Science Foundation Chapter 4
Connections to the Watersheds: The Estuarine-Terrestrial Transition Zone

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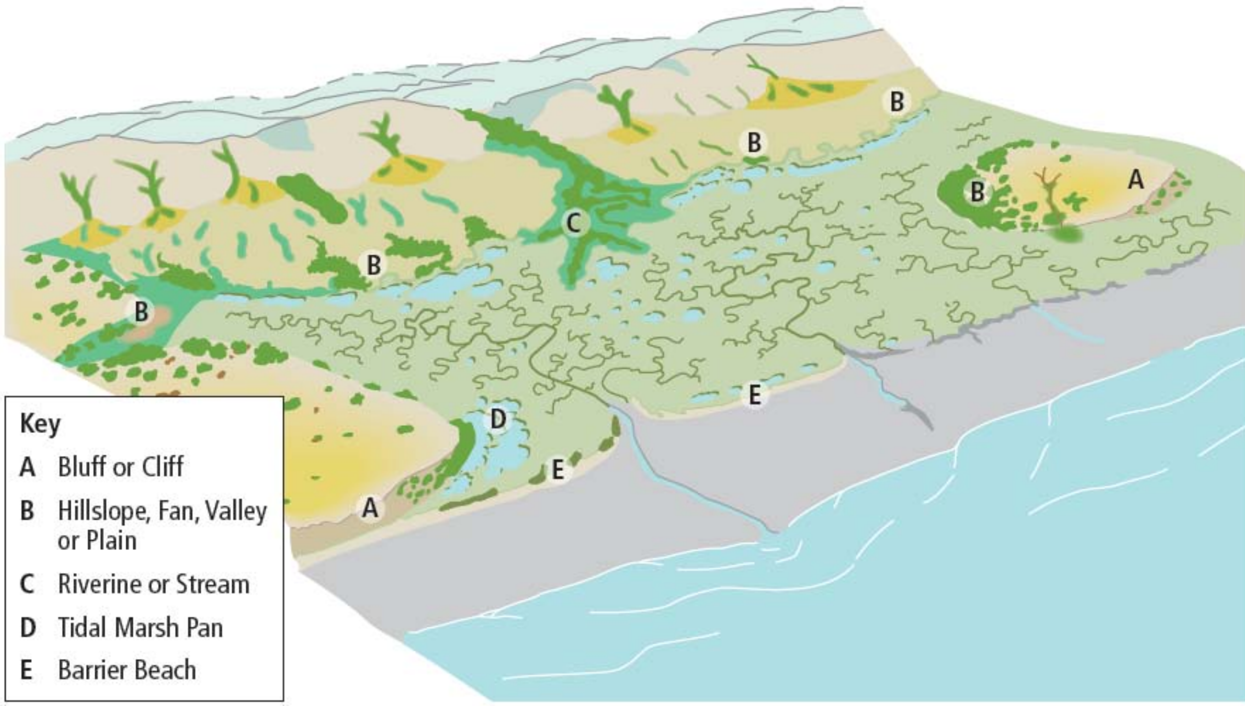
INTRODUCTION

Life in the Bay Area is concentrated along the bayshore. Most people live or work within half a mile of the Bay (US Census 2010). The history of people in the region living along the shoreline is evidenced by thousands of years of bayshore habitation and industry, with ancient shellmounds still apparent in shoreline parks to skyscrapers built over gold rush wharves in San Francisco. Maritime commerce connects the region to the rest of the world via seaports and airports built on the Bay edge. The remaining marshes of the Bay support most of the region's rare or endangered plants and animals (Harvey et al 1992). The edge of the Bay is packed with ecological, economic and cultural values.

The values of the bayshore are always changing. Historical values supported diking and filling the marshlands and shallows of the Bay for agriculture and commercial salt production, some of which was later converted to suburbs and other intensive land uses. This is one of the most urbanized estuaries in the world. In the urbanized areas, almost nothing is left of the natural shoreline. It has been fitted with major infrastructure for communications and power transmission, and for moving people, commercial goods, water, fuel, and wastes. This infrastructure rings the Bay, crossing through our current and former tidal marshes, crossing over most of our rivers and streams, and restricting connections between the Bay and its local watersheds. Much of the wildlife, water, and sediment from surrounding hills and valleys now move along unnatural channels through built environments to reach the Bay.



This figure illustrates a typical arrangement of the different transition zone types in a virtual landscape that represents the range in natural physiography around San Francisco Bay downstream of the Delta. The tidal salinity regime could be brackish or saline. This figure idealizes and integrates landscape characteristics of what are now Oakland, San Lorenzo, Hayward, Coyote Hills, Turk Island, and eastern Marin County. The foreground hillslopes (oak woodland top; coastal scrub on stabilized scarp behind barrier beach) are over-representing a local feature by perspective. Alluvial fans and plains (grassland) are realistically prominent. Tidal marsh pans (aka marsh ponds), freshwater non-tidal ponds (depressional wetlands), and wet meadows (slope wetlands) along streams and the baselines of hillsides are exaggerated to be visible. The tidal marsh is not part of the T-zone except for the backmarsh including the pans nearest the uplands and the barrier beach bordering the tidal flats. Natural salt ponds are larger than tidal marsh pans and are not represented in this figure. Artificial levees are also not included because they are not natural features.

The Bay's been rising too slowly to significantly constrain modern land use along its shoreline. We've only had to strengthen some levees and raise them a little higher, add pumps to drain lowlands behind the levees after floods, or raise diked lands above the Bay's current reach to protect our uses of the shoreline from gradually rising Bay waters. Public policies about the Bay have focused more on maintaining the bayshore as it is now than on its inevitable change due to sea level rise. For decades we've carefully minimized every activity that makes the Bay smaller, and now we need to figure out how to let the Bay get larger.

Climate change is a game changer. A rapidly rising Bay will change our economy, ecology, and culture (BCDC 2011, Heberger et al. 2012, Ayyub and Kearney 2012). Governmental agencies and other organizations responsible for the health of the Bay are exploring many ways to accommodate its expected rapid rise and expansion inland and upstream. Some of the major concerns are about managing flood hazards and protecting the essential ecosystem services[1] of the tidal flats and marshes.

The many services provided by the Bay will be lost if the tidal flats and marshes become tightly squeezed between the rising Bay and the built environment.

The challenge is not due to sea level rise per se, but the accelerated rate of rise expected by mid-century. Coastal people have been living with a gradual rate of sea level rise for thousands of years. However, the rate of its rise is expected to accelerate (IPCC 2014). How long the Bay will rise at any predicted rate is unknown. However, prudence and common sense demand that we plan our response now.

Efforts to address the threats imposed by rapid sea level rise have begun to focus on the shore of the Bay and the area of transition between the bay and the adjoining uplands. There is a growing awareness that this estuarine-terrestrial transition zone between the Bay and the uplands, hereafter termed the "T-zone", is needed to mitigate these threats. The T-zone is an integral part of a complete tidal marsh ecosystem (Science Foundation Chapter 2). It can provide space for the Bay to rise and expand without creating unacceptable flood hazards and without completely losing the ecological services of the tidal flats and marshes. There is also a growing recognition that the T-zone provides critical support for wildlife throughout the region, while also supporting its own unique plant and animal communities.

The interest in the T-zone has intensified since the first Baylands Habitat Goals Report in 1999. The forecasts of rising Bay waters were much less certain at that time than they are today. While there was a general appreciation of the need to restore and conserve the T-zone in the 1999 Goals Report, the broad range of T-zone services were much less understood, and our need for the T-zone to mitigate the threats of a rising Bay did not seem urgent. This update of the Baylands Goals Report provides an

We Aren't the First Bay Area People Facing a Rising Bay

People have been living along the central coast of North America for at least the last 11,000 years (Erlandson et al. 2008). During this time, the ocean has risen across the river plain that is now the Gulf of the Farallones, entered the Golden Gate, and formed the Bay (Atwater et al. 1977). Until about 3,000 years ago, sea level was rising so fast that every generation of people living along the coast or Bay was probably forced to retreat inland (Bickel 1978).

As the rate of sea level rise slowed, large marshes formed around the Bay and people established permanent villages near the marshes (Nelson 1907). They harvested shellfish to eat and used the shells to construct monumental mounds. Some of the mounds were more than 3 stories tall and some were built miles inland from the shore. No one knows all the reasons for these shellmounds. Were they made in memory of ancestors forced to retreat from the rising ocean and Bay? Are there shellmounds beneath the Bay and under the Gulf of the Farallones?

The Bay is rising rapidly again. Will those of us living and working along its shore retreat inland to safety? We have more infrastructure and land use to protect than ever before. Will we build walls and install pumps to keep the Bay out? Will we build islands to live on? How will future generations regard our response to a rapidly rising Bay? What will be our legacy as the next people facing this major environmental challenge?

Climate change is creating opportunities to restore the natural functions and services of the Bayshore. They were traded away for modern land uses that are threatened by the rising Bay. We can protect ourselves from the rising Bay in ways that sustain these services into the future. Will we?

[1] Ecosystem services are the processes of ecosystems and their material and energy outputs that benefit people. Essential services provide such benefits as food and water, building materials and natural fuels, flood control and disease control, recreation and spiritual healing, pollution filtration, nutrient cycling, and biological diversity.

important opportunity to address more fully the need to restore and protect the T-zone now and into the future.

Objectives

The objectives of this chapter are to define and describe the T-zone for the San Francisco Estuary downstream of the Delta, and to provide science-based guidance for conserving the ecological services of the T-zone in the context of climate change and especially sea level rise.

DEFINITION OF TRANSITION ZONE

The recommended definition is intended to be scientifically sound, comprehensive and practicable. It was developed from a set of guiding principles and evaluation criteria developed by the T-zone workgroup (see Appendix 4.1). This definition incorporates abundant local professional experience with t-zone evaluation and management, and it reflects the current scientific literature regarding the nature of environmental transition zones in general. The definition should be revised as necessary to reflect future advances in the scientific understanding of the T-zone and its services to people.

The estuarine-terrestrial transition zone, or T-zone, is the area of existing and predicted future interactions among tidal and terrestrial or fluvial processes that result in mosaics of habitat types, assemblages of plant and animal species, and sets of ecosystem services that are distinct from those of adjoining estuarine, riverine, or terrestrial ecosystems.

The T-zone as defined here does not include all the baylands. It also does not include all of the tidal marshlands. It only includes the portion of the marshlands wherein the plant community is directly and measurably influenced by terrestrial runoff and other freshwater discharges. It includes diked baylands that serve to store terrestrial flood waters, since flood control is a T-zone serviced, but it does not necessarily include other diked baylands.

The T-zone has often been visualized as the area of transition between tidal marsh vegetation and terrestrial vegetation. Such transitions are certainly part of the T-zone. However, the full suite of T-zone services indicates that the T-zone can be much broader in some settings. There is a relationship between topography, land use, runoff, T-zone services, and T-zone width that can be represented by a simple T-zone classification system. There is also a relationship between T-zone type and approaches to T-zone planning and management. These and other relationships are explained in sufficient detail to support the T-zone design and management recommendations provided later in this chapter.

DESCRIPTION OF TRANSITION ZONE

The T-zone provides the physical and ecological connection between the baylands and local watersheds. It connects the Bay to its developed as well as its undeveloped margins. It extends all along the bayshore and along the tidal reaches of rivers and streams. The T-zone includes the landward limit of the “backmarsh,” defined as the area between Mean Higher High Water and Extreme High Water or the Highest Observed

Tide (Ellis 1978, NOAA 2000)[2]. The T-zone extends uphill and upstream (i.e., landward) through the backmarsh to the limits of tidal effects on terrestrial and fluvial conditions. It extends downhill and downstream (i.e., bayward) through the backmarsh to the limits of the effects of terrestrial runoff and other freshwater discharges on conditions of the Baylands.[3]

The T-zone does not have a fixed width. It varies in width from place-to-place and over time. In the landward or upstream direction, the width of the T-zone is affected by several factors including the vertical range of the tide, the slope of the land, and the locations of built structures that control the upstream or landward movement of tidal water. In the bayward direction, the width of the T-zone mainly depends on the volume of terrestrial runoff entering the baylands. In general, for any given volume of runoff, the T-zone is wider where the tidal range is greater and where the land slopes gently to the bayshore. It is narrower where the tidal range is lesser and the land is steeper.

