LITTLE EGBERT MULTI-BENEFIT PROJECT FEASIBILITY STUDY

Attachment D – Biological Basis of Design

1 Introduction

The purpose of the Little Egbert Multi-Benefit Project (Project) is to provide flood risk reduction, support agricultural sustainability, boost ecosystem benefits, and provide recreational opportunities at the Little Egbert Tract (LET) in Solano County, California. The Feasibility Study (Study) seeks to identify and evaluate a variety of project alternatives according to their ability to meet the following multipurpose goals:

- **Enhance Public Safety:** Enhanced public safety, health, and quality of life for the State's citizens as outlined in State and local planning efforts (CVFPP, Lower Sac Delta North Regional Flood Management Plan, Solano County planning efforts). Reduce local and regional flood risk to agricultural and urbanizing areas while improving flood flow capacity by providing flood stage reductions and increased flood flow capacity within the Lower Yolo Bypass.

- **Protect and Enhance Natural Ecosystem Processes to Increase Habitat and Support Species:** Provide ecosystem and habitat restoration, as well as preserving and enhancing riparian and other native habitats to contribute to the recovery and sustainability of native species, where compatible with construction, operation, and maintenance of flood risk–reduction infrastructure, and consistent with adopted State and local plans. Create opportunities for environmental offsets and habitat restoration as outlined in local resource planning efforts (Central Valley Flood Protection Plan [CVFPP] Conservation Strategy, Delta Plan, Solano Habitat Conservation Plan, Cache Slough Habitat Conservation Plan).

- **Protect and Enhance Opportunities for Recreation:** Provide improved or new public outdoor recreation, education, and open space opportunities, where compatible with construction, operation, and maintenance of flood risk-reduction infrastructure, and consistent with the State and local plans.

This report assesses the site's potential for ecological restoration and establishes a biological basis for the design and prioritization of the alternatives. Several factors were considered including the Project site's landscape, ecological processes, special-status fish species, and habitat features that could be created.

2 Attributes and Considerations for Tidal Wetlands Restoration

Understanding the landscape context, site attributes, and the physical and biological processes that create and sustain habitats and species is valuable for informing restoration design. This information was synthesized from conceptual models prepared by the Interagency Ecological Program (IEP) Tidal Wetlands Monitoring Group (Sherman et al., 2017) and the IEP Management, Analysis, and Synthesis Team (IEP MAST) (Baxter et al. 2015), scientific literature about species and habitat requirements, and reports by the San Francisco Estuary Institute (SFEI) about Delta historical ecology and restoration (Whipple et al., 2012, SFEI-ASC 2016, SFEI 2020).

2.1 Landscape Attributes

Landscape attributes include the Project site's position on an elevation gradient (ecocline), land cover and land use, connectivity, regional transport, and seasonal patterns (Sherman et al., 2017). Understanding historical conditions informs what could be appropriate and sustainable for restoration. Landscape potential is most significant when selecting a site and predicting future influences will help with long-term sustainability. There are two ecological elevation gradients (ecocline) of importance for tidal wetlands. The site's position along the longitudinal ecocline from the ocean to the headwaters of rivers determines the relative influence of tidal and riverine (fluvial) processes, particularly the salinity and sediment regime (Sherman et al., 2017). Perpendicular to the longitudinal ecocline, the lateral ecocline extends from the river channel (subtidal aquatic habitat) to upland areas (including riparian habitat and higher elevation uplands). On this lateral ecocline tidal wetlands are generally located between mean higher high water (MHHW) and mean lower low water (MLLW).

The Project site lies at the interface of historic landscapes including the Yolo Basin, the Putah Creek alluvial fan, and expansive freshwater tidal marshes (Whipple et al., 2012). Historically, subtidal mud and sand bars, or "shoals," were present at the Delta mouth. Intertidal flats were present at the mouth of Cache Slough. Further upstream, sediment deposition from Sacramento River flood flows created natural, large levees with dense tall riparian forests. However, these natural levee deposits diminished downstream and eventually disappeared near Rio Vista. Historically, the riparian vegetation along Cache Slough primarily consisted of willow and alder scrub (Whipple et al., 2012). In-channel islands that were occasionally associated with shoals also supported riparian scrub and emergent marsh. For example, Wood Island near Rio Vista was a densely vegetated in-channel island that was removed when the Sacramento River was straightened and dredged (Whipple et al., 2012).

There are two significant habitat areas in this region: the Cache Slough Complex and the North Delta Habitat Arc. The Cache Slough Complex is currently recognized as one of the most promising areas for tidal freshwater habitat restoration due to its favorable elevation, intact regional drainage patterns, and connections with the Sacramento River (Moyle et al., 2016). The North Delta Habitat Arc, a corridor of fresh and brackish tidal aquatic habitat between the Yolo Basin and Suisun Marsh, provides essential habitat for native fishes such as Chinook salmon, delta smelt and green sturgeon. The region also plays a significant ecological role as an aquatic-upland transition zone.

