Appendix 2: Exploration of the sensitivity of proportional entrainment calculations for larval-juvenile Delta Smelt and a simple method for effects comparisons in the Reinitiation of Consultation (ROC) for the Long-term Operations of the CVP and SWP

Matt Nobriga, August 2019

Intent: The Service is working on state-of-the-art approaches to estimate delta smelt entrainment and its impacts on the species' population dynamics through its individual-based and statistical life cycle modeling efforts. Although these tools are not yet available, we expect to have them available for use in water year 2020. This memo describes an updated, but simple analysis of expected proportional entrainment of larval delta smelt for the ROC biological opinion. Edits to this document since the June 2019 version are intended to reflect updates to Reclamation's Proposed Action (PA) that have occurred since then.

Background: Proportional entrainment estimates for larval (including juvenile) delta smelt were first developed by Kimmerer (2008) using data from 1995 through 2005, a period of highly variable loss of adults and larvae. Kimmerer's estimates were developed from a combination of 20-mm Survey data, salvage data, hydrodynamics data, and several internal models needed to 'true up' these different data sets and account for inefficient sampling of small larvae by both the trawl nets and the salvage facilities. The estimates were provided to the Service for use in the development of our water operations biological opinion in 2008 and are re-plotted in Figure 1. Key findings from this initial attempt to model proportional entrainment were:

- Point estimates of annual loss to the age-0 population ranged from essentially zero percent in 1995 to 26 percent in 2002, though the upper confidence limits of these estimates exceeded 40 percent in 2002 and 2004. This suggested that entrainment losses could have been important to the species' recruitment in some, but not all, years.

- It was important to account for natural mortality of the larvae that is occurring in the ecosystem at the same time fish are being entrained to avoid over-estimating loss. Estimated losses of larvae (including small juveniles) were highest in April because larval abundance on average, was estimated to have been highest in that month.

- The estimates of proportional loss described above tracked estimates generated using neutrally buoyant particles in DSM-2 very well, suggesting that basic tidal and net water movements in the Delta were a dominant source of year to year variation in predicted proportional entrainment loss.

The Service (2008) used Kimmerer's (2008) larval-juvenile entrainment estimates to generate a regression model to predict proportional loss as a function of multiple-month averages of Delta outflow and OMR flow. Higher Delta outflow tended to decrease the estimate and more negative OMR tended to increase it. This method was one of two that the Service used in its biological opinion for California Water Fix (CWF), but it is a course approximation of data from the somewhat distant past so it will not be used in the ROC biological opinion. The second method used in the CWF biological opinion involved weighting hydrodynamic model outputs by adult delta smelt distributions from the California Department of Fish and Wildlife's Spring Kodiak Trawl (SKT) survey to reflect an assumption that the trawls collected fish in proportion to where they ultimately spawned. This memo describes an updated version of that basic approach.

In an extensive critique of Kimmerer's (2008) approach, Miller (2011) concluded that the estimates were too high. In the case of the larvae and juveniles, Miller could not estimate by how much he thought Kimmerer had over-estimated larval-juvenile entrainment, but he reviewed why he believed that six classes of assumptions that Kimmerer made had resulted in over-estimation of proportional loss. Kimmerer (2011) rebutted several of Miller's criticisms, but did concede that a transition of delta smelt catches toward the north Delta that was occurring at the time could have an effect on the calculations. This is an issue that was addressed in the second CWF method mentioned above and is addressed further in this memo using newer information from the SKT. Based on application of a more robust statistical analysis, Kimmerer (2011) lowered his *adult* delta smelt entrainment estimates by 24 percent relative to his original calculations, but the change did not apply to the larvae and juveniles.

