Suisun Marsh Tidal Marsh and Aquatic Habitats Conceptual Model

Chapter 2: Aquatic Environment

FINAL REVIEW DRAFT
29 June 2010

Suisun Marsh Habitat Management, Restoration and Preservation Plan

Authors:
Janice Engle, U.S. Fish and Wildlife Service
Cassandra Enos, Department of Water Resources
Katie McGourty, National Marine Fisheries Service
Treva Porter, California Department of Fish and Game
Brendan Reed, California Bay-Delta Authority
Jini Scammell-Tinling, Suisun Resource Conservation District
Korie Schaeffer, National Marine Fisheries Service
Stuart Siegel, Wetlands and Water Resources, Inc.
Esa Crumb, Wetlands and Water Resources, Inc.

Graphics Prepared By:
Wetlands and Water Resources, Inc.
Janice Engle, U.S. Fish and Wildlife Service

GIS Assistance Provided By:
Sarah Estrella, California Department of Fish and Game
Gina Van Klompenburg, California Department of Fish and Game
Dan Gillenwater, Wetlands and Water Resources, Inc.
Leigh Etheridge, Wetlands and Water Resources, Inc.

Table of Contents

2. TIDAL AQUATIC ENVIRONMENTS OF SUISUN MARSH AND BAY 2

2.1 TIDAL AQUATIC HABITATS IN SUISUN MARSH 3
2.1.1 Water Column and Depth 5
2.1.2 Aquatic Substrates 6
2.2 GENERAL CONCEPTUAL MODEL OF HIGHER TROPHIC LEVEL ECOLOGICAL FUNCTIONS OF SUISUN TIDAL AQUATIC ENVIRONMENTS 7
2.3 HIGHER TROPHIC LEVEL USES OF SUISUN AQUATIC HABITATS 8
2.3.1 Fish 9
2.3.2 Birds 10
2.3.3 Mammals 10
2.3.4 Adjacent Biological Communities 10
2.4 STRESSORS AFFECTING ECOLOGICAL FUNCTIONS OF SUISUN AQUATIC HABITATS 14
2.4.1 Non-Native, Invasive Aquatic Organisms 14
2.4.2 Low Dissolved Oxygen 16
2.4.3 Contaminants 16
2.4.4 Ammonia 17
2.4.5 Dredging 17
2.4.6 Industrial Cooling Water Intakes and Discharges 18
2.5 POSITIVE FACTORS INFLUENCING ECOLOGICAL FUNCTIONS OF SUISUN AQUATIC ENVIRONMENTS 18
2.5.1 Submerged Aquatic Vegetation (SAV) 18
2.5.2 Substrate and Benthic Community 19
2.5.3 Phytoplankton and Zooplankton 20
2.5.4 Larger Invertebrates 21
2.6 RESTORATION 22
2.7 UNCERTAINTIES AND ASSUMPTIONS 25
2.7.1 Stressors Uncertainties 25
2.7.2 Positive Factors Uncertainties 26
2.7.3 Conceptual Model Assumptions 27

List of Tables

TABLE 2-1. SUISUN MARSH AQUATIC HABITAT ACREAGES 5
TABLE 2-2: TIDAL HABITAT USE AND FUNCTION FOR REPRESENTATIVE FISH, INVERTEBRATE, BIRD, AND MAMMAL SPECIES IN THE SUISUN MARSH AREA 12

List of Figures

FIGURE 2-1. TIDAL AQUATIC HABITATS OF SUISUN MARSH AND BAY 4
FIGURE 2-2. HISTOGRAM OF SUISUN BAY BATHYMETRY. 6
FIGURE 2-3. HIGHER TROPHIC LEVEL ECOLOGICAL FUNCTIONS GENERAL CONCEPTUAL MODEL, TIDAL AQUATIC HABITATS 8
FIGURE 2-4. TIDAL COMMUNITIES BY AQUATIC HABITAT TYPE. 9
FIGURE 2-5. TIDAL ENVIRONMENTS BIOLOGICAL AND PHYSICAL PROCESSES. 14
FIGURE 2-6. GEOGRAPHIC DISTRIBUTION OF SUISUN DIKED, SUBSIDED LANDS 24
FIGURE 2-7. HISTOGRAM OF DIKED LANDS TOPOGRAPHY 25

2. Tidal Aquatic Environments of Suisun Marsh and Bay

The purpose of this conceptual model chapter is to discuss (1) controls on the functions of aquatic habitats in Suisun for supporting higher trophic level organisms primarily including fish and birds but also mammals and (2) how aquatic habitat functions may be enhanced and restored. This chapter will apply the physical processes background presented in Chapter 1 and it supports the species-level conceptual models presented in Chapter 4. This chapter contains the following materials:

- Section 2.1 briefly describes each of the aquatic habitats in Suisun Marsh (bays, large sloughs, minor sloughs, and sloughs within tidal marshes).
- Section 2.2 provides an overview of the primary drivers of higher trophic level ecosystem functions, as diagramed in the aquatic habitats conceptual model
- Section 2.3 presents the factors that influence higher trophic level uses of Suisun aquatic environments
- Section 2.4 describes the major stressors on tidal habitat and their implications for higher trophic levels
- Section 2.5 covers the key positive factors affecting the suitability of aquatic environments to support desired ecosystem functions
- Section 2.6 reviews the role of enhancement and restoration of aquatic habitats in Suisun, largely as integral to tidal marsh restoration
- Section 2.7 summarizes uncertainties and assumptions made in developing the Suisun aquatic environments conceptual model

Since this conceptual model drafting began originally in 2006, interest in aquatic habitats of Suisun Marsh and the Delta has grown substantially, driven largely by efforts of the Pelagic Organism Decline research group and the driving need for its formation: the significant and persistent decline in population abundances of several species (Baxter et al. 2008). Concurrently, the CALFED Ecosystem Restoration Program completed a suite of ecosystem conceptual models in 2008 as part of DRERIP (the Delta Regional Ecosystem Restoration Implementation Plan). This conceptual model draws strongly from the DRERIP Aquatic Ecology conceptual model (Durand 2008) and the DRERIP Fish Linkages conceptual model (Nobriga 2008). The linkages between aquatic productivity, stressors on aquatic species and their habitats, fish population abundances, and enhancement and restoration potential have become more clear during this period. Many of the potential tidal restoration sites in Suisun Marsh are subsided with some being below low tide, meaning their restoration would be to tidal aquatic rather than tidal marsh at least for a period time that could be decadal depending on location in the Marsh.

2.1 Tidal Aquatic Habitats in Suisun Marsh

The Suisun Marsh/Bay system occupies a unique position within the landscape of the San Francisco Estuary. As described in Chapter 1, Physical Processes Conceptual Model, the system encompasses the greatest salinity gradient within the estuary, which has important implications for overall system productivity. The system is also hydrodynamically complex and subject to long human modification, resulting in a wide variety of habitats such as marsh plains, tidal creeks, sloughs, channels, cuts, mudflats, and bays. Together, these features (and many others) have historically fostered significant biodiversity within Suisun tidal aquatic habitats.

Tidal aquatic habitat in Suisun Marsh is defined as those areas of fully tidal open water at high tide. Categories of tidal aquatic habitat were identified as part of the Suisun Marsh Plan development process (Figure 2-1). The categories were defined using physical boundaries and include bays, major sloughs, minor sloughs, and the intertidal mudflats within those areas. These categories have been broken down further to better identify habitat characteristics and functions for the tidal aquatic conceptual model. The total acreage for these tidal habitats is approximately 26,000 acres (Table 2-1).

Major embayments in the region are Suisun and Honker bays to the Contra Costa county line in the south, Grizzly Bay as an extension of Suisun Bay into the central Marsh, and Little Honker Bay in the northeastern Marsh up Nurse Slough. Bays have a combined acreage of about 22,350 acres (Table 2-1). The Baylands Habitat Goals Project (Goals Project 1999) further divided tidal aquatic into shallow and deep, with shallow bays to -18 feet MLLW and deep bay below that. Deep bay occurs along the major estuarine flows through Suisun and Honker Bay between Carquinez Strait and the Delta.

Tidal slough habitat is comprised of major and minor sloughs (Figure 2-1). Major sloughs are simply discerned as the largest sloughs in the Marsh and include Montezuma and Suisun sloughs as the two largest waterways interior to the Marsh and Cross, Cordelia, Denverton, Nurse, and Hill sloughs as the larger sloughs around the margins of Suisun. The Major sloughs of Suisun Marsh have a combined acreage of about 2,200 acres and consist of both shallow and deep channels (Table 2-1). Shallow channels extend down to -18 feet MLLW and their sediments are primarily mud. Deep channels extent deeper than -18ft MLLW to as much as -64 feet; sediments are also predominantly covered with mud (Goals Project 1999). Minor sloughs include all of the remaining sloughs in the Marsh that were not included in the major slough category, such as First and Second Mallard branches, Peytonia Slough, and Boynton Slough. Minor sloughs are made up of shallow channel habitat and have a combined acreage of about 1,100 acres (Table 2-1).