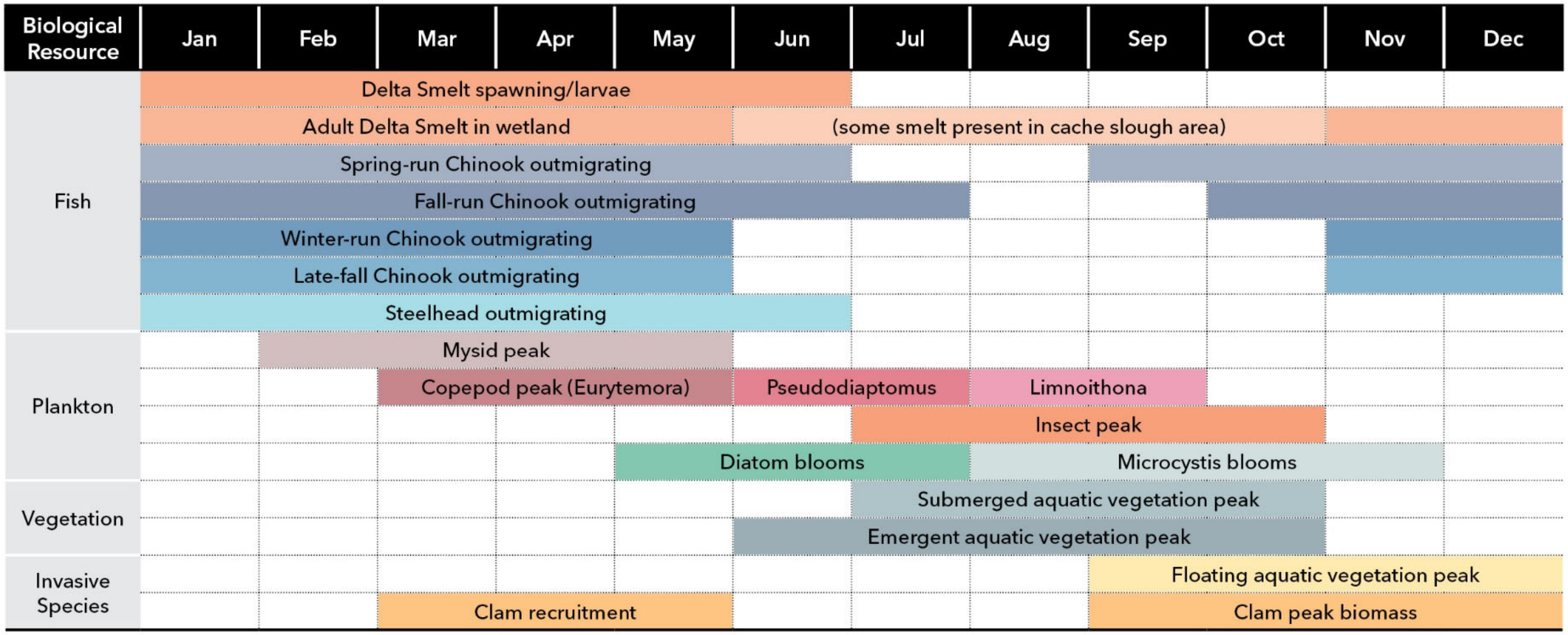
2.2 Site Attributes

Local ecological attributes encompass various elements such as the interfaces between tidal wetlands and adjacent upland and aquatic environments, hydrology, water quality, and localized sediment transport, deposition and erosion. Physical site attributes refer to characteristics within the project site itself. These attributes include internal hydrology (such as wave action, residence time, velocity, and inundation patterns), wetland evolution influenced by sedimentation and erosion, topographic heterogeneity (including channels, shoals, islands and vegetation patches), and water quality parameters (Sherman et al., 2017). Physical wetland structure and processes are key drivers of vegetation structure and biological processes including species composition and food web structure (Sherman et al., 2017).

Restoration actions, such as grading and breaching levees, significantly impact these interfaces and processes. Grading of land surfaces can create topography that will become above water habitat features (e.g., tidal emergent marsh and riparian habitat) and below water features (e.g., shoals, swales). Breaching allows varying levels of hydrological connectivity and inundation to the site depending on the size and shape of the opening. This, in turn, affects the physical and biological factors that contribute to the establishment and productivity of wetlands. The dynamic hydrologic processes interacting with the physical landscape create structural features that influence the vegetation communities that support various species. The amount and spatial arrangement of physical features will influence overall ecological function at the site (SFEI 2020). For example, providing abundant edge habitat may enhance foraging success for fishes (Gewant and Bollens 2012).

2.3 Species and Foodweb Production Attributes

Special-status fish species occur in the waterways surrounding the Study Area (Cache Slough, Sacramento River) but not within the area encompassed by flood-control levees. These species include delta smelt (*Hypomesmus transpacificus*), longfin smelt (*Spirinchus thaleichthys*), Sacramento River winter-run Chinook salmon (*Oncorhynchus tshawytscha*), Central Valley spring-, fall- and late-fall run Chinook salmon, California Central Valley Distinct Population Segment (DPS) steelhead (*Oncorhynchus mykiss*) and Southern DPS (*Oncorhynchus mykiss*) North American green sturgeon (*Ascipenser medirostris*). These species are all expected to occur in the area at various times throughout the year depending on life stage (**Figure 1**). Exchange and export of food web productivity (plankton, detritus) is another aspect of ecological function.



Biological Resource		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fish	Delta Smelt spawning/larvae	■	■	■	■	■	■						
	Adult Delta Smelt in wetland	■	■	■	■	■						■	■
	(some smelt present in cache slough area)						■	■	■	■	■		
	Spring-run Chinook outmigrating	■	■	■	■	■	■			■	■	■	■
	Fall-run Chinook outmigrating	■	■	■	■	■	■	■			■	■	■
	Winter-run Chinook outmigrating	■	■	■	■	■						■	■
	Late-fall Chinook outmigrating	■	■	■	■	■						■	■
	Steelhead outmigrating	■	■	■	■	■	■						
Plankton	Mysid peak		■	■	■	■							
	Copepod peak (Eurytemora)			■	■	■							
	Pseudodiaptomus						■	■					
	Limnoithona								■	■			
	Insect peak							■	■	■	■		
	Diatom blooms					■	■	■					
	Microcystis blooms								■	■	■	■	
Vegetation	Submerged aquatic vegetation peak							■	■	■	■		
	Emergent aquatic vegetation peak						■	■	■	■	■		
Invasive Species	Floating aquatic vegetation peak									■	■	■	■
	Clam recruitment			■	■	■							
	Clam peak biomass									■	■	■	■

SOURCE:
Sherman, S., R. Hartman and D. Contreras, editors. 2017. Effects of Tidal Wetland Restoration on Fish: A suite of Conceptual Models. Interagency Ecological Program Technical Report 91. Department of Water Resources, Sacramento, California.

