Statistical Modeling of Juvenile Salmonid Salvage in the Sacramento-San Joaquin Delta

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Date: February 13, 2020

Acknowledgments

The author would like to specifically thank Harry Spanglet (retired) Chief of the Regulatory Compliance Branch for his support to this study as well as his review of this report. The author would also like to thank my DWR colleagues including Ted Sommer, Kevin Reece, Farida Islam for their reviews of the manuscript and Geir Aasen of Department of Fish and Wildlife for his help with data and his report review. In addition, the author would like to thank Dennis Helsel of Practical Statistics for providing valuable advice during the development of the DSSM model.

Executive Summary

Chinook salmon (*Oncorhynchus tshawytscha*) and Central Valley steelhead (*Oncorhynchus mykiss)* salvage are important component of efforts by the Department of Water Resources to address the decline of these species in the Sacramento and San Joaquin watersheds. Although juvenile salmonids are salvaged to improve their survival opportunities, the California Department of Fish and Wildlife and the National Marine Fisheries Services use increased salvage beyond regulatory thresholds as an indicator of reduced survival in the Sacramento and San Joaquin Delta (Delta). Under these circumstances, water exports to south of the Delta water users are reduced.

Consequently, significant efforts have been made to better understand the physical and biological factors affecting survival of juvenile salmonids in the Delta and its tributaries. These studies reveal the complexity of factors affecting juvenile salmonid survival in the Delta and its tributaries. However, flow into the interior has been established as a very important factor negatively affecting survival of juvenile salmonids.

This study specially focuses on the relationship between interior Delta inflows and juvenile salvage at the State Water Project (SWP) and Central Valley Project (CVP) fish salvage facilities. By focusing on salvage as opposed to survival, this study is more directly associated with the regulatory criteria affecting export pumping.

These goals were achieved by developing the Delta Salmonid Salvage Model (DSSM). The DSSM is a multiple linear regression (MLR) model. The explanatory variables include flows into the interior Delta from Sacramento, San Joaquin, Mokelumne, Cosumnes, as well as Old and Middle River, X2, and export pumping. The salvage data inputs to the DSSM are the combined SWP and CVP salvage of Chinook salmon and steelhead. The development of the DSSM was based on the proper application of the assumptions of MLR. The rigorous application of these methods is described in detail in this report.

Although the DSSM is relatively simple MLR, this study demonstrated that a quantitative relationship based on an MLR model relating salvage to interior Delta inflows from upstream tributaries having juvenile salmonid habitat can be used as an effective tool to support SWP operations and modeling.

1. Introduction

This study was performed to evaluate potential relationships between Sacramento-San Joaquin Delta (Delta) inflows and the salvage of Chinook salmon (*Oncorhynchus tshawytscha*) and Central Valley (CV) steelhead (*Oncorhynchus mykiss*) at the State Water Project (SWP) and Central Valley Project (CVP) export facilities located in the southern Sacramento-San Joaquin Delta (Delta).

Salvage of these species is an important component of the efforts of the State of California, Department of Water Resources (DWR) and the federal United States Bureau of Reclamation (Reclamation) to accomplish the goals of providing a more reliable water supply for California and protecting, restoring and enhancing the Delta ecosystem in a manner that protects and enhances the values of the Delta as an evolving place. Salvage data are an important metric used by the California Department of Fish and Wildlife (DFW) and National Marine Fisheries Service (NMFS) to regulate the operations of the SWP and CVP. Consequently, a clearer understanding of salvage and Delta inflow-export relationships should provide useful insights to inform management decisions.

The goal of this study was to evaluate relationships between Delta inflows, export pumping and salvage of Chinook salmon and steelhead at the SWP Banks and CVP Jones fish salvage facilities. To accomplish these objectives, a multiple linear regression (MLR) model was developed to explore the significance of Delta inflows from major and minor tributaries. The development of this Delta Salmonid Salvage Model (DSSM) was performed by applying methods conforming to the assumptions of MLR to identify significant explanatory flow variables in the DSSM.

The DSSM is a relatively simple MLR statistical model. These simplifications include treating combined SWP and CVP salvage and exports as single variables. However, there are clear differences between the factors affecting salvage at the SWP and CVP fish salvage facilities (for example, pre-salvage mortality and louver efficiency). In the DSSM, Chinook salmon and steelhead are not differentiated in the salvage variable nor are the various types of juvenile runs (for example, winter, fall, late-fall and spring) nor does the DSSM attempt to represent different tributary sources of salvaged fish (for example, Sacramento and San Joaquin rivers). There is also no attempt to distinguish between native and hatchery fish. Another limitation is that the DSSM was developed using all the salvage and flow data during the study period. Consequently, the DSSM was not properly verified by testing with a separate dataset.

The DSSM developed in this study provides support for the concept that juvenile Chinook and steelhead salvage at the SWP and CVP facilities is related to the magnitude of interior Delta inflows from tributaries with sources of juvenile Chinook salmon and steelhead. Tidally influenced interior Delta flows in the Old and Middle River (OMR) and interior flows affecting Delta salinity (X2) were also identified as being important explanatory variables in juvenile salmonid salvage.

2. Background

This study focuses on the Delta inflows, export pumping at the SWP Harvey O. Banks and the CVP C.W. "Bill" Jones pumping plants, and fish salvage and loss at their fish salvage facilities occurring from October 1, 2008 to September 30, 2018. This time period was selected because high quality flow and salvage data were available and the operations of the SWP and CVP were consistent with the California State Water Resources Control Board (SWRCB) decision D-1640 and NMFS Biological Opinion (BiOp) in 2009.

Major tributary inflows include the Sacramento River and San Joaquin River. These rivers have mean annual flows of approximately 36,500 cfs (at Freeport) and 5,770 cfs (at Vernalis), respectively. Other significant Delta tributaries are the Cosumnes River with a mean annual flow of 492 cfs (at Michigan Bar) and Mokelumne River with a mean annual flow of 504 cfs (at Woodbridge). The other important eastside tributary is the Calaveras River, which has a mean annual flow of approximately 225 cfs (at Jenny Lind). The locations of these tributaries and gages are shown on Figure 1.

