BDFWO response to "WILL INCREASING DELTA OUTFLOW HELP DELTA SMELT?" authored by Dr. Scott Hamilton, Center for California Water Resources Policy & Management

Dr. Hamilton:

Thank you for the in-depth evaluation of historical information regarding the statistical linkages and lack thereof between Delta flows and the relative abundance of Delta Smelt at and between various life stages. We appreciate the time and thought that has gone into your analysis. We would like to start our response by thanking you and the community of State and Federal Water Contractors' technical experts for their increasing contributions to the scientific literature on Delta Smelt and its supporting food web over the past several years. Of particular relevance to this memo are first, that some of the historical Delta Smelt abundance indices may be more reliable than others. Second, that the statistical life cycle models published by Maunder and Deriso (2011) and Miller et al. (2012), as well as other recent life cycle modeling efforts (Rose et al. 2013a,b) and the model under development by Dr. Ken Newman and colleagues, have made it abundantly clear that data analyses which do not account for Delta Smelt abundance at a prior life stage when analyzing environmental effects on abundance are very likely misleading and should no longer be considered best available science.

As you are aware, the IEP has two sampling programs that target Delta Smelt: the 20-mm Survey (since 1995) and the Spring Kodiak Trawl Survey (since 2002)(SKTS). Because these surveys were designed to target Delta Smelt, they are considered by the Service to represent best available scientific information on relative abundance trends of Delta Smelt. As you have done in your report, the Service and many others have also traditionally relied on Delta Smelt abundance indices derived from longer-term juvenile Striped Bass surveys, specifically the Summer Townet Survey (STN) and the Fall Midwater Trawl Survey (FMWT). These longer-term abundance index time series have documented the decline of Delta Smelt over time, and as you did in your memo, they have also been used to evaluate environmental influences on Delta Smelt trends and population dynamics (e.g., Stevens and Miller 1983; Moyle et al. 1992; Jassby et al. 1995; Kimmerer 2002a; Bennett 2005; Sommer et al. 2007; Kimmerer et al. 2009; Mac Nally et al. 2010; Thomson et al. 2010; Maunder and Deriso 2011; Miller et al. 2012; Nobriga et al. 2013; La Tour 2016). The citations in the previous sentence represent a substantial body of published scientific work conducted over four decades. Based on our review of that literature, we agree with you that these studies (when they have attempted to) have universally supported your first Executive Summary conclusion that "There is no correlation between spring flows and abundance in the summer or fall" [Dr. Hamilton's reference omitted].

However, the most important of the conclusions in your memo regarding flow and Delta Smelt is number eight: "The existing studies and the best available public data, do <u>not</u> demonstrate that increasing outflows is a **viable method of increasing the abundance of adult delta smelt**."

[quote includes the emphasis fonts provided by Dr. Hamilton]. We would like to use the remainder of this memo to explain why we disagree with this important conclusion.

We start with the longer-term FMWT information (1967-2015) and then transition into the newer 20-mm Survey and SKTS data (2002-2015). The fundamental question is whether there is statistical support for the hypothesis that Delta outflow has a positive influence on Delta Smelt abundance. We first tested this hypothesis using a binary variable based on the ratio of the FMWT index to its value the prior year, then converted it into a binary variable coded as 1 if the index declined between years and 2 if it increased. This accounted for the influence of prior population size on current population size, but removed the excessive influence of the 1970, 1993, 1995, and 2011 data points; four Wet or Above Normal years with very high single year increases in relative abundance (Figure 1). We tested two versions of the null hypothesis Delta outflow does not affect delta smelt abundance:

(1) FMWT index ratio (termed "Grow" in Appendix A) ~ log(Delta outflow in the birth year) + Month,
(2) FMWT index ratio (termed "Grow" in Appendix A) ~ log(Delta outflow in the birth year) + Month + interaction term of outflow and month

The results of both tests provided very strong statistical support for rejection of the null hypothesis. The *P*-value of the flow term was 0.0007 in equation 1 and 0.0002 in equation 2; (Appendix A). Stated another way, the results provide strong support for a role of Delta outflow on the population trend of Delta Smelt when its abundance the year prior has been accounted for. The parameter estimates for the flow term are positive numbers supporting a positive influence of Delta outflow on the year over year growth of the Delta Smelt population. A graphical look at this analysis shows that Delta outflow has often been higher from January through August or September when the Delta Smelt population grew larger than it had been the prior year (Figure 2). We have not attempted to refine this further by trying to parse whether some of these months were more important than others.

