New and best available salmon and delta smelt science – Information assembled and vetted through the Coalition for a Sustainable Delta

Introduction

This overview of best available science information is offered to Bureau of Reclamation in response to its request for information for use and consideration in a draft document presented as *Alternatives including the Proposed Action* (with a page header "Proposed Actions Environmental Assessment" and "Draft: Subject to Revision Near-term" -- dated 19 June 2018).

The information we offer herein is not put forward as a contribution to a catalogue of relevant findings or a collection of citations. Rather, we present both scientific information (reliable knowledge) *and* clarification regarding accepted approaches for using scientific information in the process of identifying resource management actions that are intended to benefit targeted species.

The material identifies new information or corrects misinformation in the biological opinions, thereby better resolving the understanding of the ecology and behavior of the Delta's listed fishes, the resources upon which they depend, and the environmental stressors acting on both.

New and best available science on salmonids

1) Working presumption in the 2009 Biological Opinion -- Tidally averaged flows ("net" flows) strongly influence the fate of juvenile salmonids in the tidal Delta

Export restrictions associated with the 2009 Biological Opinion RPA IV.2.1 (I:E Ratio) and RPA IV.2.3 (OMR) were premised in large part upon a hypothesis that "net" flows strongly influence the survival of juvenile salmonids as they rear in and migrate through the tidal Delta. The importance of "net" flows had been hypothesized previously (see Newman 2008; Newman and Brandes 2010; Dauble et al. 2010), but had not been rigorously evaluated. The 2009 Biological Opinion relied primarily upon particle tracking model (PTM) simulations to determine "net" flows necessary for protection of juvenile salmonids.

Five lines of evidence suggest assumptions about the importance of "net" flows to juvenile salmonids in the tidal Delta were incorrect --

PTM -- The 2009 Biological Opinion used Particle Tracking Models (PTM) simulations to index "net" flow conditions in the Delta; however, empirical evidence

(Delaney et al. 2014) and independent expert reviews (Anderson et al. 2012) indicate that PTM results do not index conditions relevant to juvenile salmonids because juvenile salmonids cannot perceive "net" flows and do not appear to use "net" flows to find their way to Delta exit (also see Monismith et al. 2014)

Acoustic telemetry -- The 2009 Biological Opinion anticipated acoustic-tagging studies would affirm the importance of "net" flow to juvenile salmonids. The opposite has occurred. Acoustic tagging studies demonstrate rapid, directed migration through tidal channels where survival is independent of "net" flows (Perry et al. 2018) in tidal reaches. Survival of tagged salmon in the Old and Middle River corridor has been extremely low (<0.05) even under positive "net" flow conditions (Buchanan et al. 2018).

Expert Panels – Expert-panel reviews that have evaluated the potential for "net" flow in the tidal Delta to affect juvenile salmonids have concluded that "net" flows probably do not, except at locations close to the export facilities (Monismith et al. 2014, Anderson et al. 2012).

Proportional Entrainment Loss -- Analysis of >1,000 release groups representing more than 28 million coded wire-tagged (CWT) juvenile salmon showed that entrainment loss was generally very low (Zeug and Cavallo 2014). Most importantly, variation in entrainment losses was better explained by total export rates, than by "net" flows. This finding indicates salmon entrainment can be more effectively managed via exports than by managing to "net" flow standards.

SST -- The Salmon Scoping Team (SST), which was convened as part of the Collaborative Science Adaptive Management Program (CSAMP), reviewed mechanisms for altered hydrodynamics to influence juvenile salmonids. They concluded that velocities and flow direction could affect juvenile salmonids, while "net" flows lacked a demonstrated linkage to salmonid behavior (SST 2017).

In summary, new scientific information indicates "net" flows are unlikely to be perceived by or to influence the fate of juvenile salmonids. As such, "net" flows are not appropriate bases for managing water project operations in order to provide protection to juvenile salmonids. Proportional entrainment losses at the water export facilities provide the most appropriate basis for setting fish-protective export restrictions.

Conclusion -- Higher flows in rivers (unidirectional flows) are understood to strongly influence the habitat and behavior of juvenile salmonids; but "net" flows in a tidal estuary cannot influence fish in the same way as flow in rivers. Prior to the 2009 Biological Opinion, the idea that "net" flows were important to juvenile salmonids had not been rigorously evaluated. Analyses now available demonstrate "net" flows are unlikely to have a substantial influence on the fates of juvenile salmonids.

2) Working presumption -- Juvenile salmon in the Sacramento River basin would not go to the South Delta but for the influence of the water export operations

The management actions specified in the 2009 Biological Opinion assume far-reaching hydrodynamic changes are generated by water export operations in the south Delta. Salvage of juvenile salmonids from the Sacramento River at the south Delta export facilities were said to demonstrate those effects were real because it was presumed salmon would not move toward the south Delta under natural hydrodynamic conditions.

Considerable new data bearing on this issue have been generated since the 2009 Biological Opinion was released. Analyses of hydrodynamic conditions likely to influence fish behavior demonstrate a much smaller footprint of export effects than previously hypothesized (Cavallo et al. 2015; SST 2017). Cavallo et al. (2015) reported little or no effect of exports on total flow at the entrances to the interior Delta. A mechanistic basis thus is lacking for the supposition that substantially more migrating salmon are diverted into the interior Delta with elevated water exports.