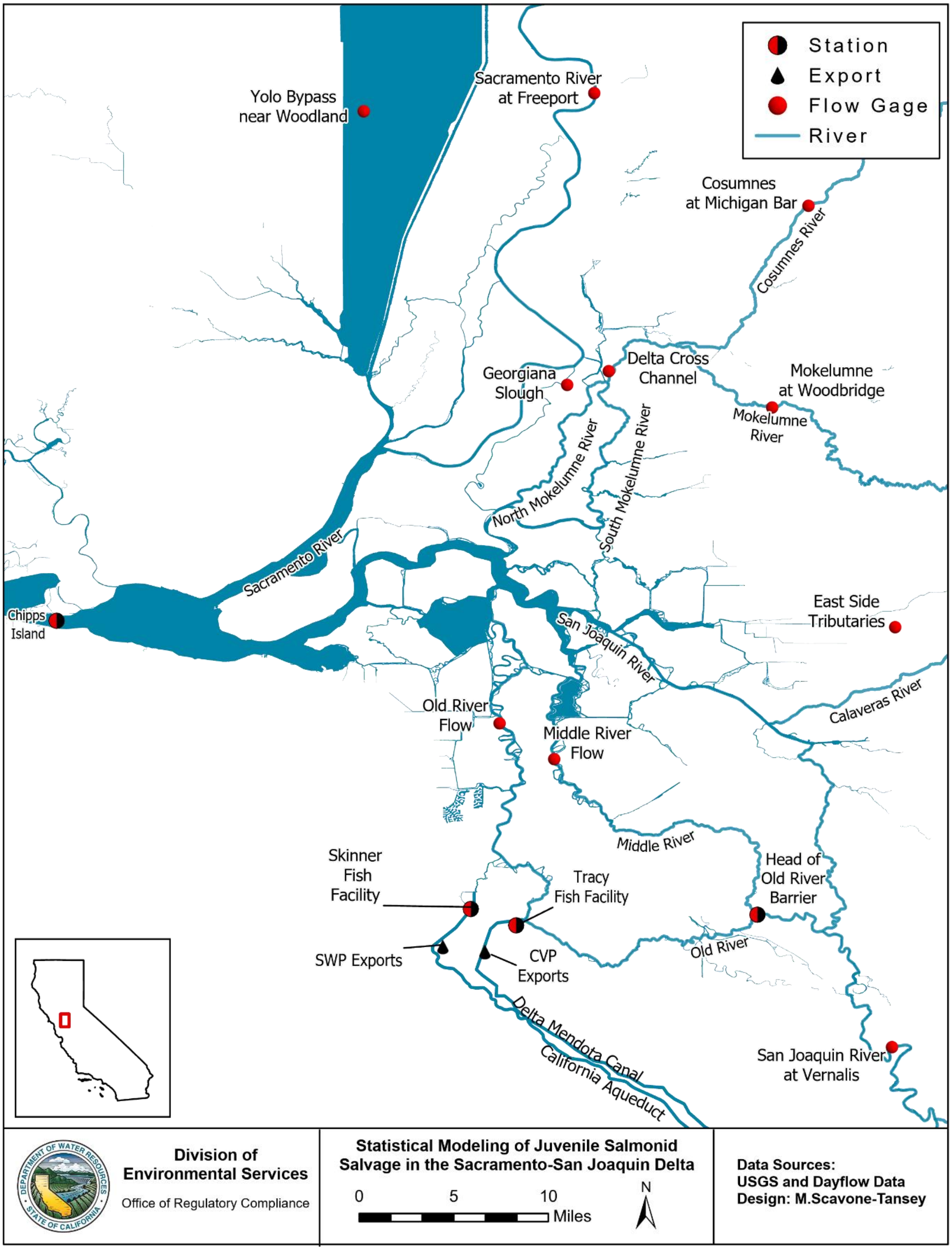

Figure 1. Location of Flow Gages and SWP/CVP Facilities

The major tributaries are also important sources of various runs of both native and hatchery juvenile salmonids. Sacramento River fish include native and hatchery fish released from the Livingston Stone and Coleman National Fish Hatcheries as well as the state Feather River and Nimbus Fish Hatcheries. San Joaquin River fish include native and hatchery fish from the Stanislaus, Tuolumne and Merced rivers. Eastside tributary fish include native fish from the Cosumnes River and native and hatchery fish from the Mokelumne River. The locations of these tributaries and hatcheries are shown on Figure 2. As well as being sources of juvenile salmonids, these tributaries also provide important spawning and rearing habitats that support the early life stages of salmonids. In high flow years, the Yolo Bypass also provides important rearing habitat for Sacramento River juvenile salmonids as they migrate toward the Delta (Sommer *et al.*, 2005).

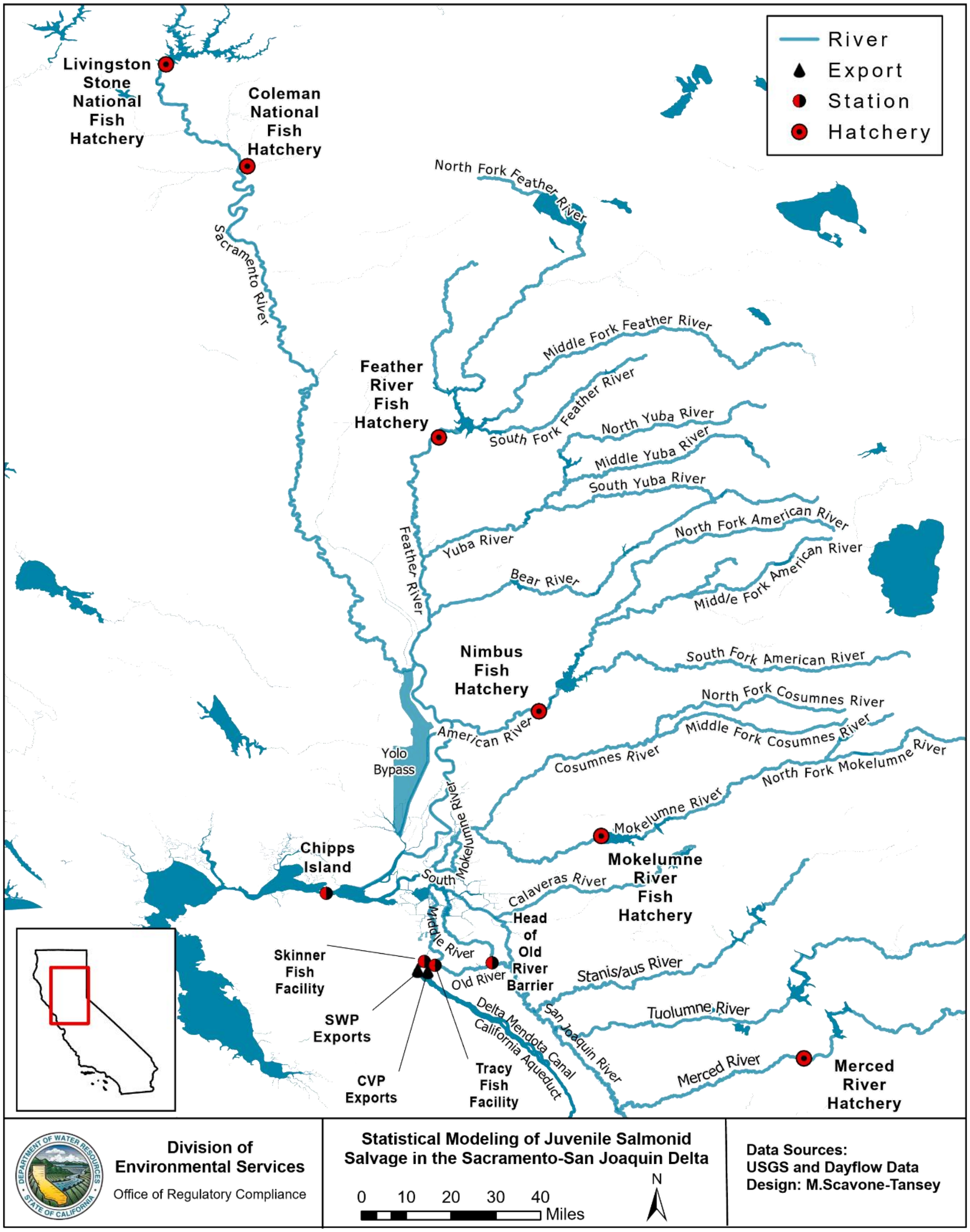

Figure 2 Locations of Delta Tributaries and Hatcheries Contributing Juvenile Salmonids

In the Central Valley watersheds, there are three evolutionary significant units (ESU) of Chinook salmon including the winter, late-fall/fall and spring runs as well as CV steelhead. In the Sacramento River watershed, the runs primarily consist of winter, spring, fall and late-fall runs. Winter-run Chinook salmon spawn in the spring or early summer and the juveniles migrate to the sea after 4 to 7 months, arriving in the Delta during the late fall and winter months. Spring-run Chinook salmon spawn from September through October and some juveniles emigrate shortly after emergence while others remain in their natal streams and emigrate later as larger yearlings (CalFish, 2018).

In the San Joaquin River watershed, the principal runs are fall and late-fall Chinook, and CV steelhead. Although some juveniles remain in freshwater for one to two years, most fall-run and late-fall-run juveniles migrate to the sea within a few months after emergence (CalFish, 2018), and about 70% of these juveniles arrive in the Delta during spring months as fry or parr rather than as larger sized smolts (Perry *et al*., 2016). These differences in size are important because increasing fish size from fry to parr to smolts increases chances of survival to Chipps Island.

Juvenile Chinook salmon and CV steelhead arrive in the Delta by three primary routes - the Sacramento, San Joaquin and Mokelumne rivers. Salvage of these fish is dependent on their entering the interior Delta and surviving long enough to be entrained into the CVP and SWP fish salvage facilities located on the Old River channel of the San Joaquin River (Figure 1).

In the Sacramento River, there are several routes through which juveniles may reach the interior Delta; one major route is through the Delta Cross Channel (DCC) and Georgiana Slough at the junction of the Sacramento River. This junction is under tidal influence at discharges of less than 20,000 cubic feet per second (cfs) at Freeport (Perry *et al.*, 2014), when reverse flows in the Sacramento River occur during flood tides. The interactions between tidal stages and Sacramento River flows exert significant effects the direction and amount flow through the DCC and Georgiana Slough (Perry *et al.*, 2014). When the DCC gates are open, flow into the DCC is lower at ebb tide than at flood tide. When the DCC gates are closed, flow into Georgiana Slough is positive and slightly higher during flood tides (Perry *et al.*, 2014).