The analysis described above is based on FMWT data, which are likely less reliable than the newer, but shorter-term data sets. The analysis presented in Appendix B tests for an influence of Delta outflow and several other flow, food, and temperature variables on the production of juvenile Delta Smelt using estimates of Delta Smelt abundance derived from the 20-mm Survey and the SKTS. As such, it focuses on conditions occurring during the spring. Our analysis found similar explanatory power for both X2 during April and May, and water temperature during April, both of which had $r^2 > 0.70$ (Table 2 in Appendix B). The relationship with Delta outflow per se had a lower r^2 due to very low recruitment during the 2014-2015 drought years (Figure 1 in Appendix B). We conclude that since 2002, near the change point of an ecosystem regime shift in the upper estuary, early juvenile production has largely been a function of the size of the adult spawning stock interacting with physical habitat conditions experienced by the egg through early juvenile stages. These mechanisms make biological sense – egg supply is predominantly a function of adult stock size and water temperature (Rose et al. 2013a), and flow variables affect X2, which in turn affects from where in the estuary individual fish are able to successfully produce young (Hobbs et al. 2007; Kimmerer 2008) because X2 indexes the intersection of several important habitat components (Kimmerer 2002b; Bever et al. 2016) and as such has the capacity to influence Delta Smelt mortality rates via numerous individual pathways (per Figure 2 in Miller et al. 2012).

