTOR ANALYSIS

EPA's proposed salinity standard rests on an assumed cause-and-effect relation between salinity patterns in the Suisun Bay complex (including Honker Bay and Grizzly Bay) and populations of certain selected estuarine organisms. There is the clear implication in the "Assessment of Benefits" section of EPA's Proposed Rule that if only salinity conditions in this area were right, populations of these organisms would respond. But both Jassby and the Workshop, relied upon heavily by EPA in support of their Proposed Rule, backed away from asserting any cause-and-effect relationship, and no attempt was made to test the response of populations of organisms to sequential *changes* in the calculated average location of X-2, as opposed to the absolute value of this parameter. In spite of all their problems, the data sets used by Jassby (1992b) do permit this type of analysis, however.

To address this question, a qualitative, graphic vector-type analysis was performed for each of the estuarine species of primary interest. This analysis simply utilizes the scatter diagram displaying the uncorrected abundance index values of each species against the calculated average calculated location of X-2, the same diagrams used by Jassby in his simple linear model analysis, and connects the points with a line (vector) in annual sequence. This procedure tends to filter out much of the potentially confusing influence of other factors which might affect annual abundance indices. In each case, the slope of the vector indicates the direction of movement of the abundance index for the species of interest, increase or decrease, with a movement of average location of X-2 from one year to the next. According to this analysis, the greater the dependency of an abundance index on calculated average location of X-2, the more consistent will be the slopes of the vectors. If a further downstream average calculated location of X-2 is "beneficial" to an organism, as indicated by its annual abundance index, vector slopes should be consistently or predominately negative (higher abundance index associated with a lower kilometer value for average X-2 location). If a further downstream average location of X-2 is detrimental in terms of the annual abundance index, vector slopes should be generally positive. *Either* a near-horizontal *or* a near-vertical vector is indicative of a lack of response of the abundance index to a change (upstream or downstream) in average location of X-2. In these graphic analyses, a dashed line indicates a vector spanning a missing year.

The parameter most often cited as being closely linked to the location of the entrapment zone, for which the calculated average location of X-2 is an upstream surrogate, is primary productivity (Fullerton, 1991, and references cited therein; Schubel, 1993). This parameter, along with riverine particulate organic carbon (calculated from flow data), is part of the data set analyzed by Jassby and, as discussed above, has also been identified as being consistently related to abundance indices for fresh water sensitive estuarine organisms (except delta smelt). The vector diagram for primary productivity and POC versus average location of X-2 is shown in Figure 7. This diagram indicates that there is a rather consistent but weak (shallow vector slope) response in the index to sequential changes in the average location of X-2. Naturally, this is to be expected because of the significant contribution to the index of riverine particulate organic carbon, which is itself calculated from river flow. Although the sample size is limited, the index values for the more recent drought years of 1987, 1988 and 1989 show a *translation* of the relationship downward relative to earlier years with similar average X-2 location (1976, 1977), but the shallow slope of the vectors connecting these years is consistent with the rest of the data. This downward translation of the data is certainly *independent* of any auto-correlation influence and *may* reflect the introduction of the Asian clam. This clam is thought to have a profound influence on the abundance of phytoplankton in the water column, which makes up the remainder of the index.

Both crustaceans, *Crangon* and *Neomysis* show evidence of a consistent response of their abundance indices to average location of X-2, with the smaller data set for *Crangon* being more consistent than that for *Neomysis* (Figure 8). The sudden discontinuity, discussed above, remains evident in the data. There are several instances for *Neomysis* where the response of the abundance index to average location of X-2 is either extremely weak or non-existent, suggesting an overriding influence of other factors.

