Effects of Delta Inflow and Outflow on Several Native, Recreational, and Commercial Species

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February 2010

Prepared for the Informational Proceeding to Develop
Flow Criteria for the Delta Ecosystem
Necessary to Protect Public Trust Resources
Before the State Water Resources Control Board

Beginning March 22, 2010

1 Introduction

The exhibit provides a Department of Fish and Game (DFG) assessment of the effect of inflow and Delta outflow on several native, recreational, and commercial species that live in or pass through the San Joaquin-Sacramento River Delta. For each species, DFG scientists have summarized the available scientific data and information related to life stage, mechanism of the relationship between water flow and species abundance or habitat, the type of relationship, and the months of the year when flows are most critical to various life stages.

This assessment is summarized in Table 1. The importance of flows for each month of the year is provided.

2 Native Species

2.1 Chinook Salmon

Delta inflow and outflow affects migration patterns of Chinook salmon (*Oncorhynchus tshawytscha)* through the Sacramento-San Joaquin estuary. Freshwater flow is an important cue for upstream migration of adult salmon and directly affects survival of juveniles moving downstream through the Delta. Decreased flows through the Delta may decrease the migration rate of juveniles moving downstream, increasing their exposure time to unsuitable water temperatures, entrainment into the interior Delta, entrainment in water diversions, contaminants, and predation. Increasing salmon survival rates through the Delta will be a critical step toward restoring natural salmon production in the Central Valley.

2.1.1 Sacramento River

Several exhibits and publications submitted to the SWRCB in previous Bay-Delta proceedings (i.e., the 1987 and 1992 Water Rights proceedings) are relevant to the scientific questions that are the focus of the current proceeding. In addition, several recent studies are available for consideration in this proceeding. USFWS (1987) presented evidence that habitat alterations in the Delta limit salmon production primarily through reduced survival during the outmigrant (smolt) stage. These lower survivals are associated with decreases in the magnitude of flow through the estuary, increases in water temperature, and water project diversions in the Delta. The survival of marked hatchery smolts through the Sacramento Delta between Sacramento and Suisun Bay was found to be positively correlated to flow and negatively correlated to water temperature. Two independent measures of survival related Smolt survival increases with increasing Sacramento River flow at Rio Vista. Maximum survival was observed at or above 20,000 to 30,000 cfs.

In addition to survival being higher with higher flows, Chinook salmon abundance was also found to be higher with greater river flow. The abundance of juveniles leaving the Delta at Chipps Island was found to be higher with higher mean daily flows at Rio Vista from April through June. The highest abundance leaving the Delta was observed when

Table 1: Timing of important species and life stage specific flow/outflows and the mechanisms of action on survival or abundance.

Species			Water Year Months[1]											
Name	**Life Stage**	**Mechanism(s)**	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**
Native														
Chinook salmon	egg	Temperature Scouring	●	●●	●									
	fry			●	●	●								
	smolt			●	●	●	●	●	●	●●	●			
Pacific herrnig	egg	Reduced salinity habitat		●	●●	●●	●●	●						
	larvae	Reduced salinity habitat, bottom currents			●	●●	●●	●●	●					
Longfin smelt	egg	Freshwater-Brackish habitat		●?	●	●●	●●	●	●					
	larvae	Freshwater-Brackish habitat; transport; turbidity			●	●	●●	●●	●●	●●	●?			
Prickly Sculpin	larvae	Freshwater-Brackish habitat; transport; turbidity				●	●	●●	●●	●●	●			
Splittail	adults	Flood plain inundating flows (can be short)				●	●	●	●					

[1] ● = Flow timing important during this month, ●● = flow timing very important during this month, ●? = flow timing may be important but the need is uncertain.

Species			Water Year Months[1]											
Name	**Life Stage**	**Mechanism(s)**	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**
	eggs and larvae	Flood plain habitat persistence				●	●	●●	●●	●●	●?			
Delta smelt	pre-adult	Transport; habitat	●	●				●	●●	●●	●	●		●
Starry Flounder	settled juvenile/juvenile-2yr old	Estuary attraction; habitat					●	●	●	●				
White Sturgeon	adult	Attraction			●	●	●							
	adult	Spawning					●	●●	●●	●●	●?			
	larvae	Larval dispersal						●●	●●	●●	●?			
	small juveniles	Nursery habitat						●	●●	●●	●●	●?		
Green Sturgeon	adult	Migration					●	●	●	●	●	●?		
	adult	Spawning						●	●●	●●	●●	●		
	adult	Over summering	●	●								●	●	●
	larvae	In-river rearing								●	●●	●●	●	●
	juvenile	Rearing/ dispersal	●	●	●	●	●	●	●	●	●	●	●	●

Species			Water Year Months[1]											
Name	**Life Stage**	**Mechanism(s)**	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**
Pacific Lamprey	adult	Migration			●?	●	●	●	●	●	●			
	adult	Prespawn/ staging	●	●	●	●	●	●	●	●	●	●	●	●
	adult	Spawning						●	●	●	●	●		
	ammo- coetes	In-streambed rearing	●	●	●	●	●	●	●	●	●	●	●	●
	juvenile/pre -adult	dispersal			●	●	●	●	●					
River Lamprey	adult	Migration	●	●	●	●●	●●	●●						
	adult	Prespawn staging	●?	●	●	●	●	●	●?	●?	●?	●?	●?	●?
	adult	Spawning					●	●	●	●				
	ammo- coetes	In-streambed rearing	●	●	●	●	●	●	●	●	●	●	●	●
	juvenile/pre -adult	Dispersal	●	●	●●	●●	●●	●●	●	●	●			●
Bay Shrimp, *Crangon franciscorum*	late-stage larvae and small juveniles	Transport					●	●	●●	●●	●●			
	juveniles	Nursery habitat							●●	●●	●●			

Species			Water Year Months[1]											
Name	**Life Stage**	**Mechanism(s)**	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**
Mysid shrimp, *Neomysis mercedis*	all	habitat	●	●				●	●	●	●	●	●	●
Eurytemora affinis	all	habitat						●●	●●	●●				
Non-Native														
American Shad	egg/larvae	Transport; dispersal; habitat						●	●●	●●	●			
Striped Bass	egg/larvae	Transport; dispersal; habitat	●?	●?	●?				●●	●●	●●	●	●?	●?

Rio Vista flows averaged above 20,000 cfs from April through June, the same level at which survival rates were maximum.

This evidence showed the inadequacy of Delta outflow standards in the 1978 Delta Plan where outflow standards in May and June were predicted to result in survival rates of only 5 percent in dry years to 35 percent in wet years. Reductions in Delta inflow combined with Delta diversions were estimated to have reduced average smolt survival through the Delta by at least 30 percent since 1940. Reduced smolt survival impacts resulting adult salmon population levels, although other factors that influence abundance both upstream and in the ocean make the impact difficult to quantify.

Similar relationships showing the benefit of increased flows were reported in previous USFWS publications (Kjelson et al., 1981, Kjelson et al., 1982). Confirming and updating the relationships reported in 1987, Kjelson and Brandes (1989) reported that survival of smolts through the Delta from Sacramento to Suisun Bay was highly correlated to mean daily Sacramento River flow at Rio Vista.

Dettman et al. (1987) reanalyzed data from the USFWS coded-wire tag experiments, comparing the return of tags recovered from spawning escapements with Sacramento River flow and Delta outflow. They found a positive correlation between an index of spawning returns, based on coded-wire tagged fish, and both June and July outflow from the Delta.

USFWS (1992) presented additional evidence, based on data collected from 1988 to 1991, that increased flow in the Delta may increase the migration rate of both wild and hatchery fish migrating from the North Delta (Sacramento and Courtland) to Chipps Island.

Brandes and McLain (2001) confirmed the direct relationships between water temperature, water flow, and juvenile salmonid survival. Updating these relationships with data through 2005, Brandes et al. (2006) found that the mean catch of unmarked Chinook salmon smolts per cubic meter in the midwater trawl survey at Chipps Island between April and June of 1978 to 2005 was positively correlated with mean daily Sacramento River flow at Rio Vista between April and June.

From 1997 to 2008, several statistical models were developed based on the USFWS juvenile salmon survival studies that indicate the importance of flow as a variable in predicting juvenile salmon survival through the Delta (Newman and Rice 1997, Newman 2002, Newman 2003, Newman 2008). Each of these models used different approaches with the effects of flow examined as a factor in each model. The models attempt to separate the effects of flow from other variables, such as water temperature and diversion rates. These models are available for further analysis in developing Delta outflow criteria for the protection of juvenile Chinook salmon.

In recent years, studies have been conducted using acoustic tag technology to determine the effects of Delta Cross Channel Gate operations on juvenile salmon survival through the Delta (Perry et al. 2008 and 2009). Modeling studies based on these experiments indicate that increasing Sacramento River flow such that tidal reversal does not occur in the vicinity of the Cross Channel Gates would lessen the proportion of fish diverted into channels off the mainstem Sacramento River. Survival was greatest for fish that remained in the mainstem river.

Delta outflow needs for Sacramento River Chinook salmon are a continuum of conditions that begin in upstream riverine habitats and progress through the Sacramento-San Joaquin Estuary. These flow conditions provide the contiguous habitat that is necessary to support the anadromous life cycle of Chinook salmon. Given this continuity, a discussion of Delta outflow needs for Chinook salmon must also involve an assessment of upstream relationships between flow and Chinook salmon survival. Exhibits submitted to the Water Board by the U.S. Fish and Wildlife Service (1987) and DFG (in 1992) in earlier proceedings remain relevant within this area of inquiry. More recent investigations provide additional information that the Department would like to bring to the attention of the Water Board.

