Science Supporting Dissolved Oxygen Objectives in California Estuaries

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Executive Summary

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1. Introduction

1.1 Background and Context for Review of Dissolved Oxygen Objectives

California Nutrient Numeric Endpoint Framework and Impetus for Review

Eutrophication of estuaries and coastal waters is a global environmental issue, with demonstrated links between anthropogenic changes in watersheds, increased nutrient loading to coastal waters, harmful algal blooms, hypoxia, and impacts on aquatic food webs (Valiela et al. 1992, Kamer and Stein 2003). These ecological impacts of eutrophication of coastal areas can have far-reaching consequences, including fish-kills and lowered fishery production (Glasgow and Burkholder, 2000), loss or degradation of seagrass and kelp beds (Twilley 1985, Burkholder et al. 1992, McGlathery 2001), smothering of bivalves and other benthic organisms (Rabalais and Harper 1992), nuisance odors, and impacts on human and marine mammal health from increased frequency and extent of harmful algal blooms and poor water quality (Bates et al. 1989, Bates et al. 1991, Trainer et al. 2002). These modifications have significant economic and social costs (Turner et al. 1998). According to EPA, eutrophication is one of the top three leading causes of impairments of the nation's waters (US EPA 2001). Scientifically-based state water quality objectives and tools that relate these criteria to management controls are needed to diagnose adverse effects from eutrophication.

EPA and the California State Water Resources Control Board (SWRCB) have previously developed and vetted a science-based approach to translate narrative water quality objectives for nutrients and biostimulatory substances to numeric targets for lakes and streams (EPA 2006). This approach, known as the Nutrient Numeric Endpoint (NNE) framework, establishes a suite of numeric endpoints based on the ecological response of the aquatic waterbody to nutrient pollution (e.g. dissolved oxygen, algal biomass). These endpoints would serve as guidance to Regional Boards in implementing narrative nutrient or biostimulatory substance objectives. In addition to numeric endpoints, the NNE framework includes a stressor-biological response tool that links these biological endpoints with nutrient loads and other potential management controls for TMDL development and implementation.

The NNE conceptual framework has since been adapted for estuaries. EPA (2007) presented a scientific framework to support the development of numeric endpoints for a suite of biological response indicators and highlight data gaps and research recommendations for their development. A subsequent document articulated a broad work plan to address data gaps, develop numeric endpoints and support the efficient and cost-effective development of TMDL tools (McLaughlin and Sutula 2009). The SWRCB has initiated a project to implement this work plan for California estuaries, which includes a review of dissolved oxygen objectives in California.

Dissolved Oxygen Objectives in California Estuaries and Need for Review

Dissolved oxygen is necessary to sustain the life of all aquatic organisms that depend on aerobic respiration. Eutrophication produces excess organic matter that fuels the development of low surface water dissolved oxygen concentration (hypoxia) as that organic matter is respired (Diaz 2001). When the supply of oxygen from the surface waters is reduced or the consumption of oxygen exceeds the resupply (via decomposition of excessive amounts of organic matter), oxygen concentrations can decline below the limit for survival and reproduction of benthic (bottom-dwelling) or pelagic (water column dwelling) organisms (Stanley and Nixon 1992, Borsuk et al. 2001, Diaz 2001). Hypoxia has a number of adverse consequences including lowered growth rates, altered behavior, reduced reproductive success, and diminished survival of aquatic organisms (Diaz and Rosenberg, 1995; Breitburg et al., 1997, 2009; Vaquer-Sunyer and Duarte, 2008). Changes in the survival and reproduction of benthic and pelagic organisms can result in a cascade of effects including loss of habitat and biological diversity, development of foul odors and taste, and altered food webs (EPA 2007). For these reasons, management of hypoxia in aquatic habitats has become a global issue (Smith et al., 1987; Karlson et al., 2002; OSPAR, 2003; Diaz and Rosenberg, 2008).

One of the tools for managing the effects of eutrophication are dissolved oxygen objectives. Under the Clean Water Act, each of the States are required to establish DO criteria for the waters of the State, determine which of the State's water are "impaired," and require the establishment of a total maximum daily load or TMDL. TMDLs are then used to establish numerical limits on loads from municipal and industrial effluent, stormwater, agricultural runoff, and other sources. In California, regulation of surface water quality occurs through the Basin Plans of each Regional Water Quality Control Board (RWQCB). A "Basin Plan" is the master policy document that contains descriptions of the legal, technical, and programmatic bases of water quality regulation in the Region. The plan includes a statement of beneficial water uses that the Regional Board will protect, the water quality objectives needed to protect the designated beneficial water uses; and the strategies and time schedules for achieving the water quality objectives.

All six coastal Regional Water Quality Control Boards (RWQCBs) have numeric dissolved oxygen objectives applicable to estuaries (Table 1.1). However, there is generally a lack of consistency among RWQCBs in their approach. First, at least one regional board utilizes narrative DO objectives, while the other five are numeric. Second, there is little consistency in the approach for setting thresholds. Objectives are expressed in units of concentration, percent saturation, or deviation from natural conditions. The time scales in which compliance is measured vary from an instantaneous minimum to an average over annual time scale annual time scales). Third, no consistency exists in how objectives relate to beneficial uses. Some of this variability is a reflection of the types of beneficial uses associated with species more prevalent in some Regions (e.g. SPWN associated with Steelhead Trout and Salmon). This lack of consistency has motivated the State Water Resource Control Board (SWRCB) to undertake a review of estuarine dissolved oxygen objectives, with the goal of developing a consistent approach statewide that protects specific designated uses and aquatic habitats. Notably, the North Coast Regional Water Quality Control Board (Region 1) is currently in the process of updating their freshwater dissolved oxygen objectives and their proposed changes are based on the life cycle requirements of sensitive aquatic species throughout the region based on the designated beneficial use(s) of individual waterbodies.

The purpose of this document is to recommend the technical approach and summarize the science supporting the development of consistent dissolved oxygen objectives for estuarine surface waters statewide.

1.2 Document Organization

This document is organized into an executive summary and six chapters:

Executive Summary

Chapter 1: Introduction

Chapter 2: Conceptual Approach

Chapter 3: Selection of Fish Species Indicative of Estuarine Beneficial Uses

Chapter 4: Selection of Macroinvertebrate Species Indicative of Estuarine Beneficial Uses

Chapter 5: Review of Existing Data on Physiological Effects of Low Dissolved Oxygen on Selected Indicator Species

Chapter 6: Additional Considerations for Implementation of Dissolved Oxygen Objectives in California Estuaries

Chapter 7: Data Synthesis

Table 1.1 Summary of Coastal Regional Water Quality Control Board Dissolved Oxygen Objectives. Information in the table was derived from the Basin Plans of each RWQCB, available on the State Water Board Website (www.waterboards.ca.gov). See Table 2.2 for beneficial use definitions.

Region	Summary of Dissolved Oxygen Objectives
North Coast[1] (Region 1)	Dissolved oxygen concentrations shall conform to those limits listed in Table 3-1. For waters not listed in Table 3-1 and where dissolved oxygen objectives are not prescribed the dissolved oxygen concentrations shall not be reduced below the following minimum levels at any time. Waters designated WARM, MAR, or SAL =5.0 mg/l; Waters designated COLD. 6.0 mg/l; Waters designated SPWN 7.0 mg/l; Waters designated SPWN during critical spawning and egg incubation periods 9.0 mg/l
San Francisco (Region 2)	*Dissolved Oxygen*: For all tidal waters, the following objectives shall apply: In the Bay: Downstream of Carquinez Bridge -5.0 mg/l minimum; Upstream of Carquinez Bridge 7.0 mg/l minimum For nontidal waters, the following objectives shall apply: Waters designated as: Cold water habitat 7.0 mg/l minimum, Warm water habitat 5.0 mg/l minimum.The median dissolved oxygen concentration for any three consecutive months shall not be less than 80 percent of the dissolved oxygen content at saturation. Dissolved oxygen is a general index of the state of the health of receiving waters. Although minimum concentrations of 5 mg/l and 7 mg/l are frequently used as objectives to protect fish life, higher concentrations are generally desirable to protect sensitive aquatic forms. In areas unaffected by waste discharges, a level of about 85 percent of oxygen saturation exists. A three month median objective of 80 percent of oxygen saturation allows for some degradation from this level, but still requires consistently high oxygen content in the receiving water.
Central Coast (Region 3)	Ocean Waters: The mean annual dissolved oxygen concentration shall not be less than 7.0 mg/l, nor shall the minimum dissolved oxygen concentration be reduced below 5.0 mg/l at any time. Inland Surface Waters, Enclosed Bays and Estuaries: For waters not mentioned by a specific beneficial use, dissolved oxygen concentration shall not be reduced below 5.0 mg/l at any time. Median values should not fall below 85 percent saturation as a result of controllable water quality conditions.MAR and SPWN: The dissolved oxygen concentration shall not be reduced below 7.0 mg/l at any time.
Los Angeles (Region 4)	At a minimum, the mean annual dissolved oxygen concentrations of all waters shall be greater than 7 mg/L and no single determination shall be less than 5.0 mg/L, except when natural conditions cause lesser concentrations. SPWN: The dissolved oxygen content of all surfaces waters designated as COLD and SPWN shall not be depressed below 7 mg/L as a result of waste discharges. For that known as the Outer Harbor Area of the LA-Long Beach Harbors, the mean annual dissolved oxygen concentrations shall be 6.0 mg/L or greater, provided that no single determination shall be less than 5.0 mg/L.
Santa Ana (Region 8)	Adequate dissolved oxygen (D.O.) is vital for aquatic life. Depression of D.O. levels can lead to fish kills and odors resulting from anaerobic decomposition. Dissolved oxygen content in water is a function of water temperature and salinity. The dissolved oxygen content of enclosed bays and estuaries shall not be depressed to levels that adversely affect beneficial uses as a result of controllable water quality factors.
San Diego (Region 9)	The dissolved oxygen concentration in ocean waters shall not at any time be depressed more than 10 percent from that which occurs naturally, as the result of the discharge of oxygen demanding waste materials. Dissolved oxygen levels shall not be less than 5.0 mg/l in inland surface waters with designated MAR or WARM beneficial uses or less than 6.0 mg/l in waters with

[1] Region 1 proposed an amendment to its freshwater dissolved oxygen objectives in September 2008. The new objectives are summarized above.

	designated COLD beneficial uses. The annual mean dissolved oxygen concentration shall not be less than 7 mg/l more than 10% of the time.

2. Conceptual Approach for Development of Dissolved Oxygen Objectives

The E-NNE technical team is recommending that the SWRCB adopt an approach to setting estuarine dissolved oxygen criteria patterned after the US EPA Virginia Province Salt Water Dissolved Oxygen Criteria (US EPA 2003). This approach consists of setting DO criteria within a biological framework that integrates time (replacing the concept of an averaging period) and establishes separate criteria for different life stages (larvae versus juveniles and adults).

The purpose of this section is to summarize this conceptual approach and process for developing DO objectives.

2.1 Nature of Hypoxia and Its Biological Consequences

Hypoxia as a stressor differs from chemical toxicants in that it can occur naturally; hypoxia is a consequence of the balance of atmospheric oxygen diffusion to surface waters, the *in situ* production of oxygen by primary producers during daylight hours, their night time respiration, in combination with the respiration of decaying organic matter and other biogeochemical processes that consume oxygen within surface waters and sediments. In cases where hypoxia has anthropogenic origins, the assumption is that hypoxia may be reduced by controlling nutrient availability and reducing the supply oxygen-demanding material to a waterbody.

Hypoxia exhibits temporal variability, on diurnal, tidal, lunar, and seasonal timescales. Seasonal hypoxia often develops in association with stratification. Hypoxic water can occur as stratified water prevents the oxygenated surface water from mixing downward or when upwelled hypoxic water is advected into an estuary from offshore (REF). Hypoxia appears in the lower waters when respiration in the water and sediment depletes oxygen faster than it can be replenished. Breakdown of the stratification allows the surface and bottom waters to mix. Stratification can occur in both deepwater habitat of perennially tidal enclosed bays, such as San Francisco Bay, or in lagoonal or river mouth estuaries that are intermittently closed to tidal exchange and that are known to "trap salt" [*Largier, et al.*, 1991]. Diel cycles of hypoxia often appear in stratified or unstratified shallow habitats where nighttime respiration, in combination with water column and sediment dissolved oxygen demand, can deplete DO. Tidal and lunar frequencies can become apparent, particularly in poorly flushed areas where greater exchange occurs on flood or ebb tides or during a spring tide.

The response of aquatic organisms to low DO will depend on the intensity of hypoxia, duration of exposure, and the periodicity and frequency of exposure (Rabalais et al. 2002). Organisms have developed several physiological and behavioral adaptations to deal with temporary periods of low oxygen availability. Organisms can: 1) temporarily utilize anaerobic pathways to produce energy (ATP); 2) scavenge oxygen from hypoxic waters and increase the efficiency of oxygen transport to cells; 3) emigrate from hypoxic zones; 3) utilize the abundant oxygen from the surface or breathing aerial sources, or 4) reduce demand for oxygen by reducing activity. However, these are all short-term strategies and will not enable the animal to survive long hypoxic periods. Adaptations are well developed in animals such as intertidal and burrowing animals that commonly experience hypoxia but poorly developed in animals that inhabit well-oxygenated environments such as the upper water column. If oxygen deficiency persists, death will ensue. Sublethal effects also occur. For example, reduced motor activity from mild hypoxia may make the animal more vulnerable to predators or decrease its growth or reproduction.

