Technical Report

Virginian Province Approach to Dissolved Oxygen in Lower South San Francisco Bay Sloughs

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Contents

Acronyms Used

CCC	Criterion Continuous Concentration
CDFW	California Department of Fish and Wildlife
CEMAR	The Center for Ecosystem Management and Restoration
CMC	Criterion Minimum Concentration
DO	Dissolved Oxygen
DWR	Department of Water Resources
EPA	Environmental Protection Agency
FAV	Final Acute Value
FCV	Final Chronic Value
FDEP	Florida Department of Environmental Protection
GMAV	Genus Mean Acute Value
GMCV	Genus Mean Chronic Value
LC50	Lethal Concentration 50%
LSB	Lower South Bay (of the San Francisco Bay)
NERR	National Estuarine Research Reserve
NOAA	National Oceanic and Atmospheric Administration's
Regional Water Board	San Francisco Bay Regional Water Quality Control Board
sDPS	southern Distinct Population Segment
SFE	San Francisco Estuary
SFEI	San Francisco Estuary Institute
SFBRWQCB	San Francisco Bay Regional Water Quality Conttol Board
SRCD	Suisun Resource Conservation District
SWMP	System Wide Monitoring Program (NOAA program)
VPA	Virginian Province Approach

1 Introduction

Aquatic life depends on having sufficient dissolved oxygen (DO) for normal metabolism and productivity. While the minimum DO concentration necessary to sustain populations varies widely among animal species even in a single waterbody, virtually all species require DO to survive and reproduce. The DO concentrations observed at a site are dependent on many factors including temperature, hydrologic dynamics, organic matter and decomposition rates, DO production by primary producers, and respiration rates of the aquatic life. Setting appropriate DO criteria or objectives for a given water body or type of water body is therefore complex because many site-specific natural factors can influence DO concentrations that are attainable at various times of day and during different seasons.

Commented [MC1]: Marine animals that live in anoxic conditions are the subject of recent scientific discoveries, so please do not use the word "all.'

Human activities can alter or exacerbate naturally occurring DO conditions in a waterbody making criteria development even more complex. In the case of Lower South San Francisco Bay (LSB) sloughs, both natural and anthropogenic factors could affect observed DO concentrations. High organic biomass and warmer temperature in some sloughs, as well as limited water exchange with more open regions of the Bay and with upstream waterbodies, may naturally depress DO concentrations when photosynthetic DO production is minimal. In addition, with a human population of over 2,000,000 people in the LSB region, anthropogenic causes of depressed DO ~~(e.g., organic carbon inputs and BOD from wastewater and stormwater runoff)~~ are possible as well. Some LSB sloughs have been prone to low dissolved oxygen (DO) due to anthropogenic influences and natural conditions in the system, and water quality management of the sloughs requires DO objectives for evaluation of impairment (MacVean et al 2018; Lewis, et al., 2018). Currently, the DO objective listed in the San Francisco Bay Regional Waterboard's (SFBRWQCB's) Basin Plan ~~DO for~~ applicable to the LSB sloughs is the minimum value of 5.0 mg/L year-round, which is applicable to all tidal waters ~~-~~south of the Carquinez Bridge (SFBRWQCB , 2022). In addition, the Basin Plan contains an objective that the median DO concentration for any three consecutive months shall not be less than 80 percent of the DO content at saturation.

Commented [MC2]: The suggestion that low DO is caused by organic carbon and BOD (classic "DO sag") is way too simplistic. Most likely the anthropogenic causes of low DO are going to be more complex (e.g., nutrients stimulating algal growth in former salt ponds, which then leads to low DO exiting the ponds). Either provide more nuance here, or eliminate the simplistic example.

Commented [MC3]: The Basin Plan also a three-month median objective, for DO to be at least 80% of saturation. Please add a reference to these objectives. The suggested text was copied from here:

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DO criteria should not be considered as "one size fits all waterbodies" because the influence of naturally occurring factors is inherently site specific. Currently the DO criteria methodology commonly used for estuarine and marine waterbodies is the Virginian Province Approach (VPA) developed by U.S. Environmental Protection Agency (EPA) (2000). As discussed in this report, the VPA is not inherently a site-specific methodology but rather an approach similar to that used by USEPA to derive criteria for toxic chemicals (Stephen et al., 1985). Tetra Tech was contracted by the San Francisco Estuary Institute (SFEI) to evaluate DO objectives for south San Francisco Bay sloughs using EPA's VPA approach because it requires a lower level of effort than more site-specific approaches (e.g., Chesapeake Bay DO approach) and it provides DO sensitivity information for many species, which with some modifications and incorporation of other site-specific lines of evidence, may provide appropriate DO criteria for LSB sloughs.

This report consists of results related to four tasks as described in Tetra Tech's approved Work Plan with SFEI, as well as recommended next steps. This analysis primarily focused on the Alviso Marsh complex sloughs (Figure 1) although other sloughs south of Dumbarton Bridge were also considered. The VPA DO criteria, like U.S. EPA's toxics criteria, are based on sensitivity data for many species, some of which may be unlikely to occur in LSB because of habitat limitations or other natural constraints.

Tasks 1 and 2 examine existing species data to refine the VPA for LSB sloughs. In Task 1 of this report, we present existing taxonomic information for LSB sloughs and examine which of the species in U.S. EPA's VPA are ecologically appropriate to LSB. In Task 2, we present available information concerning salmonid and Sturgeon species in LSB slough because early life stages of these two families of fish are some of the most sensitive species to hypoxia according to U.S. EPA (2000) and others. In DO objective development for Suisun Marsh, in the northern part of the San Francisco Estuary, Tetra Tech discriminated between sloughs with or without salmonids because of the large difference in resulting DO objectives (Flippin et al., 2017). Results of Tasks 1 and 2 help determine the extent to which species modifications to the VPA reflect site-specific DO concerns.

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Task 3 presents results of the VPA approach based on percent DO saturation rather than concentration (mg/L DO). At higher water temperatures percent DO saturation decreases, resulting in naturally lower DO concentrations. Some states such as Florida are using DO saturation rather than DO concentration to set DO criteria (FDEP 2013) and several studies of the sloughs have examined percent saturation as well as concentration of DO (e.g., MacVean et al 2018). Incorporating site specific temperature data into the VPA as percent DO saturation increases the ecological relevance of VPA DO criteria for LSB sloughs.

Task 4 presents a preliminary evaluation of habitat factors, seasonality of certain species life stages, and other site-specific information that are being examined by researchers in the region and that could be used with the VPA to refine appropriate DO objectives for the Lower South San Francisco Bay sloughs. A similar type of approach has been used in Chesapeake Bay (Tango and Batiuk 2013) and in Florida (FDEP 2013) to develop DO criteria.

This report provides results of VPA DO analyses as outlined in Tetra Tech's Work Plan and incorporates results based on different assumptions regarding specific species presence or absence in the sloughs. The different scenarios examined in this report may help SFEI and stakeholders identify critical data gaps that can help focus ongoing efforts to develop appropriate site-specific DO objectives for Lower South San Francisco Bay sloughs.

1.1 Study Area Examined

The greater portion of the Lower South San Francisco Bay is termed the Alviso Marsh Complex in Lewis et al., 2018 (Figure 1). In this report the Alviso Marsh complex refers to Alviso, Artesian, and Dump Sloughs, Coyote Creek, Upper Coyote Creek, Ponds 21 and 19, and several sites in Lower South Bay proper. This analysis focused on these sloughs as well as lower Coyote Creek because that Creek is the connection between the South Bay and Dump and Artesian sloughs. This study also considered aquatic life populations and habitat conditions in Guadalupe Slough.

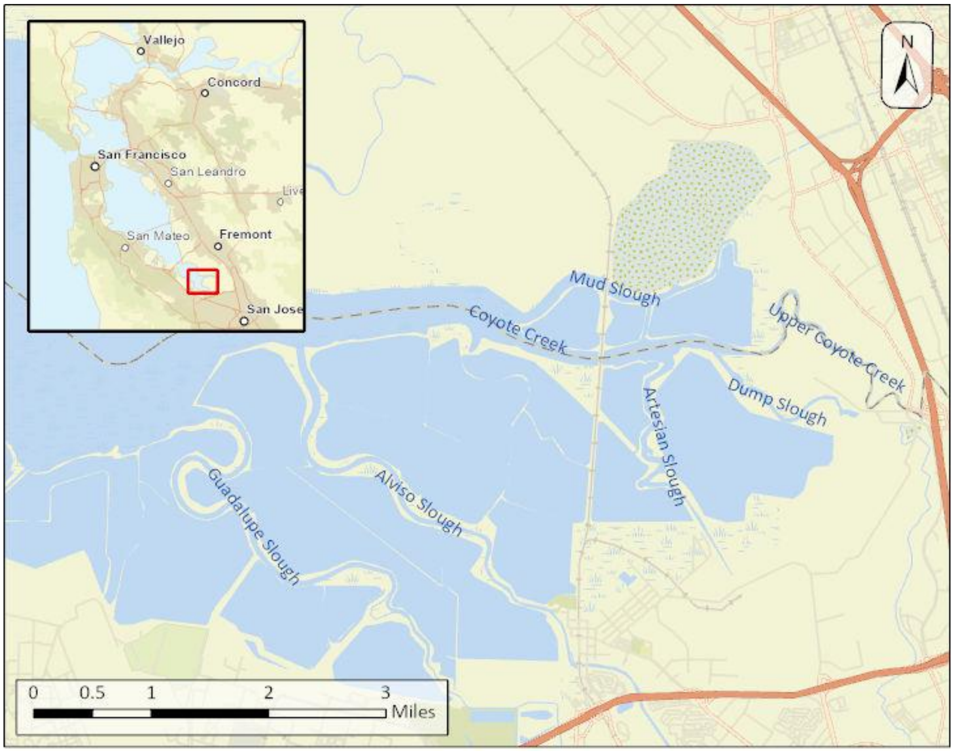

Figure 1. Lower South San Francisco Bay sloughs discussed in this analysis. The focus of the dissolved oxygen criteria in the present document are the sloughs and not open waters or marsh ponds.

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2 Task 1.1: Refined Species List for Analysis

2.1 Overview of VPA

The VPA (USEPA 2000) was developed to derive DO criteria protective of coastal and estuarine ~~organisms~~ animals living in the Virginian Province (Cape Cod, MA to Cape Hatteras, NC). The resulting criteria are based on laboratory data for organisms that may occur in the geographical region of interest and follows the general approach used to develop criteria for toxic compounds as mentioned previously. This approach has subsequently been used to develop DO criteria in estuarine waters, such as in Florida (FDEP, 2013), Chesapeake Bay (USEPA, 2003), Georgia (coastal estuaries, Tetra Tech 2014), Louisiana (coastal estuaries, Tetra Tech 2008, 2013), Massachusetts (Taunton River Estuary, Tetra Tech 2018), and Suisun Marsh (Flippin et al., 2017).

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EPA's VPA document compiles a list of DO toxicity data for aquatic species that occur between Cape Cod, MA to Cape Hatteras, NC. This method uses endpoints analogous to those used to set criteria for toxics. Acute endpoints describing lethality to 50% of test organisms (LC50) and chronic endpoints

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describing the most sensitive endpoint (growth in the case of DO) are gathered from available sources of appropriate laboratory data. Toxicity data are ranked according to genus mean acute (or chronic) values (Genus Mean Acute Values [GMAVs] or Genus Mean Chronic Values [GMCVs]), which represent the geometric mean acute or chronic endpoint value, respectively, for each genus of invertebrate or fish, based on the number of individual test values available for a given genus at the time of criteria development. Genera are ranked from most to least sensitive to DO based on acute sensitivity (GMAVs) and chronic sensitivity (GMCVs). The four most sensitive GMAVs for acute criteria or GMCVs for chronic criteria and the total number of genera for which acceptable data are available are used in a series of equations to determine the Final Acute Value (FAV) or Final Chronic Value (FCV). The FAV/FCV is designed to be protective of at least 95% of the species for which toxicity data are available (Stephan et al., 1985). The FAV can be modified by correction factors to result in the Criterion Minimum Concentration (CMC, analogous to the Criterion Maximum Concentration for traditional toxics). In the case of DO, the FAV was adjusted to the CMC by multiplying by 1.38, the average LC5 to LC50 ratio for juvenile and adult species (USEPA 2000). The FCV can be modified to result in the Criterion Continuous Concentration (CCC), but no further modifications were used in the VPA.

The VPA document also developed a modeled larval recruitment endpoint. The purpose of the larval recruitment model is to determine the cumulative impact of DO stress on the larval phase of estuarine organisms. The larval recruitment segment is the period up to the point when an organism enters the juvenile life stage. The acute DO target endpoints are considered protective of organisms already in the juvenile stage. Larvae are usually more sensitive to environmental stress such as low DO as compared to juveniles and adults. Therefore, a separate target endpoint for organisms in the larval life stage is required. This endpoint is developed using a spreadsheet tool that integrates population parameters including length of recruitment season, duration of larval development, cohort size, and sensitivity to DO. The larval recruitment model generates a final curve that describes the number of days larvae can be exposed to a certain DO concentration without negatively affecting the total population. A maximum acceptable reduction in seasonal recruitment is set at 5% as described in the VPA document (USEPA 2000).

