ELEVATION AND OPPORTUNITY IN THE DELTA:
Restoring the right thing in the right place

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INTRODUCTION

A future Sacramento-San Joaquin Delta and Suisun Marsh ("Delta" herein) that supports healthy ecosystems and native species, while also meeting flood risk reduction, water supply, water quality, carbon sequestration, economic, and cultural objectives, requires that appropriate restoration and management actions be taken in the right place at the right time. Geographic setting affects the potential opportunities available—not all actions are suitable everywhere. Physical factors determining what types of activities are appropriate now and in the future include a site's elevation, degree of tidal and fluvial influence, salinity, soil type, and local effects of climate change, which all vary spatially across the Delta. While there has been considerable progress over the last several decades, continued acceleration of the pace and scale of enhancement actions appropriate to landscape position is needed. Understanding the physical template is necessary for developing strategies that move beyond opportunistic restoration, support resilience over time, and have the potential to connect and magnify benefits across the larger landscape.

Historical perspective

Historically, landscape patterns shifted across elevation, tidal-fluvial, salinity, and soil gradients (Whipple et al. 2012). Tidal brackish wetlands (marsh) graded into tidal freshwater wetlands from Suisun Marsh to the central Delta. Through organic matter accumulation (peat), the elevation of the marsh plain increased along with gradual sea level rise over the last six thousand years. The interaction of tidal processes along branching subtidal and intertidal channels within the marsh and onto the marsh surface created local variability in soil, elevation, and vegetation patterns, and facilitated exchange of nutrients, organic matter, and organisms. Large islands of tidal marsh were delineated by the main subtidal tidal channels of the Delta. Upstream to the north and south, the Delta landscape patterns became more reflective of the influence of fluvial (riverine) processes. Natural levees lining major channels were dominated by complex riparian forest and tidal inundation of the marsh plain became less dominant and graded into non-tidal marsh (particularly in large flood basins such as the Yolo Basin) and seasonal wetlands (in the south Delta and along the transition zone at the upland perimeter of marshes). At higher elevations beyond the flood basins and floodplains lay terrestrial habitat types, including grassland and oak savanna.

Landscape change

Landscape change due to human modification has muted, eliminated, constricted, and shifted historical gradients and created novel landscapes of deeply subsided islands. With the diking and draining of wetlands in the Delta that began in the mid-1800s, the majority of the Delta was converted to agriculture. Over time, this landscape conversion led to widespread land subsidence due to peat oxidation, such that much of the land once at intertidal elevation is now well below sea level. This has fundamentally altered the physical template of the Delta and is a key determinant of potential opportunities going forward. Tidal exchange is also altered due to dredging, loss of small tidal channels, and increased hydraulic connectivity through channel cuts. Additionally, water management has changed the flow and sediment regime primarily through large upstream dams, affecting potential interactions between tidal and fluvial processes across the Delta landscape. Further, urban and agricultural development has restricted hydrologic connectivity along rivers and streams, decreased regional groundwater tables, and altered soils. Climate change (including sea level rise, runoff alteration, temperature increases, and flood/drought extremes) also profoundly affects the physical template of the current and future Delta landscape.

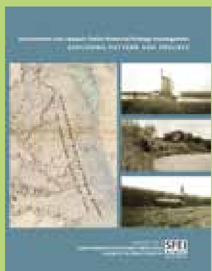
Purpose of this document

To support the planning of restoration and management actions in the Delta that are reflective of process-based opportunities within given landscape positions, geomorphic zones, or regions delineated based on elevation and tidal datum information, are described herein for their characteristics, habitat type potential, and suitability of various restoration and management actions. Physical processes, ecological functions, and recommendations associated with different zones were described as part of the Delta Landscapes project (Robinson et al. 2016) and align with elevation bands used by the Delta Plan (Siegel and Gillenwater 2020). The geomorphic zone map and associated guidance regarding physical suitability of habitat types in landscape change scenarios is part of the Landscape Scenario Planning Tool (www.sfei.org/projects/landscape-scenario-planning-tool; LSPT), a set of resources to assist users with developing, analyzing, and evaluating different Delta land use scenarios. This digest serves as a reference document to users of the LSPT and, more broadly, to scientists, managers, and landowners in the Delta considering potential options for taking process-based actions to enhance physical and ecological processes and functions.

Photo by Shira Bezalel, SFEI.

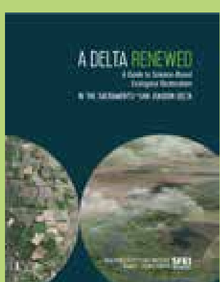
RELATED RESOURCES AND TOOLS

This geomorphic zones digest brings together information from prior work documenting landscape functioning of the Delta and scientific rationale and description of related opportunities. These resources are described below:

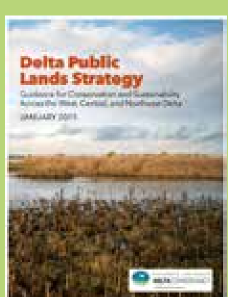


Sacramento-San Joaquin Delta Historical Ecology Investigation – Exploring Pattern and Process: This report is a historical ecology study of the Sacramento-San Joaquin Delta and includes associated mapping of historical habitat types. It improves understanding of what the Delta looked like and how it functioned prior to the significant modification that has occurred over the last two centuries. This historical reconstruction documents patterns of variation and extent of habitat types for improved understanding of controlling physical processes and species support functions within the historical landscape. Knowing how different parts of the vast historical Delta looked and functioned provides needed information for restoration strategies (Whipple et al. 2012).

A Delta Transformed: Using spatial data generated in the Delta Historical Ecology Investigation, as well as updated modern vegetation and land cover datasets, the report lays out detailed analyses of how the Delta landscape has been altered since the early 1800s. By quantifying changes using metrics relevant to native wildlife (such as the extent and timing of inundation, habitat patch sizes and length of channel networks), the report provides a foundation for defining, designing, and evaluating landscapes that support desirable ecological functions in the future (Robinson et al. 2014).



A Delta Renewed: This report offers guidance for rehabilitating and maintaining landscapes that can sustain desired ecological functions in the long term. Building on analyses of landscape history and change, and how it is likely to evolve, the report makes recommendations for how to re-establish the dynamic physical and ecological processes that can sustain native Delta wildlife as healthy populations into the future. It offers a set of process-based strategies defined by appropriate geomorphic and elevational zones, as well as more specific physical process and landscape configuration and scale guidelines (Robinson et al. 2016).



Delta Public Lands Strategy: This document offers a high-level approach toward maximizing benefits to the Delta ecosystem, regional economy, and water quality through habitat conservation, flood protection and levee improvements, land management, and recreation and tourism. It focuses on conservation opportunities on public lands in the west, central, and northeast Delta. The development of the strategy presented was guided by a working group of landowners and specialists. It includes summary information concerning appropriate actions as they relate to geomorphic zones (Sacramento-San Joaquin Delta Conservancy 2019).

Landscape Scenario Planning Tool (LSPT): The LSPT (www.sfei.org/projects/landscape-scenario-planning-tool) is a set of resources and GIS-based methods to assist users with developing, analyzing, and evaluating different land use scenarios in the Delta. The tool is designed to inform ongoing and future restoration planning efforts by assessing how proposed land use changes will affect a suite of landscape metrics relating to desired ecosystem functions. The tool uses the geomorphic zones to assess the physical suitability of scenarios evaluated by the tool. The tool also conducts basic assessments of agriculture, infrastructure, and carbon sequestration. The tool helps enable users to ground decisions in the best available science and research, compare different scenarios, evaluate proposed projects, and track progress towards regional goals.

METHODS

The geomorphic zones are defined based on a combination of land surface elevation and local tidal datums. The elevation cutoffs between the zones are aligned with the "elevation bands" defined and mapped in the Delta Plan (DSC 2021, Siegel and Gillenwater 2020). They include the terrestrial zone (>10 ft above MHHW; referred to as the “floodplain” elevation band in the Delta Plan), tidal-terrestrial zone (areas <10 ft above MHHW; referred to as the “sea level rise accommodation” band in the Delta Plan), intertidal zone (Suisun: MTL - MHHW; Delta: MLLW - MHHW), minimally subsided zone (Suisun: -4.5 ft MLLW - MTL; Delta: -8 ft MLLW - MLLW, referred to as the “shallow subtidal” elevation band in the Delta Plan), and the deeply subsided zone (areas with land surface elevations below minimally subsided elevations, referred to as the “deep subtidal” elevation band in the Delta Plan). The approach to delineate these zones followed several steps.

First, available datasets were compiled and mosaiced together. The elevation data used to establish the geomorphic zones were a synthesis of multiple topobathymetric digital elevation models. The datasets reflect the spatial extent (legal Delta and Suisun Marsh), and were chosen and prioritized based on the date, resolution, and/or extent of the data. The datasets were merged and resampled at 2 meters. Where the best topographic data overlapped with the best bathymetric data, masking was used to filter. Any voids/gaps in the dataset were filled via interpolation. The resulting compiled dataset was clipped to the extent considered by the LSPT (including the legal Delta, Suisun Marsh, and the study area of the Delta Historical Ecology Investigation). This area was chosen both for its jurisdictional relevance as well as relationship with available existing data.

The data sources were (in order of priority):