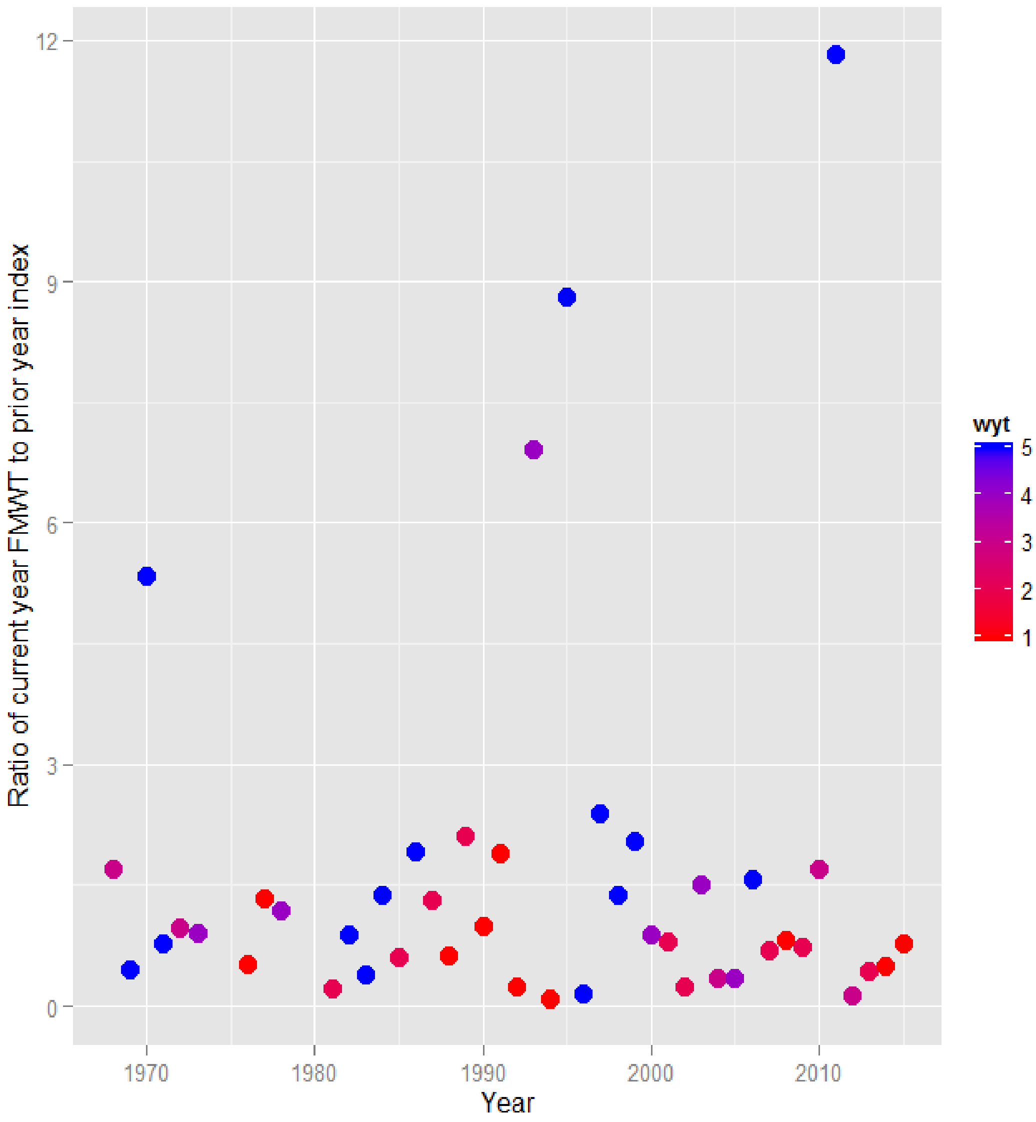

Figure 1. Time series of the Delta Smelt Fall Midwater Trawl indices as a fraction of their prior year value (1968/1967 through 2015/2014). Data points are color-coded by the DWR Water Year Type classification (see lengend).