2.2 Approach to Setting DO Objectives: the Virginia Province Salt Water DO Criteria

US EPA Virginia Province Salt Water Dissolved Oxygen Criteria document (US EPA 2003) describes an approach whose fundamental goal is <u>to maintain and support aquatic life communities and their designated uses</u>. Although the criteria are intended to protect aquatic communities, they rely primarily on data generated at the organism rather than the population level, and are designed to protect the most sensitive life stage of organisms which spend part of all of their life history within an estuary. The approach was developed for the region of the east coast of the US from Cape Cod, MA, to Cape Hatteras, NC. This approach was adapted for use in setting DO criteria for Chesapeake Bay (Batiuk et al. 2009), and has been applied, with appropriate modification, the other coastal regions of the US including Maine (REF) and Alabama (REF).

The approach combines both DO concentration and time of exposure into the criteria. Mathematical models are used to integrate effects of hypoxia over time rather than deriving one number for an averaged period of time. DO criteria are developed separately for juvenile and adults life stages of organisms versus larval stages. The need for separate criteria are based on the theory that different life stages can withstand different degrees of mortality without significant long-term impacts to the population; therefore, the criteria developed for the most sensitive life stage may not need to be applied for the entire population at all times. For example, in nature, larval life stages suffer a high degree of mortality, and the loss of a single larva is not as significant as the loss of an individual juvenile or adult and its predicted reproductive output. Anoxia was not considered since data on the effects of anoxia do not provide information on the threshold requirements of aerobic organisms.

Criteria were developed for both continuous and cyclic hypoxia scenarios, using three specific population measures for which protective criteria were designed: 1) juvenile and adult survival, 2) growth effects, and 3) larval recruitment effects. The methods for developing criteria use traditional concepts from the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses (Stephan et al., 1985; e.g. final acute value (FAV) and final chronic value (FCV)) and procedures for calculating them.

1. *Juvenile and adult survival*—A lower limit is calculated for continuous exposures by using FAV calculation procedures outlined in the *Guidelines* (Stephan et al., 1985), but with data for only

juvenile or adult stages. Limits for cyclic exposures are derived from an appropriate time-to-death curve for exposures less than 24 hr.

2. *Growth effects*—A threshold above which long-term, continuous exposures should not cause unacceptable effects is derived from growth data (mostly from bioassays using larvae). This FCV is calculated in the same manner as the FAV for juvenile and adult survival. This threshold limit as currently presented has no time component (it can be applied to exposures of any duration). Cyclic exposures are evaluated by comparing reductions in laboratory growth from cyclic and continuous exposures.
3. *Larval recruitment effects*—A larval recruitment model was developed to project cumulative loss caused by low DO. The effects depend on the intensity and the duration of adverse exposures. The maximum acceptable reduction in seasonal recruitment was set at 5% (although other percentages also may be appropriate on a site-specific basis), which is equivalent to the protective limitfor juvenile and adult survival. The number of acceptable days of seasonal exposure to low DO decreases as the severity of the hypoxic condition increases. The severity of cyclic exposure is evaluated with a time-to-death model (as in the protective limit for juveniles and adults).

This Virginia Province approach does not address direct behavioral responses (i.e., avoiding low DO) or the ecological consequences of behavioral responses such as changes in predation rates or in community structures. The document also does not address the issue of spatial extent of a DO problem; the assumption is that the environmental manager would have to judge whether the spatial extent of the low DO area is sufficient to warrant concern.

2.3 Process for Developing Dissolved Oxygen Objectives

To derive the criteria, the Virginia Province document recommends the use of data from fish and invertebrates to identify the most sensitive species representative of designated beneficial uses within the waterbody (EPA 2001, Batuik et al. 2009). Steps in this process can be identified as follows:

1. Identify target population of estuaries
2. Classify waterbodies and/or segments of waterbody and generate list of assigned beneficial uses
3. Generate list of fish and invertebrate species associated with specific beneficial uses by estuarine class
4. For each species, identify life stages with respect to seasonality, habitat type and location within estuarine and associated nearshore and/or freshwater habitat areas
5. Review and summarize data available on physiological effects of hypoxia for each individual species with respect to continuous and cyclic hypoxia scenarios
6. Run models to look at most sensitive endpoint by species for juvenile and adult survival, growth, and larval recruitment.
7. Synthesize and package recommended objectives by estuarine class and designated estuarine beneficial use

2.4 Target Population and Classification of California Estuaries: Relevance for Dissolved Oxygen Objectives

The SWRCB has existing definitions of “enclosed bays” and “estuaries.” These are as follows:

> ***Enclosed Bays*** *- Indentations along the coast which enclose an area of oceanic water within distinct headlands or harbor works. Enclosed bays will include all bays where the narrowest distance between headlands or outermost harbor works is less than 75 percent of the greatest dimension of the enclosed portion of the bay. This definition includes but is not limited to the following: Humboldt Bay, Bodega Harbor, Tomales Bay, Drakes Estero, San Francisco Bay, Morro Bay, Los Angeles Harbor, Upper and Lower Newport Bay, Mission Bay, and San Diego Bay.*
>
> ***Estuaries and Coastal Lagoons*** *- Waters at the mouths of streams which serve as mixing zones for fresh and ocean water during a major portion of the year. Mouths of streams which are temporarily separated from the ocean by sandbars shall be considered as estuaries. Estuarine waters will generally be considered to extend from a bay or the open ocean to the upstream limit of tidal action but may be considered to extend seaward if significant mixing of fresh and saltwater occurs in the open coastal waters. The waters described by this definition include but are not limited to the Sacramento-San Joaquin Delta as defined by Section 12220 of the California Water Code, Suisun Bay, Carquinez Strait downstream to Carquinez Bridge and appropriate areas of Smith River, Klamath River, Mad River, Eel River, Noyo River, and Russian River.*

The E-NNE technical team recommended an interpretation of the SWRCB’s existing definitions of “enclosed bays” and “estuaries” (Sutula et al. 2009a) to specify the target population, given as follows:

- Any marine or estuarine enclosed bay that has an enclosure ratio of < 75% of longest dimension. This would include enclosed bays, ports, harbors, marinas regardless of the amount of freshwater input to the site

- Any estuary in which seawater is measurably diluted by freshwater (bar built estuaries). The estuary does not need to have a surface water tidal connection to be considered an estuary.

This recommendation was accepted the Coastal SAG, the STRTAG, and the SWRCB. The interpretation of existing definition encompasses approximately 400 coastal drainages within California (Sutula et al. 2009a).

Give this target population, the following preliminary classification scheme was developed to describe the general geomorphic context and hypothesized susceptibility to eutrophication (Table 1, Sutula et al. 2009b).

Table 2.1. Preliminary E-NNE classification scheme. Definitions for the geoform and seasonality are given in Appendix 1.

GEOFORM	*SEASONALITY OF INLET OPENING*
Enclosed Bay	*Perennial*
Lagoon	*Perennial* *Intermittent* *Ephemeral*
River mouth	*Perennial* *Intermittent*

For the purposes of dissolved oxygen objectives, the E-NNE technical team observed that fish species do not sort in predictable patterns of species occurrence by geoform; rather, distribution of species can be described by a more simple classification scheme of "open" versus "closed" to surface water tidal influence. For those systems that do close, it will be important to specify the time period of closure, as it will influence which species or how often a species can occur there and intersect with particular parts of the life cycle.

2.5 Applicable beneficial uses

Table 2.2 give the definition of the estuarine beneficial uses applicable to dissolved oxygen objectives. Appendix 1 gives a list of California estuaries, with designated preliminary estuarine class and assigned beneficial uses. This information will be used in subsequent sections to derive species lists.

Table 2.2. Definition of beneficial uses applicable to the target population of California estuaries.

Marine Habitat (MAR) - Uses of water that support marine ecosystems including, but not limited to, preservation or enhancement of marine habitats, vegetation such as kelp, fish, shellfish, or wildlife (e.g., marine mammals, shorebirds). **Estuarine Habitat (EST)** -Uses of water that support estuarine ecosystems including, but not limited to, preservation or enhancement of estuarine habitats, vegetation, fish, shellfish, or wildlife (e.g., estuarine mammals, waterfowl, shorebirds). **Cold Freshwater Habitat (COLD)** - Uses of water that support cold water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish or wildlife, including invertebrates. **Warm Freshwater Habitat (WARM)** – Uses of water that support warm water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish or wildlife, including invertebrates. **Wildlife Habitat (WILD)** - Uses of water that support terrestrial ecosystems including, but not limited to, preservation and enhancement of terrestrial habitats, vegetation, wildlife (e.g., mammals, birds, reptiles, amphibians, invertebrates), or wildlife water and food sources. **Rare, Threatened, or Endangered Species (RARE)** - Uses of water that support habitats necessary, at least in part,

for the survival and successful maintenance of plant or animal species established under state or federal law as rare, threatened or endangered.

Spawning, Reproduction, and/or Early Development (SPWN) - Uses of water that support high quality aquatic habitats suitable for reproduction and early development of fish. This use is applicable only for the protection of anadromous fish.

Migration of Aquatic Organisms (MIGR) - Uses of water that support habitats necessary for migration, acclimatization between fresh and salt water, or other temporary activities by aquatic organisms, such as anadromous fish

Commercial and Sport Fishing (COMM) - Uses of water for commercial or recreational collection of fish, shellfish, or other organisms including, but not limited to, uses involving organisms intended for human consumption or bait purposes.

Shellfish Harvesting (SHELL) - Uses of water that support habitats suitable for the collection of filter-feeding shellfish (e.g., clams,oysters and mussels) for human consumption, commercial, or sport purposes.

Aquaculture (AQUA) - Uses of water for aquaculture or mariculture operations including, but not limited to, propagation, cultivation, maintenance, or harvesting of aquatic plants and animals for human consumption or bait purposes.

Contact Water Recreation (REC-1) - Uses of water for recreational activities involving body contact with water, where ingestion of water is reasonably possible. These uses include, but are not limited to, swimming, wading, water-skiing, skin and SCUBA diving, surfing, white water activities, fishing, or use of natural hot springs.

Non-contact Water Recreation (REC-2) – Uses of water for recreational activities involving proximity to water, but not normally involving body contact with water, where ingestion of water is reasonably possible. These uses include, but are not limited to, picnicking, sunbathing, hiking, beachcombing, camping, boating, tidepool and marine life study, hunting, sightseeing, or aesthetic enjoyment in conjunction with the above activities.

3. Selection of Fish Indicator Species

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3.1 Introduction

The purpose of this section is to present the methods, assumptions and lists of vertebrate species selected for consideration as indicator species for dissolved oxygen. The objectives of the efforts were as follows:

1) Generate a list of fish species associated with specific beneficial uses by estuarine class;

2) for each species, identify life stages with respect to seasonality, habitat type and location within estuarine and associated nearshore and/or freshwater habitat areas

3) prioritize species for review of physiological impacts

3.2 Approach and Assumptions

The contents of this section were developed and vetted through a one-day workshop, held March 16, 2010, of fisheries experts who were selected on the basis of their expertise in estuarine fisheries, knowledge of California estuaries and the natural history of fish species that utilize them. Workshop participants created criteria to determine inclusion on the list, generated the list of species, and generated recommendations for prioritization of the species on the list, based on several explicit factors.

3.2.1 Generation of Species Lists: General Criteria and Assumption for Inclusion on List

To develop the species list, a number of criteria and assumptions about the process were made. Ultimately, these criteria should be vetted with the SWRCB and its advisory groups. The criteria assumptions are as follows:

- Target population of enclosed bays and estuaries identified by E-NNE Technical Team and vetted by SWRCB and advisory groups was used as a starting point to generate species list; species unique to San Francisco Bay estuary were excluded because the scope of DO objective review is exclusive of this estuary. Thus, the list represents diversity of fish species found in the estuarine habitat throughout the state's estuaries without regard to oxygen sensitivity.

- Species which spend all or a substantial portion of their life histories in estuarine habitats . Thus, only estuarine species found within marine enclosed bays would be included.

- Emphasis was primarily on native fish. However, non-native species were added to the list under any of the following two conditions: 1) species considered recreationally or commercially important, and 2) species for which data on physiological effects of hypoxia were known to exist. The assumption was that these species would not be prioritized for development of DO objectives, but that in cases where alternative species or little data were available, they could be considered.

An extensive list of known estuarine species was produced and then tabulated in two ways: 1) by life history strategy and habitat type occupied during each life stage and 2) by geographic range and list of beneficial uses that they represent. Non-native and freshwater species are designated with footnotes in the respective tables.