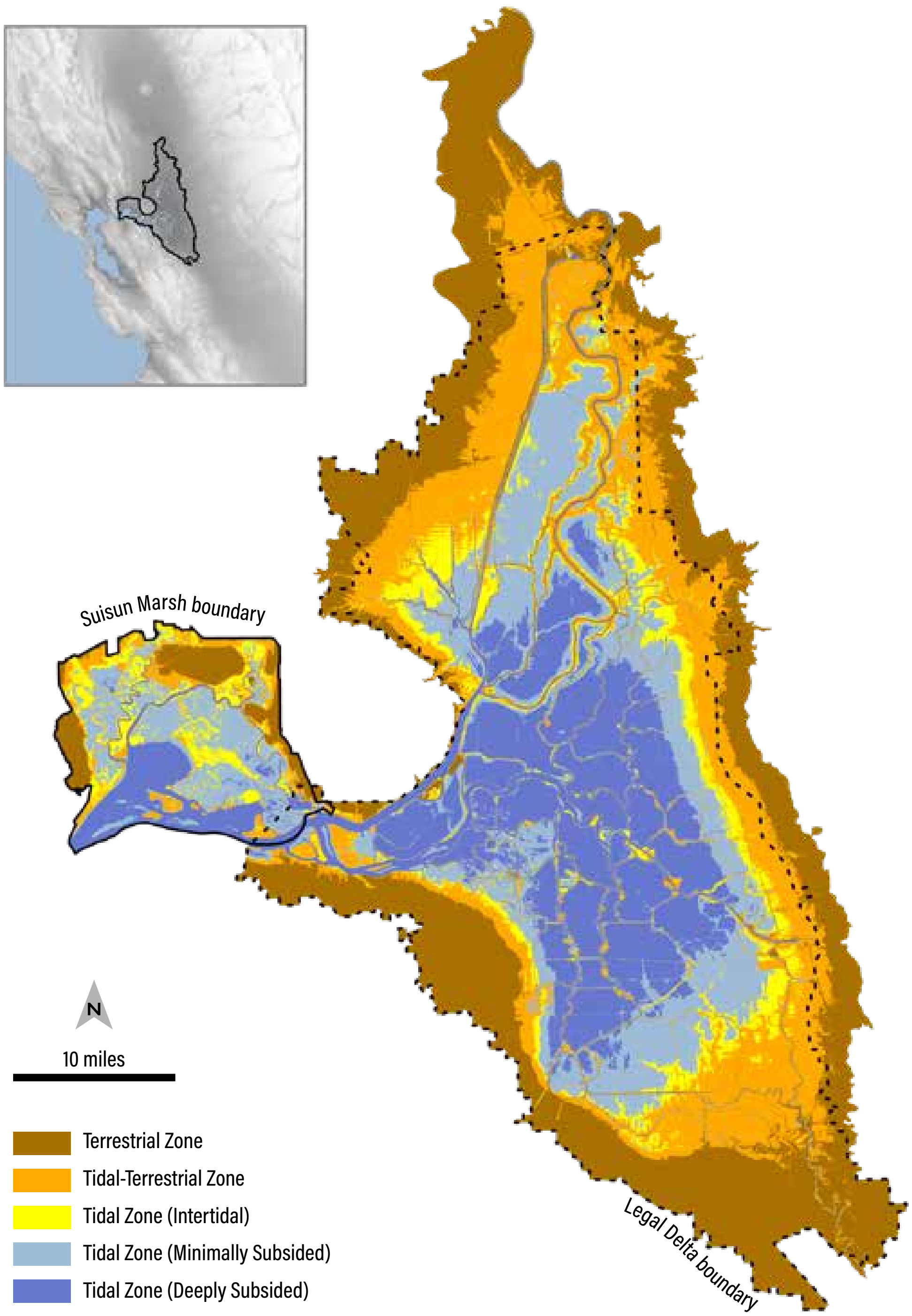
1. 2018 LEAN corrected Suisun Marsh DEM (Buffington et al. 2018)
2. 2017 Delta LiDAR (DWR and USGS 2019)
3. 2017 USGS SF Bay Delta DEM 10-m (Fergoso et al. 2017)
4. 2012 DWR SF Bay Delta DEM 10-m (Wang and Ateljevich 2012)
5. 2013 USGS ConED Topobathymetric Model of San Francisco Bay, California (USGS 2013)
6. 2019 USGS National Elevation Dataset (USGS 2019)

Tidal datums for MLLW and MHHW were derived from mapping developed by Siegel and Gillenwater (2020). These were converted to rasters and into the same projection as the mosaiced elevation dataset. To reference elevation to tidal datums, a model was then run to convert the tidal datums datasets to centimeter units. The zones were then distinguished based on those referenced elevations. This process had to be done slightly differently for Suisun and the Delta given that some of the zone definitions are different. The zones were converted from raster to polygon format, with the workflow involving some smoothing to simplify the polygons while retaining topological accuracy.

Work to define what landscape restoration and management actions are appropriate in each geomorphic zone is summarized in the Delta Plan (DSC 2019; Appendix 4A), as well as work by SFEI and partners (Robinson et al. 2016, Delta Conservancy 2019). The suitability of each habitat type in each zone is summarized for the Landscape Scenario Planning Tool and used by the physical suitability module of the tool. See boxed text on related resources.

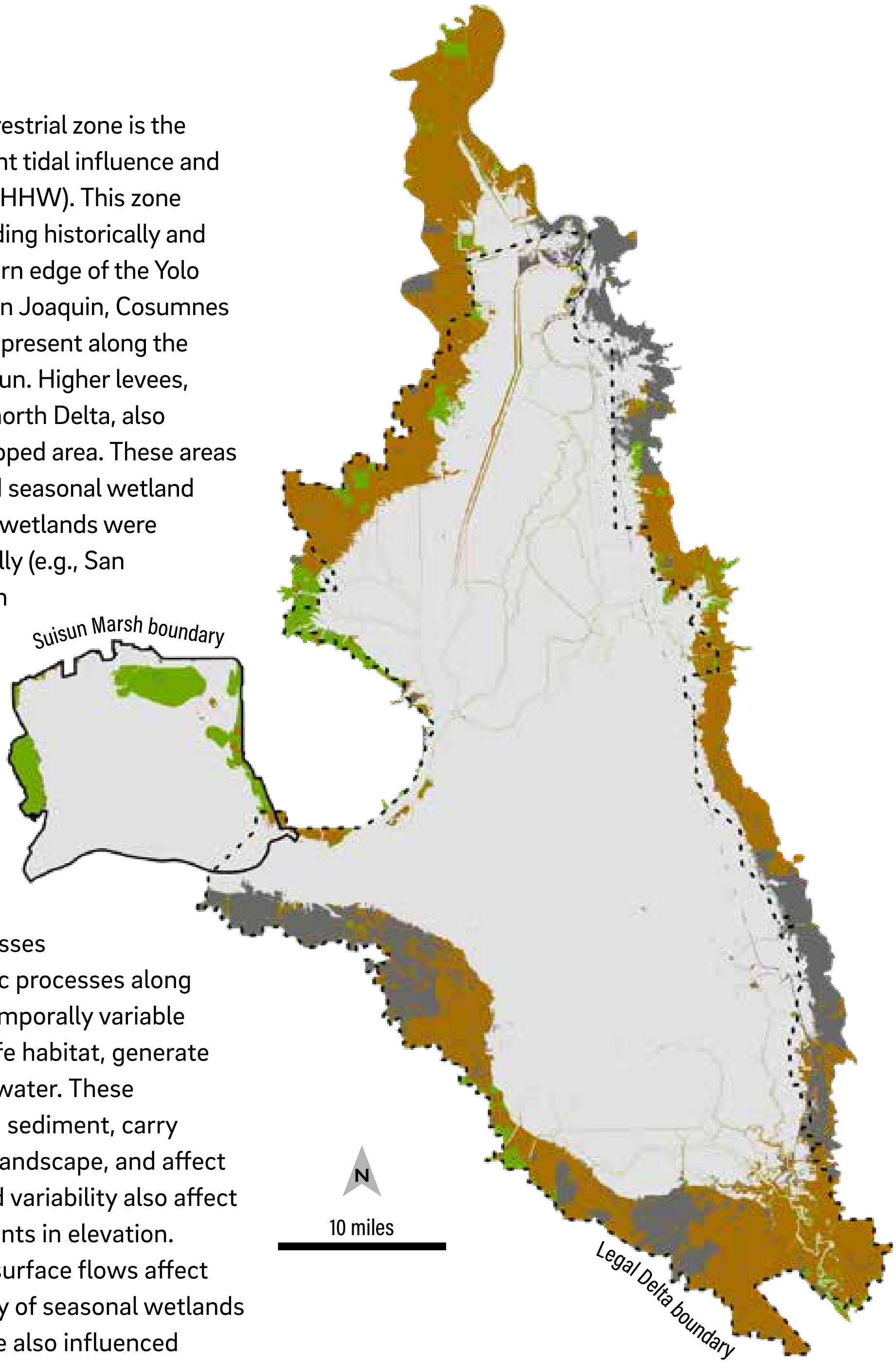
GEOMORPHIC ZONES

This section describes each of the geomorphic zones in the mapped extent of the Delta (the legal Delta and Suisun Marsh), including general description and location, dominant physical processes, suitable habitat types within the zone, potential opportunities for restoration and management action, and temporal considerations (e.g., sea level rise over time). The sections also include maps of each zone and summary of area within the zone according to whether it is heavily developed (e.g., urban), presently existing as a suitable habitat type, or is some other habitat type or land use. Tables summarizing habitat type suitability and opportunities for restoration and management actions are also provided.



Terrestrial zone

ABOUT THE TERRESTRIAL ZONE: The terrestrial zone is the portion of the Delta at elevations above current tidal influence and that expected over the next century (>10 ft MHHW). This zone occurs along the periphery of the Delta, including historically and currently active floodplains such as the western edge of the Yolo Bypass and along upstream reaches of the San Joaquin, Cosumnes and Mokelumne Rivers. Other large areas are present along the southwestern Delta and the periphery of Suisun. Higher levees, particularly along the Sacramento River and north Delta, also occupy this zone. It makes up 30% of the mapped area. These areas supported a variety of terrestrial, riparian, and seasonal wetland habitat types historically. Non-tidal perennial wetlands were also present along rivers in this zone historically (e.g., San Joaquin, Cosumnes River, Putah Creek). Much of this zone is today occupied by agriculture or urban development. Natural habitat types within these higher elevation areas and adjacent to perennial wetlands and open water provide important ecosystem functions (e.g., habitat connectivity, buffers against human stressors).



PHYSICAL PROCESSES: The terrestrial zone encompasses a range of physical processes across gradients in the landscape. Hydrologic processes along the rivers and streams include spatial and temporally variable inundation from floods, which provide wildlife habitat, generate food web productivity, and recharge groundwater. These periodic disturbances also deposit and erode sediment, carry nutrients and organic matter on and off the landscape, and affect vegetation patterns. Groundwater depth and variability also affect habitat types and their patterns along gradients in elevation. Groundwater, precipitation, and ephemeral surface flows affect the formation and maintenance of the variety of seasonal wetlands characteristic of this zone. Indigenous people also influenced terrestrial habitat types, including by managing vegetation with fire. Both water and land management practices over the last two centuries have substantially altered these processes.

HABITAT TYPE SUITABILITY: The terrestrial zone supports a variety of habitat types, including non-tidal emergent wetlands, seasonal wetlands (wet meadow, vernal pool complex, and alkali seasonal wetland), dryland habitats (grassland, oak woodland/ savanna, and sand dunes), and woody riparian habitats (willow thickets, willow riparian scrub/shrub and valley foothill riparian). Specific types of open water habitat types may also be suitable in the terrestrial zone including fluvial channels, and non-tidal ponds or lakes.

Terrestrial zone statistics		
	Urban development/barren land	81,002 ac
	Existing suitable natural habitat types	39,101 ac
	Other area	179,686 ac
	Total area	**299,789 ac**

Mapping the zone boundaries

The terrestrial zone includes areas >10 ft above MHHW. MLLW ranges from 1-8 ft NAVD88 and MHHW ranges from 5-9 ft NAVD88, depending on the location in the Delta (Siegel and Gillenwater 2019).