In the San Joaquin River, juvenile salmonids also follow complex routes prior to entrainment and salvage. Fish entering the Delta at Vernalis (Figure 1) may enter the Old River channel or continue down the main channel of the San Joaquin; juveniles migrating downstream of the Old River junction may enter the interior Delta by passage through Turner Cut and Columbia Cut (Buchanan *et al.*, 2013). Juvenile salmonid migration is further complicated by the irregular installation of physical and non-physical barriers at the junction of the San Joaquin River and the Head of Old River (HORB). These barriers, which have been installed in April or May between 1992 and 2014, are intended to prevent juvenile salmonids from entering the Old River channel based on the assumption that survival of emigrating juvenile salmonids is greater in mainstream of the San Joaquin River than in the Old River. However, during high flow years the physical barriers may not be installed. When the HORB physical barrier is not in place and the combined SWP/CVP export pumping is less than flow at Vernalis, about 50% of flow enters the Old River, whereas at a combined pumping of five times the Vernalis flow about 80% of the flow enters the Old River channel (SWRCB, 2012). When the HORB is installed, flow into the Old River is reduced to 20-50% of the San Joaquin River flow. In 2009 and 2010, a non-physical Bio-Acoustic Fish Fence (BAFF) was installed, but unlike the physical barriers which route both fish and flow down the San Joaquin River, the non-physical barrier routes only fish.

Juvenile salmonids entering the interior Delta through the Mokelumne River may arrive by several routes (Figure 1). Native and hatchery fish can travel directly downstream in the upper Mokelumne River from the hatchery to where the river splits into the North and South Forks near Walnut Grove. Migrating Cosumnes River juveniles enter the upper Mokelumne River near Mokelumne City. Sacramento River fish that pass through the DCC may enter either the North Fork or South Fork of the Mokelumne River through Snodgrass Slough near Walnut Grove. Juveniles passing through Georgiana Slough enter the Mokelumne River just downstream of the confluence of the North and South Forks which is slightly upstream of the Highway 12 Bridge. Approximately two miles downstream, the Mokelumne River discharges into the San Joaquin River near Webb Point.

There have been several studies relating river flows to survival of juvenile salmonids in the Sacramento and San Joaquin River watersheds. These studies are based on the survival of different runs of hatchery fish released at various locations upstream of the Delta. Studies prior to 2007 employed coded wire tags (CWT), which are metal wire tags marked with a numeric code that are implanted in the heads of juvenile hatchery fish. The CWT identifies each fish as a member of a specific release group, and each group is then released at a specific river location. For each group the species/run, number of fish, average size, estimated tagging rate, release location and release time/date are recorded and reported. Tagged fish are marked for identification with a clipped adipose fin for ready identification.

Recovery of these CWT fish may occur at the SWP and CVP fish salvage facilities as well as in regular trawls at Chipps Island (Figure 1). Since 2007, some studies have used acoustic telemetry to discern the migration and survival of release juvenile salmonids, but telemetry studies require use of larger fish because the transponders used in these studies are significantly heavier than CWTs. These studies also require a network of hydrophones to be located along migration routes as well as methods to discriminate between signals of migrating juveniles and those that have been consumed by predators. Tag failure during migration is also another problem that can affect the interpretation of the results.

Using CWT data, Newman (2008) and Newman (2010) found modest evidence that closure of the DCC gates improved the survival to Chipps Island of fish released in the Sacramento River. In addition, survival of fish released in Georgiana Slough was reported to be only about 40% of fish that remained in the Sacramento River channel. An analysis of 30 years of CWT studies indicates a generally positive effect of river flow on survival of juveniles in the Sacramento River (Perry *et al.*, 2014). These studies also reveal a negative effect on fish survival due to open DCC gates. Based on acoustic telemetry studies, entrainment of juvenile salmonids into the DCC typically was correlated with DCC inflows but was generally less than the inflow fraction. This effect occurs because the distribution of fish in the channel is not usually uniform (Perry *et al.*, 2016). With the DCC gates open, entrainment into the DCC during flood tide was more likely than into Georgiana Slough. With the gates closed, juvenile entrainment into Georgiana Slough increased. Entrainment in the Sacramento River varied with the tidal cycle from about 90% at ebb tides to about 10% at peak flood tide (Perry *et al.*, 2016).

Survival of juvenile fall-run emigrating in the San Joaquin River is markedly lower than in the Sacramento River. Using CWT data, Newman (2008, 2010) reported a positive effect of flow on survival. Baker and Morhardt (2001) found a positive relationship between flow and smolt survival at San Joaquin River flows above 10,000 cfs and little correlation at lower flows. Similarly, the NMFS Biological Opinion for the SWP/CVP (BiOp) (2009) concluded that a positive relationship between flow and escapement numbers 2.5 years later occurs at flows above 5,000 cfs. Based on acoustic telemetry studies conducted in 2009 and 2010 when the BAFF was employed, juvenile survival was greater in the higher flow year of 2010 (average flow of 5,100 cfs) than in 2009 (average flow of 2,260 cfs).

Once juvenile salmonids enter the Delta by any of the various routes described above, they are subject to variety of stressors before either successfully reaching Chipps Island or being salvaged at the SWP and CVP fish facilities. There are many causes of juvenile mortality in the interior Delta, including predation (e.g., striped bass, largemouth bass, channel catfish, white catfish), lack of suitable aquatic habit conditions (e.g., poor riparian cover and inadequate zooplankton food supply), poor water quality conditions (e.g., elevated water temperatures, low dissolved oxygen, toxics related to agricultural runoff), entrainment into agricultural water diversions, and others.

Another significant factor affecting juvenile migration through the Delta is the important role of tides. Except during major river floods, flows in the interior Delta are primarily driven by the tidal cycle, which changes from flood (incoming) to ebb (outgoing) every six hours, and during flood tides rivers reverse flows from downstream to upstream. Such reverse flows may be confusing to migrating juveniles because cues to the direction of the ocean are disrupted, and smaller fish with weaker swimming abilities may be carried along with the flow. Export pumping by the SWP and CWP can increase the magnitude of reverse flows and increase the likelihood that juvenile salmonids will be drawn into the South Delta. As reported in Monismith *et al.* (2014), flow in the Old River and Middle River (OMR) channels (Q_{OMR}) can be approximated by the combined SWP and CVP exports (Q_{Exp}) and San Joaquin River flows (Q_{SJR}) with and without HORB.

$$Q_{OMR} \approx -0.87\left(Q_{Exp} - 0.48Q_{SJR}\right) \text{ without HORB} \qquad \text{Eqn. 1}$$

$$Q_{OMR} \approx -0.84\left(Q_{Exp} - 0.48Q_{SJR}\right) - 406 \text{ with HORB} \qquad \text{Eqn. 2}$$

The Zone of Entrainment (ZOE) is defined as the region over which passive particles can be entrained into the SWP and CVP pumping facilities. Numerical modeling studies indicate that as exports increase and flows in the San Joaquin River decrease the ZOE expands further into the interior Delta, As indicated by Eqn. 1 and Eqn. 2, these conditions also correspond with increasing reverse (negative) flows in OMR (Eqns. 1 & 2). However, it must be noted that juvenile salmonids are not passive particles and can swim against the flow. Kimmerer (2008) noted that salvage length data indicated that juveniles are entrained more during migration but less so during their rearing life-stage. Similarly, Monismith *et al.* (2014) reported that although emigrating steelhead which are typically larger than Chinook smolts are less affected by interior Delta flows and experience greater survival.

Once juveniles enter either Clifton Court Forebay (CCF) or the channel leading to the CVP fish facilities, considerable mortality may occur due to predation. To be salvaged at the fish facilities (Sf), juveniles must survive to reach the fish salvage facility screens Fs, be captured by the louvers, be removed to the holding tanks, and survive transport to release at Jersey Point (Sjp). Therefore, salvage per day at the screens is directly proportional to the density of juveniles entrained (E, number of fish per volume) and the volume of exports (pumping rate per day).

Kimmerer (2008) estimated that pre-screen survival (Lps) to be about 15% in CCF and 85% at CVP. Estimates of efficiency of the screens (Es) range from 50-90% and losses during transport (Tl) to be approximately 4% [Kimmerer (2008), Zeug and Cavallo (2014)]. It has also been reported that the efficiency of the louvers may increase with increasing export flow rates.

Assuming a louver efficiency of 85%, salvage per unit time at the fish facilities can be expressed as:

$Sf_{swp} = 0.85 * 0.15 * E_{ccf} = 0.128 * E_{ccf}$ where E_{ccf} is entrainment at SWP's CCF

$Sf_{cvp} = 0.85 * 0.85 * E_{jns} = 0.723 * E_{jns}$ where E_{jns} is entrainment at the CVP Jones Pumping Plant.

The NMFS BiOp (2009) has an operational trigger based on entrainment rates of tagged hatchery-released groups of listed Chinook salmon, which controls combined pumping rates at the CVP and SWP export facilities. Fin-clipped (tagged) fish that are entrained and salvaged at the SWP and CVP fish salvage facilities are sacrificed and saved, and then the tag is extracted, and the group tag code is read and recorded. A running total of number of tagged fish that are salvaged is kept for the season, and the proportion of each release group that has been entrained (percent of group) is calculated with each salvaged fish. The NMFS BiOp operational trigger is reached when it is determined that 0.5% of any one release group of listed fish has been entrained, and pumping rates may need to be modified to meet specified flow conditions in the Delta.