DFG has monitored the emigration of juvenile Chinook salmon on the lower Sacramento River near Knights Landing since November 1995. Information developed from this monitoring (Snider and Titus 1998, 2000a, 2000b, 2000c, and subsequent draft reports and data) provides evidence of a relationship between timing and magnitude of flow in the Sacramento River and the migration timing and survival of Chinook salmon approaching the Delta from the upper Sacramento River basin. As described in Allen and Titus (2004), the emigration timing of juvenile late-fall, winter, and spring-run Chinook salmon from the upper Sacramento River basin is dependent upon substantial increases in river flow through the lower Sacramento River in fall. Significant precipitation in the basin by November sustains downstream migration of juvenile Chinook salmon approaching the Delta. This pattern of emigration is associated with Sacramento River flow at Wilkins Slough peaking above 20,000 cfs with accretion of flow from tributaries in the upper basin following major precipitation events.

When significant precipitation producing flows of this magnitude is delayed – in some years until after the first of the year – emigration of juvenile Chinook salmon is also delayed. Under such conditions, Chinook salmon lingering in their migration experience protracted exposure to in-river mortality factors such as predation and poor water quality. Consequently, survival of juvenile Chinook salmon to the Delta is reduced. A functional relationship in Allen and Titus (2004) suggests that the longer the delay in migration, the lower the survival to the Delta. Thus, juvenile Chinook salmon appear to need increases in Sacramento River flow that correspond to flows in excess of 20,000 cfs at Wilkins Slough by November and with such peaks continuing past the first of the year.

As discussed earlier, high levels of Chinook salmon smolt abundance and survival in the Delta are also associated with Sacramento River flow in excess of 20,000 cfs at Rio Vista (USFWS 1987). The monitoring and research being conducted independently at Knights Landing and in the Delta both indicate that flows in the lower Sacramento River and Delta on the order of 20,000 cfs and above are an important environmental threshold for Chinook salmon emigration. That is, flow levels of this magnitude are necessary to provide the continuum of conditions necessary to sustain emigration of juvenile Chinook salmon and enhance their survival throughout the lower Sacramento River and Delta system. The primary period of concern for late-fall, winter, and spring-run begins in fall, as described above, and continues through at least March. Flow needs for fall-run Chinook salmon continue through at least May in the lower Sacramento River and June in the Delta, the latter portion of this period including production releases of fall run from Central Valley anadromous hatcheries.

2.1.2 San Joaquin River

The relationship between fall run Chinook salmon production and Delta outflow is presented in DFG Exhibit 3.

2.2 Pacific Herring

The Pacific herring (*Clupea pallasii*) is a marine member of the family Clupidae that ranges along the Pacific coast from northern Baja California northward throughout Alaska and south in the western Pacific to Japan (Miller and Lea 1972). Native to the San Francisco Estuary, it uses bays and estuaries as both spawning and rearing habitats. San Francisco Bay represents the only substantial spawning area south of Puget Sound (Alderdice and Velsen 1971, Watters et al. 2004). Pacific herring support a commercial fishery in San Francisco Bay, although increased fuel prices and decreasing value of herring products led to much reduced fishing effort in the 2007-2008 season, with only 64 percent of the quota reached (Fish et al. 2009).

Mature adults (age 2 or 3 and older) return to San Francisco Bay to spawn adhesive eggs on hard structures or vegetation from November through May with peak spawning in January (Spratt 1981, Watters et al. 2004. see Table 1). Adults appear to select regions of reduced salinity (8-28 parts per thousand (‰)) for spawning (Fleming 1999). Based on laboratory experiments, eggs from the San Francisco Bay stock exhibited optimal hatching at about 16‰ (Griffith et al. 1998) and post-hatch survival was significantly higher at salinities below 32‰, and generally best at the intermediate salinity tested (4‰, 16‰ and 32‰ tested, Griffin et al. 2004). Moreover, larvae hatched in south and central San Francisco Bay subsequently are transported to San Pablo Bay (Bollens and Sanders 2004) or migrate as juveniles to San Pablo and Suisun bays (Fleming 1999). Typically, salinities are reduced upstream. High winter outflows are necessary to drive strong gravitational currents (Monismith et al. 1996) and these in turn can transport bottom-oriented organisms such as Pacific herring larvae upstream. Thus, winter and early spring outflows sufficient to reduce lower estuary salinity between November and May can function to improve egg survival to hatch, larval survival and larval transport to rearing habitats in San Pablo and less frequently Suisun bays.

Based on the aforementioned mechanisms, Kimmerer (2002a) investigated the relation between mean January through April X_2 location (related to outflow from December through April) on an index of Pacific herring survival and found that survival improved substantially as X_2 moved downstream, but the effect was not significant. A more recent analysis of X_2 location and juvenile Pacific herring abundance showed no relationship, suggesting additional factors other than habitat were involved, because both measures of herring habitat improved (one significantly) as X_2 shifted downstream (Kimmerer et al. 2009). Thus, outflow is an important component but not the sole driver of Pacific herring juvenile survival or abundance.

2.3 Longfin Smelt

The longfin smelt (*Spirinchus thaleichthys*) is a small, native, anadromous member of the true smelt family Osmeridae. Ranging from Alaska to California, the most southern breeding population inhabits the San Francisco Estuary (Moyle 2002). The longfin smelt in California is currently a candidate for threatened species status[2] (CESA).

Toward the end of its primarily 2-year life cycle, maturing adults migrate toward fresh water in late fall and stage in low salinity water, often found in Suisun Bay, before spawning (Rosenfield and Baxter 2007, CDFG 2009a and b). Spawning probably takes place in freshwater (Wang 1986, Moyle 2002) where adhesive eggs are scattered on sand substrates from November through April, peaking in January (see CDFG 2009a. Table 1). Thus, the geographic regions where adult fish stage and downstream boundary of spawning are both influenced by the prevailing location of X_2 during late fall, winter, and spring. Based on historical larval sampling, Moyle (2002) identified principal spawning regions as the lower Sacramento River from Rio Vista to the confluence and the lower San Joaquin River from Medford Island to the confluence. The Cache Slough complex is also an important spawning area, particularly during low outflow periods (CDFG 2009a and b). Longfin smelt hatch into buoyant larvae from December through May, peaking in February (Table 1 in CDFG 2009a), and are immediately transported by prevailing currents. Larval distribution is related to winter-spring outflow and initially closely associated with the position of X_2 (CDFG 1992a, Baxter 1999a, Dege and Brown 2004); that is, larvae are transported farther downstream when outflow increases and X_2 is shifted downstream. Larval and early juvenile longfin smelt habitat is modeled best by salinity and Secchi depth (Kimmerer et al. 2009, Table 3, 20mm Survey), and their resource selection based on salinity is most narrow among all life stages (Kimmerer et al. 2009, Figure 5f, 20mm Survey). The longfin smelt larva and early juvenile resource selection function peaks at about 2 ‰ and declines rapidly to about 12 ‰ before tailing off, indicating strong selectivity for low salinity habitat. Both low salinity habitat and increased turbidity are functions of outflow. As fish grow, juveniles disperse more broadly (Baxter 1999a, Rosenfield and Baxter 2007) and inhabit a broader range of salinities (Baxter 1999a, Kimmerer et al. 2009).

[2] On March 4, 2009 the Fish and Game Commission (Commission) made a final determination that the listing of longfin smelt as a threatened species was warranted. The Commission has initiated a rulemaking process to officially add longfin smelt to the California Endangered Species Act (CESA) list of threatened species found in the California Code of Regulations (CCR), Title 14, section 670.5(b)(2). At the completion of this rulemaking process, the longfin smelt's status will officially change from candidate to threatened.

In our previous testimony we identified February through May as the most critical period for longfin smelt based upon first feeding and development (CDFG 1992a). More recently we hypothesized that freshwater outflow during the incubation and early rearing periods (December through May) had a strong positive affect on longfin smelt recruitment to the juvenile stage (Baxter 1999a, CDFG 2009a). Outflow during the December through May period continues to have a significant positive relationship to longfin smelt abundance even though the relationship changed after the introduction of the over-bite clam *Corbula amurensis* (Figure LF1, see also Kimmerer 2002a and b). After 2000, the outflow-abundance relationship appeared to change once again, but not consistently across all surveys (cf, Figures LF1a&b and LF1c). The relationship did not appear to change for the Bay Study otter trawl sampling (Figure LF1c), which samples longfin smelt more effectively in the lower San Francisco Estuary, from San Pablo Bay through Central San Francisco Bay. More importantly the outflow abundance regressions for years 2001-2008 all remain positive, indicating that increasing outflow continues to be beneficial to longfin smelt.

2.4 Prickly Sculpin

The prickly sculpin (*Cottus asper*) is a common native species found in coastal streams from Alaska to southern California, and is widespread in low elevation streams of California's Central Valley (Moyle 2002). Its larvae and small juveniles are tolerant of fresh, brackish, and even marine waters (Wang 1986, Moyle 2002).

Adhesive eggs are laid on hard substrates in fresh or brackish water from January through June, but primarily in March and April in California (Krejsa 1965, Baxter 1999b, Moyle 2002. see Table 1). In coastal streams, a distinct downstream movement of adults prior to spawning has been observed (Shapovalov and Taft 1954), which presumably places eggs and larvae near estuarine rearing habitat. Larvae hatch within a month, begin swimming soon after hatching and remain planktonic for 3-5 weeks (Krejsa 1967) providing a long period for dispersal. In the San Francisco Estuary, larvae were caught from January through May, in high numbers in March and April (Baxter 1999b; see Table 1). During high outflow years larvae were collected in all embayments and their distribution expanded downstream and numbers increased with increasing outflow (Baxter 1999b), presumably based on larvae from the Sacramento and San Joaquin river systems and from smaller tributaries emptying into the San Francisco Estuary. They metamorphose to juveniles and settle to the bottom at about 12 mm total length (TL) or slightly larger (Krejsa 1967, Moyle 2002). Juveniles begin moving upstream soon after settlement (Moyle 2002), and juveniles and adults are not commonly collected in open waters of the upper estuary and Delta (Baxter 1999b).