3.2.2. List by Life History Strategy

Species were first listed, then grouped by guilds or life-history types, using modification of Allen et al.'s (2006) guilds or life-history strategies. This guilds or life history strategies are as follows:

- **Brackish species** primarily inhabit the lower salinity end of estuaries or spend a significant portion of their life history there.
- **Diadromous species**, which are further subdivided into **Anadromous** and **Catadromous** life history strategies, are species that migrate at particular stages in their life cycle between freshwater and the marine and estuarine environment. They necessarily use the estuary as a migration corridor and some utilize it as a nursery or reside there as well.
    - **Anadromous** fishes largely grow and mature in the ocean or estuary and move up into freshwater streams to spawn.
    - **Catadromous** species do the opposite, largely rearing and growing in freshwater and moving down into the estuary or ocean to spawn.
- **Resident Estuarine** fishes spend a substantial portion of their life cycle in the estuary. Marine bays and estuaries represent a small subset of fishes that spend most of their life in protected bays, and estuaries or closed lagoons in a wide range of salinities.
- **Marine** species that are widespread in the coastal marine environment but also often occur in the lower or seaward, high salinity regions of open bays and estuaries.
- **Freshwater** species in some larger rivers can invade coastal lagoons when they close and remain relatively fresh or at low salinities for extended periods.

Within each grouping, species were listed roughly in order from those most commonly found to those least prevalent. The general ecological and reproductive characteristics were noted for each species, to the extent known. Notably, since the number of truly estuarine species is relatively small and the estuarine habitat is particularly impacted by changes a relatively large number of the species have special conservation status.

3.2.3 List by Range and Applicable Beneficial Uses

This same set of species was then listed in a separate table by their range among California estuaries and assigned to applicable beneficial uses (see Table 2.2 in previous section). Range was subdivided into three categories: 1) species found through California, 2) species found primarily north of Point Conception, and 3) those found primarily south of that point. These are classified according to historical occurrence and not by the reduced ranges some have today. Within each of these three categories, the species are also listed from most to least representative of the estuarine habitat as discussed above.

3.2.4 Prioritizing the List of Species

The workshop participants then prioritized the list of species in order to reduce work load associated with the review of physiological effects data. The following rationale was use to prioritize species for inclusion:

- Native species
- State or federal threatened or endangered species
- Prominent for sport or commercial purposes
- Occurrence in the greatest number of estuaries across the state or, within a region (south or north of Point Conception)
- Representative of life history strategy
- Species having the greatest number of sensitive life stages within the estuary

3.3. Presentation of Species Lists and Prioritization

3.3.1 List of species by range and applicable beneficial uses

Table 3.1 gives the comprehensive list of species identified during this exercise, designated by range and applicable beneficial use.

Table 3.1 Comprehensive list of California estuarine species by range and applicable beneficial use. Open and closed tidal connections refers to species distribution in systems that are open (perennially. Intermittently, ephemerally tidal) to surface water tidal exchange or closed (in intermittent or ephemerally tidal systems).

RANGE	SUGGESTED INDICATOR SPECIES	Additional Designation		General Aquatic Life Use			Habitat for T&E, Migratory, or Spawning Species			Commercial and Recreational Fisheries			Upstream or Adjacent Beneficial Uses				
		Non-native	Fresh water	BIOL	EST	MAR	RARE	MIGR	SPWN	COMM	SHEL	AQUA	WARM	COLD	FRESH	WET	WLD
All California	Staghorn sculpin (*Leptocottus armatus*)			X	X	X(adult)						X		X	X		X
	Threespine stickleback (*Gasterosteus aculeatus*)			X	X	X(rarely)	X		X					X	X	X	X
	Tidewater goby (*Eucyclogobius newberryi*)			X	X	X(rarely)	X		X					X	X	X	X
	Arrow goby (*Clevelandia ios*)			X	X	X			X				X	X	X(rarely)		X
	Topsmelt (*Atherinops affinis*)			X	X	X			X			X	X		X(rarely)		X
	Steehead (*Oncorhynchus mykiss*)			X	X	X(adult)	X	X (anadr)				X		X	X		X
	Shiner surfperch (*Cymatogaster aggregata)*																
	Bay pipefish (*Syngnathus leptorhynchus*)			X	X	X	X?		X				X?	X	X(rarely)	X	X
	Longjaw mudsucker (*Gillichthys mirabilis*)			X	X	X			X	X			X		X(rarely)		
	Cheekspot goby (*Ilypnus gilberti*)			X	X	X			X				X				
	Pacific herring (*Clupea pallasii*)			X	X	X		X	X	X				X	X(rarely)		X
	Jack smelt (*Atherinopsis californiensis*)				X	X				X				X			
	Bay goby (*Lepidogobius lepidus*)			X	X	X			X					X			X
	Gray smoothhound (*Mustelus californicus*)			X	X	X			X	X				X			
	Brown smoothhound (*Mustelus henlei*)			X	X	X			X	X			X				
	Leopard shark (*Triakis semifasciata*)			X	X	X			X	X			X				
	Pacific lamprey (*Entosphenus tridentata*)			X	X	X	X	X		X				X	X (spawn)		
	Mosquitofish (*Gambusia affinis*)	X															
	Yellowfin goby (*Acanthogobius flavimanus*)	X			X	X			X	X			X		X		
	Mississippi silverside (*Menidia aurdens*)	X			X	X			X				X		X		
North of Point Conception	Starry flounder (*Platichthys stellatus)*			X	X	X(adult)				X				X	X		X
	Prickly sculpin (*Cottus asper*)			X	X	X(larvae)		X(catadr)	X					X	X		X
	Coastal cutthroat trout (*Oncorhynchus clarki clarki*)			X	X	X	X	X(anad)						X	X(spawn)	X	X
	Coho salmon (*Oncorhychus kisutch)*			X	X(juv)	X(adult)	X	X(anad)		X				X	X(spawn)	X	X
	King or Chinook salmon (*Oncorhynchus tschawytscha*)			X(juv)	X	X	X	X(anad)		X				X	X(spwn)	X	X
	Longfin smelt (*Spirinchus thaelichthys*)			X	X	X	X	X (est. anad)		X	X			X	X (spawn)	X?	X
	Green sturgeon (*Acipenser medirostris*)				X	X	X	X		X				X	X(spawn)		
	Speckled sand dab (*Citharichthys stigmaeus*)			X	X	X				X				X			

		Additional Designation		General Aquatic Life Use			Habitat for T&E, Migratory, or Spawning Species			Commercial and Recreational Fisheries			Upstream or Adjacent Beneficial Uses				
	English sole (*Pleuronectes vetulus*)			X	X	X				X				X			
	Euchalon (*Thaleichthys pacificus*)			X	X?	X	X	X(anad)		X	X			X	X (spawn)	X?	X
	Sharpnose sculpin (*Clinocottus acuticeps*)			X	X	X(adult)	X		X?					X	X(rarely)		X?
	Hitch (*Lavinia exilicauda*)		X														
	Sacramento blackfish (*Orthodon microlepidotus*)		X		X								X		X		
	Tule perch (*Hysterocarpus traski*)		X		X		X								X		
	Sacramento pikeminnow (*Ptychocheilus grandis*)		X		X								X		X		
	Western sucker (*Catostomus occidentalis*)		X		X								X	X	X		
	Western roach (*Hesperoleucas symmetricus*)		X		X		X						X		X		
	Striped bass (*Morone saxatilis*)	X		X	X	X		X		X				X	X		
South of Point Conception	California killifish (*Fundulus parvipinnis*)			X	X	X(rarely)			X				X		X(rarely)	X	X
	Deepbody anchovy (*Anchoa compressa*)			X	X	X			X				X		X(rarely)		X
	Bay anchovy (*Anchoa delicatissima*)			X	X	X			X				X		X(rarely)		X
	Shadow goby (*Quietula y-cauda)*			X	X	X			X				X				X
	Striped mullet (*Mugil cephalus*)			X	X	X(adult)						X	X		X		X
	Diamond turbot (*Pleuronichthys guttulatus*)			X	X	X			X?			X	X		X(rarely)		X
	California halibut (*Paralichthys californicus*)			X	X	X						X	X				X
	Barred pipefish (*Syngnathus auliscus*)			X	X	X(rarely)	X?		X				X		X(rarely)	X	X
	Spotted sand bass (*Paralabrax maculofasciatus*)			X	X	X			X?			X	X				X
	Bay blenny (*Hypsoblennius gentilis*)			X	X	X			X				X				X
	Arroyo chub (*Gila orcutti*)		X		X								X		X		

Table 3.2 gives the list of species by life history strategy, habitat occupied, feeding guild, salinity guild and time occupied within the estuary.

A brief summary of life history strategy, range, and special status, are given for the species within each life history strategy. Much of the information on the biology and distribution of these species is available in Emmett et al. (1991), Moser et al. (1996), Cailliet et al. (2000), Leet et al. (2001), Moyle (2002), Allen et al. (2006), other more specific documents cited below, and the collective experience of the authors. Appendix 2 summarizes the biological information for the 20 indicator species considered the most important for use.

BRACKISH SPECIES

Two species, the Tidewater goby, *Eucyclogobius newberryi*, and the Threespine stickleback, *Gasterosteus aculeatus*, are characteristic of the lower salinity areas of estuaries almost throughout California. The Threespine stickleback historically occurred throughout the state but today is absent in coastal localities south of Ventura County. The Tidewater goby occurs from northern Del Norte County to central San Diego County and is also absent from many localities it originally inhabited. The complete life cycle of each species is spent in the estuary. Threespine stickleback also have both freshwater and anadromous stocks in many systems in central and northern California. The freshwater stocks occurred throughout the state and the anadromous stocks from about San Luis Obispo County northward.

Anadromous Species

Eight anadromous species are included; four salmonids (family Salmonidae), two smelt (family Osmeridae), one sturgeon (family Acipenseridae), and one lamprey (Petromyzonidae). These all spawn in freshwater streams, spend some of their early life in freshwater or estuaries, are important commercial or game species, have special significance to native American peoples, and most, if not all, populations have special conservation status. The four salmonids include:

1) Steelhead, *Oncorhynchus mykiss*, which occurs over the whole state of California and can spend significant time (months) in the estuary if adequate such conditions present themselves.

2) Coho salmon, *Oncorhynchus kisutch*, occur in many streams north of Monterey Bay to the Oregon border and beyond but spend less time in the estuary, often passing through to the ocean fairly rapidly (days to a week or so). Both Steelhead and Coho Salmon occur in a great many small to large streams within their range.

3) King or Chinook salmon, *Oncorhynchus tschawytscha*, occur north of San Francisco Bay and only in large systems like Russian River, Eel River, Klamath River and a few others. Their juveniles spend some time in the estuaries, basically more than Coho Salmon but less than steelhead.

4) Coastal cutthroat trout, *Oncorhynchus clarki clarki*, occur from the Eel River northward (Humboldt and Del Norte counties) to the Oregon border and beyond. They occur in most of the estuaries and coastal lagoons in this area. The juveniles spend varying amounts of time in freshwater and older juveniles and adults are largely estuarine. Adults also can spend some time in the ocean (Gerstung 1997; Trotter 2008).

Table 3.2 Estuarine indicator species by habitat features occupied by different life stages organized by life history types or guilds (modified from Allen et al. 2006).

Species	BURROWS IN SUBSTRATE	ON BOTTOM, BENTHIC	IN WATER COLUMN	ROCK, GRAVEL, HARD SUBS	IN MACRO-PHYTES	SAND	MUD	MICRO-CARNI-VORE	GRAZER HERBI-VORE	CARNI-VORE	FILTER FEEDER	MARINE	EST-UARINE	FRESH-WATER	TIME IN ESTUARY, years
BRACKISH															
Tidewater goby															
Eggs	X					X							X	X	6-10 days
Larvae			X		X			X					X	X	15-30 days
juveniles		X	X	X	X	X	X	X					X	X	to 0.5 years
Adults	X, just during breeding	X		X	X	X	X	X					X	X	1-2 years
Threespine stickleback															
Eggs		X				X	X	X						X	0
Larvae		X	X		X	X	X	X					X	X	5 to 15 days
Juveniles		X	X		X	X	X	X				X	X	X	0.5 to 1.0 years
Adults		X	X		X	X	X	X				X	X	X	1-3 years
ANADROMOUS															
Rainbow or Steelhead trout															
Eggs	X			X										X	0
Larvae	X			X										X	0
Juveniles			X					X		X			X	X	1-3 years
Adults			X					X		X		X	X (anadromous)	X (spawn)	pass through (anadrom)
King or Chinook salmon															
Eggs	X(buried in gravel)													X	0
Larvae	X(buried in gravel)													X	0
Juveniles		X	X	X	X	X				X			X	X	1 to two years
Adults		X								X		X (mostly)	X(anadromous)	X(spawn)	pass through (anadrom)
Coho salmon															
Eggs	X			X										X	0
Larvae	X			X										X	0