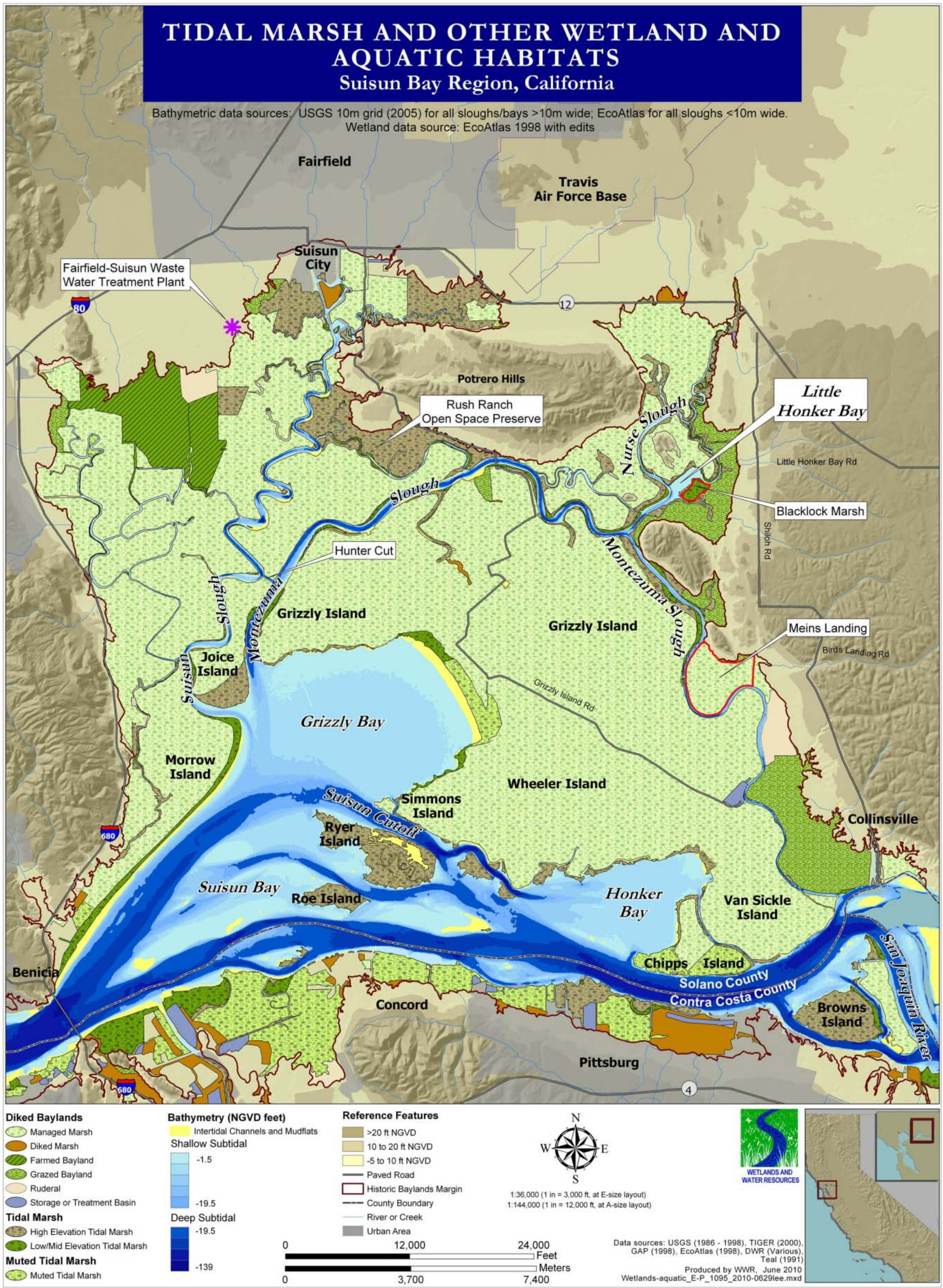

Figure 2-1. Tidal Aquatic Habitats of Suisun Marsh and Bay

Table 2-1. Suisun Marsh Aquatic Habitat Acreages

Habitat		Total
Bays[1]	Deep[4]:	
	Shallow[5]:	22,346
Major sloughs[2]	Deep:	
	Shallow:	2,212
Minor sloughs[3]	Deep:	
	Shallow:	1,108
TOTAL acres		25,666

Acreages based on the map of regions provided by SRCD and with data layers from the following sources:

- *1999 and 2003 DFG vegetation maps and associated files*
- *Interpretation of the 2003 aerial photos of the Marsh*
- *2003 SRCD property line map*
- *San Francisco Estuary Institute (SFEI). 1998. EcoAtlas: Spatial analysis of the baylands ecosystem. Version 1.50b4*
- *See also Table 1-1 in Chapter 1.*

[1] *Includes Suisun and Honker bays to the Contra Costa county line, Grizzly Bay, Little Honker Bay.*
[2] *Includes Montezuma, Cordelia, Cross, Denverton, Nurse, Suisun, and Hill sloughs.*
[3] *Includes smaller sloughs not listed under "Bays and major sloughs" such as First and Second Mallard branches, generally those that are navigable.*
[4] *Deep subtidal habitat depth is >18' below MLLW.*
[5] *Shallow subtidal habitat depth is ≤ 18' below MLLW.*

Suisun Marsh bays and sloughs support a diverse assemblage of invertebrate, fish, bird, and mammal species (see Section 2.3). At one or more points in their life cycles, these species use open water tidal areas for breeding, foraging, rearing, and/or migrating. These bays and sloughs also play an important function in water quality within the Marsh and for the Delta, especially relative to salinity.

2.1.1 Water Column and Depth

To describe water columns in Suisun Marsh, we have combined the USGS 10-m grid data set which captures most of the Suisun tidal aquatic areas (Foxgrover *et al*. 2003) with the San Francisco Estuary EcoAtlas (SFEI 1998) for the narrower sloughs not included in the USGS data set. Tidal water depths in Suisun range from the high tide line to deeper than 60 feet (18.3 m). The deepest areas of the Bay (20 to 60 feet [6 to 18.3 m]) are along the southern edge in the deepwater ship channel (Figure 2-1). Depths in larger sloughs, such as Montezuma and Suisun, generally range from 10 to 30 feet (3 to 9.1 m) with maximum depths of about 60 feet (18 m), while depths in smaller sloughs, such as Cutoff Slough, are shallower, ranging from 1 to 18 feet (0.3 to 5.5 m).

Another perspective on the nature of tidal aquatic habitats in Suisun is to examine the acreage distribution of depths; Figure 2-2 presents this histogram for the combined USGS and SFEI data sources. It shows that intertidal tidal aquatic occupies somewhat less than 1,000 acres (about 4% of tidal aquatic), the shallowest subtidal (to -6ft MLLW) occupies roughly 11,100 acres or about 43% of tidal aquatic, the remaining shallow subtidal (-6 to -18ft MLLW) accounts for about 7,500 acres (29% of tidal aquatic), and deep subtidal accounts for the remaining roughly 6,000 acres or 24% of tidal aquatic. Importantly, these data are clipped to the Suisun Marsh Planning Boundary which is the Solano-Contra Costa County line; tidal aquatic south to the Contra Costa shoreline adds several thousand acres and important ecological functions to Suisun.

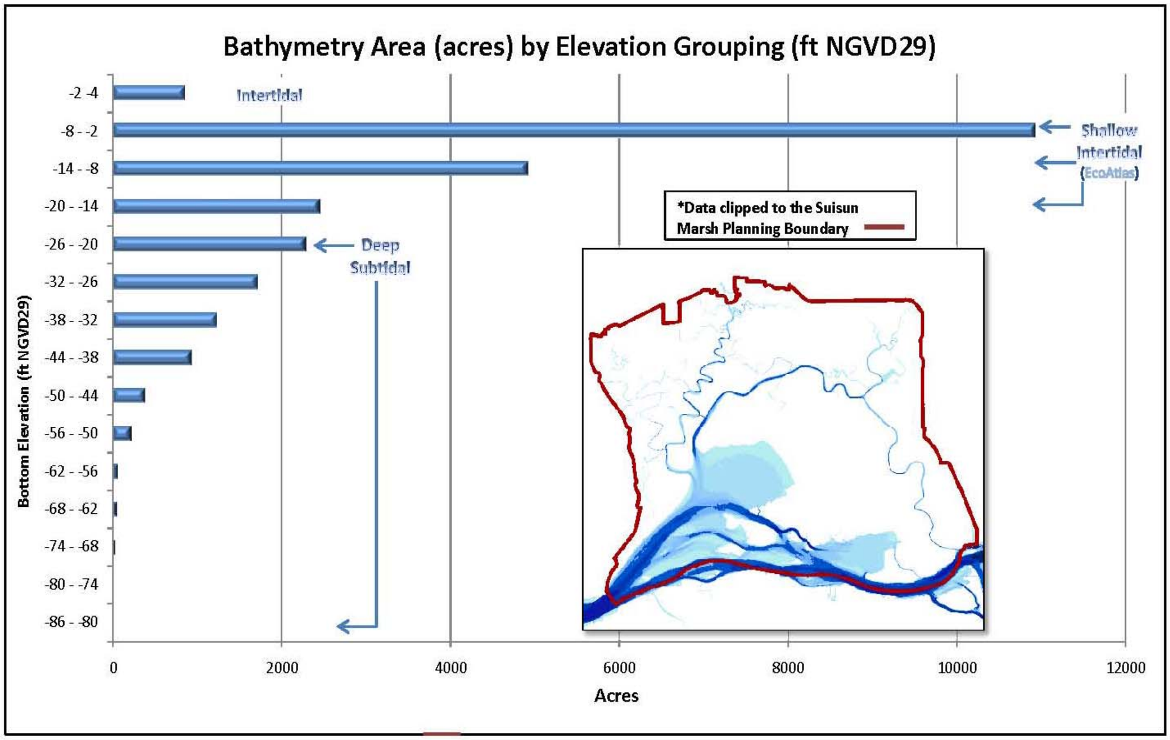

Figure 2-2. Histogram of Suisun Bay Bathymetry.

Resource Management Associates calculated the volume of the larger sloughs in the interior marsh to be approximately 46,000 acre-feet (56.7 m^3) at Mean High Water (MHW) and 34,000 acre-feet (41.9 m^3) at Mean Low Water (MLW).

2.1.2 Aquatic Substrates

Sediments in the San Francisco Bay estuary and Suisun Marsh provide an array of ecological functions for the flora and fauna of these systems. Typical soft-bottom substrates in these areas are composed of mud/silt/clay (particles 0.0001 to 0.062 mm in diameter), sand (particles 0.062-2.0mm in diameter), pebble/cobble (particles 2 to 256 mm in diameter), and shell mix (mix of mud/silt/clay or sand and shell fragments). Sediments composed of mud/silt/clay provide a substrate for invertebrate epifauna and infauna as well as important habitat substrate for fish, birds, and marine mammals to forage, reproduce, and rear. Similar functions are provided by sand substrates, which also facilitate bed load transport, and shell mix, which offers additional refuge habitat.