The width of the T-zone also varies at any given time and place based on the kinds and levels of ecosystem services it provides. For example, a broader T-zone is needed to provide marsh wildlife with refuge from high tides than if such refuge is not provided, and a broader T-zone is needed to accommodate sea level rise for the next century than for the next half-century. The relationship between T-zone width and the levels or kinds of it services is explained in more detail in the following section on ecosystem services of the T-zone.

Landward Extent of the Transition Zone

The existing field studies of the T-zone (e.g., NOS 1975, Baye 2012, Thomson 2012, Beller et al. 2013, SFEI 2014) describe it somewhat differently, depending on the factors and processes being studied. When these studies are considered together, they suggest that the following field indicators can be used to estimate the maximum width of the T-zone at any location around the Bay. The indicators are presented in an order that reflects the distance landward of the backmarsh to which they pertain. The indicators most applicable to the landward margin of the backshore are presented first.

Some of these indicators must be applied in the field, and others can be applied using historical or modern maps and landscape imagery. However, all of these indicators are based on empirical observations. Each requires further development before it can be used in standardized ways by different practitioners to map or delineate the T-zone. Additional discussion of some of these indicators is included in the later section on T-zone mapping.

Not all the indicators are always applicable, due to both natural and unnatural factors. In urbanized settings, where the indicators might not be evident, best professional judgment can be used to apply these

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[2] The landward boundary of the backmarsh can be difficult to delineate because it corresponds to the height of the uncommonly observed actual highest tide of the 19-yr metonic cycle (NOS 2000). The actual highest tide level is an "extratidal" water level because is not included in tide height predictions (VIMS 2014).

[3] The baylands are the intertidal areas of the Bay (i.e., the areas between the elevations of the actual highest tide level of the 19-yr metonic cycle (NOS 2000) and the Mean Lower Low Water tidal datum), plus any adjoining areas that would be intertidal if not for the presence of levees, dikes, and other unnatural structures that artificially limit the landward excursion of Bay waters (Goals Project 1999).

indicators to historical maps and imagery to help determined the likely historical and potential future extent of the T-zone.

- *Tidal Marsh Vegetation*. One approach to determining the landward boundary of the T-zone is to identify the position of the backshore (Ellis 1978, NOAA 2000). This indicator is applicable to all the T-zone. The backshore is synonymous with the landward limit of the backmarsh as defined above. This approach is based on measuring where rooted tidal marsh vegetation becomes nonexistent in the landward direction along transects that are perpendicular to, and that cross over, the apparent Mean Higher High Tide contour (NOS 1975, Harvey et al. 1978). The T-zone that is delineated in this way is relatively narrow (see Figure 4.1A). It generally extends landward to an elevation less than 1m above the local Mean Higher High Water contour. However, there have been many observations of tidal marsh plant species occurring at higher elevations (e.g., Baye 2008), presumably due to occasional extreme high tides over many decades and perhaps also to the long-term aerial deposition of salts entrained in winds crossing Bay waters. Furthermore, the practice of depositing dredged saline sediments from the Bay onto levee tops and the historical side-casting of such sediments onto hillsides can result in the occurrence of salt-tolerant vegetation at unnaturally high elevations. These effects can broaden the T-zone when delineated using tidal marsh plants as indicators.

- *High Water Refuge*. The existence of dense plant cover above Mean Higher High Water that provides high tide refuge for tidal marsh wildlife can indicate where the T-zone exists landward of the backmarsh (see Figure 4.1A). This indicator can be used to determine if refuge is available. However, the preferred plant species and other structural characteristics of the refuge, including its width, will vary somewhat among the wildlife species to be served. Further development of this indicator is needed to specify these characteristics for key wildlife species. In most cases, vegetation does not have to be native or indicative of tidal influences. In other words, the wildlife refuge may exist landward of the tidal marsh vegetation.

- *Head-of-Tide***.** The T-zone includes the head-of-tide (Figure 4.1B), which is defined through current studies (SFEI 2014) as the upstream limit of influences of tidal waters on channel geomorphology and hydraulics (Ensign et al. 2013, Florsheim et al. 2008, Bate 2002), aqueous salinity regimes and vegetation (Odum 1988, Brinson and Blum 1995), benthic sediment (e.g., van den Berg et al 2007, Ysebaert et al. 1993), benthic community composition (Strayer 2006, Kennish et al. 2004), and tide range (e.g., Gill and Schultz 2001). Owing to both daily and seasonal variability in tide heights (Marmer 1951), plus the variability in local river and stream flows, each HOT varies in width over time. The average width of each HOT depends on the slope of the channel bed, with steeper channels having narrower HOTs. Geomorphic, hydraulic and water quality conditions within the HOT are different than upstream and downstream conditions, such that the HOT supports unique plant and animal communities. A current study is concluding with a list of field indicators for identifying and delineating the HOT (SFEI 2014).

- *Habitat Mosaics*. The landward extent of the T-zone is influenced by complex interactions among tidal, fluvial, and terrestrial hydro-geomorphic processes that operate at the landscape scale. Collins and Grossinger (2004) and Beller et al. (2013) compiled written accounts of the landforms, habitat types, and vegetation patterns that were indicative of the landward extent of the historical T-zone of South Bay during the mid-nineteenth century (Figure 4.2). These historical data suggest that the salt marshlands were bordered in the landward direction by a band of salt-influenced vegetation, dominated by salt grass (*Distichlis spicata*), ranging in width from a few meters to more than a kilometer, depending on the steepness of the land. Near the backmarsh, the T-zone included freshwater springs and seeps, where near-surface fresh groundwater rose to the land surface over shallow intrusions of salt water (e.g., Harvey and Odum

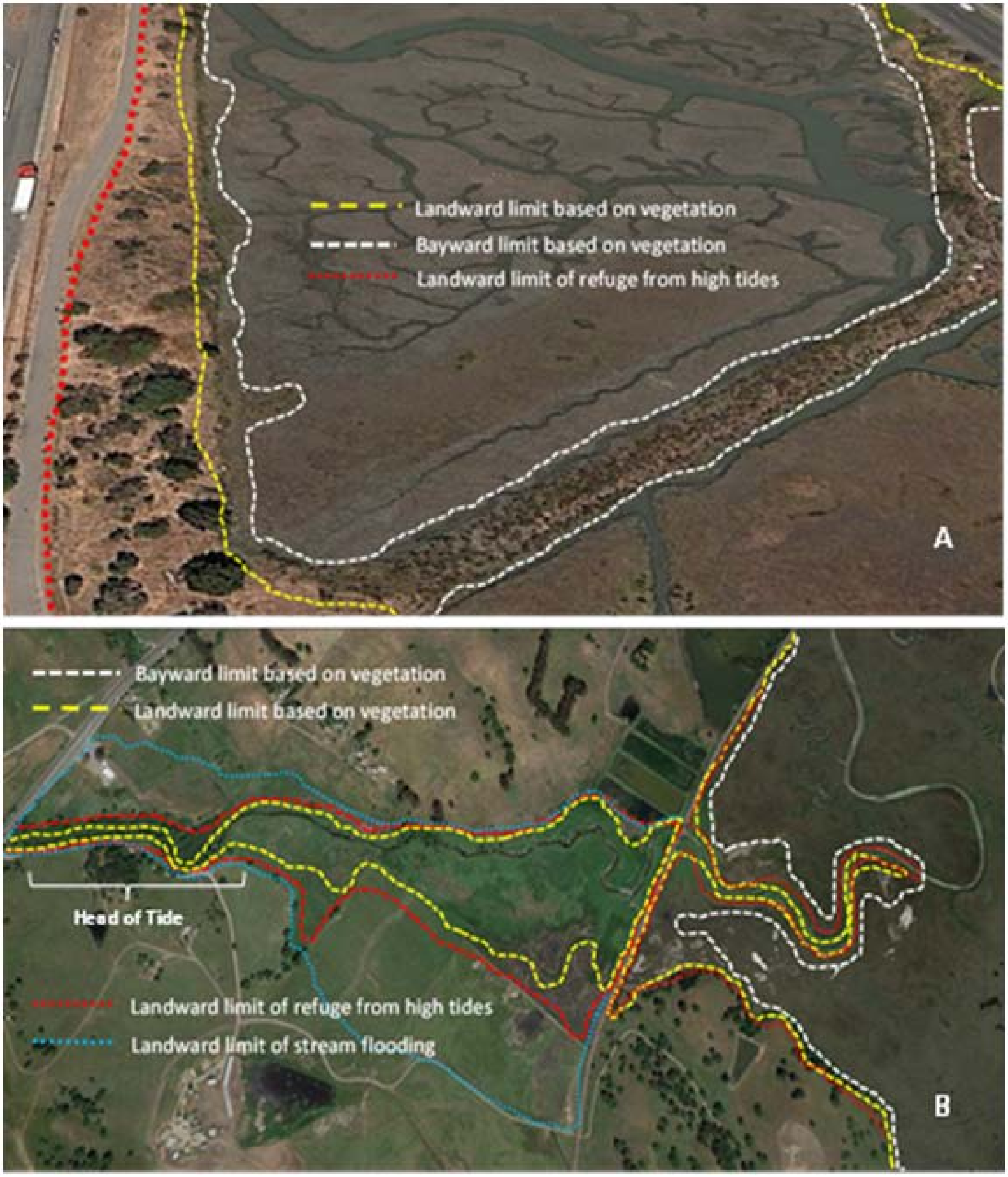

Figure 4.1. Different T-zone boundaries corresponding to different ecosystem services, showing (A) the upper and lower boundaries based on plant species assemblages indicative of the backmarsh, plus the landward boundary of the high tide refuge service for the T-zone associated with a levee (Richmond, Contra Costa County); and (B) these same kinds of boundaries plus the range in Head of Tide (HOT) and the landward limit of the flood control service for the T-zone associated with a perennial stream (San Antonio Creek, Sonoma County). The area of stream flooding in (B) relates to a railroad grade that constricts the connection between the fluvial and intertidal portions of the floodplain.

1990, Schultz and Ruppel 2002). Similar broad and complex habitat mosaics are also evident for brackish areas of the Estuary (Whipple et al, 2012). To better understand the nature of the T-zone and the full range of T-zone restoration potential, the studies recently completed for South Bay (Beller et al. 2013) and the Delta (Whipple et al. 2012) should be conducted throughout the rest of Estuary. Since most of the T-zone and adjoining uplands have been greatly modified by historical and modern land uses, there may be little existing evidence of the landward mosaics of T-zone habitats. As suggested above, these landscape-scale indicators can be applied to historical maps and imagery to estimate the potential for T-zone restoration.

- *Sea Level Rise Accommodation Space.* Planning the T-zone of the future must consider the likely landward migrations of the backshore and HOT due to sea level rise. If the T-zone becomes compressed between the rising Bay and steep natural lands or levees, its services will be diminished or lost completely. Therefore, broad areas for T-zone migration that can accommodate the full suite of local T-zone services in the future must be recognized as integral components of the existing T-zone. The width of the T-zone that is needed as accommodation space will depend on the rate and duration of sea level rise, the elevations and slopes of the lands and channels that are involved, and the presence of built structures that constrain the migration (Figure 4.3).

- *Ecological Connectivity.* In theory, the landward limit of the T-zone incorporates the movements of terrestrial wildlife to and from the baylands. The movements of small mammals and passerine birds suggest the T-zone extends 20-100m landward of the backmarsh (SFEI 2007). A wider T-zone has been noted for larger predators, such as coyotes and herons that have greater home ranges. Using wildlife movements to delineate the landward extent of the T-zone may not be practical at this time. However, local efforts to restore and protect the T-zone must consider how the particular needs of local wildlife that connect the T-zone to neighboring streams and terrestrial environments can be met through T-zone design and management. Once these needs are identified, the known natural history of the wildlife species of concern can be used to build ecological connectivity into T-Zone designs and management.

Bayward Extent of the Transition Zone

An essential aspect of the T-zone is that it extends both bayward and landward from the backmarsh. It extends bayward through intertidal areas that are clearly distinguished by the effects of terrestrial runoff, intertidal emergence of fresh groundwater, and the effects of the deposition of terrestrial sediment and other materials on intertidal conditions. These effects increase the overall complexity of the T-zone and hence its biodiversity and resilience.

