No Silver Lining Here?

Abundance, distribution, and habitat associations of Mississippi Silverside in the Delta

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Introduction

- The Mississippi Silverside (*Menidia audens*) is one of the most abundant near-shore fish species in the Sacramento-San Joaquin Delta (Delta) and has been hypothesized as an intraguild predator of larval Delta Smelt (*Hypomesus transpacificus*)
- Documenting how Silverside has persisted over the years can help inform management agencies on ways to curb their impact on the Delta ecosystem

Questions

1. **How have the abundance and distribution of Silverside changed over the years?**
2. **How does the occurrence of Silverside vary in relation to water quality variables?**
3. **Does the size of a Silverside cohort correlate with Delta flow of a particular season?**

Methods

- Long-term beach seine survey data from the Delta Juvenile Fish Monitoring Program (DJFMP) was used for this study

Question 1:

- We selected 22 beach seine sites within the Delta that have been sampled consistently since 1995 as index sites for Silverside
- Based on catch-per-m^3/CPUE plots (Fig 2),we found Silverside to be largely an annual species
- We designated months between June of one year and May of the next as a cohort year
- PRIMER version 7 was used to conduct similarity profile (SIMPROF) permutation test and non-metric multidimensional scaling (nMDS) ordination[1,2]

Question 2:

- Generalized additive model (GAM) with cubic regression spline was used to relate Silverside occurrence with water quality variables[4,5]

Question 3:

- Siverside cohort abundance index was calculated by summing the average monthly CPUE (as seen in Fig 2) for each cohort year
- Generalized linear models (GLM) were constructed with seasonal flow data from DAYFLOW as predictor variables[4]

Figure 1 Overview map of the Delta with the 22 index beach seine sites used in this study