FIGURE 7

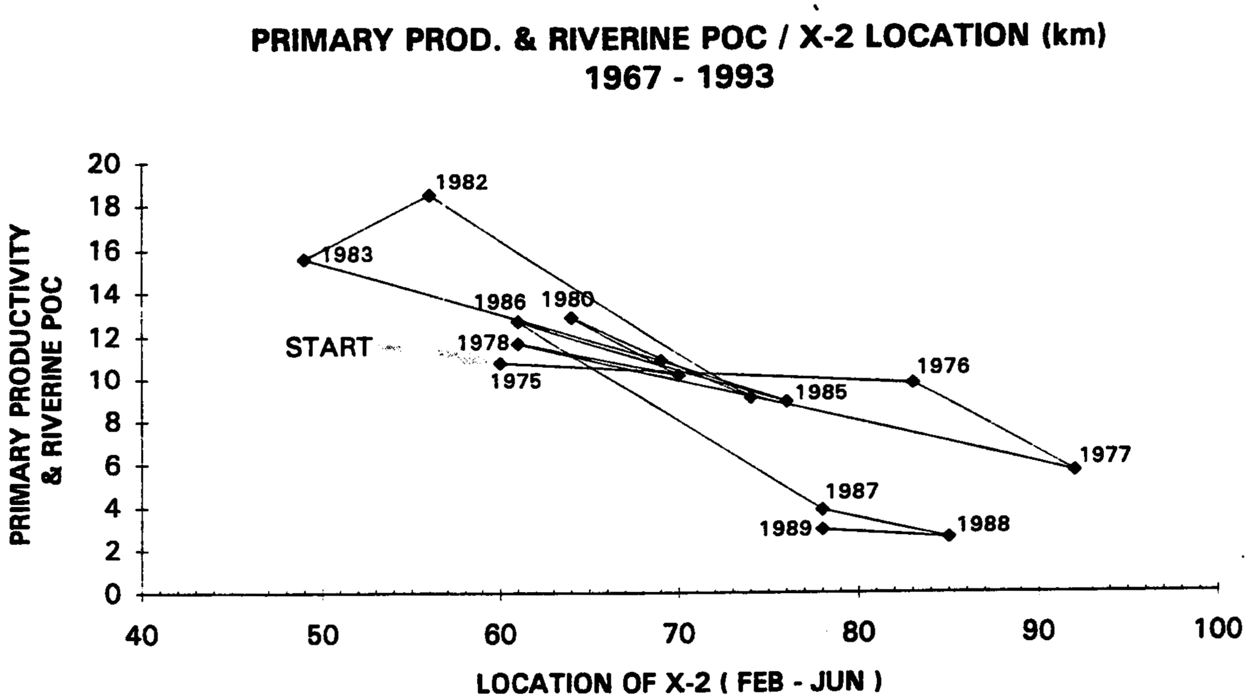