New observations of juvenile salmon rearing and migration behavior are also relevant. Hearn et al. (2014) found that acoustically tagged late fall run Chinook juveniles moved upstream into different routes (into the Petaluma River) on their way through the estuary downstream of Chipps Island. Phillis et al. (2018) analyzed winter-run Chinook otoliths and found evidence for rearing in non-natal tributaries. Hearn et al. (2014) and Phillis et al. (2018) combined demonstrate that juvenile salmonids migrate contrary to prevailing currents off of major migratory routes to find rearing habitats.

Conclusion -- New science from hydrodynamic data and fish behavioral studies indicates that export-induced hydrodynamic changes are unlikely to pull Sacramento River-origin salmon into the south Delta. Rather, some fraction of Sacramento River basin juvenile salmonids can be expected to reach the south Delta regardless of exports rates. At higher export rates, there is a greater probability of south Delta fish being entrained, but this does not appear to represent a Delta-wide attraction due to altered hydrodynamics.

3) Working presumption -- Daily salvage (loss) events provide a useful indicator of and can serve as a trigger for when exports should be reduced

The 2009 Biological Opinion established daily thresholds for juvenile salmonid entrainment losses that trigger restricted exports. Daily triggers were intended to provide additional protections to Delta juvenile salmonids by curtailing exports before larger losses could occur.

Efforts to improve entrainment estimates have revealed multiple issues that restrict the practical utility of salvage (or loss) as a trigger for water project operations. First, the 2009 Biological Opinion's loss-estimation method does not adequately account for uncertainty in parameter estimates (Anderson et al. 2013). When uncertainty in model parameters is incorporated, estimates become so variable that there is little certainty as to whether a trigger has actually been met (Simonis et al. 2016). For example, salvage observations for a series of days can yield loss estimates ranging from zero to hundreds of fish, regardless of actual daily entrainment. Managing for salvage and loss on an hourly or daily time scale is problematic because the process of salvage and loss is a continuous rather than discrete (Simonis et al 2016). The 2009 Biological Opinion effectively assumes changed operations provide a "clean the slate" for the next 24-hour period, but this is not a true phenomenon because fish are constantly moving through the system and any response to operations cannot be instantaneous. In addition, the length-at-date criteria used to determine the run identity of Chinook salmon has been found to contain considerable error (Harvey and Stroble 2013); thus, there is a high probability for false positives, which would restrict export operation even though the targeted species are not present in the abundances assumed by length-at-date data.

Recent information suggests that reducing exports in response to daily salvage/loss observations is unlikely to improve survival in the south Delta or prevent fish from entering the interior Delta from main-stem routes. Modeling of the effects of exports on Delta hydrodynamics suggests the strongest influence occurs in the channels immediate to the export facilities, with few effects at main-stem channel junctions (SST 2017). Cavallo et al (2015) reported that exports had little effect on salmon routing at tidally influenced junctions on the Sacramento and San Joaquin rivers. Thus, using daily salvage to trigger export restrictions is unlikely to affect the number of fish entering the interior Delta from main-stem routes. Furthermore, Buchanan et al (2018) found that most acoustically tagged Chinook salmon arriving at Chipps Island came through the CVP, indicating that that route may result in higher survival than volitional migration through the south Delta.

Conclusion -- High variation in loss estimates, poor performance of length-at-date criteria, and the mismatch between daily salvage and the actual entrainment suggests using salvage and loss-based metrics as triggers for short-term operations are unlikely to be effective for protecting special status populations. Daily triggers should be replaced by seasonal proportional loss estimates, which are much less sensitive to observation error and uncertainty. Seasonal entrainment loss limits would also provide for more flexible and ultimately more effective real-time management of export operations.

4) Working presumption -- Losses related to export operations are a major source of mortality in the Delta

Water-export constraints are intended to provide protection from “direct” losses due to entrainment, and also to reduce “indirect” losses thought to occur as fish approach the south Delta export facilities. Direct losses have been characterized as the “tip of the iceberg,” with indirect losses assumed to be the larger component.

Tens of millions of coded wire tagged (CWT) salmon smolts have been released in or upstream of the Delta in the last 30 years. These CWT releases allow export-facility entrainment losses (“direct losses”) to be estimated because the number of fish vulnerable to entrainment is known (allowing proportional losses to be determined). Two published studies, Kimmerer (2008) and Zeug and Cavallo (2014), have used these data to estimate proportional entrainment loss. Kimmerer (2008) used volume-based expansions of salmon caught at the Chipps trawl to estimate that the percent of salmon lost at the facilities remained ≤ 5% until exports exceeded ~6500 cfs across all assumed levels of pre-screen mortality. However, a recent report on the Chipps trawl showed that volume-based expansions of catch would vastly underestimate juvenile Chinook abundance (Pyper et al. 2013); thus the estimates from Kimmerer (2008) over-estimated proportional loss of late-fall Chinook (used as a surrogate for winter Chinook) to exports by five to eight times. Zeug and Cavallo (2014) estimated the proportion of migration mortality that could be accounted for by direct losses at the facilities for multiple CWT Chinook salmon runs released in the Sacramento and San Joaquin rivers. They found that relative losses of Sacramento River-origin fall run were < 2% across all export levels. Relative losses of late fall run Chinook were similarly low until exports exceeded ~6500 cfs. Relative losses of winter run Chinook were variable across all levels of exports, but exceeded 5% for only one individual release group. Sensitivity analyses demonstrated losses were relatively insensitive to assumptions including variability in pre-screen mortality rates.