In Suisun Marsh, small sloughs and channels provide edge habitats consisting of muddier sediments with higher organic carbon content and a more diverse benthic community. The two shallower bays, Honker Bay and Grizzly Bay, have high percentages of coarse plant material and gravel/sand substrate surfaces with lower species richness and abundance but high numbers of *Corbula amurensis.* The large sloughs, Montezuma and Suisun, have similar sediment substrates to shallow regions of Grizzly Bay (clay and silty-clay), as well as similar benthic communities, though abundances are notably lower than seen in Grizzly Bay (Thompson *et al.* 2007).

2.2 General Conceptual Model of Higher Trophic Level Ecological Functions of Suisun Tidal Aquatic Environments

Stepping back to examine what factors influence higher trophic level functions in Suisun tidal aquatic environments provides the framework for examining the specific pathways of influence on any particular outcome of interest, be that outcome a habitat attribute or functions that support a particular species. We express this framework here as the general conceptual model presented in Figure 2-3. In this framework, there are primary drivers addressing hydrology, water quality, substrate, geomorphology, biological influences, and human influences; there are “intermediate” outcomes related to specific life history requirements of any fish, bird, or mammal species of interest (i.e., support of breeding, rearing, refuge, migration); and there are the “ultimate” outcomes of ecological functions for these higher trophic levels. This chapter concerns itself with the primary drivers (including drawing extensively upon the material in Chapter 1) and the intermediate outcomes. Chapter 4 applies these concepts relative to special status species and species of management interest.

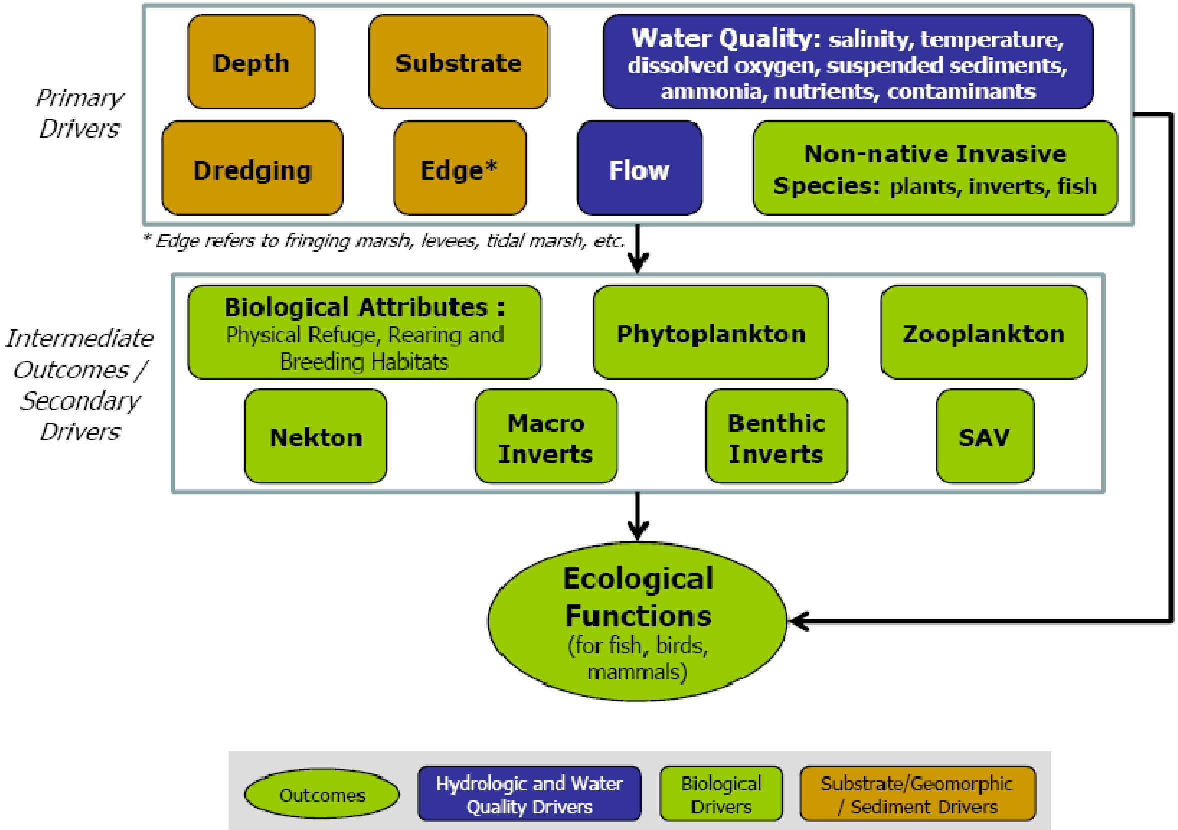

Figure 2-3. Higher trophic level ecological functions general conceptual model, tidal aquatic habitats

2.3 Higher Trophic Level Uses of Suisun Aquatic Habitats

Tidal habitats within Suisun Marsh support many aquatic and terrestrial species (Table 2-2). This section briefly identifies these biological communities and describes their use of aquatic habitats within the Suisun Marsh (Figure 2-4). In addition, the adjacent biological communities are discussed because they provide an important link to nearby terrestrial communities and have direct influences on the tidal environment.

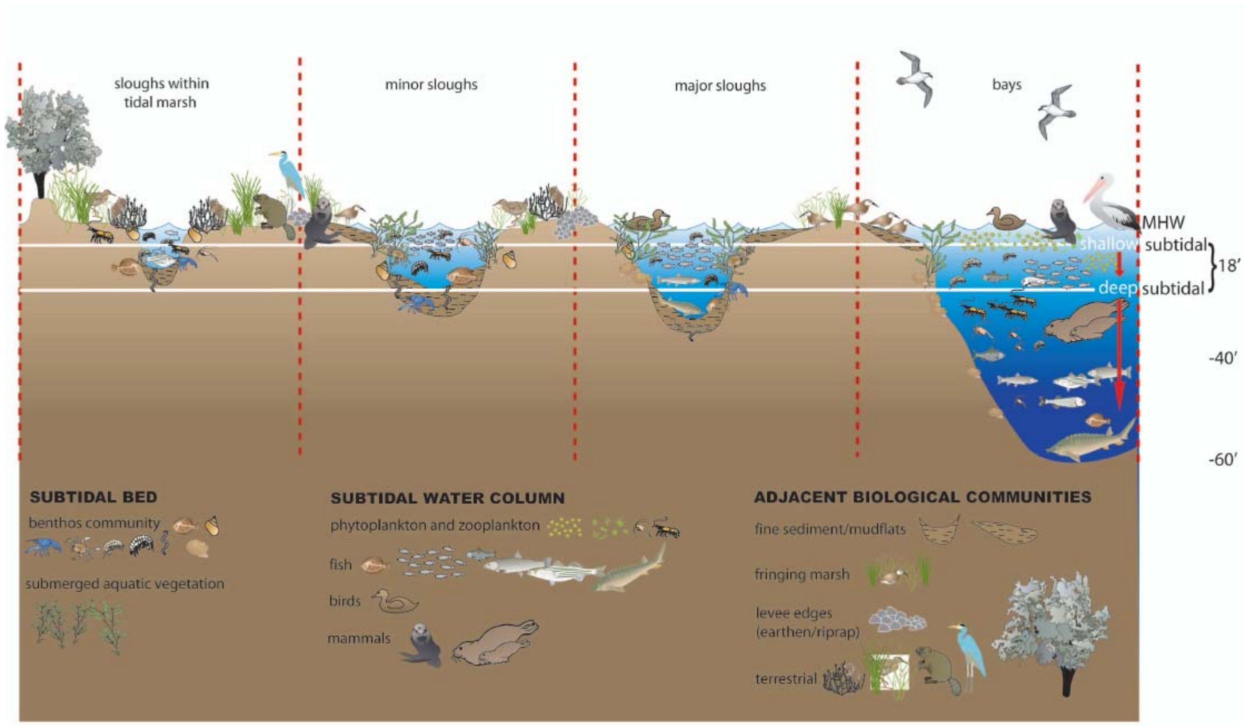

Figure 2-4. Tidal communities by aquatic habitat type.

2.3.1 Fish

Suisun Marsh's tidal habitats support a diverse assemblage of fish species (Table 2-2). At one or more points in their life cycles, these species use bays and sloughs for functions such as breeding, refuge, foraging, and/or migration. Deeper portions of bays and deep and shallow sloughs provide important habitat for migrating salmonids such as Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*Oncorhynchus mykiss*) (Goals Project 1999). The endangered Delta smelt use Suisun Bay to congregate prior to moving into river channels and Delta sloughs for spawning (Moyle 2002). In addition, shallow sloughs provide foraging and refuge habitat for juvenile salmonids and pelagic fishes such as Delta smelt and splittail.

Although there have been general declines in fish abundance over the last 20 years throughout the San Francisco Estuary, the greatest declines have been in the Suisun Bay region and the Delta. Since the early 1980s, populations of open-water fish species have declined by 85% in Suisun Bay (Bay Institute 2005), with key pelagic species having undergone recent significant declines (Baxter et al. 2008). The percentage of alien fish species has increased and now represents almost 30% of the total fish abundance (Bay Institute 2003). Fish diversity and distribution in Marsh slough habitat has been linked to slough size and environmental variability. Habitat study results presented in the Suisun Ecological Workgroup Final Report (2001) showed that species diversity and native fish abundance in the Marsh tends to be higher in smaller sloughs than in medium and large sloughs (SEW 2001). The Conceptual Model for Suisun Marsh Tidal Wetlands by Brown (2003) shows that environmental variability such as water year type (i.e., wet or dry) is important in determining reproductive success of native freshwater spawners. The model also shows that seasonal changes in Marsh conditions determine spawning success of resident species and distribution and survival of all species in large and small sloughs throughout the year (Brown 2003).