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In summary, the VPA allows for the calculation of three endpoints to protect aquatic organisms from adverse effects of low DO—acute, chronic, and larval recruitment. The CMC is protective against acute DO exposures and the CCC is protective against chronic growth effects in aquatic organisms. The larval recruitment endpoint is also protective against the cumulative effects of stress on larval organisms.

2.2 Literature Review and Data Used

A literature search was conducted to evaluate the availability of dissolved oxygen ~~toxicity~~ sensitivity data relevant to species present in Lower South San Francisco Bay sloughs. The literature search was divided in three parts: (1) compilation of invertebrate and vertebrate aquatic species that have been reported from any of the sloughs, (2) compilation of available laboratory DO ~~toxicity~~ sensitivity data in addition to those presented by EPA in the VPA (USEPA 2000) for species relevant to the sloughs, and (3) ~~Records~~ records of sturgeon and salmonid presence in the sloughs.

Species reported in the sloughs were obtained from several sources (Table 1 and Appendix A) as well as information obtained from local experts familiar with biological data from the sloughs.

Table 1. Summary of primary literature used to determine the effects of DO in species present in South San Francisco Bay sloughs.

Source Title	Author and Date of Publication	Information procured
"Community Structure of Fishes and Macroinvertebrates in the Alviso Marsh Complex"	Lewis, 2018	Species presence in sloughs
"Science supporting dissolved oxygen objectives for Suisun Marsh"	Bailey, 2014	Confirmed presence of several macroinvertebrate species
"Ambient Aquatic Life Water Quality Criteria for Dissolved Oxygen (Saltwater): Cape Cod to Hatteras"	EPA, 2000	Acute and chronic laboratory data for individual species
"Technical Support Document: Derivation of Dissolved Oxygen Criteria to Protect Aquatic Life in Florida's Fresh and Marine Waters"	FDEP, 2017	Acute and chronic laboratory data for individual species
"DO Criteria Recommendations for Suisun Marsh"	Flippin et al., 2017	Acute and chronic laboratory data for individual species
Personal communication with local expert	Levi Lewis	Request for sturgeon data collected during UC Davis Otter Trawl Survey and presence of single steelhead captured during survey
"Coastal Multispecies Plan Volume IV Central California Coast Steelhead"	NOAA Fisheries. 2016	Ideal habitat conditions for steelhead and sloughs with those conditions. Mention of Guadalupe River winter run and other creeks in the area
"Spatio-temporal distribution of GreenSturgeon (Acipenser medirostris) and White Sturgeon (A. transmontanus) in the San Francisco Estuary and Sacramento River, California"	Miller, 2020	Sturgeon movement patterns relative to San Francisco estuary
"Historical Distribution and Current Status of Steelhead *(Oncorhynchus mykiss*), Coho Salmon (*O. kisutch*), and Chinook Salmon (*O. tshawytscha*) in Streams of the San Francisco Estuary, California"	Leidy, 2003	Current and historical distribution of Coho and Chinook Salmon and Steelhead, broken down by creek/watershed

Appendix B lists the species that have DO laboratory ~~toxicity~~ sensitivity data that were compiled in this study and the life stage for which the toxicity endpoint applies. While many of the species data are reported in EPA's VPA document, Tetra Tech added several others that were made available after EPA's VPA document was published in 2000. Most of the ~~toxicity~~ sensitivity data were derived using early life stages of fish or invertebrates.

In the event that an acute or chronic endpoint was identified for a species that is not found in LSB sloughs, the possibility of using a surrogate species from the sloughs was determined. According to the EPA's VPA, a surrogate is deemed appropriate if it is of the same family and preferably, the same genus. Results from the University of California, Davis (UC Davis) Otter Trawl surveys reported in Lewis, et al., 2018 as well as personal communication with local experts on species presence in the study area were utilized in finding local replacements. The results of the surrogate evaluation are summarized in Table 2.

Table 2. Species whose chronic (yellow), acute (blue), or both chronic and acute(orange) endpoints are available. Surrogate Relation indicates whether the local surrogate was of the same genus or family.

	Common Name	Scientific Name	Surrogate Relation	
			Genus Level	Family Level
Chronic Data Available	Atlantic Croaker	*Micropogonias undulatus*	Surrogate not found	
	Florida Flagfish	*Jordanella floridae*	Surrogate not found	
	Gulf Killifish	*Fundulus grandis*		✓
	Salmonids	*Oncorhynchus sp.*	✓	
	Spider Crab	*Libinia emarginata*		✓
	Southern Flounder	*Paralichthys lethostigma*	✓	
	Weakfish	*Cynoscion regalis*		✓
Acute and Chronic	American Lobster	*Homarus americanus*	Surrogate not found	
	Atlantic Menhaden	*Brevoortia tyrannus*		✓
	Atlantic Rock Crab	*Cancer irroratus*		✓
	Atlantic Silverside	*Menidia menidia*	✓	
	Atlantic Sturgeon	*Acipenser oxyrinchus oxyrinchus*	✓	
	Blue Crab	*Callinectes sapidus*	Surrogate not found	
	Copepod	*Acartia tonsa*	✓	
	Daggerblade Grass Shrimp	*Palaemonetes pugio*		✓
	Eastern Oyster	*Crassostrea virginica*		✓
	Marsh Grass shrimp	*Paleomonetes vulgaris*		✓
	Mysid Shrimp	*Mysidae sp.*		✓
	Northern White Shrimp	*Litopenaeus setiferus*	Surrogate not found	
	Quahog (Hard clam)	*Mercenaria mercenaria*		✓
	Say Mud Crab	*Dyspanopeus sayi*	Surrogate not found	
	Sheepshead Minnow	*Cyprinodon variegatus*	Surrogate not found	
	Shortnose sturgeon	*Acipenser oxyrinchus*	✓	
	Spot	*Leiostomus xanthurus*	Surrogate not found	
	Striped Bass	*Morone saxatilis*	✓	
	Summer Flounder	*Paralichthys dentatus*	✓	
	Winter Flounder	*Pseudopleuronectes americanus*		✓
Acute Data Available	Atlantic Herring	*Clupea harengus*		✓
	Atlantic Surfclam	*Spisula solidissima*	Surrogate not found	
	Bay Anchovy	*Anchoa mitchilli*		✓
	Burry's Octopus	*Octopus burryi*	Surrogate not found	

Common Name	Scientific Name	Surrogate Relation	
		Genus Level	Family Level
Flat mud crab	*Eurypanopeus despressus*	Surrogate not found	
Four-eye Amphipod	*Ampelisca abdita*	✓	
Fourspine Stickleback	*Apeltes quadracus*		✓
Green Crab	*Carcinus maenas*		✓
Harris Mud Crab	*Rithropanopeus harrisii*	✓	
Longfin Squid	*Loligo pealii*	Surrogate not found	
Inland silversides	*Menidia beryllina*	✓	
Mummichog	*Fundulus heteroclitus*		✓
Naked Goby	*Gobiosoma bosc*		✓
Northern Pipefish	*Syngnathus fuscus*	✓	
Northern Searobin	*Prionotus carolinus*	Surrogate not found	
Pinfish	*Lagodon rhomboides*	Surrogate not found	
Pink Shrimp	*Farfantepenaeus duorarum*	Surrogate not found	
Pompano	*Trachinotus carolinus*		✓
Red Drum	*Sciaenops ocellatus*	Surrogate not found	
Sailfin Molly	*Poecilia latipinna*		✓
Sand Shrimp	*Crangon septiemspinosa*	✓	
Scaled sardine	*Harengula jaguana*		✓
Scup	*Stenotomus chrysops*	Surrogate not found	
Skilletfish	*Gobiesox strumosus*	Surrogate not found	
Spotted Seatrout	*Cynoscion nebulosus*		✓
Striped Blenny	*Chasmodes bosquianus*	Surrogate not found	
Striped Mullet	*Mugil cephalus*	✓	
Tautog	*Tautog onitis*	Surrogate not found	
Windowpane Flounder	*Scophthalmus aquosus*	Surrogate not found	

Acute LC50 values were available for 5 species that have been reported in the sloughs and 12 species that were of the same genus as a fish or macroinvertebrate found in the sloughs. An additional 18 species had acute DO toxicity data based on family level relatedness. Chronic values were available for 1 species that has been reported in the sloughs and 8 species that were of the same genus as a fish or macroinvertebrate found in the sloughs. An additional 11 species had chronic DO toxicity data based on family level relatedness. Many of the families of species collected in the sloughs are represented in the acute DO toxicity dataset. Fewer families of species reported in the sloughs are represented in the chronic DO toxicity data set due to there being fewer chronic DO toxicity studies available.

Table 3 summarizes the acute and chronic toxicity values for relevant species in the sloughs based on the literature review in this task. The extent to which salmonids and sturgeon can inhabit the sloughs is discussed under Task 1.2 in Section 3 of this report.

2.3 Calculation of Acute and Chronic Dissolved Oxygen Criteria Using the VPA

Following EPA's VPA, the ranked acute and chronic DO toxicity endpoints listed in Table 3 were subjected to the analyses EPA recommends for calculating DO water quality criteria. Based on the four most sensitive genera in Table 3, the acute DO criterion or CMC using the VPA is 3.7 mg/L. (see Appendix C with the calculations following the VPA). This criterion assumes that the genera and life stages upon which the DO toxicity data are based in Table 3 are appropriate for the sloughs, which may not be an accurate assumption for salmonids and sturgeon (see Section 3). Table 4 summarizes the chronic toxicity endpoints for early life stages of genera based on the literature review. Based on the four most sensitive genera in Table 4, the chronic DO criterion or CCC using the VPA is 5.3 mg/L (see Appendix C with the calculations following the VPA). This criterion also assumes that the genera and life stages upon which the DO toxicity data are based in Table 4 are appropriate for the sloughs (see Section 3).

Table 3. Acute data for species of interest and surrogate species toxicity data used to perform the Virginian Province Approach. Species present in sloughs were determined by results of the UC Davis report (Lewis, 2018) and Bailey, 2014. In both cases, surrogates were selected when South Bay species and surrogate species shared at least common family classifications.

South San Francisco Bay Species (Lewis, 2018; Bailey, 2014)		Surrogate Species with Available DO Data			
Common Name	Scientific Name	Common Name	Scientific Name	GMAV (DO, mg/L)	GMAV % sat
Pacific Herring	*Clupea pallasii*	Atlantic Herring	*Clupea harengus*	2.80	34.5%
Western Mosquitofish	*Gambusia affinis*	Sailfin Molly	*Poecilia latipinna*	2.60	35.2%
Rainwater Killifish	*Lucania parva*	Mummichog	*Fundulus heteroclitus*	2.40	26.9%
White Sturgeon Green Sturgeon	*Acipenser transmontanus* *Acipenser medirostris*	Atlantic Sturgeon Shortnose Sturgeon	*Acipenser oxyrinchus oxyrinchus* *Acipenser breviostrum*	2.37	29.5%
American Shad Threadfin Shad	*Alosa sapidissima* *Dorosoma petenense*	Scaled sardine	*Harengula jaguana*	2.17	28.1%
Dungeness Crab	*Engraulis mordax*	Atlantic Rock Crab	*Cancer irroratus*	2.15	24.3%
Northern Anchovy	*Metacarcinus magister*	Bay Anchovy	*Anchoa mitchilli*	2.11	15.4%
Striped Mullet	*Mugil cephalus*	Striped Mullet	*Mugil cephalus*	2.10	26.7%
White Croaker	*Genyonemus lineatus*	Spotted Seatrout	*Cynoscion nebulosus*	1.89	24.6%
Pacific Jack Mackerel	*Trachurus symmetricus*	Pompano	*Trachinotus carolinus*	1.74	21.8%
Mississippi Silverside	*Menidia audens*	Atlantic Silverside	*Menidia menidia*	1.64	20.1%