The specific hydrologic, geomorphic, and biologic processes necessary to support each habitat type (e.g., groundwater flows, hardpan formation) occur in different parts of the terrestrial zone. Riparian habitat types are supported in areas of the terrestrial zone that are connected to riverine processes. Non-tidal emergent and seasonal wetlands are best supported in areas that are affected by riverine processes and/or are supported by groundwater or soil formations (i.e., hardpan). Managed wetlands are potentially suitable in the terrestrial zone, though other terrestrial habitat types that do not require active management may be more appropriate. The terrestrial zone supports urban and agricultural land uses as well. Within these more intensively managed and developed areas, integrating measures to support ecosystem functions and biodiversity are possible, such as through wildlife friendly farming practices and urban greening.

RESTORATION AND MANAGEMENT OPPORTUNITIES: Within this zone, process-based enhancements and restoration activities involve both hydrologic as well as land-based management activities. Given continued development pressures in this zone, existing natural habitat should be conserved. Hydrologic processes in this zone can be supported through re-establishing natural drainage patterns and topography as well as groundwater recharge/pumping reductions. Habitat management through fire may also be appropriate. Restoration goals should be matched to appropriate edaphic processes and soil structures. Along rivers and streams, improving floodplain processes and hydrologic connectivity through levee removal/breaching/setbacks as well as managing flows and reducing groundwater pumping can help reintroduce natural inundation and sediment regimes. Features that reintroduce habitat complexity should also be encouraged. Additional considerations for actions include the appropriate scale and configuration of habitat types. Other actions may be coupled with process-based actions or employed where process-based actions are less feasible. Such actions include managed inundation, vegetation planting, wildlife friendly agriculture practices, and green stormwater infrastructure and other urban greening actions.

TEMPORAL CONSIDERATIONS: While elevations in this zone are expected to remain above tidal influence through this century, over time, tidal-terrestrial zone opportunities may be appropriate particularly in lower elevations of this zone. Thus, conservation and restoration of areas that can connect to tidal habitats to allow for transgression over time should be considered. Other considerations include water management and reservoir operation decisions alongside climate change impacts (which affect flood regimes, dry season flows, soil moisture, drought severity, and fire regimes).

HABITAT TYPE SUITABILITY

Habitat type	
Tidal emergent wetland	X
Non-tidal emergent wetland	✓
Woody riparian habitat types	✓
Seasonal wetlands (Vernal pool complex, Wet meadow, Alkali seasonal wetland complex)	✓
Terrestrial types (Grassland, Oak woodland/savanna, Interior stabilized dune)	✓
Open water	✓

X: Not suitable, △: Consider alternative, ✓: Likely suitable

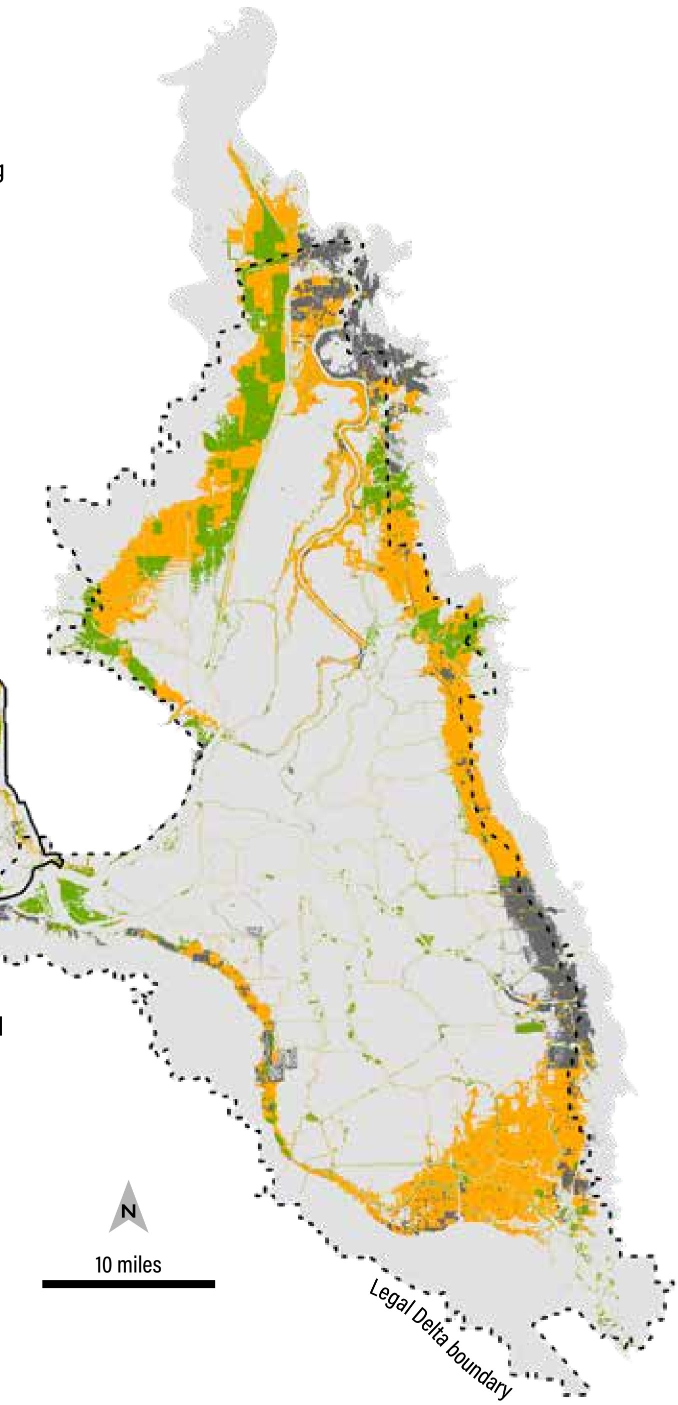
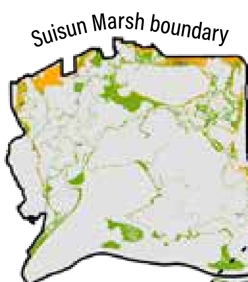
RESTORATION AND MANAGEMENT OPPORTUNITIES

Objectives	Example actions*
Conservation/Preservation	Maintain/enhance existing habitats
Seasonal Wetland Restoration	Modify topography and/or hydrology, plant native vegetation
Riparian Habitat Restoration	Modify topography and/or hydrology, plant native vegetation
Terrestrial Habitat Restoration	Manage land use, plant native vegetation
Managed Wetland	Manage hydrology, plant native vegetation
Subsidence Reversal/Carbon Storage	Manage hydrology, plant native vegetation
Wildlife Friendly Agriculture	Adjust crops/planting timing, plant hedgerows/buffers, reduce pesticide use
Control of Invasive Species	Improve water quality, introduce physical/biological controls
Urban Greening	Add green stormwater infrastructure, plant native vegetation
Water Quality Enhancement	Add green stormwater infrastructure, reduce pesticide use
Functional Flows	Manage hydrology, reoperature reservoirs
Groundwater Recharge	Manage hydrology, reduce groundwater pumping

*See Landscape Summary Section for additional detail

Tidal-terrestrial zone

ABOUT THE TIDAL-TERRESTRIAL ZONE: The tidal-terrestrial transition zone covers areas at elevations appropriate for supporting the interactions between tidal and fluvial/terrestrial processes (mapped between 0 and 10 feet MHHW). This zone accounts for 23% of the mapped area. Generally positioned along the periphery of historical tidal marsh, large areas occur along the edge of Suisun Marsh, in the Yolo Bypass, along the eastern edge of the Delta, and in the south Delta. This zone also follows natural levee deposits (and artificial levees) that extend into the Delta interior. Some areas of existing tidal wetlands at the Delta mouth and in Suisun also fall into this zone (likely due to wetland vegetation affecting elevation values). As an interface zone, the interaction of tidal and fluvial/terrestrial processes historically produced mosaics of seasonally dynamic habitat types, assemblages of plant and animal species, and ecosystem functions distinct from those of the adjoining estuarine and terrestrial ecosystems. The loss of tidal marsh and adjacent terrestrial habitat types and alteration and disconnection of riverine processes in this zone limits the opportunities for these interactions. Much of this zone is today occupied by agriculture or urban development, with areas of natural habitat types found in Suisun Marsh, Yolo Bypass, Cosumnes-Mokelumne confluence, and south of Sacramento to Stone Lakes.

PHYSICAL PROCESSES: Tidal processes interact with terrestrial and fluvial processes in the tidal-terrestrial zone. These interactions produce landscape features and conditions unique to this zone. For example, tidal inundation meeting floodwaters from the Sacramento River created large and relatively stable natural levees, in contrast to the more dynamic meandering river channel upstream of tidal influence. Soils in this zone are more variable than the organic peat soils of the central Delta, including floodplain soils with inorganic sediment from floods, alkali soils, and aeolian sands. Given proximity to tides, groundwater levels are generally high. This zone is seasonally dynamic, where tidal processes are generally more dominant in the dry season, with riverine processes dominating during periods of high flow. For a functional interface zone, processes at both ends of the gradient need to be present.

HABITAT TYPE SUITABILITY: Over the near-term, the tidal terrestrial zone is suitable for supporting similar habitat types as the terrestrial zone, including non-tidal emergent wetlands, seasonal wetlands, and riparian and dryland habitat types. Also in this zone is open water, including tidal and fluvial channels

Tidal-terrestrial zone statistics		
(grey)	Urban development/barren land	41,017 ac
(green)	Existing suitable natural habitat types	60,656 ac
(orange)	Other area	123,781 ac
	Total area	**225,453 ac**

Mapping the zone boundaries

The tidal-terrestrial zone includes areas between 0 and 10 ft above MHHW. MLLW ranges from 1-8 ft NAVD88 and MHHW ranges from 5-9 ft NAVD88, depending on the location in the Delta (Siegel and Gillenwater 2019).

and non-tidal ponds or lakes. This zone extends into the interior of the Delta along natural and artificial levees bordering channels, which are areas generally suitable for woody riparian habitats. Non-tidal emergent and seasonal wetlands are best suited in areas of this zone connected to riverine flooding and/or suitable groundwater and soil formations. Habitat types in this zone that are adjacent to tidal marshes may provide additional support for wetland wildlife, as well as migration space for tidal marshes to move into over time. Although the tidal-terrestrial zone does not generally support tidal marsh in the near-term, areas in this zone are likely to become intertidal with sea-level rise over the time, assuming there are no barriers to tidal flows. Agricultural and urban areas located in the tidal-terrestrial zones must be protected from flooding and sea-level rise with levees and other flood control infrastructure.

RESTORATION AND MANAGEMENT OPPORTUNITIES: Process-based enhancements and restoration activities in this zone are similar to that of the terrestrial zone, though with greater need to support transitional processes and allow for estuarine transgression over time with sea level rise. Actions include removal of future barriers to tidal flows and conservation of ample open space adjacent to existing intertidal areas to facilitate this transition. Given development pressures as well as sea level rise, conservation of undeveloped areas carries particular importance. Re-establishing natural drainage patterns and topography as well as groundwater recharge/pumping reductions will support natural hydrologic processes. Reintroducing hydrologic connectivity along rivers and streams to support transitional processes and allow for estuarine transgression over time includes levee removal/breaching/setbacks as well as managing flows and reducing groundwater pumping. Restoration goals should be matched to appropriate edaphic processes and soil structures. Where natural processes cannot be fully re-established or coupled with process-based actions, other actions may be warranted, such as managing inundation, vegetation planting, wildlife friendly agriculture practices, and green stormwater infrastructure and other urban greening actions.