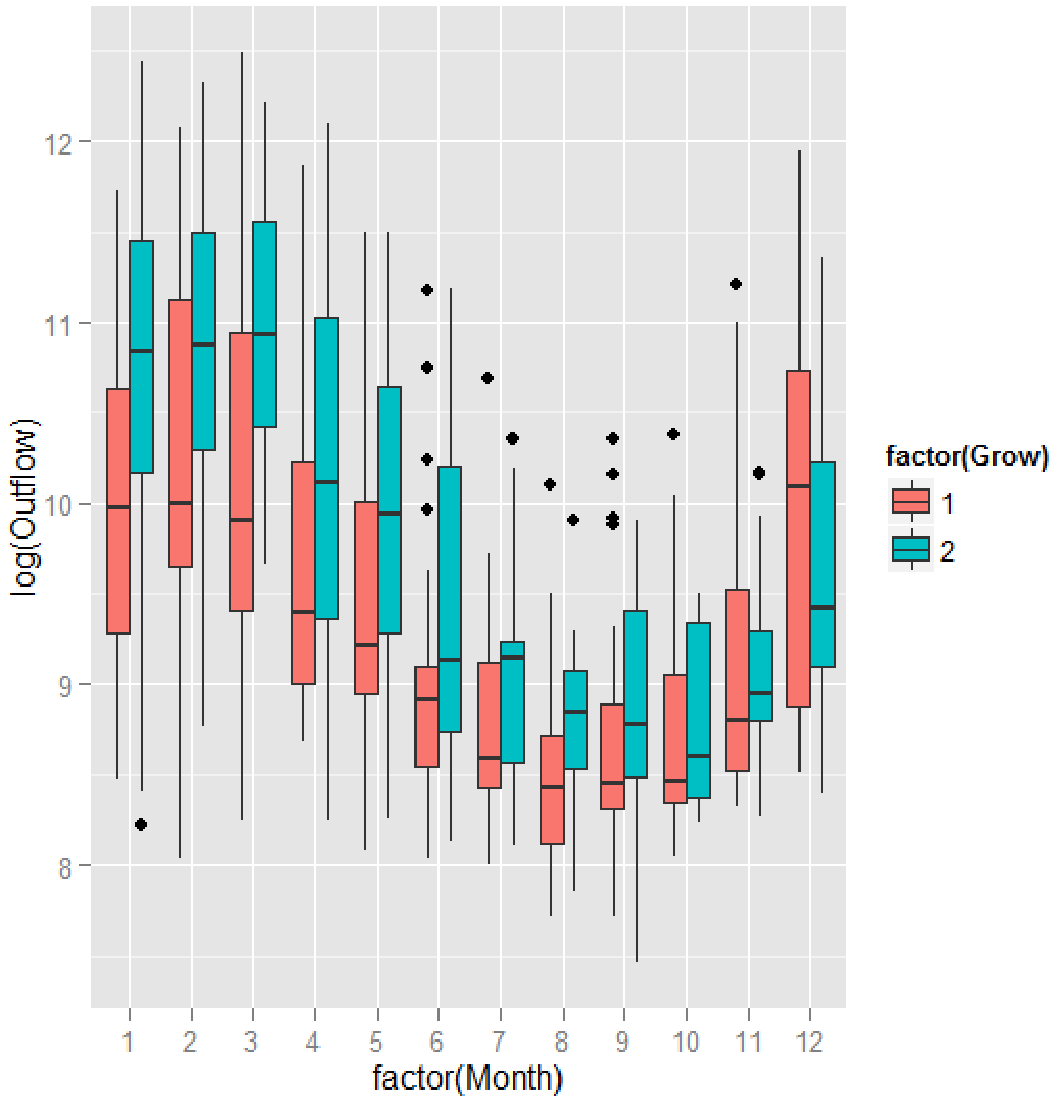

Figure 2. Boxplot of Delta outflow by month of the year (January = 1) for years the Delta Smelt population decreased, meaning Fall Midwater Trawl index was smaller than the prior year index (orange), and increased meaning Fall Midwater Trawl index was larger than the prior year index (teal). When this pattern was tested using an ANCOVA (Appendix A), the Delta outflow term was positive and statistically significant, the month term was not significant. When an outflow:month interaction term was included in the model, that term was also statistically significant because not every month contributed to the overall result.

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Appendix A: R code for statistical tests reported by FWS staff

```
R version 3.1.0 (2014-04-10) -- "Spring Dance"

Copyright (C) 2014 The R Foundation for Statistical Computing

Platform: x86_64-w64-mingw32/x64 (64-bit)

R is free software and comes with ABSOLUTELY NO WARRANTY.
You are welcome to redistribute it under certain conditions.
Type 'license()' or 'licence()' for distribution details.

  Natural language support but running in an English locale

R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in publications.

Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.

> data <- read.csv(file.choose("SmeltFlow.csv"), header = TRUE)
> result <- lm(Grow ~ log(Outflow) + Month, data = data)
> summary(result)

Call:
lm(formula = Grow ~ log(Outflow) + Month, data = data)

Residuals:
    Min      1Q  Median      3Q     Max
-0.6469 -0.3894 -0.3295  0.5670  0.7471

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.616969   0.234483   2.631 0.008771 **
log(Outflow) 0.076174   0.022228   3.427 0.000661 ***
Month        0.009978   0.006922   1.442 0.150039
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.4866 on 501 degrees of freedom
Multiple R-squared:  0.0229,    Adjusted R-squared:  0.019
F-statistic: 5.872 on 2 and 501 DF,  p-value: 0.003015

> result2 <- lm(Grow ~ log(Outflow) + Month + log(Outflow):Month, data = data)
> summary(result2)

Call:
```

```
lm(formula = Grow ~ log(Outflow) + Month + log(Outflow):Month,
    data = data)

Residuals:
    Min      1Q  Median      3Q     Max 
-0.6871 -0.4067 -0.3176  0.5601  0.8745 

Coefficients:
                     Estimate Std. Error t value Pr(>|t|)    
(Intercept)        -0.217229   0.432985  -0.502 0.616098    
log(Outflow)        0.159602   0.042659   3.741 0.000204 ***
Month               0.148843   0.061088   2.437 0.015177 *  
log(Outflow):Month -0.014306   0.006253  -2.288 0.022566 *  
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.4846 on 500 degrees of freedom
Multiple R-squared:  0.03303,   Adjusted R-squared:  0.02722 
F-statistic: 5.692 on 3 and 500 DF,  p-value: 0.0007738
```