South San Francisco Bay Species (Lewis, 2018; Bailey, 2014)		Surrogate Species with Available DO Data		GMAV (DO, mg/L)	GMAV % sat
Common Name	Scientific Name	Common Name	Scientific Name		
		Inland Silversides	*Menidia beryllina*		
Bay Pipefish	*Syngnathus leptorhynchus*	Northern Pipefish	*Syngnathus fuscus*	1.63	17.9%
Striped Bass	*Morone saxatilis*	Striped Bass	*Morone saxatilis*	1.58	18.3%
Diamond Turbot English Sole Starry Flounder Sand Sole	*Hypsopsetta guttulata* *Parophrys vetulus* *Platichthys stellatus* *Psettichthys melanostictus*	Winter Flounder	*Pseudopleuronectes americanus*	1.38	15.7%
California Halibut	*Paralichthys californicus*	Summer Flounder	*Paralichthys dentatus*	1.37	16.2%
Yellowfin Goby	*Acanthogobius flavimanus*	Naked Goby	*Gobiosoma bosc*	1.33	16.1%
Opposum Shrimp	*Neomysis mercedis*	Mysid Shrimp	*Mysidae sp.*	1.27	16.0%
Olympia Oyster	*Ostrea lurida*	Eastern Oyster	*Crassostrea virginica*	1.15	15.6%
American Shad Pacific Herring Threadfin Shad	*Alosa sapidissima* *Clupea pallasii* *Dorosoma petenense*	Atlantic Menhaden	*Brevoortia tyrannus*	1.12	13.4%
Native Bay Shrimp	*Crangon franciscorum*	Sand Shrimp	*Crangon septiemspinosa*	0.97	10.9%

South San Francisco Bay Species (Lewis, 2018; Bailey, 2014)		Surrogate Species with Available DO Data		GMAV (DO, mg/L)	GMAV % sat
Common Name	Scientific Name	Common Name	Scientific Name		
Threespine Stickleback	*Gasterosteus aculeatus*	Fourspine Stickleback	*Apeltes quadracus*	0.91	10.1%
Four-eye Amphipod	*Ampelisca abdita*	Four-eye Amphipod	*Ampelisca abdita*	0.9	10.2%
Korean Prawn Siberian Prawn	*Palaemon macrodactylus* *Exopalaemon modestus*	Marsh Grass Shrimp Daggerblade Grass Shrimp	*Paleomonetes vulgaris* *Palaemonetes pugio*	0.79	9.2%
Japanese Little Neck Clam	*Venerupis philippinarum*	Quahog (Hard Clam)	*Mercenaria mercenaria*	0.71	8.5%
Harris Mud Crab	*Rithropanopeus harrisii*	Harris Mud Crab	*Rithropanopeus harrisii*	0.51	4.6%
Green Crab	*Carcinus maenas*	Green Crab	*Carcinus maenas*	0.34	3.8%
Acartia sp	*Acartia sp*	Copepod	*Acartia tonsa*	0.19	2.1%

Table 4. Chronic data for species of interest and surrogate species toxicity data used to perform the Virginian Province Approach. Species present in sloughs were determined by lists in the UC Davis report (Lewis, 2018) and Bailey, 2014. In both cases, surrogates were selected when South Bay species and surrogate species shared at least common family classifications.

South San Francisco Bay Species (Lewis, 2018; Bailey, 2014)		Surrogate Species with Available DO Data		GMCV (DO, mg/L)	GMCV % sat
Common Name	**Scientific Name**	**Common Name**	**Scientific Name**		
Steelhead	*Oncorhynchus mykiss*	Salmonids	*Oncorhynchus sp.*	5-6	61.6%
Chinook salmon	*Oncorhynchus tshawytscha*				
Majidae sp.	*Majidae sp.*	Spider Crab	*Libinia emarginata*	4.67	64.9%
White Sturgeon	*Acipenser transmontanus*	Shortnose sturgeon	*Acipenser breviostrum*	4.26	51.5%
Green Sturgeon	*Acipenser medirostris*	Atlantic Sturgeon	*Acipenser oxyrinchus oxyrinchus*		
California Halibut	*Paralichthys californicus*	Summer Flounder	*Paralichthys dentatus*	3.33	38.7%
		Southern Flounder	*Paralichthys lethostigma*		
Mississippi Silverside	*Menidia audens*	Atlantic Silverside	*Menidia menidia*	3.30	38.2%
Japanese Little Neck Clam	*Venerupis philippinarum*	Quahog (Hard clam)	*Mercenaria mercenaria*	3.17	42.0%
Dungeness Crab	*Metacarcinus magister*	Atlantic Rock Crab	*Cancer irroratus*	2.87	32.2%
Pacific Herring	*Clupea pallasii*	Atlantic Menhaden	*Brevoortia tyrannus*	2.83	36.5%
Threadfin Shad	*Dorosoma petenense*				
American Shad	*Alosa sapidissima*				
Striped Bass	*Morone saxatilis*	Striped Bass	*Morone saxatilis*	2.8	38.3%

South San Francisco Bay Species (Lewis, 2018; Bailey, 2014)		Surrogate Species with Available DO Data		GMCV (DO, mg/L)	GMCV % sat
Common Name	**Scientific Name**	**Common Name**	**Scientific Name**		
Opposum Shrimp	*Neomysis mercedis*	Mysid Shrimp	*Mysidae sp.*	2.67	33.6%
Diamond Turbot English Sole Starry Flounder Sand Sole	*Hypsopsetta guttulata* *Parophrys vetulus* *Platichthys stellatus* *Psettichthys melanostictus*	Winter Flounder	*Pseudopleuronectes americanus*	2.2	24.8%
Korean Prawn Siberian Prawn	*Palaemon macrodactylus* *Exopalaemon modestus*	Marsh Grass Shrimp Daggerblade Grass Shrimp	*Paleomonetes vulgaris* *Palaemonetes pugio*	2.17	27.4%
Acartia sp.	*Acartia sp.*	Copepod	*Acartia tonsa*	2.14	26.4%
White Croaker	*Genyonemus lineatus*	Weakfish	*Cynoscion regalis*	2.0	24.6%
Olympia Oyster	*Ostrea lurida*	Eastern Oyster	*Crassostrea virginica*	1.5	18.5%
Rainwater Killifish	*Lucania parva*	Gulf Killifish	*Fundulus grandis*	1.34	17.1%

2.4 Calculation of the Larval Recruitment Dissolved Oxygen Criterion

The purpose of the larval recruitment model is to determine the cumulative impact of dissolved oxygen stress on the larval phase of estuarine organisms. The larval recruitment phase is the time period up to the point when an organism enters the juvenile life stage. The larval recruitment model generates a curve that describes the number of days larvae can be exposed to a certain dissolved oxygen concentration without negatively impacting the total population.

Acute dissolved oxygen toxicity values for larval estuarine organisms were derived primarily from EPA's VPA document (U.S. EPA 2000) for select species that are either known to occur in the Alviso Marsh Complex sloughs or have closely related genera or species that occur. Larval acute DO toxicity values based on controlled laboratory studies are available for relatively few species. The values, along with life history parameters derived from regional sources, were used in the larval recruitment model to calculate a dissolved oxygen target endpoint that should not adversely affect the overall species population.

The model calculations are based on the methods described in the VPA (U.S. EPA, 2000). This approach requires compilation of laboratory toxicity data describing dissolved oxygen LC_{50} values for larvae. Life history parameters including length of larval recruitment season, duration of larval development, and number of cohorts produced per season also factor into the model. To the extent possible regional information was used to characterize these input factors to the model.

Table 5 summarizes the surrogate species for which larval DO toxicity data are available, the approximate length of the larval life stage of related species in the San Francisco estuary region, the acute toxicity value reported along with the salinity and temperature tested, and sources of information.

Table 5. Summary of information used in the larval recruitment model for species relevant to South San Francisco Bay sloughs.

Surrogate Species	Larval stage duration (days)	Larval LC50 (mg/L)	Salinity (ppt)	Temp (°C)	References
Morone saxitalis	35-50	2.42	4-7	18-19	USEPA 2000; https://calfish.ucdavis.edu/species/?uid=96&ds=241; http://stripedbass.ca/lifecycle.html
Palaemonetes vulgaris	3 – 6	1.99	29-31	20-20	USEPA 2000; https://www.cabi.org/isc/datasheet/109150
Dyspanopeus sayi	20	1.98	30-32	19-26	USEPA 2000; https://www.cabi.org/isc/datasheet/66045
Menidia menidia	21 – 42	1.44	30-32	20-23	USEPA 2000; https://calfish.ucdavis.edu/species/?uid=92&ds=698

According to EPA's VPA the four most sensitive genera larval recruitment curves were for *Morone, Octopus, Chasmodes,* and *Cancer* (U.S. EPA 2000). However, of these, only *Morone* is represented in the sloughs. The other three species for which larval DO toxicity data exist are less sensitive than *Morone* (Table 5). Plotting the recruitment curve for species that either occur, or are representative of species that occur in the sloughs (Figure 2), *Morone saxitalis* is the most sensitive. Based on a mean larval recruitment period of 42 days, a DO concentration of approximately 4.3 mg/L or above would be protective of the striped bass population and probably larval stages of most other species that occur in the sloughs in that life stage.

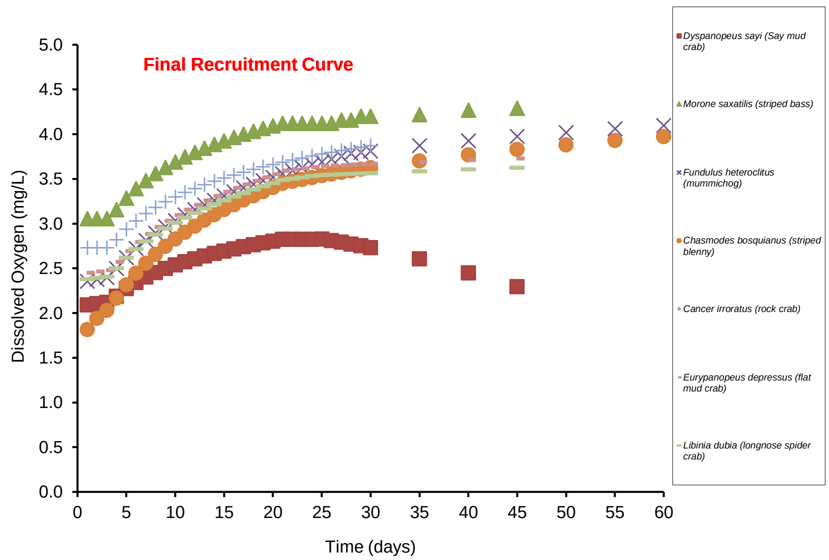

Figure 2. Results of EPA's Virginian Province Approach larval recruitment model for species representative of those that occur in South San Francisco Bay sloughs. The solid line represents the regression or final curve based on individual species recruitment curves.

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3 Task 1.2: Data Gaps for Salmonids and Sturgeon

As shown in Tables 3 and 4 in the previous section, salmonids (trout, salmon) and sturgeon are some of the most sensitive species to reduced dissolved oxygen saturation and are therefore critical species in deriving chronic DO criteria where these species occur. Therefore, the purpose of this task was to determine whether these fish species occur in the Alviso Marsh Complex and if so, at what times of year and which life stages, as that information will help inform whether the DO objectives calculated in Section 2.3 are appropriate or whether alternative objectives using the VPA are warranted.

Information regarding the presence of Salmonids and Sturgeon in Lower South San Francisco Bay was obtained using reports and peer-reviewed articles from reputable sources such as NOAA National

Marine Fisheries Service (NMFS), California Department of Fish and Wildlife (CDFW), Santa Clara Valley Water, The Center for Ecosystem Management and Restoration (CEMAR), University of California, Davis Fish Ecology lab (UC Davis), and the California Open Data Portal. Reference sections of relevant reports were also used to search for additional published materials. Some information was provided initially by SFEI such as the 2017 Sturgeon Fishing Report Card: Preliminary Data Report (DuBois and Danos, 2018) and an article from the Environmental Biology of Fishes Journal which reported on sturgeon distribution (Miller, et al., 2020). Additional key sources used in this task are listed in Table 1. The following subsections summarize the current information obtained by Tetra Tech regarding the occurrence of salmonids and sturgeon and habitat suitability of Alviso Marsh Complex sloughs for these species. The first part of this discussion is for anadromous salmonid species, followed by non-anadromous trout because their life history traits are different. The last part of this section is focused on green and white sturgeon.

3.1 Anadromous Salmonid Species

Anadromous salmonid species in the genus *Oncorhynchus* (salmon and steelhead trout) typically live up to 4 years and spend the first year of their lives in freshwater. After that time, they migrate to the ocean, remaining there until they reach spawning maturity and then return to natal streams to spawn. According to the NMFS Central California Coast Multispecies recovery plan, adult salmonids in South San Francisco Bay are most often migrating in and out of freshwater streams from November-May while the smolt period is considered to occur from January-June (NMFS, 2016, Appendix A, Marine and Large Estuarine Environments).

Several counts of salmonid occurrences were found among scientific surveys and historical literature reviews. The Center for Ecosystem Management and Restoration (CEMAR) published a document in 2005 (Leidy, et al., 2005) authored in unison with U.S. EPA and the University of California, Davis depicting the current and historical occurrence of salmonids in San Francisco Estuary by watershed. Steelhead trout (*Oncorhynchus mykiss*) are reported present in Coyote Creek and Guadalupe River watersheds as recently as 2004. A similar document also describing current and historical occurrence published by a collaboration of agencies reported Chinook salmon (*Oncorhynchus tshawytscha*) in Coyote Creek up to 2000. (Leidy and Becker, 2003). According to the California Fish and Wildlife Bay Study (CDFW, 2019) Chinook Salmon were present in the Southern San Francisco Estuary in 2017, though more specific locations were not provided.