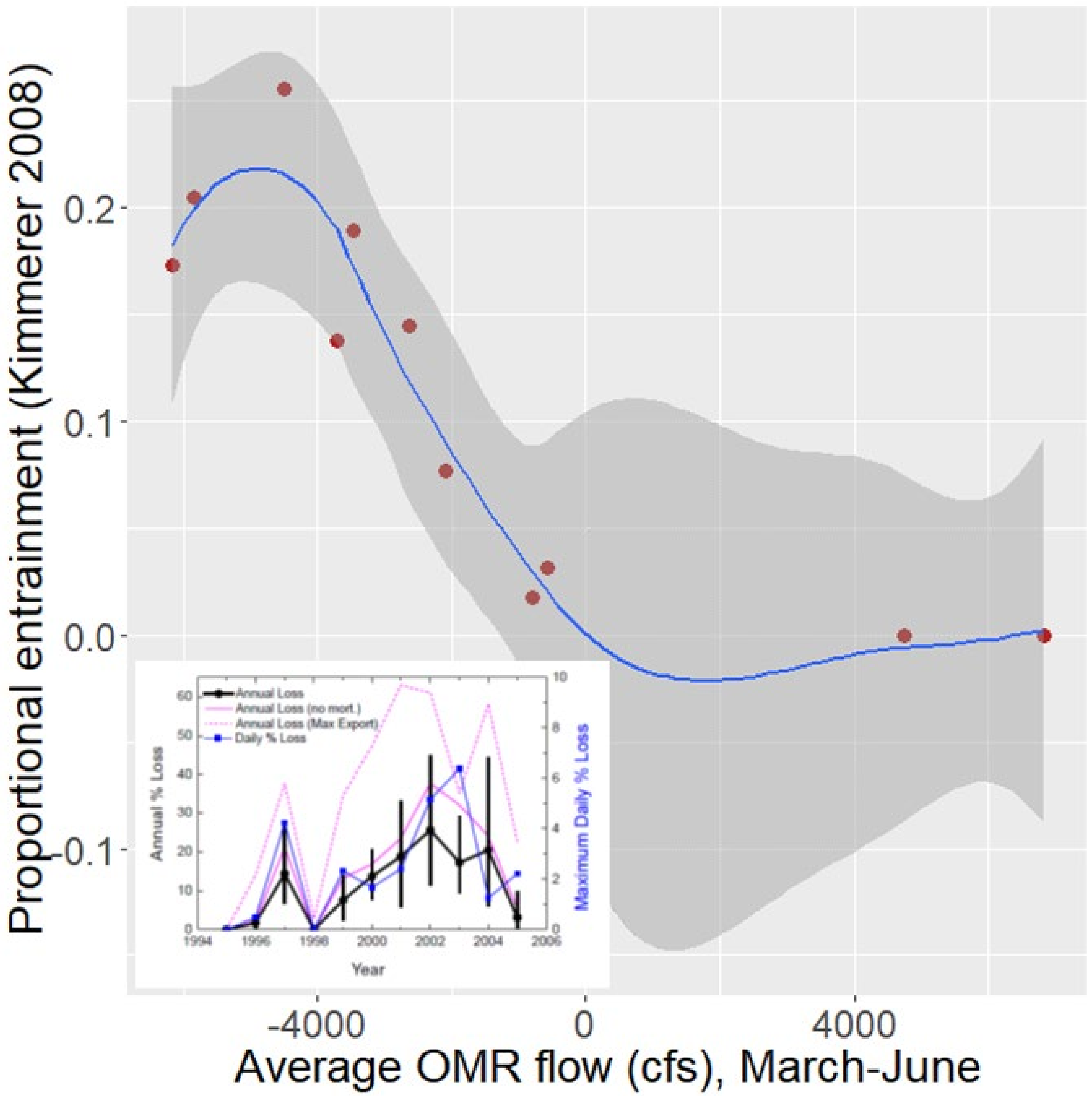

Figure 1. Scatterplot showing the relationship between OMR flow and an associated predictions of larval delta smelt proportional entrainment as developed by Kimmerer (2008) for the years 1995-2005. The dark gray shading depicts the uncertainty in the loess algorithm about where it should place the blue fitted line. The high uncertainty in this Figure compared to Figure 2 in this appendix reflects the low sample size and is not the same measure of data uncertainty as the 95% confidence intervals on these estimates that were shown in Kimmerer's Figure 15 (inset).

Conceptual model and approach: The ROC biological opinion describes current thinking on adult delta smelt dispersal during the winter. A key recent finding is that more than a decade of SKT surveys were unable to refute a null hypothesis that there was no difference in adult delta smelt distribution from year to year (or month to month), suggesting that adult distributions during the 2000s through mid-2010s were somewhat static (Polansky et al. 2018). This finding has to be tempered somewhat by the fact that other data analyses confirm some changes in distribution occur during the winter (Grimaldo et al. 2009; Sommer et al. 2011; Murphy and Hamilton 2013). However, Polansky et al.'s (2018) results suggest that at the population scale, these changes are similar from year to year. Because delta smelt abundance is so much lower now, current sampling is not likely to provide robust support for an adult spawner distribution that differs from that described by Polansky et al. (2018).

Here, similar to the assumption made in the CWF consultation, *assumption 1* is that delta smelt spawn in locations near where the adults are collected and therefore, those locations can be used to seed a particle tracking model (DSM-2 PTM) with a realistic initial distribution of 'virtual larvae'. *Assumption 2* is that larval delta smelt transport can be modeled based on the transport of neutrally buoyant particles in DSM-2 PTM. This assumption was extensively justified by Kimmerer (2008; 2011) and adapted into the individual-based life cycle model developed by Rose et al. (2013a). The ROC biological opinion reviews the evidence that most delta smelt spawn during February-May. There is a temperature-dependent amount of time that elapses between when eggs are spawned and when larvae emerge and become a part of the plankton community. Thus, *assumption 3* in this analysis is that eggs spawned during February-May hatch into larvae exposed to hydrodynamic conditions during March-June, which is the timing of the PTM runs described below.