3. Methods

To evaluate potential relationships between Delta inflows, export pumping and salvage of juvenile Chinook salmon and CV steelhead at the SWP and CVP fish salvage facilities, this study developed a Delta Salmonid Salvage Model (DSSM) based on the method and assumptions of multiple linear regression (MLR). Although a variety of statistical methods and models have already been applied by others to evaluate many of the complex factors affecting the mortality and survival of emigrating juvenile salmonids, this study focuses on developing a simple model of salvage based on the Delta inflows that are the primary sources of potentially salvageable juvenile salmonids that may be entrained by export pumping at the SWP and CVP facilities in the south Delta.

For the DSSM, the chosen response variable is the total salvage of all types and runs of juvenile salmonids at both the SWP and CVP fish facilities. The explanatory variables include Delta inflows in the DCC, Georgiana Slough, Cosumnes River, Mokelumne River, San Joaquin River and combined export pumping of the CVP and SWP. As illustrated in Figure 1, the DCC and Georgiana Slough flows are major sources of juveniles entering the Delta from the Sacramento River watershed. Although the Cosumnes and Mokelumne Rivers join together, their flows included in the DSSM are upstream of their confluence and consequently represent separate potential sources of juvenile salmonids. Flows in the San Joaquin River at Vernalis are included in the DSSM because they represent sources of juveniles entering the south Delta from the San Joaquin River watershed.

The time period selected for this study included water years (Oct. 1 – Sept. 30) 2008 - 2018. During this time period, regulatory requirements affecting management of Delta exports were generally consistently applied. During these years, salvage between the months of October-June were used as model inputs because during these months approximately 99.5% of all juvenile salmonid salvage occurs.

The data used in the development of the DSSM were obtained from several publicly available sources. Daily juvenile salvage data were obtained from the California Department of Fish and Wildlife (CDFW) Bay Delta Region Salvage Monitoring Database (ftp://ftp.dfg.ca.gov/salvage/). The combined Chinook and steelhead daily salvage data at the SWP and CVP facilities were totaled and averaged to monthly values.

San Joaquin River at Vernalis (SJR), Mokelumne River flow at Woodbridge (MOKE), Cosumnes River at Michigan Bar (CSMR), and combined Delta Cross Channel and Georgiana Slough (XGEO) flow data were obtained from the DayFlow database (https://water.ca.gov/Programs/Environmental-Services/Compliance-Monitoring-And-Assessment/Dayflow-Data). These daily mean flow values were averaged to obtain the monthly average of the daily flow values.

In order to develop a valid MLR model, it is necessary to satisfy several underlying assumptions. These requirements include:

- Normality of the model residuals
- Constant variance of the model residuals
- A linear pattern of the model's response variable

Typically, flow data are not normally distributed because low flows are bounded by zero while high flows are not bounded. This pattern results in a non-symmetric (skewed) distribution of the data with respect to the mean value. When such data are used to develop a MLR model, meeting the assumptions frequently requires some type of data transformation. These transformations may take a variety of mathematical forms including powers (for example, x^2), logarithms (for example, Ln(x)), and roots (for example, $x^{1/2}$) depending on the nature of the response and explanatory variables. Similarly, transformations may be needed to meet the requirements of constant variance and linear pattern of residuals. Another important assumption of MLR models is that the explanatory variables are not correlated with each other. When such multicollinearity occurs, statistical measures of the goodness of the fit of the MLR model such as p-values and predictive capabilities such as r^2 values are not representative of the actual capabilities of the fitted model.

The approach used to develop the DSSM included the following steps.

- Identification of the response and explanatory flow variables to be included in the MLR model.
- Run an MLR model and evaluate whether the residuals of the fitted model response variable meet the normality, constant variance and linear pattern assumptions.
- If necessary, transform the response variable and repeat the previous step until the assumptions are satisfied.
- Evaluate multicollinearity between explanatory variables and eliminate highly correlated variables.
- Use component-residual (C-R) plots and statistical tests to determine if explanatory variables need to be transformed. If necessary, transform explanatory variables until (C-R) plots are linear.
- Apply a subset model selection procedure to identify which explanatory variables should be included in the DSSM based on the Akaike Information Criterion (AIC) estimator of out-of-sample prediction error.

In this study, the DSSM was developed using statistical and graphically based methods written in the R programming language and included in the publicly available R-Commander software package as well as some scripts obtained from the Practical Stats Applied Environmental Statistics courses (Practical Stats, 2020).

4. Results

The statistical properties of response and explanatory variables considered in this study were graphically and statistically characterized prior to the development of the initial MLR model.

The response variable included in the model is the monthly average of the total combined daily SWP and CVP salvage of Chinook and steelhead at the SWP and CVP fish salvage facilities (Total Salvage). The explanatory flow variables included total combined SWP and CVP exports (Total Exports) and flows of Sacramento River at Freeport (Sacramento River), San Joaquin River at Vernalis (San Joaquin River), Mokelumne River at Woodbridge (Mokelumne River), Cosumnes River at Michigan Bar (Cosumnes River), Yolo Bypass near Woodland (Yolo Bypass), other Eastside Tributaries (Eastside Tribs) , combined DCC and Georgiana Slough (DCC + Georgiana), Net Delta Outflow, and OMR. Also included in the initial model was the location of *X2* - the location in the estuary where salinity is two parts per thousand as measured in kilometers from the Golden Gate Bridge, which is defined daily for regulatory and fisheries management purposes (X2). Except for X2, all explanatory variables flows are the monthly average of the mean daily flows measured in cubic feet per second (cfs). The locations of the gages where these flows were measured are shown on Figure 1. In Table 1, the statistical properties of the MLR model variables are reported.

Table 1. Descriptive Statistics of the Response and Explanatory Variables

MLR Variable	Number of Samples	Minimum	Maximum	Average	Median	Variance	Standard Deviation
Total Salvage	91	0	137	14	2	671	26
Total Exports	91	762	11,559	4,915	4,379	7.63E+06	2,763
Sacramento River	91	5,750	82,107	20,414	13,667	2.56E+08	16,103
San Joaquin River	91	191	29,697	3,949	1,779	3.71E+07	6,128
Mokelumne River	91	22	4,557	626	204	9.91E+05	1,001
Cosumnes River	91	3	7,772	629	234	1.26E+06	1,129
Yolo Bypass	91	57	148,442	3,735	418	2.87E+08	17,045
Eastside Tribs	91	14	3,247	235	70	2.38E+05	491
DCC + Georgiana	91	1,672	11,749	4,550	4,029	3.92E+06	1,991
Net Delta Outflow	91	3,186	269,002	23,859	11,424	1.35E+09	36,981

MLR Variable	Number of Samples	Minimum	Maximum	Average	Median	Variance	Standard Deviation
OMR	91	-7,782	13,615	-2,760	-3,144	1.10E+07	3,318
X2	91	44	90	74	76	105	10

Figure 3 provides boxplots illustrating the mean, median, 25th and 75th percentiles as well as minimum and maximum values of the MLR variables.