- **Bayward Extent of Backmarsh Processes**. Natural intertidal drainage processes and the activities of people within the backmarsh can affect the bayward extent of the T-zone. Along the bases of natural hillsides, the backmarsh commonly includes seasonal freshwater seeps. These can be prominent features in areas of abundant precipitation. They are indicated by patches of freshwater or brackish wetland vegetation in tidal marsh (Figure 4.3A). The backmarsh can also be subject to an accumulation of debris, sometimes referred to as the wrack line, deposited during high tides. Just landward of the wrack line (or contributing to it) can be eroded soils and fallen plant material originating from the adjacent areas above the backmarsh. Levees that provide public access to the backshore increase its visitation by people and pets that sometimes venture into the adjacent tidal marsh. The distance to which pets, especially feral or managed dogs and cats, can be expected to venture into tidal marsh is not well known. It is expected,

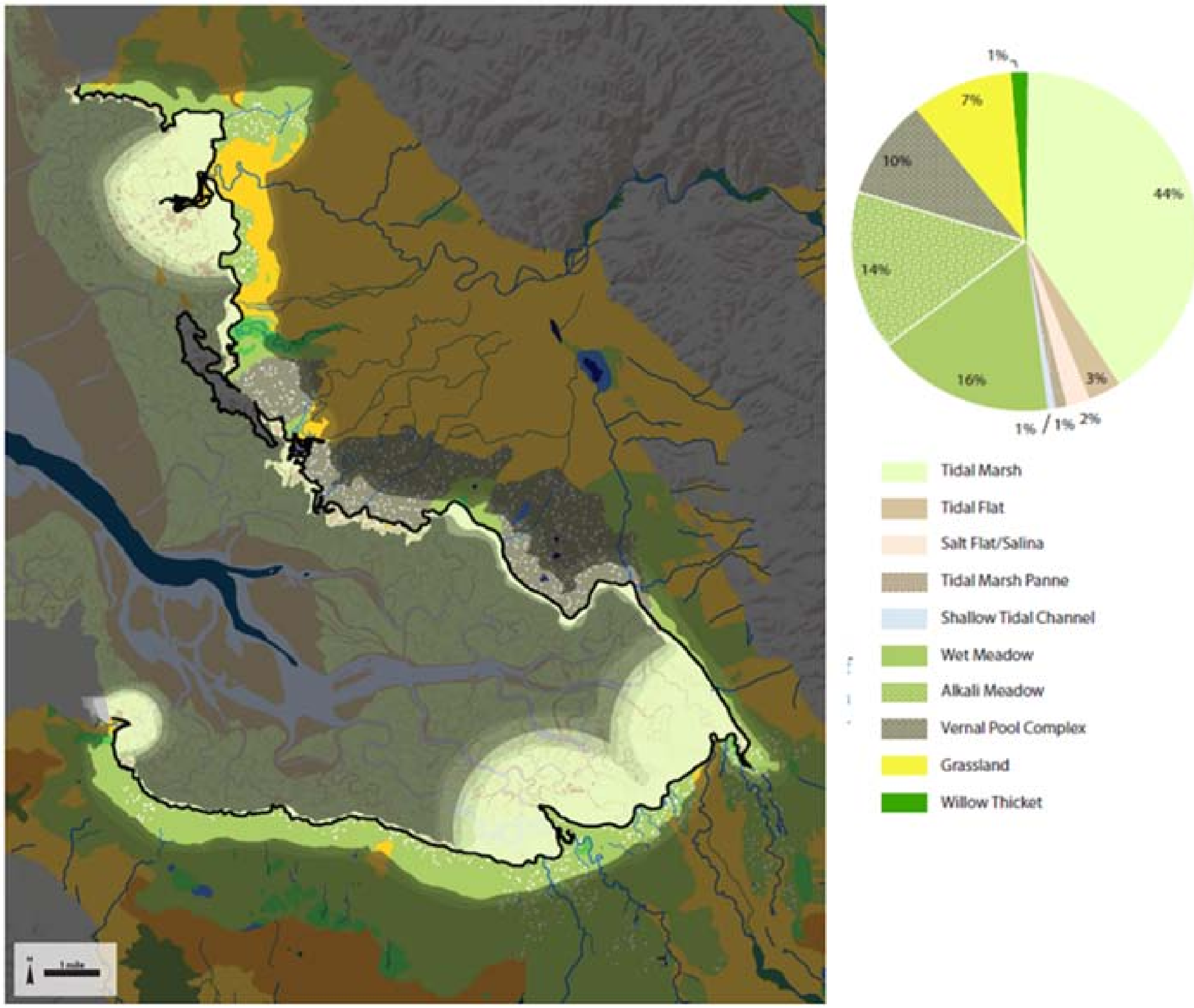

Figure 4.2. Map of the approximate historical extent of the transition zone (highlighted area) in South Bay (Beller et al. 2013). The transition zone is broadest bayward where intertidal vegetation is influenced by freshwater discharge from large streams. The transition zone is narrowest landward in the far southeast, where the adjoining land is steepest.

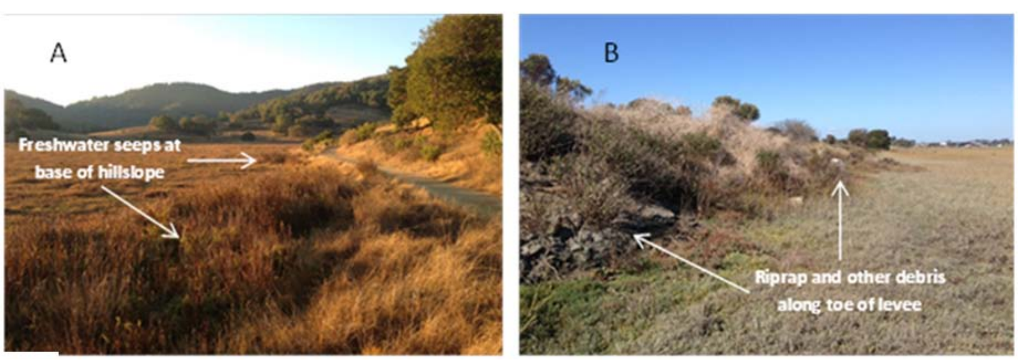

Figure 4.3. Examples of (A) freshwater and brackish vegetation indicating a freshwater seep along the backshore of saline marsh at China Camp, Marin County, and (B) riprap and other debris along the eroding bayward slope of an urban levee in Richmond, Contra Costa County.

Figure 4.4. Examples of pans that characterize the bayward habitat mosaic of the transition zone, showing (A) elongate pan at Whittell Marsh, Point Pinole, Contra Costa County; (B) diffuse pans in the area of tidal marsh landward migration into vernal pool east of Petaluma Marsh, Sonoma County; and (C) pans between hillsides and the landward limits of tidal marsh channels, China Camp, Marin County.

however, that pets can diminish the value of T-zone for wildlife (Simes 1999, Andrusiak 2003, Forrest and St. Claire 2006). Trash is a common component of the backmarsh wrack in urban settings (Figure 4.3B). In areas that are not affected by riverine discharges and that lack freshwater seeps, the backmarsh tends to develop distinctive habitat features and plant assemblages due to poor drainage and hypersaline soils. Elevated salinities are related to poor drainage. These flat intertidal areas are relatively high and landward of tidal marsh channels. The fine silts and clays deposited by high tides form dense, non-porous soils. Evaporation of the tidal waters trapped on the surface causes salts to accumulate. The combination of poor drainage and salt accumulation leads to the formation of shallow pans that lack vegetation (Figure 4.4). Once formed, these pans tend to persist as sites of salt concentration. The water in them can be brackish during the rainy season, when they trap precipitation, and hypersaline in the dry season.

- **Freshwater Discharge.** Freshwater discharge includes terrestrial runoff that reaches the T-zone through rivers, streams, canals and ditches, as well as non-saline effluent from water treatment facilities. The effects of freshwater discharge can be assessed as the bayward extent of tidal marsh plant species indicative of fresh or brackish water condition, and the bayward extent of fluvial bedload (i.e., the sediment that is transported by the discharge along the channel bed rather that in suspension). The extent of these effects is roughly proportional to the discharge volume, nutrient load, and total sediment bedload (see Figure 4.2 above). For any given volume of freshwater discharge, the extent of its effect on intertidal vegetation tends to be greater in brackish and saline areas of the Bay than in freshwater areas. That is, freshwater runoff has greater ecological effect in saline or brackish areas of the Bay than in freshwater areas. The yields of freshwater from larger watersheds and from sewage treatment facilities that discharge near the backmarsh can affect plant communities hundreds of meters bayward (H.T. Harvey and Associates. 2001 and 2002, Collins and Grossinger 2004, Grossinger et al. 2007, Hermstad et al. 2009, Grossinger 2009, Beller et al. 2010).

The bayward effects of terrestrial sediment loads can include the extension of fluvial levees into tidal marshes (Figure 4.5A), the deposition of sediments on marshes adjoining streams (Figure 4.5B), and the occurrence of brackish marsh vegetation in otherwise saline settings. The fluvial levees can serve as important avenues for the movements of terrestrial wildlife into and from intertidal areas. Trees on these levees are commonly used as roosts by birds of prey, including egrets, herons, hawks and owls that hunt in the baylands. Aggradation of channel beds (i.e., the build-up of the bed due to an accumulation of sediment and other materials) in the T-zone can decrease the physical complexity of the bed and thereby also decrease its value as habitat, while increasing the risk of riverine flooding. Deposition of inorganic sediments on the tidal marsh plain can raise its tidal elevation, increase its bulk density, decrease its porosity, and thus cause shifts in the species composition of the marsh plant community (e.g., Byrd and Kelly 2006, Baye 2008, Palaima 2012).

Some studies of the effects of nutrient loads on the bayward reaches of the T-zone have focused on extreme nutrient enrichment of tidal marshes (e.g., Deegan et al. 2012). In these cases, nutrient enrichment may cause a lowering of the marsh plain by increasing the rate of microbial decomposition of organic soils. The effects of less extreme nutrient loads are likely to include increased vigor of marsh vegetation, as well as some shifts in plant community composition (Levine et al. 1998, Boyer and Zedler 1999, Hunter et al. 2008, Morris et al. 2013).

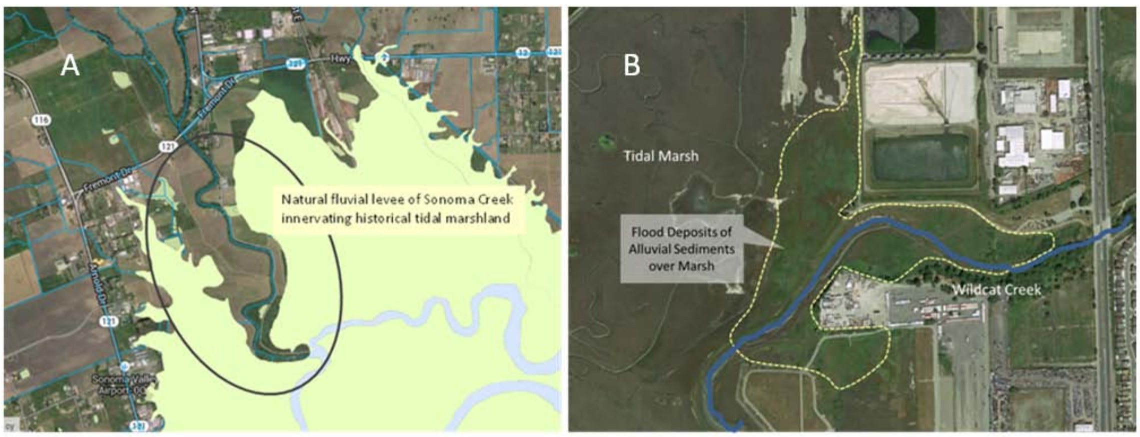

Figure 4.5. Examples of (A) a broad natural levee extending into former tidal marshland (Sonoma Creek, Sonoma County) and (B) a supratidal area caused by flood deposits of sediment on top of tidal marshland (Coyote Creek, Contra Costa County).

ECOSYSTEM SERVICES

Ecosystem Services are defined as the processes of ecosystems and their material and energy outputs that benefit people. Essential services provide such benefits as food and water, building materials and natural fuels, flood control and disease control, recreation and spiritual healing, pollution filtration, nutrient cycling, and biological diversity. In many cases, the values of the services are protected supported by laws and public policies.

The ecosystem services of the T-zone relate strongly to its role in connecting the baylands and their local watersheds (e.g., Ewel et al. 2001). This connection involves the conveyance of materials (e.g., the landward or bayward movement of water, sediment, and animals through the T-zone) and energy (e.g., the kinetic energy of moving water and the potential energy represented by the chemical bonds of the conveyed materials). The latter can be visualized as the energy released through the decomposition of trash and plant detritus that enters the T-zone from the Bay or from the local watershed. Much of the food web of the intertidal portion of the T-zone is probably based on detritus (Mitsch and Gosselink 2007).