The Service has a 21-year (84 month) library of DSM-2 PTM results for March-June of 1990 through 2010 that provide predicted particle transport and fate information for 26 regions of the Delta and Suisun Bay. In these model runs, the same number of particles was randomly released into each region by month by year combination, and the changes in particle location were reported 30 (virtual) days after their release. The years that were actually modeled are not important in the analyses described below. They can be thought of as synthetic in the same way that the years in CALSIM II get treated. What is important is that they covered a wide range of hydrodynamic conditions, which allows the creation of statistical relationships between the PTM results and the monthly average Old and Middle river (OMR) flows that were observed in the modeled months. The statistical relationships can then be used to estimate 30-day proportional entrainment at particular OMR flows.

I received estimates of the average fraction of adult delta smelt in 22 of the 26 DSM-2 PTM regions based on the spatial distribution model described by Polansky et al. (2018) (Table 1). The Delta Smelt distribution detailed in Table 1 can be thought of as a best approximation of the distribution of adult delta smelt as determined from the SKT and was used to generate an initial distribution of larvae to weight the DSM-2 PTM results, specifically:

$PL_{Rt} = E_{Rt}*D_{Rt}$,

Where, PL_{Rt} is the estimated proportional loss of the larval delta smelt population from one of the regions (R) listed in Table 1 for one of the 84 months (t) that were modeled, and it is the product of the DSM-2 PTM prediction of loss for that region in that month E_{Rt}, and the fraction of the adult delta smelt population assumed to have spawned in that region in that month D_{Rt} (Table 1). The first step toward a population-level proportional entrainment estimate for any given month is the sum of the PL_{Rt} across all of the regions.

Table 1. List of the sub-regions shown in Figure 1 and the estimated fraction of the adult delta smelt population that may spawn in each one based on Polansky et al. (2018). Note that regions west of Carquinez Strait were not included because they do not exist in the DSM-2 model domain. Delta smelt are known to spawn in the Napa River during wet winter-spring periods so this means proportional entrainment as estimated in this appendix is over-estimated – at least in wetter year types.

Spatial Region	Estimated Fraction of Adult Delta Smelt in the Region	Notes
Lower Napa River	0.0079	This region is west of DSM-2 western boundary; assumed no entrainment would occur from this far west which is consistent with results for Carquinez Strait, the adjacent region to the east.
Carquinez Strait	0.0143	
West Suisun Bay	0.0162	
Mid Suisun Bay	0.0497	
Suisun Marsh	0.0985	
Honker Bay	0.0257	
Lower Sacramento River	0.1155	
Sacramento River near Rio Vista	0.0609	
Cache Slough/Liberty Isl.	0.3478	
Sacramento River near Ryde	0.0009	
Upper Sacramento River	0.1403	There are no SKT sampling stations in this region. This high fractional catch was due to the model combining this region with Cache Slough/Liberty Island. I assumed no Delta Smelt catch in this region.
Mokelumne River forks	0.0037	
Lower San Joaquin River	0.0789	
SJ River near Twitchell Island	0.0228	
SJ River near Prisoners Point	0.0069	
SJ River near Stockton	0.0011	
Disappointment Slough	0.0008	
Holland Cut	0.0039	

Rock Slough/Disco Bay	0.0002	
Old River	0.0003	
Mildred Island	0.0032	
Middle River	0.0002	

Results: There is a clear non-linear relationship between the monthly average OMR flow during the modeled months and each month's predicted proportional loss of larval delta smelt (PL_{Rt}; Figure 2). Our data set has one very obvious outlier near an OMR flow of positive 10,000 cfs. This is clearly a modeling error and this data point was removed from further analyses.