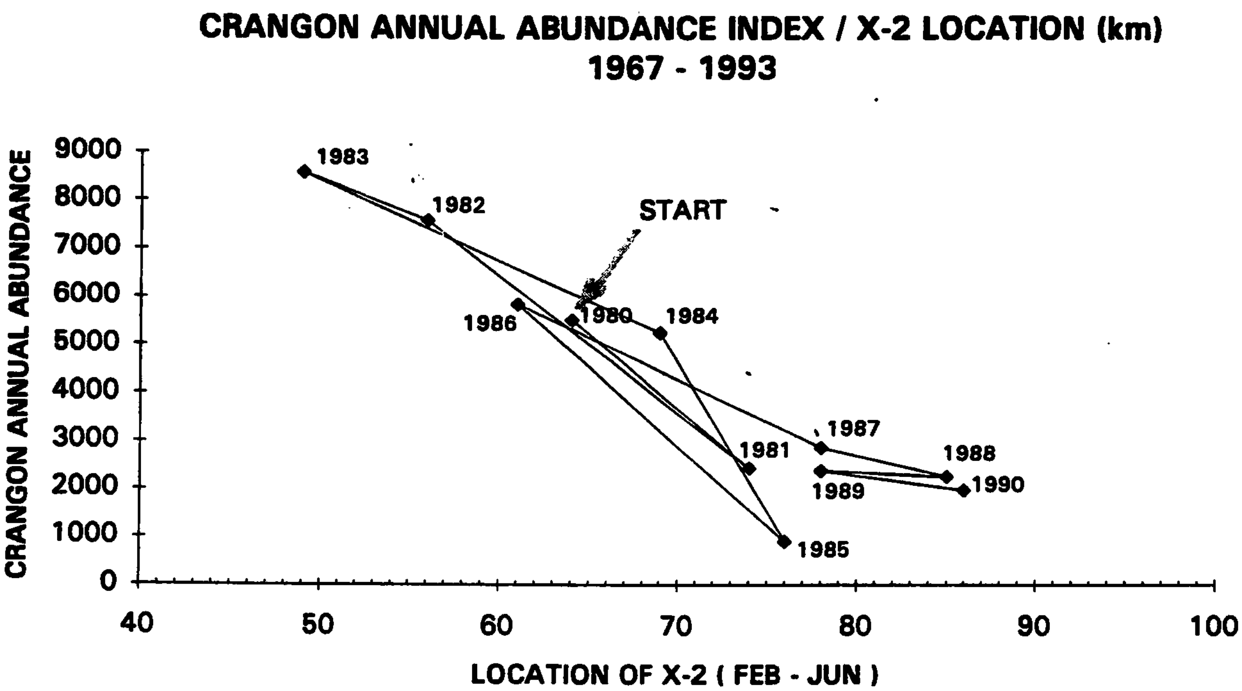
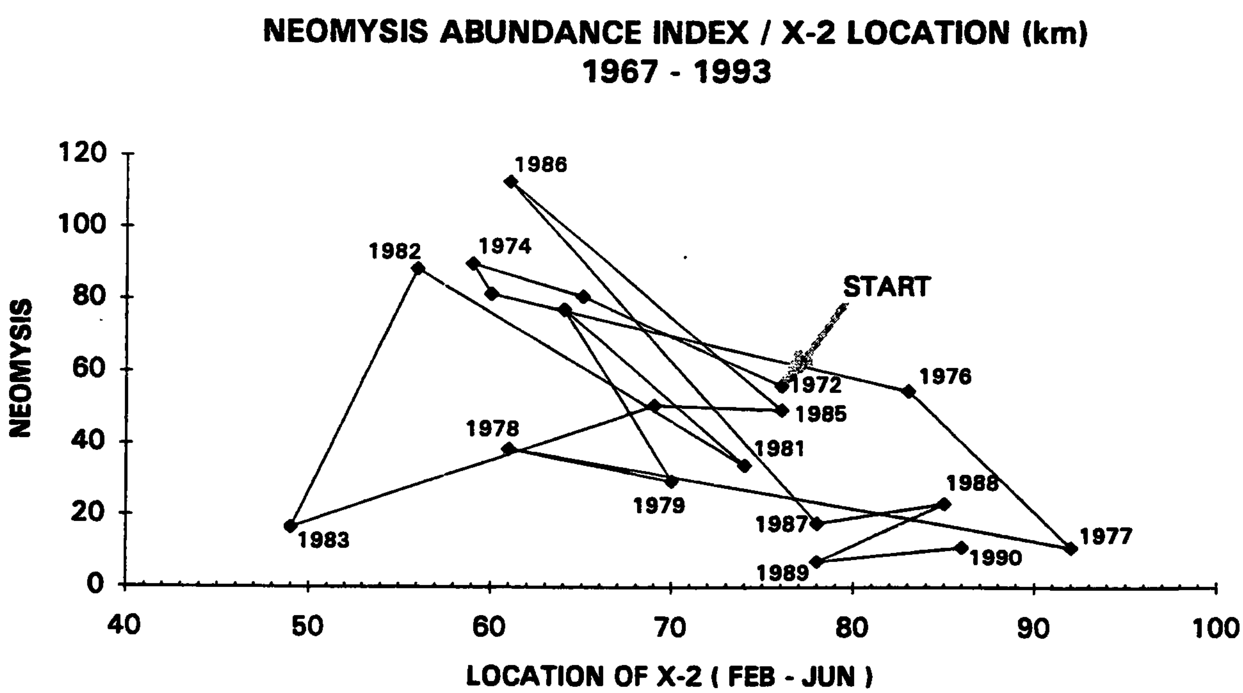