The importance of the functional relationships between the T-zone and local watersheds should be emphasized. Most of the inorganic sediment that accounts for the formation and persistence of the tidal marshes is derived from local watersheds (McKee et al. 2013). As mentioned above, the freshwater runoff from local watersheds creates salinity gradients through the baylands and into the Bay that greatly increase the overall biodiversity of the region. Many species of terrestrial and aquatic wildlife, including birds of prey and salmon between the Bay and its local watersheds move through the baylands. In many regards, the Bay and its local watersheds are linked together by the baylands, and the mechanisms of this linkage are the workings of the T-zone.

The T-zone has always been the connection between the Bay and its watersheds. It has always supported the same basic kinds of natural processes and played the same natural roles. How people have valued them as services has changed, however. They are more valued today, due in part to better scientific understanding of their benefits to society. A general description of the most recognized T-zone services is presented here.

Ecological Resilience

For the purposes of this chapter, ecological resilience is defined as the amount of disturbance that an ecosystem can withstand without undergoing major changes in its stable state, as measured by its form and structure, or the time an ecosystem takes to return to a stable state following perturbation (Holling 1973, Gunderson 2000, Walker et al. 2004). Resilience therefore varies from ecosystem to ecosystem and over time. One challenge in restoration ecology is to understand the natural self-organizing processes that lead to resilience. A major goal of BEHGU is to increase the ecological resiliency of the baylands as a whole, and it is assumed that this depends on restoring and sustaining a resilient T-zone. Providing upland buffers and accommodation space for estuarine migration, as well as assuring that Baylands designs are consistent with natural processes of Baylands formation and maintenance can help achieve resilient Baylands ecosystems.

There is a theoretical relationship between the ecological complexity of ecosystems, their overall resilience, and the success of their management (Folke et al. 2004, Holling 2004, and Campbell et al. 2009). In general, it is expected that management success increases with resiliency, which increases with complexity. Therefore, increasing the ecological complexity of the T-zone is assumed to be one strategy for increasing its resilience, as well as that of the baylands ecosystem. High levels of all of the following services are assumed to be consequences of a resilient T-zone.

Providing ecological resilience for the baylands ecosystem is regarded as an over-arching service of the T-zone. The levels of all its other services can be used to assess its own resilience and its contribution to the resilience of the Baylands.

Buffering

The T-zone serves as a buffer in two basic regards. It moderates the landward effects of tidal processes and it moderates the bayward effects of fluvial and terrestrial processes. Most of the buffering relates to controlling pollution, erosion, and flooding.

- **Pollution Control.** The vegetated portions of the T-zone can help improve the quality of tidal waters by filtering organic and inorganic pollutants, including fine sediment, from terrestrial runoff and tidal flood waters. The trapped sediment can serve to bind and sequester heavy metals and nutrients (Odum 1990).

The T-zone can include the portions of tidal marshes that are intentionally used to help treat urban runoff and effluent from sewage treatment facilities.

- **Biological Invasion Control.** If the T-zone is densely vegetated with native plant species, it can help protect adjoining intertidal habitats from invasion by non-native terrestrial vegetation by creating a barrier to their bayward dispersal (e.g., Woolfolk 1999; Baye 2008; Fetscher et al. 2010; Wasson and Woolfolk 2011).

- **Erosion Control.** Vegetated intertidal habitats help protect adjoining terrestrial habitats by reducing their risk of erosion (Seliskar and Gallagher 1983; Garbisch and Garbisch 1994; BCDC 2011). This service of the T-zone mostly occurs during very high tides that inundate the marsh plain so deeply that the marsh does not effectively the erosive energy of ship wakes and wind-generated waves.

Flood Control

The T-zone can help reduce the hazards of riverine flooding by if it includes the following landscape features or elements.

- **Channels.** The tidal reaches of channels that convey riverine floodwaters or effluent to the Bay are part of the T-zone, to the extent that the waters measurable affect marsh plant community structure.

- **Floodplains**. The landward portions of intertidal floodplains that disperse floodwaters and the riverine floodplains bordering the Head-of-Tide (HOT) are part of the T-zone. The high marsh plain can also serves to attenuate wakes and wind-generated waves that otherwise are more likely to erode levees that prevent tidal flooding.

- **Floodwater Storage Areas.** Diked baylands and natural or artificial depressions on riverine floodplains bordering HOT that store floodwaters are part of the T-zone.

Sea Level Rise Accommodation

This is a complex service relating to sustaining intertidal habitats, especially tidal marsh and the tidal reaches of rivers and streams, as well as appropriate bayshore land uses, such as flood water dispersal and storage that are threatened by accelerated sea level rise (see Science Foundation Chapter 3).

Accelerated sea level rise threatens critically important infrastructure and many land uses around the Bay (BCDC 2011). The need to plan for the future T-zones provides opportunities to examine alternative management responses to this increasingly serious threat. The undeveloped areas that are landward of the existing T-zone can provide ways for the T-zone to migrate landward and upstream with minimum social impacts.

Sea level rise causes the intertidal zone and the T-zone to migrate landward and upward into local watersheds (e.g., Wasson et al. 2013). The leading edge of this migration is usually marked by the landward margin of new backmarsh. Four factors mainly influence the width of resulting marshland: the rate of sea level rise, the steepness of the land surface across which the tidal marsh can migrate, the amount of fine inorganic sediment (i.e., silts and clays) deposited on the marsh plain during tidal and riverine flooding, and the amount of organic materials (i.e., roots and plant litter) that are produced by the marsh vegetation and contribute to the height of the marsh plain. Increases in the supply of organic and inorganic sediment can offset increases in the rate of sea level rise (e.g., Mudd et al. 2009). To some degree, sea level rise can be regulated with water control structures that are built into levees and across creeks. However, these structures can be expensive to build and maintain, and they can have unintended biological and water quality impacts. For any set of these factors, the potential width of the new marshland is mainly controlled by the topographic slope immediately landward. By providing gently sloping lands across which the T-zone can migrate, the resilience of the marsh ecosystem to sea level rise is greatly enhanced.

Sea level rise and changing precipitation patterns will drive geomorphic changes at the heads-of-tide (HOT - see description of HOT and references therein in the previous section about the bayward extent of the T-zone). By providing naturalistic stream gradients and ample floodplains upstream and adjacent to existing HOTs, their services can be conserved and the hazards of flooding can be reduced.

Nutrient Processing

Much of the T-zone consists of wetlands (see profiles of T-zone types in Appendix 4.2). All wetlands tend to have high rates of nutrient assimilation. They also tend to have very high rates of primary productivity, and they tend to retain much of the organic material they produce. The terrestrial slope wetlands that exist along the backmarsh undoubtedly provide nutrients downslope to the adjoining intertidal habitats. This is commonly indicated in the field by greater vigor or stature of tidal marsh vegetation along the immediate landward boundary of the backmarsh. It has also been hypothesized that tidal marshes export nutrients to coastal waters, where they subsidize estuarine food webs (*Valiela and Teal 1979,* Odum 1980). There have been many studies to understand the direction and magnitude of nutrient fluxes to and from tidal marshes, as well as the underlying mechanisms (Childers et al. 2002; Nixon 1980; Odum 2002; Stevenson et al. 1988). The results of these studies are equivocal. While it is certain that tidal marshes tend to be net nutrient producers (Hammer 1989, Tiner 2013), whether or not the net direct of nutrient flux is bayward may vary from one marsh to another, and over time.

Groundwater Recharge

The areas of the T-zone that include riverine floodplains or stormwater retention basins can help maintain near-surface groundwater levels through recharge during floods. Such recharge constrains near-surface saltwater intrusion, while maintaining freshwater slope wetlands, springs, and seeps in or near the backmarsh. If the groundwater is high enough it can discharge into tidal reaches of streams within the T-zone during low tide, thus maintaining downstream salinity gradients that increase biological diversity.

Biological Diversity Support

Broad ecological transitional zones tend to be biologically diverse (e.g., Naiman and Dé camps 1990, *Karka and van Rensburg 2006).* They tend to be areas where biological communities or assemblages overlap, and they can have their own endemic flora and fauna, (Odum 1953, Holland 1988, Holland et al. 1991, Harding 2000, West and Zedler 2000, Leppig and While 2006, Senft 2009). The Bay Area T-zone supports a variety of plants and animals of special management concern (Table 4.1).

The biological diversity of the T-zone is the consequence of many ecological processes. The key processes are discussed below. Additional information about the value of the T-zone to wildlife is presented in Science Foundation Chapter 5.

- **Wildlife Refuge and Predation.** The T-zone provides refuge from both physical and biological sources of stress and mortality for wildlife species. For example, it serves as a refuge from tidal and riverine flooding for both intertidal and upland biota, including numerous rare and endangered species (Chapman et al. 1996, Sedell et al. 1990, Semlitsch and Bodie 2003, BCDC 2011, Josselyn 1983, Goals Project 1999, 2000). During major flood events, tidal marsh wildlife tends to be concentrated in the T-zone, which therefore can serve as an important foraging area for many species of predators. The degree to which the T-zone serves as refuge is likely to be proportional to the width of the T-zone and its structural complexity.

- **Wildlife and Plant Movement.** The T-zone supports the migration and dispersal of plant and animal species. It enables them to move along the bayshore between patches of preferred baylands habitat. For example, the endangered California clapper rail and salt marsh harvest mouse use the T-zone to move between patches of tidal marsh that are otherwise discontinuous (Fisler 1965, Botti et al. 1986, Shellhammer 1989, Overton 2014). The T-zone will also enable baylands wildlife to track or avoid changes in salinity due to future sea level rise. There are many species of wildlife that regularly travel into the T-zone from adjacent terrestrial areas to forage (SFEI 2007). Where the T-zone involves a river or stream, it can support the seasonal movements of anadromous fishes and other wildlife between the Bay and local watersheds.

- **Evolutionary Adaptation.** *T*he survival of local populations of plants and animals depends on their adaptation to changes in habitat conditions. Such adaption is known to occur at the margins of habitats, including in ecotones where individuals encounter the limits of their physiological tolerance to environmental factors (Mayr 1970, Lesica and Allendorf 1995, Schilthuizen 2000, Gaston 2003, *Karka and van Rensburg 2006*). For some species, the T-zone may be critically important as a place for adaptations to changes in habitat conditions caused by sea level rise. For example, it can be hypothesized that the ability of larvae of coastal populations of the red-legged frog (*Rana draytonii*) to tolerate brackish water salinities reflects adaptation to increasing salinities at breeding sites within the T-zone (Collins and Collins 2007), given that the general intolerance of frogs to salinity is well known (Ruibal 1959), and other coastal species of frogs have shown adaptation to fluctuating intertidal salinity (Gomez-Mestre and Tejedo 2003, Rios-López 2008). Similarly, the adaptation of brackish-water plants to increased salinity could be occurring in the T-zone of brackish marshes, where soil salinities tend to be locally elevated.

- **Landscape Complexity.** The T-zone contributes to a complex mosaic of bayland habitat types (see discussion of habitat mosaics in the above section on factors affecting the landward extent of the T-zone) that increase the local diversity and abundance of plant and animal species across landscapes at a regional scale (Poiani et al. 2000, Moritz 20002, Huber et al 2010; also see Chapter 6).

Table 4.1. Native wildlife and plant species of concern for management of terrestrial-tidal marsh ecotones (from Baye 2008).

Species	Regional Habitat and Range
Ridgway's rail (*Rallus longirostris obsoletus*)	Tidal salt marsh, tidal brackish marsh: SF Bay, San Pablo Bay, western Suisun Marsh and Martinez marshes.
California black rail (*Laterallus jamaicensis coturniculus*)	Tidal brackish marsh (occasionally salt marsh): Suisun Marsh, Martinez Marshes, San Pablo Bay; local in SF Bay.