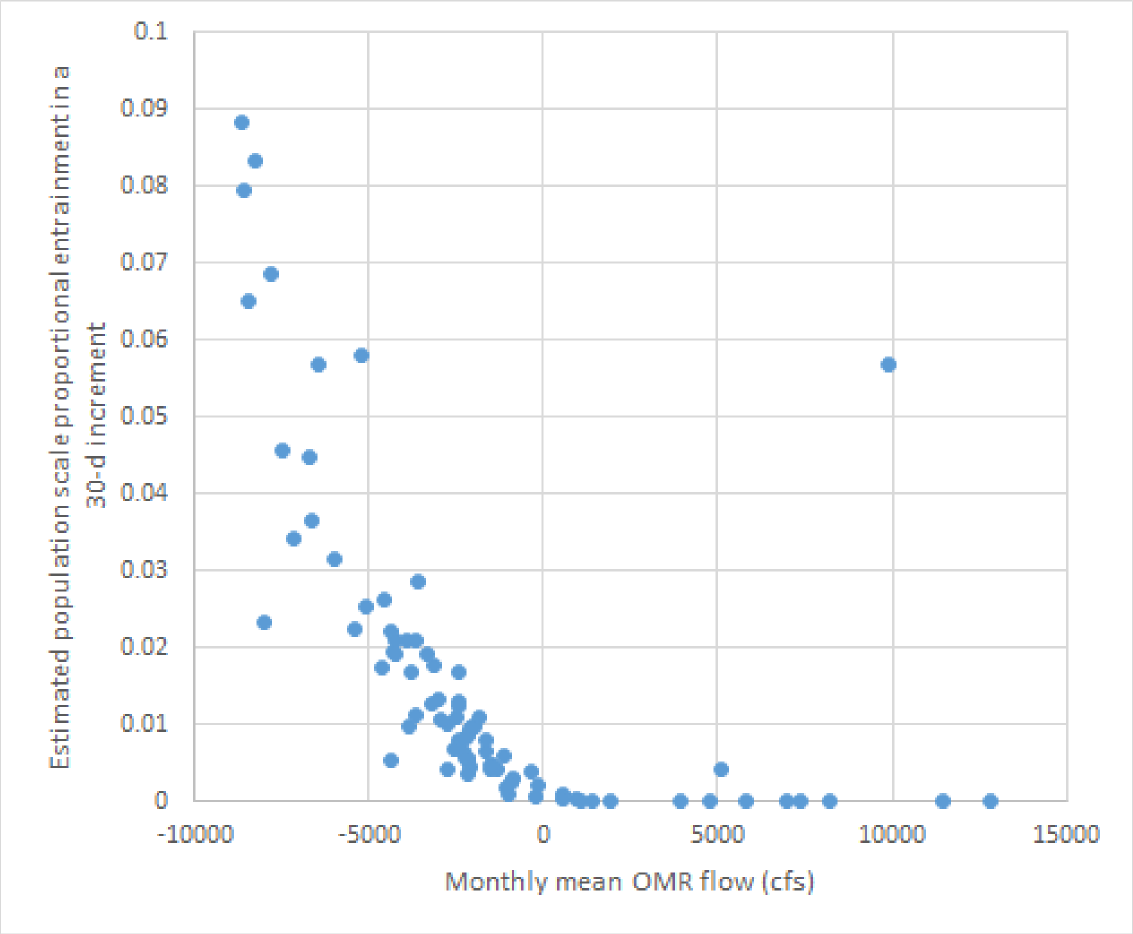

Figure 2. Scatterplot showing the relationship between OMR flow and an associated monthly prediction of larval delta smelt proportional entrainment. Note the data point near 10,000 cfs and 0.06 loss cannot be accurate and was removed from further analysis.

I evaluated four alternative versions of monthly time-step OMR flow versus PL_{Rt} relationships. Version 1 is the same one presented in Figure 2, but with the outlier removed (Figure 3). In this model, predicted proportional entrainment is essentially zero when OMR flow is positive and then increases non-linearly as a function of increasingly negative OMR flow.

The ROC biological opinion reviews the literature that suggests the infestation of the south Delta by Brazilian waterweed and other submerged aquatic vegetation has greatly diminished the suitability of the region as habitat for delta smelt. One way to test the sensitivity of the PL_{Rt} model to this assumption is to make the aggressive assumption that all delta smelt spawned in the south Delta perish. I approximated this assumption in version 2 by setting the fractional loss to 1.0 (i.e., 100 percent) for the fractions of the population in Disappointment Slough, Holland Cut, Rock Slough, Old River, Mildred Island, and Middle River regions). In this version, proportional entrainment is just over 1 percent at positive OMR flow because that is the average proportion of SKT catch that Polansky et al. (2018) predicted was in those regions. At negative OMR flow, predictions from version 2 converge with the baseline because DSM-2 PTM-predicted losses from insertion points in Old and Middle rivers are high under negative OMR flows.

In version 3, I assumed a spawning distribution for the adults that was slightly further up the San Joaquin River than what is reported in Table 1. Specifically, I moved the Middle River fraction to the lower San Joaquin River region, moved the lower San Joaquin River fraction to Twitchell Island, moved the Twitchell Island fraction to Prisoners Point, moved the Prisoners Point fraction to Stockton, and moved the Stockton fraction to Middle River. This version was intended to reflect a concern that has often been voiced by the Smelt Working Group that adult delta smelt that enter the San Joaquin River may continue moving upstream further than the catch data indicate. Under increasingly negative OMR flow conditions, the estimated proportional loss was very sensitive to even this modest change in the initial distribution assumption (compare Figure 5 to Figure 3).

Version 4 combined both the 100 percent south Delta mortality and upstream shift assumptions from versions 2 and 3. Thus, this version had both the higher loss rate at positive OMR flow and the higher loss rates under negative OMR flow conditions. Version 4 reflects uncertainty regarding the baseline impact of hypothesized elevated predation rates associated with SAV beds and the uncertainty about adult fish distribution and spawning locations in the San Joaquin River.