Juvenile and adult prickly sculpin are not well collected in open waters of the San Francisco Estuary (Baxter 1999b), so no indices of abundance are calculated and no relationship can be investigated between outflow and species abundance. Nonetheless, larval dispersal appears to be a function of winter-spring outflow (see Baxter 1999b) and such dispersal can benefit the populations by facilitating genetic transfer between streams that might otherwise be isolated from one another by high salinities.

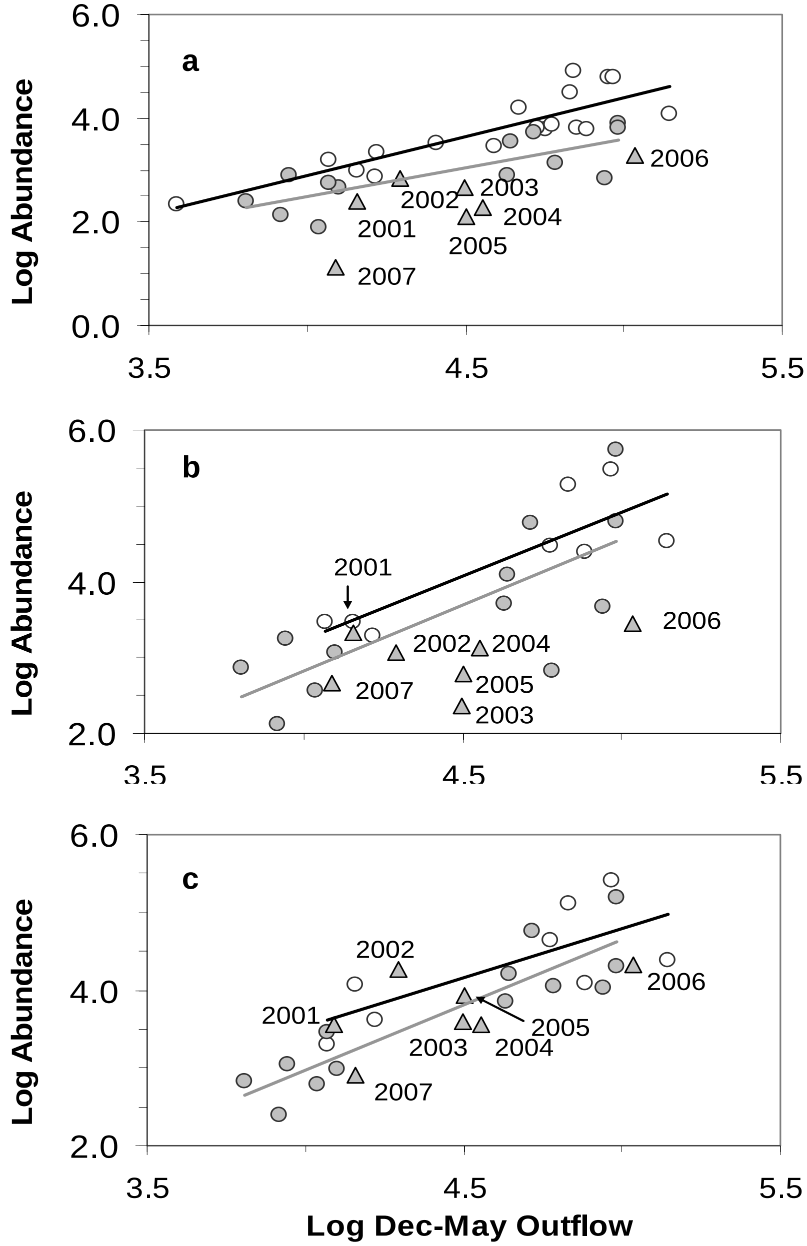
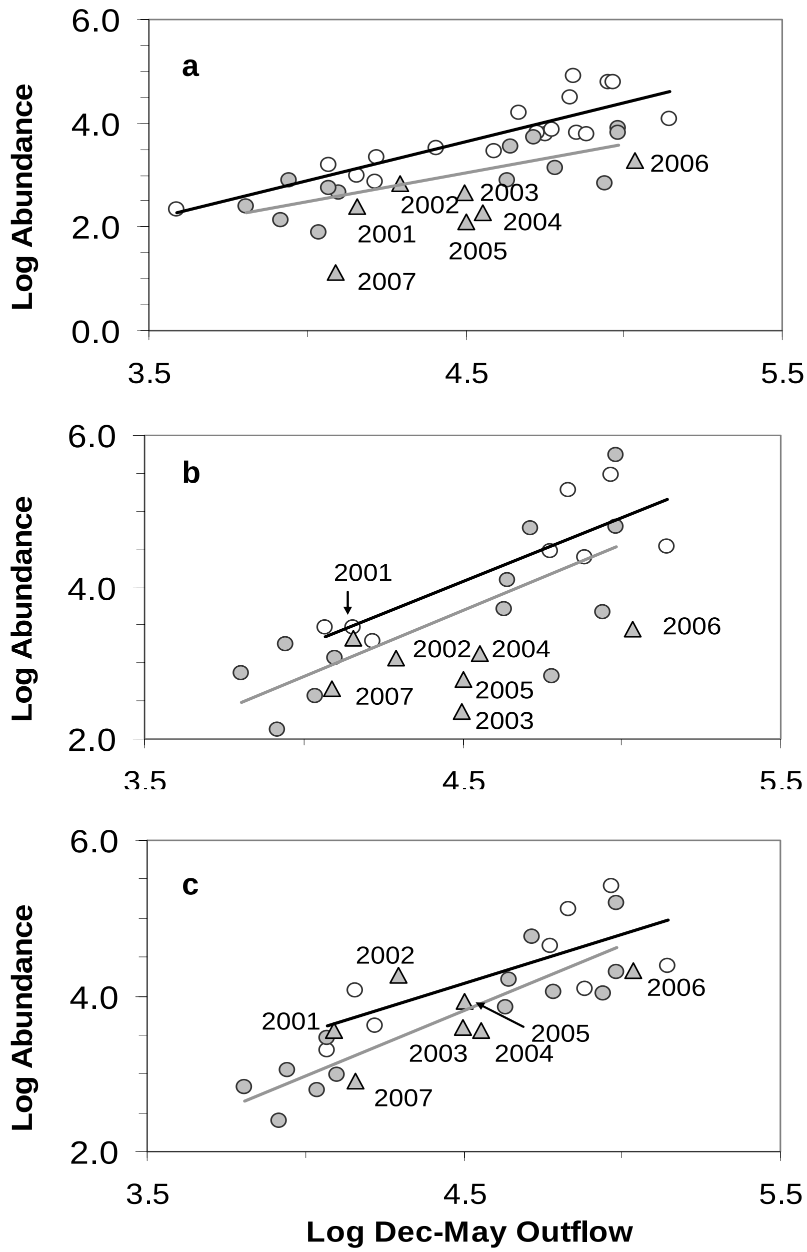


Figure LF1. Longfin smelt annual abundance indices plotted on December through May mean delta outflow for a) Fall Midwater Trawl (all ages); b) Bay Study Midwater Trawl Age 0; c) Bay Study Otter Trawl Age 0. Relationships depicted are pre- *Corbula amurensis* (1967-1987; open circles, black line) and post- *Corbula amurensis* (1988-2000; filled circles, grey line) and more recent years during the Pelagic Organism Decline (POD) (2001- 2007, grey triangles, no line). Lines indicate the relationship is significant, $p < 0.05$. Source CDFG 2009a



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2.5 Splittail

The Sacramento splittail (*Pogonichthys macrolepidotus*) is a cyprinid native to California that can live 7-9 years and has a high tolerance to a wide variety of water quality parameters including moderate salinity levels (Moyle 2002, Moyle et al. 2004). Adult splittail are found predominantly in the Suisun Marsh, Suisun Bay, and the western Delta, but are also found in other brackish water marshes in the San Francisco Estuary as well as the fresher Sacramento-San Joaquin Delta. Splittail feed on detritus and a wide variety of invertebrates; non-detrital food starts with cladocerans and aquatic fly larvae on the flood plains, progresses to insects and copepods in the rivers, and to mysid shrimps, amphipods and clams for older juveniles and adults (Daniels and Moyle 1983, Feyrer et al. 2003, Feyrer et al. 2007a). In winter and spring when California's Central Valley experiences increased runoff from rainfall and snowmelt, adult splittail move onto inundated flood plains to forage and spawn (Meng and Moyle 1995, Sommer et al. 1997, Moyle et al. 2004). Spawning takes place primarily between late-February and early July, and most frequently during March and April (Wang 1986, Moyle 2002) and occasionally as early as January (Feyrer et al. 2006a). After spawning the adult fish move back downstream. The eggs, laid on submerged vegetation, begin to hatch in a few days and the larval fish grow fast in the warm and food rich environment (e.g., Moyle et al. 2004, Ribeiro et al.2004).

Once they have grown a few centimeters, the juvenile splittail begin moving off of the flood plain and downstream into similar habitats as the adults. These juveniles become mature in 2 to 3 years. In the Yolo Bypass, 2 flow components appeared necessary for substantial splittail production (Feyrer et al. 2006a): (1) inundating flows in winter (January-February) to stimulate and attract migrating adults; and (2) sustained flood plain inundation for 30 or more days March through May or June to allow successful incubation through hatching (3-7 days, see Moyle 2002) and extended rearing until larvae are competent swimmers (10-14 days; Sommer et al. 1997) and beyond to maximize recruitment (see Table 1).

Large-scale spawning and juvenile recruitment occurs only in years with significant protracted (≥30 days) flood plain inundation, particularly in the Sutter and Yolo bypasses (Meng and Moyle 1995, Sommer et al. 1997, Feyrer et al. 2006a). Some spawning also occurs in perennial marshes and along the vegetated edges of the Sacramento and San Joaquin rivers (Moyle et al. 2004). During periods of low outflow, splittail appear to migrate farther upstream to find suitable spawning and rearing habitats (Feyrer et al. 2005).

