Interagency Ecological Program for the Sacramento-San Joaquin Estuary

An Assessment of the Likely Mechanisms Underlying the "Fish-X2" Relationships DRAFT

by:

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The 1994 Bay-Delta agreement established standards for salinity in the estuary. Specifically, the standards determine the degree to which salinity is allowed to penetrate up-estuary, with salinity to be controlled through delta outflow. The basis for the standards is a series of relationships between the salinity pattern and the abundance or survival of various species of fish and invertebrates. These relationships have been expressed in terms of X2, the distance from the Golden Gate to the point where daily average salinity is 2 parts per thousand at 1 meter off the bottom (see Jassby et al. 1995). Generally, the higher the outflow, the lower the value of X2, and the higher the abundance or survival of the species of interest.

The so-called "fish-X2" relationships were used to support the agreement because they offer convincing evidence of environmental influence on a wide variety of species, and thereby a means of increasing abundance or survival through operation of the water projects. However, the salinity standard is a rather crude management tool. More precise influence on these species in terms of quantity or timing of outflow would be desirable for efficient management. In addition, the potential influence of alternative or complementary management actions is difficult to determine from these relationships.

To improve our ability to manage for these species requires that we understand the causes of the fish-X2 relationships. It is unlikely that all of them have the same cause or that they are all causally linked. The purpose of this report is to describe the probable causes of each of the fish-X2 relationships. A later analysis will establish priorities for investigations into these mechanisms.

This report presents the collective opinion of the Interagency Ecological Program Estuarine Ecology Team (EET). It is not intended as an explanation for declines in the species discussed, nor an evaluation of the strength of the fish-X2 relationships as compared to other potential effects. The sole intent is to elucidate the most likely reasons why the abundance of these species are observed to vary with X2 or outflow.

The Effects Matrix

The EET prepared a matrix of affected species against potential mechanisms (Figure 1). Variables (species abundance indices except where noted) known to have a relationship with X2 or any of its correlates include:

- Crangon franciscorum (bay shrimp)
- Pacific herring
- Starry flounder
- White sturgeon
- American shad
- Striped bass (abundance index or survival index)
- Longfin smelt
- Delta smelt
- Sacramento Splittail
- Fall-run chinook salmon (including survival through the delta)
- Neomysis mercedis

Particulate organic carbon (POC) supply rate is also related to X2 and outflow, but it is not included in the variables examined here. The POC supply rate consists of the riverine source and in situ production. The riverine source is the river flow times the concentration of POC, so this source is inherently correlated with outflow. Local production in Suisun Bay may no longer be strongly influenced by outflow or X2 because of intense grazing pressure by the clam *Potamocorbula amurensis.*

Potential effects on the above variables that could result in a correlation with X2 of the correct sign (i.e. increasing abundance with downstream X2) are explained in the following section. The effects listed in the matrix include:

- Spawning habitat (area, volume)
- Spawning habitat access
- Habitat space: (area, volume and substrate)
- Predation avoidance through turbidity
- Predation avoidance through shallow access
- Reduced probability of encounter with predator
- Reduced entrainment (CVP-SWP)
- Reduced entrainment (PG&E)
- Reduced entrainment (agricultural)
- Toxic dilution
- Transport
- Gravitational circulation strength
- Entrapment zone residence time
- Adult habitat or habitat diversity

- Temperature (as affected by flow)
- Strong migratory cues
- Higher food production
- Ocean conditions
- Sampling bias

X2 is correlated with many different variables, including flow in upstream reaches of many of the rivers. For anadromous species this presents a problem, in that mechanisms operating entirely in the upstream areas can result in a correlation with X2. We address this problem by indicating which effects occur predominantly upstream of the delta, to make it clear that relationships are really with flow and not with X2 per se, or any other correlate of X2.

The matrix provided a working format for a series of discussions among the EET members of the various X2 effects on each species. The importance of each X2 effect on each species and the amount of information available was discussed and recorded by the team members on a working matrix, using one of four symbols to score the results:

○ Effect believed important and relatively well-understood
● Effect believed important but poorly understood
∘ Effect believed to be less important, well-understood
• Effect believed to be less important, poorly understood

Following discussions of X2-species effects matrix, the EET members organized themselves into smaller working groups to produce narratives of the EET's reasoning behind the particular "importance and information" scores that the members gave to each species. The results of these group efforts were reported back to the main group for review and refinement. Several interim versions of the X2 effects reports were discussed by the EET members and distributed to other experts for comment and input before the reports were finalized and combined into this document.

The final versions of the X2-fish effects are presented below. Each X2 effect in the individual species reports is numbered to correspond to its position on the X2-fish effects matrix (Figure 1). For example, DS-1 refers to the effect of variation with X2 of spawning habitat area or volume on the abundance index of delta smelt.

The Matrix as a Planning Tool

The EET members used and will continue to use the results of their effects-scoring efforts as guidance in planning and recommending future research. The team members found that the matrix organization of the effects scores provided a valuable overview format for evaluating the areas and relative needs for research. The EET members reviewed the X2 effects by species and gave each of the species' important effects priority scores of 1 to 3, with 1 indicating the highest priority for further investigation. The results of the team's efforts to prioritize the research need are included in the matrix (Figure 1).

The Matrix as a Model

The fish-X2 matrix is a conceptual model that implies at least a two-dimensional relationship of species' ecology to X2 effects. In a modeling sense, the matrix predicts particular changes by categories of X2 effects among each of the species included in the matrix. The two dimensional matrix does not "model" the potential for indirect X2 effects. The strength of the matrix as a model is the systematic organization of information and opinion on the interrelated nature of X2 effects on the estuary's species. The weakness in the matrix model is its absence of quantitative organization and information on explicit relationships of species' ecology to X2 effects.

This report and matrix are intended to be works in progress, not finished reports. The report could be enhanced by expanding the species' reports to include the results of (future) species-specific research on X2 effects. Investigators would be encouraged to update the matrix with new findings or hypotheses, expressed in either a narrative or graphic form.

Discussion and Conclusions

The objective of this analysis was to determine what mechanisms were most likely to be responsible for the observed, generally monotonic, relationships of fish abundance or survival to X2. The mechanisms were examined only for their importance in this regard, not for their potential importance in causing declines over time except through flow.

Of the postulated mechanisms, a small number were given high rankings in terms of importance to populations of most species (Figure 2). Mechanisms associated with habitat were considered most important overall, while production or availability of food and entrapment zone residence time were considered important for many species. Toxic dilution, transport, and temperature effects were considered less important, and sampling bias was not considered an important mechanism for producing the observed relationships.

Future efforts to determine the operative mechanisms for each species should use these results as a starting point. Investigations into the availability, characteristics, and use of habitat would appear to have the most potential for revealing underlying causes of the relationships. These investigations may be made efficient by applying them to more than one species at a time. For example, investigations into the physical dimensions and characteristics of shallow habitat of various salinity ranges would help elucidate the importance of mechanisms 1-4 and 6.