Conclusion -- Salmon impacted by direct and indirect export effects were previously assumed to represent a significant proportion of the population, but new analyses indicate a small fraction of Sacramento River-origin salmonids are entrained, except at high exports (>6,500 cfs). Management actions that are intended to reduce the number of fish encountering the salvage facilities are unlikely to reduce indirect mortality because relatively few Sacramento River basin fish appear to approach the area where such impacts can occur, see North Delta acoustic tagging study results and description of how hydrodynamic changes are unlikely to pull Sacramento River-origin salmon into the south Delta (#2 above).

5) Working presumption -- Pre-screen losses at the water export facilities are not affected by pumping rates

Entrainment of juvenile salmon has been observed to increase with export rates. The 2009 Biological Opinion argued that this pattern demonstrates the increasing severity and expanding geographic scope of export-altered hydrodynamics. However, an alternative explanation is that observed export-entrainment patterns are also influenced by pre-screen mortality. If pre-screen morality were negatively associated with export rates (rather than constant), then greater exports would produce more fish entrainment even if the number of vulnerable fish was unchanged.

New studies have affirmed that pre-screen mortality can be negatively associated with export rates. A study of salmonid behavior and Tracy Fish Collection Facility efficiency at the CVP was performed in 2013 using acoustic telemetry (Karp et al. 2017). This study found that participation (fish passing through trash rack) increased for Chinook salmon and steelhead as diversion rates increased. Chinook salmon exhibited more looping behavior and spent more time in front of the trash rack and in bypasses at low flow levels. Steelhead exhibited more variable behavior. Prescreen losses for both species decreased at higher pumping rates.

Findings at the CVP indicate salmonids are more likely to enter the water export facility at mid- and high-pumping rates, and that their pre-screen loss rates are lower under those conditions. Lower pumping rates resulted in salmon spending more time in areas where they are exposed to predators. This suggests reducing pumping levels when fish are detected at the export facility may reduce salvage, but fish that already near the facilities may be preyed upon rather than entering the facility and salvaged. That phenomenon remains to be similarly evaluated at the SWP.

Conclusion -- Observations of reduced salvage of salmon at lower export pumping rates were previously assumed to indicate fewer fish were being "pulled" toward the facility, but new information from acoustic tagging studies suggests a negative relationship between pre-screen mortality and export pumping rates.

6) Working presumption -- Increased flow in the tidal Delta can mitigate for poor salmon habitat quality

The 2009 Biological Opinion hypothesized higher (or more positive) "net" flows through the tidal Delta are an essential habitat characteristic for juvenile salmonids.

If increased Delta flows improved habitat conditions for juvenile salmonids, one would expect to see evidence for it in acoustic tagging studies. However, recent studies of juvenile salmonid survival suggest that survival is insensitive to flows in tidal reaches. For example, Buchanan et al. (2018) found that survival of San Joaquin

River-origin salmon was consistently low between Turner Cut/export facilities and Chipps Island, even in the high outflow year of 2011. Similarly, Perry et al. (2018) found that survival of Chinook salmon was insensitive to flow in reaches where flow is always bi-directional (tidal). Michel et al. (2015) reported higher juvenile Chinook salmon survival in the Sacramento River upstream of the Delta in wet versus dry years, whereas estimates overlapped in the Delta and bays across all years. Thus, higher total survival through the migration route was primarily a function of the flow-survival relationship upstream of the Delta (in riverine areas, and in the transition from riverine to tidal).

Conclusion -- Prior conceptualization of the Delta did not adequately consider spatial differences of potential flow effects; flow was assumed to have the same effects on salmon survival in all areas of the Delta. Acoustic studies completed since the 2009 Biological Opinion indicate that greater inflow can influence survival in riverine areas and in the transitions between river and tidal areas, but increased river flows are unlikely to increase salmon survival in the extensive areas of the Delta where flow is bi-directional, that is, tidal.

7) Working presumption -- Higher flows cause juvenile salmonids to emigrate more quickly which increases their survival

The 2009 NMFS BiOp hypothesized higher flows increased migration rate and thereby also improved survival of juvenile salmonids.

Michel et al. (2012) modeled the migration rate of acoustically tagged juvenile Chinook salmon from the upper Sacramento River to the Golden Gate Bridge. They found a positive relationship between flow and migration rate, although a model with year effects was a better fit to the data, reducing the predictive ability of the model for making management decisions. A study of Chinook salmon survival from the upper Sacramento River to the Golden Gate revealed that in a year with high flows, survival and migration rate were higher than in four low flow years (Michel et al 2015); however, relationships between migration rate and survival were not quantitatively examined. In the Delta, Perry et al. (2018) found a significant relationship between flow and travel time in seven out of eight reaches examined. Despite this finding, greater migration rates did not translate into higher survival in all reaches. Only three of eight reaches were found to have significant flow-survival relationships. This indicates that flow influence survival by mechanisms other than increasing migration rate. A recent study by Phillis et al. (2018) found that juvenile winter run Chinook salmon use non-natal rearing habitat that was considerably downstream from spawning habitat. Acoustic tagging studies have also showed delayed passage during very high flows. These finding suggests that outmigration may be delayed when juvenile salmonids find suitable rearing habitats. It seems likely that rearing habitat (particularly non-natal rearing habitat) becomes more available and is more heavily utilized during higher flows, but further studies are needed to test this hypothesis, during higher flows when new, productive habitats become accessible.