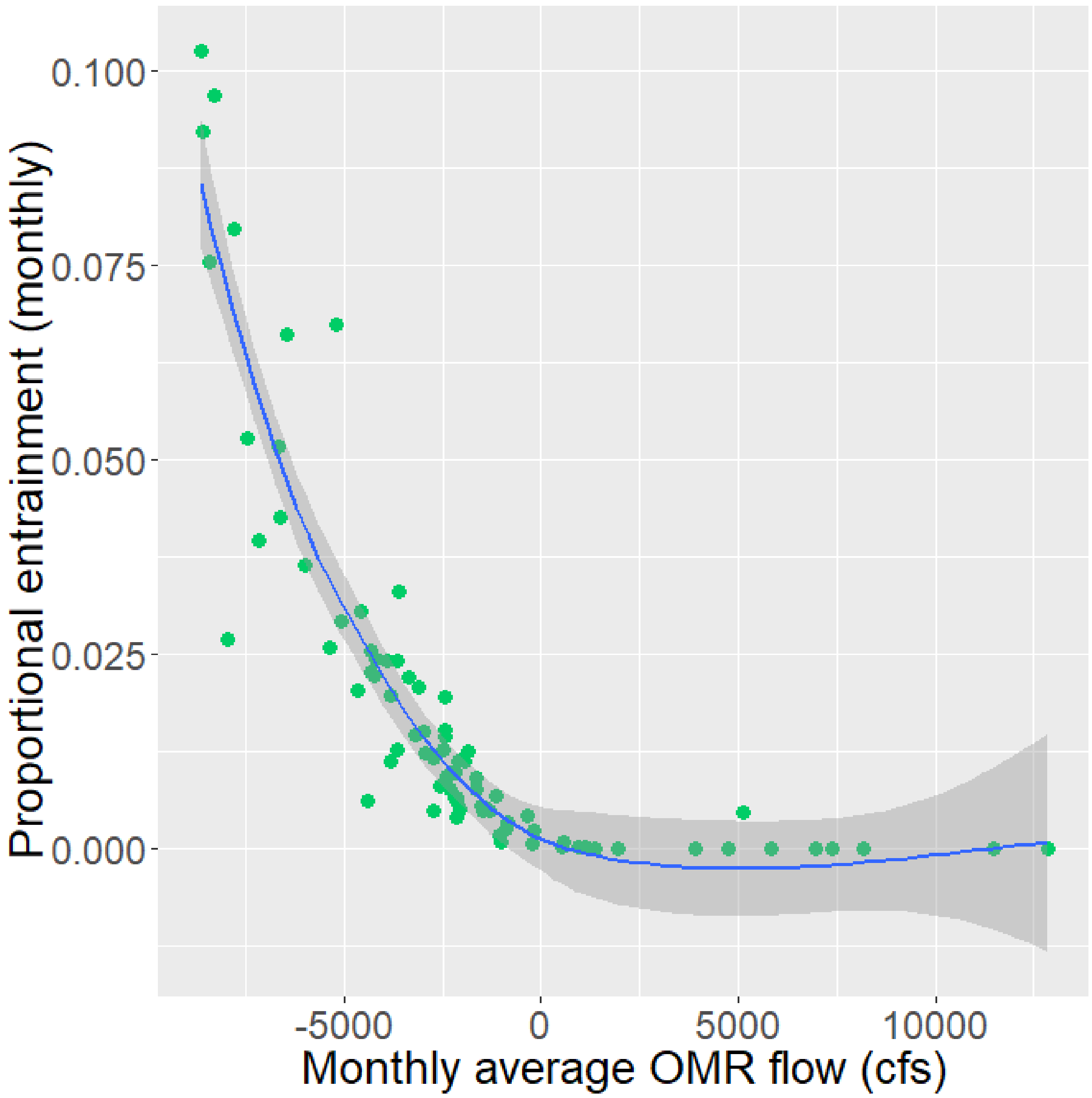

Figure 3. Same as Figure 2, but with the outlier removed and a loess regression spline showing the empirical relationship between OMR flow and the estimated monthly population loss of delta smelt.