Definitions for X2-Fish Effects Matrix

Effects of X2 are defined by how birth rates of fish species could increase or death rates decrease as X2 moves downstream. Effects of opposite sign, or of varying sign, are not considered since they would not produce the observed, largely monotonic, increases in population size or survival with downstream movement of X2. As discussed below, these effects could occur through X2 directly or through any of its correlates such as delta inflow or outflow. Effects occurring entirely upstream are designated as such in the discussions to follow; although it is illogical to include these as "X2" effects, correlations with X2 through flow are included. Each of these definitions is stated in the form of a hypothesis, although few if any would be directly testable as stated.

1. **Spawning habitat:** X2 or its correlates (especially area of flooded vegetation) affect the quantity of habitat used by the species for egg deposition, fertilization, incubation, and hatching (or juvenile birth in the case of ovoviviparous species).
2. **Spawning habitat access:** The correlates of X2, particularly river flow, affect the conditions or routes required by the species to reach suitable spawning areas.
3. **Habitat:** Co-occurrence of Food: X2 influences the co-occurrence in time and space of the fish species' various life stages with their food supply.
4. **Habitat Space:** X2 is correlated with the area and volume of habitat having characteristics that provide for optimal growth and reproduction of the species.
5. **Predation Avoidance through Turbidity:** turbidity in and near the entrapment zone increases as X2 moves downstream, possibly providing additional refuge from visual predation
6. **Predation Avoidance through Shallow Access:** X2 affects the quantity or availability of shallow water habitat that provides a refuge from predation. This differs from 4 above in being more specific.
7. **Reduced Probability of Encounter with Predator:** Prey and predator species have different responses to X2, such that increasing X2 reduces the probability of encounter between them. The previous effect is more specific as to location.
8. **Reduced Entrainment (CVP and SWP):** A downstream position of X2 reduces entrapment, entrainment, or impingement of the fish species' eggs, larvae, juveniles, or adults at state and federal projects.
9. **Reduced Entrainment (PG&E):** A downstream position of X2 reduces losses of the fish species' eggs and larvae due to water temperatures and mechanical damage during transit of the Contra Costa and Pittsburg cooling water systems.
10. **Reduced Entrainment (Agricultural):** A downstream position of X2 reduces of entrapment, entrainment, or impingement of the fish species' eggs, larvae, juveniles, or adults at agricultural diversions in the delta.
11. **Toxic Dilution:** A downstream value of X2 is correlated with high river flow and delta outflow, which dilutes the toxicity of the estuary's waters.
12. **Transport:** Transport here refers to direct or indirect movement of a life stage as influenced by flow or salinity. X2 affects transport through its effect on migratory cues (direction and position) or hydrologic residence times.
13. **Gravitational Circulation:** As X2 moves downstream the longitudinal density gradient averaged over the estuary steepens, providing a larger force for gravitational circulation; however, the strength of gravitational circulation is also greatly influenced by bathymetry and may be constrained locally. This effect could occur anywhere that stratification occurs.
14. **Entrapment Zone Residence Time:** The residence time of species that concentrate for all or part of their lives in the entrapment zone increases as X2 moves downstream.

15. **Adult Habitat:** X2 or its correlates affects the quantity or characteristics of habitat for adult fish.
16. **Temperature (As affected by flow):** X2 is inversely correlated with delta inflow, which in turn has some effect on temperature in the rivers and the delta.
17. **Strong Migratory Cues:** X2 is correlated with the cues used during migration.
18. **Higher Production of food:** X2 is correlated with the rate of input of particulate organic carbon and the population size of several species in lower trophic levels. Increases at lower trophic levels are reflected in the production or survival of fish, particularly in early life stages.
19. **Ocean Conditions:** ENSO (El Nino/Southern Oscillation) refers to a Pacific Ocean condition that along the California's coast is characterized by warmer surface water temperatures, weak spring/summer upwelling and longer fall periods of northward flowing currents. This condition is also correlated with changes in precipitation, which ultimately influences X2; thus, X2 is related to abundance or survival through its correlation with ocean conditions.
20. **Sampling bias:** The effect of X2 on habitat, flow conditions, or fish distributions alters the performance of various sampling gears and methods or the bias in estimates of the fish species' density or distribution. Note that to be included in this category, the mechanism must bias fish abundance high when flow is high.

Summary of Effects

This section presents a description of the individual effects depicted in Figure 1. Each effect is discussed in terms of a mechanism, and the affected life stages and locations of effects are listed. The symbol used to depict each effect in the matrix is also listed in the margins. Effects are discussed by species, i.e. in column order in Figure 1.

Bay shrimp *(Crangon franciscorum; CF)*

Bay shrimp have a strong negative relationship with X2, although points in the last few years are lower than expected from the regression model.

○ **CF-4. Habitat space**
Mechanism: Area of brackish shallow water nursery habitat increases as X2 decreases.
Life Stage: juveniles
Location: San Pablo Bay to west delta

• **CF-6. Predator avoidance in shallow areas**
Mechanism: Predation may decrease as X2 decreases and the amount of brackish shallow water habitat increases.
Life Stage: juveniles
Location: San Pablo Bay to west delta

• **CF-7. Reduced probability of encounter with predator**
Mechanism: As X2 decreases, juveniles are distributed over a larger area (nursery area is larger) and predation may decrease.
Life Stage: juveniles

Location: San Pablo Bay to lower rivers

- **CF-9. Reduced entrainment (PG&E)**

Mechanism: As X2 increases, the nursery area moves from San Pablo and Suisun bays to the lower Sacramento and San Joaquin rivers, possibly increasing entrainment by the PG&E plants.
Life Stage: juveniles
Location: upper Suisun Bay and west delta

- **CF-11. Toxic dilution**

Mechanism: Although no dose-response information is available for this species, studies on related species suggest that concentrations of pesticides or other contaminants measured in the northern Estuary are below concentrations that could cause acute problems, but sublethal effects or exposure to lower concentrations are not known. The Central Valley Regional Board has determined that episodic pulses of pesticides can cause death in Ceriodaphnia, and could therefore also affect Crangon.
Life Stage: juveniles and adults
Location: estuary-wide

- **CF-12. Transport**

Mechanism: Downstream transport from hatching area increases with outflow; degree to which larvae rear outside of the Bay may be positively correlated with year class strength
Life Stage: early stage larvae
Location: San Pablo Bay to ocean

- **CF-13. Gravitational circulation strength**

Mechanism: Transport to the nursery area is probably aided by gravitational circulation.
Life Stage: late stage larvae, post-larvae
Location: Central Bay to west delta

- **CF-17. Strong migratory cues**

Mechanism: Increased outflow may aid in the location of entrance of the Bay and the nursery area (decreased salinity or other property of estuarine water may be "sensed" by immigrants).
Life Stage: late stage larvae, post-larvae
Location: Central Bay

- **CF-18. Higher production of food**

Mechanism: During low flow, one food item, Neomysis, is reduced to a density that may limit C. franciscorum.
Life Stage: juveniles
Location: San Pablo Bay to west delta

Pacific Herring (PH)

Pacific herring spawn in south and central San Francisco Bay in the winter, depositing their eggs on eelgrass, rocks, pilings, and almost any other firm substrate. Older larvae and juveniles are broadly distributed in the estuary, and San Pablo Bay is an important nursery area. With the exception of years with very strong outflow (i.e. 1983 and 1995), abundance of young-of-the-year (YOY) Pacific herring is strongly correlated with outflow. Ocean conditions, especially temperature, have been correlated with the condition of returning broodstock and the production of eggs. Thus, broodstock and winter-spring outflow better predict the abundance of YOY Pacific herring than just outflow.