Managing water operations to improve migration rate and survival may have advantages in some reaches of the Delta. These relationships may occur upstream of the Delta, but mechanisms are less clear. In some cases, upstream reservoir releases to enhance flows may result in some fish migrating more slowly if rearing habitat availability or accessibility improves with increased flows. More targeted flow management may be more prudent than system-wide flows.

Conclusion -- Predictions from theoretical models of predation such as the XT model (Anderson et al. 2005) suggest as juvenile salmon migration rates increase, predator encounter rates decrease, and survival probability increases. Though additional information from field studies is needed, scientific information currently available suggests this mechanism can occur, though not in tidal areas of the Delta. Migration and rearing behavior studies indicate some flow events may facilitate rearing behaviors that may delay migration.

8) Working presumption -- Rearing juvenile salmonids are more vulnerable to export-altered hydrodynamics than are migrating juvenile salmonids

The 2009 Biological Opinion implicitly hypothesized that export-altered hydrodynamics would adversely impact rearing juvenile salmonids.

In the Delta, juvenile salmonids likely switch back-and-forth between migration and rearing modes, and are exposed to different risks and opportunities in each. During active migration, juvenile salmonids utilize open water areas where there is potential (depending largely on proximity to the export facilities) for altered hydrodynamics to influence behavior. In contrast, rearing salmonids would be holding along channel margins (or other shallow areas) in order to prey upon benthic invertebrates including dipterans, amphipods, cladocerans, and harpacticoid copepods (Healey 1980; Chittenden et al. 2018; Kennedy et al. 2018). Being oriented to physical habitat features associated with benthic foraging, rearing juvenile salmonids are less vulnerable to being displaced or disoriented by water-export effects than fishes migrating or feeding in open waters. It is important to recognize that reversing tidal flows are normal features of the Delta; rearing fishes should be capable of maintaining position at desirable habitat features despite rapidly and constantly changing hydrodynamics.

Although salmonids are known to feed on krill in the pelagic marine environment (for example Wells et al. 2012), the Delta's pelagic food web consists primarily of copepods and like zooplankton taxa (Slater and Baxter 2004, Kimmerer and Slaughter 2016), which are inconsistent with typical juvenile Chinook estuarine forage items (Healey 1979; Schabetsberger et al. 2003; Bollens et al. 2010). Thus, rearing juvenile salmonids in the Delta are unlikely to utilize pelagic, open water habitats that might make them more vulnerable to displacement or disorientation from water-export effects.

Conclusion -- Though additional information from field studies is needed, juvenile salmonids rearing in the Delta are expected to be associated with benthic rather than pelagic prey; they therefore should be less vulnerable to altered hydrodynamics in the tidal Delta.

9) Working presumption -- Installing the Head of Old River Barrier (HORB) improves through-Delta survival of juvenile salmonids that approach from the San Joaquin River basin

The 2009 Biological Opinion required HORB installation in years with SJR inflows less than 6,000cfs with the intention of keeping fish away from the export facilities and improving through-Delta survival.

Findings reported by Buchanan et al. (2018) indicate that natural migration by salmon via the San Joaquin River route -- regardless of HORB presence or absence -- does not provide improved survival in comparison to migration via the Old River route. The Head of Old River Barrier blocks access to the CVP export facilities, which can provide some of the highest survival rates for salmon exiting the Delta. Collectively these findings suggest a HORB would at best be neutral, and could cause a net reduction in to survival of out-migrating juvenile Chinook salmon.

Less information is currently available to evaluate the likely effect in April and May of the HORB on San Joaquin River steelhead. Steelhead acoustic study results for 2011-2012 reported in the SST (2017) indicate the following:

- Survival from Mossdale to Turner Cut did not improve with increased San Joaquin River inflows (SST 2017; E.8-5).
- Survival from Mossdale to Chipps Island was positively associated with export rates (SST 2017; Figure E.6-6)
- Survival from the CVP facilities to Chipps Island was positively associated with export rates (SST 2017; Figure E.6-7)
- Survival through the CVP facilities with CVP exports greater than 1,500cfs was equal to or higher than natural migration via the San Joaquin River route (SST 2017; compare Figure E.6-6 to E.6-7).

The mechanisms driving geographic patterns in steelhead survival have not yet been fully analyzed or reported; however, patterns in steelhead survival appear similar to those reported from Chinook salmon acoustic-tagging studies (Buchanan et al. 2018).

Conclusion -- Contrary to the case presented in the 2009 NMFS BiOp, installation of the HORB appears unlikely to improve survival of juvenile salmonids. While the HORB may reduce entrainment risk, it may cause net harm by cutting off salmonid access to CVP salvage, a management mechanism that results in comparatively high through-Delta survival rates.