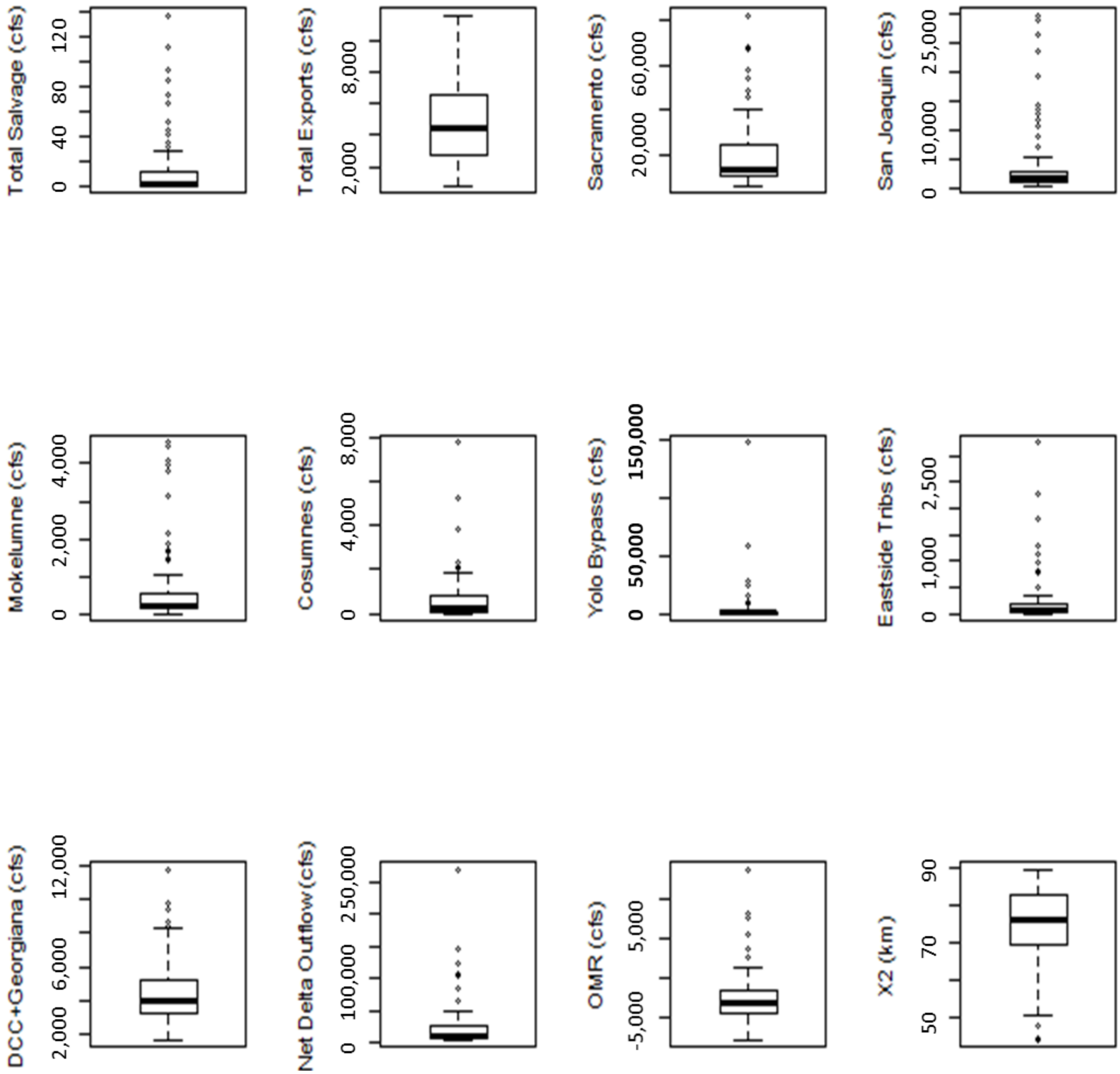

Figure 3 Boxplots of the MLR Response and Explanatory Variables

Figure 4 presents scatterplots illustrating the relationship between the explanatory variables and the total salvage response variable.

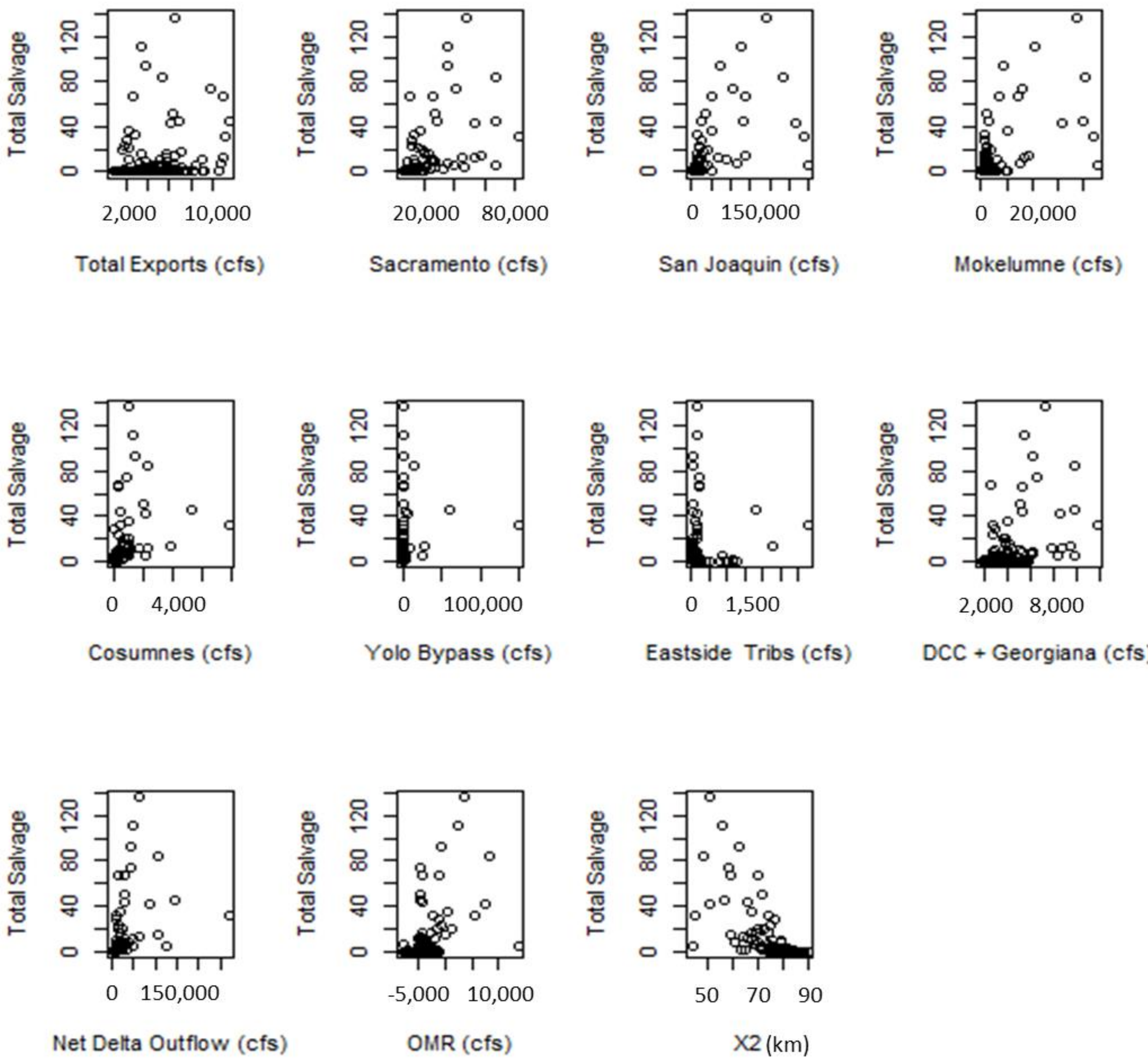

Figure 4 Relationships between Total Salvage and Explanatory Variables

Net Delta outflows were eliminated as an explanatory variable based on the concept that the DSSM should be based on upstream tributaries providing interior Delta inflows with the potential to contribute to salvaged juvenile salmonids. As described previously, juvenile salmonids enter the interior Delta from the Sacramento River at the DCC and Georgiana Slough. San Joaquin, Mokelumne and Cosumnes River juveniles may enter the interior Delta through the Old River, Middle River as well as Turner and Columbia cuts. OMR and X2 were retained to represent tidally controlled interior Delta flows that contribute to salvage. The Yolo Bypass flows were included because of their potential be sources of juveniles benefiting from improved rearing conditions.

The first step in developing the DSSM was to evaluate whether the Total Salvage response variable required transformation to meet the assumptions of MLR. Initially, these criteria were not met. After trying various transformations, a fifth-root transformation (Total Salvage$^{1/5}$) was found to meet the normality, constant variance and linear pattern of residuals criteria, but did not satisfy the assumption of linearity. Consequently, transformations of the explanatory variables were evaluated until it was determined that a fifth-root transformation these variables reasonably met these criteria.

Figure 5 illustrates that the assumptions of residual linearity (Residuals vs Fitted), normality (Normal Q-Q) and constant variance (Scale-Location) were met by these transformations. These visual evaluations were confirmed by applying the Breusch-Pagan test for constant variance (p-value = 0.11) and the Shapiro-Wilk normality test (p-value = 0.93).