Species	BURROWS IN SUBSTRATE	ON BOTTOM, BENTHIC	IN WATER COLUMN	ROCK, GRAVEL, HARD SUBS	IN MACRO-PHYTES	SAND	MUD	MICRO-CARNI-VORE	GRAZER HERBI-VORE	CARNI-VORE	FILTER FEEDER	MARINE	EST-UARINE	FRESH-WATER	TIME IN ESTUARY, years
Juveniles			X					X		X			X	X	1 year
Adults			X					X		X		X(mostly)	X (anadromous)	X (spawn)	pass through only (anadrom)
Coastal cutthroat trout															
Eggs	X			X										X	0
larvae, alevins	X			X										X	0
Juveniles			X					X		X			X	X	1-3 years
Adults			X					X		X		X	X(anadromous, resident)	X (spawn)	3-8 years
Euchalon															
Eggs		X		X										X	0
Larvae			X					X				X	X	X(drift to estuary and ocean)	few days or weeks drifting down
juveniles			X					X				X(mostly)	X		mostly in ocean
Adults			X					X				X	X(anadromous)	X(anadromous)	mostly in ocean
Green sturgeon															
Eggs														X	
Larvae		X											X	X	
juveniles		X											X	X	1-100
Adults		X								X		X	X (anadromous)	X (spawn)	
Pacific lamprey															
Eggs	X, burried in gravel			X										X	0
Larvae	X, burried in gravel										X			X	0
juveniles	X	X				X	X							X	1-2 years
Adults		X								X				X, spawning only	passage only (anadromous)
CATADROMOUS															
Prickly sculpin															

Species	BURROWS IN SUBSTRATE	ON BOTTOM, BENTHIC	IN WATER COLUMN	ROCK, GRAVEL, HARD SUBS	IN MACRO-PHYTES	SAND	MUD	MICRO-CARNI-VORE	GRAZER HERBI-VORE	CARNI-VORE	FILTER FEEDER	MARINE	EST-UARINE	FRESH-WATER	TIME IN ESTUARY, years
Eggs		X		X									X	X	10-30 days
Larvae			X					X				X	X	X	10-30 days
juveniles		X		X		X	X			X			X	X	0.5 to 1.0 years
Adults		X		X		X	X			X			X	X	1-3 years
ESTUARINE SUBSTANTIALLY															
Staghorn sculpin															
Eggs		X		X								X			20-40 days
Larvae			X					X				X	X		20-40 days
juveniles	X	X				X	X			X			X	X	1-Jan
Adults	X	X				X	X			X		X	X		1 to 3
Topsmelt															
Eggs					X								X		5-10 days
Larvae			X					X				X	X	X	10-30 days
juveniles			X					X	X			X	X	X	1-2 years
Adults			X		X			X	X			X	X		1-3 years
Starry flounder															
Eggs			X									X	X		0
Larvae			X					X				X	X		30-Oct
juveniles		X				X	X	X					X	X	1-2 years
Adults		X				X	X	X				X (mostly)	X		1-2 years
Arrow goby															
Eggs	X											X	X		5-10 days
Larvae			X					X				X	X	X	10-30 days
juveniles	X	X				X	X	X				X	X	X	1 year
Adults	X	X				X	X	X				X	X	X	1-3 years
California killifish															
Eggs		X		X	X							X	X		1-5 days
Larvae			X, days only					X				X	X		1-5 days
Juveniles		X													0.25-0.50 years
Adults	X, occasion-ally burrow into	X		X	X	X	X	X				X	X	X	1-3 years
California halibut															

Species	BURROWS IN SUBSTRATE	ON BOTTOM, BENTHIC	IN WATER COLUM N	ROCK, GRAVEL, HARD SUBS	IN MACRO-PHYTES	SAND	MUD	MICRO-CARNI-VORE	GRAZER HERBI-VORE	CARNI-VORE	FILTER FEEDER	MARINE	EST-UARINE	FRESH-WATER	TIME IN ESTUARY, years
Eggs			X									X, mostly	X		0
Larvae			X					X				X	X		3-6 weeks, mostly ocean
Juveniles		X				X	X			X		X	X,mostly		1-3 years
Adults		X				X	X			X		X	X		25-30 yrs, mostly ocean
Deepbody/Bay anchovy															
Eggs			X									X	X		4-6 days
Larvae			X								X	X		X	30-40 days
Juveniles			X								X	X	X		0.5-1 year
Adults			X								X	X	X		1-3 years
Pacific herring															
Eggs		X			X								X	X	10-15 days
Larvae			X					X				X	X, mostly	X	2-3 months
juveniles			X					X			X	X	X	X	1-2 years
Adults			X					X			X	X	X	X (spawn)	3-15 years
Diamond turbot															
Eggs			X									X	X		5-10 days?
Larvae			X					X				X	X		5-6 weeks
juveniles		X				X	X	X				X	X	X	half to one year
Adults		X				X	X	X				X	X		8-9 years old
Longjaw mudsucker															
Eggs	X											X	X		5-10 days
Larvae			X					X				X	X		25-40 days
juveniles	X	X				X	X			X		X	X	X	half to one year
Adults	X	X				X	X			X		X	X		3-5 years
Shadow goby															
Eggs	X														5-10 days
Larvae			X					X				X	X		10-30 days
juveniles		X				X	X	X				X	X		0.5-1 year
Adults	X	X				X	X	X				X	X		1-3 years
Bay/Barred pipefish															

Species	BURROWS IN SUBSTRATE	ON BOTTOM, BENTHIC	IN WATER COLUMN	ROCK, GRAVEL, HARD SUBS	IN MACRO-PHYTES	SAND	MUD	MICRO-CARNI-VORE	GRAZER HERBI-VORE	CARNI-VORE	FILTER FEEDER	MARINE	EST-UARINE	FRESH-WATER	TIME IN ESTUARY, years
Eggs	Brooded by male, see adult														
Larvae	Brooded by male, see adult														
juveniles					X			X				X	X	X(rarely)	0.5-1 year
Adults					X			X				X	X	X(rarely)	1-3 years
Longfin smelt															
Eggs		X											X	X	0
Larvae			X					X					X	X	30-60 days
juveniles			X					X				X	X		0.5-1 year
Adults			X					X				X	X	X(spawn)	2-4 years?
Striped mullet															
Eggs			X									X	X		0
Larvae			X					X				X	X		1-4 weeks
juveniles			X						X		X	X	X	X	1-3 years
Adults		X	X			X	X		X		X	X, mostly to spawn	X	X	2-7years
Cheekspot goby															
Eggs	X					X						X	X		5-10 days
Larvae			X					X				X	X		20-40 days
juveniles	X	X				X		X				X	X		0.5-1 year
Adults	X	X				X		X				X	X		1-3 years
Shiner surfperch															
Eggs	live-bearing														
Larvae	live-bearing														
juveniles												X	X		0.5-1 year
Adults		X	X	X	X			X				X	X		1-3 years
MARINE BAYS, ESTUARIES															
Bay blenny															
Eggs		X		X								X	X		5-10 days?
Larvae			X					X				X	X		30-50 days?
juveniles		X		X				X	X			X	X		0.5-1.0 years

Species	BURROWS IN SUBSTRATE	ON BOTTOM, BENTHIC	IN WATER COLUMN	ROCK, GRAVEL, HARD SUBS	IN MACRO-PHYTES	SAND	MUD	MICRO-CARNI-VORE	GRAZER HERBI-VORE	CARNI-VORE	FILTER FEEDER	MARINE	EST-UARINE	FRESH-WATER	TIME IN ESTUARY, years
Adults		X		X				X	X			X	X		1-3 years
Spotted sandbass															
Eggs			X									X	X		1-2 DAYS
Larvae			X					X				X	X		20-30 DAYS
juveniles		X		X	X	X				X		X	X		1-2 years
Adult		X													6-20 YEARS
OTHER MARINE															
Jacksmelt															
Eggs					X							X	X		7 days
Larvae			X									X	X		24-40 days
juveniles			X					X	X			X	X		1-6 mos
Adults			X					X	X			X	X		to 11 yrs
English sole															
Eggs			X									X			3-4 days
Larvae			X					X				X			8-10 wks
juveniles		X								X		X	X		0.5-1..0 yrs
Adults		X								X		X			
Yellowfin croaker															
Eggs			X									X	X		?
Larvae			X					X				X	X		?
Juveniles		X						X				X	X		0.5-1.0 yrs
Adults		X								X		X	X		5+ yrs?
Speckled sand dab															
Eggs			X									X			
Larvae			X									X	X (?)		
Juveniles		X				X	X			X		X			0.5-1 yr
Adults		X				X	X			X		X	X (?)		1-3 yrs
Gray smoothhound															
Eggs	live bearing														
Larvae	live bearing														
juveniles		X				X	X			X		X	X		~one year
Adults		X				X	X			X		X	X		Mulitpl4e years
Leopard shark															
Eggs	live bearing														
Larvae	live bearing														

Species	BURROWS IN SUBSTRATE	ON BOTTOM, BENTHIC	IN WATER COLUMN	ROCK, GRAVEL, HARD SUBS	IN MACRO-PHYTES	SAND	MUD	MICRO-CARNI-VORE	GRAZER HERBI-VORE	CARNI-VORE	FILTER FEEDER	MARINE	EST-UARINE	FRESH-WATER	TIME IN ESTUARY, years
juveniles		X				X	X			X		X	X		~ one year
Adults		X				X	X			X		X	X		Multiple years
Spotted turbot															
Eggs			X									X	X		4-6 days?
Larvae			X									X	X		5-7 wks?
juveniles		X				X	X					X	X		0.5-1.0 yrs
Adults		X				X	X					X	X		3+ yrs
Round stingray															
Eggs	live bearing														
Larvae	live bearing														
juveniles	X	X				X	X	X				X	X		Multiple years
Adults	X	X				X	X	X				X	X		
Barred sand bass															
Eggs			X									X	X		Few weels
Larvae			X									X	X		
Juveniles		X	X(rarely)	X		X	X			X		X	X		1+ years
Adults		X	X(rarely)	X		X	X			X		X	X		3-8 years
Bat Ray															
Eggs	Live bearing														
Larvae															
Juveniles		X	X			X	X	X				X	X		1+ years
Adults		X	X			X	X	X				X	X		2+ years
FRESHWATER															
Pikeminnow															
Eggs		X		X										X	
Larvae			X					X						X	
Juveniles		X	X	X		X	X						X	X	2-3 mos.
Adults		X	X	X		X	X			X			X	X	1-3 mos
Western sucker															
Eggs		X		X										X	
Larvae			X			X	X	X					X	X	1-2 wks
juveniles		X		X		X	X	X	X				X	X	2-8 wks
Adults		X		X		X	X		X				X	X	1-2 yrs
Hitch															

Species	BURROWS IN SUBSTRATE	ON BOTTOM, BENTHIC	IN WATER COLUMN	ROCK, GRAVEL, HARD SUBS	IN MACRO-PHYTES	SAND	MUD	MICRO-CARNI-VORE	GRAZER HERBI-VORE	CARNI-VORE	FILTER FEEDER	MARINE	EST-UARINE	FRESH-WATER	TIME IN ESTUARY, years
Eggs		X		X										X	
Larvae			X											X	1-2 wks
juveniles			X					X					X	X	1-6 mos
Adults			X					X					X	X	1-2 yrs
Blackfish															
Eggs					X									X	5-10 days
Larvae			X		X			X					X	X	15-30 days
juveniles			X					X					X	X	1-6 mos
Adults			X								X		X	X	0.5-3 yrs
Tule perch															
Eggs	live bearing														
Larvae	live bearing														
juveniles		X	X	X	X	X	X	X				X	X	X (rarely)	1-6 mos
Adults		X	X	X	X	X	X	X				X	X	X (rarely)	0.5-3 yrs
NON-NATIVE SUBSTANTIALLY ESTUARINE															
Striped bass															
Eggs			X										X	X	2-4 days
Larvae			X					X					X	X	15-30 days
juveniles			X	X	X	X	X			X			X	X	0.5-3 yrs
Adults			X	X	X	X	X			X		X	X	X	3-20 yrs
Mississippi silverside															
Eggs					X								X	X	4-30 days
Larvae			X					X					X	X	3-5 wks
juveniles			X		X			X					X	X	0.3-3 yrs
Adults															
Yellowfin goby															
Eggs	X					X	X						X		20-30 days
Larvae			X										X		few wks?
juveniles						X	X	X					X	X	1-6 mos
Adults		X				X	X	X				X	X	X	1-3 yrs
Mosquitofish															
Eggs	livebearing														
Larvae	livebearing														
juveniles			X		X			X					X	X	1-30 days
Adults			X		X			X					X	X	0.1-2 yrs

Species	BURROWS IN SUBSTRATE	ON BOTTOM, BENTHIC	IN WATER COLUMN	ROCK, GRAVEL, HARD SUBS	IN MACRO-PHYTES	SAND	MUD	MICRO-CARNI-VORE	GRAZER HERBI-VORE	CARNI-VORE	FILTER FEEDER	MARINE	EST-UARINE	FRESH-WATER	TIME IN ESTUARY, years
Rainwater killifish															
Eggs					X							X	X	X	9-12 days
Larvae		X										X	X	X	7-10days
juveniles		X	X	X	X	X	X	X				X	X	X	1-6 mos
Adults		X	X	X	X	X	X	X				X	X	X	1-2 yrs
Sailfin molly															
Eggs	live bearing														
Larvae	live bearing														
juveniles					X			X	X				X	X	0.1 to 0.2
Adults					X			X	X				X	X	1 to 2

The Euchalon (*Thaleichthys pacificus*) is an osmerid fish occurring north of San Francisco Bay to Oregon and beyond. The marine adults migrate through the estuary to spawn in freshwater in early spring and the larvae hatch out and return downstream to the ocean in a few days to a few weeks. Their residence time in the estuary is brief but in the larval and early juvenile stage which is probably one of the most oxygen sensitive stages in their life cycle. During this well-watered late winter to early spring time period, the water is usually cold and well oxygenated.