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New and best available science on delta smelt

1) Working presumption in the 2008 Biological Opinion -- The position of X2 can serve as a "surrogate indicator" for the location and extent delta smelt habitat

A key premise supporting the Fall X2 Action is that the position of X2 in the estuary is a direct measure of the location and extent of the portion of the low-salinity zone that is occupied by delta smelt and, therefore, "a surrogate indicator of habitat suitability and availability for Delta Smelt in all years" (Service 2008). The reference to a "surrogate indicator" combines two concepts -- surrogates and ecological indicators -- that individually have valuable application in conservation planning. But a growing body of literature warns against use of surrogates or ecological indicators without validation of the relationship between the target and the surrogate/indicator (Murphy and Weiland 2014, Murphy et al. 2011, Wenger 2008) and post-Biological Opinion data and analyses on delta smelt provide strong evidence that the premise is false.

There are three criteria that an *ecological indicator* must fulfill to establish its validity to indicate or represent the habitat for delta smelt in conservation planning (consistent with Dale and Beyeler 2001, Hunsaker and Carpenter 1990, Niemi and McDonald 2004) --

1) The location of X2 (the indicator) must spatially and temporally occur over much of the range of the target species and the distribution of its habitat,

2) There must be an ecological mechanism by which X2 (the indicator) controls or affects the distribution or abundance of delta smelt, or the extent or condition of its habitat, and

3) The location of X2 (the indicator) must be anticipatory of changes in the status of the delta smelt or its habitat; that is, a measurable change in the position of X2 will predict changes in the size of the delta smelt population or the extent and/or condition of its habitat, which can be averted by a management action.

The location of X2 in the Delta fails to fulfill those criteria for delta smelt habitat. Delta smelt are frequently and consistently found outside of X0.5-6.0 zone used to define its habitat boundaries in the estuary (Feyrer et al. 2007, 2011, Brown et al. 2014), and large portions of the available lens of X2 in the estuary are unoccupied by delta smelt in the autumn (Murphy and Hamilton 2014); therefore, the location and extent of the low-salinity zone fails to represent delta smelt habitat for purposes of conservation planning. While delta smelt do inhabit waters within the portion of the low-salinity zone ranging from X0.5 and X6 in the estuary that was characterized as the suitable range of salinity for delta smelt habitat in the 2008 Biological Opinion; it is plainly established from available survey data and has been long appreciated that the fish are found in circumstances from freshwater (X0) to estuary areas with salinities of X16 and greater (see Heib and Fleming 1999, Moyle et al. 2010). No data exist that indicate that delta smelt performance is lesser in salinities inside or outside of the range salinities that are represented as habitat in the biological opinion, and in Feyrer et al. (2007 and 2011) and Brown et al. (2014).

The MAST report (IEP MAST 2015) states that “data generally supported the idea that lower X2 and greater area of the LSZ would support more sub-adult Delta Smelt” and the “position and area of the LSZ is a key factor determining the quantity and quality of low salinity rearing habitat available to Delta Smelt.” But, neither assertion is supported by quantitative evidence provided in any previous report or publication. That the position of the low-salinity zone in the estuary does not define or reflect the location, extent, and quality of delta smelt habitat is best supported by the fundamental observation that delta smelt do not appear to track X2 as it moves east-west in the estuary accompanying outflow volumes through the Delta. The sustained (continuous) presence of delta smelt in habitats in western portions of its range in the Delta and adjacent Suisun Bay and Suisun Marsh, in even the driest years when X2 is located in more eastern positions, invalidates the assertion that X2 is a valid proxy measure for the location and extent of delta smelt habitat.

Surrogates or proxies are commonly used to deduce salient ecological attributes of harder-to-assess federally listed animals and plants, and to inform their determinations and decisions made in exercising their authorities under the ESA (see Caro 2010, Cushman et al. 2015). Inferences drawn from co-occurring, more-readily observed and better-studied species or from biological or physical features of a species’ habitat may provide useful to resource managers. However, no surrogate species for delta smelt has been proposed, and considering the points above, it is unlikely that a surrogate or proxy measure that co-occurs with and varies predictably across the spatial extent of delta smelt habitat exists. In any case should a surrogate for delta smelt or an ecological indicator its habitat be proposed, it must be put through a rigorous validation procedure before it were to be institutionalized in management planning, rather than simply asserted (see Murphy and Weiland 2014).

The best habitat for delta smelt is defined not by X2 as a surrogate indicator; rather, the best habitat is defined by its comparative capacity to support and sustain the fish. That habitat can be found east in the Delta, in the lower Sacramento River near continuous freshwater conditions, and west in the Delta and in and around Suisun Bay and Suisun Marsh, where salinity conditions are typically highest in the delta smelt's geographic range. While San Francisco Bay's saline waters to the west and the freshwater Sacramento River to the east bound the range of delta smelt, the location of X2 in the Bay-Delta tidal zone by and large neither predicts nor determines the location of other resources that contribute to delta smelt habitat or the survival and successful reproduction of the species.