Several species of salmonids have been recorded in San Francisco Bay and in the Guadalupe River and Coyote Creek watersheds (Leidy and Becker , 2003). Sources reviewed by Tetra Tech, as well as discussion with Levi Lewis, U.C. Davis and Joseph Dillon from NOAA indicate that anadromous salmonid species including Coho and Chinook salmon and steelhead trout, currently migrate primarily to the Guadalupe River and some of its tributaries during the winter spawning run (NMFS, 2016). Larvae and juvenile life stages of these species feed for a period of time in these cooler streams before migrating to the ocean from January-June (NMFS, 2016).

According to literature sources reviewed by Tetra Tech (Appendix A and Table1, above) adult anadromous salmonids migrate from the lower South San Francisco Bay to upstream freshwater spawning areas chiefly in the fall, winter and spring when tides and stream flows are generally higher. It appears there are fewer records of salmonid migrations from lower South San Francisco Bay in the summer (NMFS, 2016). Monthly fish sampling in the Alviso Marsh Complex sloughs between 2010 and

2018 (Lewis, et al., 2018) reported more than 50 fish species collected thus far, including migratory striped bass (*Morone saxitalis*) but no salmonids. This report notes that adult steelhead trout and Chinook salmon have been observed in upper portions of these watersheds. In 2021 a steelhead, larger that a smolt was collected in Artesian slough in the late fall (Levi Lewis, personal communication).

Habitat conditions in LSB sloughs are not conducive to juvenile steelhead and salmon rearing, particularly during the summer months, according to NMFS 2016. Natural water quality conditions including high water temperature, especially between late spring and early fall, and brackish salinity have been cited as critical factors precluding juvenile salmonid rearing in these sloughs. Additional factors cited are lack of suitable benthic substrate and lack of satisfactory cover in many of these sloughs (NMFS 2016). Based on this literature review and input from local experts, there is insufficient evidence currently as to whether juvenile salmon and steelhead are able to inhabit the sloughs in the Alviso Marsh Complex other than during short periods when migrating to the Bay and ocean.

3.2 Non-Anadromous Trout

Several reports reviewed by Tetra Tech provided by SFEI and local experts suggest that non-anadromous trout occur upstream of the sloughs in cooler freshwater streams that have habitat features that can support all life stages (see Appendix B for a list of sources reviewed). Upper Coyote Creek and Upper Guadalupe River are a few of the streams that have resident trout populations to varying degrees. The most downstream sites sampled in these and other creeks and rivers that eventually drain to the Alviso Marsh Complex sloughs and LSB are several kilometers upstream of the sloughs where habitat conditions (temperature, cover, salinity) are conducive to trout spawning and rearing . Based on the literature reviewed and discussion with local experts, it is highly unlikely that juvenile (or adult) trout are able to live in the sloughs long-term. This is supported by the fact that trout have not been collected during intensive monthly fish sampling in many of these sloughs over the past 8 years. (Lewis, et al., 2018). However, it is noted that the sampling gear used (Otter trawl) may not be efficient for sampling trout at any life stage.

3.3 Sturgeon

Green and white sturgeon are highly migratory species often found in coastal marine waters or estuaries and generally migrate up large rivers to reach freshwater during spawning season (January-May). Every 1-4 years after reaching maturity, white and green sturgeon inhabit the freshwater tributaries of San Francisco Estuary (SFE) searching for deep, turbulent pools with hard cobble or gravel bottom substrate in which they can spawn. Both sturgeon species have been known to migrate into freshwater reaches to spawn in the early spring/late winter (Feb/March) through June. (CDFW, 2021; UC Davis, 2021). Once hatched, sturgeon gradually migrate towards the SFE in search of habitat suited to their adapted salinity preferences, usually spending much of their young life in freshwater rivers and in less saline estuarine waters. As adults, white sturgeon primarily inhabit brackish estuaries, but will occasionally exist in coastal waters while traveling between estuaries. Green sturgeon adults prefer to spend most of their time in higher salinity coastal marine waters, but will occasionally enter SFE during summer months to feed. (CDFW, 2021). Green and White Sturgeon are benthic feeders, trending towards a diet of crustaceans, mollusks, other macroinvertebrates, and fish. (UC Davis, 2021)

According to the NMFS 2018 recovery plan (NMFS, 2018), the southern distinct population segment (sDPS) of green sturgeon spawns primarily in cool sections of the upper mainstem Sacramento River in deep pools (averaging 8-9m in depth) containing small to medium sized sand, gravel, cobble, or boulder substrate. Post-spawn fish may hold for several months in the Sacramento River and out-migrate in the fall or winter or move out of the river quickly during the spring and summer months, with the holding behavior most commonly observed.

Sturgeon reporting in the Alviso Marsh Complex has provided evidence of occasional sightings, all of which appear to be white sturgeon adults or subadults (personal communication with Levi Lewis, UC,Davis; Alison Weber-Stover, NMFS; Joe Dillon, NMFS; and Kevin Lunde, California Waterboard). According to Hublein et al (2017), larval and juvenile green sturgeon fitness is impaired at water temperatures above 20^{o} C, which frequently occur in the Alviso Marsh Complex sloughs in late spring through early fall (MacVean, et al., 2018). No juvenile sturgeon have been reported in fish sampling conducted in these sloughs by Lewis and others over the past 8 years (Lewis, et al., 2018); But similar to salmonids, the sampling gear used may not be efficient for sampling sturgeon. More extensive sturgeon monitoring is continuing to be conducted, so more information regarding life history and movement of green and white sturgeon in lower South Bay tributaries may be available in the near future. Currently, it appears that habitat constraints would preclude at least early life stages of sturgeon from inhabiting the sloughs for any period of time.

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3.4 Evaluation of Salmonid and Sturgeon Species Using VPA to Develop DO Objectives

As noted in the above discussion, early life stages (e.g., juveniles) of salmonids and sturgeon may be unlikely to inhabit the Alviso Marsh Complex sloughs for rearing and feeding. Natural habitat constraints in these sloughs, including suboptimal water temperature and salinity, during the seasons over which early life stages of these species occur in the region (i.e., primarily spring and early summer), may preclude those life stages from occurring in the LSB sloughs for extended periods of time (e.g., weeks). Adult or subadult salmonid and sturgeon may occur in some sloughs as migratory individuals heading upstream to freshwater spawning and rearing areas and, in the case of steelhead, heading back downstream to the Bay and ocean to feed. Currently it is uncertain how long adults or subadults of steelhead or sturgeon stay in the sloughs but thus far it appears that these species spend very limited time in the sloughs.

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Under Task 1.1 in section 2.1 of this report we noted that DO toxicity data for most species listed in Table 3 are based on testing with juveniles and in some cases, even earlier life stages (larvae). In general, early life stages of organisms are more sensitive than adults or subadults to physicochemical stressors such as decreased DO concentration and/or percent saturation due to proportionately greater surface area (including gill area in the case of most fish) as compared to body size resulting in greater susceptibility to water quality stressor exposure (e.g., Franklin 2014). Numerous field studies have reported greater effects of hypoxia on juvenile fish than adults (e.g., Urbina and Glover 2013).

The VPA focuses on DO toxicity data derived from tests using primarily early life stages of aquatic species, particularly for fish where it is often feasible to test juveniles in the laboratory setting. The focus on early life stages is also evidenced by having an additional analysis based on larval recruitment. Water quality criteria protective of early life stages of different species is almost certainly protective of adult life stages as noted above. However, if only adult or subadult life stages of certain species are capable of inhabiting a type of waterbody such as the Alviso Marsh Complex sloughs, then DO objectives based on results of tests with early life stages of those species, may be over-protective. A DO objective based on early life stages of salmonids and sturgeon may be subject to even greater over-protection considering that early life stages of these species spend much (or in some cases all) of their time in freshwater not brackish water that typically occurs in the sloughs.. Furthermore, the DO toxicity data used for these species in the VPA (and shown in Tables 3 and 4) were derived from tests conducted in freshwater. Available information suggests that DO sensitivity for euryhaline species is greater as salinity decreases. Thus, the DO sensitivity data used in the VPA for these species may over-estimate their sensitivity as juveniles in brackish or saline waters in the sloughs.

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To determine the effect of including salmonids and sturgeon on VPA DO objectives for the sloughs, Tetra Tech ran the VPA calculations with either salmonids or sturgeon excluded or with both genera excluded in Appendix C. Tables 6 and 7 summarize acute and chronic DO objectives based on the VPA for the different scenarios. Factors that affect the outcome of the CMC and CCC values are not only the DO thresholds of the most sensitive species, but also the total number of species for which there is acute or chronic data available, which changes whether species such as sturgeon or salmonids are removed. It is worth noting that in some cases removing salmonids or sturgeon results in a more conservative threshold. This could be because the species that replaces it has a similar threshold value and yet the total number of species in the calculation is decreasing.

Table 6. Recommended acute (CMC) thresholds calculated based on the inclusion and exclusion of sturgeon.

Genera with most sensitive acute values		Value (DO mg/L)
With Sturgeon	*Clupea*	3.7
	Poecilia	
	Fundulus	
	Acipenser	
Without Sturgeon	*Clupea*	3.8
	Poecilia	
	Fundulus	
	Harengula	

Table 7. Recommended chronic (CCC) thresholds calculated based on the inclusion and exclusion of salmonids and/or sturgeon

Genera with most sensitive chronic values		Value (DO mg/L)
With Sturgeon and Salmonids	*Oncorhynchus*	5.3
	Libinia	
	Acipenser	
	Paralichthys	
Without Salmonids	*Libinia*	4.3
	Acipenser	
	Paralichthys	
	Menidia	
Without Sturgeon	*Oncorhynchus*	5.7

	Libinia	
	Paralichthys	
	Menidia	
Without Sturgeon and Salmonids	*Libinia*	4.5
	Paralichthys	
	Menidia	
	Mercenaria	

4 Task 1.3: Adding Percent DO Saturation to VPA Criteria

The Virginian Province guidance (EPA, 2000) presented DO data as a concentration mg/L and subsequent efforts typically use these units as well. However, recent efforts in Suisun Marsh, Massachusetts, and Florida discussed the option of using percent saturation to account for the behavior of oxygen solubility at different water temperatures and salinities. There are also advantages to using saturation to acknowledge physiological aspects regarding how organisms assimilate dissolved oxygen. As mentioned previously, Florida DEP (2013) uses percent saturation to set saltwater DO criteria across the state. The equation below from FDEP, 2013 (originally from APHA, 1989) was used to convert DO in mg/l to percent saturation.

$$DOsat = (Exp((-139.34411 + (157570.1/Temp) - (66423080/Temp^{2}) + (12438000000/Temp^{3}) - (862194900000/Temp^{4})) - (Sal * (0.017674-(10.754/Temp)+(2140.7/Temp^{2})))))$$

$$\% \; DO = (DOmeasure/\; DOsat)*100$$

Where:

DOsat = DO concentration in mg/L at 100 % saturation,
Temp = water temperature in °K (°C + 273.15 = °K)
DOmeasure = Measured DO concentration in mg/L.

Tetra Tech developed an Excel spreadsheet that converts DO concentration toxicity thresholds (e.g., LC50 as mg/L) to percent saturation based on the temperature and salinity reported for the toxicity tests from the VPA or other sources. An average value of 25ºC and 25 ppt was used in the conversion equation for temperature and salinity, respectively, which is representative of most of the acute and chronic tests reported either in the VPA or other sources.

Table 8. shows the acute and chronic threshold values and their subsequent percent saturation values once converted from mg/L.

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Table 8. Percent saturation calculated from acute and chronic DO toxicity tests reported as mg/L

Criterion	Value (DO mg/L)	% Saturation
CMC (with Sturgeon)	3.7	45.6%
CMC (without Sturgeon)	3.8	46.8%
CCC (with Salmonids and Sturgeon)	5.3	65.3%
CCC (without Salmonids)	4.3	52.9%
CCC (without Sturgeon)	5.7	70.2%
CCC (without Salmonids and Sturgeon)	4.5	55.4%

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Mean temperature, salinity, and DO (mg/L) data collected during the UC Davis otter trawl survey from 2011-2018 were used in determining the mean DO (percent saturation) in four South Bay sloughs (Artesian, Coyote, Dump, and Alviso) (Table 9). It is noted that mean salinity of Artesian slough is much lower compared to the other three locations as a result of treated wastewater that is discharged into this system daily. A comparison of Tables 8 & 9 demonstrates that the objectives recommended based on the VPA, whether in mg/L or percent saturation, are being met or are very close to being met. Given that information provided by local experts points toward the potential for seasonal DO criteria based on the migrations of key species, it should be noted that values are not separated by season in Table 9 but averaged over several years of collection during all 12 months. This indicates that during particular seasons there is a possibility that DO measurements could be meeting and potentially exceeding recommendations.