Figure 1
Seasonal Occurrence of Special-Status Fish Species and Aquatic Biota
in the Sacramento-San Joaquin River Delta

3 Ecological Ranking Criteria

The Study ranks numerous alternatives according to their relative performance meeting Project goals, including ecological goals. The ecological ranking criteria are based on the Central Valley Flood Protection Plan (CVFPP) Conservation Strategy (Conservation Strategy), which was designed to contribute to the attainment of CVFPP goals, while focusing on improving ecosystem quality, quantity, function, and sustainability within the Systemwide Planning Area (SPA) (California Department of Water Resources 2022). The four goals of the Conservation Strategy promote ecosystem functions by integrating recovery and restoration of key physical processes, self-sustaining ecological functions, riverine habitats, and native species into flood management activities:

1. **Ecosystem Processes.** Improve dynamic hydrologic (flow) and geomorphic processes in the State Plan of Flood Control (SFPC) plan area or systemwide planning area (SPA).

2. **Habitats.** Increase and improve the quantity, diversity, and connectivity of riverine and floodplain habitats.

3. **Species.** Contribute to the recovery and sustainability of native species populations and overall biotic community diversity.

4. **Stressors.** Reduce stressors related to development and operations of the SPFC that negatively affect at-risk species.

The ecological ranking criteria defined for the Feasibility Study are presented in Table 1 and described in following sections.

TABLE 1
ECOLOGICAL RANKING CRITERIA AND CVFPP CONSERVATION STRATEGY GOALS

Criteria	Description	Ecosystem Processes	Habitats	Species	Stressors
RR-10	Increase and improve the quantity, quality, and connectivity of tidal wetland habitats (intertidal)		X		
RR-11	Increase and improve the quantity and quality of tidal habitats (tidal hydrological regime)	X			
RR-12	Increase and improve the quantity, quality, and connectivity of tidal aquatic habitats (open water, subtidal flats) for native aquatic species		X	X	
RR-13	Increase and improve the quantity, quality, and connectivity of floodplain habitats (riparian and upland), including upland transition zones to accommodate sea level rise (SLR).	X	X		
RR-14	Minimize conditions that would support significant infestations of priority invasive species (aquatic vegetation)				X

3.1 RR-10 Increase and Improve Tidal Wetland Habitats

Restoration of tidal wetland habitat can benefit native fishes both directly, through creation of new areas for rearing and refuge (Herbold et al., 2014), as well as indirectly, through food subsidies exported from intertidal habitats into adjacent open water habitat (Odum and de la Cruz, 1967, Sherman et al., 2017). This criterion considers whether alternative designs increase and improve the quantity, quality, and connectivity of intertidal wetlands.

Historically, the central and north Delta were dominated by expanses of freshwater tidal marsh laced with dendritic channel networks (Whipple et al. 2012). Currently, tidal wetlands are limited to isolated patches and narrow strands of emergent vegetation along channels.

Tidal processes and river inflows interact with site elevation and bathymetry to result in an inundation regime that influences which vegetation species can establish at a site (Sherman et al., 2017, *Chapter 6 Tidal Wetland Aquatic Vegetation Conceptual Model*). Factors that affect the colonization, establishment and growth of wetland vegetation include bathymetry (elevation, shape, patch size, channel network), substrate (soil characteristics, sediment inputs, nutrients), hydrology (inundation regime, hydrodynamics, water quality especially salinity), and availability of propagules (seed, rhizomes, vegetative fragments). Emergent vegetation in freshwater tidal marshes such as the Cache Slough Complex includes native species such as tules (*Schoenoplectus californicus* and *S. acutus* var. *occidentalis*) and cattails (*Typha*). In the high marsh several non-native species can invade wetlands, such as common reed (*Phragmites australis*) and perennial pepperweed (*Lepidium latifolium*) (Sherman et al., 2017).

Estuarine wetlands are important nursery habitat for juvenile Chinook salmon (reviewed by Sherman et al., 2017, *Chapter 9 Tidal Wetland Chinook Salmon Conceptual Model*). Marshes and riparian wetlands are characterized by high insect production, refuge from predation, and shade. Estuarine wetlands also contribute to salmon habitat complexity along the migration corridor by connecting floodplain and riverine habitats to freshwater tidal wetlands and brackish marshes. Juvenile Chinook salmon are known to forage in shallow areas with protective cover such as intertidal and subtidal mudflats, marshes, channels, and sloughs. Areas within 20 m of a wetland via channel networks are presumed to be most suitable for juvenile salmonids (SFEI 2020). Although juvenile steelhead are usually larger than juvenile Chinook salmon in the Delta, beneficial habitat features, and foraging use, are likely similar to those described previously for Chinook salmon (Weitkamp et al., 2022).

Emergent vegetation such as tules contribute to the food web dynamics of adjacent pelagic open water habitat by serving as substrate for epibenthic invertebrates, facilitating carbon export through plant detritus, and supporting plankton populations. Like juvenile salmonids, Delta smelt can have greater foraging success with increased tidal wetlands due to increased access to prey, such as zooplankton, exported into open water habitat (Odum and de la Cruz 1967, Dame et al., 1986), and/or foraging within or along the edge of tidal wetland before returning to the open water (Herbold et al., 2014, Hammock et al., 2019).