TEMPORAL CONSIDERATIONS: Seasonal and inter-annual variability within this zone are key drivers of the landscape patterns and habitat complexity and should be factored into restoration and enhancement actions. The lower elevations within this zone are currently experiencing sea level rise and more of the zone will transition over this century. As sea levels rise, this interface zone should be considered to shift accordingly. In addition to sea level rise, other climate change impacts to hydrologic and ecological processes should be considered, including changes to flood regimes, dry season flows, soil moisture, drought severity, fire regimes, as well as human responses to climate change (e.g., water management).

HABITAT TYPE SUITABILITY

Habitat type	
Tidal emergent wetland	△
Non-tidal emergent wetland	✓
Woody riparian habitat types	✓
Seasonal wetlands (Vernal pool complex, Wet meadow, Alkali seasonal wetland complex)	✓
Terrestrial types (Grassland, Oak woodland/savanna, Interior stabilized dune)	✓
Open water	✓

X: Not suitable, △: Consider alternative, ✓: Likely suitable

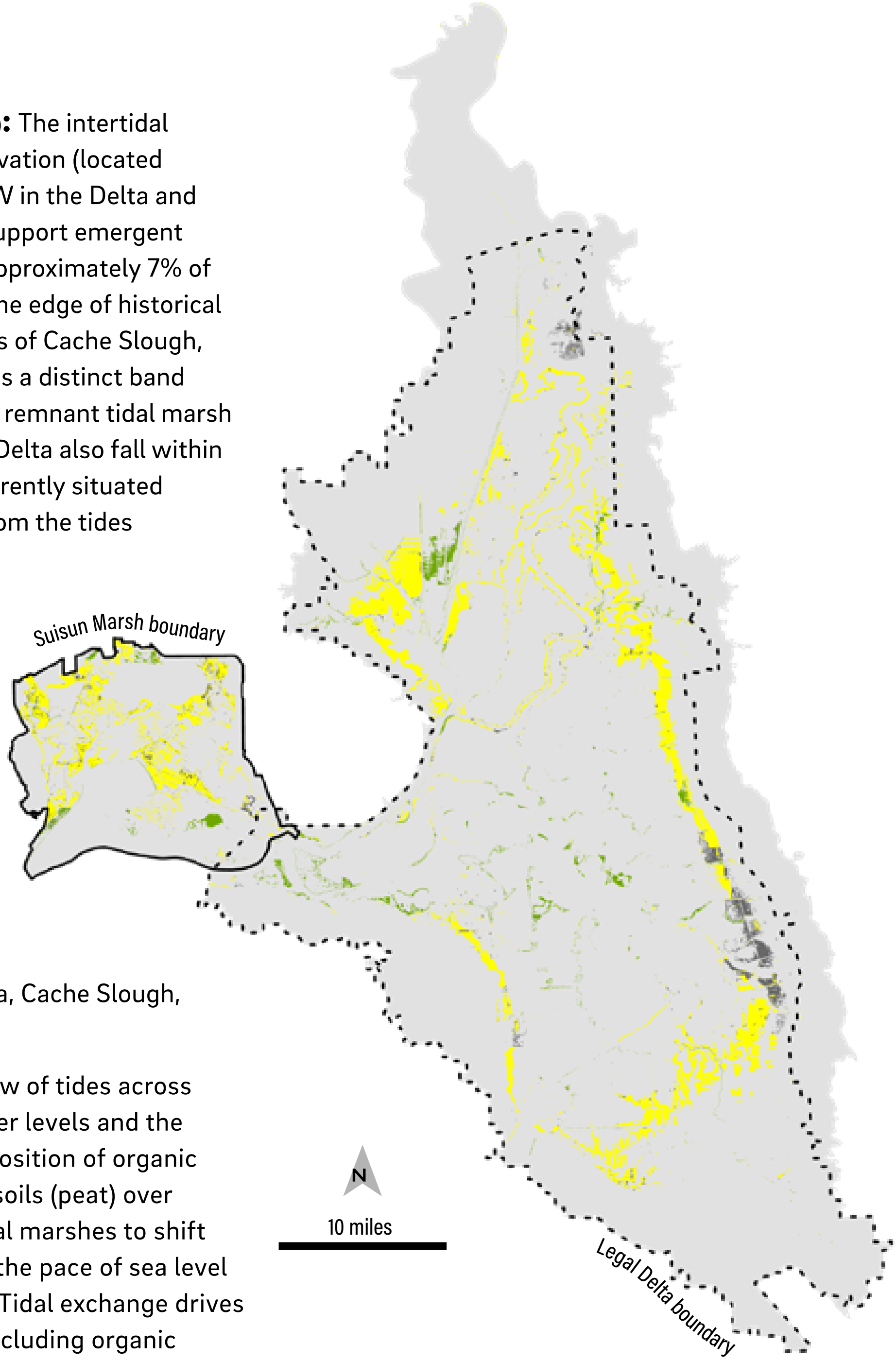
RESTORATION AND MANAGEMENT OPPORTUNITIES

Objectives	Example actions*
Conservation/Preservation	Conserve tidal wetland transgression space
Tidal Wetland Restoration	Remove barriers to wetland transgression
Seasonal Wetland Restoration	Modify topography and/or hydrology, plant native vegetation
Riparian Habitat Restoration	Modify topography and/or hydrology, plant native vegetation
Terrestrial Habitat Restoration	Manage land use, plant native vegetation
Managed Wetland	Manage hydrology, plant native vegetation
Subsidence Reversal/Carbon Storage	Manage hydrology, plant native vegetation
Wildlife Friendly Agriculture	Adjust crops/planting timing, plant hedgerows/buffers, reduce pesticide use
Control of Invasive Species	Improve water quality, introduce physical/biological controls
Urban Greening	Add green stormwater infrastructure, plant native vegetation
Water Quality Enhancement	Add green stormwater infrastructure, reduce pesticide use
Functional Flows	Manage hydrology, reoperature reservoirs
Groundwater Recharge	Manage hydrology, reduce groundwater pumping

*See Landscape Summary Section for additional detail

Tidal zone (interidal)

ABOUT THE TIDAL ZONE (INTERTIDAL): The intertidal zone covers areas currently at intertidal elevation (located between the elevation of MLLW and MHHW in the Delta and MTL and MHHW in Suisun Marsh) which support emergent marsh vegetation. This zone accounts for approximately 7% of the mapped area. Falling within but along the edge of historical tidal wetlands, this zone is broadest in areas of Cache Slough, south Delta, and Suisun Marsh. It also forms a distinct band along the eastern and western Delta. Many remnant tidal marsh patches and higher land within the central Delta also fall within this zone. Large portions of the area are currently situated at intertidal elevations but are separated from the tides by levees and other human infrastructure. These areas have the greatest potential to support tidal marshes with minimal management intervention now and into the future because, if connected to tidal action, they would be inundated at a depth and frequency that is appropriate for the establishment and persistence of emergent marsh vegetation. Much of this zone is today occupied by agriculture or urban development, with existing tidal marshes found primarily in the central Delta, Cache Slough, and Suisun Marsh.



PHYSICAL PROCESSES: The ebb and flow of tides across intertidal areas maintains high groundwater levels and the saturation prevents oxidation and decomposition of organic matter, allowing accumulation of organic soils (peat) over time. This process allows elevations of tidal marshes to shift over time as sea levels change, so long as the pace of sea level change does not exceed that of accretion. Tidal exchange drives other physical and ecological processes, including organic sediment deposition and erosion, flooding, and exchange of organisms, nutrients, and energy between the marsh plain and aquatic habitats. These processes helped form and maintain the detritic intertidal channel networks intersecting the marsh plain, as well as subtle but distinct zones of elevation and hydroperiod across the marsh plain that maintain a complex habitat mosaic, an array of plant communities, and a mix of microhabitats.

HABITAT TYPE SUITABILITY: Land in the intertidal zone that is hydrologically connected to channel networks is likely to support tidal emergent marsh or open water. In freshwater areas, woody vegetation (e.g., willows) may be suitable in

Tidal zone (intertidal) statistics		
	Urban development/barren land	7,452 ac
	Existing suitable natural habitat types	8,387 ac
	Other area	56,860 ac
	Total area	**72,699 ac**

Mapping the zone boundaries
The tidal zone (intertidal) includes areas MTL - MHHW in Suisun Marsh and MLLW - MHHW in the Delta. MLLW ranges from 1-8 ft NAVD88 and MHHW ranges from 5-9 ft NAVD88, depending on the location in the Delta (Siegel and Gillenwater 2019).

the intertidal zone, intermixed with emergent vegetation, reflective of willow-fern swamps described in the historical central Delta. Open water is naturally part of a tidal marsh landscape, in the form of tidal channels and tidal ponds/lakes, but excavating to create large areas of subtidal open water is not considered suitable. While other habitat types can technically be maintained within diked areas of the intertidal zone, this requires management (e.g., water control structures), making these habitat types less resilient over time. In addition to their vulnerability in the intertidal zone, seasonal wetland habitat types are also generally more suitable in the tidal-terrestrial and terrestrial zones because they require particular physical processes and edaphic/hydrologic conditions that generally do not currently exist in the intertidal zone. Woody riparian and terrestrial habitat types are also generally more suitable in the tidal-terrestrial and terrestrial zones.

RESTORATION AND MANAGEMENT OPPORTUNITIES: Given the relatively limited extent of the intertidal zone and ecological importance of tidal marsh, restoring and enhancing this habitat type should generally be prioritized over other habitat types in this zone. Actions primarily involve a process-based focus on reconnecting land to tidal action, such as levee setback/removal/breaching and tidal channel network creation. Resloping levees or creating inter-tidal elevation benches on the channel-side of levees can also support narrow bands of tidal marsh with limited benefits compared to large areas of tidal marsh. These actions also support subsidence reversal. Addressing invasive species and water quality concerns through actions such as wastewater treatment improvements, and physical/biological controls will also support overall ecological health within this zone. Where natural processes cannot be fully re-established or to augment process-based actions, other actions may be warranted, such as vegetation planting and wildlife friendly agriculture practices.

TEMPORAL CONSIDERATIONS: Daily and seasonal patterns of inundation are key drivers of tidal wetland formation and maintenance. Re-establishing tidal connection to land within this zone is urgently needed as rising sea levels mean that there is a small window of opportunity to establish tidal marsh vegetation before inundation depth and duration exceeds the threshold of vegetation establishment. Over time, without marsh accretion, this zone will no longer be at intertidal elevations, and should be considered to shift accordingly. Other climate change impacts and human responses to climate change will also affect the trajectory of landscape patterns and the ecological resilience of this zone.