Virginia rail (*Rallus limicola*)	Tidal brackish marsh, non-tidal brackish or freshwater marsh; throughout Estuary.
Salt marsh harvest mouse (*Reithrodontomys raviventris*)	Tidal or non-tidal salt or brackish marsh, middle and high marsh zone; abundant pickleweed; throughout Estuary.
Salt marsh wandering shrew (*Sorex vagrans halicoetes*)	Tidal salt marsh, middle marsh zone, abundant invertebrate prey, driftwood; San Francisco Bay south of Golden Gate
San Francisco Estuary song sparrow subspecies (*Melospiza melodia* sspp)	Tall high tidal marsh vegetation near tidal creeks and adjacent terrestrial scrub.
San Pablo vole (*Microtus californicus sanpabloensis*)	Tidal marshes around the mouth of San Pablo Creek (Contra Costa County)
Suisun shrew (*Sorex ornatus sinuosus*)	Tidal salt or brackish marsh, northern San Pablo Bay, Suisun Marsh, dense low vegetation with woody debris
Red-legged frog (*Rana draytonii*)	Occasionally breeds in brackish marsh backshore pools
Soft bird's beak (*Cordylanthus mollis* ssp. *mollis*)	Tidal brackish or salt marsh, high marsh zone with sparse, low cover; northern San Pablo Bay to Suisun Marsh, Martinez Marshes
Northern salt marsh bird's-beak (*Cordylanthus maritimus* ssp. *palustris*)	Tidal salt marsh, high marsh zone with sparse, low cover; Sausalito to Petaluma River (Marin County)
Suisun thistle (*Cirsium hydrophilum* var. *hydrophilum*)	Tidal brackish marsh, middle to high marsh zone, Suisun Marsh
Salt marsh owl's-clover (*Castilleja ambigua* ssp. *ambigua*)	Tidal salt or brackish marsh, high marsh zone, San Pablo Bay and Suisun Marsh (historic range also in SF Bay)
California sea-blite (*Suaeda californica*)	Tidal salt marsh bordering sandy beaches, Central and South San Francisco Bay (historic range)

Cultural Support

Cultural support refers to the importance of the T-zone to regional and local human history, and to its value for environmental science, education, recreation, and spiritual healing.

The transition zone provides most of the public access to the Bay. For example, the popular Bay Trail traverses much of the T-zone. Most recreational fishing in the Bay occurs at piers and along the backmarsh of the T-zone. Environmental science, education, and recreation are major aspects of the region's culture, and much of this involves the T-zone.

Ongoing research in the T-zone is focused on such fundamentally important topics as the effects of sea level rise on nearshore habitats, the effects of human visitation on wildlife, and how coastal engineering might mitigate the hazards of sea level rise. Numerous environmental education programs use the T-zone as an outdoor laboratory. Many non-governmental environmental organizations (e.g., Students and

Teachers Restoring A Watershed (STRAW), Save The Bay, Marin Audubon Society, Acterra) work to clean the T-zone of trash, and to restore the T-zone's native plant communities.

This intensive public interest in the T-zone is not new. There are many cultural resources representing prehistoric to historical communities of peoples that are associated with the T-zone. These include ancient shellmounds and other evidence of Indian occupation and use, the embarcaderos of the mission period and gold rush, the remnants of railroads and Chinese fishing villages of the early industrial period, and historical ranching, dairying, and military buildings. The T-zone retains important evidence of many distinctive cultures in the region.

Carbon Sequestration

Wetlands are important in the global carbon balance (Mitra et al. 2005, Bridgham et al. 2006, Crooks et al. 2014). They serve as important carbon sinks, due to their fast rates of primary productivity, large standing biomass, and tendency to retain much of this material in the form of highly organic sediments (Zedler and Kercher 2005). The amount of carbon sequestered in the T-zone is probably proportional to the amount of the T-zone that is comprised of wetlands. Carbon sequestration in the baylands is not limited to the T-zone, however, and it is covered in more detail in Science Foundation Chapter 6.

TRANSITION ZONE TYPOLOGY

Based on the existing studies of the historical T-zone (Collins and Grossinger 2004, Beller et al. 2013), field surveys that characterize its present-day condition (NOS 1975, Baye 2012, Thomson 2012, Beller et al. 2013, SFEI 2014), and the current scientific understanding about how the T-zone is formed and naturally sustained, a T-zone typology in two parts has been developed. One part organizes the T-zone into types based on formative processes and physical structure. The second part organizes the T-zone into Sub-zones based on the different spatial limits of its ecosystem services.

Types of Transition Zones

Seven T-zone types have been identified based on differences in the environmental factors and processes that govern T-zone formation (Table 4.2). Each type is profiled in detail in Appendix 4.2. In aggregate, these seven types of T-zone represent the full range of existing T-zone conditions for the Estuary downstream of the Delta.

The typology can serve to guide T-zone restoration and management. For example, successful restoration will require knowing what type of T-zone is best suited for a given restoration site, based on the local controlling factors and processes. Mismatches between T-zone types and settings will cause restoration efforts to fail expensively.

As explained in Appendix 4.2, one type of T-zone, the Barrier Beach type, is usually dissociated from the backmarsh and HOT. It often occurs at the bayward margin of tidal marsh. It is identified as a type of T-zone because it provides many of the same ecosystem services as the other T-zone types. For example, Barrier Beaches can serve as high tide refuge and they support evolutionary adaptation and movement of intertidal plants and animals.

Sub-zones of the Transition Zone

Each type of T-zone can be sub-divided into 2-4 Sub-zones (SZ) based on the different extents (i.e., "footprints") of key ecosystem services (Figure 4.6). The levels of service provided by each Sub-zone vary among the T-zone types. There are many factors that influence the levels of services provided by any particular Sub-zone (see Figure 4.7). But, in general, the wider and less disturbed sub-zones provide higher levels of their characteristic services (Table 4.2).

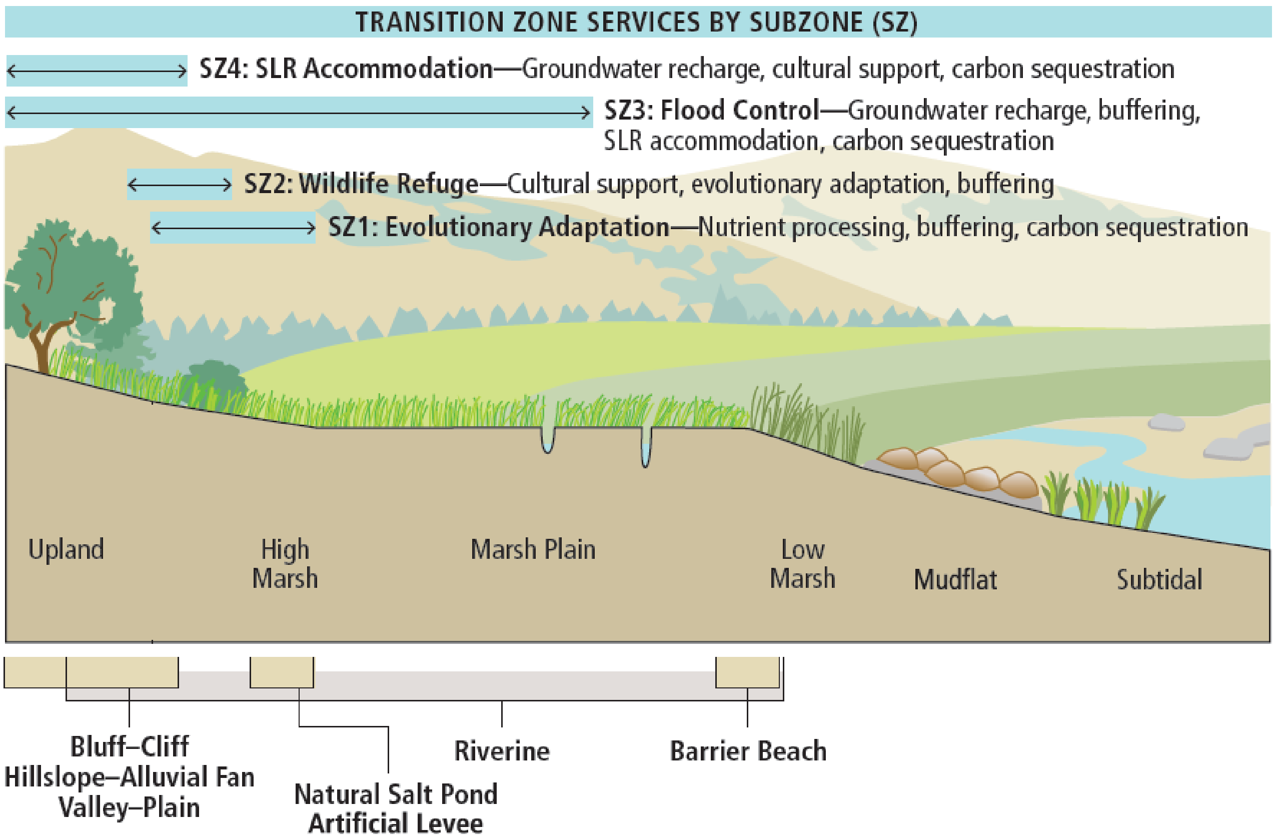

Figure 4.6. Diagram of spatial relationships among T-zone types, Sub-zones, and tidal datums of the baylands ecosystem. Sub-zones SZ# and SZ4 extend landward of the upland shown in this figure. The Riverine Type extends bayward to the limits of the effects of freshwater discharge on the intertidal vegetation. The primary services of each Sub-zone are shown in bold. Ubiquitous services (e.g., ecological resilience, animal movement, landscape complexity) are not shown because they do not help differentiate the Sub-zones.

The differentiation of the T-zone into Sub-zones helps to organize efforts to achieve specific kinds or levels of services through T-zone design and management. In other words, the levels of different services can be controlled to some degree by the design and management of the Sub-zones. One step in T-zone planning or restoration is to decide what type of T-zone is best suited to the restoration site, and another step is to decide how wide each Sub-zone should be to provide needed kinds and levels of service (see section below on T-zone planning and management).

For convenience, the Sub-zones are numbered in the order they would be encountered by a person walking landward from the backmarsh. For example, anyone walking uphill from the landward edge of a tidal marsh would first encounter Sub-zone 1 (SZ1). Assuming that the T-zone has an area of dense vegetation

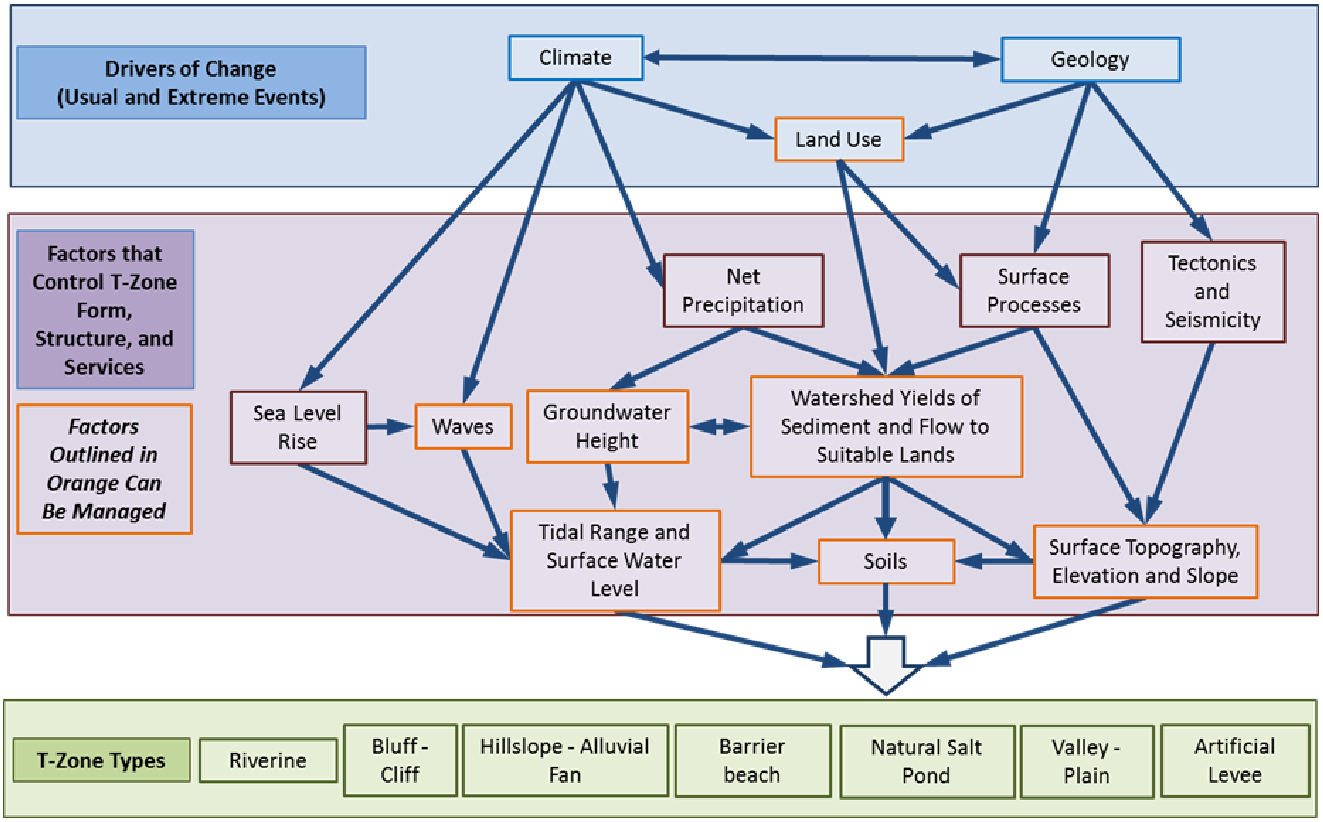

Figure 4.7. Conceptual model of the effective relationships among drivers and factors affecting type, condition, and ecosystem services of the transition zone. Factors that can be managed to achieve desired transition zone conditions are outline in orange.

above the backmarsh that serves as wildlife refuge, the person would encounter Sub-zone 2 (SZ2). Walking further uphill or landward from the backmarsh the person might encounter an area of diked marsh used to store riverine floodwaters or to buffer the refuge and tidal marsh. This would be Sub-zone 3 (SZ3). Walking further landward the person would be entering Sub-zone 4 (SZ4), which is the area dedicated to sea level rise accommodation.