A high ranking for this criterion would include extensive bands of tidal emergent wetlands along the shoreline (i.e., ≥200ft of tidal habitat edge) and a wide berm in the intertidal zone. Current conceptual designs would show this as large patches of tidal emergent wetlands with adjacent channels. A medium ranking would have narrow bands of tidal emergent wetlands along the shoreline (i.e., 50-200 ft of tidal habitat edge) and most likely a narrow habitat berm, though a large habitat berm may be present, in the intertidal zone. In concept, this would look like narrow patches of tidal emergent wetlands with limited or no interior channels. A low ranking would be small/limited bands of tidal emergent wetlands with no interior channels (i.e., ≤50 ft of tidal habitat edge) and narrow to no habitat berm. Conceptual designs would show limited to no patches of tidal emergent wetlands with no interior channels present.

3.2 RR-11 Increase and Enhance Tidal Hydrologic Regime

Restoring full tidal inundation and fluctuation is key to creating tidal habitat. This criterion ranks the alternative designs based on whether they improve the quality of the tidal hydrologic regime. Higher residence time is associated with higher productivity, although stagnant conditions can cause water quality problems (CHABS, low DO) and may promote invasive aquatic vegetation.

Marsh topography that increases water residence time and traps detritus can foster increased productivity of juvenile salmon prey and concentration of terrestrial drift invertebrates (Simenstad et al., 2000). Juvenile Chinook salmon use these tidal flows as well as active swimming to move in and out of tidal wetlands, as demonstrated by tagged fish (Hering et al., 2010). In addition to the benefits to juvenile salmon, delta smelt may also benefit from an increased and enhanced tidal hydrologic regime because they are most frequently collected in water where tidal currents exist but are not excessive (Moyle et al., 1992) but are also found in large channels with strong tides (Sommer and Mejia 2013). Furthermore, delta smelt larvae require adequate flow to prevent entrainment (USFWS 2017). Enhanced water quality and food export resulting from an increased and enhanced tidal hydrologic regime could contribute to or promote benthic invertebrates (e.g., corophiid amphipods) in nearby areas thereby enhancing foraging habitat for green sturgeon.

A high ranking for this criterion would have open flow with full tidal exchange. There would be no tidal muting. Based on the conceptual designs of the preliminary alternatives (Feasibility Study, Section 5.2 Preliminary Alternatives) this level could be defined as two full levees breaches. A medium ranking for this criterion would have tidal exchange but it would be muted due to breech size and configuration, topography or other site characteristics. On the alternative conceptual designs this could be defined as a single, full breech and a second compound breech or breech with a sill at plus 7.5 ft or greater. Finally, a low ranking for this criterion would have limited or no tidal exchange with substantial tidal muting. On the alternative conceptual designs, any breaches would be defined as compound or with a sill plus 7.5 ft or greater.

3.3 RR-12 Increase and Enhance Tidal Aquatic Habitats

This criterion ranks alternative designs based on whether they increase and improve the quantity, quality, and connectivity of open water (pelagic) and sub-tidal flats for native aquatic species. **Figure 1** illustrates the seasonal occurrence of aquatic species in the Delta. Because of the differing habitat preferences among fish species, the design guidance is to create a mosaic of diverse habitats of various depths (bathymetric heterogeneity).

Delta smelt are estuarine specialists that are primarily pelagic. They typically occupy open water and favor conditions of high turbidity, low salinity and relatively low water velocities (Moyle et al., 1992, Moyle 2002, Baxter et al. 2015, Sherman et al., 2017). Juvenile Delta smelt are most frequently collected in somewhat shallow water (1.5 – 4.5m [~4-15 ft] deep) (Moyle et al., 1992). Sub-adult and adult delta smelt also use shoal and edge habitats as tidal current refuges (Bever et al., 2016), migratory corridors to spawning habitats (Bennett and Burau 2015), and foraging habitat (Hammock et al., 2019). Hydrodynamic modeling of historic catch and metrics of environmental complexity (salinity, current speed and turbidity) found the velocity metric was a better predictor of the historical delta smelt catch than water depth, suggesting that lower-velocity areas may be a more important habitat characteristic than shallow water depth for delta smelt (Bever et al., 2016). Delta smelt have been documented foraging in the Liberty Island restoring wetland, which includes extensive shallow open-water areas as well as marsh and tidal channels (Whitley and Bollens 2014).

Longfin smelt frequently occur in shallow, tidal marshes, especially in low-flow years (Merz et al., 2013; Grimaldo et al., 2020). High densities of newly hatched longfin smelt larvae observed in open-water shoals (1-5 m [3.3-16.4 ft] deep) and tidal sloughs (3-10 m [9.8-33 ft] in width and 1-3 m [3.3-9.8 ft] in depth) indicate these are spawning habitats (Grimaldo et al., 2017). Successful spawning and growth has been documented in recently restored tidal marshes in the South Delta approximately 2 to 3 m (~ 6.5-10 ft) in depth (Lewis et al., 2020).

Chinook Salmon of all four ESUs (Sacramento River winter-run, Central Valley spring-, fall-, and late-fall run) can rear in intertidal and subtidal marshes, channels, and sloughs. Juvenile salmonids use habitat between 0.4-4 ft deep with flow velocities less than 1.6 feet per second depths (USFWS 2005). Shallow water foraging habitat is important for juvenile Chinook salmon. Small size classes favor shallow water habitats, with the smallest rearing in shallow peripheral channels regardless of vegetation types (Bottom et al., 2012). Marsh corridors and shallow water habitat that fringes channels may also have a large beneficial effect on out-migrating salmon (Hanson et al., 2012, Jones et al., 2014, Goertler et al., 2017). Providing abundant edge habitat may enhance foraging success for fishes (Gewant and Bollens 2012).