HABITAT TYPE SUITABILITY

Habitat type	
Tidal emergent wetland	✓
Non-tidal emergent wetland	△
Woody riparian habitat types	△
Seasonal wetlands (Vernal pool complex, Wet meadow, Alkali seasonal wetland complex)	△
Terrestrial types (Grassland, Oak woodland/savanna, Interior stabilized dune)	△
Open water	✓

X: Not suitable, △: Consider alternative, ✓: Likely suitable

RESTORATION AND MANAGEMENT OPPORTUNITIES

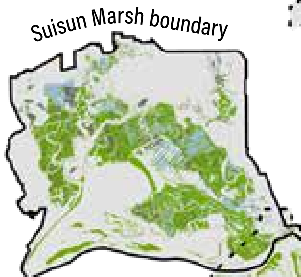
Objectives	Example actions*
Conservation/Preservation	Maintain/enhance existing habitats
Tidal Marsh Restoration	Reconnect tidal action, plant native vegetation
Subsidence Reversal/Carbon Storage	Manage hydrology, plant native vegetation
Control of Invasive Species	Improve water quality, introduce physical/biological controls
Water Quality Enhancement	Reduce pesticide use, improve wastewater treatment
Functional Flows	Manage hydrology, reoperature reservoirs

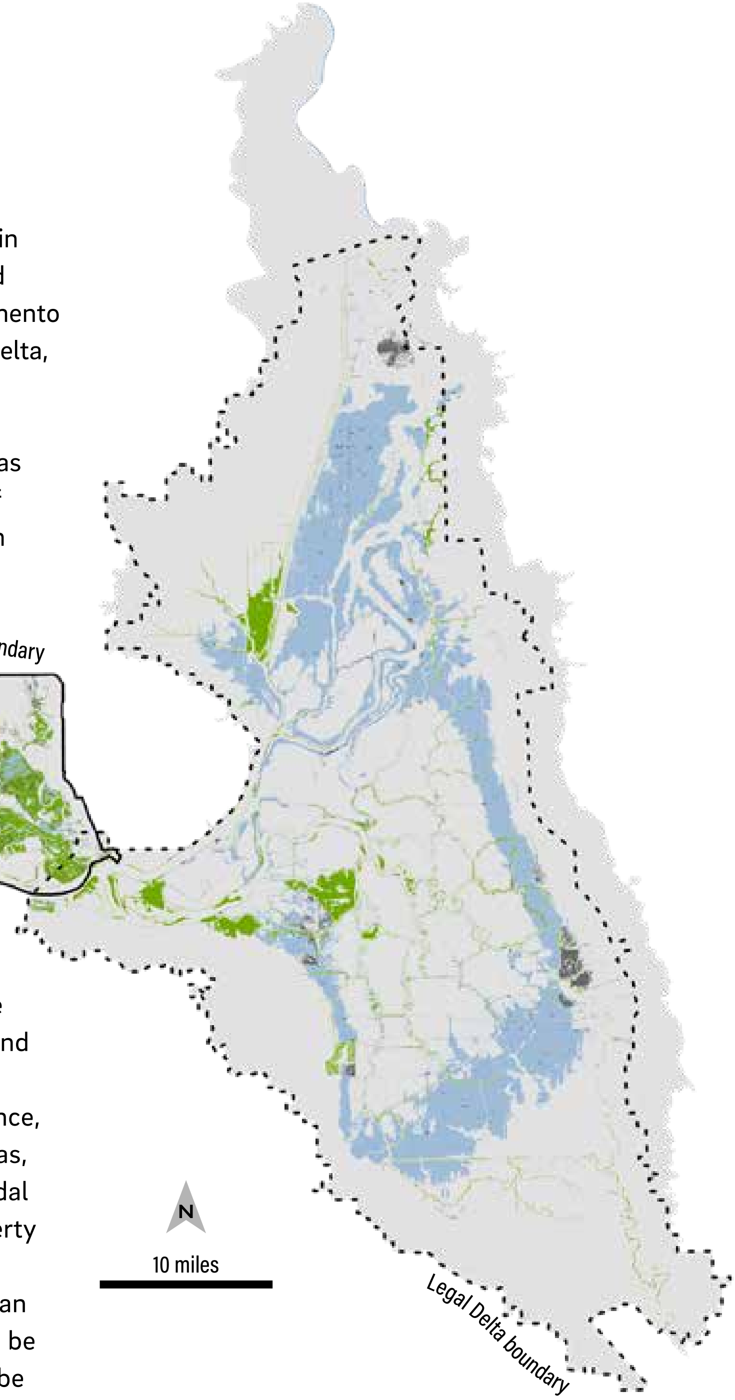
*See Landscape Summary Section for additional detail

Photo by Shira Bezalel, SFEI.

Tidal zone (minimally subsided)

ABOUT THE TIDAL ZONE (MINIMALLY SUBSIDED): The minimally subsided zone includes areas below elevations supportive of emergent vegetation, at elevations between -8 ft MLLW and MLLW in the Delta and -4.5 ft MLLW and MTL in Suisun Marsh. It makes up approximately 19% of the mapped area. Large areas are found in Yolo Bypass (east of the Sacramento Deep Water Ship Channel), along the eastern and southern Delta, and in Suisun Marsh. This zone is made up of areas of former tidal wetlands where elevations have been reduced over time as a result of subsidence due to peat oxidation. These are areas that could potentially recover intertidal elevations, capable of supporting tidal marsh, before the end of the century through subsidence-reversal efforts. Without levees, much of this zone would be open water. Much of this zone is today occupied by agriculture in the Delta as well as managed wetlands in Suisun Marsh. Areas of existing currently suitable natural habitat types (e.g., managed non-tidal wetlands, tidal open water) are found primarily in Suisun Marsh, the flooded island of Franks Tract, and Liberty Island in Cache Slough.





PHYSICAL PROCESSES: As a highly modified area, natural tidal marsh processes that were once characteristic of the region are no longer possible. Where land continues to be drained and farmed, land subsidence due to peat oxidation is ongoing. Without first addressing subsidence, reconnecting tidal inundation to currently disconnected areas, either purposefully or due to levee failure, would result in tidal open water (examples include Franks Tract and parts of Liberty Island). However, natural physical processes of accretion of organic matter and sediment deposition, supported by human interventions (managed inundation, levee maintenance) can be employed to reverse subsidence such that tidal marsh may be possible in the future. Large changes in area accessible to tidal inundation affects the region's hydrodynamics, altering the volume and range of tides.

HABITAT TYPE SUITABILITY: In hydrologically disconnected areas in the subtidal zone (e.g. on subsided islands protected by levees), managed and non-tidal wetlands can help halt ongoing subsidence, reduce the risk of levee failure, sequester carbon, provide habitat to waterbirds and other species, and potentially enable the restoration of tidal marshes in the future. Managed wetlands are more likely to recover intertidal elevations in shallowly subsided areas than deeply subsided areas (with

Tidal zone (minimally subsided) statistics		
(dark gray)	Urban development/barren land	11,994 ac
(green)	Existing suitable natural habitat types	44,477 ac
(light blue)	Other area	130,473 ac
	Total area	**186,944 ac**

Mapping the zone boundaries

The tidal zone (minimally subsided) includes areas from -4.5 ft MLLW to MTL in Suisun Marsh and -8 ft MLLW to MLLW in the Delta. MLLW ranges from 1-8 ft NAVD88 and MHHW ranges from 5-9 ft NAVD88, depending on the location in the Delta (Siegel and Gillenwater 2019).

time frames on the order of decades instead of centuries). Other habitat types, including grassland, riparian shrub/scrub and non-tidal ponds, are also potentially suitable in these areas so long as levees and suitable conditions are maintained. Seasonal wetlands habitat types could conceivably be created in subsided zones, but these wetlands require particular physical processes and edaphic/hydrologic conditions that generally do not exist in the current subsided zones of the Delta and would be difficult and cost-prohibitive to restore. Agriculture in this zone must be protected from flooding and sea-level rise with levees and other flood control infrastructure. Certain crop types, including rice, can help reduce or halt the rate of ongoing subsidence and thereby limit future increases in levee instability and flood risk, while also providing some benefits to native wildlife. In the event of levee failure, these areas would rapidly transition to open water. Multiple factors, including the degree of subsidence, local turbidity, and resulting flows will influence the ecological characteristics of any newly flooded islands and the resulting value to native aquatic species.

RESTORATION AND MANAGEMENT OPPORTUNITIES: With sea levels rising, subsidence reversal actions should generally be prioritized for this zone. These actions primarily involve the establishment of managed non-tidal wetlands (e.g., tule farming) to encourage the accumulation of organic matter that could eventually be reconnected to tidal action once elevations were recovered. Where active subsidence reversal wetlands cannot be established, other actions such as converting to paludiculture (e.g., rice farming) can help halt, though not reverse, subsidence. Sediment augmentation or fill placement may also be reasonable options for some areas. In conjunction with these actions or when wetland or rice farming is not possible, other actions may be warranted, such as vegetation planting and wildlife friendly agriculture practices. Along levees, resloping or establishing benches can provide localized habitat benefits.

TEMPORAL CONSIDERATIONS: Measures to halt and reverse subsidence in this zone are of paramount concern, as the time horizon to reach intertidal elevations due to accretion extends as sea levels rise over time. These measures require active management in the near term such that natural tidal processes may be restored in the long term. Over time, without such actions, elevations relative to sea level will continue to fall, becoming increasingly vulnerable in the event of levee failure. As elevations in this zone shift relative to sea level, the zone should be considered to shift accordingly. Other climate change impacts and human responses to climate change will also affect the trajectory of landscape patterns and the ecological resilience of this zone.