- ○ **PH-1. Spawning Habitat (Area, volume)**

Mechanism: The amount of spawning habitat may increase with increased delta outflow, as Pacific herring often spawn when salinities are decreasing. In the laboratory, maximum fertilization and hatching success occurs at approximately 16 ppt. Local inputs of freshwater (i.e. creeks, storm drains) would also decrease salinities and stimulate spawning. Note that spawning peaks from December through February, prior to the X2 window, but winter outflow is well correlated with spring outflow.
Life Stage: eggs, larvae
Location: South and Central San Francisco Bay

- ● **PH-3. Habitat: Co-occurrence of Food.**

Mechanism: As most Pacific herring hatch in the winter, timing of plankton blooms may be important to larval growth and survival. There are several references supporting the match-mismatch theory as a controlling factor for Atlantic herring populations. As for Spawning Habitat, most of the effect would be prior to the X2 window.
Life Stage: larvae
Location: South Bay to San Pablo Bay

- ● **PH-4. Habitat space**

Mechanism: The area or volume of intermediate salinity habitat (ca 12-25 ppt), which is used as a nursery, increases with delta outflow.
Life Stage: larger larvae and juveniles
Location: South Bay to San Pablo Bay

- • **PH-5. Predation avoidance through turbidity**

Mechanism: Pelagic larvae and juveniles could avoid predation through increasing turbidity.
Life Stage: larvae and juveniles
Location: South Bay to San Pablo Bay

- • **PH-6. Predator avoidance in shallow areas**

Mechanism: Small juveniles migrate to very shallow areas in the spring to rear, per CDFG beach seine data. The amount of shallow water nursery habitat increases with delta outflow, especially in San Pablo Bay.
Life Stage: Small juveniles
Location: South Bay to San Pablo Bay

- • **PH-11. Toxic dilution**

Mechanism: Toxic dilution is a possible effect via the food chain and direct exposure.
Life Stage: all, but most likely eggs and larvae
Location: South Bay to San Pablo Bay

- ○ **PH-13. Gravitational circulation strength**

Mechanism: Movement to and retention in nursery areas is possibly aided by gravitational circulation.

Life Stage: larger larvae, juveniles
Location: San Pablo Bay

- **PH-17. Strong migratory cues**

Mechanism: Adult Pacific herring enter the Bay up to two months prior to spawning, possible searching for areas with decreased salinities. What triggers immigration into the Bay is not known. As with Spawning Habitat and Habitat Match-Mismatch, any effect occurs in the winter.
Life Stage: Adults
Location: South and Central bays

- **PH-18. Higher production of food**

Mechanism: Food production may increase with outflow.
Life Stage: All, but probably most important for larvae and small juveniles
Location: South Bay to San Pablo Bay

- ○ **PH-19. Ocean Conditions**

Mechanism: Broodstock condition is poorer during ENSO events (lower production of food in the nearshore ocean), resulting in fewer, lower quality eggs.
Life Stage: adults, eggs, and larvae
Location: Ocean for adults, South and Central bays for eggs and larvae

- ● **SF-4. Habitat space**

Mechanism: Shallow-water nursery habitat for starry flounder juveniles increases with outflow.
Life Stage: juveniles
Location: San Pablo Bay to delta

- **SF-6. Predator avoidance in shallow areas**

Mechanism: Predation may decrease with higher outflows, as the amount of brackish shallow water nursery habitat increases with outflow.
Life Stage: juveniles
Location: San Pablo Bay to delta

- **SF-8. Reduced entrainment (CVP and SWP)**

Mechanism: Loss to exports increases as X2 increases, as the nursery area moves from San Pablo and Suisun bays to the delta.
Life Stage: juveniles
Location: delta

- **SF-9. Reduced entrainment (PG&E)**

Mechanism: As in SF-8
Life Stage: juveniles
Location: upper Suisun Bay and west delta

- **SF-10. Reduced entrainment (Agriculture)**

Mechanism: As in SF-8.
Life Stage: juveniles
Location: delta

- **SF-11. Toxic dilution**

Mechanism: Toxic dilution is possibly important, as trace organic compounds (PCB's and

PAH's) have been associated with reproductive impairment of fish collected from the Bay. Pesticide effects are not known, but could be important in reducing prey for starry flounder.
Life Stage: juveniles and adults
Location: South, Central, and San Pablo bays to the delta

- **SF-13. Gravitational circulation strength**

Mechanism: Transport from the nearshore ocean to brackish water nursery area may be aided by gravitational circulation, which may increase as X2 decreases.
Life Stage: transforming larvae, small juveniles
Location: Central Bay to delta

- **SF-17. Strong migratory cues**

Mechanism: Increased outflow may aid in the location of the entrance to the Bay and the nursery area (decreased salinities or some other property of estuarine water is "sensed" by immigrants).
Life Stage: transforming larvae, juveniles
Location: Central Bay to delta

- **SF-19. Ocean Conditions**

Mechanism: There is some evidence that warm water and nearshore currents associated with ENSO events may be detrimental to hatching success and larval survival. To the extent that ocean conditions are correlated with estuarine conditions, this could confound the relationship of starry flounder to X2.
Life Stage: eggs, larvae
Location: Nearshore ocean

White Sturgeon (WS)

White sturgeon apparently have occasional strong year classes, when outflow is high. We don't have a good sampling method for white sturgeon larvae or larger juveniles, although adults are easily sampled with long lines or trammel nets.

- **WS-1. Spawning Habitat (Area, volume)**

Mechanism: White sturgeon spawn in the lower Feather and Yuba rivers and the upper Sacramento River. Mechanisms controlling spawning locations that are related to X2 are not known. Note: this is an upstream effect.
Life Stage: Adults
Location: Rivers.

- **WS-2. Spawning Habitat Access**

Mechanism: Adult white sturgeon "stage" in the delta prior to migrating upstream to spawn. Attraction flows may be key in prompting their upstream migration. Note: this is an upstream effect.
Life Stage: Adults
Location: Delta and rivers.

- **WS-3. Habitat: Co-occurrence of Food**

Mechanism: There are more white sturgeon larvae and juveniles in Suisun Bay and the western delta, and subsequently stronger year classes, in years with high outflow. This suggests that there may be a benefit to a more downstream distribution of larvae and juveniles. Although food availability could be a factor, we don't have the data to determine just how important it might be.
Life Stage: Larvae and small juveniles
Location: Suisun Bay and the western delta.

- **WS-4. Habitat space**

Mechanism: The nursery area of white sturgeon is largely unknown. Suisun Bay and the western delta may be a major nursery area for white sturgeon, especially in years with high outflow (also years with strong year classes).
Life Stage: Larvae and small juveniles
Location: Suisun Bay and the western delta.