PRIMARY PROD. & RIVERINE POC / X-2 LOCATION (km)
1967 - 1993
PRIMARY PRODUCTIVITY & RIVERINE POC
LOCATION OF X-2 (FEB - JUN)
START
1982
1983
1986
1980
1978
1975
1976
1985
1977
1987
1989
1988
0
2
4
6
8
10
12
14
16
18
20
40
50
60
70
80
90
100

FIGURE 8



CRANGON ANNUAL ABUNDANCE INDEX / X-2 LOCATION (km)
1967 - 1993
CRANGON ANNUAL ABUNDANCE
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
40
50
60
70
80
90
100
LOCATION OF X-2 (FEB - JUN)
START
1983
1982
1986
1980
1984
1987
1988
1981
1989
1990
1985



NEOMYSIS ABUNDANCE INDEX / X-2 LOCATION (km)
1967 - 1993
NEOMYSIS
120
100
80
60
40
20
0
40
50
60
70
80
90
100
LOCATION OF X-2 (FEB - JUN)
START
1986
1982
1974
1972
1976
1985
1978
1981
1988
1979
1987
1977
1983
1990
1989

Both striped bass indices (midwater trawl and survival) show generally very weak responses or no response to changing average location of X-2, with an interesting vertical translation in the midwater trawl data (Figure 9). This is strong evidence that other factors are more important than average location of X-2 in governing the abundance indices for this species. Several inverse responses (positive vector slopes) are evident in the data.