The Longfin smelt, *Spirinchus thaleichthys*, occurs in San Francisco Bay and from the Eel River northward, and is largely an estuarine species as a juvenile and adult. It is federally listed as noted above. Larvae may occur in the estuary as well as they descend from nearby freshwater spawning tributaries.

The Green sturgeon (*Acipenser medirostris*) primarily occurs in the Klamath River as juveniles and to some extent as adults in addition to passing through to spawn up river. It may occur in a few other major north coast rivers such as the Eel, Russian, Smith, and Mad rivers. The youngest juveniles occur on the bottom in the estuary in at least the Klamath River estuary and possibly the others now or in the future as this species recovers.

The Pacific lamprey, *Entosphenus tridentata*, historically occurred from northern Baja California to north of California. The adults are marine but pass up through estuaries to spawn in freshwater streams and usually die after spawning. The larvae, or ammocoetes, burrow into fine sand to muddy substrates and filter feed both in freshwater streams and lower salinity areas of upper estuaries. The larval and juvenile stages are the only life stage to spend significant time in the estuary, possibly up to months. This species has declined precipitously in the last ten years or so (Moyle et al. 2010). The Euchalon, Longfin smelt, Green sturgeon, and Lamprey are very rare today or found in only a few estuaries and should be indicators primarily based on their species conservation status rather than being very representative of many estuaries.

CATADROMOUS SPECIES

The Prickly sculpin is the only species considered catadromous based on studies in central California and observations north of California (Shapavalov and Taft 1954; Kresja 1965; McPhail 2007). Adults typically reside in freshwater streams and lakes and in some populations migrate down into coastal estuaries to spawn. The larvae occur in estuaries and coastal ocean and the juveniles are often abundant in coastal estuaries. With age and growth the fish migrate back upstream into freshwater.

Allen et al. (2006) considered Striped mullet, *Mugil cephalus*, to be a catadromous species and we consider it an estuarine species. While some juveniles and adults will invade freshwater streams only a small proportion of the mullet population does so in California and then only in wet years when fresh water flows are higher and of longer duration.

ESTUARINE SPECIES

We consider sixteen species to be primarily or substantially estuarine in their life histories, the largest guild or life history category presented here. This includes:

- Three species of clupeomorphs (Clupeidae, Engaulidae)
- Two species of pipefishes (Syngnathidae)
- Four species of gobies, Gobiidae,
- Three species of flatfishes (Bothidae, Paralichthyidae, Pleuronectidae)
- Topsmelt, *Atheriops affinis* (Atherinopsidae),
- Califonia killifish, *Fundulus parvipinnis* (Fundulidae),
- Staghorn sculpin, *Leptocottus armatus* (Cottidae),
- Shiner surfperch, *Cymatogaster aggretaga* (Embiotocidae).

At least ten of these are almost completely estuarine or have populations that are, namely California killifish, the four species of gobies, the two anchovies, two species of pipefishes, and the topsmelt. The remaining estuarine species have most of the adult population as marine but much of the first year or more of juvenile life is spent in bays or estuaries. This latter group includes all three flatfishes, the Pacific herring, *Clupea pallasi*, the Staghorn sculpin, *Leptocottus armatus*, Striped mullet, *Mugil cephalus*, and the Shiner Surfperch. They typically arrive in the estuaries as advanced larvae or newly settled juveniles in late winter or early spring, live and grow in the estuary, and often leave to the ocean the following winter. The juvenile California halibut and Striped mullet often stay for two to three years. The species of gobies follow a somewhat reverse pattern in that the adults reside in the estuaries and the larvae concentrate in the deeper portions of the estuary, often near its mouth and also disperse along the coast in nearshore waters.

One additional species, the Longfin smelt listed above as an anadromous species, spends most of its life in estuaries and might be classified in this estuarine category as well. An argument could be made for including the Tidewater goby and some populations of Threespine stickleback as "estuarine"; they are currently included in the brackish category above.

The four species of gobies roughly divide up the estuarine benthic habitat by substrate: the Longjaw mudsucker, *Gillichthys mirabilis*, lives in high to low intertidal muddy tidal sloughs or channels. The Arrow goby, *Clevelandia ios*, occurs on both sandy and muddy shallow flats as do the Shadow goby, *Quietula y*-cauda, and Cheekspot goby, *Ilypnus* gilberti, but the Shadow goby is usually found in muddier situations than the sandier areas inhabited by the Cheekspot gobies. As juveniles all of the latter three species of goby can be found over the same substrates. All of these species live in burrows of other invertebrates or in some cases of their own making. The eggs are brooded in the burrows and the larvae occur in the estuary and nearby nearshore ocean. The larval stage probably only lasts for a few weeks but reproduction lasts for several months so larvae and juveniles are present for much of the year.

The Topsmelt and California killifish also reproduce over an extended time period at least in southern California where small juveniles can be taken in almost all months and are least abundant in the coldest winter months. The reproductive season is probably progressively shorter to the north. Both species attach their eggs to vegetation, brush, and possibly firmer substrates in the estuary. Most if not all their larvae develop in the estuary although some of the more pelagic topsmelt may be carried out to the nearshore ocean. It is much less likely that any significant numbers of killifish larvae are carried out since they hatch at a more advanced stage with a very short or non-existent larval life. The small hatchlings remain on the bottom and quickly begin foraging as small juveniles.

The two species of pipefishes[2], Bay pipefish, *Syngnathus leptorhynchus*, and Barred pipefish, *S. auliscus*, are the two estuarine species of pipefishes in California and have similar life histories. The males brood the young in a pouch so there is no free-living egg or larval stage. The duration of the breeding season is not well-known but possibly not as extensive as the other estuarine species. The adults are relatively sedentary and usually occur in macrophytes like eel grass or masses of *Ulva* or *Enteromorpha*-like green algae.

Two species of fishes come into the estuaries to either lay their eggs in the coldest months (Pacific herring) or to give birth to living young in the warm months (Shiner surfperch). The larvae and juveniles spend weeks to months in the estuary as do a proportion of the adults but substantial populations of adults occur in the ocean as well. It is uncertain whether some populations may be largely estuarine with separate life history strategies from more marine stocks.

The remaining estuarine species of fishes spend some or most of their multi-year adult life in nearshore marine waters and spawn there. However their larvae orient towards bays and estuaries and the juveniles settle out or transform there. The juveniles spend several months growing in the estuary. These species are the three flatfishes, Starry flounder, *Pleuronectes stellatus*, Diamond turbot, *Pleuronichthys guttulatus*, and California halibut, *Paralichthys californicus*, Striped mullet, and Staghorn sculpin. The young of all but the California halibut arrive in the winter-early spring time period in southern California and undoubtedly progressively later to the north. The California halibut tend to be later in the spring and summer in southern California and probably do not utilize estuaries north of San Francisco Bay to a large extent. The Starry flounder and the Diamond turbot are somewhat complementary in distribution, occurring north and south of Pt. Conception, respectively whereas the California halibut is primarily south but does range north to San Francisco Bay.

Two marine species occasionally but regularly occur in a few estuaries north of San Francisco Bay; the Sharpnose sculpin, *Clinocottus acuticeps*, and the Saddleback gunnel, *Pholis ornata*. The Saddleback gunnel appears to be a marine fish that occasionally invades estuaries whereas the Sharpnose sculpin is a regular inhabitant of a few estuaries like Ten Mile River, Eel River, and tributaries of Crescent City Harbor.

MARINE BAY, ESTUARIES

Two species occur primarily in more saline, perennially open marine bays and estuaries but are rare or absent from the many closed systems with lower salinity and varying degrees of connection with the ocean. These are the Spotted sand bass, *Paralabrax maculofasciatus* (Serranidae), and Bay blenny, *Hypsoblennius gentilis* (Blennidae). Both have long-lived larvae in bays and nearshore ocean waters

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[2] Note that the taxonomy is difficult and that up to four or five species exist of pipefishes, the other species apparently are marine and rarely in estuaries.

with the Bay blenny attaching its eggs to hard substrate and the Spotted sand bass spawning in surface and mid-waters of bays and ocean.

MARINE FISH

The nine species of bony fishes, sharks, and rays are found in this category (Table 3.2) are primarily marine but can occur in and near bay and estuary mouths, particularly in larger systems that are perennially open or open much of the time. Despite such occurrence they are generally more representative of the marine environment or are dispersing into larger bays and estuaries with high tides only retreat to the ocean or the deepest channels near the mouth of the estuary at low tide. In addition the sharks and rays enter the bays in the warm months to give birth to young and the bays provide nursery areas for the juveniles for months or more. This is particularly true for the leopard shark, *Triakis* semifasciata, gray smoothhound, *Triakis* californicus, and the Round stingray, *Urolophus halleri.* The nine species of bony fishes, sharks, and rays are somewhat regularly taken in estuaries and we refrained from listing many more marine species that can occur in some enclosed systems like L. A. Harbor, Tomales Bay, Humboldt Bay, and a few others that are much more marine in character. We think their sensitivity would be more relevant as marine rather than estuarine indicators. However, as pointed out by Allen et al. (2006) large artificial systems like Los Angeles Harbor can have particular sections, regions, or areas of habitat that take on the fish fauna characteristic of estuaries.

FRESHWATER SPECIES

In a similar vein several freshwater species can prevail in some estuarine habitats downstream of streams and lakes with freshwater species. Five species of freshwater fishes are included because they have been noted in lagoons associated with major drainages north of Point Conception and include native minnows, suckers, and Tule perch. These species occasionally can be taken at low salinities at the upper end of these estuaries and even in large numbers in the spring when larvae and juveniles drift downstream and can become concentrated at the stream-lagoon or estuary interface. In addition, when these systems remain closed for long periods and salinities decline below about 5-7 ppt., juveniles and adults of these species may become widespread in the lagoons. These species are necessarily limited by the small number of coastal streams with significant native freshwater fish faunas. The native species recorded from California estuaries are Western sucker, *Catostomus* occidentalis, Sacramento pikeminnow, *Ptychocheilus grandis*, Hitch, *Lavinia exilicauda*, Blackfish, *Orthodon microlepidotus*, Roach, *Hesperoleucas symmetricus*, and Tule perch, *Hysterocarpus traski*. The Roach from different drainages may prove to be separate species (Moyle 2002). These species are primarily occur in a few estuaries of the largest streams like the Salinas, Pajaro, San Lorenzo, Russian, and Eel rivers. The species could include one from southern California also, the arroyo chub, *Gila orcutti*, since it can be dispersed in the Santa Clara River lagoon at times when it is relatively fresh. The arroyo chub is not considered native to the Santa Clara River (Swift et al. 1993) but occurs as native in the Malibu Lagoon and historically should have occurred in systems on the Los Angeles Basin. Several other non-native or invasive freshwater species could be added to this list as well, particularly Green sunfish, *Lepomis cyanellus*, Largemouth bass, *Micropterus salmoides*, Black bullhead, *Ameiurus melas*, mosquitofish, and Mississippi silverside. Drakes Estero on Pt. Reyes National Seashore has an established non-native population of Sacramento perch, *Archoplites interruptus*.   However, they, along with the native freshwater species, may be best utilized as freshwater indicators with the truly estuarine species designated as estuarine indicators.

NON-NATIVE OR ALIEN SPECIES

The remaining estuarine species are the non-native species of significance known to occur outside the San Francisco Bay. As noted by Schroeter and Moyle (2006) few non-native or alien species are known from California estuaries.   However, the few that are present may provide sensitivity data not currently available from native species and can serve as surrogates for native species until the latter can be studied.   The Mosquitofish is the only alien species that occurs in a large number of the estuarine systems throughout the state.   The Yellowfin goby occurs primarily in large, open systems including harbors and only rarely strays into smaller and closed systems. As predicted by Scroeter and Moyle (2006) the alien Mississippi silverside has been expanding its range in coastal southern California in the last five years or so (Camm Swift, unpublished observations). This species has been called the inland silverside, *Menidia beryllina*, a coastal, brackish water species in the Gulf of Mexico, in recent literature (Schroeter and Moyle 2006). The freshwater source population for California fish (Oklahoma) has recently been shown to be a separate species, *Menidia audens*, by Suttkus et al. (2005) as accepted by Nelson et al. (2004). A few additional alien species like Sailfin molly, *Peocilia latipinna*, and Rainwater killifish, *Lucania* parva, may also become more widewpread in California estuaries, particularly in warmer southern California systems.

3.3.2 Designated Priority Species

Criteria for prioritization of species favored: 1) widespread estuarine residents and fishes typically with both multiple life cycle stages and extended residence in the estuary within their life cycle, 2) threatened and endangered species, and 3) commercially important or sport fisheries.   In some cases these criteria apply in a historical sense and these species are not as widespread or prevalent today. This may necessitate consideration of alternate or substitute species to accommodate the possible need to actually have fish present to justify using them for regulatory purposes. In some cases the selections may conflict with efforts to recover these species, i.e. physiological investigations may be hindered by limitations on use of a particular species for such studies. Also several species are in multiple categories in being representative of estuaries, having special conservation status, and also having long standing sport fishing importance.