2.3.2 Birds

Birds use the water column for foraging and loafing. Dabbling and diving ducks, herons, egrets, cormorants, pelicans, grebes, gulls, and other piscivorous waterbirds feed from the water column on fish, invertebrates, and submerged aquatic vegetation. Rafting birds loaf on the water surface. Bird use of the tidal environments is also discussed in Section 2.4 under Submerged Aquatic Vegetation and in this section under Adjacent Biological Communities.

2.3.3 Mammals

Mammals such as the harbor seal (*Phoca vitulina*), California sea lion (*Zalophus californianus*), North American river otter (*Lutra canadensis*), and American beaver (*Castor canadensis*) utilize tidal habitat (Table 2-2) (DFG 2005 and Goals Project 1999). Harbor seals typically forage in tidal habitat 20 meters or less in depth. Prey items include fish, crustaceans, cephalopods, and benthic and schooling fishes (DFG 2005). California sea lions utilize deep tidal habitat and feed on fish and cephalopods (DFG 2005). River otters occur throughout the Marsh in tidal habitats primarily associated with good river bank cover (Goals Project 2000). Scat analysis of river otters in the Marsh showed that crayfish were the most frequent prey item, followed by birds and fish which were the second most frequent prey items depending on season (Goals Project 2000). American beavers can be found in slough habitats and utilize aquatic vegetation, such as tules and cattails, as a portion of their diet. Beavers also use sloughs for reproduction and cover (Zeiner et al. 1990).

2.3.4 Adjacent Biological Communities

The most common environments that bound Suisun tidal areas are managed wetland levees (earthen or covered with riprap), fringing marsh, and mudflats (Figure 2-1). Within the tidal marshes of Suisun are tidal sloughs that are both tidal aquatic habitats and integral elements of tidal marshlands; this “dual” nature of tidal marsh sloughs blurs the boundary between these two classification and drives the merged nature of this conceptual model. The characteristics of adjacent habitats directly affects the amount of organic matter supplied to sloughs, suitability to support species found in the water column, and potential to supply negative influences (e.g., contaminants and low dissolved oxygen).

Mudflat areas are relatively few in Suisun Marsh. Mudflats are found on eastern shoreline of Grizzly Bay, the northwestern shore of Suisun Bay, in a few shoals in the middle of Suisun Bay, and with the restored Ryer Island. Mudflats harbor a rich assemblage of benthic invertebrates such as worms, clams, crabs, and shrimp (Goals Project 1999). At low tide, many terrestrial and avian species forage in tidal mudflats including the endangered California clapper rail (*Rallus longirostris obsoletus*). When inundated by the tide, bottom-feeding fish and dabbling and diving ducks migrate into mudflats to forage as well (San Francisco Estuary Project 1992).

Fringe marsh, primarily found along the boundary between levees and sloughs, are characterized by stands of bulrushes (*Schoenoplectus californicus* and *S. acutus*), common reeds (*Phragmites australis*) and cattails (*Typha* spp). These vegetated ecotones provide habitat corridors to the limited extent they are continuous within Suisun, allowing animals some protection in moving between the few tidal marshes in Suisun. California clapper rails, otters, beavers, muskrats, and mink commonly use fringe marshes for movement and refugia. Bird species utilize the vegetated stands along fringe marsh for nesting and roosting (Herzog *et al*. 2004).

The tidal marshes in Suisun are characterized by channel networks that comprise tidal channels in a network of generally fewer and larger channels relative to the saline tidal marshes lower in the Estuary. These and adjacent tidal environments benefit from the available food resources (tidal marshes are well documented for providing organic matter in many forms [Weinstein and Kreeger 2000]), spawning habitat, and refuge (see Chapter 3).

Barren levees and levees protected with riprap provide little ecological support for the tidal environment and can be the source of adverse conditions for biological resources (BCDC 1988).

Table 2-2: Tidal habitat use and function for representative fish, invertebrate, bird, and mammal species in the Suisun Marsh area

(A=Adult, J=Juvenile, L=Larvae, E=Egg; B=Breeding, R=Rearing, F=Foraging, M=Migrating, Lo=Loafing, *=Nonnative)

	Species		Tidal Habitat			
	Common Name	Species Name	Bays	Major Sloughs	Minor Sloughs	Sloughs w/in Tidal Marsh
INVERTEBRATES	Amphipods	*Corophium* spp.	RFB	RFB	RFB	RFB
	Asian Clam*	*Corbicula fluminea*			RFB	
	California Bay Shrimp	*Crangon franciscorum*	RFB	RFB	RFB	RFB
	Dungeness Crab	*Cancer magister*	J/F	J/F		
	Oposum Shrimp	*Neomysis mercedis*	RFB	RFB	RFB	RFB
	Oriental Shrimp*	*Palaemon macrodactylus*			RFB	
	Overbite Clam*	*Corbula amurensis*	RFB	RFB		
FISH Salmonids	Chinook Salmon	*Oncorhynchus tshawytscha*	A/M, J/M, J/F	J/M, J/F	A/M, J/M, J/F	J/F
	Steelhead	*Oncorhynchus mykiss*	A/M, J/M, J/F	A/M, J/M, J/F	J/M, J/R, J/F	J/F
Pelagic	Delta Smelt	*Hypomesus transpacificus*	A/F, J/F, L	A/F, A/B, J/F, L, E	A/F, A/B, J/F, L, E	A/B , L, E
	Longfin Smelt	*Spirinchus thaleichthys*	A/F, J/F, L	A/F, A/B, J/F, L, E	A/F, A/B, J/F, L, E	A/B, E, L
	Northern Anchovy	*Engraulis mordax*	A/F, J/F	A/F, J/F		
	Splittail	*Pogonichthys macrolepidotus*	A/F, J/F	A/B, A/F, J/F, L, E	A/B, A/F, J/F, L, E	A/B, A/F, J/F, L, E
	Striped Bass*	*Morone saxatilis*	A/M, A/F, J/F, L, E	A/M, A/F, J/F, L, E	A/F, J/F , L	
	Tule Perch	*Hysterocarpus traski*		A/B, A/F, J/F	A/B, A/F, J/F	A/B, A/F, J/F
Benthic	Prickly Sculpin	*Cottus asper*	L	A/F, J/F, L, E	A/B, A/F, J/F, L, E	A/B, A/F, J/F, L, E
	Starry Flounder	*Platichthys stellatus*	A/F, J/F	A/F, J/F	A/F, J/F	A/F, J/F
	White Sturgeon	*Acipenser transmontanus*	A/M, A/F, J/M, J/F	A/M, A/F, J/M, J/F		
	Yellowfin Goby*	*Acanthogobius flavimanus*	A/F, J/F, L	A/F, J/F, L	A/F, J/F, L	A/F, J/F, L

Table 2 (continued): Tidal habitat use and function for representative fish, invertebrate, bird, and mammal species in the Suisun Marsh area (A=Adult, J=Juvenile, L=Larvae, E=Egg; B=Breeding, R=Rearing, F=Foraging, M=Migrating, Lo=Loafing, *=Nonnative)

	Species		Tidal Habitat			
	Common Name	Species Name	Bays	Major Sloughs	Minor Sloughs	Sloughs w/in Tidal Marsh
BIRDS	American Coot	*Fulica americana*	F	F	F	F
	Bufflehead	*Bucephala albeola*	F	F	F	
	California Gull	*Larus californicus*	F, Lo	F, Lo		
	Canvasback	*Aythya valisineria*	F	F		
	Clark's Grebe	*Aechmophorus clarkii*	F	F		
	Common Goldeneye	*Bucephala clangula*	F	F		
	Double-Crested Cormorant	*Phalacrocorax auritus*	F	F		
	Eared Grebe	*Podiceps nigricollois*	F	F		
	Lesser Scaup	*Aythya affinis*	F	F		
	Pied-Billed Grebe	*Podilymbus podiceps*	F	F	F	F
	Redhead	*Aythya Americana*	F	F		
	Ring-Billed Gull	*Larus delawarensis*	F, Lo	F, Lo		
	Ring-Necked duck	*Aythya collaris*	F	F		
	Ruddy Duck	*Oxyura jamaicensis*	F	F		
	Surf Scoter	*Melanitta perspicillata*	F	F		
	Western Grebe	*Aechmophorus occidentalis*	F	F		
MAMMALS	American Beaver	*Castor canadensis*		F	F	F
	California Sea Lion	*Zalophus californianus*	F	F		
	Harbor Seal	*Phoca vitulina*	F	F		
	Muskrat	*Ondatra zibethicus*		F	F	F
	North American River Otter	*Lutra canadensis*		F	F	F

(DFG 2005, Goals Project 1999, K. Hieb DFG pers. comm. 2006, Liguori 1995, M. Nobriga DWR Pers. Comm. 2006, Moyle et al. In Review, Orsi 1999, Stevens 1977, SEW 2001, and USFWS 1996)

2.4 Stressors Affecting Ecological Functions of Suisun Aquatic Habitats

The ecological functions supported by the tidal aquatic environment can be influenced by numerous stressors that may alter the physical and biological processes and characteristics of the aquatic system (Figure 2-3, Figure 2-5). These stressors have both local (e.g., land use and management) as well as external (e.g., water exports from Delta) sources and can vary in spatial and temporal extent and severity. While some stressors may be individually innocuous, their cumulative impact can lead to serious environmental degradation of the tidal habitats within Suisun Marsh.