Both longfin smelt and splittail vector diagrams show mixed responses (Figure 10). Longfin smelt data show occasional strong responses to shifts in average location of X-2, but with a single exception, *only* for average location of X-2 *downstream of the entire Suisun Bay complex*. This location would place the entrapment zone in Carquinez Strait, completely outside of Suisun Bay. This is outside the entrapment zone location argued for by EPA, the Workshop and primary source documents as being the most beneficial for the health of the estuary, specifically the shoals, marshes and tidal flats of Suisun Bay, Honker Bay and Grizzly Bay. The vast majority of data demonstrate no response of the abundance index for longfin smelt to average location of X-2 which would indicate location of the entrapment zone in the Suisun Bay complex.

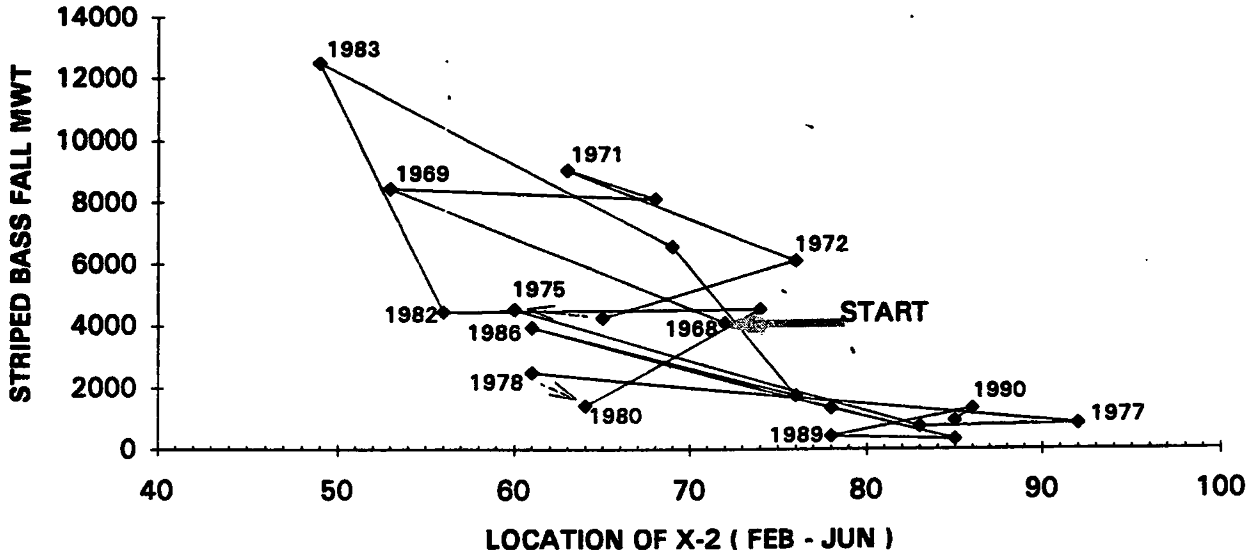
The vector diagram for splittail indicates a positive but usually very weak response of the abundance index for this species to a more downstream average location of X-2 in only a few years. Most vectors indicate no response. This is strongly indicative of either a nearly insignificant relationship or overriding influences of other factors (or both). Note that the conditions in 1983, an unusually high outflow year, produced opposite responses of the abundance index for longfin smelt and splittail. A similar phenomenon occurred in 1969.

The vector diagram for delta smelt is shown in Figure 11. This diagram clearly demonstrates a random relationship between the abundance index and the average location of X-2. In most cases, sequential movement of the average location of X-2 produced no response. For those cases when a change does occur, the response is *independent of the direction of the shift* in average location of X-2 (upstream or downstream). Of all the fish species being scrutinized, this is the species for which one would expect the closest relationship *if* location of X-2 is relevant, since it has a short (1-year) life cycle, which would normally require a rapid population response to a favorable set of circumstances.