People who rarely visit any part of the bayshore except via a trail atop a bayshore levee might understandably regard the levee as the entire T-zone. Assuming that the levee supports the kind of vegetation needed to provide some amount of wildlife refuge, and that no floodwaters are stored behind the levee, and that there is no possible accommodation space further landward, the T-zone is effectively

Table 4.2. Expected kinds and levels of ecosystem service for T-zone types and their Sub-zones (dark green = high level of service; light green = medium level; white = low level). Indicated levels of service are generalities and can be adjusted through T-zone design and management (e.g., see table footnotes pertaining to SZ3 of Riverine Type and SZ 4 of Levee Type).

Ecosystem Service		T-zone Sub-zones and T-zone Types			
		Sub-zone 1 (SZ1) Endemism	**Sub-zone 2 (SZ2) Refuge**	**Sub-zone 3 (SZ3) Flood Control**	**Sub-zone 4 (SZ4) Sea Level Rise Accommodation**
		All Types	All Types	Riverine[A]	Hillslope-Fan Valley-Plain Riverine Levee[B]
Buffering	Pollution Control	**H**	**M**	**M**	**L**
	Non-native Invasion Control	**M**	**M**	**L**	**M**
	Erosion Control	**H**	**H**	**L**	**L**
Flood Control		**L**	**L**	**H**	**L**
Sea Level Rise Accommodation		**L**	**L**	**H**	**H**
Nutrient Processing		**H**	**L**	**M**	**L**
Groundwater Recharge		**L**	**L**	**H**	**H**
Biological Diversity Support	Wildlife Refuge and Predation	**H**	**H**	**M**	**M**
	Wildlife and Plant Movement	**M**	**H**	**M**	**M**
	Evolutionary Adaptation	**H**	**M**	**L**	**L**
	Landscape Complexity	**M**	**M**	**M**	**H**
Cultural Support		**L**	**H**	**L**	**H**
Carbon Sequestration		**H**	**L**	**L**	**M**

[A] Includes diked baylands used to store floodwaters.

[B] Sea Level Rise Accommodation can be enhanced for the Levee Type of T-zone by greatly reducing the slope of the side of the levee facing the Bay to create uplands for the Bay to migrate onto. This concept has been termed the "horizontal levee" (The Bay Institute 2013).

restricted to SZ1 (i.e., a narrow area along the bayward levee face), SZ2 (a narrow area of wildlife refuge on the levee face and perhaps atop the levee), and a bayward component of SZ3 (the tidal marsh plain that attenuates wave energy). The T-zone in this case would probably support evolutionary adaption along the backmarsh at the base of the levee, provide some refuge from high tides, attenuate waves to some degree, and provide some amount of cultural support in the form of passive recreation (e.g., hiking, jogging, and bird watching along the levee). The levels of these services could be significantly reduced by the narrowness of the sub-zones, their lack of physical complexity, and prevalent visitation by people and terrestrial predators (Foerster and Takekawa 1991, Baye 2008). These considerations notwithstanding, the services provided by the Levee Type of T-zone can be locally very important to the health and safety of people and wildlife.

SZ2 deserves special consideration because of its value as a high tide refuge for residential birds and small mammals, some of which are rare or endangered. Furthermore, it supports a unique plant community adapted to very infrequent tidal flooding that includes several rare, threatened, and endangered plant species. It generally extends from just above the local Mean Higher High Water (MHHW) contour to the ecologically effective limit of tidal influence, assumed to be the locally Highest Observed Water Level (HOWL) (Harvey et al 1978, NOS 1978, Thomson 2013, Fulfrost and Thomson 2014). Using these tidal datums to bound SZ2 can facilitate its mapping. SZ2 is especially sensitive to invasion by non-native plants and excessive visitation by people. In the current landscape, SZ2 is one of the most threatened features of Pacific coast tidal salt marshes (Traut 2005). Bay Area losses of natural SZ2 have been estimated to be 90% (Shellhammer 1982), and the ecological services of the remaining areas of SZ2 have been severely degraded (Baye 2004). More information on SZ2 particular to transitions between tidal marsh and upland is in Appendix 4.3.

The stratification of the T-zone into a number of contiguous sub-zones based on the spatial distributions or "footprints" of its services has precedent in the design and management of riparian buffers. Many public agencies responsible for riparian buffers subdivide them into three or more component zones that correspond to different kinds or levels of buffering (e.g., Wenger 1999*,* Collins et al. 2006, Johnson and Buffler *2008*). The riparian definition recommended by the National Research Council recognizes that the ecological functions or services indicative of riparian areas tend to extend different distances from the adjoining bodies of water (NRC 2002). The T-zone as defined here, absent sub-zone SZ4, is generally consistent with the NRC riparian definition. From the perspective of riparian science, the T-zone as defined here is essentially the riparian zone of the Bay.

TRANSITION ZONE MAPPING

None of the efforts to map the tidal wetlands of the Bay Area (Jones and Stokes Associates et al. 1979, Dedrick 1989, Dedrick and Chu 1993, SFEI 2011) have explicitly identified any part of the T-zone. However there has been some effort dedicated to mapping the Bay Area T-zone alone. Two such projects have explicitly identified parts of the historic (Beller et al. 2013), current and future (Fulfrost and Thomson 2014) T-zone. Important regional efforts to map non-aquatic terrestrial habitats and land use, such as the Conservation Lands Network (http://www.bayarealands.org/about/), the head-of-tide (HOT) mapping project (SFEI 2014), the California Vegetation Classification and Mapping Program (VegCAMP) (http://www.dfg.ca.gov/biogeodata/vegcamp/system), and the National Land Cover database (Collin et al. 2012) have also not explicitly identified the T-zone. Efforts to map floodplains (FEMA 2003), flood infrastructure (SFEI 2013), the riparian zone of tidal marshlands (SFEI 2010), and to predict the effects of climate change on future Bay water levels (Veloz et al. 2012, NOAA 2012), will provide essential data for mapping the T-zone, but will not by themselves or in combination provide a comprehensive regional T-zone map, based on the definition and classification of the T-zone recommended here.

Ecological transitions are challenging to map because of the dynamic nature of their formative processes that result in abundant variability from place to place and over time. The challenge is made more difficult by the need to resolve the complexity of the T-zone into a practical map that planners and managers can use to track local and regional changes in T-zone extent and condition, and to prioritize T-zone restoration and protection needs and opportunities (Fulfrost and Thomson in preparation, SFEI 2014).

The optimal approach to mapping the T-zone will probably involve estimating the extent of each type of T-zone and the width of their Sub-zones. This will facilitate linking the map to expected ecosystem services and management actions. Furthermore, there should be guidelines for mapping the T-zone at two spatial scales: local (project-specific), and regional (i.e., across multiple projects within a subregion or for the Bay as a whole. The two spatial scales of mapping are needed to assess the local performance of projects as well as their cumulative impacts on T-zone extent and condition. A regional map is especially important for prioritizing restoration and protection efforts, assessing the relative effects of projects and ambient climate change, and evaluating the efficacy of state and federal policies used to govern land use affecting the T-zone.

Regional Scale

Mapping efforts at the regional scale can be completed with GIS-based techniques using, as much as is feasible, existing datasets. It is also possible to manually map from aerial imagery or even conduct surveys. However, the time and expense of these approaches can limit the ability of practitioners to employ them across broad geographic areas. Efforts to comprehensively map the T-zone across the region need to be developed for a variety of reasons, including but not limited to the following: the T-zone cannot be protected if its existing a likely future extents are unknown; a map of the T-zone is needed to guide assessments of its condition, understand baseline conditions for assessing future change, and to prioritize conservation actions.

Much work is needed to identify the best indicators and supporting data for mapping the T-zone types and their service-based Sub-zones. The previous section describing the landward and bayward extents of the T-zone present some of the empirical field indicators that could be further developed to support accurate T-zone mapping. Any regional efforts to map the T-zone should be coordinated with efforts to map other landscape elements, such as wetlands, streams, flood-prone areas, and flood control infrastructure. A plan for such coordination is needed. In support of such a plan, the alignment between existing regional mapping efforts and the need for a regional T-zone map has been explored (Table 4.3). This is only an initial look - it should only serve as a starting place for a more thorough assessment of ways to coordinate and advance a regional T-zone mapping effort.

Of the various mapping efforts reviewed, several stand out as essential components of a regional T-zone map. These three efforts together will greatly increase the capacity of environmental planners and managers to protect the ecosystem services of the T-zone. It must be emphasized, however, that there is, at this time, no concerted effort to integrate these efforts or others into a comprehensive methodology for mapping the T-zone.

<u>Landward Extent of the effects of tidal processes on vegetation</u> (Fulfrost and Thomson, in preparation). This is a regional effort to map the likely current landward extent of tidal marsh vegetation, as affected by extreme high tides and wave run-up. When combined with existing maps of tidal marshes, flood infrastructure, and HOT (i.e., SFEI 2011 and 2013, SFEI 2014), this map will depict the habitat composition and topography of the landward portion of SZ1 (i.e., the portion of SZ1 that is landward of local Mean Higher High Water), and the bayward portion of SZ3 (i.e., the tidal marsh plain for distributing riverine flood waters at low tide and for attenuating waves).

- **Landward Extent of Tidal Flood Risk (NOAA 2012)**. The purpose of this model and its online visualization tool is to provide coastal managers and scientists with a preliminary look at potential sea level rise and coastal flooding hazards. The viewer is a screening-level tool that uses nationally consistent data sets and analyses. The data and maps can be used at several scales to help gauge trends and prioritize actions for different sea level rise scenarios. This model and its output maps could be augmented with other existing and forthcoming regional maps that more accurately depict topography (e.g., OPC 2012), hydrography (SFEI 2011), flood infrastructure (SFEI 2013), and land use (e.g., Collin et al. 2012, Conservation Lands Network http://www.bayarealands.org/about/) to better estimate the landward extent of SZ4.

- **Head-of-Tide** (SFEI 2014). An existing study will establish a protocol for mapping the HOTs around the Bay, starting with a pilot project on six local streams (SFEI 2014). The resulting protocol will allow multiple practitioners to estimate the location of HOT for any natural or artificial drainage channel connected to the intertidal area of the Bay. When combined with existing maps of tidal marshes, levees, and flood-prone areas (FEMA 2003), this map will depict the extent of the landward component of SZ3 (i.e., terrestrial areas and diked baylands used to disperse or store riverine floodwaters). This composite map could be combined with the map of tidal marsh (SFEI 2013) to visualize the approximate entire extent of SZ3.

Local Scale

Local mapping refers to the development of maps to inform local planning and management of T-zone restoration projects. Project-specific maps can also be used to analyze levels of ecosystem services and their controlling processes, to assess the regional diversity and extent of the T-zone, and to track the effects of sea level rise that are not detectable at coarser scales. High-resolution local re-mapping of the T-zone can be used for early detection of sea level rise impacts on T-zone conditions. Greater map resolution and accuracy are needed to support these local purposes of T-zone mapping.