Table 9. Mean DO percent saturation for four LSB sloughs based on mean temperature, salinity, and DO (mg/l) collected during UC Davis otter trawl survey 2011-2018 (Lewis et al., 2018)

Slough	Temperature	Salinity	DO (mg/L)	DO (% saturation)
Artesian	21	7	6.5	73.2%
Coyote	19	19	5.9	64.4%
Dump	20	13	5	55.5%
Alviso	18	16	6	64.0%

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5 Task 1.4: Habitat Resolution and Geographic Scope of Assessment

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Comparison of Water Quality Conditions in Sloughs

In the report titled "Dissolved Oxygen in South San Francisco Bay: Variability, Important Processes, and Implications for Understanding Fish Habitat", MacVean describes shallow sloughs of LSB reaching summertime highs of 27°C with DO concentrations falling below Basin Plan water quality objectives of 5 mg/L 11-65% of the time during the period of study (Alviso Slough 2013-2017; Guadalupe Slough and Coyote Creek 2015-2017). At times, Alviso and Guadalupe sloughs experienced DO measurements below 2.3 mg/L for durations <24 hours. MacVean used data from moored sensor stations to compare the DO fluctuations in Guadalupe Slough and Alviso Slough and determined that the Pond A8 complex, with its muted velocities and long residence times, appears to supply connected sloughs with oxygenated water during times of elevated productivity and organic matter that results in oxygen demand farther down the slough. Despite receiving treated effluent from the Sunnyvale Wastewater Treatment Facility and discharge from Ponds A8 and A3, the relatively stagnant Guadalupe Slough more frequently has DO concentrations below the water quality objective of 5 mg/L (65% of the time since mooring stations were established), regardless of tidal stage when compared to Coyote Creek and Alviso Slough. Coyote Creek and Guadalupe slough were found to have higher DO during high tides than low tides unlike Alviso slough where no difference was found in the percent of observations below 5 mg/L at low tide than at high tide. Measurements of high DO in winter and spring in Coyote Creek is attributed to runoff from winter storms (MacVean, 2018). A universal finding across all sloughs was the measurement of lower DO values in the summertime and higher concentrations in the winter.

The different degrees of available flow seasonally in the different sloughs as noted above and in communications with local experts is a major factor determining whether juveniles of sturgeon and salmonids can use certain sloughs and if so, over what time of year. Connectivity of the sloughs to upstream salmonid spawning areas, and therefore, the ability of adults to migrate through the sloughs and reach spawning areas, appears to be dictated by the timing of precipitation in the region, tides, and other factors affecting flows into and out of the sloughs. Likewise, the degree of connectivity between the LSB and upstream spawning areas via the sloughs in the Alviso Marsh Complex, is a major factor affecting the timing and the occurrence of juvenile salmonid downstream migration to LSB. As noted in Sections 3.1 and 3.3 of this report, adult salmonid migration to upstream spawning areas occurs in fall, winter, or early spring while juvenile migration to LSB occurs in winter and spring when flows are higher and temperatures are cooler. Sturgeon in the LSB, specifically white sturgeon subadults, have also been sighted and captured during the UC Davis Otter Trawl Survey during spring, fall, and winter months. Only once was a sturgeon recorded during the summer since 2012, which was in August of 2016. It is suspected that sturgeon use the LSB sloughs as feeding habitat when conditions are preferable.

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Comparison of Biological Conditions in the Sloughs

Figures 3 and 4 depict the spatial variation among sites in mean annual abundance (in units of Catch-per-Unit-Effort or CPUE) and percent composition distribution among sloughs for the 12 most commonly collected fish and macroinvertebrate species as reported by Lewis et al (2018). According to these data spanning 8 years of monthly sampling, total mean fish abundance and fish community structure varied little among sites, with Coyote Creek exhibiting the lowest mean fish abundance (Lewis, et al., 2018).

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Temperature and salinity in the Alviso Marsh Complex is variable within and among sloughs in the Alviso Marsh Complex according to Lewis et al (2018), as well as across seasons and years due to differences in water availability (I.e., upstream flows to the sloughs), precipitation, tides, and many other factors. The variability in certain water quality conditions observed within and among sloughs appears to be a dominant driver of the abundance and structure of fish and macroinvertebrate communities in the sloughs. Lewis et al. (2018) note that a variety of habitat types are provided that support a diverse assemblage of aquatic species . Statistical analyses conducted by UC Davis researchers determined that the strongest relationships between observed biota assemblage structure or abundance and environmental conditions were seasonal, with greater than 20 °C changes in temperature from summer to winter, and inverse changes in dissolved oxygen, which were lowest during summer as noted in the previous section. Despite concerns over the potential negative effects of hypoxia on fish and macroinvertebrate communities, species abundances are high throughout the summer low-DO period, and many species exhibited highest abundances in waters with lower-DO concentrations (e.g., California Halibut, Striped Bass, and Leopard Sharks).

Although much similarity was observed in fish assemblage structure among sloughs, some sloughs exhibited unique patterns in community structure. For example, Mississippi Silversides were common at most sites, especially Alviso Slough (ALV in Figures 3 and 4) and Artesian Slough (ART), but were rare in both Lower South Bay (LSB) and Coyote Creek (COY). Similarly, Threespine Sticklebacks were ubiquitous, except for in Lower South Bay. Pacific Staghorn Sculpin were particularly abundant in Alviso Slough while Shokihaze gobies and English Sole were commonly observed in Lower South Bay, Alviso Slough, and Coyote Creek, but rare at other sites. Striped Bass were commonly observed in Artesian Slough, Dump Slough (DMP), and Upper Coyote Creek (UCOY), but rarely observed elsewhere. Lower South Bay appeared unique from sites within Alviso Marsh, with catches overwhelmingly dominated by Northern Anchovies, and lacking in American Shad, Mississippi Silversides, and Threespine Sticklebacks.

The differences observed in fish assemblage structure by Lewis et al (2018) may provide clues as to dissolved oxygen conditions minimally required to maintain productive populations of aquatic life in the sloughs, both seasonally and year to year. Statistical analyses conducted by UC Davis on their extensive fish and macroinvertebrate dataset were unable to distinguish significant relationships between assemblage structure observed and specific water quality conditions observed in each slough; i.e., their analyses did not identify specific dissolved oxygen, salinity, or temperature thresholds that defined presence or absence of certain species or were significantly correlated with certain species abundance in different sloughs. However, the differences observed in summer versus “non-summer” water quality conditions (specifically temperature, salinity, and dissolved oxygen) in all of the sloughs examined appears to be a driver that favors certain species in summer versus other seasons.

Figure 3. Spatial variation among sites in mean annual CPUE (top) and percent composition (bottom) for the 12 most abundant macroinvertebrate taxa (paracarids omitted) at all sites from the 2015-2018 UC, Davis otter trawl. Error bars reflect 2 standard error for the total combined abundance. UID -unidentified (Lewis et al., 2018)

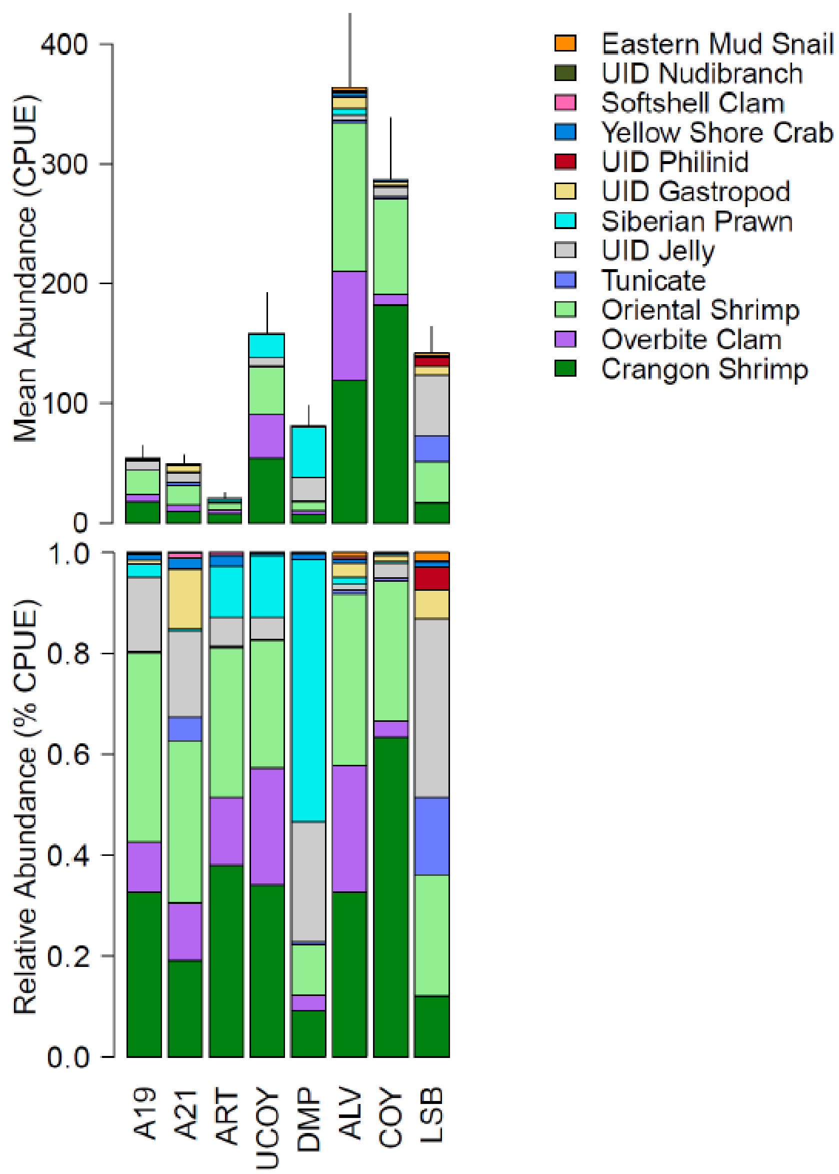

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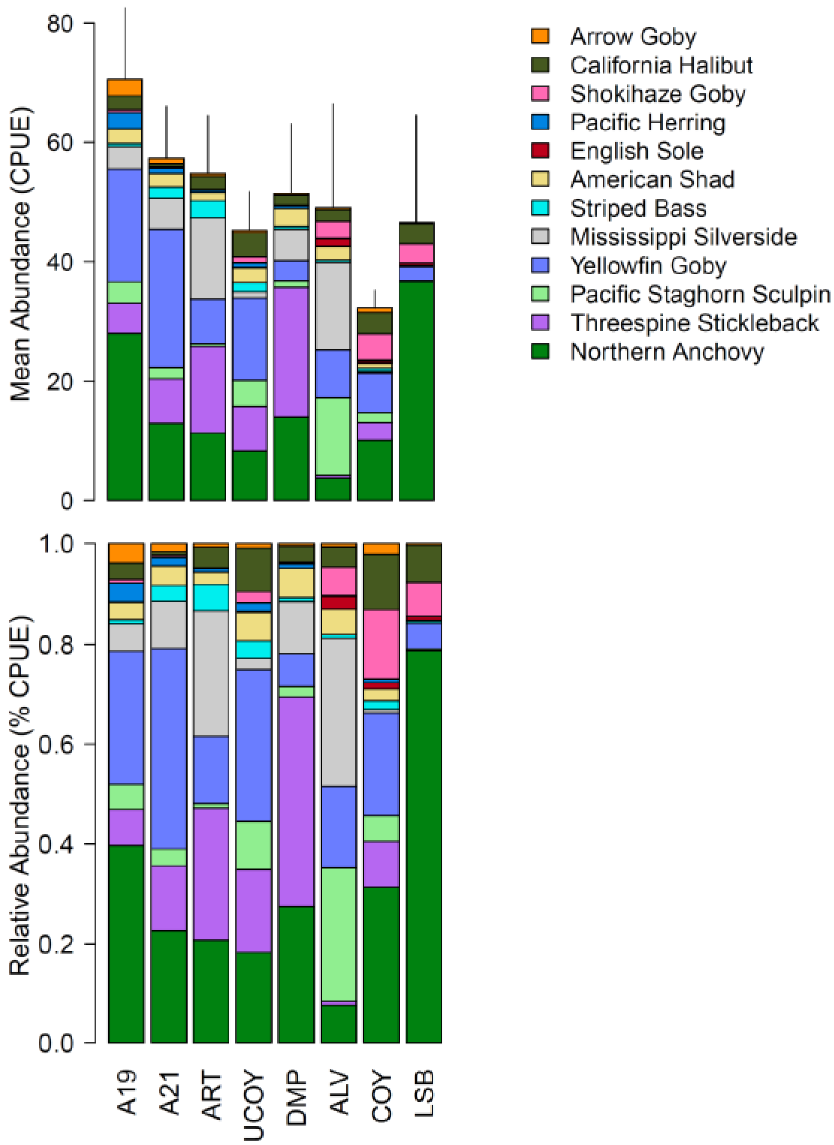
Figure 4. Spatial variation among sites in mean annual CPUE (top) and percent composition (bottom) for the 12 most abundant fish taxa at all sites from the 2015-2018 UC, Davis otter trawl. Error bars reflect 1 standard error for the total combined abundance. UID-unidentified (Lewis et al., 2018)



6 Summary and Recommendations

Results of VPA analyses suggest that an appropriate **acute dissolved oxygen criterion** for the sloughs is between 3.7 and 3.8 mg/L (46% saturation) depending on whether juvenile sturgeon are included in the calculation ~~or not~~. Some jurisdictions express the acute criterion as an instantaneous threshold; any observation below this value, regardless of duration, is considered as possible impairment of aquatic life uses. However, laboratory data on which this criterion is based~~,~~ were derived from testing conducted over at least a 24-hour period (in many cases up to 96 hours for fish). In addition, most jurisdictions acknowledge that aquatic life can tolerate brief periods below the acute criterion as discussed in EPA's VPA document (USEPA 2000). Therefore, many states, for example, express the acute criterion as a daily average or in some cases subdaily average (e.g., one hour average). If an instantaneous threshold is desired, further analyses of the available DO data compiled in this report could be used to derive such a value.