- **WS-8. Reduced Entrainment (CVP and SWP)**

Mechanism: Low salvage of YOY white sturgeon in 1983 compared to the strong year class identified by trawl surveys suggests that very high flows (decreased X2) transport larval white sturgeon downstream and reduces their vulnerability to entrainment by the SWP and CVP.
Life Stage: larvae
Location: delta

- **WS-11. Toxic Dilution**

Mechanism: Given the body burdens of various toxic materials that have been found in white sturgeon in several studies, this is a potential problem.
Life Stage: all
Location: all

- **WS-12. Transport**

Mechanism: Larvae are transported downstream to Suisun Bay and the western delta in years with higher outflow (and stronger year classes), so transport appears to play a significant role.
Life Stage: Larvae
Location: Suisun Bay and western delta.

- **WS-17. Strong Migratory Cue**

Mechanism: High flows may be necessary to attract large number of mature females to the spawning areas. Note: this is an upstream effect.
Life Stage: adults
Location: delta and the rivers

American Shad (AMS)

The abundance index of American shad in the fall midwater trawl is correlated with the log of net delta outflow in the previous spring, and therefore also with X2. Several recent years have fallen above the values predicted by the regression.

- **AMS-1. Spawning Habitat (Area, volume)**

Mechanism: The distribution of American shad spawners between tributaries is strongly affected by flow. The attraction of shad to higher streamflow implies that spawning success may be regulated by this factor. However, shad broadcast spawn over a wide variety of habitat types and are less likely to be limited than more selective species such as splittail (vegetation spawners) or salmon (gravel redds)
Note: this is an upstream effect.
Life Stage: Adults
Location: Tributaries and Delta

- **AMS-2. Spawning habitat access**

Mechanism: Migration barriers to reach upstream spawning habitat are reduced in wet years.
Life Stage: Adult spawning
Location: The most likely locations where migration barriers are an issue are the Yuba, Mokelumne and Stanislaus rivers.

- **AMS-3. Habitat: Co-occurrence of Food**

Mechanism: Outflow affects the timing of spawning (via water temperature) and larval transport. Variability in the timing and location of larval rearing could play an important role with respect to the availability of food resources.
Life Stage: Larvae
Location: Tributaries and Delta

- **AMS-4. Habitat Space**

Mechanism: Young shad abundance may be limited by the amount of low salinity habitat available for rearing and foraging. The fact that most shad rear upstream of Suisun Bay until at least August suggests that salinity is not a primary issue for larvae.
Life Stage: Larvae and juveniles.
Location: Suisun Bay

- **AMS-5. Predation avoidance through turbidity**

Mechanism: Ligon et al (1994) showed that largemouth bass predation is significantly lower at high turbidity. Increased turbidity during high flows may have a similar effect on striped bass, a known predator of shad. However, shad spawn relatively late in the year after turbidity begins to decrease, so the importance of this mechanism is questionable
Life Stage: Eggs and larvae.
Location: Tributaries and Delta

- **AMS-8. Reduced Entrainment (CVP and SWP)**

Mechanism: In dry years, a higher proportion of young shad may be drawn into the central and south Delta where vulnerability to entrainment in diversions is greater
Life Stage: Eggs, larvae, and juveniles.
Location: Delta

- **AMS-9. Reduced Entrainment (PG&E)**

Mechanism: In dry years a higher proportion of outflow may be diverted into PG&E's facilities, increasing entrainment loss. Shad are relatively sensitive to entrainment stress and mortality may be high even though PG&E is a "flow-through" diversion rather than "dead-end".
Life Stage: Eggs, larvae and juveniles.
Location: Delta, confluence

- **AMS-10. Reduced Entrainment (Agricultural)**

Mechanism: In dry years a greater proportion of outflow may be diverted into agricultural diversions. However, peak emigration through the Delta (August-November) does not occur until after the primary season of diversion.
Life Stage: Eggs, larvae and juveniles.
Location: Delta

- **AMS-11. Dilution of toxics**

Mechanism: All life stages of American shad may be affected by toxic material entering the Sacramento-San Joaquin system from agricultural runoff, discharge of industrial and municipal waste, and runoff from non-point sources.
Life Stage: All
Location: All

- **AMS-12. Transport**

Mechanism: High flow years may provide greater dispersal of eggs and larvae, thereby increasing total rearing habitat.
Life Stage: Eggs and larvae
Location: Tributaries and Delta

- **AMS-16. Temperature (as affected by flow)**

Mechanism: Adult migration, spawning and rearing are strongly affected by water temperature, which is inversely correlated with outflow.
Life Stage: Spawning adults, eggs and larvae.
Location: Tributaries and Delta.

- ***AMS-17. Strong Migratory Cues***

Mechanism: Higher flows may draw more adults into upstream spawning areas. As evidence, there are a number of strong relationships between the proportion of flow in tributaries and the proportion of repeat spawners.
Life Stage: Adults
Location: Attraction of adults from the Bay and Ocean to the tributaries

- ***AMS-18. Higher Production of Food***

Mechanism: Abundance of zooplankton, Neomysis and amphipods is higher in wet years, so grow rates and survival may be higher.
Life Stage: Delta and Suisun Bay
Location: Suisun Bay

Striped Bass (SB)

Striped bass have responses to flow or X2 at several life stages: survival between egg and 6mm larval stage or egg and young-of-the-year (YOY), and the YOY and fall midwater trawl indices. Survival from egg to YOY may also be a function of percent diverted or food biomass.

- ***SB-1. Spawning Habitat (Area, volume)***

Mechanism: Habitat for spawning on the San Joaquin is expanded downstream as well as upstream when X2 is further downstream.

Life Stage: adults
Location: Delta

- ***SB-2. Spawning habitat access.***

Mechanism: Spawning access is increased particularly on the San Joaquin River to areas further upstream by high inflow which removes salinity barriers to spawning and increases the size of spawning habitat.
Life Stage: adults
Location: Delta

- ***SB-3. Habitat: Co-occurrence of Food.***

Mechanism: Survival should be higher when windows of high food abundance correspond to windows when larvae reach the feeding stage. Food match-mismatch at larval stages is thought to be a major reason for poor or good year classes in many fish populations, particularly pelagic-spawning marine species.
Life Stage: larvae and juveniles
Location: Delta

- ***SB-4. Habitat space***

Mechanism: There is a well-defined positive relationship between outflow and the abundance of 38 mm striped bass. This occurs when habitat volume of low salinity water in Suisun Bay and other lower bays is expanded in relation to X2 moving downstream.
Life Stage: larvae and juveniles
Location: Delta and Suisun Bay

- ***SB-5. Predation avoidance through turbidity***

Mechanism: Striped bass larvae and juveniles generally are most abundant near the turbidity maximum. In years since 1977 when the striped bass declined there has only been one initially strong year class produced in 1986, which was a year of high turbidity. However there have been other years when water transparency was lower than average and strong year classes were not produced, such as 1980.
Life Stage: larvae and juveniles
Location: Suisun Bay

- ***SB-8. Reduced entrainment (CVP and SWP).***

Mechanism: Losses of all stages of young striped bass are greater when X2 is upstream and the population is mainly in the Delta and more susceptible to being entrained or displaced by water exports (CDFG WRINT exhibits 2 and 3). Jassby et al. (1995) noted also that percent diverted explained a significant amount of variance (along with X2) in a regression model of survival from egg to YOY. An upstream position of X2 increases the susceptibility of young striped bass to entrainment. Clearly, losses are well documented, but the effects of such losses on striped bass population dynamics needs to be more clearly evaluated.
Life Stage: larvae and juveniles
Location: Delta

- ***SB-9. Reduced entrainment (PG&E)***

Mechanism: X2 or its correlates are very important in determining the entrainment losses for striped bass, because of the location of the intakes at Antioch and Pittsburg. However PG&E is able to minimize entrainment by operational changes when striped bass are present up to the 38 mm size.