More precisely, delta smelt habitat includes areas in the northern estuary, primarily from Suisun Marsh east into the Cache Slough complex of waterways. While delta smelt can be found in the open waters of bays and larger channels, they are more frequently associated with complex bathymetry, in deep channels close to shoals, shallows, and, in spring, shore lines, in areas with little submerged vegetation, but in proximity to extensive tidal or freshwater marshlands and other wetlands. Such situations contribute to local production of diatom-rich phytoplankton communities that support copepods, in particular *Eurytemora* and *Pseudodioptomus*, and certain cyclopoid zooplankton that are frequent in the diets of delta smelt. Habitat conditions may be most conducive to delta smelt survival and growth in waters with 1) high densities of calanoid copepods (~5,000 gC/m) in all seasons, 2) surface salinities of less than 6,500 Ec in spring, less than 17,500 Ec in summer, and less than 19,500 Ec in fall, 3) water transparency less than 100 cm (although performance increases when transparency is closer to 50 cm), and 4) summer water temperatures below 22 degrees Celsius and relatively low flow velocities, with preferred conditions varying somewhat with life stage. Before spawning, delta smelt initiate a diffuse landward dispersal to fresher-water circumstances. Delta smelt performance, hence habitat quality, appears to have been greatest for delta smelt in years with wet winters and springs (average X2 less than 68km) when the first flush occurs in December and is moderate in volume (30 day average inflow of <80,000 cfs), and when flows across the Yolo Bypass are prolonged (more than 50 days of flow between January and April).

Conclusion -- The position of X2 does not determine the extent and quality of delta smelt habitat. No surrogate species that could represent delta smelt for purposes of conservation planning or as monitoring proxy for it has been identified, and no individual environmental variable has been identified that can serve as an ecological indicator of delta smelt habitat.

2) Working presumption -- A combination of physical (water quality) variables is the primary determinant of delta smelt distribution

The Fish and Wildlife Service relied on the conclusion that salinity, turbidity, and temperature determine delta smelt distribution when the agency developed the Fall X2 Action (FWS 2008). The conclusion was drawn from findings from Feyrer et al. (2007). Since then, a number of questions have been raised regarding the analysis.

Of primary concern was that the search for environmental correlates of delta smelt distribution was limited to salinity, turbidity, and temperature. It ignored other physical variables that appear in conceptual ecological models linking delta smelt population responses to environmental attributes, and it disregarded biotic variables altogether. The three variables combined to explain just a quarter of the variance in delta smelt distribution. Therefore, it would be incongruous to characterize them as determinants of, or proxies for, delta smelt distribution. In addition, the study drew occurrence data on delta smelt from the FMWT survey stations, but used just 75 of more than 100 locations for which data were available. Among the sites missing from the analysis were those most proximate to Cache Slough in the northeast Delta, where more than a third of the total number of delta smelt was recorded from the estuary in the decade preceding the 2008 Biological Opinion and where delta smelt resided year-round in near-freshwater circumstances.

In a companion paper Feyrer et al. (2011) drew from the previous work in developing a "habitat index," that "accounted for both the quantity and quality of abiotic habitat" and used it "to model the index as a function of estuarine outflow." The model used "general additive modeling to identify habitat suitability based on combinations of water temperature, clarity, and salinity from surveys conducted during fall" applying it "using outflow predictions under future development and climate change scenarios." Both the independent and dependent variables incorporated measures of relative salinity compromised the findings (Manly et al. 2015). Manly and his colleagues found that geography was as good as, or better than, salinity in explaining the pattern of landscape occupancy by delta smelt, and indicated that an effective habitat index required static regional (geographic) effects, dynamic salinity and turbidity effects, and an independent abundance index.

Conclusion -- Studies that asserted a relationship between fall X2 and delta smelt distribution were flawed by assumptions and design shortcomings.

3) Working presumption -- A combination of physical (water quality) variables is the primary determinant of delta smelt survival and abundance

The Fish and Wildlife Service asserted in the 2008 Biological Opinion that implementing the Fall X2 Action would increase survivorship and performance of delta smelt and accordingly its subsequent abundance in proportional response to increased available habitat. The Service relied on an unpublished manuscript (identified in the biological opinion as Feyrer et al. 2008) to support its assertion regarding the relationship between water quality variables and delta smelt survival and abundance. But the published version of the manuscript, which subsequently appeared as Feyrer et al. (2011), did not include the analysis presented in the 2008 Biological Opinion as support for the Fall X2 Action.

After the appearance of the 2008 Biological Opinion, a number of multivariate studies used diverse approaches to explore how both physical and biotic factors may affect the delta smelt abundance. Multivariate autoregressive models indicated substantial support for a relation between abundance of delta smelt and one of 19 covariates, summer water temperature (Mac Nally et al. 2010). A Bayesian change-point analysis found that two of 19 covariates, water clarity and the volume of water exported from the Delta in winter, were associated with the FMWT-derived autumn abundance of delta smelt (Thomson et al. 2010). A state-space life-cycle model indicated that delta smelt abundance is affected by density dependence, temperature from April through June and specifically in July, prey density from April through June and July through August, abundance of predators from April through June and September through December, turbidity in January and February, and adult entrainment (Maunder and Deriso 2011). Five covariates -- stock, entrainment, water temperature, prey densities, and predation from April through June appeared to affect delta smelt abundance in an investigation by Miller et al. (2012). None of those studies indicated that a Fall X2 Action would contribute to increasing the subsequent abundance of delta smelt.

Hamilton and Murphy (2018) recently investigated factors limiting the abundance of delta smelt, extending on those multivariate analyses. The concept of "limiting factors," derived from observations that applying more of a nutrient that was not limiting does not improve crop yields, asserts that the abundance of an organism is controlled not by the total amount of resources available, but by the availability of the scarcest resource. More recently the concept has been applied in population ecology, and in studies of imperiled species.