Splittail age-0 abundance has been significantly correlated to mean February through May Delta outflow and days of Yolo Bypass flood plain inundation, representing flow/inundation during the incubation and early rearing periods (Meng and Moyle 1995, Sommer et al. 1997). Splittail abundance was highest when the Yolo Bypass remained flooded for 50 days or more (Meng and Moyle 1995). Since Feyrer et al. (2006a) observed adult migrations stimulated by flow and estimated spawning could occur as early as January, January is included in recommendations for outflow (Table 1). Flood plain inundation during the months of March, April and May appears to be most important (see Wang 1986 and Moyle 2002).

Managing the frequency and duration of floodplain inundation during the winter and spring, followed by complete drainage by the end of the flooding season, could favor splittail and other native fish over non-natives (Moyle et al. 2007, Grimaldo et al. 2004). Duration and timing of inundation are important factors that influence ecological benefits of floodplains. PWA and Opperman (2006) have defined a flood plain activation flow on the Sacramento River.

2.6 Delta Smelt

The delta smelt (*Hypomesus transpacificus*) is a small silvery fish that is slightly translucent with a blue sheen in its sides, and is a true smelt of the family Osmeridae. It is endemic to the upper San Francisco Estuary, where it inhabits low salinity waters in channels and shoals of Suisun Bay, Suisun Marsh, and Delta (Moyle et al. 1992, Moyle 2002). In high outflow periods they can be transported into San Pablo Bay, but they do not reside there. Delta smelt is currently listed as endangered under the California Endangered Species Act (CESA) and threatened under the Federal Endangered Species Act (FESA).

Delta smelt is an annual fish and most adults die following spawning in the spring, but a few do survive to a second year (Moyle et al. 1992). Young delta smelt grow rapidly during summer and reach adult lengths (55-70 mm standard length (SL)) by September (Moyle 2002). A diffuse upstream migration to spawning areas begins in September and October (Moyle 2002). Spawning occurs in freshwater from late January to late June or early July (Wang 2007), with the majority occurring in April and May (Moyle 2002) in temperatures 7-15°C (Wang 1986). Spawning areas include the lower Sacramento, Mokelumne, and San Joaquin rivers, the west and south Delta, Suisun Bay, Suisun Marsh, and occasionally in wet years, the Napa River (Wang 2007). Female delta smelt have a low fecundity. Mager (1996) reported female (56-66 mm fork length (FL)) egg counts ranged 1,190-1,856 and Moyle et al. (1992) reported slightly larger counts 1,247-2,590 for females in a larger size range (59-70 mm SL). Eggs are negatively buoyant and adhesive (Wang 1986). Larvae hatch at around 13 days (Mager 1996). Delta smelt at hatch are semi-buoyant keeping near the bottom, which might prevent them from being swept downstream until the air bladder and swimming ability have developed (Mager 1996). Within a few weeks, larvae develop an air bladder and become pelagic, utilizing vertical movement in the water to better maintain position (Moyle 2002, Bennett et al.2002).

Freshwater outflow during spring (March-June) affects distribution of larvae by carrying them to the low salinity habitat (1-7 ‰) (Dege and Brown 2004, Table 1). High spring outflows transport larvae and juveniles farther downstream than low flows, but both life stages were centered well above X_2 in spring and their distributions shifted toward X_2 in summer (Dege and Brown 2004). Flows that locate X_2 into the shallow waters of Suisun Bay are noted to result in high survival rates (Moyle 2002) and high abundance of delta smelt (Jassby et al. 1995). Extremely high outflow events can carry some delta smelt downstream out of rearing areas in the west Delta and Suisun Bay and into San Pablo Bay. During periods of low outflow Delta residence time increases thus prolonging exposure to higher water temperatures and increased risk of entrainment at the State and Federal pumping facilities (Moyle 2002). Delta smelt are zooplanktivores and calanoid copepods are a major prey type; *Eurytemora affinis* is an important food of larvae and small juveniles in spring, and the introduced *Pseudodiaptomus forbesii* becomes the dominant food in summer (Lott 1998, Nobriga 2002).

In previous testimony (CDFG 1992b), multiple factors were identified as potentially responsible for decline in delta smelt abundance including, but not limited to, non-optimal flows, low food supply, and entrainment (Moyle 2002). Delta smelt abundance does not respond to freshwater outflow in a predictable (linear) manner as for other estuarine fishes (Stevens and Miller 1983, Kimmerer 2002a). Delta smelt distribution is influenced by outflow through its influence on the location of X_2 (Moyle et al. 1992, Dege and Brown 2004). Outflows that locate X_2 in Suisun Bay (mean April through July location) produce the highest delta smelt abundance levels (Table 1), however, low abundance has also been observed under the same conditions, which indicates several mechanisms must be operating (Jassby et al. 1995). Although outflow did not positively affect delta smelt abundance, outflow did have significant positive effects on several measures of delta smelt habitat (Kimmerer et al. 2009), and spring outflow significantly increased spring abundance of *E. affinis* (Kimmerer 2002a), an important delta smelt prey item.

2.7 Starry Flounder

The starry flounder (*Platichthys stellatus*) is native to the San Francisco Estuary and ranges from Santa Barbara, California northward to Arctic Alaska and in the western Pacific south to the Sea of Japan (Miller and Lea 1972). Within that range juvenile and adult habitats are segregated, with juveniles seeking shallow, fresh to brackish water of bays and estuaries to rear, and adults primarily inhabiting coastal marine waters (Haertel and Osterberg 1967, Bottom et al. 1984, Wang 1986, Baxter 1999c). The starry flounder, though not targeted, shows up commonly in both recreational and commercial fisheries in central and northern California (Haugen 1992, Karpov et al. 1995).

Spawning occurs between November and February and generally takes place over shallow coastal marine areas, often near river and slough mouths (Orcutt 1950). Eggs and larvae are pelagic and found high in the water column (Orcutt 1950, Wang 1986). Larvae are pelagic for about 2 months before settling to the bottom at about 7 mm standard length (see Baxter 1999c). During this pelagic period, larvae depend upon favorable ocean currents to transport them to or keep them near their estuarine nursery areas prior to settlement. Transforming larvae and small juveniles migrate from coastal marine waters to brackish and fresh waters where they rear for their first 1-3 years of life (Haertel and Osterberg 1967, Bottom et al. 1984, Wang 1986, Baxter 1999c). Juveniles initially seek shallow, relatively warm brackish and freshwaters to rear, and move to more saline water as they grow, but generally remain within estuaries through at least their second year of life (Haertel and Osterberg 1967, Bottom et al. 1984, Wang 1986, Baxter 1999c). Maturity is reached at the end of their 2nd (males) or 3rd- 4th years of life (females) (Orcutt 1950) by which time starry flounder is at most a seasonal visitor to the San Francisco Estuary. The starry flounder is believed to be an estuarine dependent species (Emmett et al. 1991).

Starry flounder abundance in the estuary is significantly and positively correlated to March through June outflow, when larvae and juveniles are locating the estuary, immigrating and beginning to rear (CDFG 1992a, Jassby et al. 1995, Kimmerer 2002a and 2002b, Kimmerer et al. 2009,. Table 1). There are several direct mechanisms by which outflows can enhance starry flounder abundance: (1) outlfows can provide chemical cues to larvae and juveniles to facilitate locating estuarine nursery habitat; (2) high outflows generate bottom-oriented upstream-directed gravitational currents that assist immigration; (3) flows enhance the area of low salinity habitat selected by young starry flounder (see CDFG 1992a). Indirectly, high river flows strongly correlate with the abundance of the bay shrimp, *Crangon franciscorum*, (CDFG 1992a) an important food source for starry flounder.

2.8 White Sturgeon

White sturgeon (*Acipenser transmontanus*) is a very long-lived native anadromous fish. Its longevity allows it to reach a large size, reportedly as large as 1,300 pounds and over 100 years of age. The California sport fishing record is a 468-pound fish that was probably 40 to 50 years old. The white sturgeon is found along the west coast of North America from Monterey to southern Alaska, but is most abundant in large river systems such as the Fraser, Columbia, and Sacramento-San Joaquin. It spends most of its life in rivers and estuaries and only occasionally migrates to the ocean. It is the most common sturgeon in the San Francisco Estuary and an important sport fish.

Adult white sturgeons migrate from the San Francisco Estuary through the Delta to the major Central Valley rivers in winter and early spring to spawn. The primary spawning area is in the Sacramento River from Knights Landing to just above Colusa (Kohlhorst 1976). Adult sturgeon have also been reported in the Feather and San Joaquin rivers during spawning season, but no eggs or larvae have been collected at these locations (Miller 1972, Kohlhorst et al. 1991). Spawning occurs from mid-February through early June and peaks from March through May (Kohlhorst 1976, Schaffter 1997). Larvae were collected primarily in the rivers during periods of low flow, but were transported to the Delta and Suisun Bay by higher flows (Stevens and Miller 1970, Kohlhorst 1976).

Small juvenile white surgeon had a strong downstream swimming behavior in the laboratory (Kynard and Parker 2005), which could quickly disperse them to estuarine nursery habitat. Young sturgeon grow rapidly, reaching approximately 30 cm (12 inches) total length (TL) by the end of their first year and 46 cm (18 inches) TL by the end of their second year (Kohlhorst et al. 1980). However, they mature slowly – most females are at least 135 cm (53 inches) TL or 14 to15 years old at first spawning (Kohlhorst et al. 1980, Chapman et al. 1996). In addition, mature females are capable of spawning only every 2 to 4 years, not annually (Chapman et al. 1996).

There is periodically strong recruitment of young white sturgeon in the San Francisco Estuary (Figure 1). A strongly positive relationship between juvenile sturgeon abundance and spring to early-summer Delta outflow was previously reported (Kohlhorst et al. 1991, CDFG 1992c) and has been updated through 2007 (Figure 1, Fish 2010). The strongest year classes occurred in years with mean monthly March-June Delta outflow >60,000 cfs. It has been proposed that high river and Delta flows may improve larval white sturgeon survival by transporting larvae to areas with higher productivity, dispersing larvae downstream to a larger nursery area, transporting larvae more quickly through the Delta lessening the influence of the water diversions, or by enhancing productivity in the nursery area (Kohlhorst et al. 1991). Higher river and Delta flows would also provide the same benefits for small juveniles.