Life Stage: larvae and juveniles
Location: western Delta

- ***SB-10. Reduced entrainment (Agriculture)***

Mechanism: Entrainment is likely to be important but less so than export pumping. Effects of local agricultural diversions are being evaluated by DWR to help quantify the impacts of local diversions on several species including striped bass. X2 being further downstream would most likely diminish such losses.
Life Stage: Eggs to juveniles
Location: Delta and Suisun Bay

- ***SB-11. Toxic dilution***

Mechanism: Likely to be one of several factors influencing annual fluctuations in the 38-mm index but not a major factor driving the population. Recycling of rice herbicides on the rice fields during the spring since 1991 has not caused a rebound in the 38 mm abundance index as would be expected if toxicants were the driving factor suppressing bass abundance. Dilution or flushing of toxicants has been thought to be greater when X2 is downstream. However, some recent analyses by Bennett on pesticide loadings for 1992 and 1993 suggests that, for some toxicants, more are flushed into the estuary when flows are high. Striped bass abundance is higher in high flow years suggesting minimal population impacts for these toxicants.
Life Stage: Eggs to juveniles
Location: Delta and Suisun Bay

- ***SB-12. Transport***

Mechanism: Annual survival rates between egg stage and 6 mm stage are positively correlated with river flow. This correlation suggests that the shorter the time spent by eggs and early larvae in the river system the higher the survival. However the exact mechanism (e.g. exposure to toxicants or diversions) is unknown. The center of the larval and juvenile population is further downstream when X2 is downstream.
Life Stage: Eggs to juveniles
Location: Delta

- ***SB-13. Gravitational circulation strength***

Mechanism: Striped bass smaller than 38 mm are generally found in the EZ or upstream. This is a potential mechanism retaining young striped bass where their food supply, i.e. copepods and Neomysis, also tends to be high. Recent work on the vertical distribution of striped bass larvae in the EZ, suggests that they migrate vertically using tidal currents to maintain themselves near X2 at times when gravitational circulation is rare. This behavior presumably reduces advection downstream. The importance of gravitational circulation for larval retention in the EZ is under investigation.
Life Stage: larvae and juveniles
Location: Entrapment zone

- ***SB-14. Entrapment Zone Residence Time***

Mechanism: Overall, food for first-feeding larval striped bass is higher near the upstream end of the EZ. Location of X2 in Suisun Bay may both increase the proportion of the larval population in the EZ and cause them to reside there longer because they can arrive there earlier due to higher transport flows, and thus experience potentially higher feeding success
Life Stage: larvae and juveniles

Location: Delta and Suisun Bay

- ***SB-16. Temperature (as affected by flow)***

Mechanism: Temperature affects growth rate which in turn could affect survival. Growth rates can determine the length of exposure time to size specific predation. However, interannual variation in X2 does not seem to markedly influence average temperature, unlike other estuaries (e.g. Chesapeake). Differences in the spring-time pattern of temperature change can influence spawning times and production of food for larvae. Such effects are included under the Match-Mismatch category.
Life Stage: larvae and juveniles
Location: Delta and Suisun Bay

- ***SB-17. Strong migratory cues***

Mechanism: High flows likely have a role in attracting adults to spawning areas but there are no quantitative data.
Life Stage: Adults
Location: Delta

- ***SB-18.Higher Production of food***

Mechanism: Likely positive effect on fish production. The EPRI striped bass model and recent regression analyses have suggested that food biomass may be important to the survival of young striped bass
Life Stage: larvae and juveniles
Location: Delta and Suisun Bay

Longfin smelt (LFS)

Longfin smelt have a strong negative relationship between abundance and X2 that is dominated by 4 years of high values. The value for 1983 is an outlier, in that it is far from the curve, but this may be a result of inadequate sampling in that high-flow year. Values in recent years have been lower than expected.

- ***LFS-1. Spawning Habitat (Area, volume)***

Mechanism: Increased spawning habitat (submerged vegetation) with increased outflow.
Life Stage: eggs, larvae
Location: delta, rivers and tributaries

- ***LFS-3. Habitat: Co-occurrence of Food***

Mechanism: Longfin smelt spawn as early as January, prior to most phytoplankton blooms, so larval habitat match-mismatch may be important. There is some evidence that the timing and duration of spawning is dependent on the timing and magnitude of outflow events.
Life Stage: larvae
Location: San Pablo Bay to delta

- ***LFS-4. Habitat space***

Mechanism: Area/volume of brackish water nursery habitat increases with outflow.
Life Stage: larger larvae, juveniles
Location: San Pablo Bay to delta

- ***LFS-5. Predation avoidance through turbidity***

Mechanism: Turbidity increases with outflow so this is a possible mechanism, since larvae and juveniles are pelagic.
Life Stage: larvae and juveniles
Location: San Pablo Bay to delta

- ***LFS-7. Reduced probability of encounter with predator***

Mechanism: **Longfin smelt are distributed over a larger area with high outflow (increased nursery area), so predation may decrease with outflow.**
Life Stage: **larger larvae, juveniles**
Location: **San Pablo Bay to delta**

- **LFS-8. Reduced entrainment (CVP and SWP)**

Mechanism: **Loss to exports increases with lower outflow, as the nursery area move upstream to the delta and a higher percentage of water is exported in the winter and early spring, when hatching occurs in the delta.**
Life Stage: **Primarily larvae and juveniles**
Location: **Delta**

- **LFS-9. Reduced entrainment (PG&E)**

Mechanism: **Lower outflow may increase entrainment loss to PG&E plants, as larvae are not transported as far downstream and the brackish water nursery area moves from San Pablo and Suisun bays to the delta.**
Life Stage: **larvae, small juveniles**
Location: **upper Suisun Bay and west delta**

- **LFS-10. Reduced entrainment (Agriculture)**

Mechanism: **Lower outflow may increase entrainment losses to agricultural diversions, as larvae are not transported as far downstream and the brackish water nursery area moves from San Pablo and Suisun bays to the delta.**
Life Stage: **larvae, small juveniles**
Location: **delta**

- **LFS-11. Toxic dilution**

Mechanism: **Toxic dilution is a possible effect via the food chain and direct exposure.**
Life Stage: **all, but most likely eggs and larvae**
Location: **estuary wide, but especially the delta**

- **LFS-12. Transport**

Mechanism: **Transport from spawning areas to nursery area aided by higher flows.**
Life Stage: **larvae**
Location: **San Pablo Bay to delta**