HABITAT TYPE SUITABILITY

Habitat type	
Tidal emergent wetland	X
Non-tidal emergent wetland	✓
Woody riparian habitat types	△
Seasonal wetlands (Vernal pool complex, Wet meadow, Alkali seasonal wetland complex)	△
Terrestrial types (Grassland, Oak woodland/ savanna, Interior stabilized dune)	△
Open water	✓

X: Not suitable, △: Consider alternative, ✓: Likely suitable

RESTORATION AND MANAGEMENT OPPORTUNITIES

Objectives	Example actions*
Tidal Marsh Restoration	Manage non-tidal wetlands for subsidence reversal, modify levees
Managed Wetland	Manage hydrology, plant native vegetation
Subsidence Reversal/Carbon Storage	Manage hydrology, plant native vegetation, augment sediment
Wildlife Friendly Agriculture	Adjust crops/planting timing, plant hedgerows/buffers, reduce pesticide use
Control of Invasive Species	Improve water quality, introduce physical/biological controls
Water Quality Enhancement	Reduce pesticide use, improve wastewater treatment

*See Landscape Summary Section for additional detail

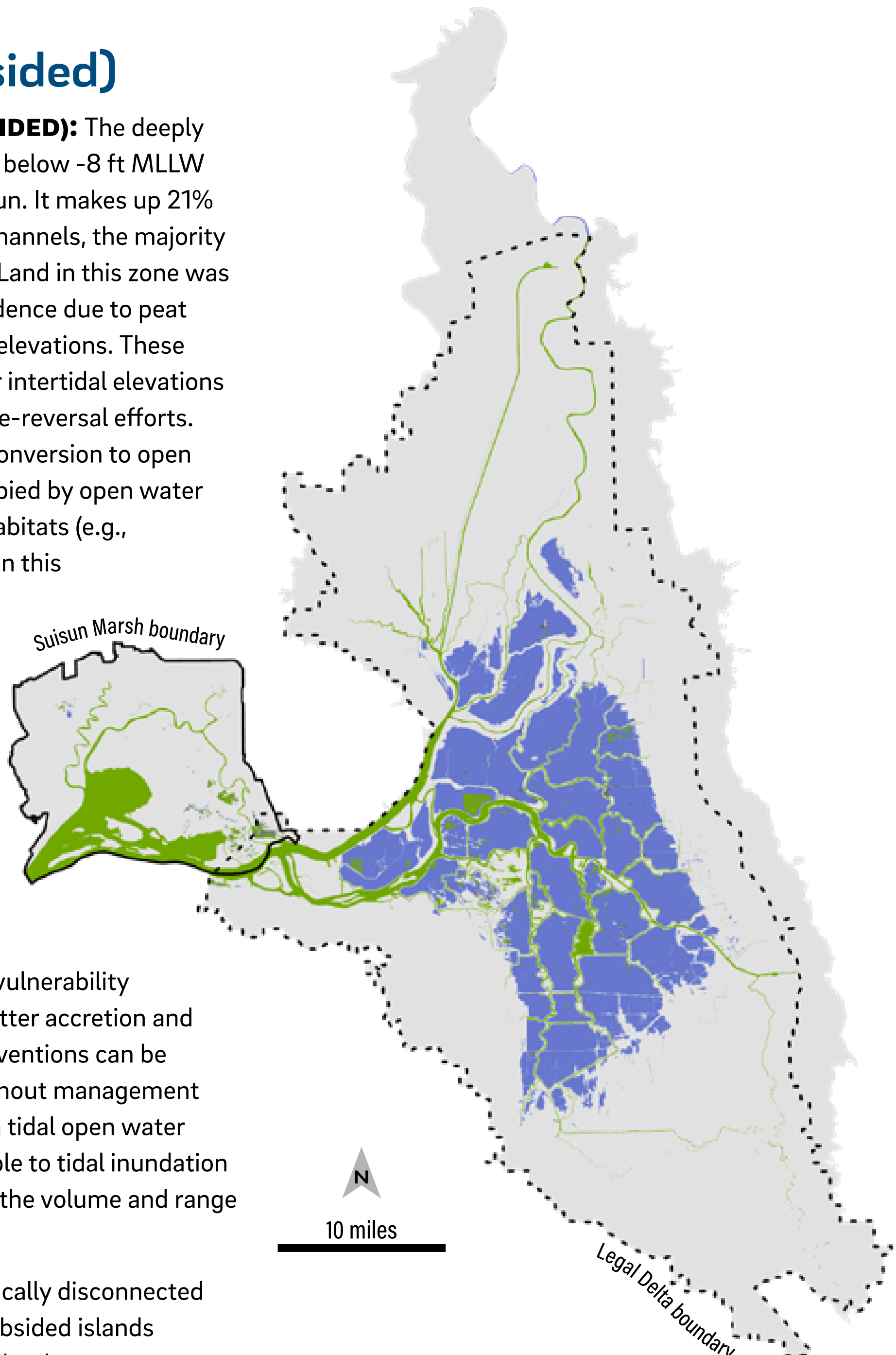

Photo by Shira Bezalel, SFEI.

Tidal zone (deeply subsided)

ABOUT THE TIDAL ZONE (DEEPLY SUBSIDED): The deeply subsided zone covers subtidal areas that are below -8 ft MLLW in the Delta and below -4.5 ft MLLW in Suisun. It makes up 21% of the mapped area. In addition to subtidal channels, the majority of central Delta islands fall within this zone. Land in this zone was formerly at intertidal elevation, where subsidence due to peat oxidation has resulted in lower land surface elevations. These deeply subsided areas are unlikely to recover intertidal elevations by the end of the century through subsidence-reversal efforts. These areas require levees to prevent their conversion to open water areas. Much of the zone today is occupied by open water and agriculture. The land uses and natural habitats (e.g., seasonal wetlands) that are currently found in this zone are increasingly vulnerable to flooding from sea level rise and levee failure, often requiring intensive management to persist.

PHYSICAL PROCESSES: Similar to the minimally subsided tidal zone, natural tidal marsh processes that were once characteristic of the region are no longer possible. Where land continues to be drained and farmed, land subsidence due to peat oxidation is ongoing, increasing vulnerability to flooding. Natural processes of organic matter accretion and sediment deposition, as well as human interventions can be employed to halt or reverse subsidence. Without management and interventions, this zone would become a tidal open water environment. Large changes in area accessible to tidal inundation affects the region's hydrodynamics, altering the volume and range of tides.

HABITAT TYPE SUITABILITY: In hydrologically disconnected areas of the deeply subsided zone (e.g. on subsided islands protected by levees), managed non-tidal wetlands are considered appropriate to help halt and reverse ongoing subsidence, reduce the risk of levee failure, sequester carbon, provide habitat to waterbirds and other species, and potentially enable the restoration of tidal marshes in the future (beyond the end of the century). Other natural habitat types, including grassland, riparian shrub/scrub, and non-tidal ponds, are potentially suitable when non-tidal wetlands are not feasible, but would also require management and maintenance of levees. Well-functioning seasonal wetland habitat types could conceivably be created in subsided zones, but these wetlands require particular physical processes and edaphic/hydrologic conditions that generally do not currently



Tidal zone (deeply subsided) statistics		
	Urban development/barren land	1,519 ac
	Existing suitable natural habitat types	57,068 ac
	Other area	150,210 ac
	Total area	**208,797 ac**

Mapping the zone boundaries

The tidal zone (deeply subsided) includes areas below -4.5 ft MLLW in Suisun Marsh and below -8 ft MLLW in the Delta. MLLW ranges from 1-8 ft NAVD88 and MHHW ranges from 5-9 ft NAVD88, depending on the location in the Delta (Siegel and Gillenwater 2019).

exist in this zone and would be difficult and cost-prohibitive to restore. Agriculture in this zone must be protected from flooding and sea-level rise with levees and other flood control infrastructure. Land in the deeply subsided tidal zone is more vulnerable to these risks. Certain crop types, including rice, can help reduce the rate of ongoing subsidence and thereby limit future increases in levee instability and flood risk, while also providing some benefits to native wildlife. In the event of levee failure and/or cessation of pumping, these areas would be open water. Multiple factors, including the degree of subsidence, local turbidity, location, and hydrodynamics will influence the ecological characteristics of any newly flooded islands and the resulting value to native aquatic species.

RESTORATION AND MANAGEMENT OPPORTUNITIES: Actions to reverse or halt subsidence are priority for this zone, although these areas will continue to require protection from flooding over the long term (beyond the end of the century) given the amount of time required to reach sea level. These actions primarily involve the establishment of managed non-tidal wetlands (e.g., tule farming) to encourage the accumulation of organic matter. Managed inundation and water control structures will be required to maintain conditions other than open water. Where active subsidence reversal wetlands cannot be established, other actions such as converting to paludiculture (e.g., rice farming) or other farming practices can help halt, though not reverse, subsidence. Sediment augmentation or fill placement may also be reasonable options for some areas (though for large areas is likely impractical). In conjunction with these actions or when wetland or rice farming is not possible, other actions may be warranted, such as vegetation planting and wildlife friendly agriculture practices.

TEMPORAL CONSIDERATIONS: Measures to halt and reverse subsidence in this zone are of paramount concern, as this can help reduce vulnerability to sea level rise and flooding and potentially allow for the reconnection of tidal marsh in the long term (beyond the end of the century). The costs of inaction increase over time. These measures require active management in the near term such that natural tidal processes may be restored in the long term. Other climate change impacts and human responses to climate change will also affect the trajectory of landscape patterns and the ecological resilience of this zone.

HABITAT TYPE SUITABILITY

Habitat type	
Tidal emergent wetland	X
Non-tidal emergent wetland	✓
Woody riparian habitat types	△
Seasonal wetlands (Vernal pool complex, Wet meadow, Alkali seasonal wetland complex)	△
Terrestrial types (Grassland, Oak woodland/ savanna, Interior stabilized dune)	△
Open water	✓

X: Not suitable, △: Consider alternative, ✓: Likely suitable

RESTORATION AND MANAGEMENT OPPORTUNITIES

Objectives	Example actions*
Tidal Marsh Restoration	Manage non-tidal wetlands for subsidence reversal
Managed Wetland	Manage hydrology, plant native vegetation
Subsidence Reversal/Carbon Storage	Manage hydrology, plant native vegetation, augment sediment
Wildlife Friendly Agriculture	Adjust crops/planting timing, plant hedgerows/buffers, reduce pesticide use
Control of Invasive Species	Improve water quality, introduce physical/biological controls
Water Quality Enhancement	Reduce pesticide use, improve wastewater treatment

*See Landscape Summary Section for additional detail

Photo by Kate Roberts, SFEI.

LANDSCAPE SUMMARY

Just as landscape patterns and associated physical and ecological processes of the historical Delta were reflective of physical gradients, functional landscapes in the current and future Delta must be reflective of the physical template and how it may change over time. While some actions may seem reasonable in the current landscape, and engineering and management might overcome constraints of physical setting, implementing restoration and management in the right places and at the right time means taking advantage of the geomorphic setting and physical processes that will help confer long-term ecological resilience to the Delta. Further, given the altered physical template of the Delta, functional landscapes in the future will be configured differently from the past and present. With limited resources, space, and time, investments must be made wisely, based on the best available science, to achieve multiple benefits and to coordinate efforts such that individual actions add up to resilient landscapes that support native ecosystems and provide desired human benefits.