There is also evidence that higher flows attract more adults to migrate upstream in late winter and spring, which results in increased spawning (Kohlhorst et al. 1991). Indeed, all of the strong white sturgeon year classes occurred in years with high December to February Delta outflow, >60,000 cfs (Figure 2), but not all years with high winter outflow resulted in a strong year class (e.g. 1980, 1984, 1986, 1999). River flows reportedly cue spawning, as no spawning was detected at Sacramento River flows <180 cms (≈ 6,400 cfs) near Colusa (Schaffter 1997). In addition, white sturgeon stopped their upstream migration and drifted downstream when Sacramento River flows dropped below 150 cms (≈ 5,300 cfs) near Colusa (Schaffter 1997).

Our working hypothesis is that adult white sturgeon respond to winter flows from and through the Delta that stimulate migration (attraction flows) and spring flows February through May in the rivers that cue spawning (Table 1). Larvae benefit from spring river and Delta flows that transport them downstream to estuarine nursery areas. Juvenile white sturgeon may also benefit from spring river and Delta outflows that aid their downstream dispersal and spring Delta outflow, if it enhances nursery habitat quantity and quality. The high winter and spring Delta and river flows needed to attract migrating adults, cue spawning, transport larvae, and enhance nursery habitat happen only periodically in the San Francisco Estuary. Historical flow patterns combined with the unique life history of white sturgeon (long-lived, late maturing, long intervals between spawning, high fecundity) resulted in infrequent strong recruitment in the San Francisco Estuary.

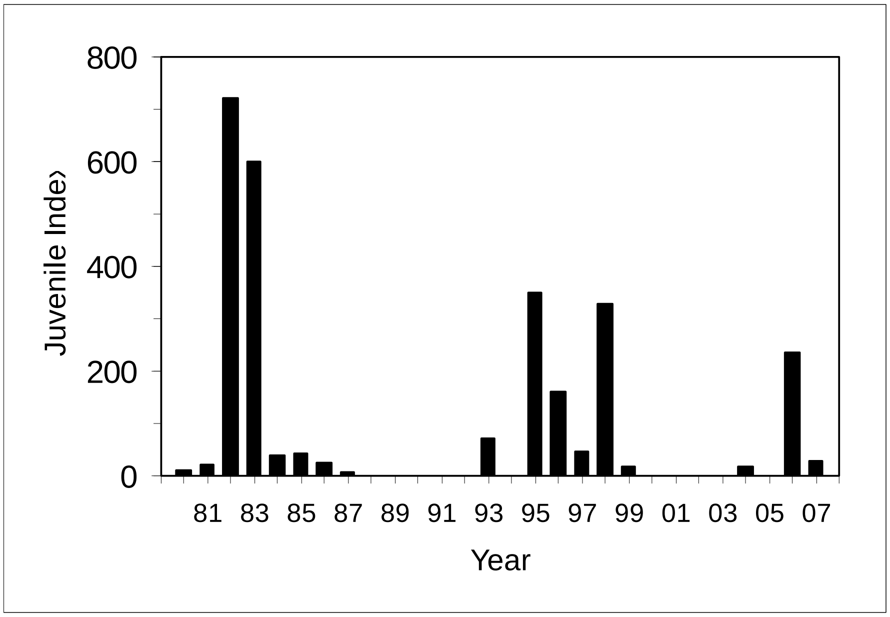

Figure 1. Annual abundance index of juvenile (age-0 and age-1) white sturgeon from CDFG's San Francisco Bay Study otter trawl, 1980-2007.

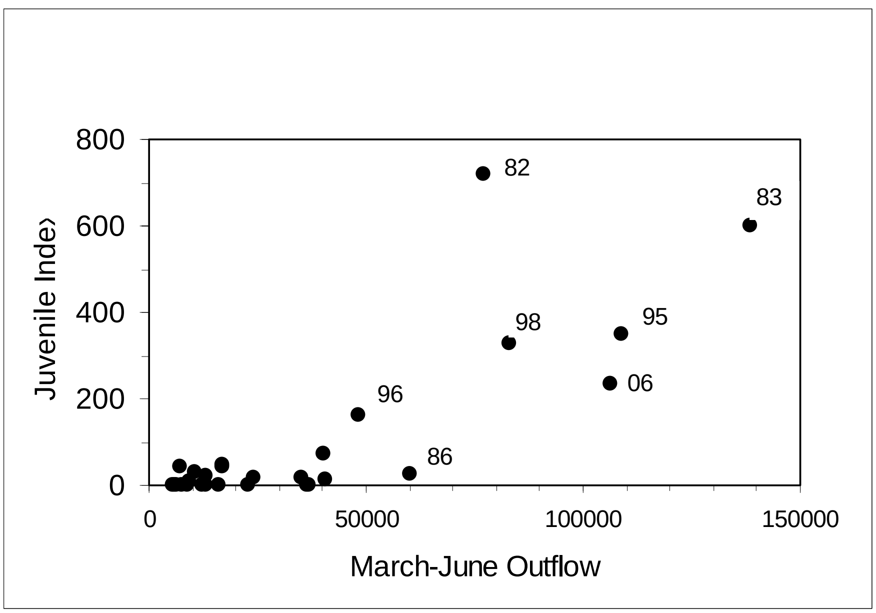

Figure 2. Annual abundance index of juvenile (age-0 and age-1) white sturgeon from DFG's San Francisco Bay Study otter trawl vs. March to June mean monthly Delta outflow (cfs) at Chipps Island, 1980-2007.

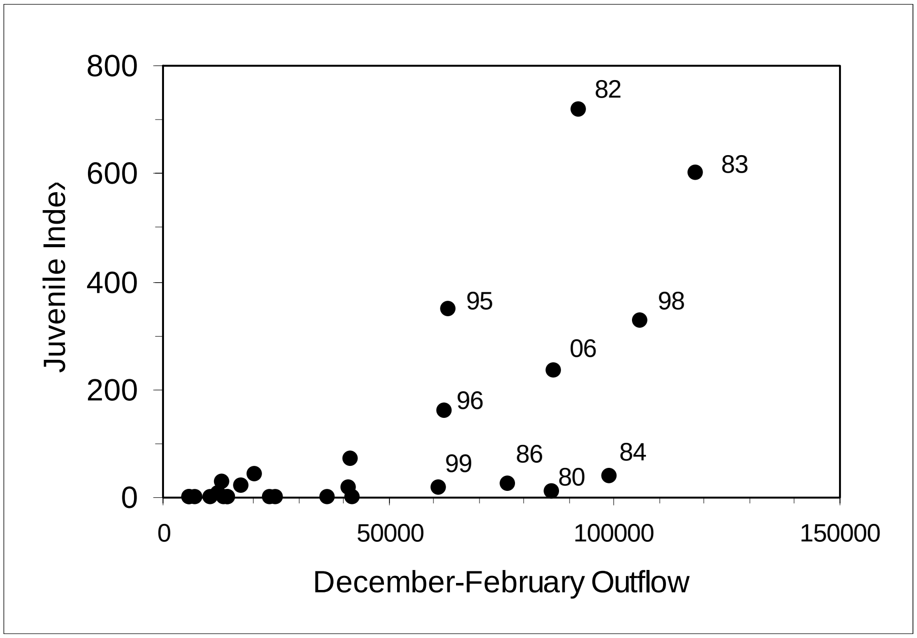

Figure 3. Annual abundance index of juvenile (age-0 and age-1) white sturgeon from DFG's San Francisco Bay Study otter trawl vs. December to February mean monthly Delta outflow (cfs) at Chipps Island, 1980-2007.

2.9 Green Sturgeon

Green sturgeon (*Acipenser medirostris*) is an anadromous species found around the rim of the North Pacific Ocean, from Monterey, California to Japan (Miller and Lea 1972). The green sturgeon is less abundant in North America than the white sturgeon. In the San Francisco Estuary, ratios of adult green to white sturgeon have ranged from 1:5 to 1:175 during tagging studies, but have averaged near 1:25 (CDFG, unpublished). The green sturgeon Southern Distinct Population Segment (sDPS), which includes all waters of the San Francisco Estuary, is listed as threatened under the federal Endangered Species Act and all local green sturgeon fisheries are currently closed.

Little is known about green sturgeon life history. The green sturgeon is the most marine of the North American sturgeon and it makes extensive ocean migrations, so that most recoveries of individuals tagged in San Pablo Bay have come from the ocean and Washington and Oregon rivers and estuaries (CDFG, unpublished).

Adult green sturgeon migrate from the San Francisco Estuary through the Delta to the Sacramento River in spring, spawn in late spring and early summer, oversummer, and move downstream with the first fall flow event (Heublein et al. 2009). Spawning is presumed to occur in the mainstem Sacramento River from the confluence of Battle Creek to upstream of Los Molinos. Red Bluff Diversion Dam collection of juvenile (25-50mm) green sturgeon peaked between May and August. Green sturgeon likely spawn in the Feather River, but this has not yet been substantiated (Adams et al. 2002). Unlike white sturgeon, which have a distinct swim-up post-hatch stage, green sturgeon are photophobic and exhibit a benthic "hiding" behavior for the first few days following hatching (Deng 2000). This likely results in different dispersal patterns between the two sturgeon species.

Most juveniles disperse from the upper rivers within several months of hatching, but spend 1 to 4 years in freshwater. Subadults are migratory, spending their next 12 to 16 years foraging in the coastal ocean (Lindley et al. 2008). Adults migrate out of San Francisco Bay and northward along the coast, returning to spawn every two to four years (Erickson and Webb 2007, Lindley et al. 2008). Mature males range from 15 to 30 years old and mature females range from 17 to 40 years old.