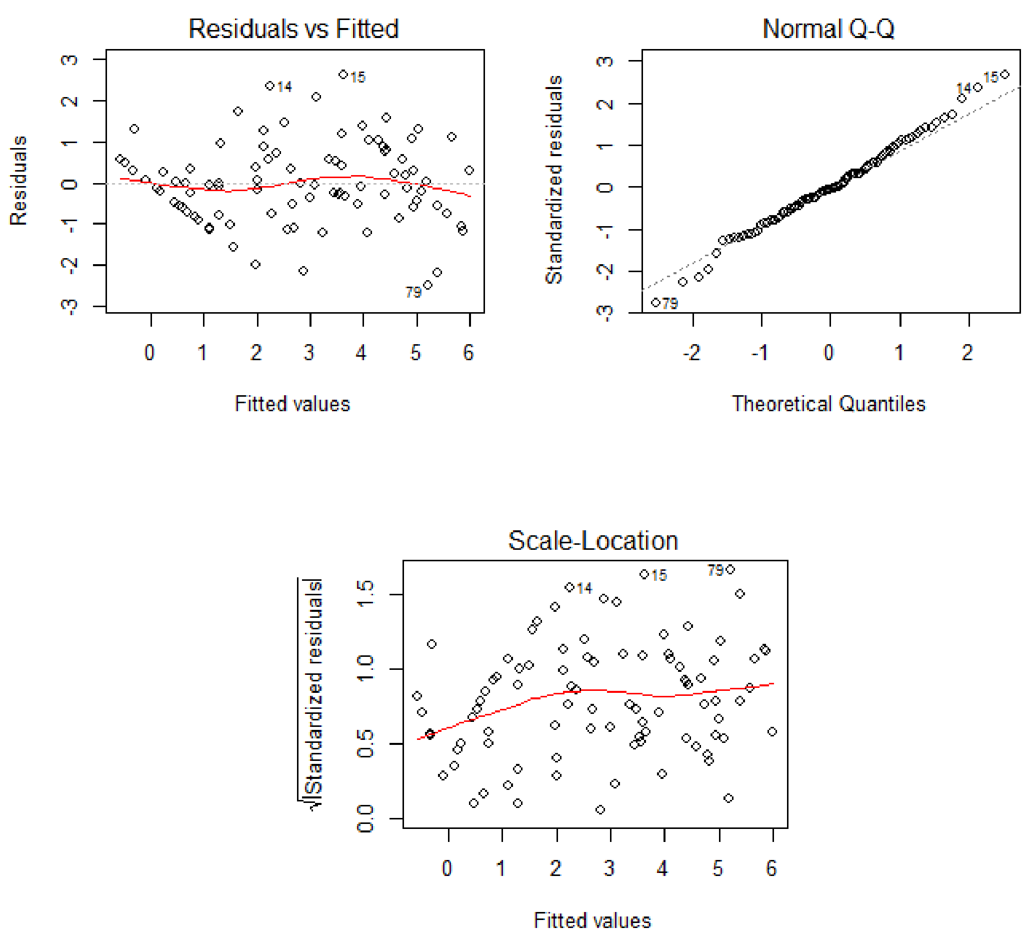

Figure 5 Plots of MLR Residuals versus Fitted Values

Another verification of suitability of the transformations was to examine the linearity of Component + Residual (C-R) plots. Figure 6 illustrates these C-R plots for each of the explanatory variables.

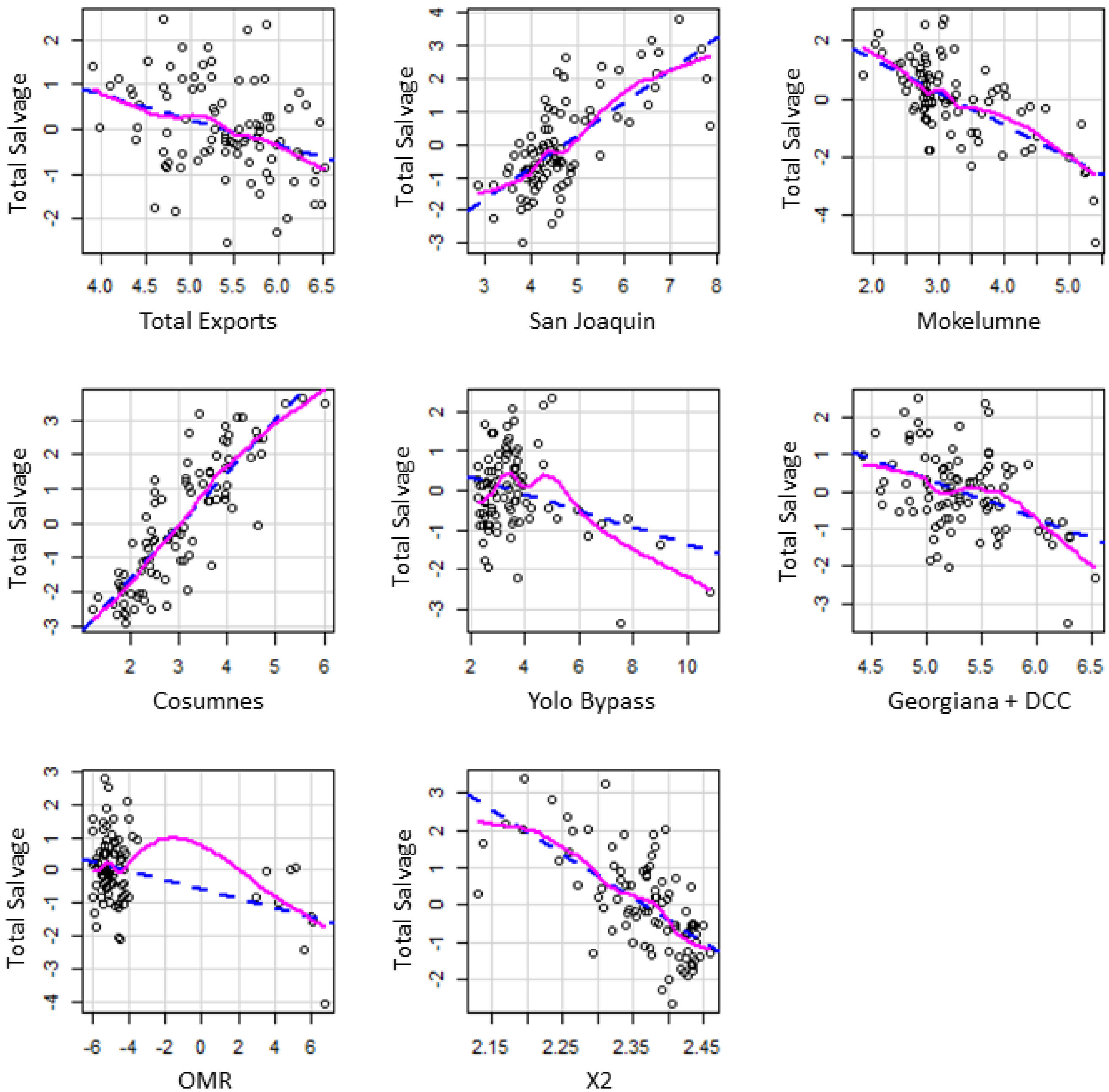

Figure 6. C-R plots of the Response and Explanatory Variables

Although there is considerable scatter, these plots confirm the linearity of the transformed explanatory and response variables.

The potential effect of multicollinearity between the explanatory variables was also evaluated by computing the Variance Inflation Factor (VIF). This evaluation confirmed that explanatory variable VIFs were less than 10 indicating that multicollinearity did not affect validity on the DSSM.

The next step in the development of the DSSM was to identify which of the explanatory variables should be included in the model. Frequently, MLR models are developed by applying a stepwise elimination of explanatory variables based on whether the variable's p-value is greater or less than 0.05. One of the advantages of the methods available in R-Commander is that combinations of the explanatory variables can analyzed to evaluate which combinations of explanatory variables provide better representations of the response variable.

There are a variety of statistical measures of the goodness-of-fit which can be employed. Often an MLR model's fit is judged based on its adjusted R-squared value (Adj-R^2). For a predictive model such as the DSSM, there are more relevant measures such as Akaike's Information Criterion (AIC). Unlike Adj-R^2 model selection, a "better" fit MLR model has a lower AIC score. For the DSSM, AIC values were computed using an R script obtained from the PraticalStats' AES course.

The application of the subset model selection procedure is illustrated by Figure 7.