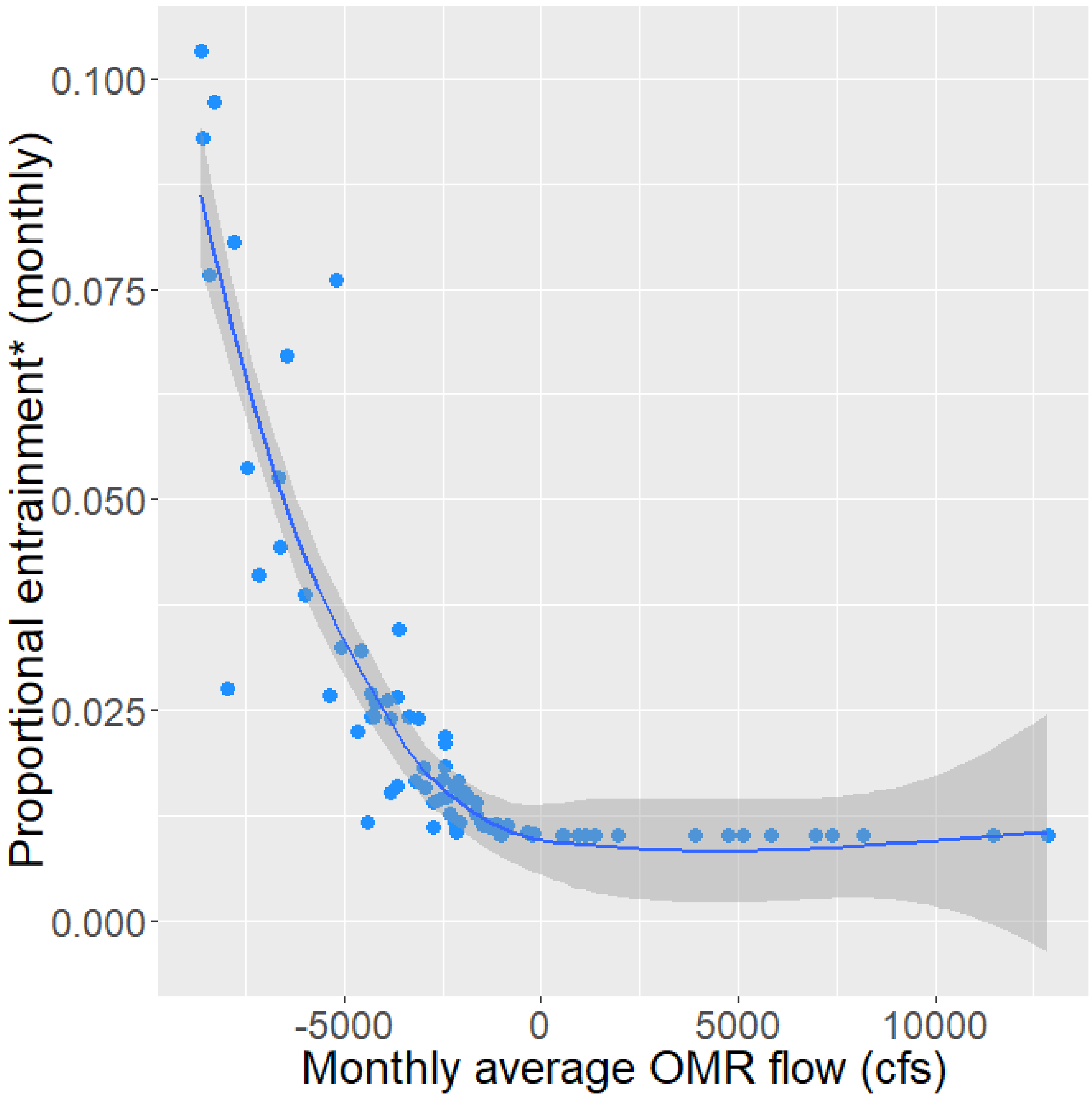

Figure 4. Same as Figure 3, but with south Delta mortality set to 100% under all conditions.