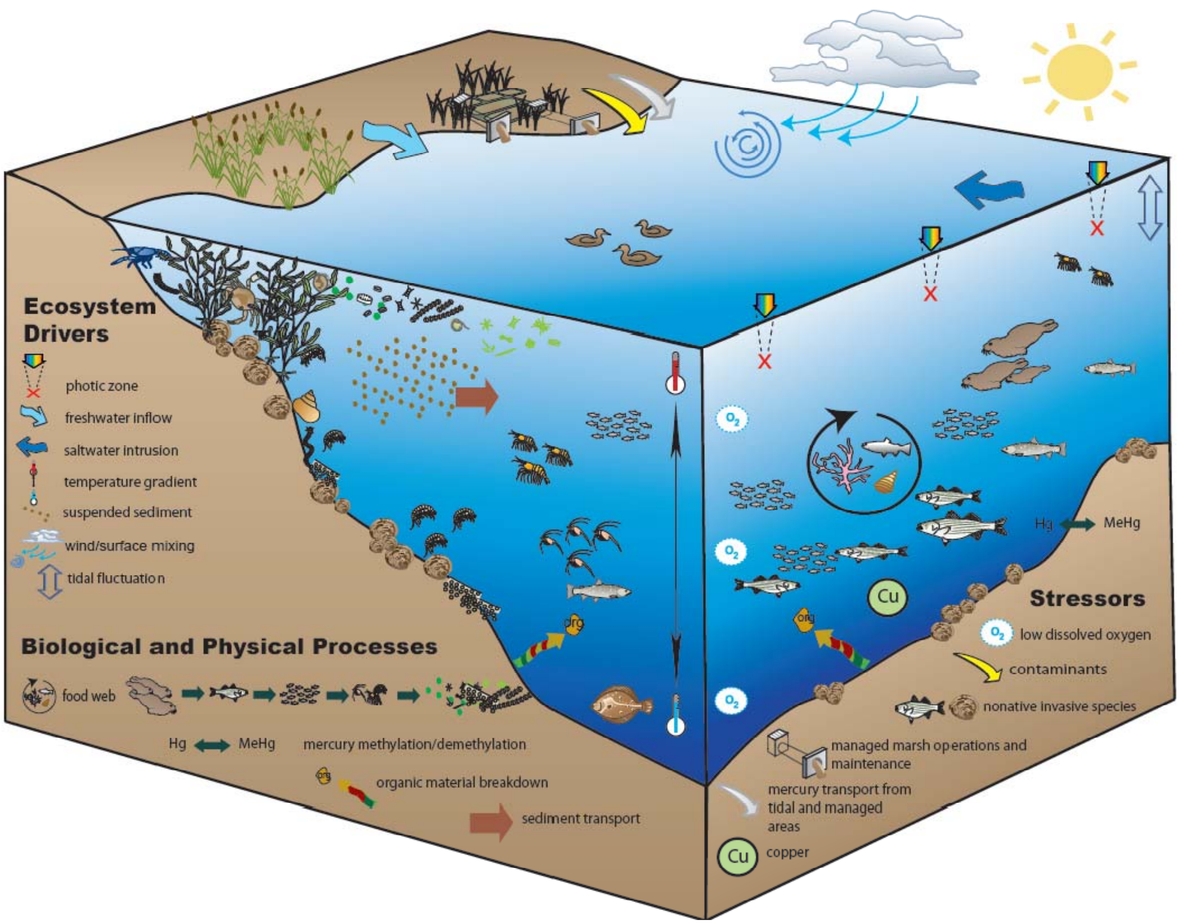

Figure 2-5. Tidal environments biological and physical processes.

2.4.1 Non-Native, Invasive Aquatic Organisms

Non-native, invasive species (NIS) are a stress to all natural systems including tidal aquatic habitats and can have both direct and indirect effects on native biological communities and processes. NIS can directly consume or out-compete native species for limited resources and dramatically change trophic interactions and structure. In addition, NIS may spread exotic diseases or hybridize with native stocks causing lower overall fitness and genetic diversity in indigenous populations. Once established, NIS may alter the physical habitat leading to indirect negative impacts on native communities (Hanson et al. 2003). In Suisun, NIS have drastically modified species composition and abundance. The overbite clam (*Corbula* spp.), which can number on average 19,000/m^2, has decimated native zooplankton levels due to its high filtering rate and its preference for copepod larvae (Cohen 2005). The introduced copepod *Limnoithona tetraspina* has replaced native copepod species leading to a reduction in food quantity and quality for Delta smelt (*Hypomesus transpacificus*), splittail (*Pogonichthys macrolepidotus*), and striped bass (*Morone saxatilis*) (itself a non-native species) (Moyle 2002).

Fish abundance as a whole in Suisun Marsh has declined over the past 20 plus years; however, the relative percentage of non-native species within this assemblage has increased and currently encompasses nearly 30% of total fish abundance (Bay Institute 2003). Two more recently introduced exotic fish species, shimofuri goby (*Tridentiger bifasciatus*) and yellowfin goby (*Acanthogobius flavimanus*), have been found to be the only species to experience an increase in abundance in recent years (Matern *et al.* 1996). Catch studies have indicated that a majority of common exotic fish species within Suisun Marsh prefer warmer temperatures and lower outflows typical of late-season marsh conditions (Meng and Matern 2001), while lower salinity periods and therefore typically inhabit the Marsh in spring to early summer, while outflow is high (Matern *et al.* 2002). In spite of the variation in the time of usage of Suisun Marsh habitats by native and non-native fish species, non-native fish have been attributed to the decline of native species (Moyle 2008). It is currently unknown if changes to the aquatic food web plays a role in the decline of native fish species abundance and diversity and it is thought that reproductive success is a determining factor (Brown 2003).

Shallow inner-tidal habitats in Suisun Marsh have also recently been affected by the ramped invasion of exotic stands of common reed (*Phragmites australis).* Though this species is native to California, certain genetic strains are believed to be of non-native origin and due to the aggressive expansion of common reed in brackish tidal areas and wetlands, this species has been added as to the California Invasive Plant Council's (Ca-IPC) inventory database (2006). Expansion of *Phragmites* in Suisun Marsh has numerous implications for both terrestrial and aquatic native species, including loss of biodiversity and subsequent reductions in insect, avian, and other animal assemblages. Additionally, encroachment of common reed into lower tidal areas and fringe habitats can affect connectivity by filling in marsh surface areas between open water and small creek openings and thereby limiting access of fish and crustaceans to foraging areas (Chambers *et al.* 1999). The spread of *Phragmites* in Suisun Marsh has increased by nearly 100-fold (92.89%) since 1999, and has been primarily localized to stands of native wetland graminoids (*Typh* and*,* *Scirpus* complexes) (DFG 2008). It is currently unclear to what extent impacts of common reed may become an issue in restoration areas of Suisun Marsh; because of this species ability to rapidly vegetate open habitats, dominance of *Phragmites* in these areas is likely. However, research to date currently does not indicate that *Phragmites* dominated marsh habitats suffer from reduced productivity and in some instances, this species may accrete sediment in lower marsh areas and act to maintain marsh habitat elevations in the face of sea level rise (Chambers *el al.* 1999).

2.4.2 Low Dissolved Oxygen

Patterns of dissolved oxygen levels are poorly understood for Suisun aquatic environments, though it has been suggested by Cloern et al. (1983) that Suisun may typically sustain DO levels below 100% saturation with seasonal variations. Further review by Kimmerer (2004) linked incidences of below saturation levels of DO in Suisun to decreased freshwater inflows during late summer/early fall leading to salt water intrusion into the Delta, a phenomenon which facilitates a boost in secondary consumption and high oxygen demand. This combination creates stratification of oxygen transport in the tidal water column, and presumably creates lower oxygen concentrations near the bottom (Kimmerer 2004).

UC Davis researchers first noted Suisun Marsh water quality concerns in Peytonia Slough and Goodyear Slough as early as 1993. In fall of 1999, UC Davis researchers began measuring and reporting low DO sags in detail in response to increased fish mortality observed during monthly sampling activities. These events were most typically observed in the fall months in the northwest Marsh along Peytonia, Boynton and Suisun sloughs and coincided with managed wetlands discharges. Researchers have observed fish kills during some of these events, though investigations were not conducted to determine if all fish deaths were related to low DO nor the precise reasons for the low DO conditions. Suisun Resource Conservation District in cooperation with several landowners and the Department of Fish and Game and Department of Water Resources, began monitoring and working to minimize or avoid low DO events. The State Water Resources Control Board funded a study in 2007 to examine improved diked wetland management practices related to low DO and methyl mercury; the results of that study should be available in later 2010.

The consequence of low dissolved oxygen to higher trophic level ecological functions is particularly significant to fish passage and mortality (Suisun Marsh Workshop 2004). Though studies have suggested that estuarine fish have a higher threshold for low DO concentrations, oxygen stratification may act as a barrier to fish passage (Kimmerer 2004). Additionally, as discussed in Chapter 1, other water quality issues for aquatic organisms including methyl mercury concentrations, elevated ammonia (discussed below), and hydrogen sulfide levels have been correlated with dissolved oxygen sags (Mark Stephenson pers. comm.)

2.4.3 Contaminants

A detailed discussion of contaminates, sources, and their effects on the Suisun Marsh broader ecosystem are described in Chapter 1- Physical Processes. The overall effect of contaminants on aquatic ecosystem health is difficult to ascertain and currently there is no clear evidence quantifying the effect of contaminants on aquatic populations and communities (Kimmerer 2004). Contaminant concerns in Suisun aquatic environments remain centered on elevated levels and production of methyl mercury because of risks to ecological and human health. As discussed in the Mercury Conceptual model, open water locations are less of a concern as compared to high elevation tidal marsh and floodplain environments; however, water quality components of open water habitats can influence production of waterborne methyl mercury including levels of organic matter (Wiener et al. 2003) and dissolved oxygen. Selenium originating from agricultural runoff in the Central Valley and from refinery operations in San Pablo and Suisun Bays also have deleterious effects on fish and birds through food web accumulation. Selenium enters the food web through benthic invertebrate pathways, affecting species such as sturgeon and certain waterbirds (Presser et al in preparation). Organic contaminants in Suisun aquatic systems have also raised concern due to the tendency of compounds to become bioavailable, move into the food web, and accumulate in higher trophic level organisms. The Suisun Bay shoreline along Benicia in Solano County and along much of Contra Costa County is home to numerous industrial enterprises including oil refineries, chemical plants, steel plants, boatyards, and the like. These industries as well as toxic hot spots contribute organic and inorganic pollutants into Suisun Bay waters which can have deleterious effects on aquatic organisms. Suisun Bay is also home to the U.S. Navy's Ready Reserve Fleet (mothball fleet), a collection of retired naval ships anchored semi-permanently. This fleet may contribute small quantities of organic and inorganic pollutants into Suisun Bay via exterior paint deterioration and bilge pump discharge water.