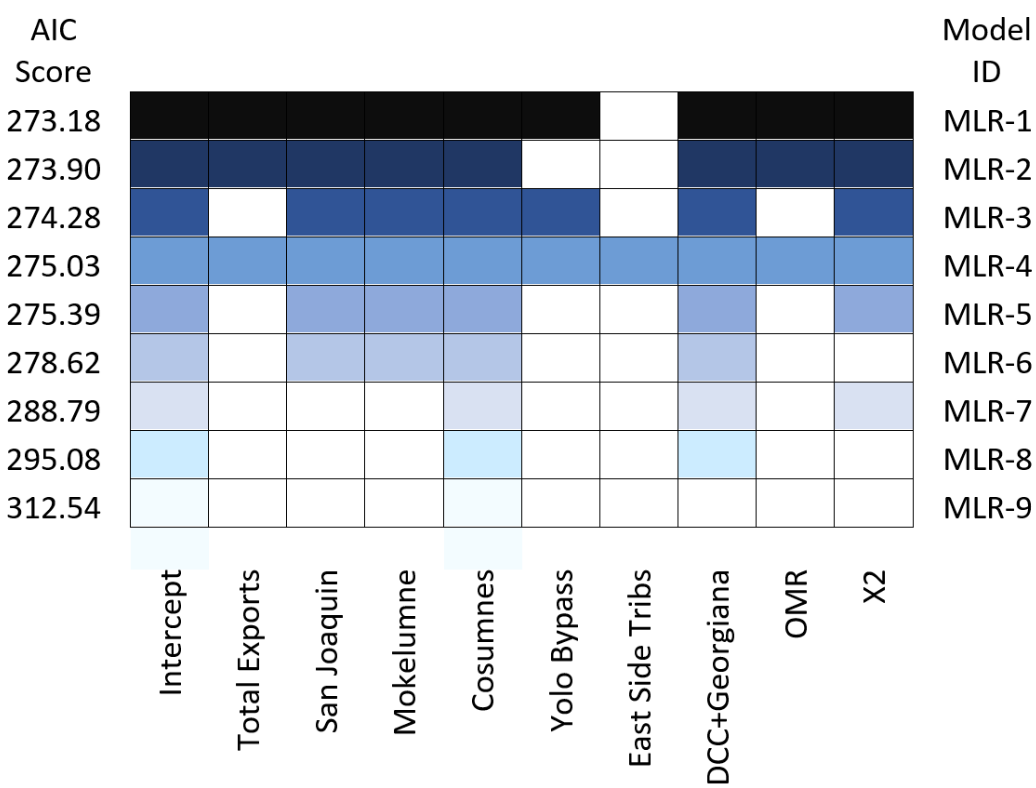

Figure 7 Subset Model Explanatory Variables and AIC Scores

Table 2 presents p-values for the intercept and each of the explanatory variables included in each of the subset MLR models.

Table 2 MLR Subset Model Intercept and Explanatory Variable p-values

Model ID	p-values									
	Intercept	Total Exports	San Joaquin	Mokelumne	Cosumnes	Yolo Bypass	East Side Tribs	DCC+Georgiana	OMR	X2
MLR-1	0.004	0.077	0.005	0.001	3.0E-10	0.118		0.013	0.039	0.009
MLR-2	0.01	0.106	0.002	0.001	8.2E-10			0.001	0.026	0.023
MLR-3	0.003		0.025	8.6E-05	1.4E-10	0.091		0.002		0.008
MLR-4	0.004	0.073	0.005	0.002	2.5E-09	0.300	0.717	0.013	0.037	0.010
MLR-5	0.011		0.010	6.4E-05	4.8E-10			6.5E-05		0.028
MLR-6	0.008		2.3E-05	4.3E-05	3.3E-16			1.1E-04		
MLR-7	0.001				8.0E-10			6.2E-07		0.005
MLR-8	0.002				< 2e-16			1.5E-05		
MLR-9	9.3E-06				< 2e-16					

Table 3 presents the regression coefficients associated with each explanatory variable included in each MLR subset model.

Table 3 Explanatory Variable Regression Coefficients for each MLR Subset Model

Model ID	Intercept	Total Exports	San Joaquin	Mokelumne	Cosumnes	Yolo Bypass	East Side Tribs	DCC+Georgiana	OMR	X2
	Regression Coefficients									
MLR-1	34.13	-0.56	0.98	-1.14	1.54	-0.21		-1.07	-0.14	-11.91
MLR-2	30.16	-0.51	1.07	-1.18	1.46			-1.34	-0.16	-10.08
MLR-3	34.51		0.73	-1.35	1.55	-0.22		-1.26		-11.85
MLR-4	34.47	-0.58	0.99	-1.11	1.52	-0.17	-0.08	-0.08	-0.15	-11.91
MLR-5	28.70		0.84	-1.39	1.48			-1.52		-9.22
MLR-6	4.32		1.23	-1.45	1.76			-1.50		
MLR-7	30.61				1.57			-1.96		-9.37
MLR-8	5.43				2.05			-1.67		
MLR-9	-2.11				1.61					

6. Discussion

Based on the AIC scores shown on Figure 7, subset model MLR-1 with a score of 273.18 is the "best” performing MLR model for the explanatory variables included in this study. It includes all the explanatory variables except for the Eastside tributaries. In fact, only one of the models (MLR-4) includes the Eastside tributaries but its AIC score is considerably higher (275.03) than MLR-1. MLR-2 has only a slightly higher score (273.90) than MLR-1. The primary difference between these models is that MLR-1 includes Yolo Bypass flows while MLR-2 does not. The third lowest scoring model is MLR-3 with an AIC score of 274.28. It differs from the higher-ranking models because it does not include either Total Exports or OMR flows. The remaining models have significantly higher scores and are not considered as candidates for the DSSM.

P-values for the intercepts on all the MLR models were less than the usually accepted null hypothesis rejection criteria of 0.05 (Table 2). For all the explanatory variables, p-values were relatively consistent between models. The Cosumnes River p-values were significantly less than all other explanatory variables followed by Mokelumne, San Joaquin, DCC+Georgiana, X2, OMR, Total Exports and Yolo Bypass. The high significance of the Cosumnes flows may be related to the occurrence of increased floodplain habit supporting greater salmonid survival during high flow years. In both the MLR-1 and MLR-2 models, p-values for Total Exports and Yolo Bypass explanatory variables slightly exceeded 0.05.

Like p-values, the regression equation coefficients were relatively consistent between models (Table 3). Both the San Joaquin River and Cosumnes River had positive coefficients while the remaining explanatory variables had negative coefficients. The interpretation of regression coefficients is not straightforward because of the transformations of the explanatory variables in the MLR models. A comparison of the C-R plots with the regression coefficients demonstrates that the transformed variables have slopes that reflect the direction (positive or negative) and magnitude of the regression coefficients. However, the scatterplots (Figure 4) indicate different relationships between the untransformed explanatory variables and Total Salvage. Although there is considerable variability, the scatterplots of Mokelumne and DCC+Georgiana indicate a generally positive relationship between flow and Total Salvage. However, the fifth-root transformations of these variables necessary to meet the MLR assumptions have effectively reversed these relationships (Figure 6).

For the DSSM, model MLR-1 was selected not just because of its lowest AIC score but also because it includes explanatory variables that are important in the management of the SWP and CVP exports including OMR, DCC, Georgiana Slough and X2. It also meets the intended inclusion of the primary sources of juvenile salmonids entering the interior Delta with the potential to be salvaged at the SWP and CVP fish facilities.

Figure 8 illustrates the DSSM (solid line) with the transformed response and explanatory variables data (open circles) used in the study.