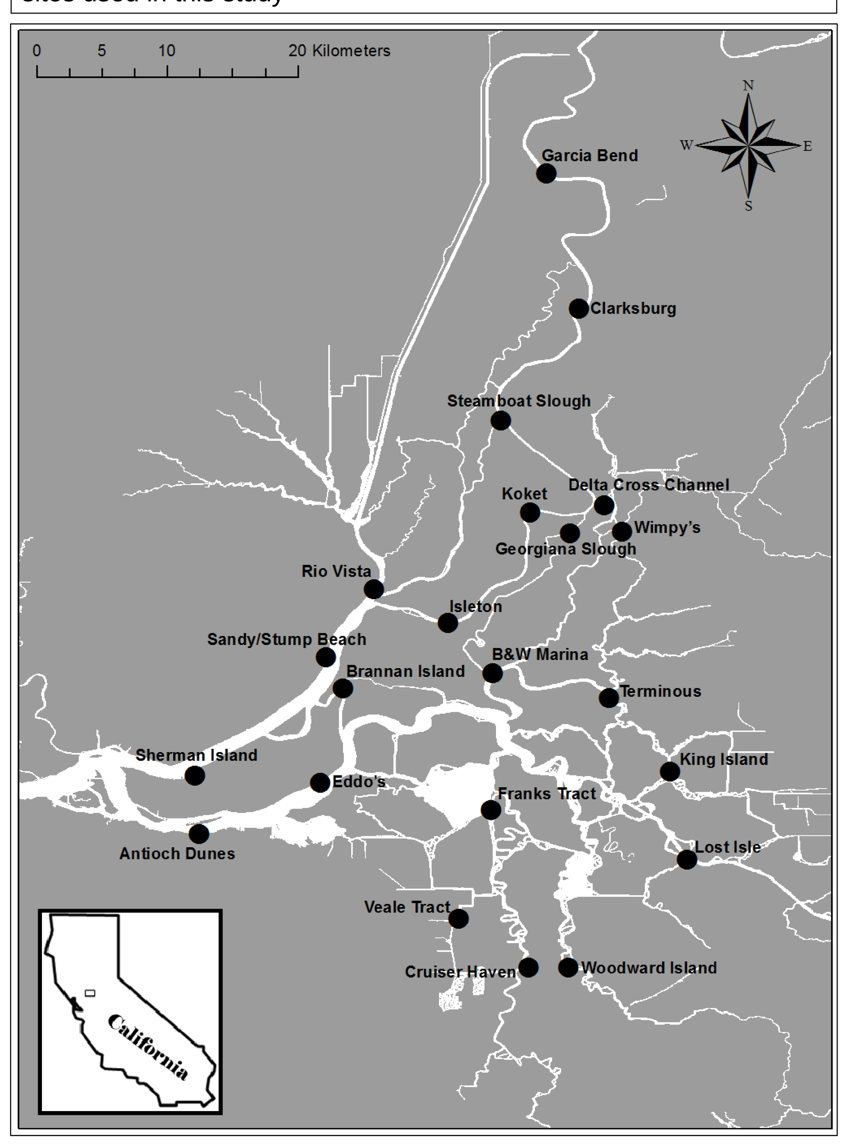
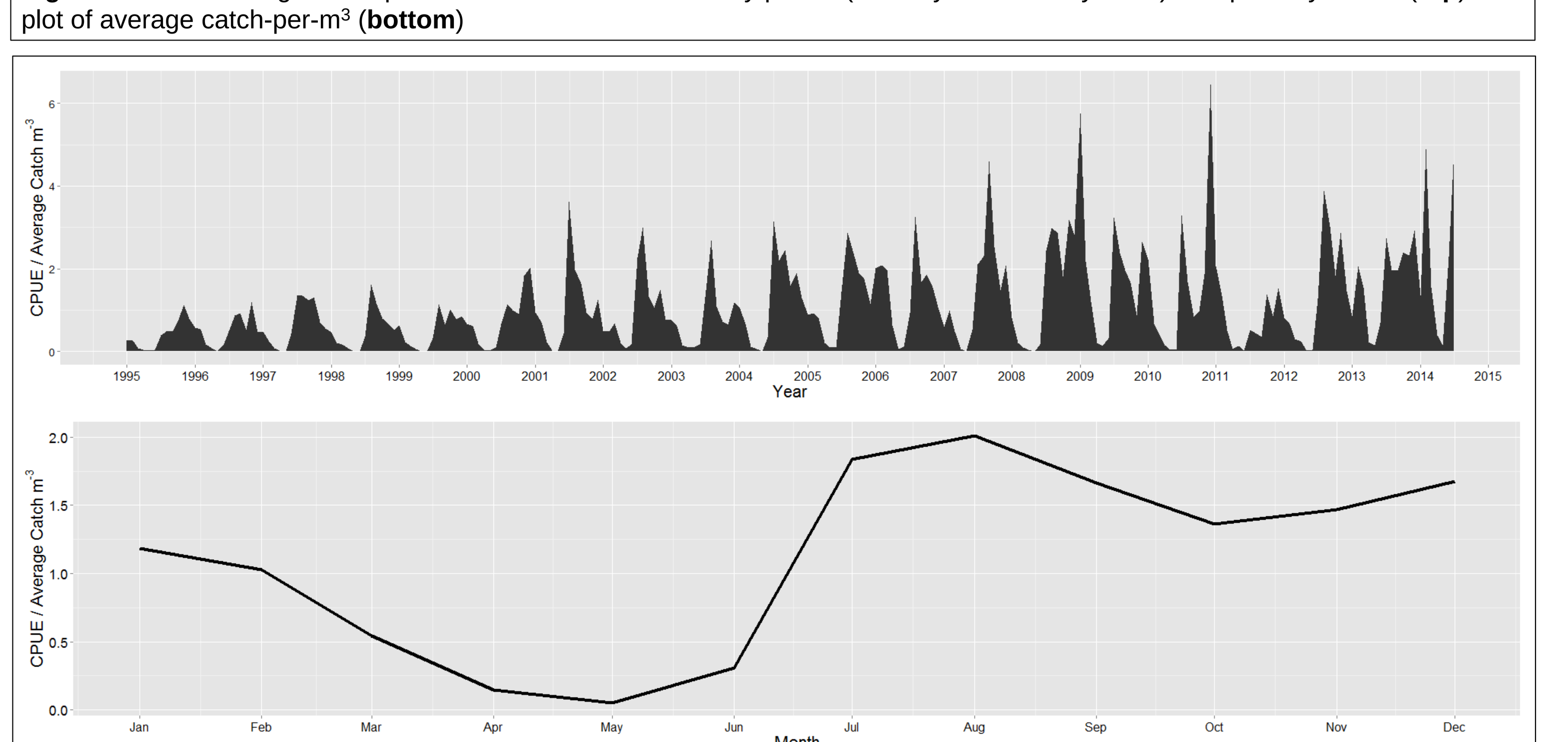


Figure 2 Plot of average catch-per-m^3 across time for the study period (January 1995 to July 2014) collapsed by month (**top**) and plot of average catch-per-m^3 (**bottom**)