Flow regulation from reservoirs has had mixed effects on habitat suitability for green sturgeon. Many reaches have increased suitability in winter and spring, but some reaches have decreased suitability, particularly from late spring through early autumn, when adults are oversummering and juveniles rearing. Combined with restricted access to some historical spawning areas, it appears that the large water-storage reservoirs have curtailed the distribution of and spawning and rearing habitat for green sturgeon within the Sacramento–San Joaquin river basin (Mora et al. 2009).

Increased early spring Delta and river flows would likely increase attraction and successful migration of adult green sturgeon to the upstream spawning areas (Table 1). Increased late-spring to summer river flows would likely increase hatching success and survival of larval and young juvenile green sturgeon. Since the adults oversummer in the rivers post-spawning, sufficient river flows through fall are also important. It is not known when the juveniles disperse downstream, but since they spend at least one year in freshwater, river and Delta flows necessary to maintain quality nursery habitat should also be considered.

2.10 Pacific Lamprey

The Pacific lamprey,(*Lampetra tridentata)* is an anadromous parasite. It is collected throughout the North Pacific rim, ranging from Japan to Alaska and down to Baja California. It is the largest of the California lampreys, though dwarfed landlocked populations do exist upstream of major barriers.

Adult Pacific lamprey migrate upriver to spawn in late spring, though earlier and later migrations have been reported (Moffet and Smith 1950, Moyle 2002, Trihey and Associates 1996a). Adults generally migrate upriver several months to a year prior to spawning, with final maturation occurring in the river (Beamish 1980). In large river systems, there may be several distinct runs with unique migration and spawning timing. It has been suggested that in the Klamath River there are at least 2 distinct runs: a spring run which spawns immediately upon reaching spawning grounds, and a fall run which may migrate in the fall and hold over in the river to spawn the following spring (Anglin 1994).

Pacific lamprey generally migrates upstream nocturnally during periods of high flow, although they are capable of migrating across a wide range of flows. In the Santa Clara River, flows from 900-60,000 cfs supported active migration (Moyle 2002).

After spawning, embryos hatch in approximately 19 days (at 15°C) and spend a short time in the nest gravel. Ammocoetes then swim up into the current and settle out over soft substrate, which they bury in and begin the filter-feeding portion of their life (Moyle 2002). Ammocoetes can be active, moving and changing locations (mostly at night), but will remain in the river feeding on organic material in substrate for the entirety of the ammocoete stage, which probably lasts 5 to 7 years. Ammocoetes mature and develop eyes, teeth and a new suite of physiological functions and then commence their downstream migration, apparently during high flow events in the winter and spring, possibly coincidental with the adult upstream migration. CDFG collections of subadult Pacific lampreys in San Francisco Bay Estuary peaked from December through February. The median size was 120-140 mm TL (CDFG unpublished data).

Based on its life history, increased flows in the spring would likely support upstream migration of Pacific lamprey adults, and possibly downstream migration of newly transformed sub-adults. Summer and fall flows should be maintained such that stream temperatures remain below lethal levels and stranding of ammocoete colonies on streambed margins is avoided.

2.11 River Lamprey

The river lamprey (*Lampetra ayresi*) is a small anadromous predator, as parasitism often results in (and continues after) death (Beamish 1980). It can be found in rivers and streams throughout the west coast of North America from San Francisco Bay, California to southern Alaska.

Little is known about river lamprey life history in California. Information reported here is from British Columbia, Canada, so timing of events may be slightly different due water temperature, flow patterns, etc.

Adult river lamprey migrate upstream from the ocean to freshwater in fall. They mature and spawn in smaller tributaries from February to May. Adults generally die after spawning. Ammocoetes will remain in soft-substrate backwaters for probably 3 to 5 years. Ammocoetes begin transformation into adults during summer and after 9 to 10 months they begin their downstream migration to the ocean. CDFG collected subadult river lampreys in San Francisco Estuary year round, but collections peaked from December through March (CDFG unpublished data). Adult river lamprey only spend 3 to 4 months in saltwater before returning to the estuarine environment (Beamish 1980, Beamish and Youson 1987). CDFG collected adult river lamprey in San Francisco Estuary from November through May, with most collected in February and March (CDFG unpublished data).

Since river lamprey spawn in small tributaries, large-scale water projects will not likely have a large impact on spawning or hatching. Maintaining sufficient fall flows to support upstream migration and maintaining summer flows so that lethal temperatures and stranding of ammocoete colonies are avoided are likely the most important manageable actions. Increased spring flows would likely support downstream migration of newly transformed subadults.

2.12 Bay Shrimp

Six species of Caridean shrimp are common in the San Francisco Estuary: *Crangon franciscorum, C. nigricauda, C. nigromaculata, Heptacarpus stimpsoni, Palaemon macrodactylus, and Exopalaemon modestus*. The 3 species of Crangon and Heptacarpus are native while *Palaemon* and *Exopalaemon* are introduced. The life histories, predators, prey, and salinity and temperature preferences of *Crangon*, *Heptacarpus*, and *Palaemon* were reviewed in CDFG 1987a and Hieb 1999.

Crangon spp. are commonly referred to as "Bay shrimp" or "grass shrimp" and are fished commercially by trawl fishermen in the lower estuary, downstream of Suisun Bay. Bay shrimp are primarily sold as bait for sport fishermen and *C. franciscorum* is targeted because of its relatively large size. Earlier in this century, when there was a large market for dried shrimp, over 3 million pounds per year were landed (Reilly et al. 2001). Landings have declined over the past 3 decades, averaging 140,000 pounds per year in the 1980s but only 65,00 pounds from 2000-2008 (Reilly et al. 2001, CDFG 2000-2008 California Commercial Landings).

Crangon franciscorum ranges from southeastern Alaska to San Diego and is the dominant caridean shrimp in most Pacific coast estuaries. It is an estuary-dependent species that does not rear in the ocean. Larvae hatch from eggs carried by the females in the higher salinity waters of the lower estuary in winter. Small juveniles (5-10 mm total length) migrate upstream to the shallow brackish water nursery area in spring, where they grow for 4 to 6 months, and mature shrimp migrate downstream to higher salinity waters to complete the life cycle (Hatfield 1985). *C. franciscorum* mature at one year and have a short life span, with males living one to 1.5 years and females 1.5 to two years. Some females hatch more than one brood of eggs during a breeding season.

Juvenile *C. franciscorum* were most common in San Pablo and Suisun Bays during years with high freshwater outflow and their center of distribution moved upstream to Honker Bay and the lower portions of the Sacramento and San Joaquin rivers during low outflow years (CDFG 1992a, Hieb 1999). In the past 3 decades, the abundance of juvenile *C. franciscorum* was lowest in 1992, at the end of a prolonged drought, and highest in the late 1990s (Figure CF1). There is a strong positive relationship between the abundance of juvenile *C. franciscorum* and spring Delta outflow (Hatfield 1985, CDFG 1992a, Kimmerer 2002a, Hieb 2008), that has continued in recent years (Figure CF2).

Freshwater outflow from the Delta affects *C. franciscorum* at every life stage. With higher outflows, mature shrimp move further downstream and early stage larvae are transported to Central Bay and the nearshore coastal area. We hypothesize that freshwater outflow creates salinity gradients that are used by late-stage larvae and small juveniles to identify the mouth of the estuary and cue their upstream migration from the nearshore coastal area to the brackish-water nursery area (CDFG 1992a, Kimmerer 2002a, Kimmerer et al. 2009). Tidal and non-tidal landward bottom currents aid this migration to the nursery area and one of the non-tidal components, gravitational circulation, increases with increased freshwater outflow (Smith 1987, Monismith et al. 2002). Freshwater outflow also affects the size and location of the nursery area, the abundance of predators and food organisms, and the timing of the downstream movement of mature shrimp.

The period from March to May was selected as the time when freshwater outflow is most critical in the establishment of a strong year class of *C. franciscorum* in the estuary. Most late-stage larval and small juvenile *C. franciscorum* migrate into the estuary and upstream to the nursery area between April and June and then begin a period of rapid growth. In years with low freshwater outflow the salinity gradient moves upstream and there is much less shallow brackish-water habitat then in high outflow years (CDFG 1992a). The size of the brackish-water nursery area is important to juvenile *C. franciscorum* for several reasons, including increased food and space, reduced inter- and intra-specific competition, and reduced predation (CDFG 1992a).

Crangon franciscorum has evolved to use San Francisco Estuary as a nursery area in the spring and early summer when freshwater outflow results in a salinity gradient that helps immigrating late-stage larvae and small juveniles identify the mouth of the estuary and cues their upstream migration. Freshwater outflow also produces strong landward bottom (gravitational) currents that aids this upstream migration and creates a large area of shallow brackish water in San Pablo and Suisun bays used for rearing (CDFG 1992a).