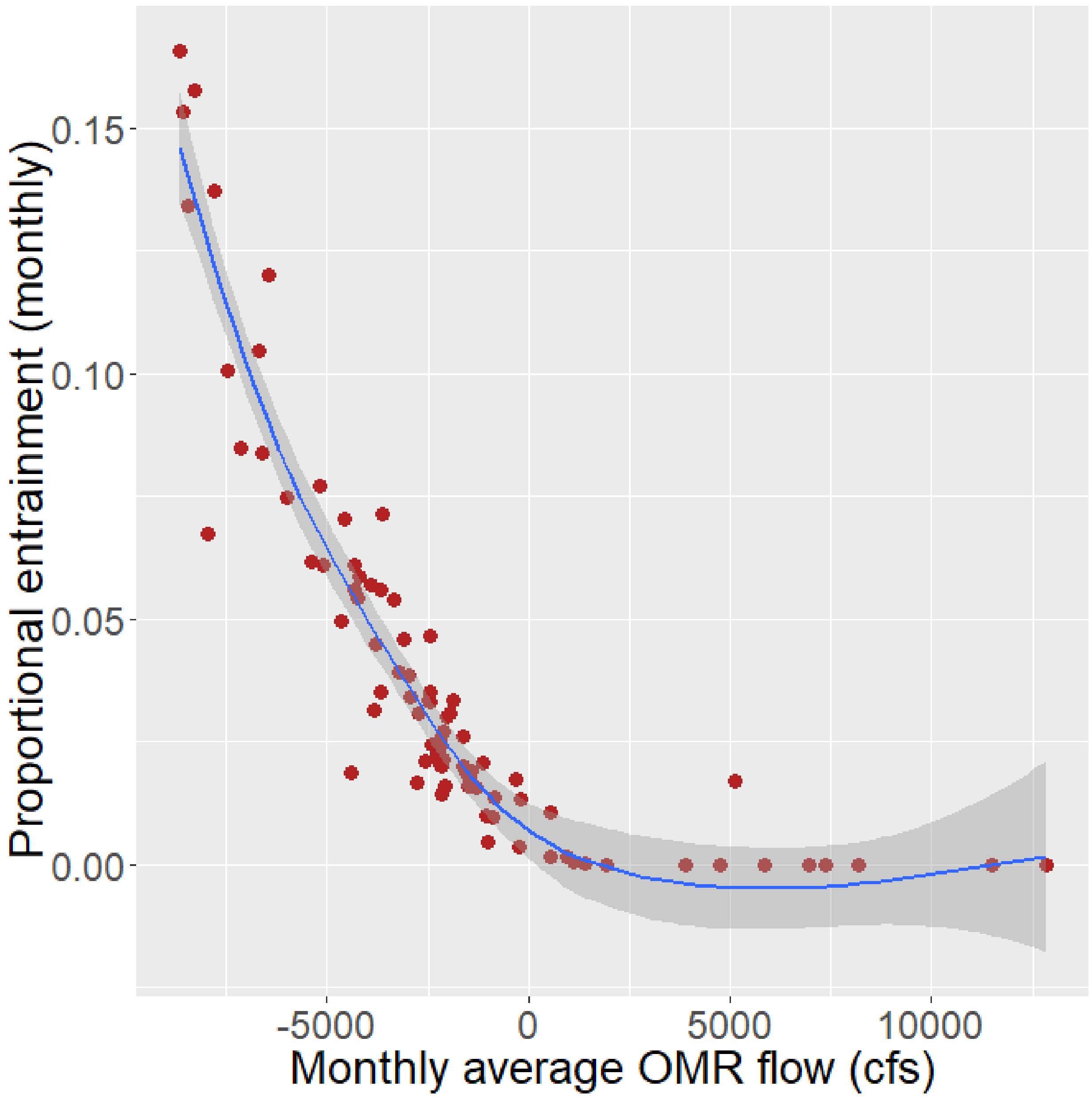

Figure 5. Same as Figure 3, but with the alternative assumption about adult delta smelt distribution along the San Joaquin River mainstem.

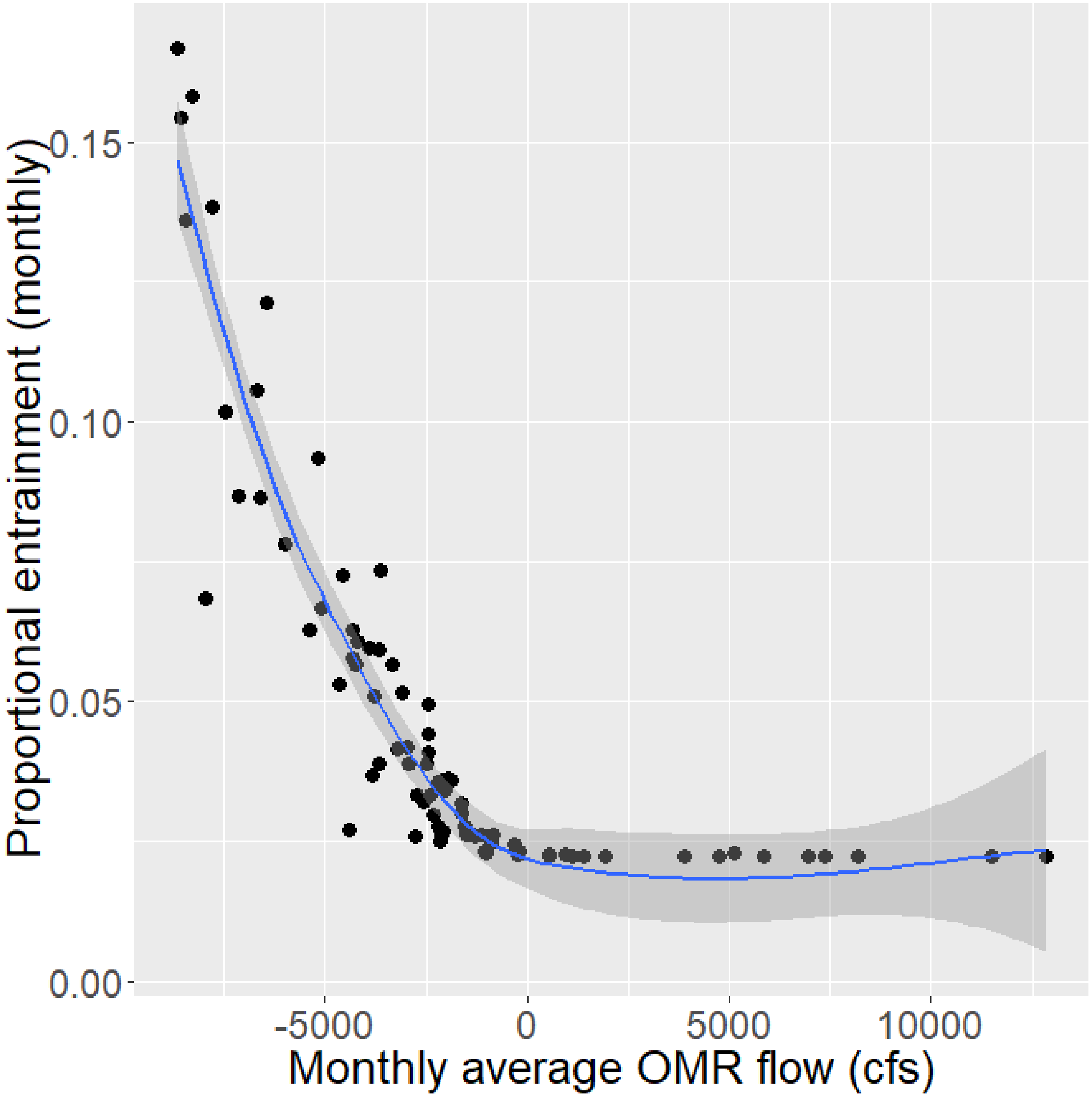

Figure 6. Same as Figure 5, but also including the 100% mortality in the south Delta assumption.