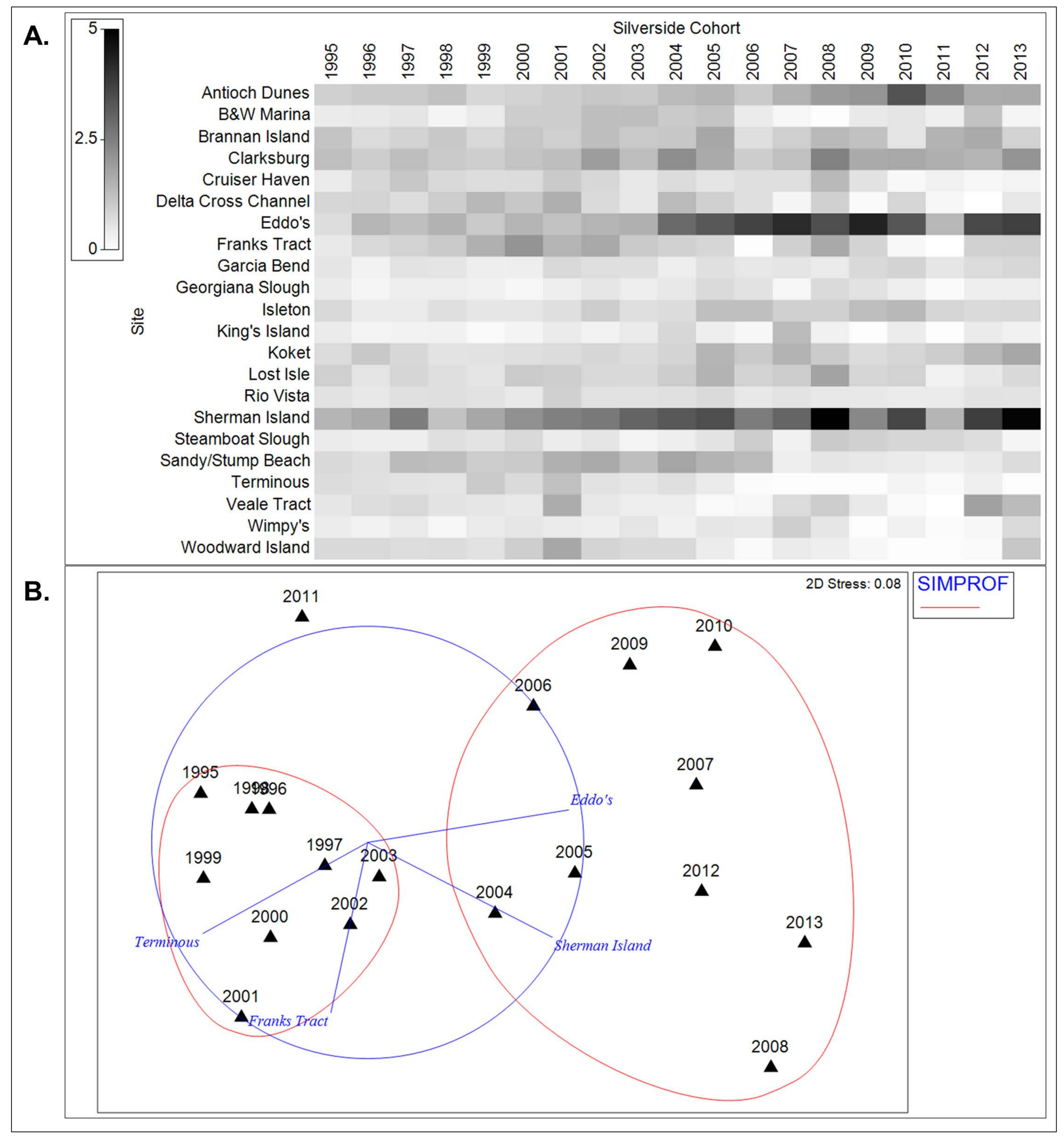


Results

1. How have the abundance and distribution of Silverside changed over the years?

- SIMPROF test split the 19 Silverside cohorts into three groups:
  1. Group consisting of cohorts prior to Pelagic Organism Decline (POD) event around 2002
  2. Group consisting of cohorts subsequent to POD
  3. Cohort of 2011 on its own
- Eddo's and Sherman Island sites were highly influential in differentiating between the pre-POD (1995-2003) and post-POD group (2004-2013), contributing 36.8% and 21.0% to the difference respectively

Figure 3 (A) Heat map of the square-root transformed catch-per-m^3 data for the 22 index stations ordered by Silverside cohort years. **(B)** The nMDS plot of the 19 Silverside cohorts based on the Euclidean distance matrix with Pearson correlation vectors of >0.8 shown. Red clusters represent statistically significant SIMPROF grouping.