Table 3.3 lists the priority species selected, and provides summary information on range, life history strategy and applicable beneficial uses.

Eight species are on the federal or state threatened and endangered species list:

- Steelhead (Federally endangered or threatened over much of coastal California),
- Coastal cutthroat trout (sport species in northwestern California),
- Coho and Chinook Salmon (Federally endangered or threatened in central and northern California),
- Pacific herring (prominent sport and commercial species),

- Tidewater goby (Federally endangered),
- Green sturgeon (Federally threatened),
- Eulachon (Federally Threatened)

All but one of these species were already selected as being broadly representative of estuaries in most or a significant portion of California. The one relatively rare species, Green sturgeon, occurs primarily in San Francisco Bay and the Klamath River in California and possibly a few of the other largest river systems north of San Francisco Bay (Eel, Mad, Smith rivers). Thus it would represent only one or a few of the more than 400 identified estuaries (excluding San Francisco Bay) under consideration here. The southern population segment (DPS) of the Eulachon, *Thaleichthys pacificus* (Osmeridae), from Humboldt and Del Norte counties on the north coast, was recently listed as Federally threatened and has possibly been extirpated from northwestern California estuaries (Federal Register, 75 FR 13012 [March 18, 2010]). It is anadromous, traveling through the estuary to spawn in fresh water and the larvae pass back down largely to the marine environment in one or a few weeks. Thus it relies on the estuary for passage but otherwise makes only brief use of estuaries in California albeit during a sensitive period of the life cycle (larvae). Its conservation status may require its priority to be raised under our analysis.

Some of these species also have special legal or conservation status in the State of California in addition to their federal status, either as threatened biologically to some extent or regulated as sport or commercial species. The California Halibut and Pacific herring are two examples of important and highly regulated commercial and sport species.

WIDESPREAD SPECIES

The two species with the highest priority are found throughout California: the Threespine stickleback and Tidewater goby. Both species occur almost throughout the state, occur in the smallest to largest estuarine systems, and use the estuarine habitat for all four stages of the life cycle utilized here (Table 3.2), namely eggs, larvae, juveniles, and adults. Both are small species (typically less than 75 mm long) and live one to three years. The Tidewater goby has a larval life of about three weeks (Michael Hellmair, Humboldt State U., unpublished studies) and the larvae life of the stickleback is shorter. Stickleback larvae are benthic near the nest for a few days before the juveniles become free-swimming and leave the protection of the guarding male. Tidewater gobies require relatively well-oxygenated sandy substrates to dig burrows for deposition of the eggs 50-150 mm under the surface.

Table 3.3 Priority species selected with summary information on range, life history strategy and applicable beneficial uses. Range designations are as follows: All= throughout California, N=North of Point Conception, S= South of Point Conception. Life history designations are as follows

Species	Range	Life History	Applicable Beneficial Uses					
			EST	MAR	RARE	MIGR	SPWN	COMM
Staghorn sculpin, *Leptocottus armatus* (Cottidae)	All	Nursery	X	X				
Tidewater goby, *Eucyclogobius newberryi* (Gobiidae)	All	Residence	X		X		X	
Topsmelt, *Atherinops affinis* (Atherinopsidae)	All	Residence	X	X			X	X
Starry flounder, *Platichthys stellatus* (Pleuronectidae)	N	Nursery	X	X				X
Arrow goby, *Clevelandia ios* (Gobiidae)	All	Residence	X	X			X	
Threespine stickleback, *Gasterosteus aculeatus* (Gasterosteidae)	All	Residence	X	X	X		X	
Prickly sculpin, *Cottus asper*, (Cottidae)	N	Nursery	X	X		X	X	
Deepbody/Bay anchovy, *Anchoa compressa, delicatissima* (Engraulidae)	S	Residence, Nursery	X	X	?		X	
Rainbow trout/Steelhead, *Oncorhynchus mykiss* (Salmonidae)	All	Nursery	X	X	X	X		?Sport
Coastal cutthroat trout, *Oncorhynchus clarki clarki* (Salmonidae)	N	Residence	X	X	X	X		?Sport
Coho salmon, *Oncorhynchus kisutch* (Salmonidae	N	Nursery	X	X	X	X		X
King or Chinook salmon, *Oncorhynchus tshawytscha* (Salmonidae)	N	Nursery	X	X	X	X		X
California killifish, *Fundulus parvipinnnis* (Fundulidae)	S	Residence	X	X			X	X
California halibut, *Paralichthys californicus* (Paralichthyidae)	S	Nursery	X	X				X
Bay/Barred pipefish, *Syngnathus leptorhynchus, S. auliscus* (Syngnathidae)	S,All	Residence	X	X	X?		X	
Pacific herring, *Clupea pallasi* (often called *C. harengus* in the past) (Clupeidae)	All	Nursery	X	X			X	X

Shadow goby, *Quietula y-cauda*(Gobiidae)	S	Residence	X	X			X	
Cheekspot goby, *Ilypnus gilberti* (Gobiidae)	S	Residence	X	X			X	
Longjaw mudsucker, *Gillichthys mirabilis* (Gobiidae)	S	Residence	X	X			X	X
Diamond turbot, *Pleuronichthys guttulatus* (Pleuronectidae)	S	Nursery	X	X				X

The only native estuarine species that turns up more frequently than Tidewater gobies and Threespine stickleback in small to large estuaries is the Staghorn sculpin which is given third priority. The larvae and early juveniles come in from the ocean to settle in small to large systems in winter to early spring during winter flows and will spend much of the year feeding and growing in estuaries and bays. At the end of the year most will leave to the ocean or the mouths of estuaries near the ocean. Thus they spend most of a year in the estuary and more in larger or open systems. At southern localities they can be held in closed systems multiple years when low rainfall and runoff fails to initiate breaching of lagoons to the ocean. However, their likely most sensitive stages, eggs and larvae are primarily marine which makes them lower priority than the stickleback and tidewater goby. The Staghorn sculpin is listed first on Table 3.3 since frequency of occurrence was given more weight that presence of the sensitive egg and larval stages in the less prevalent Tidewater goby and Threespine stickleback.

The fourth and fifth species in priority, Topsmelt and Arrow goby, are less prevalent than the first three in tending to occur only in the larger more open systems, particularly north of Point Conception. As noted in the discussion about classification of estuaries (Section 2.2), these two species will occur in more of the smaller estuaries in wet years when they open more and acquire more of the estuarine species available. This also means their consistent presence is more restricted to larger systems that open more frequently or are perennially open. These two species both have all four life stages in the estuary with very different strategies and habitats. The Topsmelt is a midwater planktivore and benthic grazer, attaches it eggs to vegetation in the estuary, and the larvae are in mid-water and the surface for a few weeks. The topsmelt typically reaches 20 cm in length in estuaries and lives up to three or four years depending on latitude. The arrow goby reaches about 75 mm and lives on the bottom or in burrows, and like the tidewater goby lays its eggs in burrows in sand or mud on estuarine flats. The larval stage occurs in the estuary and nearshore coastal zone and probably lasts for a few weeks. Although the larval stage is only two or three weeks, larvae are produced for much of the year, at least in southern California. The topsmelt and arrow goby, after staghorn sculpin, are probably the most consistently present and abundant species in larger, more open coastal systems throughout the state. The topsmelt becomes less prevalent in some of the cooler systems in the northern part of the state.

The sixth species in the priority of the whole state is the Rainbow trout/Steelhead which is anadromous. It also occurred in a large number of systems historically but its requirement for substantial tributary spawning streams means it occurs in fewer systems than Tidewater goby or Threespine stickleback. The number of systems it occurs in is even lower today with its loss at many historical sites, particularly south of Pt. Conception. The steelhead eggs and larvae are upstream in the gravel of freshwater streams and the small juveniles, 40-200 mm can occur in coastal lagoons and estuaries for several months to a year before leaving for the ocean. They may remain for a second year in the northern part of the state due to slower growth or in the south with failure of lagoons to open to the ocean in dry years. Steelhead are relatively sensitive to oxygen but probably not as sensitive as the larval stages of Threespine stickleback and Tidewater gobies.

The remaining eleven species listed for most or all of California are each individually somewhat less representative of all estuaries but better represent the subset of open or larger "closed" systems, namely the closed systems that open frequently or are larger in size. As such they have lower priority than some species discussed below that are restricted in occurrence to north or south of Point Conception but better represent all estuaries in each region. Some of these eleven species are more prevalent south of Point Conception and occur only in the largest, systems that get warm in the summer north of Point Conception; such as Shiner perch, Cheekspot goby, and Longjaw mudsucker. One species, Bay goby, is more oceanic in the south and occurs only in the largest and deepest estuaries south of Point Conception and then in the lower intertidal zone. It is also only in the largest tidal systems north of Point Conception. Bay pipefish are also restricted to the largest systems that still have eelgrass or other healthy macrophytes. Among these, all but the Shiner perch spend all or most of their life history in these larger systems. The others like jacksmelt and the sharks and rays spend less time in estuaries and during the relatively less sensitive portions of their life histories. Pacific herring occur today effectively only north of Point Conception although historically south to San Diego Bay. It is an important commercial and sport species, has its most sensitive life stages, eggs and larvae, in the estuary, but only occurs in the largest open or mostly open systems north of Point Conception today.

NORTH OF POINT CONCEPTION

Of the species occurring north of Point Conception (Table 3.1), only the Starry flounder and Prickly sculpin are found in a large number of estuaries throughout the area. The Starry flounder come in as larvae and transformed juveniles and spend months growing in the estuary. The Prickly sculpin come down from freshwater tributaries to spawn in the upper estuary and the larvae and juveniles are usually common to abundant in the upper estuary. In the Big Sur area Prickly sculpin could be considered an estuarine indicator since among the many streams draining this steep terrain, only those few with actual developed estuaries, like the Big and Little Sur Rivers and Carpoforo Creek have populations of prickly sculpin. This is true despite the known marine dispersal of Prickly sculpin larvae. Prickly sculpin spend more of their life cycle in the estuary (than Starry flounder) and in the more sensitive life-stages of larvae and juveniles. Thus these two species rank among the best or highest ranked indicator species north of Point Conception including Threespine stickleback, Tidewater goby, Staghorn sculpin, and Steelhead. These species have higher priority than Arrow goby and Topsmelt [and Pacific herring] which are in a limited number of larger systems in the north. The remaining high priority species north of Point Conception are much more limited in distribution: Coho salmon north of Monterey Bay only, Coastal cutthroat trout Eel River and northward; King salmon, San Francisco Bay northward, and Longfin smelt, a few estuaries in Humboldt and Del Norte counties. Of these only the Coho salmon and Coastal cutthroat trout are found in a large number of estuaries within their distribution limits and only the

Coastal cutthroat trout spends enough significant time (several months or more) in the estuary to be considered important as indicator species. The remaining eight species are much more limited in estuarine occurrence and were included for various reasons noted above. Thus, in the group of species restricted to north of Point Conception, three species have strong qualifications for indicator species, Prickly sculpin, Starry flounder, and Coastal cutthroat trout and then only as close seconds to Threespine stickleback, Tidewater goby, Staghorn sculpin, and Steelhead from the group found throughout California. The three priority species for North of Point Conception are also higher priority than Topsmelt and Arrow goby which are restricted to a small number of larger and warmer systems in northern California.

SOUTH OF POINT CONCEPTION

All of the species restricted to south of Point Conception are characteristic the fewer and larger perennially open and the larger closed systems. Thus for the larger systems South of Point Conception species like California killifish, Shadow goby, Deepbody and Bay anchovy, Diamond turbot, and Striped mullet could augment high priority indicator species that represent the whole state like Tidewater goby, Longjaw mudsucker, Cheekspot goby, Arrow goby, Threespine stickleback, Topsmelt, Staghorn sculpin, and Steelhead. Ten of these fifteen species have all four life stages, eggs, larvae, juveniles, and adults primarily in the estuary: the California killifish, the two species of anchovy, the five species of goby, Topsmelt, and Threespine stickleback. These species also cover the benthic, midwater, shallow, deepwater, and both low and high salinity areas of estuarine systems in southern California. As such the estuaries South of Point Conception have a larger complement of good to excellent potential indicator species whose complete life cycle can occur in the estuary. The California halibut would not be given high priority based on its sensitive life stages, eggs and larvae, which are marine rather than estuarine. However, as a very important commercial and sport species, it could be given a high priority. However, likely standards for the more sensitive stages of other species may satisfy the requirements of the young 0-3 year old juvenile life stage of California halibut that require larger bays and estuaries to complete their life cycle.