Green sturgeon juveniles can rear in riverine, subtidal, and inter-tidal habitats in the lower mainstem of rivers (Klimley et al., 2015). Juveniles may also utilize shallow water habitat (1-3 m [~3.3-10 ft] deep; Radtke 1966). An acoustic tracking study of six juvenile green sturgeon individuals in the Sacramento-San Joaquin Delta showed that depths utilized by the sturgeon ranged from >3 to 20 m (10- (Thomas et al., 2019).

Suitable water depths for juvenile salmon were adapted from criteria for the Lower Willamette River (Friesen 2005) and the winter-run life cycle model (Hendrix et al., 2014) as reviewed by SFEI (2020). Water depths between 0.2 and 1.5 meters (~0.6-5 ft) were considered most suitable. Water depths between 1.5 and 3 m (~5-10 ft) were the next most suitability. Water depths between 3 and 6 m (~10-20 ft) were given the lowest suitability. Water depths of 0 to 0.2 m (~0-

0.6 ft) were considered unsuitable habitat because these waters are too shallow. However, they may provide other benefits (vegetation, refuge, etc.) so are given a very low suitability overall but are not entirely discounted. Water depths greater than 6 m were considered unsuitable as rearing habitat (SFEI 2020).

Pelagic open water (>15 feet deep) habitat is important for pelagic fish species such as delta smelt, longfin smelt, and green sturgeon. Adult smelt and sturgeon prefer deeper water, with smelt orienting to the mid-water and green sturgeon orienting to the bottom. Subtidal flats are shallow unvegetated shoals at elevations between mean lower low water (MLLW) and 10-15 feet deep. These shoals provide refuge and foraging habitat for juvenile fishes, including salmonids and smelt, and may provide spawning areas for delta smelt and longfin smelt. Green sturgeon may also use subtidal flats during nocturnal foraging.

A high ranking for this criterion would have a mosaic of open water and sub-tidal flats to increase aquatic habitat diversity, including shallow areas at depths preferred by juvenile salmonids (less than 5 ft deep). In the context of the current conceptual drawings, there would be substantial bathymetric heterogeneity (swales, flats, inlets, channels, etc.). A medium ranking in this criterion would have a less diverse mosaic of open water and sub-tidal flats that are more than 5 ft deep. In the context of current conceptual drawings, this would consist of some bathymetric heterogeneity but tending towards either shallow or deeper habitats (e.g. – primarily swales with limited flats, inlets or channels or primarily deep channels with limited swales and flats). A low ranking would be dominated by either pelagic open water (i.e. – mostly > 3 m (10 ft) in depth) or shallow sub-tidal flats (i.e. – mostly < 1.5m (5 ft) in depth). Current conceptual drawings would show little to no bathymetric heterogeneity (i.e. – complete or functional absence of one or more bathymetric habitat types) that would normally be added to design drawings.

3.4 RR-13 Increase and Enhance Floodplain Habitats

Functional, connected floodplain habitats that provide hydraulic and hydrologic connectivity, necessary nutrient fluxes between terrestrial and aquatic habitats, and physical processes that support establishment and growth of riparian habitats are critical for promoting a healthy, integrated ecosystem. This criterion rates alternative designs by whether they increase and improve the quantity, quality, and connectivity of riparian and upland floodplain habitats, including upland transition zones to accommodate anticipated sea level rise and climate change events.

Seasonal floodplain inundation diversifies and expands the available habitat for juvenile Chinook salmon, provides an alternative migratory route, and promotes juvenile growth through increased food resources (Sommer et al., 2001 and 2005, Goertler et al., 2018). The value of floodplain habitat is similar for delta smelt. Mahardja et al., (2019) suggest that the Yolo Bypass, the primary floodplain of the Sacramento River, acted as a nursery and refuge for delta smelt during the drought years of 2012-2016. Their results indicated that, when compared to other areas of the estuary, offspring experienced both higher quality feeding conditions and growth rates.

Creation and restoration of areas in the tidal-terrestrial zone is important to support interactions between tidal and fluvial/terrestrial processes and thus allow transgression of habitats over time in response to sea level rise (SFEI-ASC 2016, Whipple et al., 2022). The tidal-terrestrial zone, also known as the "sea level rise accommodation" band in the Delta Plan, is characterized by areas located between elevations 0 and 10 ft above MHHW (Mean Higher High Water). This zone supports a mosaic of habitat types, ranging on a gradient from riparian habitat along channels and bordering tidal marsh (elevations above MHHW) to upland habitat such as grasslands and oak woodland (SFEFI-ASC 2016). The criterion assessing how the design alternatives provide tidal-terrestrial zone habitat is based on the amount of area (linear feet and width of habitat bench) defined within the tidal-terrestrial zone (<10 ft above MHHW).

Woody riparian habitats in the Delta are typically found on natural and artificial levees bordering channels (Whipple et al., 2022). Suitable conditions for woody riparian vegetation include areas above MHHW elevation that have appropriate hydrological conditions (e.g., riverine flooding and depth to water table within woody vegetation rooting zone), and suitable soil texture (e.g., alluvial soils with sand and silt) (Griggs 2009, Whipple et al., 2022). Restoring woody riparian habitat adjacent to marshes would recreate historic landscape patterns, improve habitat complexity and function and benefit a wide array of wildlife (SFEI-ASC 2016). Many terrestrial species benefit from access to upland habitat that is adjacent to wetlands.