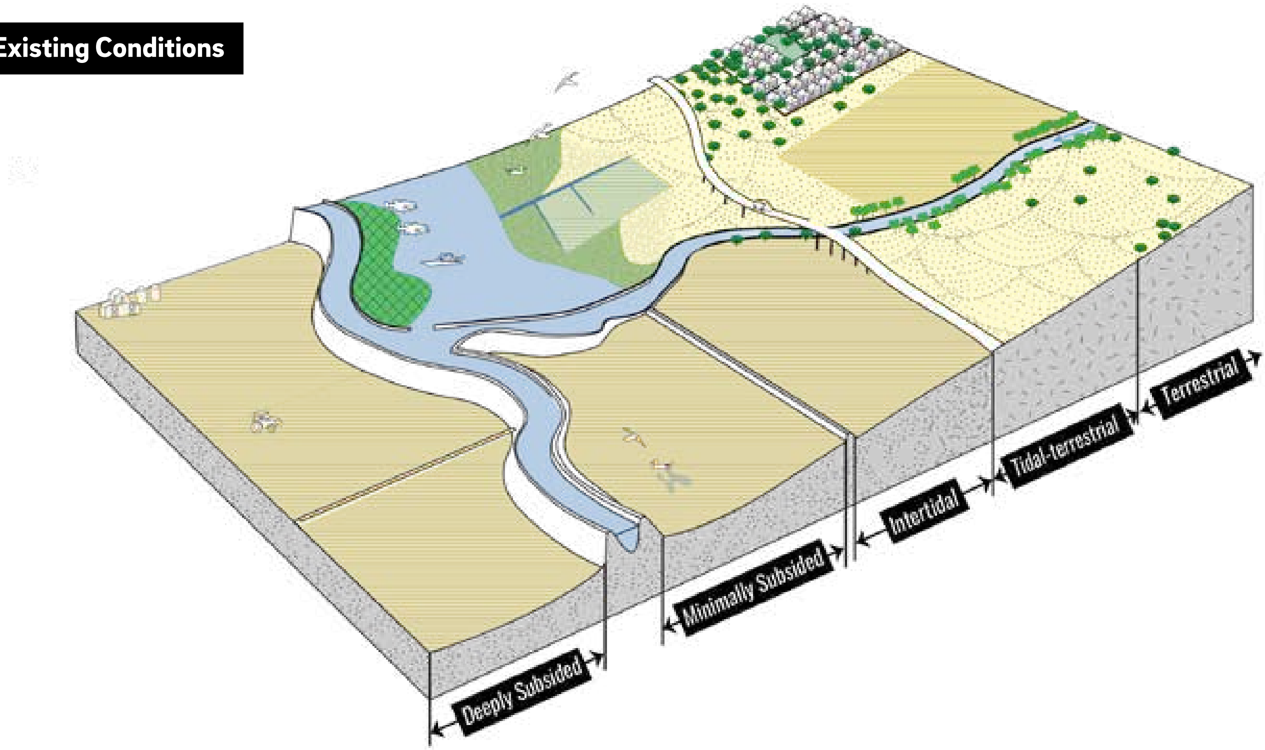
A fundamental consideration is that restoration and management actions are taken at appropriate elevations. The geomorphic zones presented in this document, which align with the elevation bands defined in the Delta Plan, divide the Delta into five different regions based on elevation relative to tidal influence, for which different actions are more or less suitable. By describing projects within the context of these zones, planners can help demonstrate whether actions are appropriate and will be sustainable in the long term given ongoing subsidence, sea level rise, and other changes. For example, tidal marsh restoration must be conducted where tidal inundation is possible now or in the near term, and should also consider impacts of sea level rise and accommodation space for marsh migration over time. In currently subsided areas, actions must reflect the potential for future inundation and ideally prioritize investments where active management over time may eventually allow for transition to more sustainable landscapes (e.g., subsidence reversal actions in the minimally subsided zone).

The following conceptual cross-sectional diagrams illustrate where restoration and management objectives may be addressed related to the geomorphic zones and what that might look like within a landscape context that is also supportive of the agricultural, urban, and recreational aspects of the Delta. Existing and potential landscapes are shown for comparison purposes. The different objectives relate to the protection, restoration, and enhancement of natural habitat types, reconnection and enhancement of natural physical and ecological processes, native species support, as well as ecosystem services.

Each of the objectives depicted in the illustrations relate to one or more different actions. Different actions taken in appropriate locations are together required to support future functional landscapes. Conversely, many actions address multiple objectives. For example, an area of clear synergy is that of actions for wetland restoration to improve ecosystem health and to reduce flood risk and sequester carbon by reversing or halting subsidence. These relationships are summarized in the following Objectives and Actions Table. Connections between actions and the appropriate geomorphic zone are shown subsequently in the Actions and Geomorphic Zones Table, which includes whether actions are process-based, what are potential supported ecosystem functions, and additional notes and caveats.

CONCEPTUAL LANDSCAPE VIEW OF GEOMORPHIC ZONES AND APPROPRIATE RESTORATION AND MANAGEMENT OBJECTIVES

Existing Conditions



Potential Future

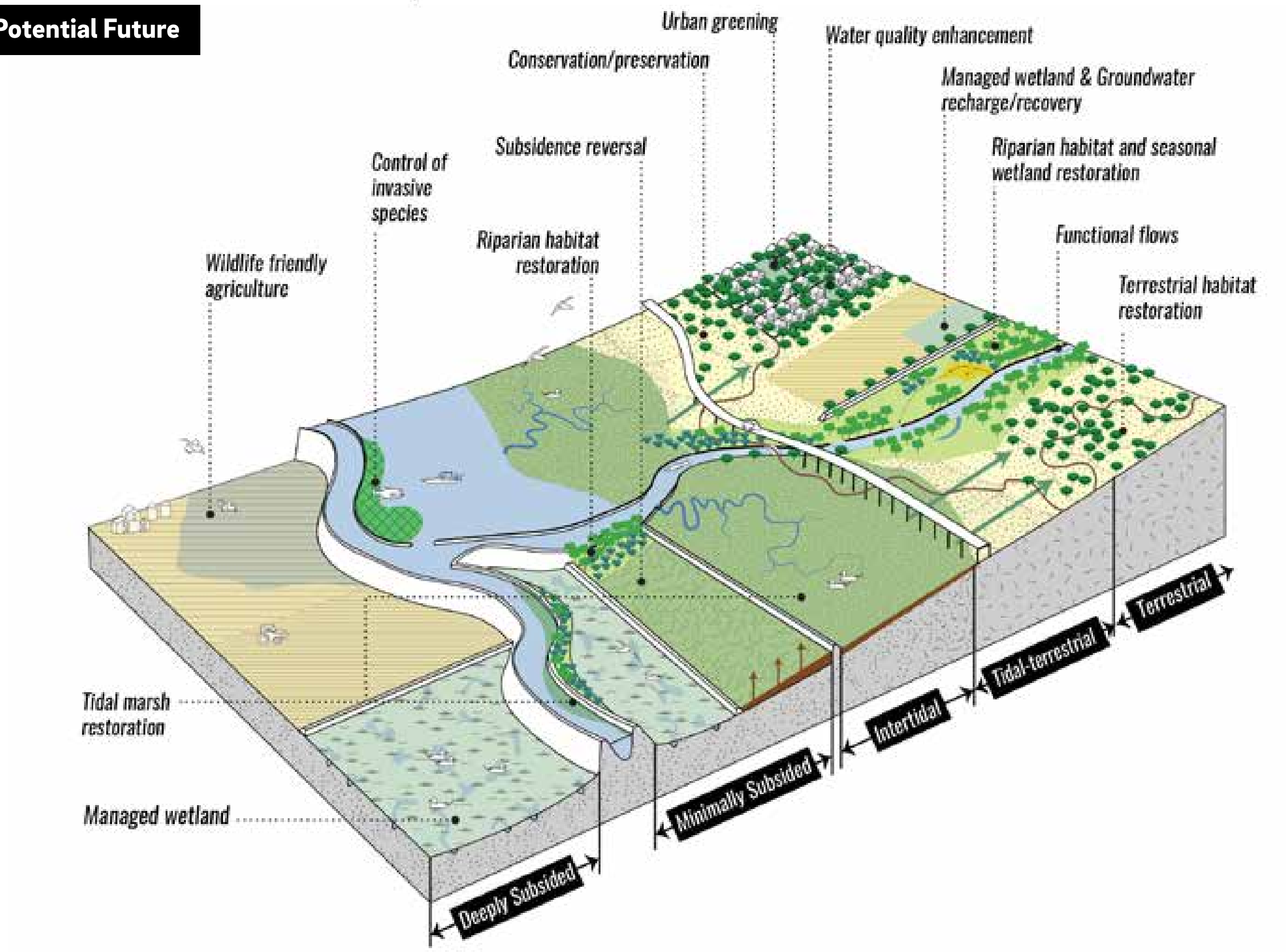


Photo by Shira Bezalel, SFEI.

OBJECTIVES AND ACTIONS TABLE

Restoration/ Enhancement Actions	Management/Restoration Objectives												
	Conservation/ Preservation	Tidal Marsh Restoration	Seasonal Wetland Restoration	Riparian Habitat Restoration	Terrestrial Habitat Restoration	Managed Wetland	Subsidence Reversal/Carbon Storage	Wildlife Friendly Agriculture	Control of Invasive Species	Urban Greening	Water Quality Enhancement	Functional Flows	Groundwater Recharge
Conservation of natural habitats	X												
Conservation of tidal wetland transgression space	X												
Remove barriers to wetland transgression		X											
Channel/floodplain modifications		X	X	X									
Levee setback/removal/breaching		X	X	X			X						X
Levee reslope/horizontal levee		X		X	X								
Levee wetland/planting benches creation		X		X									
Remove riprap				X									
Land surface grading/tidal channel network creation		X											
Tule farming						X	X						
Managed inundation regime/hydrologic connectivity			X	X		X	X					X	X
Water control structures/structure modification			X	X		X	X					X	X
Sediment augmentation (fill placement)							X						
Native wetland vegetation planting		X	X			X	X						
Native riparian vegetation planting				X						X			
Native upland vegetation planting					X					X			
Inundation tolerant crops/crop timing adjustments								X					
Hedgerows								X					
Wetland/vegetation buffers								X			X		
Reduce pesticide use								X			X		
Water diversion screens								X					
Reduce groundwater pumping				X								X	X
Reduce stormwater runoff (green stormwater infrastructure)										X	X		
Wastewater treatment improvements									X		X		
Beneficial reuse of wastewater										X	X		X
Reservoir reoperation and/or water use management												X	X
Rangeland management					X			X					
Fire management					X								
Physical/biological controls of invasive species										X			