NON-NATIVE SPECIES

A small number of non-native species are listed since they may be valuable in the absence of physiological data on native species. One of these species, the striped bass, *Morone saxatilis*, is already a well-known estuarine indicator species on the east coast of the United States and considerable information its physiology is available. It is also a prominent sport species in California. However, it primarily occurs in San Francisco Bay and is at best a rare and non-breeding species up and down the coast from San Francisco Bay. Another San Francisco Bay species, the Mississippi silverside, *Menidia audens*, has become common in a few southern California estuaries like the mouth of the Santa Clara River and Malibu Creek and may spread to other southern California localities. Much physiological data is available on the genus *Menidia* based on more marine species and presumably could apply to this species in California. The yellowfin goby is also primarily a San Francisco Bay species but is present in several California estuaries like Ballona Marsh/Marina del Rey complex, Los Angeles Harbor, Elkhorn Slough, Tomales Bay, San Diego Bay, and a few others. It is perhaps less likely that it would become important as an indicator given the several other native goby species available with similar life history characteristics. The live bearing mosquitofish, *Gambusia affinis*, probably occurs in a majority of the coastal estuaries in California but is often uncommon in those north of Point Conception. This is probably due to the fact that it requires two and a half to three weeks at water temperatures of 20^{o} C. or more to produce a brood of young. These conditions are often not met or restricted to a few protected areas where solar radiation can warm the water sufficiently in summer. In any case, mosquitofish can absorb oxygen from the surface film via vascularized skin on the top of the head. So they are very tolerant of low oxygen levels in the water and the eggs and larvae are contained in the live bearing females. Mosquitofish would not be expected to be good oxygen indicator species. These arguments against mosquitofish undoubtedly would largely apply also to sailfin molly, another live-bearing alien species in some southern California estuaries. The egg-laying Rainwater killifish, present today only in San Francisco and Newport bays, might become valuable if it became more widespread. It would have many of the same life-history characteristics as California killifish in having all life stages in the estuary.

Chapter 4. Selection of Macroinvertebrate Species

Howard Bailey, Martha Sutula

4.1 Introduction

The purpose of this section is to present the assumptions, methods and invertebrate species selected for consideration as indicator species for dissolved oxygen in bays and estuaries. The objectives of this effort were similar to those described in the Chapter 3 for the selection of fish, including:

1) Generate a list of invertebrate species characteristic of enclosed bays and estuaries;

2) Identify beneficial uses associated with each species;

3) For each species, identify life stages with respect to seasonality, habitat type and location within estuarine and associated nearshore and/or freshwater habitat areas;

4) Prioritize species for review of literature for physiological impacts associated with hypoxic conditions.

4.2 Approach and Assumptions

For consistency, criteria used select fish species (Chapter 3) were also used to elect candidate invertebrate species that would serve as the focus of a literature review of studies evaluating adverse effects associated with low DO concentrations (i.e., hypoxia). This list has not been vetted by an external list of experts.

4.2.1 General Criteria and Assumptions for Inclusion on Species List

The list of enclosed bays and estuaries found along the California coast, as identified by E-NNE Technical Team and vetted by SWRCB and advisory groups, was used as the primary basis for identifying invertebrate species likely to be associated with these habitats; note species unique to San Francisco Bay estuary were excluded this estuary is not within the scope of DO objective review. Thus, the potential breadth of species considered reflected the full complement of invertebrate species found in appropriate habitat throughout the state. Subsequent criteria were then used to focus the species selection process; these criteria included:

- Species must spend all or a substantial portion of their life histories in estuarine habitats; thus, only estuarine species found within marine enclosed bays would be included.

- Species should be clearly associated with regulatory categories and specific beneficial uses; thus, species that are considered rare or endangered, support recreational or commercial fisheries, or are of known ecological significance would be included.

~~Additional considerations included:~~

- ~~Species that are identical or closely related to species used to generate the East Coast Virginia Province Dissolved Oxygen Criteria.~~

- Species that are native to California; non-native species were considered if they met either of the following two conditions: 1) species that are considered recreationally or commercially important, and 2) species for which data on physiological effects of hypoxia are known to exist; thus, in cases where data were not available for native species, they could provide a basis for assessing effects.

Collectively, the species selection process incorporated several elements to ensure that it was comprehensive in terms of species considered, that it represented the desired species and habitat relationships, and that the species selected could be readily interpreted in the context of beneficial uses. In general, benthic invertebrate infauna were not included because of their innate tolerance to low dissolved oxygen concentrations~~.~~, unless the species has a pelagic life stage Therefore, fundamental considerations included presence in estuaries and bays, either as residents or during key life history stages, classification as rare or endangered, focus of recreational or commercial fisheries, and ecological importance. [MS1]

Life histories of identified species were reviewed through internet searches and compendia of coastal marine invertebrates (e.g., Light's Manual) to assess the extent of their potential association with estuaries. Identifying (or eliminating) species for further consideration was complicated by the fact that the objective of this study is related to developing DO criteria for enclosed bays *and* estuaries. By definition, estuaries encompass a range of salinities that can range temporally and spatially from freshwater to marine, thus supporting a wide range of species that vary in their tolerance to salinity. Conversely, enclosed bays typically exhibit a relatively narrow range of salinities, and are populated by primarily marine species. To reduce the extent to which nominally freshwater and marine species were included in the dataset, the following criteria were used:

- Species were included if they were associated with enclosed bays and estuaries, either as permanent residents or during key life history stages;
- Species were excluded if their distribution patterns and abundance did not depend on the specific habitats (i.e., enclosed bays and estuaries) of interest.

Thus, the selected species should be representative of species that depend upon these habitats for overall survival and well-being (e.g., critical spawning and nursery areas). This approach eliminated species that utilize these habitats opportunistically, but are more widely distributed and can complete their life cycles in other marine or freshwater habitats.

Species that could be readily related to specific beneficial uses were also identified. Rare and endangered species were identified through an internet search of California and Federal listings, first looking for invertebrates, and then invertebrates that fit the remaining selection criteria. The fisheries status of individual species was evaluated by review of California Department of Fish and Game fishery management plans and status reports. Species that supported identifiable commercial and/or recreational fisheries were noted, and further subjected to the remaining selection criteria before being added to the species list. Species not considered rare or endangered, or of significance to commercial or sport fisheries, were included if they could be clearly linked to "ecological significance"; e.g., were a significant dietary component of fish found in estuaries or enclosed bays (Moyle 2nd ed. Inland Fishes of California).

Given that data were already available for species used to generate the East Coast Virginia Province Dissolved Oxygen Criteria, ~~we also compared~~ species in that database were compared against California species to identify California species for which data ~~is~~ are already available, either as the same species or for a related species in the same genus or family. Thus, in the absence of data specifically for a California species, data would be available for a closely related species. California species identified as part of this "nearest neighbor" analysis were further evaluated to ensure that they were associated with the requisite habitat types (i.e., enclosed bays and estuaries).

This process resulted in a preliminary list of species that was then cross-referenced against literature available through the Aquatic Sciences and Fisheries Abstracts database to determine if the list was complete, or if additional species that met the above criteria needed to be added. The literature search focused on the list of enclosed bays and estuaries identified by SCCWRP (M. ~~Setula~~Sutula, SCCWRP, pers. comm.), cross-referenced against descriptive terms for invertebrates to identify references that associated specific invertebrates with specific water bodies. These invertebrates were then compared against the preliminary list to validate species already selected, and also to identify additional species for consideration. Additional species that met the general selection criteria were subsequently added to the list. Because California estuaries are classified according to "type", this review also provided a basis for determining whether there were sufficient data to associate specific species with particular estuary types. Thus, presence or absence of certain species from a given estuary might provide insight into the site-specific extent of DO-related impacts. Conversely, if a particular estuary type could not be associated with an identifiable species assemblage, or if DO sensitivity data for these species were lacking, these observations would represent data gaps that could be addressed in future studies.

Other key data sources included general internet inquiries, U.S. Fish and Wildlife and California Department of Fish and Game species accounts, and compendia of coastal marine invertebrates (e.g., Light's Manual).

Unlike for fish species, no initial prioritization of the list was conducted. Recommendations for elimination of species from list, typically because the species is predominantly marine, are included in descriptions of the text and table.

4.3 Species Lists and Rationale

4.3.1 Preliminary List of Species

The preliminary list of species is shown in Table 4.1. This is a comprehensive list representing species of special concern, as well as those associated with specific beneficial uses. Each of the listed species is briefly described below, with comments regarding its preliminary selection, as well as whether it meets all of the criteria for inclusion in the final list. Finally Table 4.1 provides notes as to whether a "nearest neighbor" exists within the EPA or Chesapeake Bay database on physiological effects of low dissolved oxygen.

Abalone—*Haliotis rufescens, H. cracherodii, H. wallensis* and *H. kamstchatkana*. Abalone are typically associated with hard substrates in intertidal and subtidal zones. The genus ranges along the California coast, with more restricted ranges associated with particular species. Some species currently or used to support important commercial and/or recreational fisheries, but populations have been markedly reduced by overfishing and withering foot disease, particularly in southern California. *H. cracherodii* is considered endangered by both state and federal agencies. Although abalone are a significant fisheries resource, and also represent one listed species, they are primarily marine with respect to salinity tolerance and are widely distributed along the open coast. Moreover, they do not depend on bays or estuaries either as preferred or essential habitat. Consequently, they do not meet the criteria for inclusion in the final list.

Barnacles—*Balanus sp*. and *Pollicipes sp*. Typically associated with hard substrate in intertidal zones, with planktonic larvae. Some species support limited commercial or recreational fisheries. While present in bays and estuaries, these habitats are not preferred or limiting. Consequently, they do not meet the criteria for inclusion in the final list.

Clams—a wide variety of clam species are found along the California coast. Adults are typically sessile, found inter or subtidally, and are generally associated with soft or gravelly bottom substrates where they may be buried at depth or located at or near the surface. Most species support commercial and/or recreational harvest. Early life stages typically involve a free-swimming larval period. Species include:

- Basket cockle—*Clinocardium nuttali*. Found along the California coast, preferred habitat includes bays and estuaries.
- Bent-nose clams—*Macoma nasuta, M. balthica*. Harvested in commercial and recreational fisheries; preferred habitat includes bays and estuaries.
- Butter clam—*Saxidomas giganteus, S. nuttali*. The focus of commercial and recreational fisheries, distributed from central California north along the coast. Preferred habitat includes protected bays and estuaries.
- Gaper clams—*Tresus nuttali, T. capax*. Found along the California coast, but relatively uncommon. Preferred habitat includes bays and estuaries.

- Geoduck—*Panopea generosa, P. abrupta*. Found in central and northern California, preferred habitat includes bays and estuaries.
- Jacknife clams—*Tagelus californianus, T. affinis, Solen sicarius, S. rostiformis (rosaceus*?). *T. californianus* and *S. rosaceus* are found from Santa Barbara south, whereas *S. sicarius* is found throughout California. All three species prefer quiet bays.
- Littleneck clams—*Chiones californiensis, C. fluctifraga, C. undatella, Protatheca laciniata, P. staminea, Tapes phillipinarum* (introduced). Found along the coast of California, although some species have more limited regional representation. Harvested in commercial and recreational fisheries, typically found intertidally and subtidally in bays and estuaries.
- Northern quahog—*Mercenaria mercenaria*. Introduced; very limited distribution (Colorado Lagoon, Alamitos Bay, Long Beach).
- Razor clams—*Siliqua patula, S. lucida*. *S patula* is found from central California north, and *S. lucida* from Monterey south, generally along open coasts. Consequently, these two species are not considered suitable for inclusion in the final species list.
- Soft shell clam—*Mya arenaria*. Introduced; prefers quiet bays and estuaries. Found from San Francisco north.

Crabs—a wide variety of crab species are found along the California coast, and include:

- Box crab—*Lopholithodes foraminatus*. This species has been reported from bays, and is taken in commercial and recreational fisheries. Widely distributed along the California coast subtidally to deep water. Because bays and estuaries are not preferred or essential habitat, it does not meet the criteria for inclusion in the final list.
- Cancer Crabs—*Cancer magister, C. productus, C. antennarius, C. productus, C. anthonyi* and *C. gracilis*. Cancer crabs represent several species that support significant commercial and/or recreational fisheries. While found in a variety of habitats, bays and estuaries are often preferred and are considered essential nursery areas for early life stages. Thus, these species meet the criteria for inclusion in the final list.
- Fiddler crab—*Uca crenulata*. Found intertidally in estuaries south of Santa Barbara. This species is recommended for inclusion in the final list.
- Hermit crab—*Isochelis sp., Pagurus sp*. While some species may be found in bays, bays and estuaries are not preferred or essential habitat. Consequently, these species are not recommended for inclusion in the final list.
- Mud crab—*Lophopanopeus bellus*. Intertidal to subtidal; found in California in bays and open coast, but rare south of San Luis Obispo. Bays and estuaries are not preferred or essential habitat; therefore, this species is not recommended for inclusion in the final list. The related Harris Mud crab (*Rhithropanopeus harrisii*) has been introduced to California, but is largely restricted to San Francisco Bay and estuary.
- Sheep crab—*Loxorhynchus grandis*. Found subtidally to depths exceeding 400 feet along the California coast from Marin County south, this crab supports a commercial fishery. There is an onshore migration associated with spawning, but no known dependence on bays or estuaries

for rearing of early life stages. Therefore, it is not recommended for inclusion in the final list of species.