Levee setbacks, full removal, or breaching at selection locations can enhance hydrological connectivity and establish desired floodplain inundation to areas above MHHW elevation to promote processes that drive habitat complexity and variability (Whipple et al. 2022). Most areas of LET are below MHHW (i.e. intertidal or subtidal) except for a portion in the southern area. Additional areas that would be suitable for riparian habitat could be created as planting benches on the channel side of the levee or in-channel islands, which would provide not only riparian habitat for terrestrial wildlife but also shaded habitat for adjacent channel aquatic habitat.

In summary, a high ranking for this criterion would have extensive lengths of shoreline in the tidal-terrestrial zone (0 to 10 ft above MHHW). It would also have wide benches greater than 200 feet wide in the tidal-terrestrial zone and islands for riparian habitat that are greater than 50 feet wide. Conceptual designs would show this as a wide habitat berm and islands. A medium ranking for this criterion would be 50-200 feet wide tidal-terrestrial zone and with narrow (about 30-50 feet wide) and limited areas for riparian habitat. Conceptual designs would show this as a narrow habitat berm and no islands. A low ranking for this criterion would be less than 50 feet wide tidal-terrestrial zone and areas for riparian habitat less than 30 feet wide. Conceptual designs would show this as a very small, narrow, or non-existent habitat berm.

3.5 RR-14 Minimize Invasive Species

Minimizing conditions that would support significant infestations of priority invasive species, including *Egeria spp*., water hyacinth, and non-native predatory fish, is critical for creating successful and productive aquatic habitat. This criterion ranks designs based on creating appropriate depths (and flow velocities) to reduce establishment of invasive plant species and providing habitat types and configurations to limit non-native predator residency and effectiveness.

Brazilian waterweed (*Egeria densa)* is an invasive submerged aquatic vegetation (SAV) that establishes in shallow water and can increase water clarity by trapping sediments, lower dissolved oxygen, and provide habitat for non-native predatory fish (black bass species). These species can establish in depths up to 7m (~21ft) making the inclusion of pelagic channels important for maintaining high quality habitat. Depth and turbidity are strongly correlated with *Egeria,* which is commonly found at water depth from 1 m above to 2 m below MLLW (range 11 m [36 feet] below MLLW to 1.1 m [3.6 feet] above MLLW), turbidity between 5– 10 NTU, and mean flow velocity 0–0.5 meters per second (1.6 feet per second) (Durand et al., 2016). Increasing water column depth strongly limits *Egeria* occurrence, especially when depth at MLLW exceeds 2 m (3.3 feet) (Durand et al. 2016). In Lindsey Slough, a tidal backwater located just upstream of the Project area, *Egeria* was present at sites with mean depth 1.2–1.8 m and absent at sites with mean depth 5.1–6.9 m (Lacey et al. 2021). If established, these plants could dominate open water areas, forming a thick canopy that alters hydrodynamics and reduces flow velocity, shades out phytoplankton, increases temperatures, filters sediment from the water column, and reduces dissolved oxygen when the excess material decomposes (Downing-Kunz and Stacey 2012, Durand et al., 2016, Lacy et al. 2021).

Water hyacinth (*Eichhornia crassipes*) is an invasive floating aquatic vegetation (FAV) that shades out phytoplankton (primary productivity), covers open water in marshes and sloughs (habitat for giant garter snake), alters water clarity and can decrease dissolved oxygen, nitrogen, phosphorous, heavy metals and other contaminants (Villamagna and Murphy 2010). Effects on fish communities are largely dependent on original composition and food-web structure. However, the decreased phytoplankton is likely to lead to lower dissolved oxygen and reduced abundance of juvenile fish that feed on them (Villamagna and Murphy 2010). Most fish living in water hyacinth patches in the Delta were non-native, such as smallmouth bass and bluegill (Toft 2000).

Invasive plant and fish species are inter-related as submerged aquatic vegetation can provide habitat for invasive warmwater fishes (e.g., centrarchids, black bass) that compete with and prey on native fishes (Grossman 2016, Durand et al., 2016). Narrow channels creating pinch points and velocity gradients or eddies may create favorable ambush conditions for predator species as small-bodied, native fish species may be unable to detect predators or may become disoriented in turbulent flows making them more susceptible to predation.

A high ranking for this criterion would have sub-tidal elevations greater than -15 ft (i.e., water depth greater than 15 ft). Conceptual designs would display this as full tidal exchange and subtidal swales with no shoals. A medium ranking would have sub-tidal elevations between -8 feet and -15 feet. Conceptual designs would display this as full tidal exchange and swales with shoals or no swales or shoals. A low ranking would have sub-tidal elevations less than -8 feet. Conceptual designs would display muted tidal exchange with or without swale/shoals.

4 Qualitative Ranking Values

Qualitative values of high, medium and low ecological benefits were defined for each criterion (**Table 2**) to allow scoring and ranking of the Project Alternatives in the Feasibility Study.