In the aggregate, this analysis demonstrates that there is a pattern of response to annual changes in average location of X-2 for primary productivity plus POC (much of which is due to auto-correlation) and several fresh water sensitive species of estuarine organisms, but that this pattern is inconsistent or absent for others. The importance of primary productivity is reflected in testimony at the Bay/Delta Hearings and the conclusions of Williams (1987) and Ball (1987). The only other *consistent* pattern is that for *Crangon*. Several species show vertical translations in their response vector patterns, or only occasional positive responses, suggesting other overriding factors at work. Splittail and longfin smelt data indicate positive responses of

FIGURE 9

STRIPED BASS MWT ABUNDANCE INDEX / X-2 LOCATION (km) 1967 - 1993



STRIPED BASS SURVIVAL INDEX / X-2 LOCATION (km) 1967 - 1993

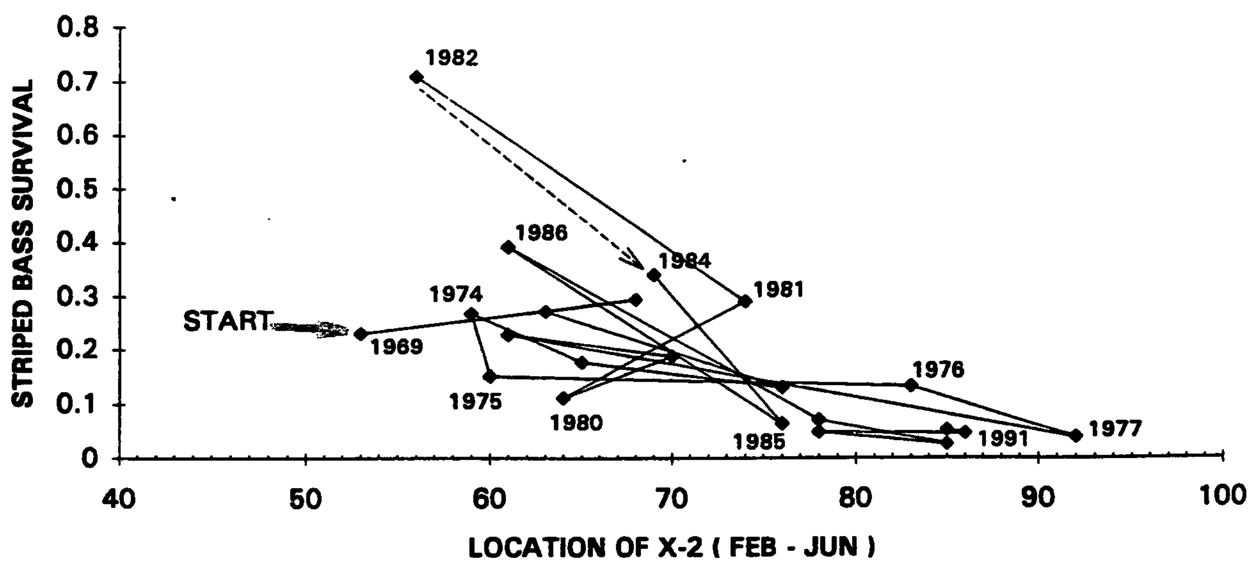
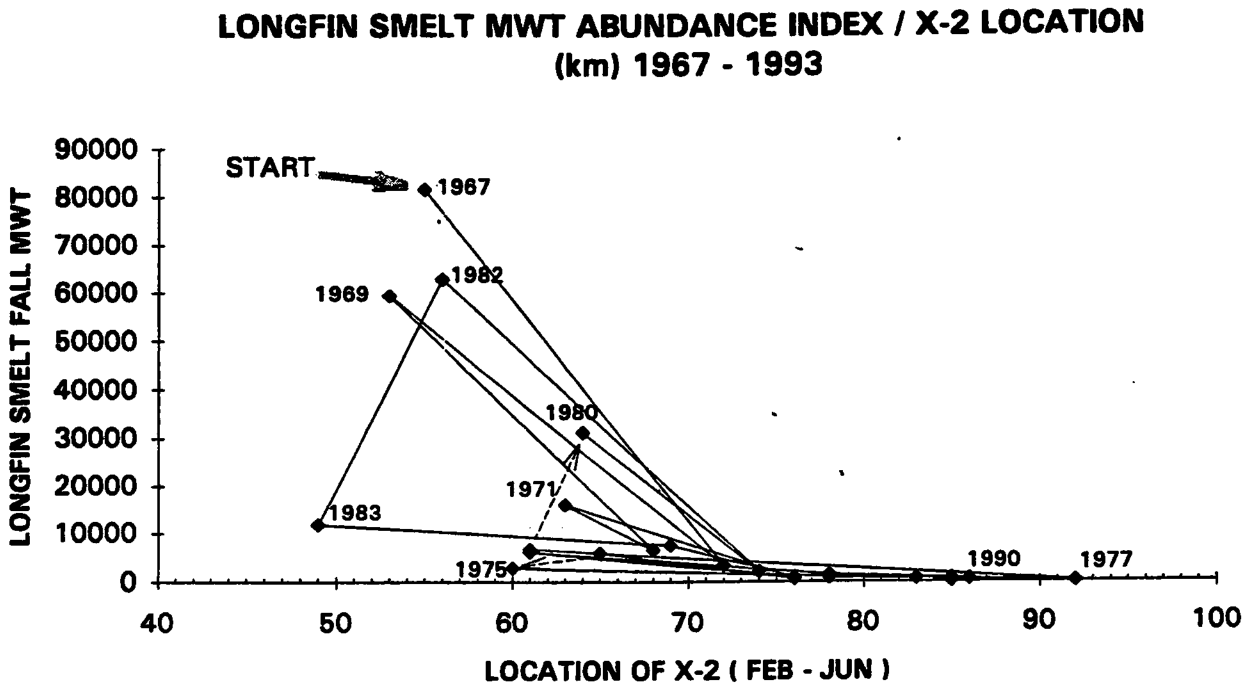