2.4.4 Ammonia

Two primary concerns regarding ammonia on the Bay-Delta ecosystem, and thus Suisun aquatic environments, have been raised by the CALFED Science Program. The first concern is the hypothesized role of ammonia in contributing to the pelagic organism decline (POD) (Baxter et al. 2008) and the second concern being the potential influence of ammonia on aquatic food web shifts and the associated ramifications in Suisun Bay. It is unknown as to whether these two issues function concomitantly or independently of one another, which is confounded by numerous other anthropogenic contaminants present in Suisun Marsh. Because of the complexity of contributing stressors on Suisun aquatic ecological functions, CALFED has prepared a conceptual framework to help address the role of ammonia in the Bay-Delta ecosystem and to guide future research efforts and management decisions relating to ammonia (CALFED, Meyer *et al.* 2009).

Studies have shown that ammonia inhibits phytoplankton blooms in Suisun Bay and thereby limits overall productivity in aquatic habitats (Wilkerson *et al.* 2006, Dugdale *et al.* 2007). Tidal marsh restoration in Suisan Marsh may offer promising method of limiting the adverse affects of excess ammonia. Tidal freshwater marsh habitats in nutrient rich estuaries have been shown to retain up to 40% of ammonia during a flood event, most of which has been linked to nitrification (Gribsholt *et al.* 2005).

2.4.5 Dredging

Tidal environs are susceptible to a suite of industrial and commercial activities that may degrade habitat quality and quantity. Removal of substrate from the bay floor for dredging and mining purposes causes a direct physical loss of tidal habitat. Sand mining is currently allowed within 107 acres around Middle Ground shoal and adjacent shoals in Suisun Bay. The mined sand is used as aggregate in concrete for commercial construction within the greater San Francisco Bay area. Although mining operations can significantly impact benthic infauna and epifauna, it generally has a low likelihood of entraining macro-invertebrates and fish (MEC 1993). Dredging in order to maintain navigation channels also occurs in portions of Suisun Bay. The "Suisun Bay Channel" extends from the Carquinez Strait at Martinez to Pittsburg and is dredged annually to maintain its 300' wide and 35' deep profile. The "New York Slough" continues upstream from Pittsburg to Antioch and is dredged every four years to maintain its 250' wide and 20' deep channel (GS 2005).

2.4.6 Industrial Cooling Water Intakes and Discharges

Two power generating stations along the Contra Costa shoreline create a potential stressor on Suisun tidal systems. These power plants draw as much as 3,240 cubic feet per second of water from Suisun Bay through unscreened pipes to cool their turbines. As a result, fish and invertebrate species are impinged and entrained by the plants' cooling system. Biological surveys in 1979 estimated as much as 86 million Delta smelt (*Hypomesus transpacificus*) and their larvae were being impinged or entrained annually (Taugher 2006). Moreover, thermal discharges from the plants into Suisun Bay can create lethal conditions for aquatic life, especially species' larval stages. Elevated temperatures can alter the biochemical processes of the environment and the behavior (e.g., migration) and physiology (e.g., metabolism) of marine organisms (Hanson et al. 2003).

2.5 Positive Factors Influencing Ecological Functions of Suisun Aquatic Environments

The habitat components of the tidal regions of Suisun Marsh include the bed and water column are described in the following subsections and are shown in the conceptual model (Figure 2-3) and the conceptual diagram (Figure 2-5): submerged aquatic vegetation, substrate and benthic community, phytoplankton and zooplankton, and larger invertebrates.

2.5.1 Submerged Aquatic Vegetation (SAV)

Shallow tidal areas within the Marsh support two types of submerged aquatic vegetation (SAV), wigeongrass (*Ruppia maritima*) and sago pondweed (*Potamogeton pectinatus*). The abundance and distribution of SAV is highly dependent on salinity conditions. Although wigeongrass can maintain optimum growth up to 22 ppt salinity (Kantrud 1991), sago pondweed vegetation can dieback when water salinity exceeds 15 ppt (Kantrud 1990). In the Suisun region, the precise abundance and distribution of SAV has not been well documented, but anecdotal evidence suggests that SAV beds are mainly located in the shallow areas of Suisun Bay surrounding Simmons, Ryer, and Roe Islands (N. Cosentino-Manning Pers. Comm.). Little Honker Bay has been observed to have SAV beds as have the shallows surrounding Chipps Island (S. Siegel and C. Enright, field observation, Nov 2009). Other factors that affect SAV distribution and species composition include turbidity and thus light penetration, water quality, water depth, and bottom sediment (USFWS 2006).

These rooted plants provide crucial habitat for numerous aquatic organisms such as juvenile fish, shrimp, and benthic invertebrates (Thayer *et al*. 2003). Verhoeven (1980) found invertebrates associated with wigeongrass-dominated communities in western Europe number up to 43,800/ m^2 with biomasses of up to 22.9 g/m^2 ash-free dry weight. The plants' surfaces serve as a substrate for epiphytes as well as sessile barnacles and sponges. Epifaunal invertebrates and juvenile fish feed on the plant material or associated fouling species and seek refuge from predators in the plant cover. Recent work by Grimaldo et al (2009) to examine SAV role in the Delta found for the native freshwater species that the waxy surface of stems limited the abundance and composition of SAV-associated invertebrate communities.

SAV also functions as a valuable food source for migrating and resident waterfowl that forage along the base of the plants for seeds, roots, and tubers. Martin *et al*. (1951) found wigeongrass composed 10-25% of the diet of redheads (*Aythya americana*) and scaup (*Aythya* spp.); 5-10% of the diet of pintails (*Anas acuta*) and ruddy ducks (*Oxyura jamaicensis*); and 2-5% of the diet of mallards (*Anas platyrhynchos*), canvasback (*Aythya valisineria*), and green-winged teal (*Anas crecca*). Sago pondweed has been found to compose 50% or more of the diet of canvasbacks; 25-50% of the diet of mallards and redheads; and 10-25% of the diet of pintails, green-winged teal, and scaup (Martin *et al*. 1951).

2.5.2 Substrate and Benthic Community

Benthic areas in the Suisun Marsh region are characterized by unconsolidated or soft bottoms. The benthic floor is generally smooth with limited furrow and sand wave bottom morphologies formed by tidal flow and other physical processes. In addition, some areas of the Bay floor are incised by anchor drag, trawling, and keel marks (Hampton *et al.* 2003). In general, larger channels have sandy bottoms due to tidal scouring, while lower energy areas such as shoals generally have finer sediments (Kimmerer 2004). Data collected by the Regional Monitoring Program have found sandy sediments in the deeper channels of Suisun, with fine sediments in shoal areas of Honker and Grizzly Bays (Regional Monitoring Program unpublished).

At shallower depths, the substrate is primarily composed of silt and clay particles (Goals Project 1999). Sediment size in the shallow regions tends to exhibit low spatial variability and is consistent over time (Hampton *et al.* 2003). If adequate light levels are present (a function of depth and turbidity), soft-bottom, shallow zones can support submerged aquatic vegetation such as wigeongrass (*Ruppia maritima*) and sago pondweed (*Potamogeton pectinatus*). Aquatic plants serve to dampen erosive wave energy, filter sediments from the water column, and absorb excess nutrients (Fonseca *et al.* 1998). Deeper regions of the benthic floor have higher spatial variability in grain size distributions (Hampton *et al.* 2003). Light levels in deep areas are generally too low to support benthic vegetation.

Suisun Marsh's tidal habitats support diverse and dynamic benthic biological communities (Figure 2-4). The main ecological functions of benthic organisms are to break down organic material and provide an important link between primary producers, such as phytoplankton, and higher trophic levels.

Three groups of benthic organisms occur in the Marsh: infauna (organisms that live in the sediment), epifauna (organisms living on the surface of the sediment or other substrate), and demersal (bottom-feeding or bottom-dwelling fish and other free moving organisms) (Thayer *et al*. 2003). Infaunal organisms such as bivalves and polychaete worms burrow into soft substrate for protection and typically filter or suspension feed by extending parts of their body above the substrate surface. Epifaunal invertebrates such as crabs and snails wander along the bay floor scavenging for food and may return to burrows for shelter (Waller 1996). Demersal fish such as starry flounder (*Platichthys stellatus*), sturgeon (*Acipenser transmontanus*), and other bottom-dwelling fish species (Table 2-2) forage and rest along the Bay floor

Benthic community composition in Suisun Marsh's bays and sloughs is largely driven by seasonally alternating river inflows that can influence sediment texture and salinity regimes (Nichols 1979). The benthic community in Suisun Bay, which is composed equally of sand and fine-grain sediments, is dominated by the polychaete, *Marenzellaria viridis*, and the barnacle, *Balanus improvisus*. The nonnative invasive overbite clam, *Corbula amurensis*, is also found in high abundances in the Suisun Bay; its traits of high fecundity, high filter volume rate, and selective prey size have allowed *Corbula* to displace many other native and non-native species as well as alter the pelagic plankton community and thus the many aquatic species dependent on that community (Kimmerer 2004). Grizzly Bay, which is characterized by finer sediment types, is dominated by *Marenzelleria* spp. as well as two amphipod species, *Corophium alienense* and *Corophium stimpsoni* (IEP 2004). Due to salinity variability and sediment loading, benthic invertebrate species richness in the Suisun region is typically lower than other parts of the San Francisco estuary (Nichols 1979). Stressors that affect benthic community composition include low dissolved oxygen, poor water quality, and dredging.