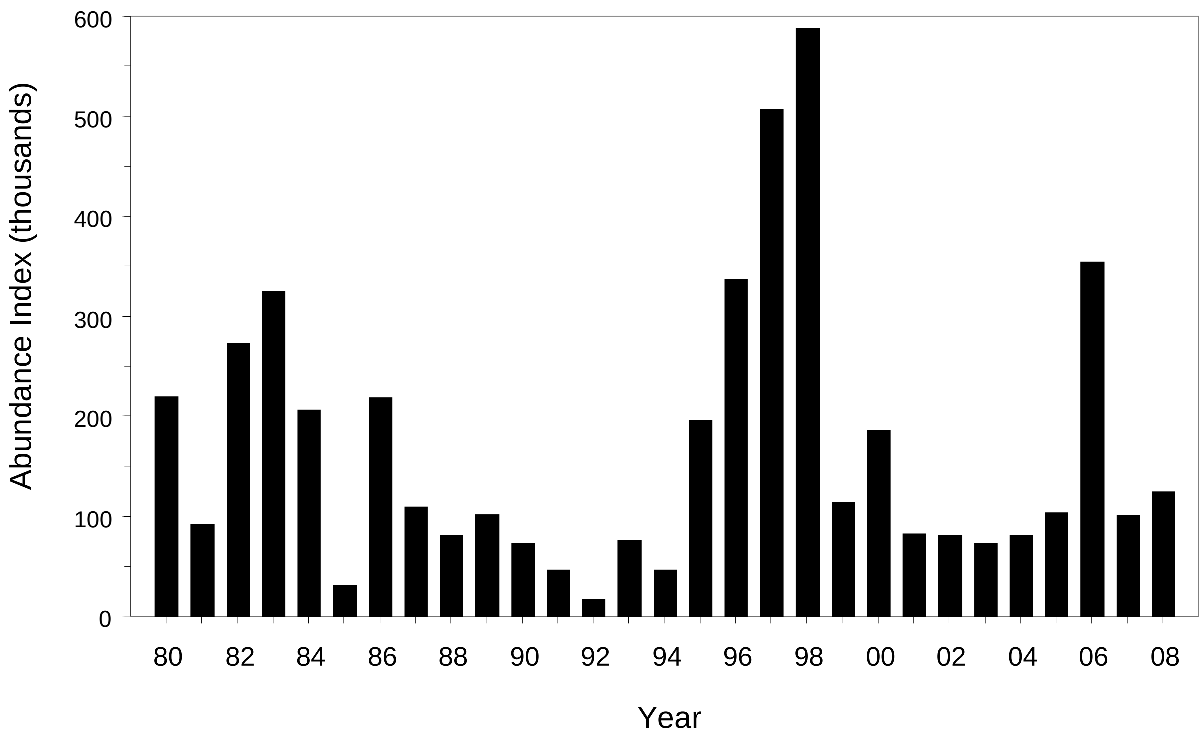

Figure CF1. Annual abundance of juvenile *Crangon franciscorum* from CDFG's San Francisco Bay Study, 1980-2008.

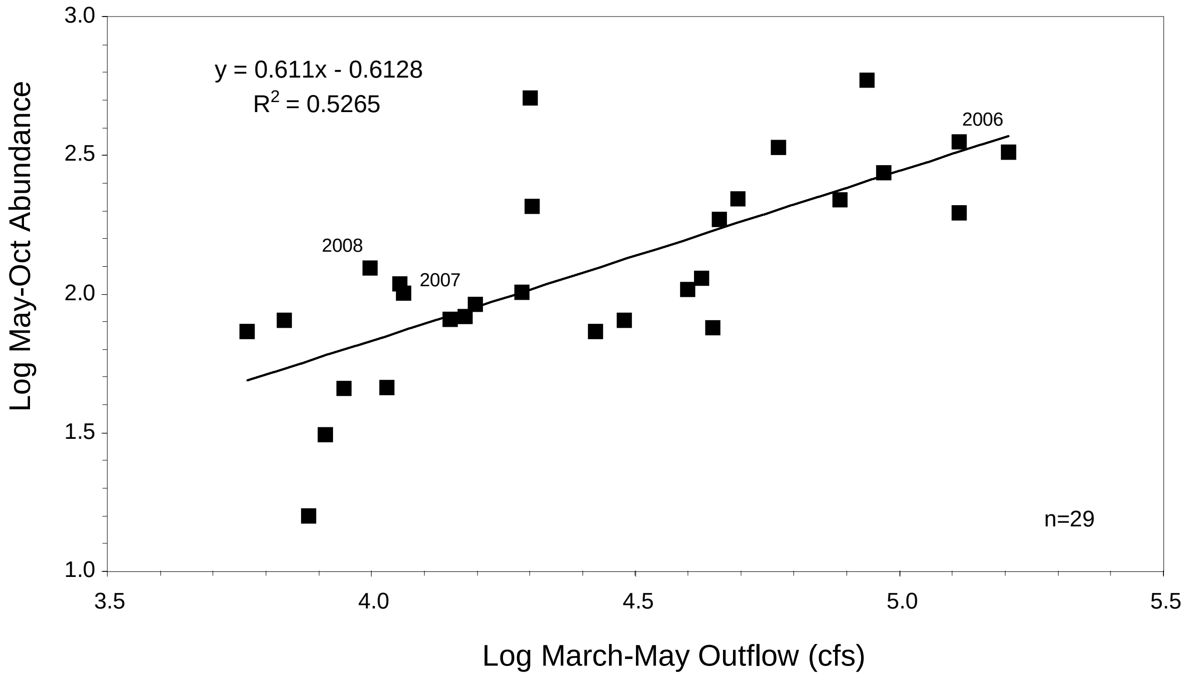

Figure CF2. Annual abundance index of juvenile *Crangon franciscorum* from DFG's San Francisco Bay Study vs. mean March to May monthly outflow at Chipps Island, 1980-2008.

2.13 Zooplankton

Zooplankton is a general term for small aquatic animals that constitute an essential food source for fish, especially young fish and all stages of pelagic fishes that mature at a small size, such as longfin smelt and delta smelt (CDFG 1987b, and see previous fish sections). Although CDFG follows trends of numerous zooplankton taxa (e.g., Hennessy 2009), two upper estuary zooplankton taxa of particular importance to pelagic fishes have exhibited abundance relationships to Delta outflow. The first is the mysid shrimp *Neomysis mercedis*, which before its decline beginning in the late 1980s was an important food of most small fishes in the upper estuary (see Feyrer et al. 2003). Prior to 1988, *N. mercedis* mean summer abundance (June-October) increased significantly as X_2 moved downstream (mean March-November location, Kimmerer 2002a. Table 1). After 1987, *N. mercedis* abundance declined rapidly and is currently barely detectable (cf., Kimmerer 2002a, Hennessy 2009). The second is a calanoid copepod, *Eurytemora affinis*, which also declined sharply after 1987, but more so in summer than in spring (Kimmerer 2002a). Before 1987, *E. affinis* was abundant in the low salinity habitat (0.8-6.3 ‰) throughout the Estuary (Orsi and Mecum 1986). *E. affinis* is an important food for most small fishes, particularly those with winter and early spring larvae, such as longfin smelt, delta smelt and striped bass (Lott 1998, Nobriga 2002, Bryant and Arnold 2007, CDFG unpublished). *E. affinis* was historically abundant throughout the year, particularly in spring and summer, but after 1987 abundance declined in all seasons, but particularly in summer and fall (Hennessy 2009). After 1987, *E. affinis* spring abundance (March-May) has significantly increased as spring X_2 has moved downstream (Kimmerer 2002a. Table 1). Relative abundance in recent years is highest in spring and persistence of abundance is related to spring outflow. As flows decrease in late spring, abundance decreases to extremely low levels throughout the Estuary (Hennessey 2009).

3 Non-Native Species

3.1 American Shad

The American shad (*Alosa sapidissima*) is an anadromous fish, introduced into California in the late 1880's, that has become an important sport fish within the San Francisco Estuary. American shad range from Alaska to Mexico and use major rivers between British Columbia and the Sacramento watershed for spawning (Moyle 2002).

American shad adults, at 3-5 years of age, return from the ocean and migrate into the freshwater reaches of the Sacramento and San Joaquin rivers during March through May, with peak migration occurring in May (Stevens et al. 1987). Within California, the major spawning run occurs in the Sacramento River up to Red Bluff and in adjoining American, Feather, and Yuba rivers with lesser use of Mokelumne, Cosumnes, and Stanislaus rivers and the Delta (Moyle 2002). Spawning takes place from May through early July (Stevens et al. 1987). Following their first spawning event, American shad will return annually to spawn up to 7 years of age (Stevens et al. 1987). It is believed that river flow will affect the distribution of first time spawners, with numbers of newly mature adults spawning in rivers proportional to flows at time of arrival (Stevens et al. 1987). Spawning takes place in the main channels of the rivers with flows washing negatively buoyant eggs downstream. Depending upon temperature, larvae hatch from eggs in 3-12 days and will remain planktonic for 4 weeks (Moyle 2002). The lower Feather River and the Sacramento River from Colusa to the northern Delta provide the major summer nursery for larvae and juveniles, and flows drive the transport of young downstream, with wet years changing the location of the concentration of young and nursery area further downstream into the northern Delta (Stevens et al. 1987). Out migration of young American shad through the Delta occurs June through November (Stevens 1966). American shad spawned and rearing in the Delta and those that travel through the Delta during out migration are vulnerable to entrainment at the State and Federal pumping facilities; catches at the facilities some years have numbered in the millions (Stevens and Miller 1983). During migration to ocean, young fish feed upon zooplankton, including copepods, mysids, and cladocerans, as well as amphipods (Stevens 1966, Moyle 2002). Most migrate to the ocean by the end of their first year, but some remain in the estuary (Stevens et al. 1987).

In earlier testimony (CDFG 1987c), we have shown that American shad year class strength correlates positively with freshwater outflow during spawning and nursery periods April through August, with the highest correlations April-June (Steven and Miller 1983), and this relationship has continued into recent years (Figure AS1, Kimmerer 2002a, Kimmerer et al. 2009). Although the outflow abundance relationship is based on

Delta outflow, and transport to and through the Delta comprise important components of the relationship, actual flows in spawning tributaries are also important for both attraction flow (Stevens et al. 1987) and for proper incubation and early rearing conditions.

3.2 Striped Bass

The striped bass (*Morone saxatilis*) is an anadromous, long-lived member of the family Moronidae first introduced into California waters from the east coast of the United States in the summer of 1879 and again in the summer of 1882 (Dill and Cordone 1997). Both introductions were made into the upper estuary (Carquinez Strait and Suisun Bay) and the population exploded soon after, supporting a commercial fishery within about 10 years and the start of a sport fishery soon thereafter (Dill and Cordone 1997). The commercial fishery flourished through the early 1900s, but was closed in 1935 in response to pressure from sport fishing interests (Dill and Cordone 1997). By 1900 sport fishing for striped bass surpassed commercial fishing and continued to expand in popularity, ranking second only to trout fishing early in the 1900s (Dill and Cordone 1997). Stevens and Kohlhorst (2001) described the sport fishery as the most important fishery in San Francisco Bay estuary and one of the most important fisheries on the Pacific Coast. Though highly variable there has been a general decline in adult striped bass abundance since the 1960s (Kohlhorst 1999) with a recent slight upsurge in the late 1990s (Stevens and Kohlhorst 2001).