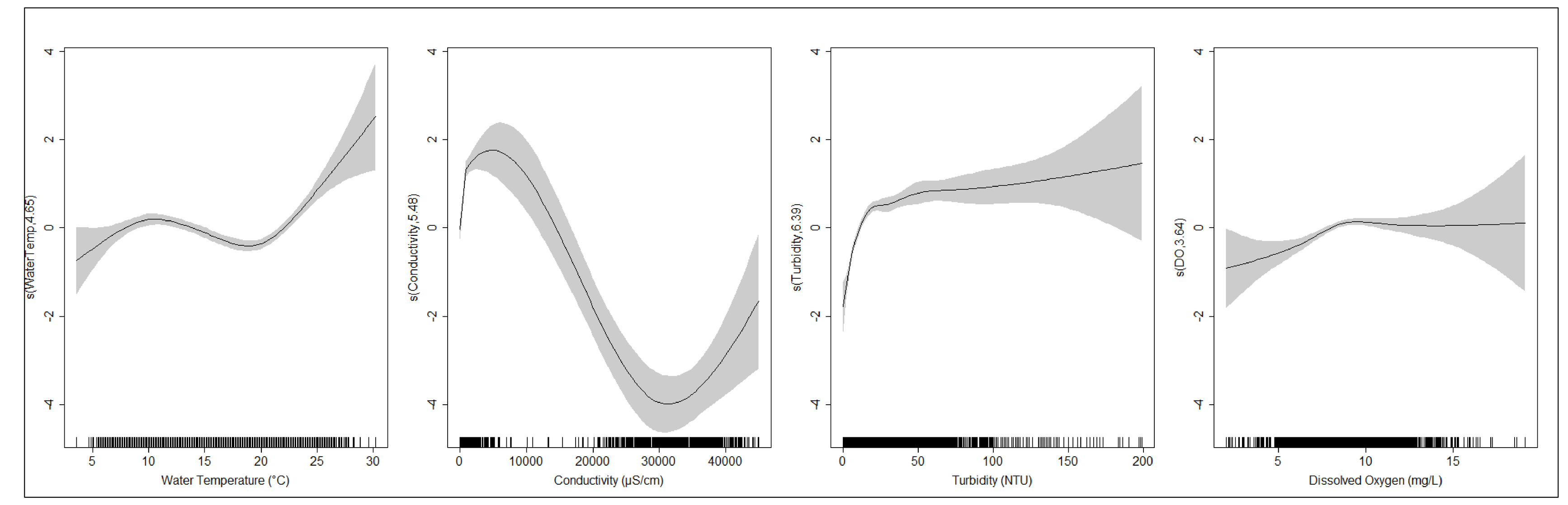


- **We were able to differentiate years prior and subsequent to POD by solely using Silverside catch data, highlighting the ability of Silverside to serve as an indicator of ecosystem change**
- Our results also showed that the 2011 Mississippi Silverside cohort was fairly unique; resembling the early, pre-POD cohorts (1995-2003) more than the latter, post-POD cohorts (2004 and on)

2. How does the occurrence of Silverside vary in relation to water quality variables?

- Temperature, specific conductance, turbidity, and dissolved oxygen were all important in predicting the presence of Mississippi Silverside
- Predicted occurrence of Silverside respond similarly to Delta Smelt with respect to conductivity and turbidity, while the opposite was true for temperature[3]

Figure 4 Partial GAM plots showing associations of habitat variables with presence of Silverside with 95% confidence intervals (y-axis units are logit transformed; i.e. zero represents 50/50 odds)



- **Silverside occurrence probability appeared to be higher at warmer temperatures (>20 °C), greater turbidity (>20-30 NTU), and higher dissolved oxygen (>10 mg/l)**
- **Occurrence probability also increased as conductivity increased, but declined rapidly after ~5000 µS/cm**

3. Does the size of a Silverside cohort correlate with Delta flow of a particular season?

- We used seasonal total Delta inflow and export with the following season delineations as covariates in the GLMs: March-May for spring, June-August for summer, September-November for fall, and December-February for winter
- We sequentially dropped collinear terms with highest variance inflation factor[6], removing summer inflow and export in the process.