ACTIONS AND GEOMORPHIC ZONES TABLE

Restoration/ Enhancement Actions	Geomorphic Zones: Deeply subsided	Minimally subsided	Intertidal	Tidal-terrestrial	Terrestrial	Process-based?	Functions
Conservation of natural habitats			Likely suitable	Likely suitable	Likely suitable	Yes	Terrestrial wildlife; Riparian wildlife; Marsh wildlife; Waterbirds; Native biodiversity
Conservation of tidal wetland transgression space				Likely suitable		Yes	Terrestrial wildlife; Riparian wildlife; Marsh wildlife; Waterbirds; Native biodiversity
Remove barriers to wetland transgression				Likely suitable		Yes	Marsh wildlife; Native biodiversity
Channel/floodplain modifications			Possibly suitable, consider other actions	Likely suitable	Likely suitable	Yes	Terrestrial wildlife; Marsh wildlife; Fish; Waterbirds; Productivity; Native biodiversity
Levee setback/removal/breaching	Possibly suitable in the long term	Possibly suitable in the long term	Likely suitable	Likely suitable	Likely suitable	Yes	Riparian wildlife; Fish; Waterbirds; Productivity; Native biodiversity
Levee reslope/horizontal levee	Possibly suitable, consider other actions	Likely suitable	Likely suitable	Likely suitable	Likely suitable	No	Terrestrial wildlife; Riparian wildlife
Levee wetland/planting benches creation	Possibly suitable, consider other actions	Likely suitable	Likely suitable			No	Riparian wildlife; Marsh wildlife; Fish
Remove riprap	Possibly suitable, consider other actions	Possibly suitable, consider other actions	Likely suitable	Likely suitable	Likely suitable	Yes	Terrestrial wildlife; Riparian wildlife
Land surface grading/tidal channel network creation	Possibly suitable in the long term	Possibly suitable in the long term	Likely suitable	Possibly suitable, consider other actions		Yes	Marsh wildlife; Fish; Waterbirds; Productivity
Tule farming	Likely suitable	Likely suitable				Variable	Marsh wildlife; Waterbirds; Productivity
Managed inundation regime/ hydrologic connectivity	Likely suitable	Likely suitable	Possibly suitable, consider other actions	Likely suitable	Likely suitable	No	Marsh wildlife; Waterbirds; Riparian wildlife; Productivity; Native biodiversity

Likely suitable

Possibly suitable, consider other actions

Possibly suitable in the long term

Narrative benefit descriptions	Caveats/Contingencies
Conservation of existing natural habitat and associated natural processes is essential for sustaining current populations for native wildlife and providing areas in the landscape to which future restoration can connect.	
Conservation of undeveloped land at the upland edge of the tidal zone will allow for wetland migration with sea level rise and promote ecotonal connectivity across wetland and upland habitats for native vegetation and wildlife.	
Removing potential barriers (e.g., roads) to wetland transgression will promote habitat connectivity in the short term and support the long-term resilience of tidal marsh habitat under climate change	
Physical channel or floodplain alterations (e.g., floodplain lowering, excavation of backwater side-channel habitat) can enhance hydrologic connectivity and establish desired floodplain inundation regime, promoting abiotic and biotic processes that drive habitat complexity and variability and overall support a variety of ecological functions	
Levee setbacks, full removal, or breaching at select locations can enhance hydrologic connectivity and establish desired floodplain inundation regime, promoting abiotic and biotic processes that drive habitat complexity and variability and overall support a variety of ecological functions	Cannot do in the near term in areas that subsided. Subsidence reveral would need to happen first
Where levee removal/breaching is not feasible, resloping the land side of a levee to be more gradual can allow for wider zones of habitat	Would do in the near term in subsided areas or in other areas where levees are necessary
Where levee removal/breaching is not feasible, creating narrow planting benches for wetland and riparian habitat on the channel side of the a levee can provide refuge and potentially foraging habitat for fish and riparian vegetation can provide shade and channel-riparian connectivity and riparian habitat for wildlife.	Would do in the near term in subsided areas or in other areas where levees are necessary
Where levee removal/breaching is not feasible but where alternatives to hardened levees are, removal of riprap can allow natural habitats for wildlife.	Would do in areas where levees are necessary
As part of tidal marsh restoration, the excavation of blind tidal channel networks may be practical for some sites (particularly if remnant channels exists or historical mapping suggests the past existence of such features).	
Active form of growing tules to maximize the sequestering of inorganic material for subsidence reversal. This is an practice to undertake in the near term where, over the long term, areas could begin to be opened to tidal action if/when they reach intertidal elevations. Though this does not provide habitat for fish, primary and secondary production could be exported to nearby channels to support the Delta food web. The farmed tules could also provide habitat for marsh wildlife and waterbirds. This action has the greatest potential for benefits in the shallowly subsided zone, given that more time is required to meet intertidal elevations in the deeply subsided zone.	
By managing the amount, timing, and duration of inundation within floodplain habitats (which could include wetlands as well as agriculture), various benefits could be provided depending on the practices. These benefits include productivity for export to the Delta food web, juvenile salmon rearing (as well as Sacramento splittail), waterbird foraging habitat, and support of marsh and riparian habitats.	Different practices would be appropriate for different zones. For example, water would need to be pumped on and off the land in subsided areas.

Restoration/ Enhancement Actions	Geomorphic Zones: Deeply subsided	Minimally subsided	Intertidal	Tidal-terrestrial	Terrestrial	Process-based?	Functions
Water control structures/structure modification	Likely suitable	Likely suitable	Possibly suitable	Likely suitable	Likely suitable	No	Terrestrial wildlife; Marsh wildlife; Fish; Waterbirds; Productivity; Native biodiversity
Sediment augmentation (fill placement)	Likely suitable	Likely suitable				No	
Native wetland vegetation planting	Possibly suitable	Possibly suitable	Likely suitable	Likely suitable	Likely suitable	No	Marsh wildlife; Fish; Waterbirds; Productivity
Native riparian vegetation planting			Possibly suitable	Likely suitable	Likely suitable	No	Terrestrial wildlife; Riparian wildlife; Productivity; Native biodiversity
Native upland vegetation planting					Likely suitable	No	Terrestrial wildlife; Native biodiversity
Inundation tolerant crops/crop timing adjustments	Likely suitable	Likely suitable	Possibly suitable	Likely suitable	Likely suitable	No	Terrestrial wildlife; Waterbirds; Fish
Hedgerows				Likely suitable	Likely suitable	No	Terrestrial wildlife; Riparian wildlife; Waterbirds
Wetland/vegetation buffers	Likely suitable	Likely suitable	Possibly suitable	Likely suitable	Likely suitable	Variable	Terrestrial wildlife; Waterbirds; Fish
Reduce pesticide use	Likely suitable	Likely suitable	Possibly suitable	Likely suitable	Likely suitable	NA	Terrestrial wildlife; Marsh wildlife; Fish; Waterbirds; Productivity
Water diversion screens	Likely suitable	Likely suitable	Possibly suitable	Likely suitable	Likely suitable	No	Terrestrial wildlife; Waterbirds
Reduce groundwater pumping				Likely suitable	Likely suitable	NA	Riparian wildlife; Fish
Reduce stormwater runoff (green stormwater infrastructure)					Likely suitable	No	Terrestrial wildlife; Native biodiversity
Wastewater treatment improvements	Likely suitable	Likely suitable	Likely suitable	Likely suitable	Likely suitable	No	Marsh wildlife; Fish; Waterbirds; Productivity; Native biodiversity
Beneficial reuse of wastewater					Likely suitable	No	Terrestrial wildlife; Native biodiversity
Reservoir reoperation and/or water use management			Likely suitable	Likely suitable	Likely suitable	Yes	Riparian wildlife; Fish; Productivity; Native biodiversity
Rangeland management				Likely suitable	Likely suitable	Yes	Terrestrial wildlife; Waterbirds; Native biodiversity
Fire management				Likely suitable	Likely suitable	Yes	Terrestrial wildlife; Native biodiversity
Physical/biological controls of invasive species	Likely suitable	Likely suitable	Likely suitable	Likely suitable	Likely suitable	Variable	Marsh wildlife; Fish; Waterbirds; Productivity; Native biodiversity

- Likely suitable
- Possibly suitable, consider other actions
- Possibly suitable in the long term

Narrative benefit descriptions	Caveats/Contingencies
Placing or modifying water control structures could promote hydrologic connectivity or to address issues such as flow direction and velocities that disturb fish migration/cues.	
As opposed to accretion of organic material through tule farming, placing inorganic fill sediment in subsided land can support subsidence reversal, though few ecological benefits are offered in the near term, until those areas provide habitat or reach intertidal elevations and tidal connection can be restored.	
Active planting to support the development of wetland habitats may be necessary where natural processes do not support the regeneration of native habitat.	If natural processes are not present
Active planting to support the development of riparian habitats may be necessary where natural processes do not support the regeneration of native habitat.	If natural processes are not present
Active planting to support the development of upland habitats may be necessary where natural processes do not support the regeneration of native habitat.	If natural processes are not present
Altering agricultural practices, through crops planted, the timing of crop rotation/fallowing, and/or inundation timing, can provide habitat for native wildlife (e.g., waterbirds, rearing juvenile fish) at certain times of year.	
Hedgerows within agriculture can provide habitat for birds and help promote landscape connectivity that allows the movement of wildlife.	
Wetland or other vegetative buffers along agricultural fields, near ditches and natural waterways can reduce water temperatures and reduce nutrients and pesticides entering the aquatic environment.	
Reducing the use of pesticides addresses water quality issues at the source, reducing nutrients and toxins that enter the aquatic environment.	
Direct entrainment of aquatic organisms, including fish, can be reduced through water diversion screens.	
Reducing groundwater pumping allows recovery of groundwater tables which can increase surface water flows that support fish and riparian vegetation and other groundwater-dependent ecosystems	
In urban landscapes, impervious surfaces quickly move stormwater and its pollutants to the nearby waterways, which can be reduced through the placement of green stormwater infrastructure.	
Upgrading wastewater treatment facilities to remove nutrients and pollutants improves water quality, which can support the food web, and potentially discourage growth of invasive vegetation	
Depending on the circumstances, wastewater can be used in agriculture to recharge groundwater or to offset water used for landscaping irrigation in urban environments.	
Taking a functional flows approach for managing flows in rivers and streams can help support a hydrologic regime that promotes natural physical processes, generates habitat for native fish and wildlife, and provides important life history cues.	Mostly addressed outside the Delta proper
Applying best management practices for rangeland can improve aquatic and riparian habitats as well as terrestrial habitat condition.	
Restoration of fire regimes into terrestrial landscapes can promote natural regeneration processes and habitat complexity.	
Control measures on invasive fish and aquatic vegetation help alleviate pressures on native fish and wildlife.	

CONCLUSIONS

This geomorphic zones digest presents five major elevation-based regions in the Delta, the terrestrial, tidal-terrestrial, intertidal, shallowly subsided, and deeply subsided zones. These zones are used by the Delta Plan and by the Landscape Scenario Planning Tool (www.sfei.org/projects/landscape-scenario-planning-tool) to guide project development and large-scale landscape planning. These zones are useful for understanding the physical template upon which different restoration and management actions may be taken to support more resilient future Delta landscapes. As illustrated in the conceptual diagrams of the Landscape Summary, different actions appropriate for the different zones together can add up to future landscapes that address multiple ecosystem, water supply, carbon sequestration and economic needs. The Delta of the future will not look like the past or present, and the planning guidance to match actions to appropriate locations on the ground provided in this document and associated map is intended to support a future Delta serving multiple benefits.

Photo by California Department of Water Resources.

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