TABLE 2
ECOLOGICAL BENEFITS CRITERIA WITH RANKING LEVELS

Criterion	Description	High	Medium	Low
RR-10	Increase and improve the quantity, quality, and connectivity of tidal wetland habitats (intertidal)	Wide band of tidal emergent wetlands (>200ft edge) with a wide intertidal berm, forming large patches with adjacent channels.	Narrow band of tidal emergent wetlands (50-200 ft edge) with a narrow intertidal berm, resulting in narrow patches with limited interior channels.	Limited tidal emergent wetlands (<50 ft edge) with no interior channels and narrow to no berm.
RR-11	Increase and improve the quantity and quality of tidal habitats (tidal hydrological regime)	Open flow with full tidal exchange	Tidal exchange muted due to breech size/configuration, topography or other site characteristics	Limited or no tidal exchange with substantial tidal muting
RR-12	Increase and improve the quantity, quality, and connectivity of tidal aquatic habitats (open water, subtidal flats) for native aquatic species	Diverse mosaic of open water and sub-tidal flats with a variety of depths	Mosaic of open water and sub-tidal flats.	Simple bathymetry of pelagic open water or shallow sub-tidal flats
RR-13	Increase and improve the quantity, quality, and connectivity of floodplain habitats (riparian and upland), including upland transition zones to accommodate sea level rise (SLR).	Wide habitat berm with ≥200 ft wide shoreline in the tidal-terrestrial zone and islands that provide extensive and wide areas of riparian habitat (≥50 ft wide).	Narrow habitat berm with 50-200 ft wide shoreline in the tidal-terrestrial zone and extensive areas of riparian habitat (30-50 ft wide).	Little or no habitat berm with <50 ft wide shoreline in the tidal-terrestrial zone and limited or narrow areas of riparian habitat (<30 ft wide).
RR-14	Minimize conditions that would support significant infestations of priority invasive species (aquatic vegetation)	Subtidal elevations greater than – 15 ft to discourage SAV	Subtidal elevations between -8 feet and -15 feet	Subtidal elevations less than -8 feet

5 Design Considerations and Guidelines

All alternatives would provide net gains in aquatic, tidal wetlands, and riparian habitat, in varying amounts and spatial arrangements. Dynamic hydrologic processes interacting with the physical landscape create structural features, which result in vegetation communities that support various species. The amount and spatial arrangement of physical features will influence overall ecological function at the site (SFEI 2020). Restoration design plays a significant role in shaping the physical attributes of the site, influencing its structure and the underlying processes. This section summarizes guiding principles for desired habitat types: tidal aquatic, intertidal wetlands, riparian and upland transition.

5.1 Tidal Aquatic

Elevation (bathymetry) and hydrologic processes (tidal and fluvial) influence aquatic habitat structure and complexity and hence affect fish communities. Restoring tidal hydrologic processes is a key driver for creating tidal habitat. Food web production is an important component during the life cycle of many species of special concern such as Chinook salmon, green sturgeon, longfin smelt, Sacramento splittail, and delta smelt. Marsh topography that increases water residence time and traps detritus can foster increased productivity of juvenile salmon prey and concentration of terrestrial drift invertebrates (Simenstad et al. 2000). Allowing tidal waters to inundate the LET would increase aquatic food resources in this area of the Cache Slough Complex, with the greatest production likely from emergent marsh.

Key parameters for fish habitat suitability include water depth and temperature, as well as wetland proximity and wetland edge (SFEI 2020). Different species and lifestages have varying depth preferences, so providing bathymetric heterogeneity maximizes habitat opportunities. Depth thresholds defined for juvenile salmon rearing habitat suitability are as follows: 0.0 – 0.6 ft (less than 0.4 m) insufficient depth (unsuitable), 0.6 – 5 ft (0.4 – 2 m) shallow habitat (highest suitability), 5 – 10 ft (2 – 3 m) deep habitat (suitable), 10 – 20 ft (3 – 6 m) pelagic habitat (unsuitable) (Sherman et al., 2017, SFEI 2020, Ayers et al. 2022). Delta smelt are midwater fish that are most frequently collected in areas 4 – 15 ft deep (deep habitat) that have turbid water and moderate tidal currents (Moyle et al., 1992). Green sturgeon are bottom-oriented fish that utilize the depths of pelagic habitat, ranging from 10 – 65 ft deep, although juveniles may also use shallower areas from 4 – 10 ft deep.

Grading designs for the LET should consider creating diverse topography that will maximize bathymetric heterogeneity and thus provide diverse habitat for multiple species. This can be achieved by excavating swales for deeper habitat, while grading areas and building berms to create in-channel islands (above MHHW) bordered by shoals and shallow water habitat. One challenge will be balance cut and fill to meet needs of levees and terrestrial habitat features (habitat benches above MLLW).

Areas lacking sufficient tidal flushing may experience stagnant conditions with poor water quality (low dissolved oxygen, CHABs). Shallow areas with minimal currents may be colonized by invasive aquatic vegetation, which can reduce turbidity needed by delta smelt and support non-native predatory fish. Depths greater than 2 m (3.3 ft) below MLLW are recommended to discourage establishment of *Egeria* (Durand et al., 2016, Lacy et al. 2021). Placement of shoals and in-channel island features should avoid creating backwater areas that could become stagnant or harbor dense aquatic vegetation.

Aquatic food web productivity is crucial for fish species of special concern including Delta smelt, longfin smelt, Chinook salmon, and green sturgeon. Allowing tidal waters to inundate the LET would increase the productivity of aquatic food resources in the Cache Slough Complex, with emergent marshes likely contributing the most. Marsh topography that increases water residence time and traps detritus promotes increased productivity of juvenile salmon prey and concentration of terrestrial drift invertebrates (Simenstad et al., 2000). However, stagnant conditions in dead-end channels can lead to water quality problems (cyanobacteria harmful algal blooms (CHABs), low DO) and may facilitate the growth of invasive aquatic vegetation.