The investigators reassessed all of the environmental factors from the previous multivariate studies in an attempt to identify the environmental factor or factors that limit(s) the distribution, abundance, and reproduction of delta smelt. The effects of four factors appeared to limit delta smelt performance. Entrainment at two power plants in Contra Costa County was identified as a significant contributor to delta smelt declines in the 1990s and earlier. More recently, predation and competition by Mississippi silversides had demonstrable effects on delta smelt numbers. But it is the availability of food that appears most frequently to limit delta smelt. A shortage of zooplankton in summer appeared to affect delta smelt numbers in more than 40 percent of the years that were evaluated, and, not surprisingly, the availability of food earlier in the year may influence survival of the delta smelt's early life stages. When food availability in the spring was included in models that best-explain delta smelt abundances, the frequency of food limitation in summer decreased and food limitation in the spring showed elevated effects.

The Hamilton and Murphy investigation observed that allocating resources for management actions that do not address limiting factors, such as attempts to position and expand the extent of the low-salinity zone in the estuary in the autumn, are unlikely to contribute to the recovery of delta smelt. Instead, actions that improve food production, such as restoration of tidal marshlands, enhanced management of freshwater wetlands, and increased seasonal flows across floodplains might be expected to contribute to elevated delta smelt survival and reproduction, and should be prioritized in action plans targeting the species. Strategies for controlling non-native fishes preying on and competing with delta smelt also need to be developed.

Conclusion -- The best available evidence now indicates that management actions that are shown to increase the availability of the zooplankton prey that are used by delta smelt are most likely to benefit delta smelt. That observation suggests that the application of through-Delta flows on floodplains and across marshlands in the springtime could benefit the fish by enhancing food availability for delta smelt. It can be inferred from the limiting-factors study that increasing through-Delta outflow in the autumn is unlikely to benefit delta smelt.

4) Working presumption -- Delta smelt migrate eastward through the Delta to spawn and dispersal by maturing juveniles and pre-spawning adults put them in peril from entrainment at the water export facilities in the south Delta

In presentations, personnel from the Service and other agencies have suggested that delta smelt undertake a spawning migration, wherein (i) sub-adult delta smelt move en masse eastward from Suisun Bay and the area of the Sacramento-San Joaquin rivers confluence to the central Sacramento-San Joaquin Delta in the winter and spring to spawning grounds on the main-stem rivers and other Delta tributaries and (ii) their offspring subsequently disperse back through the central Delta, returning to a more western distributional footprint by summer. That description of inter-seasonal movements by delta smelt stands in contrast to findings drawn from studies, which describe movements by pre-spawning delta smelt from open waters in bays and channels to adjacent marshlands and freshwater inlets (for example, Moyle et al. 1992, Bennett 2005). Murphy and Hamilton (2014) used publically available data drawn from trawl surveys to generate maps from which they inferred seasonal patterns of dispersal. In the fall, prior to spawning, delta smelt are most abundant in Suisun Bay, the Sacramento and San Joaquin rivers confluence, the lower Sacramento River, and the Cache Slough complex. By March and April, the period of peak detection of spawning adults, relative densities in Suisun Bay and the rivers' confluence have diminished in favor of higher concentrations of delta smelt in Montezuma Slough and the Cache Slough complex. A relatively small percentage of fish are observed in areas of the Sacramento River above Cache Slough. They concluded that inter-seasonal dispersal of delta smelt is more circumscribed than had been previously inferred and suggested that their findings support a conservation strategy for delta smelt that focuses on habitat restoration and directed management actions in and adjacent to tidal marsh and other wetlands along the northern Delta arc of shoals, shallows, and open waters that have been documented support high concentrations of delta smelt. That interpretation of available data is consistent with Polansky et al.'s (2018) observation of a lack of dispersal by juvenile delta smelt during the Kodiak Trawl survey period in the spring.

Conclusion -- The assertion that delta smelt migrate from a distribution in the west and central Delta and adjacent bays upstream to freshwater and near-freshwater circumstances to spawn misrepresents the ecology and dispersal behavior of the fish in ways that can misinform conservation planning. Habitat restoration and other management actions should focus on the northern areas of Suisun Bay and Suisun Marsh eastward through the rivers confluence up to freshwaters in the lower Sacramento River that are known to be occupied by delta smelt throughout the year.

5) Working presumption -- Delta smelt is a pelagic fish the population status and trends of which can be inferred from the existing fish surveys, including the EDSM

The sampling schema of the four trawler-based surveys generally share a common geographic footprint; the Fall Mid-water Trawl (FMWT) among those has been the most frequently invoked in support of the assertion that delta smelt are collapsing demographically. The FMWT provided the abundance data for delta smelt that was used to assert that the position of X2 in the autumn determines the extent of delta smelt habitat and its subsequent abundance. The FMWT was originally designed to sample Age-1 striped bass at set survey stations on the open estuarine waters of San Pablo Bay east into Suisun Bay, past the confluence of the Sacramento-and San Joaquin rivers, deep into the Delta. The trawls take a broad array of the Delta's fishes, both native and non-native, from the estuary's open waters. In a gross sense, the footprint of the FMWT trawl overlaps with much of the distributional range of delta smelt -- but not completely. Because the FMWT does not sample a closed population of delta smelt, its catch cannot be translated with correction into census population numbers. Importantly the FMWT, which largely samples the deep-waters of bays and broader channels, misses the many of the habitat associations occupied by delta smelt. Bennett (2005) describes delta smelt as more abundant in shallows and "shoal areas" than deeper channels, and Bennett and Burau (2015) make clear that the fish's habitat is the not the open waters and mid-channel benthos that the FMWT draws its nets through, rather it is found at shoal-channel interfaces during flood tides and near-shoreline situations during ebb tides, which are inaccessible to the FMWT gear.