There is currently no single accepted method for high-resolution local mapping of the T-zone, as defined here. It is likely that the optimal methodology will involve validation through field delineation. Trial use of remotely sensed vegetation indicators to estimate the landward and/or bayward limits of SZ1, SZ2, and SZ3 (See Table 4.3) suggest that vegetation might also be used to delineate these Sub-zones on the ground. As noted above, vegetation indicators have been used to delineate both the landward and bayward limits of SZ1 and SZ2 (e.g., NOS 1975, Harvey et al 1978, H.T. Harvey and Associates 2002, Collins and Goodman-Collins 2010).

Mapping Needs

No combination of existing mapping efforts in the Bay Area provides the map that is needed to protect the ecological services of the T-zone. While some aspects of the needed map are being addressed, there is currently no map of the T-zone Types or the Sub-zones. This minimizes the ability of T-zone designers and managers to assess constraints and opportunities to restore or enhance T-zone services.

Table 4.3. Brief descriptions of mapping efforts in the Bay Area relevant to transition zone restoration and protection, with initial considerations for improving the efforts with additional modeling and transition zone data.

Existing Mapping Efforts	Sub-zones: SZ1 Evolutionary Adaptation	SZ2 Refuge	SZ3 Flood Control	SZ4 Sea Level Rise Accommodation
Fulfrost and Thomson (in Preparation)	GIS model of the landward limit of backmarsh based on DEM and interpolated tidal datums			
H.T. Harvey and Associates 2002	Combination of field methods and remote sensing used to estimate bayward limit of freshwater discharge effects on tidal marsh vegetation			
Collins and Goodman-Collins 2010, Harvey et al. 1978, NOS 1975	Relative abundance of tidal marsh plant species along field transects used to assess the landward extent of the backmarsh			
SFEI 2013; FEMA 2003			Local Maps of flood infrastructure based on LiDAR plus maps of flood-prone areas used to estimate landward extent of flood control needs and opportunities.	
SFEI 2014	Physical and botanical field indicators used to delineate the upstream and downstream limits of local heads-of-tide.			
NOAA 2012				GIS model used to forecast future Bay margins based on interpolated tidal datums, coarse DEM, and selected sea level rise rates.

Possible Augmentations of Existing Mapping Efforts	Sub-zone	
	SZ1, **SZ2**	Use field methods (e.g., NOS 1975, Harvey et al. 1978, H.T. Harvey and Associates 2002, Sawyer et al. 2008) to calibrate remotely sensed spectral and structural signatures of plants indicative of the landward and bayward aspects of SZ1, and the landward extent of SZ2, and add these signatures to a hybrid of existing GIS models (e.g., based on SFEI 2010, NOAA 2012, Fulfrost and Thomson in Preparation) to improve maps of SZ1 and SZ2.
	SZ3	Combine existing numerical hydrological models used to manage flood risks with new models of combined effects of storm surge and terrestrial runoff plus new maps of flood infrastructure (SFEI 2013) and HOT (SFEI 2014) to forecast effects of sea level rise and changing precipitation patterns on flood hazards, and to test the efficacy of dispersing riverine floodwaters across accommodation spaces, tidal marsh plains, and diked baylands (i.e., SZ3).
	SZ4	Augment the existing federal approach to sea level rise mapping (NOAA 2012) with high-resolution DEMs, new flood infrastructure maps (SFEI 2014), BAARI (SFEI 2011), and detailed land use maps to provide local estimates of accommodation space needs and opportunities for selected sea level rise scenarios.

TRANSITION ZONE FUTURE CHANGE

There is a growing consensus among climate scientists that the Bay Area will undergo significant climate change consisting of a rapidly rising Bay and changes in temperature and precipitation patterns by 2100. Although many factors can affect the local or sub-regional accuracy of the forecasts (e.g., Knowles and Cayan 2004, Flint and Flint 2012), most point to higher average air temperatures, greater warming in summer than winter, earlier warming in the spring, more variable rainfall between years and decades, more intense rainstorms, longer and perhaps more extreme droughts, increased flood risks (due to more intense rainstorms), and decreased average annual stream discharge (Knowles and Cayan 2004, Cloern et al. 2011, PRBO Conservation Science 2011, Cayan et al. 2012). Simply stated, the region can expect increased aridity in the context of more extreme weather events. The estimates of how high the Bay will rise by 2100 range broadly, due mainly to different assumed rates of global greenhouse gas accumulation. For the purposes of BEGHU, it is assumed that the mean level of the Bay will rise 1.4 to 5.5 ft above the current mean level (NRC 2012). The likely response of the tidal marsh plain to these different sea level rise scenarios is discussed in Chapter 2. With regard to the T-zone, the different rates of sea level rise mainly translate into different rates of upstream and landward migration of the T-zone or its compression against the built environment. Additional factors affecting these possible responses are outlined in the following conceptual model of T-zone formation, structure, and services.

Conceptual Model of Drivers and Factors of Transition Zone Form, Structure, and Services

Successful T-zone restoration and management requires understanding how its dimensions, condition, and ecosystem services vary around the Bay due to basic controlling processes and factors. The following conceptual model (Figure 4.7) identifies the major controls on the extent and condition of the T-zone as defined and described above. The purpose of the model is to help identify the controls that can be intentionally managed to restore and protect the T-zone.

According to this model, there are three main drivers of T-zone change: climate, geology, and land use. In this context, geology means the greater formative processes of a landscape, including tectonics, seismicity, and orogeny, as well as its geologic structure. The drivers of T-zone change operate through a complex network of interacting factors.

Of these three drivers, only land use can be managed to affect desired T-zone conditions. For example, waves along the shoreline, groundwater height, and runoff can be managed to achieve the surface hydrology, soil conditions, and topography necessary to achieve target levels of ecosystem services, while accommodating factors that cannot be easily managed such as seismicity, deep landsliding, changes in precipitation, and sea level rise.

The T-zone changes over time. It is subject to relatively gradual changes in some factors, such as sea level rise, biological invasion, subsidence due to groundwater extraction, and increases in recreational use. It can also be subject to sudden and sometimes extreme natural events with major consequences, such as levee beaches and wild fires. The relative importance of the various controlling factors can also change. For example, as sea level rise accelerates it will probably gain importance relative to other factors and processes.

Comprehensive knowledge of the historical T-zone throughout the Estuary would be helpful to calibrate the model and to understand all the restoration possibilities. The existing remnants of the historical T-zone do not represent its full range of natural condition, and they have been severely altered by land use (Shellhammer 1982, Shellhammer et al. 1982, Goals Project 1999). Furthermore, the construction of levees has added to the possible range of T-zone conditions, and levees are likely to be part of the future T-zone.

General Considerations

While the relationships among the basic processes and factors that control the extent and condition of the T-zone can be conceptualized (see Figure 4.7), there are few models to quantify the controls or predict the resulting levels of T-zone services. Models for predicting tidal marsh response to sea level rise (see Chapter 2), or to estimate levels of wildlife support, or to estimate the ability of the T-zone to attenuate wave energy pertain to the tidal marsh portions of Sub-zones 1 and 3 (SZ1 and SZ3). Models used to predict flood hazard reduction through flood water storage pertain mainly to Sub-zone 3 (SZ3). There are essentially no quantitative models to predict levels of other services of the T-zone. The following discussion of the likely responses of the different types of T-zone to climate change and sea level rise is therefore general and qualitative.

The T-zone will be affected by climate change in local watersheds as well as sea level rise (see Figure 4.7). The expected increase in the intensity of rainstorms could result in more erosion of hillsides and streams, which in turn could increase the volumes of sediment delivered to the Hillslope-Alluvial Fan T-zone, Bluff T-zone, and Riverine T-zone. The expected increase in dry season air temperatures and the possibility of longer droughts could result in more frequent fires in the undeveloped landward Sub-zones of each T-zone type. It's very difficult to predict how the terrestrial vegetation of the T-zone will be affected by climate change, but increased invasion of non-native plant species is likely, given that these species tend to exploit disturbed environments. Changes in the plant community of the T-zone will in turn lead to changes in how the T-zone supports wildlife.

The basic effects of the rising Bay on T-zone conditions are perhaps more predictable. As the Bay rises, the T-zone will tend to migrate landward, if there is adequate accommodation space. Otherwise it will be increasingly compressed until Sub-zones 1-3 are very narrow or drowned. Since the diversity of services of the T-zone increases with the number of intact Sub-zones, and since the levels of service of any Sub-zone tend to increase with its width, compression of the T-zone will result in a loss of both the diversity and levels of its services. This highlights the importance of a broad SZ4 that can accommodate the landward migration of all the Sub-zones.

While having a broad SZ4 will certainly increase the resilience of the T-zone to climate change, it will not guarantee that the T-zone will remain intact. The landward migration of the T-zone is not a simple process. Migrating plant species may encounter unsuitable soils and moisture regimes, resulting in some amount of secondary succession[4]. As the plant communities of the four Sub-zones change, so will their habitat functions. There may be no way to prevent some degree of net ecological change in the T-zone due to climate change and sea level rise, even if the T-zone has ample accommodation space.

Extreme weather events can significantly affect conditions of the T-zone. For example, the distributions of plants and animals tend to reflect variations in soils, environmental moisture, and disturbance regimes along the elevation gradient from SZ1 through SZ4. These environmental factors are commonly influenced by road grades, levees, tide gates, and other unnatural structures that control either tidal or riverine flooding. Extreme storm events that overtop these structures can suddenly alter conditions of the T-zone, especially for SZ2-4, by changing soil and moisture conditions. An increase in the frequency of riverine flooding has the potential to increase the rate of change in T-zone conditions, causing them to be less predictable and less manageable.

[4] Ecological succession is the process by which a biological community evolves over time. Primary succession involves the initial colorization of an area by vegetation. Secondary succession involves the replacement of some plant species in an area by others plant species.

Likewise, as the average height of the Bay increases, and the HOTs migrate upstream, the likelihood that wind-generated waves, boat wakes, and extreme high tides, including "king tides", will overtop levees and berms increases. Conditions in the T-zone are likely to be as affected (or perhaps more affected) by such extreme tidal events than by the increase in average Bay height.

Under natural conditions, the T-zone can be resilient to climate change and extreme weather. For example, barrier beaches can naturally gain height with the deposition of materials during storm wave run-up (Baye, unpublished data), and alluvial fan vegetation buried by episodic riverine flood sedimentation can regenerate after a few years (Goman et al. 2008). The perennial native vegetation of the backmarsh has also shown the ability to grow through flood deposits of sediment (Allison 1996). In general, tidal and non-tidal wetlands show remarkable resilience to moderate levels of disturbance and normal variations in hydrology (e.g., Mitsch and Gosselink 2007, Culberson 2001). This does not mean that the ecosystem services of the T-zone will withstand climate change and sea level rise without human intervention, but rather that careful intervention is likely to be able to sustain appreciable levels of the services.

The impacts of climate change on the T-zone are likely to accumulate over time. For any given rate of sea level rise and T-zone migration, the frequency and extent of T-zone compression will tend to increase. As MHHW increases, the likelihood of levee failures and major riverine flooding will also increase. If the Bay rises fast enough and long enough to drown the tidal marshes, waves from the Bay that would otherwise be damped by the marshes will have greater energy, and the rate of erosion of SZ1-2 could increase.

If nothing is done to protect and restore the T-zone, its ecosystem services will decline. There will be fewer kinds of service and their levels will be reduced. The primary reasons for this are the lack of accommodation space (SZ4), the increased vulnerability of the T-zone to erosion and disturbance as the adjoining tidal marsh erodes (mostly effecting SZ1-2), the increased vulnerability of the T-zone to biological invasion due to increased frequency and magnitudes of disturbance (SZ-4), and increased fragmentation of the T-zone along the bayshore due to its extreme compression against the built environment. Without intervention to prevent or minimize these impacts, they are likely to become increasingly severe as the climate continues to change and the Bay continues to rise.

Responses of Transition Zone Types

The impacts of climate change and sea level rise are likely to vary among the types of T-zone. For a more detailed description of the T-zone types see Appendix 4.2.

<u>Artificial Levee.</u> Bayshore levees are typically very narrow, steep, and poorly maintained T-zones that were not designed as habitat or for long-term flood protection. Without intervention, their services as a T-zone are likely to be lost because they are fixed features that cannot dynamically build upward and landward in response to increasing Bay levels. Unlike the natural T-zone types, this artificial type is not resilient to extreme weather events. The levees are at risk of wave erosion and overtopping. The "Horizontal levee" is a recent concept for building resilience and ecosystem services into unnatural bayshore levees (The Bay Institute 2013). According to this concept, the bayshore levee is augmented with carefully graded fill that extends the T-zone bayward to create a wide, low-gradient, terrestrial slope. Non-tidal wetlands can be designed into the Horizontal Levee. The concept is perhaps most applicable to urbanized areas that lack accommodation space. Implementation of the Horizontal Levee concept might require partially filling diked Baylands or filling shallow areas of the Bay adjacent to the existing T-zone.