FIGURE 10


LONGFIN SMELT MWT ABUNDANCE INDEX / X-2 LOCATION (km) 1967 - 1993
START
1967
1982
1969
1980
1971
1983
1975
1990
1977
LONGFIN SMELT FALL MWT
LOCATION OF X-2 (FEB - JUN)
0
10000
20000
30000
40000
50000
60000
70000
80000
90000
40
50
60
70
80
90
100

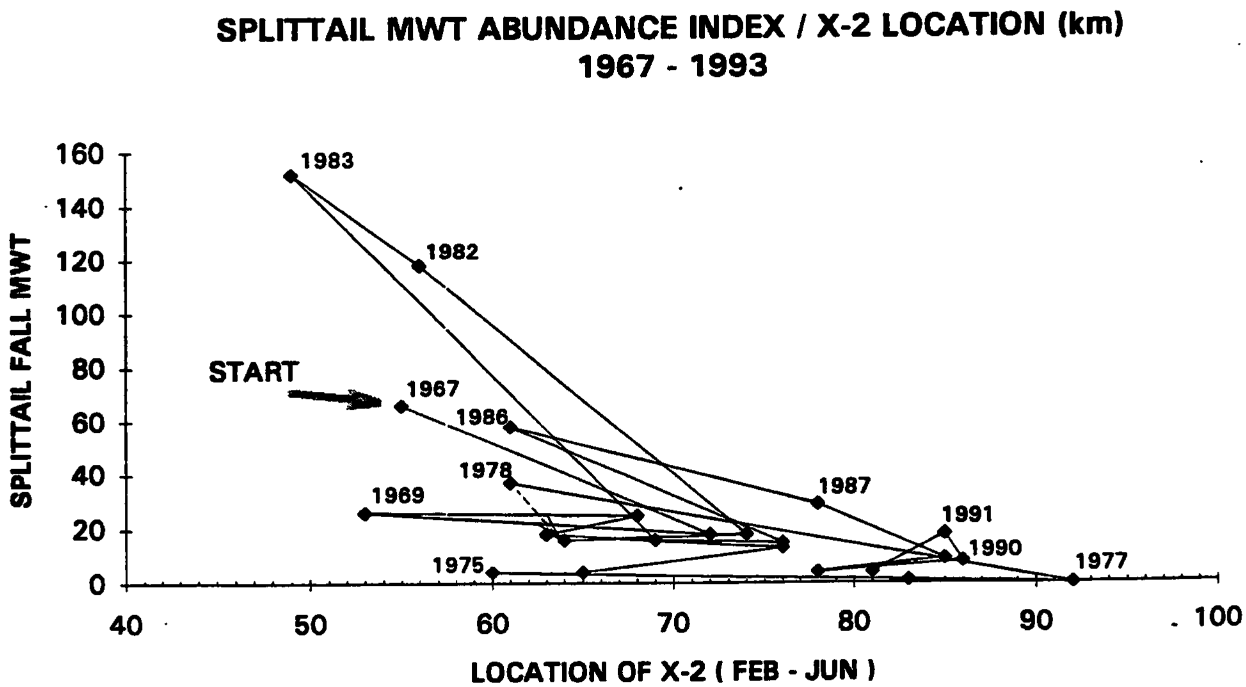
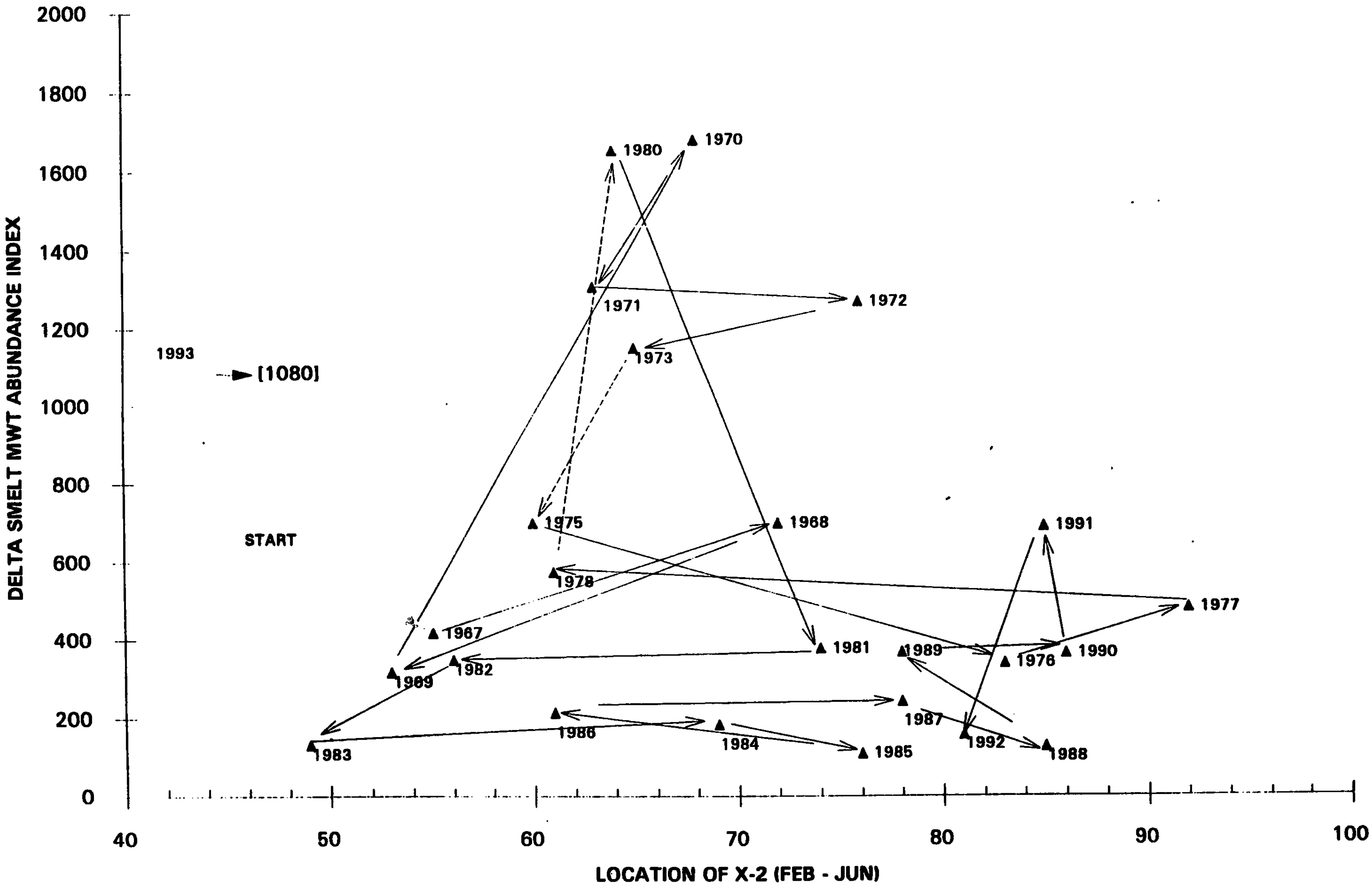