Commented [MC22]: I think this paragraph should go further and state that the 3.7 or 3.8 is indeed a 24-hour value. It's left too vague.

The VPA analyses in this report identified a **chronic DO criterion** between 4.3 and 5.7 mg/L (corresponding to 53-70% saturation) depending on whether juvenile salmonids and/or sturgeon are included in the calculation. Chronic toxicity data on which these criteria are based~~,~~ were generally derived from tests conducted over a few weeks or more. Therefore, the chronic criterion is often expressed as a monthly or perhaps weekly average. The larval recruitment criterion of 4.3 mg/L derived in this report, could also be used as a weekly average particularly during the spawning and larval period of biota if appropriate.

As noted in this report, the VPA results are based on laboratory test data and much of it pertains to surrogate species that may or may not be appropriate for biota that occur in the sloughs. In addition, the laboratory data used for the VPA analyses are based on testing with juvenile (sometimes larval) stages of fish and invertebrates. This is particularly critical in considering salmonid and sturgeon species because laboratory toxicity data for these species is based largely on freshwater testing (which juveniles of these species require) and their occurrence as juveniles in the sloughs is presently uncertain.

While much relevant biological data have been collected from sloughs in the Alviso Marsh complex, data are limited with respect to salmonid and sturgeon occurrence and potential use of the sloughs as juvenile rearing habitat. Based on current information from local experts and monitoring studies, it appears that salmonid use of the sloughs, either as adults migrating upstream or as juveniles migrating downstream to LSB, may be limited to the fall, winter, and spring months and less so or not at all between June and September. This timing may support having a lower DO objective for the summer months (e.g., 4.3 mg/L which was derived without salmonids) when salmonids are unlikely to be present and a higher DO objective (5.0 - 5.7 mg/L) in other seasons when juvenile salmonids could potentially use the sloughs. For sturgeon, it appears that spawning activity is limited to the northern part of the Bay and that sturgeon rarely use LSB tributaries for spawning. Thus, a chronic DO objective based on the VPA may not include sturgeon in the calculation, which, with the salmonid spawning timing just noted, would translate to a chronic objective of 4.5 mg/L in summer months and 5.7 mg/L in other seasons. Given the sensitivity of these genera to DO, focused monitoring information is needed that targets the juvenile life stage timing of their migrations to the Bay and how they use the sloughs in terms of timing and duration. This information would help determine how DO objectives should account for these genera temporally and spatially.

Current information suggests that DO objectives may not necessarily differ among sloughs based on fish and invertebrate monitoring data and general water quality characteristics. However, this may need further evaluation given differences in size and connectivity of sloughs to the Bay. If certain sloughs are shown to have different biological expectations, then DO objectives may need to be adjusted accordingly.

Commented [MC23]: This paragraph is too vague.

It may be worthwhile to further explore paired fisheries/DO field data from the sloughs to derive species sensitivity distributions and develop an objective based on extirpation or avoidance. This approach was previously used to develop a conductivity benchmark in Appalachian streams. This would provide grounding for VPA- derived DO objectives, which are driven by taxonomic rather than ecological factors.

7 Literature Cited

Acadia University.2016. Life Cycle of the Striped Bass. Access online via: http://stripedbass.ca/lifecycle.html

APHA. 1989. Standard methods for the examination of water and wastewater, seventeenth edition. American Public Health Association, Washington, DC.

Bailey H, Curran C, Poucher S, and Sutula M. 2014. Science supporting dissolved oxygen objectives for Suisun Marsh. Southern California Coastal Water Research Project, Technical Report 830.

CABI. 2022. *Palaemon macrodactylus* (oriental shrimp). In: Invasive Species Compendium. Wallingford, UK: CAB International. Accessed March 9, 2022 online at: https://www.cabi.org/isc/datasheet/109150

CABI. 2022. *Rhithropanopeus harrisii* (Harris mud crab). In: Invasive Species Compendium. Wallingford, UK: CAB International. Accessed March 9, 2022 online at: https://www.cabi.org/isc/datasheet/66045

California Department of Fish and Wildlife (2021). "Green Sturgeon." Retrieved March 15, 2021, from https://wildlife.ca.gov/Conservation/Fishes/Sturgeon/Green-Sturgeon.

California Department of Fish and Wildlife's San Francisco Bay Study and the Interagency Ecological Program for the San Francisco Estuary. 2019. San Francisco Bay Study Documentation for Fish Catch Matrices

California Regional Water Quality Control Board 2017. San Francisco Bay Basin (Region 2) Water Quality Control Plan (Basin Plan). Accessed online Feb 7, 2022 at: San Francisco Bay Basin Plan - Chapter 3: Water Quality Objectives (ca.gov)

DuBois, J., A. Danos. 2018. 2017 Sturgeon Fishing Report Card : Preliminary Data Report. California Department of Fish and Wildlife Bay Delta Region.

Flippin, J., S. Roy, J. Diamond, J. Rath, J. Harcum and T. Grieb (2021). DO Criteria Recommendations for Suisun Marsh, Technical Report prepared for the San Francisco Bay Regional Water Quality Control Board, June 23, 2017.

Florida Department of Environmental Protection (FDEP). 2013. Technical Support Document: Derivation of Dissolved Oxygen Criteria to Protect Aquatic Life in Florida's Fresh and Marine Waters. DEP-SAS-001/13. Florida Department of Environmental Protection, Division of Environmental Assessment and Restoration Tallahassee Florida.

Franklin, P.A. 2014. Dissolved oxygen criteria for freshwater fish in New Zealand: a revised approach. New Zealand Journal of Marine and Freshwater Research 48:112-126.

Leidy, R.A., G.S. Becker, B.N. Harvey. 2005. Historical distribution and current status of steelhead/rainbow trout *(Oncorhynchus mykiss)* in streams of the San Francisco Estuary, California. Center for Ecosystem Management and Restoration, Oakland, CA.

Leidy, R. A. and G. S. Becker (2003). Historical Distribution and Current Status of Steelhead (*Oncorhynchus mykiss*), Coho Salmon (*O. kisutch*), and Chinook Salmon (*O. tshawytscha*) in Streams of the San Francisco Estuary, California. NOAA Fisheries, U.S. E.P.A., Fish and Wildlife Committees of Contra

Costa, Alameda, Santa Clara, and San Mateo counties, Marin County, As You Sow Foundation, Rosem Foundation for Communities and the Environment, William H. Donner Foundation, California State Coastal Conservancy, Center for Ecosystem Management and Restoration.

Lewis, L., J. Hobbs, M. Willmes, P. Crain, A. Barros, and C. Denney. 2018. Community Structure of Fishes and Macroinvertebrates in the Alviso Marsh Complex2011-2018. Hobbs Biogeochemistry & Fish Ecology Laboratory Department of Wildlife, Fish and Conservation Biology University of California, Davis.

MacVean, L.J., L.S. Lewis, P. Trowbridge, J.A. Hobbs, D.B. Senn. 2018. *Dissolved Oxygen in South San Francisco Bay: Variability, Important Processes, and Implications for Understanding Fish Habitat*. Technical Report. San Francisco Estuary Institute, Richmond, CA.Mahardja B, Conrad JL, Lusher L, Schreier B. 2016. Abundance Trends, Distribution, and Habitat Associations of the Invasive Mississippi Silverside (*Menidia audens*) in the Sacramento–San Joaquin Delta, California, USA. San Francisco Estuary and Watershed Science, 14(1)

Miller, E. A., G.P. Singer, M.L. Peterson, E.D. Chapman, M.E. Johnston, M.J. Thomas, R.D. Battleson, et al. 2020. *"Spatio-temporal distribution of Green Sturgeon (Acipenser medirostris) and White Sturgeon (A. transmontanus) in the San Francisco Estuary and Sacramento River, California.*" Environmental Biology of Fishes **103**(5).

National Marine Fisheries Service(NMFS). 2016. Final Coastal Multispecies Recovery Plan. National Marine Fisheries Service, West Coast Region, Santa Rosa, California.

Tango, P. J. and R. A. Batiuk, 2013. Deriving Chesapeake Bay Water Quality Standards. Journal of the American Water Resources Association (JAWRA) 1-18.

University of California-Davis.2022. California Fish Species: Mississippi Silversides. Accessed online via: https://calfish.ucdavis.edu/species/?uid=92&ds=698

University of California-Davis.2022. California Fish Species: Striped Bass. Access online via: https://calfish.ucdavis.edu/species/?uid=96&ds=241

University of California-Davis (2021). "California Fish Species-White Sturgeon." Retrieved March 15, 2021, from http://calfish.ucdavis.edu/species/?ds=241&uid=113.

Urbina MA, Glover CN. 2013. Relationship between fish size and metabolic rate in the oxyconforming inanga *Galaxias maculatus* reveals size-dependent strategies to withstand hypoxia. *Physiol Biochem Zool* 86: 740–749.

USEPA. 2000. Ambient Aquatic Life Water Quality Criteria for Dissolved Oxygen (Saltwater): Cape Cod to Cape Hatteras. EPA-822-R-00-012. U.S. Environmental Protection Agency, Washington, DC.

USEPA 2003. Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries (Regional Criteria Guidance) April 2003. EPA 903-R-03-002. Region III Chesapeake Bay Program Office, Annapolis, MD.

Appendix A: Sources for acute and chronic endpoints and the life stage during laboratory testing for each species.

Species	Acute Source	Chronic Source	Life Stage	
			Acute	Chronic
American Lobster *Homarus americanus*	EPA, 2000	EPA, 2000	juvenile	larvae
Atlantic Croaker *Micropogonias undulatus*		Thomas and Rahman, 2009; Thomas, et al., 2007 as reported in FL DEP, 2012		adult
Atlantic Herring *Clupea harengus*	DeSilva and Tytler, 1973 as reported in FL DEP, 2012		larvae	
Atlantic Menhaden *Brevoortia tyrannus*	EPA, 2000	McNatt and Rice 2004 as reported in FL DEP, 2012	juvenile	juvenile
Atlantic Rock Crab *Cancer irroratus*	Poucher and Coiro, 1997 as reported in FL DEP, 2012	EPA, 2000	larvae	larvae
Atlantic Silverside *Menidia menidia*		EPA, 2000		embryo
Atlantic Sturgeon *Acipenser oxyrinchus oxyrinchus*	Flippin, et al., 2017	Niklitschek and Secor 2009; Secor and Gunderson,1998 as reported in FL DEP, 2012	unknown	YOY, juvenile
Atlantic Surfclam *Spisula solidissima*	EPA, 2000		juvenile	
Bay Anchovy *Anchoa mitchilli*	Breitburg, 1994; Chesney and Houde, 1989(as reported in USEPA, 2000) as reported in FL DEP, 2012		larvae, eggs, 12-24 hr yolk sac	
Blue Crab *Callinectes sapidus*	EPA, 2000	DeFur, et al., 1990 and Das and Stickle, 1993 as reported in FL DEP, 2012	adult	juvenile, adult
Burry's Octopus *Octopus burryi*	Poucher and Coiro, 1997 as reported in FL DEP, 2012		Embryo-hatch	