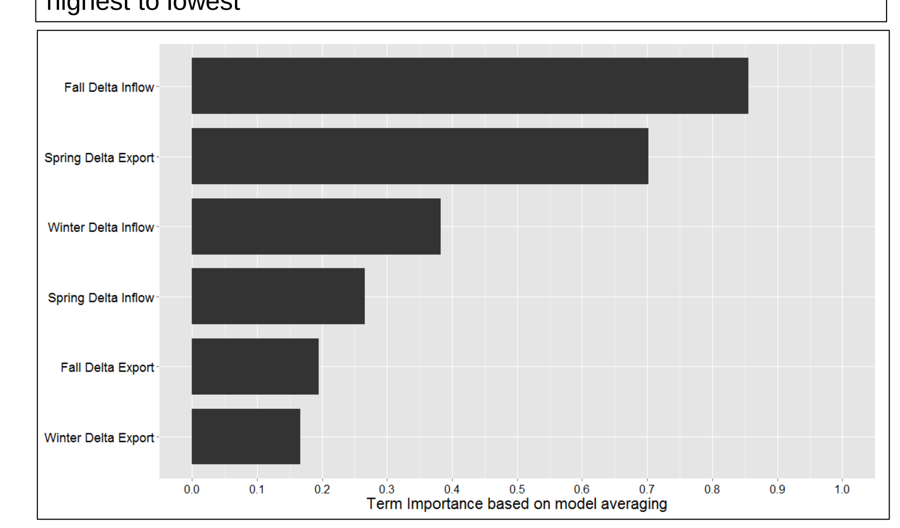
Table 1 Summary of the top 10 GLMs. Values under each covariate column are the resulting coefficients. *p<0.05; **p<0.01, ***p<0.001

Model	Spring Delta inflow	Fall Delta inflow	Winter Delta inflow	Spring Delta export	Fall Delta export	Winter Delta export	Intercept	AICc	ΔAICc	w_i	Adjusted R^2
1	-	-0.001090***	-	-0.002129*	-	-	40.52	115.5	0.00	0.251	0.56
2	-	-0.000960**	-0.000038	-0.002021*	-	-	39.70	117.0	1.56	0.115	0.58
3	-	-0.001079**	-	-	-	-	30.86	118.1	2.66	0.066	0.44
4	-	-0.001243**	-	-0.002814*	0.000665	-	40.53	118.4	2.95	0.057	0.55
5	-0.000024	-0.000919*	-	-0.002122*	-	-	38.81	118.9	3.37	0.046	0.54
6	-	-0.001173**	-0.000050	-0.003131*	0.001113	-	39.46	119.0	3.55	0.043	0.61
7	-	-0.001089***	-	-0.002473	-	0.000222	40.41	119.0	3.57	0.042	0.54
8	-0.000091**	-	-0.000063*	-0.001910	-	-	28.92	119.1	3.63	0.041	0.53
9	-	-0.000929**	-0.000044	-	-	-	30.48	119.2	3.73	0.039	0.47
10	-	-0.001087**	-	-	-	-0.000573	35.16	119.5	4.06	0.033	0.46

Table 2 Model-averaged coefficients using AICc weights

Variable	Model-averaged coefficient
Fall Delta inflow	-0.000881
Spring Delta export	-0.001592
Winter Delta inflow	-0.000019
Spring Delta inflow	-0.000016
Fall Delta export	0.000074
Winter Delta export	-0.000032

Figure 5 Term importance based on model averaging, ordered from highest to lowest



- **Fall inflow and spring export are the two most important predictors of Silverside annual abundance**
- Model-averaging results showed that there were negative relationships between Silverside cohort size and Delta inflow for all three seasons
- Of the three Delta export terms tested, spring and winter export were found to have negative relationships with cohort size, while fall export appear to have a positive relationship
- **Our results will allow resource managers to predict Silverside responses to various management actions**

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Acknowledgements

This study was conducted under the auspices of the Interagency Ecological Program. We thank the past and present staff of the U.S. Fish and Wildlife Service who took part in data collection for the Delta Juvenile Fish Monitoring Program. Additionally, we would like to thank the staff of California Department of Water Resources: Division of Environmental Services, including (but not limited to): J. Frantzich, N. Ikemiyagi, K. Gehrts, P. Goertler, D. Messer, L. Takata, T. Sommer, and S. Spaar.