SPLITTAIL MWT ABUNDANCE INDEX / X-2 LOCATION (km) 1967 - 1993
1983
1982
START
1967
1986
1978
1969
1987
1991
1990
1975
1977
SPLITTAIL FALL MWT
LOCATION OF X-2 (FEB - JUN)
0
20
40
60
80
100
120
140
160
40
50
60
70
80
90
100

FIGURE 11

DELTA SMELT MWT ABUNDANCE INDEX / X-2 LOCATION (km)
1967 - 1993



abundance indices to a downstream movement of average X-2 location primarily when the entrapment zone is pushed *beyond* Suisun Bay into Carquinez Strait; these species show no response to changes in average X-2 location when the entrapment zone is located in the most broadly acknowledged beneficial location. Delta smelt data strongly demonstrate no relationship whatever.

AVERAGE LOCATION OF X-2 AND GEOMORPHOLOGY OF SUISUN BAY

The geomorphology of the area surrounding the apparent average X-2 threshold location for potential increases in abundance indices for fresh water sensitive estuarine organisms gives important insights into why this relationship might be valid. Downstream of Chipps Island, about 74 km from Golden Gate, there is a relatively abrupt widening of the estuary into Honker Bay and its associated shoals and tidal flats. Further widening occurs near the upstream end of Ryer Island at Suisun Cutoff, eventually taking in Suisun Bay, Grizzly Bay, and the extensive shoals, marshes and tidal flats surrounding Suisun Slough and Montezuma Slough. This entire area is often referred to as "Suisun Bay" in background and primary source documents. This convention has not been followed here, since it tends to confuse the issue of location of the entrapment zone and interfere with an orderly consideration of the data.

As is pointed out in the Workshop and various supporting documents, and in EPA's Proposed Rule, the important entrapment zone, *not to be confused or used interchangeably with the theoretical surrogate X-2*, extends downstream from the approximate X-2 location for a distance of at least several km. An average location of X-2 near Chipps Island (about 72 km from Golden Gate) means that the entrapment zone distribution will extend over most or all of Honker Bay, Grizzly Bay, Suisun Bay, and, at high tide, the associated tidal flats and marshes and their distributaries (small intertidal sloughs and drainage channels). This is precisely the entrapment zone situation argued for in the Proposed Rule and in primary source documents. This is *not* the entrapment zone situation which would result from implementation of the Proposed Rule, however.

When the entrapment zone is situated throughout the Suisun Bay complex, and as tidal surges and currents promote mixing and distribution of nutrients and organisms over this broad area, it is easy to see how biological processes and productivity might be enhanced. However, if the entrapment zone were located upstream of this wide area, or at or below its downstream end, as would be the case with implementation of EPA's Proposed Rule with X-2 at Roe Island, it is equally easy to see how the beneficial influence of the entrapment zone would be limited to a significantly smaller area. Thus, the calculated average X-2 location threshold near Chipps Island apparent in the abundance data for most of the species appealed to by EPA in support of their Proposed Rule corresponds rather precisely with those geomorphic features that allow the benefits of the entrapment zone to be optimally expressed.

In his synopsis of Bay/Delta Hearings evidence, Fullerton (1991) points out that "the entrapment zone cannot be exactly correlated with either outflow levels or salinity. But [*sic.*] will vary with tides, wind and the recent flow patterns [antecedent conditions]." The entrapment zone location can be *calibrated* with respect to outflow and/or the location of X-2 (which is calculated from outflow), however, and reasonably reliable projections of the area of entrapment thus developed. In seeking to maximize the coverage by the entrapment zone of the shoal, marsh and tidal flat complex associated with Honker, Grizzly and Suisun Bays, Williams (1987) proposed placing X-2 at Chipps Island. At this [daily average] location, the entrapment zone length was determined by Williams to be about 10 miles long, spanning the entire complex. Placing X-2 further downstream would reduce the coverage by the entrapment zone of potentially more productive shallow and intertidal areas.

The great majority of the biological and physical evidence indicates that Williams, Ball, the Workshop and others were correct in their understanding that presence of the entrapment zone throughout the Suisun Bay complex (Honker Bay, Grizzly Bay, Suisun Bay and associated tidal flats and marshes) being moved about and acted upon by tidal and other forces over the lunar cycle, will provide the greatest opportunity for the widest variety of fresh water sensitive estuarine resources to flourish. This situation would result from an average calculated location of X-2 at or near Chipps Island, also being allowed to move back and forth in response to tidal forces over the lunar cycle.