- **LFS-13. Gravitational circulation strength**

Mechanism: **Recent studies on the vertical distribution of larval fishes in the EZ indicate that older longfin smelt larvae, migrate vertically to utilize tidal currents, facilitating their retention in the EZ habitat when gravitational circulation is rare. The influence of gravitational circulation on larval retention is under investigation.**
Life Stage: **larger larvae, juveniles**
Location: **San Pablo Bay to delta**

- **LFS-14. Entrapment Zone Residence Time**

Mechanism: **Overall, food for larval and juvenile longfin smelt is higher near the upstream end of the EZ. Larval monitoring data indicates that when X2 is positioned in Suisun Bay a higher proportion of the larval population occurs in and near the EZ. They may also reside there longer because they can arrive there earlier due to higher transport flows, and thus experience potentially higher feeding success.**
Life Stage: **larger larvae, juveniles**
Location: **San Pablo Bay to delta**

- **LFS-18. Higher production of food**

Mechanism: **Increased production of food (zooplankton) with increased outflow**
Life Stage: **all, but probably most important for larvae and small juveniles**
Location: **San Pablo Bay to delta**

Delta Smelt (DS)

The relationship between abundance of delta smelt and X2 is more complex than that for other species, and explains less of the variance. Delta smelt are abundant only when X2 is in Suisun Bay, but they are not always abundant under that condition. Abundance of inland silversides appears to be negatively related to delta smelt abundance.

- **DS-1. Spawning Habitat (Area, volume)**

Mechanism: **Amount of flooded vegetation increases with increasing outflow.**
Life Stage: **Spawning adults, Eggs, larvae**
Location: **delta, rivers and tributaries**

- **DS-3. Habitat: Co-occurrence of Food**

Mechanism: **Often considered of major importance for many fish species with pelagic larvae; X2 may affect the co-occurrence of young DS with their food organisms and potential predators. While there has been very little work on the importance of this mechanism for DS, there is a significant relationship between DS annual year-classes and the amount of time during spring X2 is located in Suisun Bay. However, the high amount of variability not explained by this relationship suggests other factors may be operating as well.**
Life Stage: **Larvae, juveniles**
Location: **Delta, Rivers and entrapment zone**

- **DS-4. Habitat space**

Mechanism: **Also of potentially great importance: the idea is that more suitable habitat should produce more fish. This may occur when X2 is located downstream in Suisun Bay, which supplies considerably more shallow-water habitat than the river channels upstream. The Herbold X2 model and Phil Unger's salinity model may reflect some of this potential effect.**
Life Stage: **Larvae, juveniles, adults**
Location: **Primarily EZ and Suisun Bay**

- **DS-5. Predation avoidance through turbidity**

Mechanism: **Often cited as an important regulator of visual predation, turbidity tends to increase when X2 is located downstream. However, DS have also produced poor year-classes in high turbidity years.**
Life Stage: **Larvae, juveniles, adults**
Location: **Delta, Rivers & EZ**

- **DS-7. Reduced probability of encounter with predator**

Mechanism: **Exotic inland silversides have been identified as larval predators, and occur in high density only in shoreline areas of the Delta and western Suisun Bay, where DS spawn. In dry years, DS larvae and juveniles are typically distributed in the Delta and lower Sacramento river, where they have a higher probably of occurring in shoreline habitat with inland silversides. Annual DS year-classes exhibit a significant negative association with inland silverside abundance in years when X2 is located upstream during spring. DS larvae and juveniles are more common in Suisun Bay with downstream location of X2 and thus away from shoreline habitat. A more highly significant relationship occurs when the effect of predation (silverside abundance) is weighted by X2 in all years since the silverside invasion. The assumptions of these relationships need to be studied in more detail.**
Life Stage: **Eggs, larvae**
Location: **Delta, rivers**

- **DS-8. Reduced entrainment (CVP and SWP)**

Mechanism: **The effect of X2 on entrainment losses is very well documented. In low outflow years DS may exhibit a higher probability of entrainment mortality. However, as with most species, the consequences of this mortality for the population dynamics of DS are unclear.**
Life Stage: **Larvae, juveniles, adults**
Location: **Delta**

- **DS-9. Reduced entrainment (PG&E)**

Mechanism: **Similar effects of X2 on entrainment losses in PG&E diversions could be very important, but have been less well documented.**
Life Stage: **Larvae, juveniles, adults**
Location: **Western delta**

- **DS-10. Reduced entrainment (Agriculture)**

Mechanism: **As for DS-9**
Life Stage: **Larvae, juveniles, adults**
Location: **Suisun Bay**

- **DS-11. Toxic dilution**

Mechanism: **Higher outflow and downstream X2 is presumed to facilitate dilution or flushing of various toxicants from the Delta. The majority of DS appear to spawn on the Sacramento side of the Delta, where recent application practices have greatly reduced toxic runoff, during the DS spawning season. Although the potential exists for impacts no such effects have been identified.**
Life Stage: **Eggs, larvae, juveniles, adults**
Location: **Delta, rivers, Suisun Bay**

- **DS-12. Transport**

Mechanism: **DS distribution appears to be influenced by X2, although it is unclear if this is related to hydrodynamic effects on movement, or habitat selection by DS. Annual spawning migration to freshwater does not seem to be influenced by X2.**
Life Stage: **Larvae, juveniles**
Location: **Delta, rivers, Suisun Bay**

- **DS-13. Gravitational circulation strength**

Mechanism: **Recent studies on the vertical distribution of larval fishes in the EZ indicate that older longfin smelt larvae, migrate vertically to utilize tidal currents, facilitating their retention in the EZ habitat when gravitational circulation is rare. Limited information for delta smelt suggests they employ a similar strategy. The influence of gravitational circulation on larval retention is under investigation.**
Life Stage: **Larvae, juveniles**
Location: **EZ and Suisun Bay**

- **DS-14. Entrapment Zone Residence Time**

Mechanism: **Overall, food for larval and juvenile delta smelt is higher near the upstream end of the EZ. Larval monitoring data indicates that when X2 is positioned in Suisun Bay a higher proportion of the larval population occurs in the EZ. They may also reside there longer because they can arrive there earlier due to higher transport flows, and thus experience potentially higher feeding success.**
Life Stage: **Larvae, juveniles**
Location: **EZ and Suisun Bay**

- **DS-16. Temperature (as affected by flow)**

Mechanism: **Interannual position of X2 does not seem to markedly influence average temperature, unlike other estuaries (e.g. Chesapeake). However, differences in the springtime pattern of temperature change can influence spawning times and production of food for larvae. Such affects are included under the Match-Mismatch category.**
Life Stage: **Larvae, juveniles, adults**
Location: **Delta, rivers, Suisun Bay**

- **DS-18. Higher production of food**

Mechanism: **The abundance of many food organisms for DS larvae and juveniles is affected by mean X2 during spring. Thus, overall growth and condition of DS may be better in higher outflow years, producing higher year-class success. Limited studies suggest this may be important for striped bass, but this has not yet been evaluated by DS (or any other fish species).**
Life Stage: **Larvae, juveniles, adults**
Location: **Delta, rivers, Suisun Bay**

- **DS-20. Sampling Bias**

Mechanism: **The overall low abundance of DS increases the probability of sampling bias, although there is no obvious mechanism for producing the observed relationship through bias.**
Life Stage: **Larvae, juveniles, adults**
Location: **Delta, rivers, Suisun Bay**

Sacramento Splittail (ST)

Splittail abundance is negatively related to X2, owing to several high points occurring in high-flow years.