2.5.3 Phytoplankton and Zooplankton

Primary production in the Suisun region's tidal areas is dominated by phytoplankton, but green algae and blue-green algae also contribute to overall production (San Francisco Estuary Project 1992). Phytoplankton abundance, species composition, and distribution can be limited by temperature, light, nutrients including micronutrients, inorganic carbon or grazing, and high levels of contaminants such as copper which can inhibit phytoplankton production (Kimmerer 2004). The distribution of phytoplankton with regard to salinity has not been shown (Kimmerer 2004). Changes in these environmental conditions cause extreme seasonal and annual variability in phytoplankton standing stocks (San Francisco Estuary Project 1992). Phytoplankton thrive in conditions of greater residence time, more nutrients, warmer temperatures, and more light (i.e., shallow, less turbid). These conditions vary in dependent and independent ways and the resulting alignment across each of these factors at any particular time controls production (Kimmerer 2004). Factors controlling these conditions include Delta outflow (e.g., volumes, sediment load, and temperature), depth, incident sunlight, seasonal variation, and thermal discharges.

Outflow from the Sacramento-San Joaquin Delta can alter the juxtaposition of the entrapment zone[1] to Suisun Bay and directly impact residence time. Flows between 5,000 and 8,000 cubic feet per second (cfs) (0.14- 0.22 cubic meters per second (cms)) have typically resulted in the greatest phytoplankton concentrations (San Francisco Estuary Project 1992). High water turbidity generally restricts the photic

[1] The entrapment zone is the area where freshwater meets saltwater in the Estuary. The entrapment zone is very productive and a critical component of the aquatic food web (Goals Project 2000).

zone in Suisun Marsh's tidal areas to shallower depths. The photic zone is approximately 10% of the water depth, bounded by broad expanses of shoals which are approximately 2 meters in depth where the photic zone is 50 to 100% of the water depth (Cole and Cloern 1984); this area covers nearly half the extent of tidal aquatic habitat in Suisun (Figure 2-2). In addition, water circulation patterns in shallower areas maximize algal growth, creating patterns of higher phytoplankton concentrations in the shallow bays compared to offshore waters (Cloern 1979).

Summer months generally have produced the highest densities in phytoplankton concentrations with historical ranges between 40-100 µg/liter (Ball and Arthur 1979). Phytoplankton community composition has been mainly comprised of diatom species such as *Melosira distans*, *Cyclotella* spp., *Skeletonema costratum*, and *Thalassiosira decipiens* (Cole *et al*. 1986).

Over the last 20 years there has been a dramatic decline in phytoplankton biomass in Suisun Bay which may be due to stressors such as "overgrazing" by the nonnative invasive overbite clam, *Corbula* spp. (Kimmerer 2004). Since its establishment in 1986, densities of the clam have increased to a mean of 19,000 individuals per square meter (m^2) with maximum observed densities up to 48,000 clams/m^2 (Cohen 2005).

The functions of zooplankton species include grazing on phytoplankton and providing a critical food web link to small fish and higher trophic levels in open water environments (Figure 2-4). Zooplankton communities are generally dominated by tintinnids, rotifers, and copepods. However, zooplankton species respond differently to a number of environmental conditions (especially salinity) causing species abundances to exhibit seasonal and annual variability (Kimmerer 2004). Similar to phytoplankton, there has been a substantial decrease in abundances of native zooplankton species over the last few decades coupled with establishment of nonnative species, (especially the small copepod *Limnoithona tetraspina*) (Bay Institute 2004). One particular effect of this shift in species composition is a change in prey size, distribution, and palatability which alters food availability dynamics. These nonnative zooplankton species have directly and indirectly affected the food supply of fish species such as Delta smelt (*Hypomesus transpacificus*), splittail (*Pogonichthys macrolepidotus*), and striped bass (*Morone saxatilis*) (Moyle 2002).

2.5.4 Larger Invertebrates

The tidal water column in Suisun Marsh supports several native invertebrate species including several large shrimp of the genera *Palamenon*, *Exopalaemon*, and *Crangon* (the California bay shrimp, *C. franciscorum*), as well as macrozooplankton of the genus *Acanthomysis* and *Neomysis* (opossum shrimp *N. mercedis*) and Dungeness crab (*Cancer magister*) (See Table 2-2) (Suisun Marsh Workshop 2004, Goals Project 2000; DFG 2006; and K. Hieb, pers. comm. 2006). California bay shrimp are a member of the crangonid family (grass shrimp) that are usually distributed from the western Delta to Suisun and Honker bays, but have been collected as far upstream as the San Joaquin River at Middle River (DFG 2006). Juvenile bay shrimp are found in shallow (<15'), low salinity waters and migrate to deeper, higher salinity waters as they grow (DFG 2006). The diet of bay shrimp varies with size and includes copepods, amphipods, bivalves, caridean shrimp, and polychaets. In addition, bay shrimp are an important food source for estuarine fishes such as green and white sturgeon, striped bass, and starry flounder (Reilly *et al.* 2001). Opossum shrimp are a member of the mysid shrimp family and are found in the greatest abundance in Suisun Bay and the western Delta. The diet of opossum shrimp also varies with size and includes phytoplankton, rotifers, and copepods (Goals Project 2000). Juvenile Dungeness crabs forage in bay and major slough habitat in Suisun Marsh. Juvenile crabs feed opportunistically on clams, crustaceans, and small fishes. Juvenile crabs are food source for bottom dwelling fishes such as starry flounder (Goals Project 2000). In addition to the native invertebrates, the non-native oriental shrimp (*Palaemon macrodactylus*) occurs in Suisun Marsh. Although large numbers of juveniles have not been collected, it is believed that oriental shrimp spend their first months in very shallow areas or tidal sloughs and creeks and migrate to deeper waters as they grow (DFG 2006).

2.6 Restoration

The preceding sections of this Chapter have described the range of conditions and influences on tidal aquatic functions for higher trophic level species, and Chapter 4 describes how selected species utilize different aquatic habitats in Suisun at various life history stages. Restoration has the potential to improve provision of these ecosystem functions. The locations for restoration are the subsided diked lands of Suisun Marsh (Figure 2-6). Interestingly, about half of the diked lands within Suisun are at or below MLLW (Figure 2-7), indicating a great broad opportunity for tidal aquatic restoration. Restoration is likely to occur within the context of tidal marsh restoration though restoring specifically for tidal aquatic functions may also take place. Lands currently subsided below MLLW would provide subtidal aquatic habitat for as long as sedimentation and plant matter accumulation would allow these areas to remain subtidal, a process controlled by sediment supply, wind-wave energy, salinity, and plant species composition. Lands above MLLW at the outset of restoration would provide intertidal aquatic habitats alongside evolving tidal marsh, with the duration of tidal aquatic attributes controlled by the same processes as for the deeper sites. In general, the more southern lands closer to larger sediment supply would accrete more rapidly, as has been the case at the San Souci duck club on the northern shoreline of Honker Bay. Little Honker Bay along Nurse Slough in the northeast Marsh also has a greater sediment supply; restoration of the Blacklock property in 2006 has included substantial tidal aquatic habitat, as its starting elevations ranged roughly 1 ft below to 1 ft above MLLW. The proposed restoration of Mein’s Landing in the southeast Marsh would likely be more tidal aquatic as about half the site is below MLLW and Montezuma Slough has generally low sediment supply.

Design factors would be expected to influence the nature of the aquatic functions established through restoration as well as the trajectory of evolution at a restoration site from tidal aquatic to tidal marsh (where that evolution would be expected to occur) and thus the evolving ecological functions over time as sites evolve. The primary design control rests around the nature of tidal connections between the restoration site and its tidal source (the number, size, and location of levee breaches), the movement of that water within the restoration site (the nature and extent of tidal channels), and the extent of emergent vegetation. From these design parameters would extend ecosystem drivers of residence time to support phytoplankton productivity, presence of refuge habitats, benthic community production, potential for velocity shears at breaches that can foster predation, establishment of SAV, and so forth.