Figures 3-6 employ a statistical visualization tool called loess regression to depict the non-linear relationships between OMR flow and predicted loss. The loess predictions of monthly (30-day) and seasonal (March-June) proportional loss are reported in Table 2 to demonstrate the sensitivity of the calculation to the alternative assumptions. The median modeled OMR flows based on the exceedance plots in the biological assessment were about -4,000 cfs in March and June, -3,000 cfs in April and -3,500 cfs in May (ROC biological assessment Figures 5.16-44 through 5.16-47). The most negative OMR flows modeled in these months were about -5,000 cfs in March and June, and -4,000 cfs in April and May. The loess predictions for each of the four model versions at each of these four OMR flows are reported in Table 2.

I used a *very approximate* way to evaluate a 10 percent loss threshold by summing monthly results across the four months using the appropriate monthly OMR flows (see Table 2 caption). I checked for influences of abundance ranging over three orders of magnitude and natural survival ± 15 percent surrounding the baseline survival reported by Rose et al. (2013b). These factors had no effect on the results presented in Figures 3 through 6 or Table 2). Thus, variation in the abundance of delta smelt or their background 'natural' survival does not affect these simple calculations. Proportional loss estimates would be affected by *spatial* variation in larval mortality rate (e.g., version 2), and would also be affected by seasonal variability in mortality rate if the fish remain vulnerable to entrainment for more than 30 days, and by interannual variation in mortality rate interacting with the other two sources mentioned (Kimmerer 2008). It was beyond the scope of this analysis to explore these factors. It will be possible to explore them using the updated delta smelt individual-based model when it is finished. It should also be possible to do so for the juvenile life stage using DSLCM-3.

The results of this analysis indicate that a median seasonal loss of delta smelt larvae would range from about 8 percent to 20 percent depending on which assumptions are used as input and assuming that losses accumulate similarly across the four-month larval emergence season (Table 2). If worst-case OMR flows were realized in four consecutive months, larval losses might accumulate to 11 percent to 24 percent.

Conclusions: The survival of the 'unentrained' fraction of the delta smelt population likely varies by a lot more than the fractions predicted to be entrained here (Kimmerer 2011; Rose et al. 2013b) and the more careful management of OMR flow over the past 12 years has likely limited larval proportional entrainment to values similar to, or lower than, those in Table 2. However, fully accounting for the movement of multiple delta smelt cohorts and differences in their survival is extremely computationally involved and the tools we are developing to do those calculations are not finished. Given the sensitivity of predictions to minor change assumptions explored in this memo, I recommend that we revisit the proportional loss issue more carefully once DSLCM 3 and the updated IBM have been publicly vetted and peer-reviewed.

Table 2. Summary of estimates of proportional loss of larval delta smelt over a 30-day time-step under four alternative assumptions at four Old and Middle river flows (OMR). The standard error of the mean predictions are provided. Note that the standard error is reflecting uncertainty about where the loess spline should move through the data. This is a much smaller error estimate than e.g., a 95 percent confidence interval would predict. The two columns on the right use combinations of the monthly proportional loss estimates that reflect the OMR flows presented in exceedance plots provided by Reclamation in their biological assessment. For instance, the "Median CALSIM II OMR" column represents a seasonal estimate of proportional delta smelt loss assuming a March OMR of -4,000 cfs, an April OMR of -3,000 cfs, a May OMR of -3,500 cfs, and a June OMR of -4,000 cfs. Note that the loess calculation algorithm in R does not interpolate so the OMR flows listed in the columns are not precisely those from the loess calculations; however the loess OMRs were all within 120 cfs of the listed value.

	Median OMR in April	Median OMR in May	Median OMR in March and June and most negative OMR in April and May	Most negative OMR in March and June		
Model version	OMR = -3,000	OMR = -3,500	OMR = -4,000	OMR = -5,000	Median CALSIM II OMR	Worst-case CALSIM II OMR
1	0.015 (± 0.003)	0.019 (± 0.003)	0.021 (± 0.002)	0.032 (± 0.003)	0.076 (0.066 - 0.086)	0.106 (0.096 - 0.116)
2	0.019 (± 0.003)	0.022 (± 0.003)	0.023 (± 0.002)	0.034 (± 0.003)	0.087 (0.077 - 0.097)	0.114 (0.104 - 0.124)
3	0.038 (± 0.003)	0.048 (± 0.004)	0.050 (± 0.003)	0.064 (± 0.004)	0.186 (0.173 - 0.199)	0.228 (0.224 - 0.242)
4	0.043 (± 0.003)	0.051 (± 0.003)	0.053 (± 0.003)	0.068 (± 0.003)	0.20 (0.188 - 0.212)	0.242 (0.230 - 0.254)

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