- **ST-1.Spawning Habitat (Area, volume)**

Mechanism: **Floodplain inundation in wetter years appears to provide important spawning habitat for splittail . As evidence, there is a strong relationship between the frequency of floodplain inundation and midwater trawl abundance. IEP studies in 1995 showed that adult and larval densities were higher in the bypass areas than in the main channel of Sacramento River.**
Life Stage: **Adults:**
Location: **Floodplain areas of the tributaries and Delta.**

- **ST-2. Spawning habitat access**

Mechanism: **Wet years provide access to adjacent floodplain areas such as the bypasses. IEP studies in 1995 confirmed that these areas area important for spawning. In the case of the bypasses, these areas are only accessible in wet years during flood control.**
Life Stage: **Adult.**
Location: **Floodplain areas of the tributaries and Delta.**

- **ST-3. Habitat: Co-occurrence of Food**

Mechanism: **Spatial and temporal variability in the timing of splittail spawning and the production of larval food resources could affect survival of young splittail.**
Life Stage: **Larvae**
Location: **San Pablo Bay to tributaries**

- **ST-4. Habitat Space**

Mechanism: **When X2 is further downstream, the lower range of the species expands as salinities become suitable. However, strong year classes are prominent well before salinities in the lower portion of the range become unsuitable, so this could not be the sole mechanism for the X2 relationship.**
Life Stage: **Larvae, juveniles.**
Location: **Suisun Bay to Delta.**

- **ST-5. Predation avoidance through turbidity**

Mechanism: **Largemouth bass predation is significantly lower at high turbidity. Increased turbidity during high flows may have a similar effect on striped bass, a known predator of splittail.**
Life Stage: **eggs, larvae and juveniles.**

- **ST-6. Predation Avoidance in Shallow Areas**

Mechanism: **Floodplain rearing habitat may make it easier for young to avoid predation. However, reduction in predation may be offset by higher risk of entrapment in ponds as high flows recede.**
Life Stage: **Larvae and juveniles.**
Location: **Tributaries and Delta.**

- **ST-7. Reduced probability of encounter with predator**

Mechanism: **Although not conclusively demonstrated, high flows and low water temperature may delay the upstream spawning migration of one of their major**

predators, striped bass. Early spawning splittail may therefore have higher survival in wet years.
Life Stage: **Larvae, juveniles, and adults.**
Location: **Tributaries and Delta.**

- **ST-8. Reduced Entrainment (CVP and SWP)**

Mechanism: **In drier years, a higher proportion of Delta inflow is diverted, perhaps increasing mortality. However, entrainment rates are lowest in dry years, so the importance of this mechanism is questionable.**
Life Stage: **Larvae, juveniles and adults.**
Location: **Delta**

- **ST-9. Reduced Entrainment (PG&E)**

Mechanism: **In low flow years a greater percentage of the population may be shifted upstream near the intake of PG&E. However, the limited studies performed to date indicate that entrainment is not exceptionally high. Moreover, a salinity-based upstream shift in habitat is expected in the summer, yet year class strength appears to be set before this time. This is clearly not the primary factor responsible for the X2-abundance relationship.**
Life Stage: **Larvae and juveniles.**
Location: **Suisun Bay**

- **ST-10. Reduced Entrainment (Agricultural)**

Mechanism: **In low flow years a greater percentage of the population may be shifted upstream near the intakes of agricultural diversions. A shallow-water oriented species such as splittail may be vulnerable to bankside diversions. Another possibility is that entrainment losses are lower in wet years because there may be less irrigation diversion flow due to high precipitation and soil moisture. However, strong year classes are often apparent before agricultural entrainment is likely to become a major factor, so the importance of this mechanism is questionable.**
Life Stage: **Larvae and juveniles.**
Location: **Delta**

- **ST-11. Dilution of toxics**

Description: All life stages of splittail may be affected by toxic material entering the Sacramento-San Joaquin system from agricultural runoff, discharge of industrial and municipal waste, and runoff from non-point sources.
Life Stage: **All**
Location: **System-wide**

- **ST-12. Transport**

Mechanism: **In wetter years, more young splittail are transported to Suisun Bay, where USFWS believe the most suitable habitat is located. However, strong year classes are prominent well before most splittail reach Suisun Bay, so this could not be the sole mechanism for the X2 relationship.**
Life Stage: **Larvae and juveniles.**
Location: **Tributaries and Delta**

- **ST-15. Adult Habitat**

Mechanism: **Inundation of floodplain area creates foraging habitat during the pre-**

spawning period, which may increase reproductive success.
Life Stage: **Adults**
Location: **Delta and tributaries.**

- **ST-17. Strong Migratory Cues**

Mechanism: **Creel census data suggests that adult abundance was higher in 1993, a wet year, than previous dry years. If high flows are necessary as cues for spawning migration, abundance could be reduced in dry years because of less reproductive activity.**
Life Stage: **Adults**
Location: **Delta and tributaries**

- **ST-18. Higher Production of Food**

Mechanism: **Abundance of some food resources (e.g. Neomysis) is higher in wet years so splittail growth rates and survival may be enhanced. This is unlikely to be a primary mechanism because strong year classes are prominent well before splittail reach the food-enriched region of the estuary.**
Life Stage: **Juveniles**
Location: **Delta and Suisun Bay**

- **ST-20. Sampling bias**

Mechanism: **DFG studies suggest that splittail behavior may cause midwater trawl abundance to be overestimated in wet years and underestimated in dry years. However, sampling bias is not a primary mechanism for the X2 relationship because other estimates (e.g. salvage) demonstrate similar abundance trends.**
Life Stage: **juveniles**
Location: **Delta and Suisun Bay**

Chinook Salmon (KS)

The population size of chinook salmon is affected by a wide variety of factors, most of which operate outside the estuary; thus most of the effects of flow referred to here act upstream of the estuary. There is no direct relationship between chinook salmon abundance and X2, although flow in the rivers affects abundance in a variety of ways. However, survival of chinook salmon through the delta appears to be positively related to outflow and therefore negatively related to X2. It is likely that the survival of fry rearing in the delta is also related to flow conditions, but there are no data to support that.