Copepod *Acartia tonsa*	Lutz et al, 1994(as reported in EPA, 2000) as reported in FL DEP, 2012	Richmond, et al., 2006 as reported in FL DEP, 2012	eggs	eggs
Daggerblade Grass Shrimp *Palaemonetes pugio*	EPA, 2000	Brouwer, et al., 2007 as reported in FL DEP, 2012	juvenile	adult
Eastern Oyster *Crassostrea virginica*	EPA, 2000	Baker and Mann, 1992 as reported in FL DEP, 2012	juvenile	juvenile
Flat mud crab *Eurypanopeus despressus*	FL DEP, 2012 (EPA not used because no temp was recorded to convert to %sat)		larvae, juvenile	
Florida Flagfish *Jordanella floridae*		Hale, et al., 2003 as reported in FL DEP, 2012		embryo
Four-eye Amphipod *Ampelisca abdita*	EPA, 2000		juvenile	
Fourspine Stickleback *Apeltes quadracus*	EPA, 2000		juvenile, adult	
Green Crab *Carcinus maenas*	EPA, 2000		juvenile, adult	
Gulf Killifish *Fundulus grandis*		Landry, et al., 2007 as reported in FL DEP, 2012		Juvenile, adult
Harris Mud Crab *Rithropanopeus harrisii*	EPA, 2000		juvenile	
inland silversides *Menidia beryllina*	Coiro, 2000; Poucher & Coiro, 1997 as reported in FL DEP, 2012		larvae, juvenile, adult	
Longfin Squid *Loligo pealii*	Poucher and Coiro, 1997 as reported in FL DEP, 2012		newly hatched	
Marsh Grass shrimp *Paleomonetes vulgaris*	EPA, 2000	EPA, 2000	juvenile	newly hatched, larvae, post larvae
Mummichog *Fundulus heteroclitus*	Voyer and Hennekey, 1972 as reported in FL DEP, 2012		embryo	
Mysid Shrimp *Mysidae sp.*	EPA, 2000	EPA, 2000	Juvenile	juvenile
Naked Goby *Gobiosoma bosc*	Breitburg, 1994; Saksena and Joseph, 1972 as reported in FL DEP, 2012		larvae	

Northern Pipefish *Syngnathus fuscus*	EPA, 2000		juvenile	
Northern Searobin *Prionotus carolinus*	EPA, 2000		juvenile	
Northern White Shrimp *Litopenaeus setiferus*		Rosas, et al., 1997; Rosas, et al., 1998 as reported in FL DEP, 2012		post larvae, juvenile
Pinfish *Lagodon rhomboides*	Campbell and Goodman 2007 as reported in FL DEP, 2012		juvenile	
Pink Shrimp *Farfantepenaeus duorarum*	Campbell and Goodman 2007 as reported in FL DEP, 2012		adult	
Pompano *Trachinotus carolinus*	Campbell and Goodman 2007 as reported in FL DEP, 2012		juvenile	
Quahog (Hard clam) *Mercenaria mercenaria*	EPA, 2000	EPA, 2000	1-4 days	embryos
Sailfin Molly *Poecilia latipinna*	Peterson, 1990 as reported in FL DEP, 2012		Juvenile, adult	
Salmonids *Oncorhynchus sp.*		EPA, 1986 as reported in Flippin, et al. 2017		Early life stages
Sand Shrimp *Crangon septiemspinosa*	EPA, 2000		Juvenile, young adult	
Say Mud Crab *Dyspanopeus sayi*	Coiro, 2000; Poucher and Coiro, 1997 as reported in FL DEP, 2012	EPA, 2000	larvae	larvae
Scaled sardine *Harengula jaguana*	Campbell and Goodman 2007 as reported in FL DEP, 2012		juvenile	
Scup *Stenotomus chrysops*	EPA, 2000		juvenile	
Sheepshead Minnow *Cyprinodon variegatus*	Peterson, 1990; Poucher and Coiro, 1997 as reported in FL DEP, 2012	EPA, 2000	larvae, juvenile, adult	larvae
Shortnose sturgeon *Acipenser oxyrinchus*	Campbell and Goodman 2004 as reported in FL DEP, 2012	Flippin, et al., 2017	juvenile	unknown
Skilletfish *Gobiesox strumosus*	Saksena and Joseph, 1972 as reported in FL DEP, 2012		newly hatched	
Spider Crab *Libinia emarginata*		EPA, 2000		larvae

Spot *Leiostomus xanthurus*	EPA, 2000	McNatt and Rice 2004 as reported in FL DEP, 2012	juvenile	juvenile
Spotted Seatrout	Campbell and Goodman 2007 as reported in FL DEP, 2012		juvenile	
Striped Bass *Morone saxatilis*	EPA, 2000	EPA, 2000	juvenile	juvenile
Striped Blenny *Chasmodes bosquianus*	Saksena and Joseph, 1972 as reported in FL DEP, 2012		newly hatched	
Striped Mullet *Mugil cephalus*	Campbell and Goodman 2007; Sylvester 1975 as reported in FL DEP, 2012		juvenile	
Summer Flounder *Paralichthys dentatus*	EPA, 2000	EPA, 2000	juvenile	newly metamorphosed
Tautog *Tautog onitis*	EPA, 2000		juvenile	
Weakfish *Cynoscion regalis*		Stierhoff, et al., 2009 as reported in FL DEP, 2012		juvenile
Windowpane Flounder *Scophthalmus aquosus*	EPA, 2000		juvenile	
Winter Flounder *Pseudopleuronectes americanus*	EPA, 2000	Bedja, et al., 1992 as reported in FL DEP, 2012	juvenile	juvenile

Appendix B: Literature reviewed for information regarding species presence/absence, life history, age ranges, and seasonality in South San Francisco Bay sloughs

Author/Organization	Year of Publication	Title
Valley Water	2021	2020 Stevens Creek Fisheries Monitoring
Valley Water	2021	2020 Guadalupe River Watershed Fisheries Monitoring
Valley Water	2021	2020 Coyote Creek Watershed Fisheries Monitoring
Valley Water	2020	2019 Guadalupe River Watershed Fisheries Monitoring
Lewis, L./University of California, Davis (U.C.Davis)	2020	Analysis of Fish Abundance Patterns in the Alviso Marsh Complex (AMC)-Summary
Stompe, Moyle, Kruger, et al./ U.C. Davis	2020	Comparing and Integrating Fish Surveys in the San Francisco Estuary: Why Diverse Long-Term Monitoring Programs are Important
Lewis, L./University of California, Davis (U.C.Davis)	2020	Analysis of Fish Abundance Patterns in the AMC
DuBois, Danos, & Chalfin/CADFW	2020	Sturgeon Fishing Report Card: Summary Data Report
Miller et al	2020	Spatio-temporal distribution of Green Sturgeon (Acipenser medirostris) and White Sturgeon (A. transmontanus) in the San Francisco Estuary and Sacramento River, California
SFPUC Water Enterprise Natural Resources and Lands Management Division West Bay Biology Section and Stillwater Sciences	2019	San Mateo Creek 2018 Aquatic Resources Monitoring
Valley Water	2019	2018 Guadalupe River Watershed Fisheries Monitoring
Bogan, M. et al	2019	Biodiversity value of remnant pools in an intermittent stream during the great California drought
NOAA National Marine Fisheries Service (NMFS)	2018	Recovery Plan for the Southern Distinct Population Segment of North American Green Sturgeon (*Acipenser medirostris)*
NMFS	2018	Appendix A: Southern DPS Green Sturgeon Recovery Plan Threats Assessment Methodology and References
Smith/San Jose State University (SJSU)	2018	Stevens Creek Environmental Conditions and Fish Resources in 2013-2018

SFPUC Water Enterprise Natural Resources and Lands Management Division West Bay Biology Section and Stillwater Sciences	2018	San Mateo Creek 2017 Aquatic Resources Monitoring
Cochran, S./CADFW	2018	Guadalupe Creek Juvenile Steelhead Trout (*Oncorhynchus mykiss*) Sampling Survey 2017
Smith, J. /SJSU	2018	Upper Penitencia Creek Fish Resources Through 2018
Lewis, L. et al/U.C. Davis	2018	Community Structure of Fishes and Macroinvertebrates in the Alviso Marsh Complex 2011-2018
MacVean, et al/ SFEI & U.C. Davis	2018	Dissolved Oxygen In South San Francisco Bay: Variability, Important Processes, And Implications For Understanding Fish Habitat
DuBois & Danos/ CADFW	2018	2017 Sturgeon Fishing Report Card: Preliminary Data Report
J. Heublein, et al/NMFS	2017	Improved Fisheries Management Through Life Stage Monitoring: The Case for the Southern Distinct Population Segment of North American Green Sturgeon and the Sacramento-San Joaquin River White Sturgeon
Smith/SJSU	2017	Stevens Creek Environmental Conditions and Fish Resources in 2017
Santa Clara County Creeks Coalition	2017	Stevens Creek Draft Steelhead Passage Improvement Project Feasibility Report
SFPUC Water Enterprise Natural Resources and Lands Management Division West Bay Biology Section and Stillwater Sciences	2017	San Mateo Creek 2016 Aquatic Resources Monitoring
Santa Clara Valley Water District	2017	Guadalupe River Project AMT- Santa Clara Valley Water District Chinook salmon spawning
Smith, J. /SJSU	2017	Fish Population Sampling In 2017 on Coyote Creek
Smith, J. /SJSU	2017	Upper Penitencia Creek Fish Resources in 2017
ICF International/ Santa Clara Valley Transportation Authority	2017	Alum Rock Fish Passage Project Mitigation Monitoring Report Year Four, 2016
Heublein J. et al /NMFS	2017	Life History and Current Monitoring Inventory of San Francisco Estuary Sturgeon
Flippin, et al/Tetra Tech	2017	Technical Report: DO Criteria Recommendations for Suisun Marsh
NMFS	2016	Coastal Multispecies Plan Volume IV Central California Coast Steelhead
Smith & Leicester/ SJSU &California Dept of Fish and Wildlife (CADFW)	2016	Stevens Creek Environmental Conditions and Fish Resources in 2016
Santa Clara Valley Water District	2016	Stevens Creek Fish Passage Assessment

SFPUC (San Francisco Public Utilities Commission) Water Enterprise Natural Resources and Lands Management Division West Bay Biology Section and Stillwater Sciences	2016	San Mateo Creek 2015 Aquatic Resources Monitoring
Leicester & Smith /CADFW & SJSU	2016	Guadalupe Creek Fish Sampling in October 2015 and 2016
Smith, J. /SJSU	2016	Fish Population Sampling In 2016 on Coyote Creek
Diamond & Snyder/ Pathways for Wildlife	2016	Coyote Valley Linkage Assessment Study Final Report
ICF International/ Santa Clara Valley Transportation Authority	2016	Alum Rock Fish Passage Project Mitigation Monitoring Report Year Three, 2015
Crauder et al/SFEI and the Aquatic Science Center	2016	Lower South Bay Nutrient Synthesis
NMFS	2015	Southern Distinct Population Segment of the North American Green Sturgeon *(Acipenser medirostris)* 5-Year Review: Summary and Evaluation
Leicester & Smith/CADFW & SJSU	2015	Guadalupe Creek Fish Sampling on 6 October 2015
Leicester & Smith/ CADFW & SJSU	2015	Fish Population Sampling In 2015 on Coyote Creek
ICF International/ Santa Clara Valley Transportation Authority	2015	Alum Rock Fish Passage Project Mitigation Monitoring Report Year Two, 2014
Bancroft, M.	2015	Thesis: An Experimental Investigation of the Effects of Temperature and Dissolved Oxygen on the Growth of Juvenile English Sole and Juvenile Dungeness Crab
East Bay Municipal Utility District Natural Resources Dept. Fisheries and Wildlife Division	2014	Salmonid Habitat Assessments for the Pinole and San Leandro Creek Watersheds
Smith, J. /SJSU	2014	Fish Population Sampling In Fall 2014 on Coyote Creek
ICF International/ Santa Clara Valley Transportation Authority	2014	Alum Rock Fish Passage Project Mitigation Monitoring Report Year One, 2013
NMFS	2013	Central California Coast Steelhead Distinct Population Segment Map
Will & Stern	2012	Upper Penitencia Creek Steelhead Oncorhynchus mykiss Redd Survey Report 2010-2011
Florida Department of Environmental Protection Division of Environmental Assessment and Restoration	2012	Technical Support Document: Derivation of Dissolved Oxygen Criteria to Protect Aquatic Life in Florida's Fresh and Marine Waters