Appendix B: Assessing Delta Smelt Recruitment Success

Assessing Delta Smelt Recruitment Success
DRAFT

Ken Newman, Lara Mitchell, and Matt Nobriga

June 6, 2016

This note presents initial answers to the following question:

- "How are environmental factors associated with reproductive success, *recruitment*, of delta smelt?"

Recruitment for a given cohort was defined as the ratio of the number of juveniles in June to the number of adults in February. We recognize the imprecision in this definition as the particular times within February and June are not specified.

1 Recruitment estimation

Recruitment was estimated using estimates of adult and juvenile abundances that were based on fish survey data from 2002 through 2015. For both adults and juveniles, stratified random sample ratio expansions were used to estimate abundance. Within a stratum the ratio was total catch at all sampling locations divided by total volume sampled (m^3).

1.1 Juvenile abundance estimation

The abundance of juveniles was estimated using Delta Smelt catches from all samples taken during the month of June by the 20mm survey. 20mm gear was assumed to have the following length-based capture probability.

$$\pi_{20mm}(L) = \frac{\exp(-11.577 + 0.699L)}{1 + \exp(-11.577 + 0.699L)}$$

where $\pi_{20mm}(L) = \Pr(\text{Catch a length } L \text{ fish}|\text{fish was present in 20mm tow volume})$. We think $\pi_{20mm}(L)$ likely overestimates selectivity for fish between 15 and 20mm and perhaps underestimates fish less than 15mm. Somewhat arbitrarily, calculated values < 0.02 were set equal to 0.02. We assumed that juvenile fish occupied a horizontal stratum between 0.5m and 4.5m from the surface. To remove the portion of tow volume that was above or below that stratum, a geometric calculation was carried out assuming an oblique tow from the maximum tow depth to the water surface. A further assumption was that the height of the gear opening was 1.292m (4.2 feet). The formula for estimating juvenile abundance:

$$\hat{n}_{Juveniles} = \sum_{h=1}^{H_{20mm}} V_{h,4m} \frac{\sum_{i=1}^{m_h} \frac{c_{20mm,h,i}}{\pi_{20mm}(\overline{L}_{h,i})}}{\sum_{i=1}^{m_h} v_{adj,20mm,h,i}} \quad (1)$$

where $V_{h,m}$ is the estimated volume to 4m depth in stratum h, $c_{h,i}$ is the catch at location i in stratum h, $\overline{L}_{h,i}$ is the average length, and $v_{adj,h,i}$ is the adjusted volume.

1.2 Adult abundance estimation

The abundance of adults during the month of February was estimated using catches from the SKT surveys taken in January and February, assuming that survival was relatively high during this time period. The Kodiak trawl gear was assumed 100% effective For adult abundance estimation, we assumed that adult fish occupied the top 4m and the fish density declined linearly from the surface to 4m depth. Further assuming that the Kodiak trawl fished the top 2m, the catch densities were biased high by a multiplier of 1.5, thus catches were reduced by a multiplier of 1/1.5 = 2/3. The formula for estimating "adult" abundance:

$$\hat{n}_{Adults} = \frac{2}{3}\sum_{h=1}^{H_{SKT}} V_{h,4m} \frac{\sum_{i=1}^{m_h} c_{SKT,h,i}}{\sum_{i=1}^{m_h} v_{SKT,h,i}} \quad (2)$$

Strata for the 20mm and SKT surveys differed but both were based on the sub-region partitioning of the DSM2 hydrology model. Sub-regions without sampling locations were merged with neighboring regions which did have sampling. Volume calculations were provided by USGUS who carried out tide-adjusted bathymetric calculations.