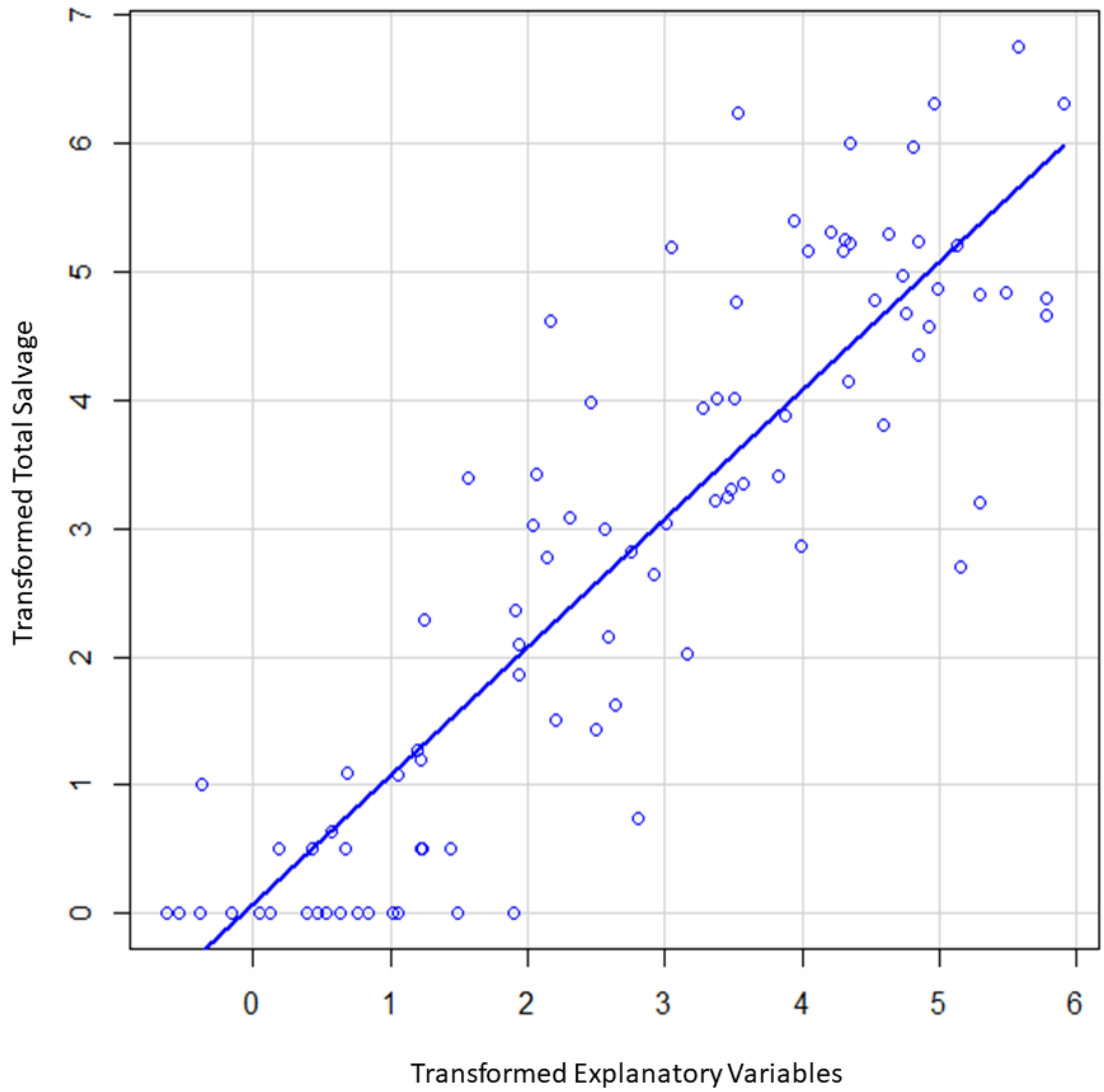

Figure 8. Transformed DSSM with the Transformed Response and Explanatory Variables

Similarly, Figure 9 illustrates with untransformed DSSM along with the untransformed response and explanatory variables.

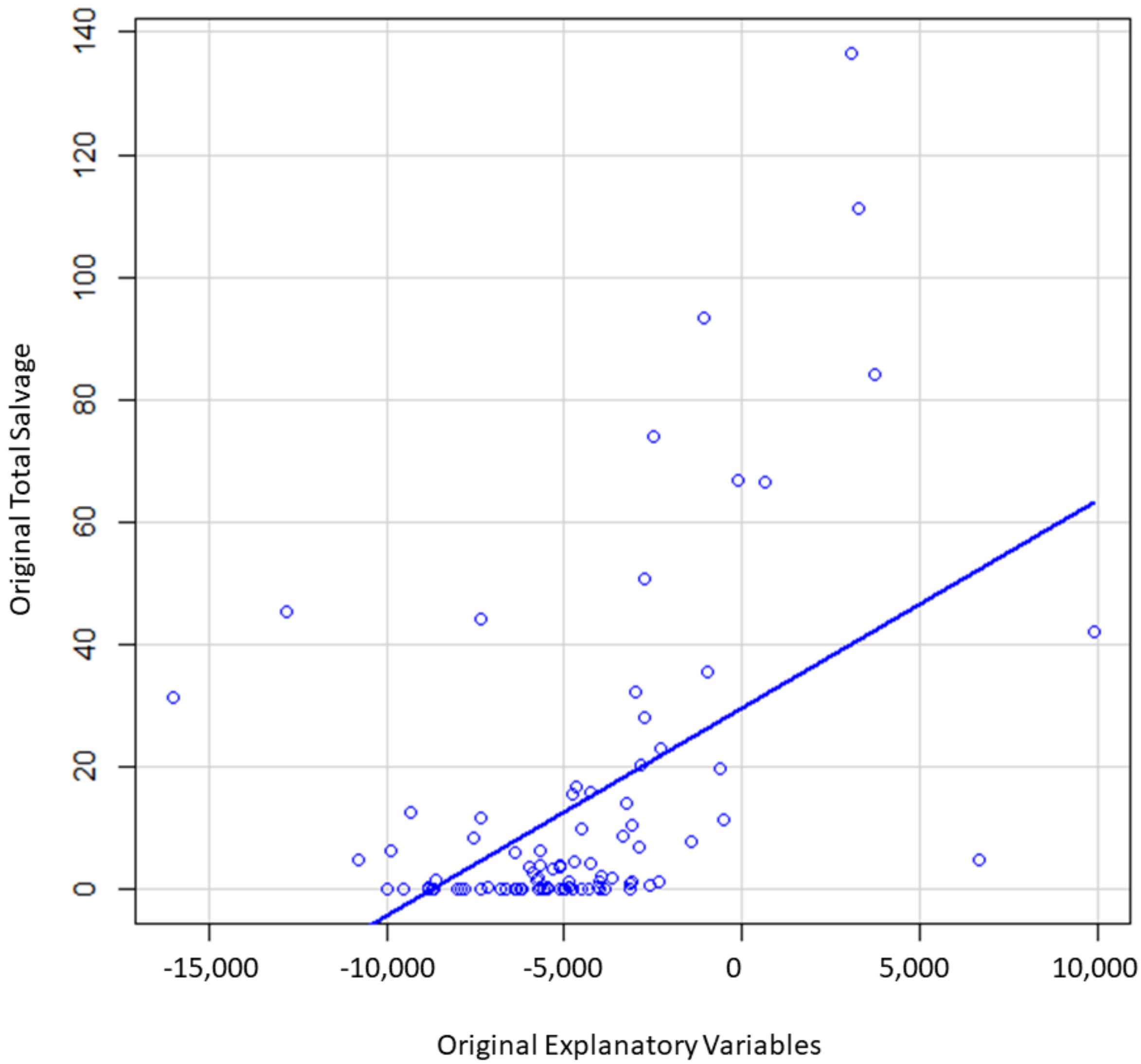

Figure 9 Original (Untransformed) DSSM with the Original (Untransformed) Response and Explanatory Variables

7. Summary and Next Steps

The development of the DSSM was based the concept of including tributary flows entering the interior Delta as important sources of juvenile Chinook and CV steelhead salmonids, as well as explanatory variables related to important management decisions. The significant explanatory variables included in the DSSM support the concept that salvage can relate to Delta inflows from tributaries supporting juvenile salmonids survival and that salvage increases proportionally with increased flow in these tributaries carrying juveniles into the interior Delta.

The high significance of Cosumnes River flows with its floodplain rearing habitat especially in high flow years supports this concept.

The lack of significance of the Yolo Bypass flows in the DSSM is primarily related to the importance of the DCC operations in juvenile salmonids entering the interior Delta. Typically, high flows in the Yolo Bypass correspond with high flow in the Sacramento River at the DCC and Georgiana Slough. The closure of the DCC gates promotes the passage of juveniles downstream to Chipps Island. Consequently, Yolo Bypass flows are not significant explanatory variables in DSSM.

In the development of the DSSM, all available salvage and flow data were included in the application of the MLR methods. Because of this, there was no opportunity to validate the DSSM with an independent set of data. This testing can be important because it is possible to obtain a model with a reasonable goodness-of-fit, yet the model will not perform well with an independent set of data.

The DSSM is a relatively simple MLR statistical model. These simplifications include treating combined SWP and CVP salvage and exports as single variables in the DSSM. However, there are clear differences between the factors affecting salvage at the SWP and CVP fish salvage facilities (for example, pre-salvage mortality and louver efficiency). In the DSSM, Chinook salmon and steelhead are not differentiated in the salvage variable nor are the various types of juvenile runs (for example, winter, fall, late-fall and spring).

An additional difficulty in the development of the DSSM is the frequent occurrence of no measurable salvage. This issue is especially evident in the scatterplots of salvage versus flow (Figure 4) as well as Figures 8 and 9 above. In these plots, there are dense groupings of zero-salvage across a wide range of explanatory variables. First, the occurrence of zeros in the salvage data prevents the use of logarithmic transformations such as often used with environmental data. Consequently, zero salvage data are not well represented by the DSSM. Zeug and Cavallo (2014) addressed this problem by developing 2 models of juvenile Chinook salvage; one for salvage and another for no measurable salvage.

Although both these limitations exist in the DSSM, there are alternative approaches which could be explored to improve the DSSM. The lack of an independent data set could be addressed by dividing the available data into two data sets before applying the MLR procedures. The problem of zero salvage could also be addressed by developing an MLR model that represents zero salvage as non-detect, which would be included as an integral part of the MLR model. This approach seems reasonable since the fish louvers are only about 85% efficient.

An additional methodology that could potentially improve the model would be to apply Principal Components Analysis (PCA) to the explanatory variables prior to model development. PCA offers the potential to more formally identify which explanatory might be included in model.

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