- Shore crabs—*Pachygrapsus crassipes, Hemigrapsus oregonensis*. Found intertidally on rocky coasts, as well as in bays and estuaries throughout California. Larvae are planktonic. Bays and estuaries are not essential habitat, but these crabs are widely distributed in estuaries and associated marshes due to salinity tolerance where they are important in the diet of a number of species, including birds. Consequently, they are recommended for inclusion in the final list.
- Swimming crabs—*Callinectes bellicosus, C. arcuatus*. Found in shallow bays and lagoons in southern California, from Los Angeles south. Recommended for inclusion in final list.
- Umbrella crab—*Criptolithodes sitchensis*. Found along the California coast south to San Diego primarily in the intertidal zone. Bays and estuaries are not preferred or essential habitat; consequently, it is not recommended for inclusion in the final list of species.

Copepods—*Acartia* sp., *Eurytemora affinis*. Numerous species of copepods makeup part of the zooplankton present in bays and estuaries. Because of their importance to local food webs, they are recommended for inclusion in the final species list.

Mussels—*Mytilus californianus, M. galloprovincialis (edulis), M. trossulus, Modiolus rectus*. Mussels are bivalves that are typically attached to hard substrate as juveniles and adults, but early life stages are pelagic. Adult mussels support primarily recreational fisheries. They are widely distributed along the California coast, with one species (*M. galloprovincialis (edulis)* typically associated with bays and estuaries. *Modiolus rectus* is also associated with bays, but the distribution is more limited; i.e., from Bolinas Bay south. Both *M. galloprovincialis* and *M. rectus* are recommended for inclusion in the final species list.

Octopus—*Octopus bimaculoides, O. bimaculatus*. Range from Santa Barbara south; while found in bays, bays are not considered essential or primary habitat. Consequently, these species is not considered for inclusion in the final list.

Opossum shrimp—*Neomysis mercedis*. Opossum shrimp (Mysidae) are important components of nearshore food webs. One species in particular, *N. mercedis*, is associated with estuaries along the central and northern California coast. Consequently, this species is recommended for inclusion in the final list; other species associated with bays may be added to the list if it can be determined that bays are preferential habitat.

Oysters—*Ostrea lurida*. A native oyster, widely distributed along the coast of California, preferred habitat includes bays and estuaries.

Scallops—*Argopecten aesquilatus, Crassodoma gigantean*. The speckled scallop *A. aesquilatus* formerly supported a small fishery, but is currently rare. It is typically found in shallow bays and lagoons, usually in association with eelgrass, north to Elkhorn slough. The rock scallop *C. gigantean* is distributed along the entire California coast. It is associated with hard substrate in bays but also occurs on offshore reefs. Bays and estuaries are not preferred or essential habitat for this species. Thus, only the speckled scallop is recommended for inclusion on the final list.

Sea cucumbers—*Parastichopus californicus, P. parvimensis*. *P. californicus* occurs along the entire California coast, whereas *P. parvimensis* is present from Monterey Bay south. Both species support fisheries, but neither uses bays or estuaries as preferred or essential habitat. Consequently, sea cucumbers are not recommended for inclusion in the final list.

Spiny lobster—*Panulirus interruptus*. This species is found from Monterey Bay south, and is the focus of significant commercial and recreational fisheries. Their presence in bays is largely opportunistic and associated with rocky or hard substrate (jetties, breakwaters); onshore migrations are associated with spawning, but bays and estuaries are not a requirement for growth and development of early life stages. Nonetheless, eelgrass beds are considered important nursery areas. Consequently, due to its importance as a fishery, and the significance of eelgrass beds as nursery areas, this species is recommended for inclusion in the final list.

Snails—a variety of snails are found in nearshore habitats and support commercial or recreational fisheries.

- Kellet's whelk—(*Kelleta kelletii*). A relatively large gastropod, it is taken in both commercial and recreational fisheries, often in deeper water. It is primarily found in southern California, but has been observed in Monterey Bay. Because it does not use bays or estuaries as preferred or essential habitat, it is not recommended for inclusion in the final list.
- Moon snail—*Polinices sp*., *Euspira sp*. Often present in bays and estuaries, where it preys on clams and other bivalves. It is recommended for inclusion in the final list.

Sea urchins and sand dollars—*Strongylocentrotus purpuratus, S. franciscanus* and *Dendraster excentricus*. These echinoderms are widely distributed in inter- and subtidal habitats along the California coast. Sea urchins are associated with hard substrate, and sand dollars are typically found in sand. Sea urchins are the focus of commercial and recreational fisheries. However, these three species are primarily marine in terms of salinity tolerance, and do not depend on bays or estuaries as preferred or essential habitat. Thus, they do not meet the criteria for inclusion in the final list.

Shrimp—several species of decapods crustaceans are found in nearshore areas of California.

- Bay or Grass shrimp—*Crangon franciscorum, C. nigrocauda, Palaemon macrodactylus*. These medium-sized decapods are most frequently found in bays and estuaries, primarily in Central and Northern California. Typically epibenthic, but also found on pilings, and in eelgrass beds. Where abundant, they support commercial and recreational fisheries. Note that *P. macrodactylus* (Korean prawn) is an introduced species, but often co-occurs with *Crangon sp*.
- Ghost shrimp—*Callianassa* (now *Neotrypaea*) *californiensis*, *C. gigas, C. affinis*. These burrowing shrimp are found in soft bottom substrate in bays and estuaries along the California coast. Adults are tolerant of hypoxia, but larvae are planktonic. Ghost shrimp support recreational fisheries.
- Mud shrimp—*Upogebia pugettensis*. This species inhabits similar habitat to ghost shrimp, but is more tolerant of lower salinities. It also supports recreational fisheries.

- Coon-striped shrimp—*Pandalus danae*. Found from San Luis Obispo north, this species is found off-shore, as well as in bays. Thus, bays and estuaries are not preferred or essential habitat, and this species is not recommended for inclusion in the final list.
- Red rock shrimp—*Lysmata californica*. Found in rocky substrate from Santa Barbara south, with an apparently discontinuous population in Monterey Bay. It supports commercial and recreational fisheries, but its presence in bays appears largely associated with localized presence of substrate (habitat) in the form of rip or rock walls (e.g., breakwaters) and not to any other particular attributes associated with bays. Thus, bays and estuaries are not considered preferred or essential habitat, and this species is not recommended for inclusion in the final list.

Table 4.1 List of candidate invertebrate species with applicable beneficial use. [MS2]Designation coding: R= recommended, E= Eliminate

Category	Species Name (common)	Species Name (Latin)	RARE	COMM	SHELL	AQUA	MAR	EST	WARM	COLD	Design-ation	Nearest Neighbor for which DO physiology data available
Abalone	Black	*Haliotis cracherodii*	X	X	X	X	X	X			E	
	Red	*Haliotis rufescens*		X	x	x	X	X			E	
	Flat	*Haliotis wallensis*			X	X	X	X			E	
	Pinto	*Haliotis kamtschatkana*			X	X	X	X			E	
Barnacles	Acorn	*Balanus sp.*		X			X	X			E	
	Gooseneck and Stalked	*Pollicipes sp.*		X			X	X			E	
Crabs	Box	*Lopholithodes foraminatus*		X			X	X			E	Lithodidae
	Brown rock	*Cancer antennarius*		X			X	X			R	Genus level; Cancridae
	Red rock	*Cancer productus*		X			X	X			R	Genus level; Cancridae
	Yellow rock	*Cancer anthonyi*		X			X	X			R	Genus level; Cancridae
	Dungeness	*Cancer magister*		X			X	X			R	Genus level; Cancridae
	Slender	*Cancer gracilis*		X			X	X			R	Genus level; Cancridae
	Sheep	*Loxorhynchus grandis*		X			X	X			E	Family level (Pisidae)
	Umbrella	*Cryptolithodes stichensis*					X	X			R	Lithodidae
	Shore	*Pachygrapsus sp.; Hemigrapsus sp.*					X	X			E	Grapsidae
	Hermit	*Pagurus sp.; Isochelis sp.*					X	X			E	Paguridae
	Mud	*Lophopanopeus bellus*					X	X			R	Family level; (Panopeidae)
	Harris Mud	*Rhithropanopeus harrisii*					X	X			R	Introduced; same species (Panopeidae)
	Fiddler	*Uca crenulata*					X	X			R	Ocypodidae
	Green	*Carcinus maenus*					X	X			R	Introduced; same species (Portunidae)
	Swimming	*Callinectes bellicosus; C. arcuatus*					X	X			E	Genus level (Portunidae)
		Portunas xantusii					X	X			R	Family level (Portunidae)

Clams	Chiones	*Chione californiensis; C. fluctifraga; C. undatella*		X	X		X	X			R	Family level (Veneridae)
	Butter	*Saxidomus giganteus; S. nuttali*		X	x		X	X			R	Family level (Veneridae)
	Gaper	*Tresus capax; T. nuttalli*		X	X		X	X			R	Mactridae (or Hiatellidae)
	Geoduck	*Panopea generosa; P. abrupta*		X	X		X	X			R	
	Japanese littleneck	*Tapes (Venerupis) japonica; T. philippinarum*		X	X		X	X			R	Introduced; Family level (Veneridae
	Northern quahog	*Mercenaria mercenaria*		X	x		X	X			R	Introduced; same species (Veneridae)
	Razor	*Siliqua patula; S. lucida*		X	X		X	X			E	Penaeoideia or Cultellidae
	Rosy razor	*Solen sicarius; S. rostiformis*		X	X		X	X			R	Solenidae
	Common littleneck	*Protothaca staminea*		X	X		X	X			R	Family level (Veneridae)
	Rough-sided littleneck	*Protothaca (Leukoma) laciniata; P. staminea*		X	x		X	X			R	Family level (Veneridae)
	Thin-shelled littleneck	*Protothaca tenerrima; now Callithaca tenerrima*		X	X		X	X			R	Family level (Veneridae)
	Softshell	*Mya arenaria*		X	X		X	X			R	Myidae
	Jacknife	*Tagelus californianus; T. affinis*		X	X		X	X			R	Solecurtidae
	Bent-nose/Pink	*Macoma nasuta; M. balthica*		X	x		X	X			R	Tellinidae
	Basket cockle	*Clinocardium nuttallii*		X	X		X	X			R	Cardiidae
	Manila clam	*Venerupis philippinarum*		X	X	X						
Mussels		*Mytilus californianus; M. trossulus; M. galloprovincialis*		X	X		X	X			R	
		Modiolus sp.		X	X		X	X			R	
Octopus	Two-spot	*Octopus bimaculoides; O. bimaculatus*		X			X	X			E	
Oyster	Olympic	*Ostrea lurida*		X	X	X	X	X			R	Family level; (Ostreidae)
	Eastern	*Crassostrea virginica*		X	X	X	X	X			R	Introduced; same species

Shrimp	Bay	*Crangon franciscorum; C. nigricauda; C. nigromaculata*		X			X	X			R	Genus level
		Palaemon macrodactylus		X			X	X			R	Introduced; family level
	Coon-striped	*Pandalus danae*		X			X	X			E	
	Red rock	*Lysmata californica*		X			X	X			E	
	Blue mud	*Upogebia pugettensis*		X			X	X			R	
	Ghost	*Callianassa (now Neotrypaea) californiensis;*		X			X	X			R	
		C. gigas; C. affinis		X			X	X			R	
Scallop	Speckled	*Argopecten aequisulcatus*		X	X		X	X			R	Pectinidae
	Rock	*Crassadoma gigantea*		X	X		X	X			E	Pectinidae
Sea cucumbe r		*Parastichopus californicus; P. parvimensis*		X			X	X			E	
Snails	Moon	*Polinices (Euspira or Glossaulax) sp.*		X			X	X			R	
	Three-wing murex	*Pteropurpura trialata*		X			X	X			R	
	Trivia	*Trivia solandri; T. californiana*		X			X	X			R	
	Kellet's whelk	*Kelletia kelletii*		X			X	X			E	
Spiny lobster		*Panulirus interruptus*		X			X	X			R	
Top shell		*Trochidae; Turbinidae; Tegula (Chlorostoma) sp.*		X			X	X			R	
		Lirularis sp.		X							R	
Wavy top shell		*Turbinidae Astraea undosa; now Pomaulax gibberosa*		X			X	X			R	
		or Lithopoma undosum		X							R	
Echinode rms	Red urchin	*Strongylocentrotus franciscanus*		X			X	X			E	
	Purple urchin	*Strongylocentrotus purpuratus*		X			X	X			E	

	White urchin	*Lytechinus pictus*					X	X			E	
	Sand dollar	*Dendraster excentricus*					X	X			E	
Opossum shrimp		*Neomysis mercedis*					X	X			R	Family level; Mysidae
Copepods		*Eurytmora affinis*					X	X			R	Same species
		Acartia tonsa					X	X			R	

Note to reader:

Next sections involve comparisons with species used to derive Virginia Province DO criteria, and any additional species identified from the search on the list of specific bays and estuaries. [Hint: Bay and estuarine amphipods showed up consistently, and are an important dietary component of larger fish and invertebrates, as well as birds. Species whose distribution can be shown to be largely confined to estuaries and bays will be added to the list.]

Chapter 5 Review of Physiological Effects Data

5.1 Introduction

5.2 Approach

5.3 Findings

Chapter 6 Additional Considerations Supporting the Use of Dissolved Oxygen Objectives in California Estuaries

Chapter 7. Synthesis of Data Supporting DO Criteria and Recommendations

Literature Cited