Mature striped bass (age 3 and older for males, age 5 and older for females) enter the Delta and rivers to spawn in spring. Spawning commences when water temperature surpasses 60ºF, and usually occurs from April through mid-June or until water temperatures reach about 70º F (Moyle 2002). Striped bass spawn in schools broken into small groups of 5 or more males and one or more females who broadcast gametes into freshwaters possessing a moderate current. Important spawning areas include the Sacramento River from above Colusa downstream of the mouth of the Feather River, and the San Joaquin River from Venice Island downstream to Antioch (Moyle 2002). Eggs and early larvae are slightly heavier than water and require river or tidal currents keep them suspend. Dependence on currents for suspension and survival continues through the 2+ day incubation period and for an additional 7+ days post-hatch as larvae develop while subsisting on their yolk (Wang 1986). By the time larvae develop sufficiently to feed on tiny crustaceans they're also able to swim and remain suspended. During incubation and early rearing, currents transport embryos and larvae to tidal fresh and brackish water nursery areas and the proportion of young bass rearing in the Delta declines with increasing April-July outflow (CDFG 1992d). Larvae and small juveniles tend to reside upstream of X_2 initially, shifting downstream toward X_2 in summer (Dege and Brown 2004). Through summer and fall juvenile striped bass disperse downstream into low salinity water eventually inhabiting Suisun Bay and Marsh and portions of San Pablo Bay (e.g., Fish et al. 2009).

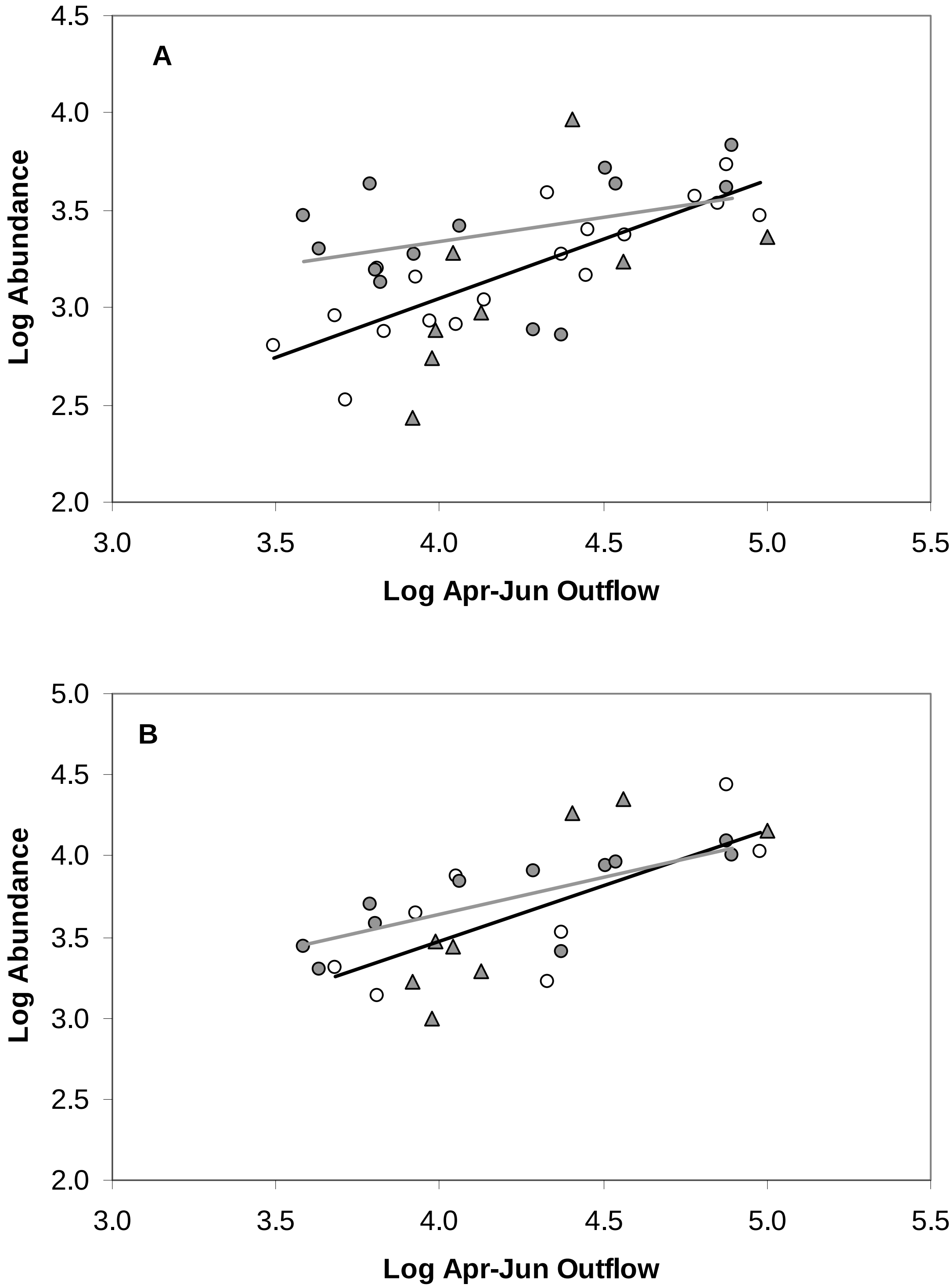

Figure AS1. Update of DFG (1987) American shad annual abundance indices plotted on April through June mean Delta outflow (cfs) for A) Fall Midwater Trawl (all ages) and B) Bay Study MWT (age-0). Relationships depicted are pre-Corbula amurensis (1967-1987; open circles, black line) and post-Corbula amurensis (1988-2000; filled circles, grey line) and more recent years during the Pelagic Organism Decline (POD) (2001- 2007, grey triangles). Lines indicate significant relationships, $p < 0.05$, except for AS 1a where post-clam line does not indicate a significant relationship.

The abundance of young striped bass in summer has been positively correlated to Delta outflows during the early rearing period (June-July, Stevens et al. 1985). Survival from egg to 38mm has been significantly correlated to April through July X_2 position and fall abundance to July through November X_2 position (Jassby et al. 1995). These relationships suggest both flow and habitat (derived from flow) influenced striped bass juvenile abundance. In previous testimony, CDFG (1992d) noted that most Sacramento River spawning occurred above the city of Sacramento from late-April into June, and that when Sacramento River flows declined below 13,000 cfs the survival index (eggs to 6mm larva stage) was always low, again suggesting a direct influence of flow and the flows needed of a strong year class. More recent analyses indicated that survival from egg to 38mm significantly increased as X_2 shifted downstream in the estuary (Kimmerer 2002a), however subsequent to the establishment of the introduced over-bite clam *Corbula amurensis* in the estuary, the relationship between April through July outflow and the Fall Midwater Trawl age-0 striped bass abundance was no longer significant (Sommer et al. 2007, Figure SB1). Kimmerer et al. (2009) showed that as X_2 location moved downstream several measures of striped bass survival and abundance significantly increased, as did several measures of striped bass habitat. These results indicate that April though July flows still positively affect striped bass survival and summer abundance, and are positively related to some measures of age-0 striped bass abundance. Further, Kimmerer et al. (2009) found that X_2 position downstream later in the year was significantly related to important measures for age-0 striped bass habitat (May-December and September-December time periods were used to develop habitat selection functions used to define limits to habitat area), and that these relations between X_2 and measures of habitat appeared consistent with X_2 relationships to abundance.

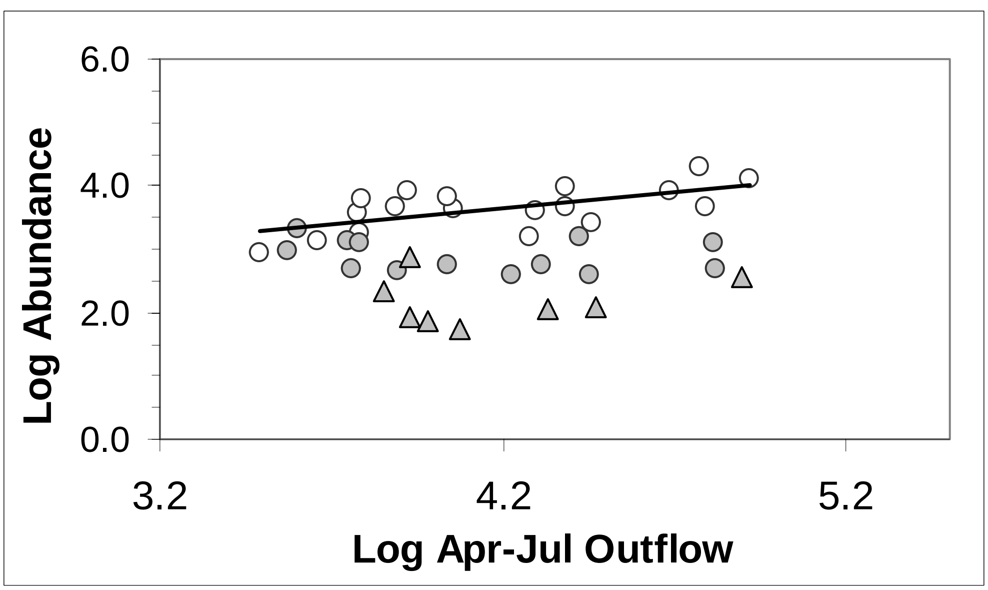

Figure SB1. Striped bass age-0 annual abundance indices based on Fall Midwater Trawl sampling plotted on mean April through July Delta outflow. Relationships depicted are pre- *Corbula amurensis* (1967-1987; open circles, black line) and post- *Corbula amurensis* (1988-2000; filled circles) and more recent years during the Pelagic Organism Decline (POD) (2001- 2007, grey triangles). Lines indicate a significant relationship, $p < 0.05$.

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