Mulchaey, B. et al/East Bay Municipal Utility District Natural Resources Dept. Fisheries and Wildlife Division	2011	Upper San Leandro Reservoir Watershed Salmonid Habitat Assessment
EOA, Inc. & SFEI/ Santa Clara Valley Water District	2011	Ecological Monitoring & Assessment Framework Stream Ecosystem Condition Profile: Coyote Creek Watershed Including the Upper Penitencia Creek Subwatershed
S. Hosseini, et al/Capital Program Services Division	2010	Stevens Creek Fish Passage Enhancement Report
Launer/Stanford	2010	Supplemental Information for reports on San Francisquito Creek by Launer and Spain (1998) and Launer and Holtgrieve (2000)
SFPUC Natural Resources and Lands Management Division Fisheries and Wildlife Section	2009	San Antonio Creek, Indian Creek and Arroyo Hondo Fish Trapping Data Summary 2005
SFPUC	2009	2007 Alameda Creek Aquatic Resource Monitoring Report
Moore, M. et al/ Santa Clara Valley Water District	2009	Mid-Coyote Creek Flood Protection Project: Baseline Fisheries Monitoring Report Year 2 (2008)
Moore, M. et al/ Santa Clara Valley Water District	2008	Mid-Coyote Creek Flood Protection Project: Baseline Fisheries Monitoring Report Year 1 (2007)
Spence, B. et al/NMFS	2008	A Framework for Assessing the Viability of Threatened and Endangered Salmon and Steelhead in the North-Central California Coast Recovery Domain
SFPUC Natural Resources and Lands Management Division Fisheries and Wildlife Section	2007	2004 San Antonio Creek, Indian Creek and Arroyo Hondo Fish Trapping Data Summary
SPFUC Water Enterprise Natural Resources and Lands Management Division Fisheries and Wildlife Section	2007	Alameda Creek Aquatic Resource Monitoring Report 2005
McBain & Trush, Inc.	2007	Alameda Creek Population Recovery Strategies and Instream Flow Assessment for Steelhead Trout
Leidy, R./ U.S. EPA & SFEI	2007	Ecology, Assemblage Structure, Distribution, and Status of Fishes in Streams Tributary to the San Francisco Estuary, California
Jones & Stokes/Santa Clara Valley Water District	2006	Lower San Francisquito Creek Watershed Aquatic Habitat Assessment and Limiting Factors Analysis (Work Product N.1)
ENTRIX, Inc	2006	Fish Passage Assessment Report On Polhemus Creek, San Mateo County, California
SFPUC Natural Resources Division Fish and Wildlife Group	2006	Alameda Creek Aquatic Resource Monitoring Report 2004

Grossinger, R. et al/ SFEI (San Francisco Estuary Institute)	2006	Coyote Creek Watershed Historical Ecology Society: Historical Condition, Landscape change, and restoration potential in the Eastern Santa Clara Valley, California
Entrix/Santa Clara Valley Water District	2006	Coyote Creek: Montague ex. To Interstate 280 Baseline Fisheries Habitat Study
Da Costa, Manny	2005	SLZ Steelhead Sighting -email documentation
SPFUC Water Quality Bureau	2005	Population Size Estimates for Adult Rainbow Trout (*Oncorhynchus mykiss*) in San Antonio and Calaveras Reservoirs
Agrawal, A.et al/NMFS	2005	Predicting The Potential for Historical Coho, Chinook and Steelhead Habitat in Northern California
Leidy, Becker, & Harvey/CEMAR	2005	Historical Distribution and Current Status of Steelhead/Rainbow Trout (Oncorhynchus mykiss) in Streams of the San Francisco Estuary, California
Leidy, Becker, & Harvey / California Fish and Game	2005	Historical Status of Coho Salmon in Streams of the Urbanized San Francisco Estuary, California
Santa Clara Valley Urban Runoff	2004	Stevens Creek Limiting Factors Analysis
D.W. Alley and Assoc.	2004	Report of Construction Monitoring Leading to Isolation of Construction Sites and Fish Capture/Relocation on San Francisquito Creek at the Sand Hill Road Bridge and the Golf Cart Crossing in the Stanford Golf Course, 4 June-2 September 2004
Fong/ National Park Service (NPS)-Golden Gate National Recreation Area	2004	Summer Stream Habitat Inventory and Fish Surveys for Upper West Union Creek Survey 1996-2001
San Francisquito Creek Joint Powers Authority	2004	San Francisquito Creek Watershed Analysis and Sediment Reduction Plan
SPFUC Water Quality Bureau	2004	San Antonio Creek, Indian Creek and Arroyo Hondo Fish Trapping Data Summary 2003
Herron, King, and McDonald	2004	A Preliminary Assessment of Potential Steelhead Habitat in Sinbad Creek, Alameda County
Jones & Stokes/ U.S. Army Corps of Engineers (USACE)	2004	Simulated Water Temperature Effects of Bypassing Almaden Lake
Buchan & Randall/ Santa Clara Valley Water District	2004	Mid-Coyote Creek Environmental Data Compilation Project
Abel, J.	2004	Penitencia Percolation FacilityFish Species Occurrence
Michael Love and Associates & Graham Matthews and Associates	2003	Providing Steelhead Passage through Lower San Lorenzo Creek A Feasibility Scoping Report for the Alameda County Flood Control and Water Conservation District

Grossinger &Brewster/San Francisco Estuary Institute (SFEI) Regional Watershed Program	2003	A Geographic History of San Lorenzo Creek Watershed: Landscape Patterns Underlying Human Activities in the Lands of the Yrgin
Entrix/San Francisco Bureau of Strategic and Systems Planning Public Utilities Commission	2003	2002 Fish Trapping Study Data Summary For San Antonio Creek and Arroyo Hondo
Nielsen, J.	2003	Population Genetic Structure of Alameda Creek Rainbow/Steelhead Trout - 2002
Entrix/San Francisco Bureau Of Strategic And Systems Planning Public Utilities Commission	2003	Aerial Survey of the Upper Alameda Creek Watershed to Assess Potential Rearing Habitat for Steelhead Fall 2002
Buchan & Randall/ Santa Clara Valley Urban Runoff Pollution Prevention Program	2003	Assessment of Stream Ecosystem Functions for the Coyote Creek Watershed
Leidy, Becker, & Harvey/U.S. EPA & CEMAR	2003	Historical Distribution and Current Status of Steelhead (Oncorhynchus mykiss), Coho Salmon (O. kisutch), and Chinook Salmon (O. tshawytscha) in Streams of the San Francisco Estuary, California
Modrell, Paul	2002	SLZ Steelhead Sighting -email documentation
Buchan, Randall & Dovorsky/ Santa Clara Valley Urban Runoff Pollution Prevention Program	2002	Stream Classification for the Coyote Creek Watershed: Coyote Creek Watershed Integrated Pilot Assessment Technical Memorandum: Task 2.0
Smith & Harden/San Francisquito Watershed Council	2001	Adult Steelhead Passage in the Bear Creek Watershed
Santa Clara Valley Water District	2000	Stevens Creek Barrier Assessment
Launer & Holtgrieve/Stanford	2000	Fishes and Amphibians of the San Francisquito and Matadero Creek Watersheds, Stanford University: Report on 1998 & 1999 Field Activities
Launer & Spain/Stanford	1998	Biotic Resources of the San Francisquito Creek Watershed: Report on 1997 Field Activities Associates with Streambed Alteration Agreement #934-96
Kobernus	1998	Thesis: A Feasibility Scoping Report for the Alameda County Flood Control and Water Conservation District
Gillies, E./ SJSU	1998	Thesis: Effects of Regulated Streamflows on the Sycamore Alluvial Woodland Riparian Community
P. Alexander/ East Bay Regional Parks District	1994	San Leandro Creek Historical Rainbow Trout
Gall, Bentley, and Nuzum	1990	Genetic Isolation of Steelhead Rainbow Trout in Kaiser and Redwood Creeks, California
Leidy, R./ University of California Division of Agriculture and Natural Resources	1984	Distribution and Ecology of Stream Fishes in the San Francisco Bay Drainage
Smith & Kato	1979	The Fisheries of San Francisco Bay: Past, Present and Future
California Dept of Fish and Game (CADFG)	1975	San Leandro DFG Survey

San Francisco Bulletin	1880	Spearing Sturgeon: How the Sport is Followed in San Francisco Bay
Smith, J./ SJSU	Not provided	Precarious Steelhead Populations in Northern Santa Clara County
Israel, Drauch, & Gingras/ U.C. Davis & CADFG	Not provided	Life History Conceptual Model for White Sturgeon

Appendix C: Components used in calculations of CCC and CMC results

Table C-1. CMC Calculation (with Sturgeon)

Rank	Genus	GMAV	1/GMAV	LN GMAV	$(LN\ GMAV)^2$	P=R/(N+1)	sqrt P
4	*Acipenser*	**2.37**	**0.46**	0.8629	0.7446	0.857	0.926
3	*Fundulus*	**2.40**	**0.42**	0.8755	0.7664	0.893	0.945
2	*Poecilia*	**2.60**	**0.38**	0.9555	0.9130	0.929	0.964
1	*Clupea*	**2.80**	**0.36**	1.0296	1.0601	0.964	0.982
			Sum	3.72	3.48	3.64	3.82

N = 27

Variables:

P = cumulative probability
N = sample size
R = rank

S^2= 10.300796

S= 3.209485

L=-2.131246

A= 0.996973

FAV= 2.710067

Ratio= 1.38 (EPA, 2000)

CMC= 3.7 mg/l

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Remaining 23 genera: *Harengula, Cancer, Anchoa, Mugil, Cynoscion, Trachinotus, Menidia, Syngnathus, Morone, Pseudopleuronectes, Paralichthys, Gobiosoma, Mysidae, Crassostrea, Brevoortia, Crangon, Apeltes, Ampelisca, Paleomonetes, Mercenaria, Rithropanopeus, Carcinus, Acartia*

Table C-2. CMC Calculation (Without Sturgeon)

Rank	Genus	GMAV	1/GMAV	LN GMAV	$(\text{LN GMAV})^2$	P=R/(N+1)	sqrt P
4	*Harengula*	**2.17**	**0.46**	0.775	0.600	0.8519	0.9230
3	*Fundulus*	**2.40**	**0.42**	0.875	0.766	0.8889	0.9428
2	*Poecilia*	**2.60**	**0.38**	0.956	0.913	0.926	0.9622
1	*Clupea*	**2.80**	**0.36**	1.030	1.060	0.9630	0.9813
			Sum	3.64	3.34	3.63	3.81

N = 26

Variables:

P = cumulative probability
N = sample size
R = rank

S^2= 18.962369

S= 4.354580

L= -3.238170

A= 1.006149

FAV= 2.735049

Ratio= 1.38 (EPA, 2000)

CMC= 3.8 mg/l

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Remaining 22 genera: *Cancer, Anchoa, Mugil, Cynoscion, Trachinotus, Menidia, Syngnathus, Morone, Pseudopleuronectes, Paralichthys, Gobiosoma, Mysidae, Crassostrea, Brevoortia, Crangon, Apeltes, Ampelisca, Paleomonetes, Mercenaria, Rithropanopeus, Carcinus, Acartia*

Table C-3. CCC Calculation with Salmnids and Sturgeon.

Rank	Genus	GMCV	1/GMCV	LN GMCV	$(LN\ GMCV)^2$	P=R/(N+1)	sqrt P
4	*Paralichthys*	**3.33**	**0.30**	1.2030	1.4471	0.765	0.874
3	*Acipenser*	**4.26**	**0.23**	1.4493	2.1004	0.824	0.907
2	*Libinia*	**4.67**	**0.21**	1.5412	2.3752	0.882	0.939
1	*Oncorhynchus*	**5.00**	**0.20**	1.6094	2.5903	0.941	0.970
			Sum	5.802	8.5130	3.412	3.691

N = 16

Variables:

P = cumulative probability
N = sample size
R = rank

S^2= 18.634890

S= 4.316815

L= -2.533105

A= 1.674406

FCV= 5.335624

CCC= 5.3 mg/l

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Remaining 12 genera: *Menidia, Mercenaria, Cancer, Brevoortia, Morone, Mysidae(family, genera unknown),Pseudopleuronectes, Paleomonetes, Acartia, Cynoscion, Crassostrea, Fundulus*

For salmonids, EPA's 1986 DO criteria (USEPA, 1986) report a moderate growth impact over a 7-day period when DO is 5mg/L.

Table C-4. CCC Calculation (Without Salmonids)

Rank	Genus	GMCV	1/GMCV	LN GMCV	(LN GMCV)^2	P=R/(N+1)	sqrt P
4	*Menidia*	**3.3**	**0.30**	1.194	1.425	0.75	0.866
3	*Paralichthys*	**3.33**	**0.30**	1.203	1.447	0.813	0.901
2	*Acipenser*	**4.26**	**0.23**	1.449	2.100	0.875	0.935
1	*Libinia*	**4.67**	**0.21**	1.541	2.375	0.938	0.968
			Sum	4.193	5.923	2.625	2.805

N = 15

Variables:

P = cumulative probability
N = sample size
R = rank

S^2= 2.320233

S= 1.523231

L= -0.019834

A= 1.464828

FCV= 4.326799

CCC= 4.3 mg/l

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Remaining 11 genera: *Mercenaria, Cancer, Brevoortia, Morone, Mysidae(family, genera unknown),Pseudopleuronectes, Paleomonetes, Acartia, Cynoscion, Crassostrea, Fundulus*