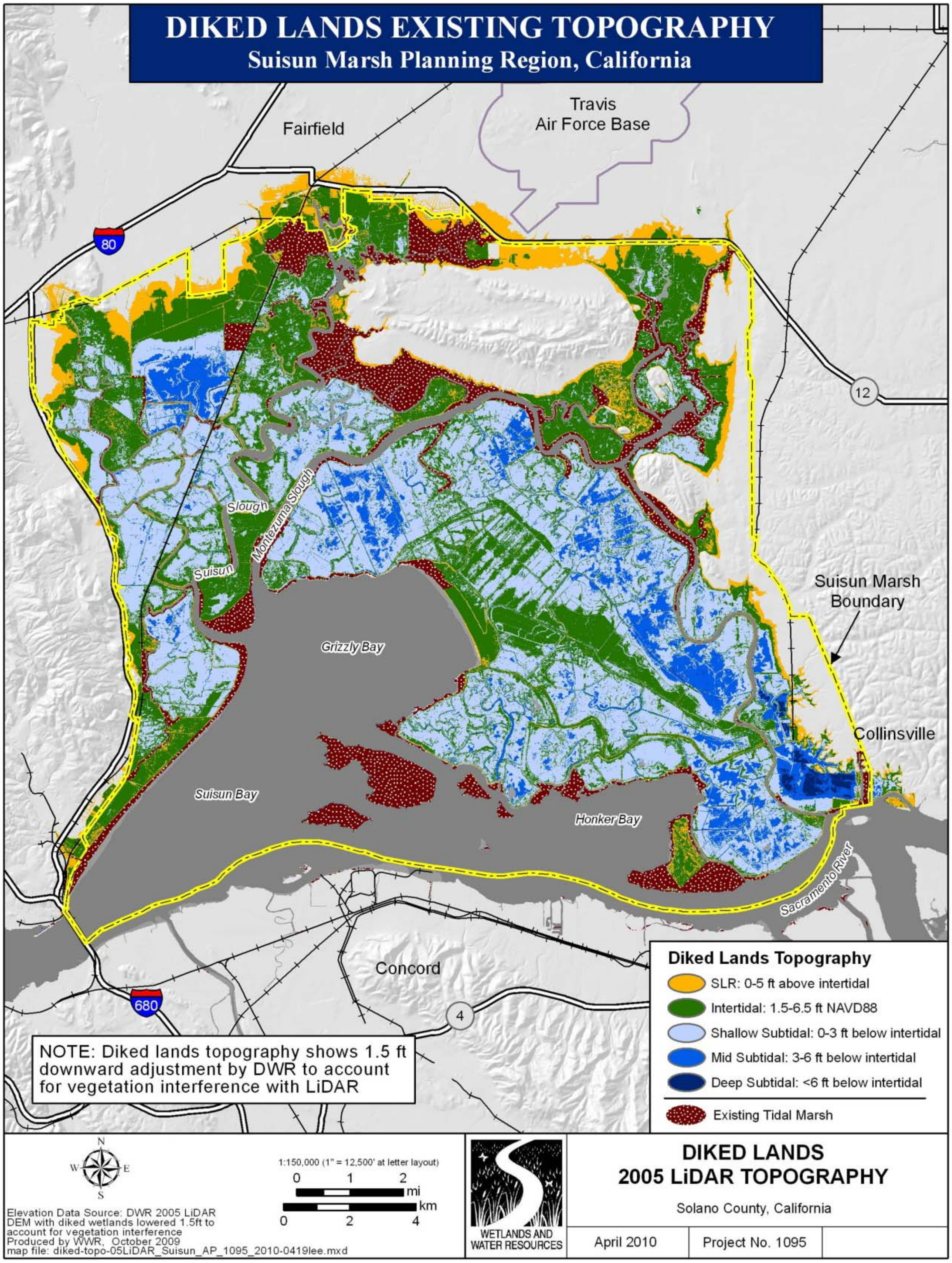

Figure 2-6. Geographic distribution of Suisun diked, subsided lands

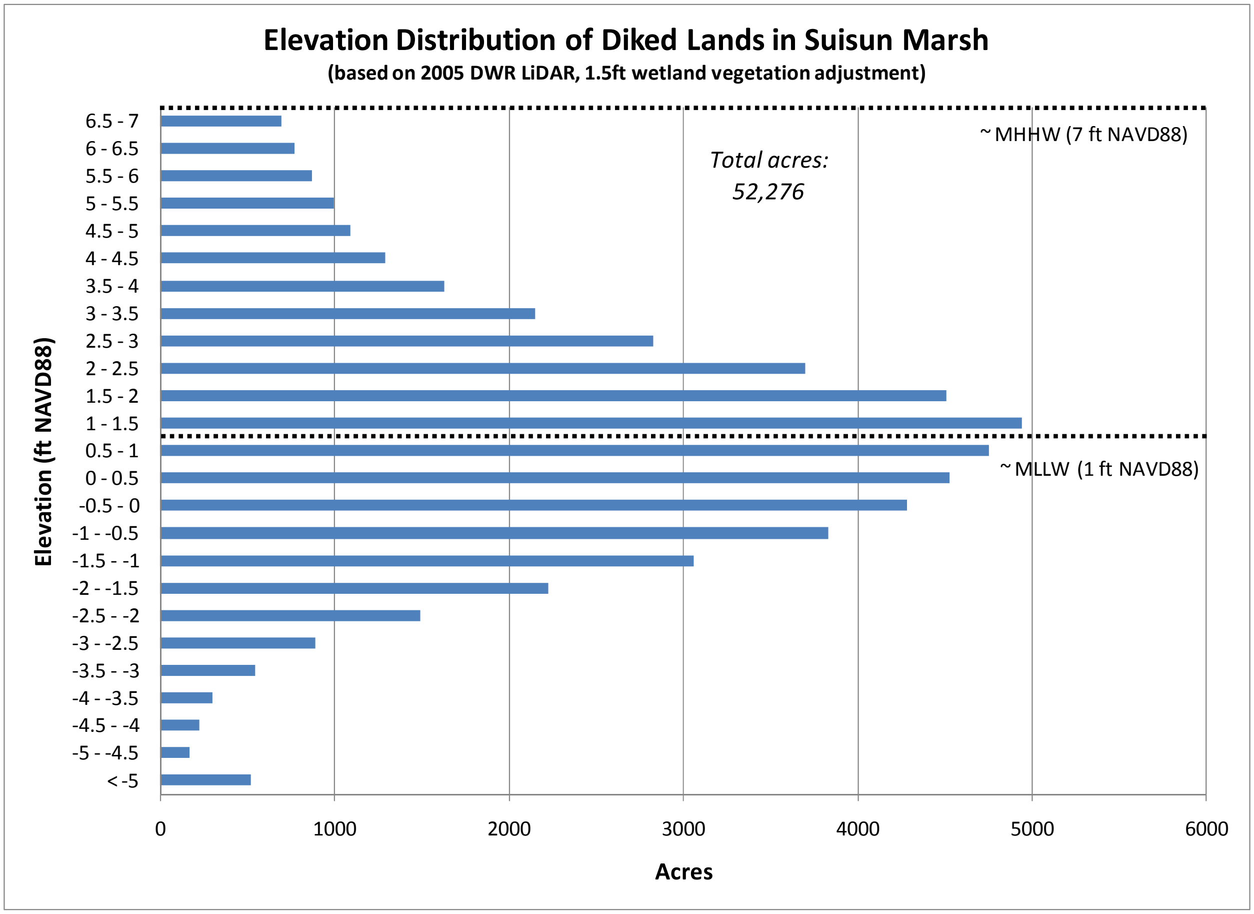

Figure 2-7. Histogram of Diked Lands Topography

2.7 Uncertainties and Assumptions

This section summarizes the uncertainties and assumptions for the material presented in this chapter.

2.7.1 Stressors Uncertainties

Non-native, Invasive Aquatic Organisms

- There is not agreement on the overall impact of the invasive clam, *Corbula amurensis,* in the Estuary (Kimmerer 2004)
- There is currently a lack of understanding of the threats posed by *Phragmites australis* in tidal marsh and adjacent shallow aquatic habitats. Additionally, genetic research is needed to understand the status of native versus non-native stands of common reed in invaded areas

Low Dissolved Oxygen

- The full process understanding that generates low DO events is incomplete, relative to the role of managed wetlands, the Fairfield-Suisun City wastewater treatment plant, watershed inputs from upstream agricultural and urban areas of Solano County, the role of low Delta outflow pulling more saline waters into Suisun fueling secondary production and associated water column respiration, and decomposition of in-situ tidal marsh and tidal aquatic productivity.

Contaminants

- Methyl mercury production and bioavailability from diked marsh, tidal marsh, and aquatic sources
- Hydrological, biochemical, geomorphic, and ecological processes influencing bioavailability of organic contaminants

Ammonia

- Little is known about the toxicity of Ammonia/um to pelagic organism decline (POD) (CALFED Science Workshop 2009)

Restoration

- Specific effects of tidal aquatic restoration on food web productivity at levels that could support fish and wildlife are not yet quantified due to few restoration sites to study and lack of studies at the available restoration sites
- Appropriate restoration approaches geared towards higher productivity levels have not advancement in Suisun Marsh due to the lack of restoration projects moving forward
- The long-term trends in sediment supply into Suisun Marsh and Bay from the Delta predict declines; in combination with projected sea level rise, the effects on suspended sediment concentrations available for tidal restoration site accretion is difficult to predict
- The potential for establishment of *Corbula* in restoration sites is not clear and the extent to which such establishment could render the ecological benefits of restoration has not been determined

2.7.2 Positive Factors Uncertainties

Submerged Aquatic Vegetation

- Abundance, distribution, and detailed species composition of SAV is not well known in Suisun Marsh
- Extent of use of SAV by waterfowl and fish has not been studied extensively in Suisun Marsh

Phytoplankton

- Distribution of phytoplankton with regard to salinity; no explicit analysis has been published (Kimmerer 2004)
- Causes of decline in phytoplankton biomass has not been resolved for Suisun
- Phytoplankton bloom dynamics of Suisun Bay have not been studied since the introduction of the invasive clam, *Corbula amurensis* (Kimmerer 2004)

- The relative importance of different mechanisms relating river flow to chlorophyll concentration is not yet resolved (Kimmerer 2004)

2.7.3 Conceptual Model Assumptions

Depth

- EcoAtlas bathymetric data used for all open water bodies smaller than 10 m width; USGS data set used for all water bodies larger than 10 m width. The data summarizing open water area, volume and percent shallower than 2 m do not consider open water bodies smaller than 10 m in width; the expected affects on the values are likely very small.
- Calculation of the amount of subtidal habitat is all inclusive (accounts for entire subtidal volume)
- The ecological differences between shallow subtidal habitat from deep subtidal habitat is clearly understood

Water quality

- Salinity is a significant factor in fish abundance and diversity
- Decreases and shifts in zooplankton populations and species composition have affected food supply of marsh fish species
- Water clarity increase in the western Delta and Suisun is due to the introduction of *Corbula* and other exotic invertebrates

Tidal habitat

- Channel habitats support a more diverse benthic community and thus higher food-web productivity
- Primary production is highest in shallow waters and tidal sloughs draining mature marsh
- Tidal habitat quality and quantity have been identified as important factors determining fish abundance and distribution in Suisun Marsh (SEW 2001)
- The non-native opossum shrimp (*Palaemon macrodactylus*) utilizes all tidal habitats in Suisun Marsh for rearing, foraging, and breeding (DFG 2006)
- Although large numbers of juvenile oriental shrimp (*Palaemon macrodactylus*) have not been collected, it is believed that oriental shrimp spend their first months in very shallow areas or tidal sloughs and creeks and migrate to deeper waters as they grow.

Restoration of Tidal Aquatic Habitats

- Restoration of deep tidal areas will provide ecological functions important to Suisun Marsh
- Restoring large ecosystem complexes including uplands, tidal marshes, and tidal aquatic habitats would provide greater ecological function that smaller, isolated, less diverse restoration efforts
- Controlling the abundance of *Corbula* and other invasive species will reduce adverse affects to native ecosystems