The Fall Mid-water Trawl neither surveys a closed population nor samples the habitats occupied by delta smelt, and other shortcomings of the data collection effort make it likely to be an unreliable monitoring tool for delta smelt. The FMWT generates sampling error from biases that include (1) survey depth, sampling creep by trawl boats over time, shifting to deeper positions adjacent to historical survey stations combine with gear that now cannot reach fish species that inhabit the bottom, and as many as half the contemporary trawls do not sample the bottom as they did three decades ago, (2) the time of day of sampling, which under samples species that are nocturnal or crepuscular in many of their activities, (3) gear avoidance, it is now evident that many fish see the nets coming and escape capture, especially under increasingly frequent low-turbidity conditions, (4) gear-capture inefficiencies, wherein both very small and very large fish are differentially excluded from the catch, creating capture bias that can extend to different life stages of the same species, and (5) species misidentification, a chronic problem in earlier years, which may have affected 20% or more of smaller species and early life stages, likely confounding the abundance indices for the delta smelt and the co-occurring longfin smelt, creating false trend patterns for each.

The data generated by the Fall Mid-water Trawl and the other seasonal fish surveys are freighted with uncorrected and uncorrectable biases, making it fundamentally flawed as a survey tool for delta smelt. (Even use of the inter-annual survey data to assess relative abundance over time may be problematic in light of certain of the causes of sampling error described above.) In fact, the U.S. Fish and Wildlife Service has recognized shortcomings in the FMWT and the accompanying seasonal surveys in informing conservation planning and directing species-specific management actions and a year ago instituted an Enhanced Delta Smelt Monitoring (ESDM) Program in an effort to address a subset of these. The agency recognized that “the declining delta smelt population has resulted in the need to develop a high precision sampling program with the ability to detect delta smelt at low densities in order to support real-time management decisions and to continue to monitor population dynamics” (Fish and Wildlife Service 2016a). Over the past year, the EDSM has intensified the seasonal surveys for delta smelt represented in the figure above, incorporating stratifies-random sampling and increasing the frequency of sampling, estimating survival, and inferring dispersal. In September and October 2017, using more efficient gear, the EDSM caught 40 times the number of delta smelt than did concurrent sampling via the FMWT, reinforcing the conclusion that the FMWT and other seasonal surveys are not competent in sampling the delta smelt population. An incremental upgrade over the historical surveys, which are limited to offering abundance-index values, the EDSM is designed to estimate life stage-specific abundance using catch-per-unit-effort values and volumetric multipliers, spatial distribution, and survival. Unfortunately, like the FMWT, the EDSM does not sample the complete range of delta smelt and, like the FMWT, it does not sample the breadth of habitat strata that appear to support the highest densities of the fish, hence it perforce under-samples the population. Further, the EDSM estimates vary greatly from sample to sample, in large part because sampling effort is almost negligible relative to the overall distribution of the species and catch per unit effort is anemic (see the Table below).

That said, data consistently indicate across seasons that the delta smelt population in the wild could well be between one and two orders of magnitude greater than is disclosed in U.S. Fish and Wildlife Service publications (see, for example, USFWS 2016b, USFWS 2017).

Conclusion -- The long-tenured fish surveys in the estuary, a couple of them entering their sixth decade, are just that -- surveys -- they are not monitoring schemes that can *accurately evaluate the status of delta smelt or track their trends in numbers, nor can they now be mobilized to assess the performance of delta smelt in response to management actions given the rare observations of delta smelt in those surveys.*

Table -- Select 2017 delta smelt population estimates with 95 percent confidence intervals generated by U.S. Fish and Wildlife Service using EDSM data. The data are characterized by dramatic differences in population size estimates between sampling periods and the absence of the predictable monotonic decline in numbers of juvenile delta smelt that is expected during the "rearing" period after June.

Date	Low	Mid	High
January 6-12	88,351	260,115	602,494
January 17-19	26,116	74,688	158,855
March 6-9	1,472	4,437	10,424
March 13-16	4,654	15,773	39,651
May 15-17	404,295	2,921,908	10,561,727
May 22-24	0	0	0
July 17-21	271,688	895,843	2,217,295
July 24-27	445,671	647,357	909,671
September 18-22	123,786	364,211	843,295
September 25-29	14,720	44,055	103,053
October 2-5	4,687	20,046	57,087
October 10-13	149,575	924,907	3,123,178

Sources: USFWS (2017a, 2017b).

https://www.fws.gov/lodi/juvenile_fish_monitoring_program/data_management/EDSM_report_Mar_31_2017.pdf (for January and March)

https://www.fws.gov/lodi/juvenile_fish_monitoring_program/data_management/EDSM_report_2017_11_03.pdf (for July and October)

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