1.3 Results

The resulting estimates are shown in Table 1. Standard errors for abundance estimates were calculated assuming design based estimation and ignored error in the 20mm gear capture probabilities. Recruitment, λ, was estimated by dividing the juvenile abundance estimate by the adult abundance estimate.

Table 1: Estimated abundances of juveniles and adults and associated standard errors and estimated recruitment ($\hat{\lambda}$).

Year	$\hat{n}_{adult}$	se_{adult}	$\hat{n}_{juv}$	se_{juv}	$\hat{\lambda}$
2002	597	118	1632	1035	2.74
2003	519	206	3941	3237	7.6
2004	527	154	1029	717	1.95
2005	385	86	3706	2475	9.63
2006	151	28	5109	3338	33.91
2007	235	75	580	934	2.46
2008	262	105	966	1258	3.68
2009	295	128	863	822	2.92
2010	134	33	2336	1962	17.4
2011	234	118	4320	2914	18.42
2012	623	186	5067	5351	8.14
2013	171	52	1548	1571	9.04
2014	167	52	165	255	0.99
2015	112	42	47	98	0.42

2 Modeling recruitment

A multiplicative model for juvenile abundance was assumed.

$$n_{juv,t} = n_{adult,t}\lambda_t \tag{3}$$

where λ_t can be interpreted as the number of juveniles produced per adult. Interest was in the factors that might influence λ_t. Allowing for environmental variation the following univariate models were fit:

$$n_{juv,t} = n_{adult,t}\exp(\beta_0 + \beta_1 X_{j,t} + \epsilon_t) \tag{4}$$

where $X_{j,t}$ denotes a covariate and ϵ_t is environmental variation. Estimates of abundances were substituted for the true abundances and taking a natural log transformation of both sides of equation (4) yielded the following linear regression model.

$$\ln(\hat{n}_{juv,t}) = \ln(\hat{n}_{adult,t}) + \beta_0 + \beta_1 X_{j,t} + \epsilon_t, \quad t = 2002, \ldots, 2015 \tag{5}$$

Table 2 lists some of covariates considered along with R^2 values. Figure 1 shows plots of $ln(\hat{n}_{juv}/\hat{n}_{adult})$ against the first four covariates. Estimated recruitment had the strongest association with the average $X2$ value for the months of April and May (R^2=0.74), although the association with water temperatures during April was nearly the same (R^2=0.71). All these results should be viewed critically given the many assumptions made to construct the recruitment estimate and the relatively small data set of 14 observations. Work is on-going. Specific tasks are to (a) improve the estimates of the 20mm capture probabilities, (b) extend the time period of analysis to 1991, including Spring Midwater Trawl survey data for adult abundance estimation, and (c) integrate estimation of recruitment within the fitting of a life cycle model which connects abundance between cohorts.

Table 2: Covariates used to model recruitment and corresponding linear regression R^2 values.

Covariate		R^2
Label	Definition	
Outflow.Apr.May	average daily inflow during April and May	0.55
Exports.Apr.May	average daily export volume during April and May	0.49
OMR.Apr.May	average daily OMR value during April and May	0.38
X2.Apr.May	average daily X2 value during April and May	0.74
Water.Temp.Apr	average 20mm survey water temperatures during April	0.71
Water.Temp.May	average 20mm survey water temperature during May	0.32
Secchi.May	average 20mm survey Secchi measurements during May	0.23
Prey.NJ.Apr	measure of nauplii and copepodids in April	0.31
Prey.JACM.May	measure of copepodids, copepods, claudicerans, and mysids in May	0.35
Prey.Eury.May	measure of *Eurytemora* in May	0.45
Feb.length	estimated average length of adults in February	0.21

Figure 1: $ln(\hat{n}_{juv}/\hat{n}_{adult})$ versus Outflow, Exports, OMR, and X2.