- ○ **KS-1 Spawning Habitat (Area, volume)**

Mechanism: **Spawning habitat area is a function of flow. Note: this is an upstream effect.**
Life stage: **Adult**
Location: **Tributaries**

- ● **KS-2 Spawning habitat access**

Mechanism: **Access to spawning habitat is a function of flow. Note: this is an upstream effect.**

Life stage: **Adult**
Location: **Tributaries**

- **KS-3 Habitat: Co-occurrence of food**

Mechanism: **Food supply for fry and smolts may vary with flow.**
Life stage: **Juveniles**
Location: **Tributaries, delta, bays**

- **KS-4 Habitat space**

Mechanism: **Rearing habitat in the tributaries varies with stage and therefore flow. Rearing and migration habitat in the delta and estuary may also vary in terms of quality (e.g. salinity) as flow changes.**
Life stage: **Juveniles**
Location: **Tributaries, delta, bays**

- **KS-5 Predation avoidance through turbidity**

Mechanism: **High flow increases turbidity throughout the system, which may provide a refuge from visual predators.**
Life stage: **Juveniles**
Location: **Tributaries, delta, bays**

- **KS-6 Predation avoidance through shallow access**

Mechanism: **High flow provides access to shallow areas relatively free of predators**
Life stage: **Juveniles**
Location: **Tributaries, delta, bays**

- **KS-7.Reduced probability of encounter with predator**

Mechanism: **Rapid movement through the estuary under high-flow conditions may reduce the probability that KS are eaten.**
Life stage: **Juveniles**
Location: **Delta, bays**

- **KS-8. Reduced Entrainment (CVP and SWP)**

Mechanism: **Increased streamflow associated with a downstream location of X2 increases the speed at which out migrating salmon move downstream and reduce their exposure to the zone of influence for export pumping in the Delta. This is very important for San Joaquin salmon, and less so for salmon from other rivers, for which indirect effects in the delta may be more important.**
Life stage: **Juveniles**
Location: **Delta, bays**

- **KS-9. Reduced Entrainment (PG&E)**

Mechanism: **As for CVP and SWP entrainment, but a smaller effect.**
Life stage: **Juveniles**
Location: **Delta, bays**

- **KS-10. Reduced Entrainment (PG&E)**

Mechanism: **As for CVP and SWP entrainment, but a smaller effect.**
Life stage: **Juveniles**
Location: **Delta, bays**

- **KS-11. Toxic dilution**

Mechanism: **X2 has a small effect on the dilution of toxic substances in the migration path of juvenile and adult salmon and the concentration of toxic substances in shallow water areas used by juveniles.**
Life stage: **All**
Location: **Tributaries, delta, bays**

- **KS-16. Temperature (as affected by flow)**

Mechanism: **Temperature is an important predictor of smolt survival through the delta, based on experiments with coded-wire tagged fish. Stream flow has some effect on temperature, so downstream X2 would be somewhat related to better survival.**
Life stage: **All**
Location: **Tributaries, delta, bays**

- **KS-17. Migratory cues**

Mechanism: **High flows may provide a clearer directional signal for adult and smolt migration, reducing the time of passage and improving survival. This is an upstream effect for adults.**
Life stage: **All**
Location: **Tributaries, delta, bays**

Neomysis Mercedis (NEO)

Neomysis **abundance is negatively related with X2. Under extremely high-flow conditions (1983) abundance is reduced, possibly because of inadequate sampling. Since the spread of *Potamocorbula amurensis* in 1987, *Neomysis* abundance in the entrapment zone has been greatly reduced so the above relationship may no longer hold. However, they may hold for the introduced mysid *Acanthomysis* sp..**

- **NEO-3. Habitat: Co-occurrence of Food**

Mechanism: **X2 apparently affects phytoplankton abundance and mysid abundance is significantly correlated with chlorophyll concentration. Mysids also appear to be most abundant where turbidity is greatest.**
Life Stage: **Juveniles will be more affected than adults by phytoplankton concentrations. Relationship between life stages and turbidities has not been investigated.**
Location: **Western delta and Suisun Bay**

- **NEO-4. Habitat space**

Mechanism: **Habitat for Neomysis essentially comprises the entrapment zone. The volume of this zone does not change much with X2, but area may change.**
Life Stage: **All.**
Location: **Suisun Bay to eastern delta.**

- **NEO-5. Predation avoidance through turbidity**

Mechanism: **Mysids are eaten both by visual predators (fish) and by tactile predators (Crangon and Palaemon). Mysids tend to be most abundant at high turbidities, suggesting that habitat may be selected for avoidance of visual**

predators.
Life Stage: **All.**
Location: **Generally Suisun Bay.**

- **NEO-8. Reduced entrainment (CVP and SWP)**

Mechanism: **CVP and SWP entrainment probably does not pump out significant numbers of mysids regardless of X2.**

- **NEO-9. Reduced entrainment (PG&E)**

Mechanism: **Mysids are entrained at the PG&E plants but the effect on population size appears to be small. Hence, X2 will have little effect but an X2 location in the western Delta should keep mysids away from the PG&E plants.**
Life Stage: **All.**

- **NEO-10. Reduced entrainment (agriculture)**

Mechanism: **Mysids are likely to be pumped out of Delta channels by agricultural diversions. Nothing is known about the effects of such losses but they are obviously higher when mysids are abundant in the Delta and hence when X2 is in the western Delta.**
Life Stage: **All.**
Location: **Western Delta.**

- **NEO-11. Toxic dilution**

Mechanism: **Agricultural toxins enter the Delta from the San Joaquin River and from the Colusa Drain. Mysid abundance is not correlated with the application rates of the most common rice field herbicides and the herbicide concentrations have almost always been below DFG criteria in Delta channels that receive Colusa Drain water. Mysids are short-lived animals that will not have opportunity to accumulate toxins and hence chronic, sublethal effects are unlikely. However, high outflow and X2 in western Suisun Bay would logically minimize any effects of agricultural toxins on mysids.**
Life Stage: **All.**

- **NEO-13. Gravitational circulation strength**

Mechanism: **Mysids migrate vertically to remain in the EZ, at least under low-flow conditions. This effect would be stronger when gravitational circulation is strong. Loss rates seaward of the entrapment zone are probably lower when gravitational circulation is strong, since mysids are more abundant near the bottom than high in the water column.**
Life Stage: **All.**

- **NEO-14. Entrapment Zone Residence Time**

Mechanism: **Neomysis is an entrapment zone species that apparently uses vertical movement to set its longitudinal position. Residence time of mysids in the EZ could be strongly influenced by X2 through depth and stratification effects as well as lateral circulation cells**
Life stage: **All**
Location: **EZ**

- **NEO-16. Temperature (as affected by flow)**

Mechanism: **Flow effects on temperature would occur mainly in spring; high**

outflow of cold water would reduce the rate of increase of temperature. This would reduce mysid birth rates by prolonging egg development time but would probably lengthen life spans of the most productive adults, the largest ones. These are the first to disappear as temperature rises in spring.
Life Stage: **Adults and embryos.**

- **NEO-18. Higher production of food**

Mechanism: **Juvenile mysids feed primarily on phytoplankton and their growth and survival may depend on phytoplankton concentrations. Correlations between mysid abundance and chlorophyll are significant; food limitation is the only realistic mechanism to explain the decline in Neomysis in 1988 when Potamocorbula amurensis became abundant. Before that time, X2 in Suisun Bay produced the highest chlorophyll concentrations in the entrapment zone, but now chlorophyll and Neomysis abundance decline with increasing salinity, and the effect of X2 on food and on mysids may be reduced.**
Life Stage: **Juveniles.**
Location: **Suisun Bay, western Delta.**

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