5.2 Intertidal Wetlands

The focus should be on increasing the area within intertidal elevations by site grading and/or addition of fill material. In general, marshes should be as large as possible, with more core and less edge, and distance between marsh patches should be minimized (SFEI-ASC 2016). Certain physical processes and habitat functions may not naturally occur in small patches, such as evolution of a full channel network (over 1,200 acres) (SFEI-ASC 2016). Tidal marshes should experience full tidal action to provide access for foraging aquatic organisms, enhance export of productivity, and promote marsh accretion via sediment deposition and accumulation of vegetative matter (SFEI-ASC 2016).

Establishment of wetland vegetation is affected by inundation regime, water velocity (including exposure to waves), salinity, substrate, and connectivity to existing patches of vegetation (Sherman et al, 2017). Vegetation in freshwater emergent tidal marshes of this area includes native species such as tules (*Schoenoplectus californicus* and *S. acutus* var. *occidentalis*) and cattails (*Typha*). In the high marsh several non-native species can invade wetlands, such as common reed (*Phragmites australis*) and perennial pepperweed (*Lepidium latifolium*) (Sherman et al., 2017). Studies of Liberty Island (Sloey et al., 2015) found that *S. californicus* typically occupies lower elevations (up to 0.2m below MLLW) and more exposed sites because it is more tolerant of flooding than *S. acutus*. Native vegetation can naturally colonize sites, but plantings can accelerate establishment and minimize risk of invasion. Transplants of adult tules and cattail can establish more successfully than rhizomes, especially in compacted soils that hinder underground growth (Sloey et al., 2015). Exposure to wind fetch and wave action can affect establishment and should be considered in placement and configuration of tidal marsh within the site.

5.3 Riparian and Uplands

Riparian habitat occurs along channels and bordering tidal wetlands at elevations above MHHW. These areas undergo seasonal flooding, leading to the deposition of fine sediment and promoting the growth of vegetation. A key design consideration is creating an elevation gradient from intertidal to riparian and higher uplands (tidal-terrestrial transition zone). Where possible, the total length, longitudinal continuity and width of the tidal-terrestrial transition zone (between elevations 0 and 10 ft above MHHW) should be maximized as much as feasible (SFEI-ASC 2016). The area within 250 m of the tidal wetland is important as a buffer zone (California Wetlands Monitoring Workgroup 2012) and habitat for terrestrial species. In addition, a broad transition zone will also accommodate sea level rise by providing space for habitat migration or transgression to higher elevations. The amount of intertidal wetland and riparian habitat will be determined by the size (width) and elevation of habitat benches constructed along the levee toe.

Historically, the riparian habitat in the North Delta consisted of riparian scrub (Whipple et al., 2012). Sandy dredge spoils provide suitable conditions for recruitment of sandbar and arroyo willow. Additional plantings can be used to initiate vegetation growth with a desired mix of tree, shrub and herbaceous species. **Table 3** summarizes ecological tolerances of riparian plant species in the Central Valley and Delta (Griggs 2009).

TABLE 3
ECOLOGICAL TOLERANCES OF RIPARIAN PLANT SPECIES

Species	Water Table Required	Maximum depth to water table	Tolerates long duration flooding	Optimal landscape setting[1]
Black willow *Salix gooddingii*	Yes	3 meters	Yes	Heavy clay soils; seasonal wetland basins; perimeter of permanent wetlands
Sandbar willow *Salix exigua*	Yes	2 meters	Yes	Sandy soils; on point bars
Arroyo willow *Salix lasiolepis*	Yes	3 meters	Moderate	Loamy soils; upper bankfull flow
Red willow *Salix lasiandra*	Yes	7 meters	No	Upper floodplain, on tributaries
Fremont Cottonwood *Populus* fremontii	Yes	7 meters	Yes	Sandy and loamy soils, lower floodplain
Buttonbush *Cephalanthus occidentalis*	Yes	3 meters	Yes	Perimeter of permanent wetland; freshwater tidal marsh
White alder *Alnus rhombifolia*	Yes	< 1 meter	No	Edge of channel
Western sycamore *Platanus racemose*	Yes		No	Sandy loams; well-drained
Oregon ash *Fraximus latifolia*	No		Yes	Edge of channel; loamy soils in basins
Valley Oak *Quercus lobata*	No		Yes	Upper lloodplain; fine textured, well-drained soild during growing season
Box-Elder Acer negundo	No			Mid to upper floodplain; loamy soils
Blue Elderberry Sambucus mexicana	No			Loams on upper floodplain
Coyote Brush Baccharis pilularis	No			Upper floodplain
Rose Rosa intermontana	No			Thickets across floodplain
Blackberry Rubus ursinus	Yes	3 meters		Thickets lower on floodplain
Creeping rye grass Leymus triticoides	No			Sun or shade across floodplain
Mugwort *Artemesia douglasiana*	No			Sun, mineral soil
Gumplant *Grindelia camporum*	No			Sun

SOURCE: Griggs 2009

1. Individuals of all species can be found anywhere on the floodplain. This table describes conditions where the species dominates stands of vegetation.

In general, wider swaths of riparian vegetation provide greater habitat benefits and ecological function **(citation)**.

Another important consideration is the creation of an elevation gradient from intertidal to riparian areas and higher uplands. This gradient would serve as a transition zone, allowing habitat migration to higher elevations in response to sea level rise. The extent of intertidal wetland and riparian habitat will depend on the width and elevation of the habitat benches constructed along the waterside of the levee toe.

5.4 Key Habitat Features

The following habitat features are considered beneficial for target native species, especially fish:

- Substantial amounts of high-quality aquatic habitat for target fish species
- Enhanced riparian and tidal marsh habitat along perimeter of LET
- Shoals to create a "third habitat edge" within subtidal aquatic habitat
- Improved juxtaposition and spatial arrangement of aquatic features, such as tidal marsh adjacent to woody riparian habitat along an elevation gradient

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