<u>Bluff or Cliff.</u> This T-zone type is characterized by near-vertical slopes between marshes and uplands. Given its steepness, the bluff-cliff type is very narrow. Its steepness results from either the presence of titled, erosion-resistant bedrock or fractured, friable bedrock that has been undercut by waves. Freshwater seeps are common along fractures

in the bedrock and along the cliff bottoms. This seepage can sometimes help weaken the bluff or cliff and make it more susceptible to erosion.

Since the adjoining tidal marsh tends to reduce the energy of ship wakes and wind-generated waves, the loss of the marsh due to rapid sea level rise could increase the rate at which the waves undermine the bluff or cliff, resulting in mass wasting processes, such as slumping and landsliding. Such erosion would likely cause the bluff or cliff to retreat (i.e., migrate landward), and therefore would not necessarily cause a loss in this T-zone type. One possible consequence of increased erosion of a bluff of cliff is that the eroded material accumulates as an area of natural, supratidal fill over the top of the backmarsh, resulting in a narrow sea level rise accommodation space (i.e., a narrow SZ4).

<u>Valley Plain – Alluvial Fan.</u> Over long time periods, eroded sediments from the steeper areas of local watersheds have accumulated in less steep downstream areas, forming gently sloping alluvial fans and valleys. Broad T-zones form on the fans and in the valleys that extend to the Bay. The landward Sub-zones (SZ3 and SZ4) of this T-zone type have mostly been converted to agriculture and more intensive land uses during the last two centuries. However, there are significant efforts underway to reestablish open spaces on alluvial fans and in the valleys adjoining the Bay, using combinations of natural and engineered topography and hydrology.

Looking forward, the expected increase in rainstorm intensity and riverine flooding could be used to increase the supply of sediment through the fans and valleys and to the backmarsh, pushing the T-zone bayward and enlarging its accommodation space. At the same time, the expected decrease in average annual precipitation and the expected increase in air temperatures during the dry season could decrease surface and groundwater flow through the fans and valleys, and thus reduce or eliminate the associated slope wetlands, depressional wetlands, and brackish marshland that are naturally associated with this T-zone. Creative ways to improve safe yields of sediment and to assure adequate flows of water through the fans and valleys that adjoin the Bay are needed to protect and restore the Valley-Fan T-zone.

The urban development that has occurred along the bases of alluvial fans and gently sloping hillsides, and along the valley bottoms adjoining the Bay will be subject to increased susceptibility of flooding due to climate change and sea level rise. These areas will be the focus of much public debate about whether to build and maintain a flood control infrastructure to protect existing land uses or retreat to safer lands. The outcome is likely to vary around the Bay, depending on the value of the existing land uses. The debate is more likely to favor T-zone restoration if the long-term costs to maintain the infrastructure are considered, given that the Bay is likely to continue rising at a rapid rate for the foreseeable future. In the meantime, the costs to secure the remaining areas of relatively undeveloped accommodation space associated with valleys, plains and alluvial fans will continue to rise.

<u>Barrier Beach.</u> Barrier beaches are narrow, relatively steep, naturally high areas between tidal flats and tidal marshes created by the deposition of materials during wave run-up (Figure 4.8). In profile, they often consist of sand foreshores grading up to steeper mixed coarse sand, gravel, and shell hash. The vegetation on top of barrier beaches typically resembles that of the landward limits of the backmarsh. The barrier Beach T-zone usually only consists of SZ1-2. It persists where there are adequate supplies of sand delivered by wind-generated waves. Barrier beaches can migrate landward as the Bay rises. Where tidal marshes drown, barrier beaches could persist along the landward margin of the backshore.

The supply of sand needed to sustain barrier beaches is mainly provided as bedload by local rivers and streams. Its ability to reach the Bay and thus sustain the barrier beaches is limited by its entrapment behind dams and within constructed flood control channels. Sand is typically a very small portion of the total sediment load of local streams, except during high flows, at which time nearly 70% of the sediment load can be sand; as much as 50% of the annual load can be sand during very wet years (Patrick et al. 2013). While waves are locally generated by wind, waves propagating across deeper water experience less attenuation and are consequently more erosive. Mudflat erosion due to inadequate supplies of fine sediment (i.e., silts and clays) therefore exacerbates sea level rise by further increasing water depths and hence the erosive power of waves. The interaction between wave erosion and coarse sediment transport differs among geomorphic settings, but Figure 4.9 illustrates how barrier beaches are not sustainable without a supply of coarse sediment. For some "pocket marshes" that exist in coves along cliffs and bluffs, the source of sediment to build barrier beaches can be cliff or bluff erosion.

Riverine. Many factors will affect the future conditions of the Riverine T-zone. It is characterized by spatially and temporally complex interactions of fluvial, tidal, and terrestrial processes that create dynamic gradients in salinity, stream power, channel form and structure, and water chemistry, all of which can be affected by climate change. It is important to consider that, under natural conditions, the riverine channel tends to migrate slowly across its valley, with the Sub-zones of the Riverine T-zone generally extending laterally from the riverine channel. Unfortunately, many streams around the Bay are moderately to deeply incised, laterally constrained by land use and riverine levees, or fixed in place as flood control channels, such that they cannot migrate and their Sub-zones are very narrow. Furthermore, the HOTs of urban streams are usually constrained in the upstream direction by artificial grade control structures associated with bridges, trestles, culverts, and sewer lines.

These grade control structures and artificial levees, in combination with the predicted increase in Bay levels and increased frequency of large stream discharges may result in sudden large-scale changes in conditions of the River T-zone. As the Bay rises, the higher tides will eventually overtop the grade control structures, allowing the HOTs to rapidly advance upstream. In these cases, the upstream migration of HOT is therefore likely to proceed in at least two phases, one before the grade-control structure is regularly overtopped at high tide, and one afterward (SFEI 2014).

After the obstacles to its upstream migration are overcome, the HOT will sudden migrate upstream. The rate of migration will be greater where the channel bed is not steep. The upstream HOT migration could significantly increase local risks of riverine flooding during high tide, while the rising Bay increases the risk that wave run-up or storm surges will overtop levees along the tidal reaches of Riverine T-zone.

To prevent this increase in riverine and/or tidal flooding, levees will need to be raised and extended upstream. Much riverine levee work can be anticipated as part of many local responses to increased flood risks. However, alternatives to longer and higher levees should be considered. For example, the restoration or construction of terrestrial floodplains should be considered, as should the ability to shunt floodwaters across tidal marsh plains during low tide and into diked baylands during high tide. In some areas, it might be possible to move riverine levees farther apart, to make room for floodplains between the levees (i.e., inset floodplains of multi-stage channels). Flood control designs can be integrated with the realignment of infrastructure and planned retreat of land uses at the landscape scale to create accommodation spaces with abundant riverine ecosystem services. The concept of incorporating diked baylands and tidal marsh restoration into flood control planning is already gaining acceptance (SFEP 2014). One can imagine a stream with restored floodplains above the HOT, new floodplains created by filling landward areas of adjacent diked baylands, new floodwater retention basins or restored tidal marsh in the bayward areas of the diked baylands, and Horizontal Levees bayward of the retention basins. These concepts and others could be integral elements of landscape designs that reconnect the Bay to its local watersheds in ways that restore the ecosystem services of the baylands as a whole (SFEP 2014). Implementing such plans will require deciding how to manage the increasing risk of tidal and riverine flooding, including how to repurpose diked baylands. Future policy and decision-making around watershed-based sediment management and flood control will largely determine if flooding is used to nurture the Riverine T-zone. Watershed-based sediment management, as envisioned for rivers and streams impaired by fine sediment (e.g., SWRCB 2007), should consider the effects of sediment management on the Riverine T-zone and other components of the baylands. If a sediment management plan (e.g., AMBAG 2008, SANDAG 2009) is developed for this region, it should fully incorporate the sediment needs of the baylands.

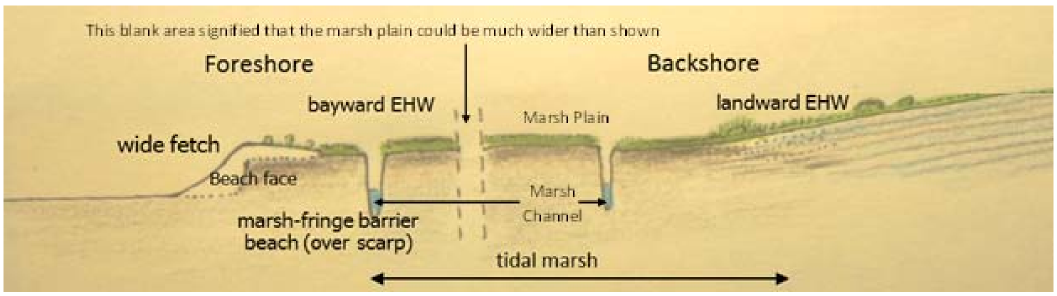

Figure 4.8. Profile of the Barrier Beach T-zone. Vertical dashed lines indicate that an unnecessary portion of the profile has been intentionally omitted.

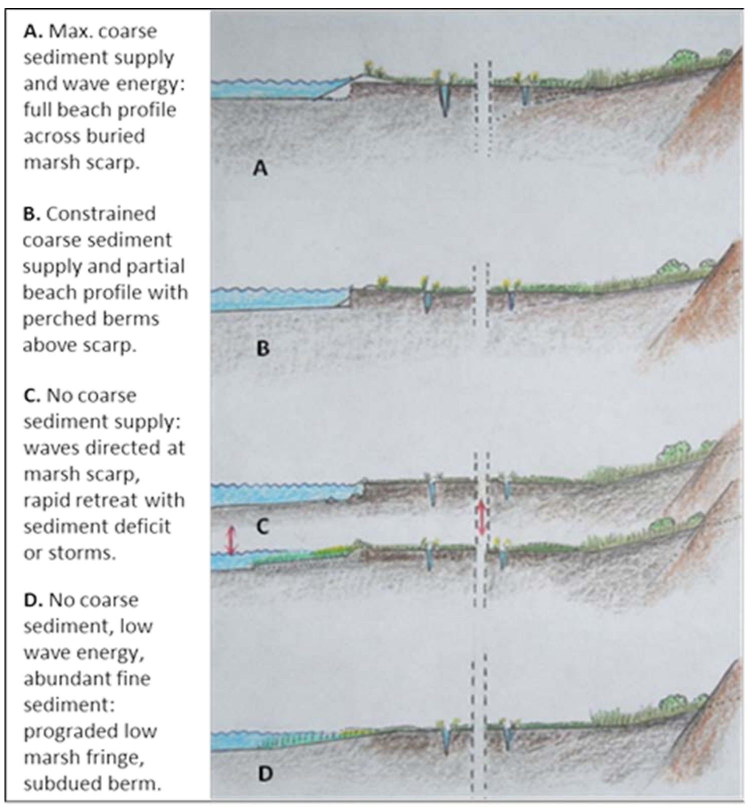

Figure 4.9. Cross section of tidal marsh landscape showing effects of sediment supply and wave energy on barrier beach development. Vertical dashed lines indicate where a redundant portion of the profile has been intentionally omitted.

TRANSITION ZONE DESIGN AND MANAGEMENT

The T-zone presents difficult management challenges because of the need to balance demands for numerous ecosystem services often requiring different management practices with limited resources. Managing natural services, such as wildlife refuge, requires strictly limiting public access to the T-zone, whereas managing the T-zone for various kinds of cultural services requires providing abundant access. The challenge is greatest in the urban environment, where the pressures for access are most intense and the wildlife habitats are most threatened. Also, numerous forms of artificial drainage, including urban runoff and discharges from publically owned treatment plants, connect the urban environment to the Bay through the T-zone. This and other infrastructure, including roadways, fuel lines, and communications and power transmission lines bring additional management interests into the T-zone. Meeting the challenge of managing the T-zone for a diverse set of services requires ongoing coordination between managers and agencies at all levels of government. There is no single "T-zone agency" or advisory group that can provide all the authority or expertise that are needed. However, with the required breadth of technical input, the conflicts among T-zone management objectives can be mitigated through T-zone design.

This purpose of this section is to provide basic guidance to T-zone designers and managers. This guidance is intended to maximize the chance for project success by helping planners and managers choose or develop appropriate design concepts. It is based on the assumption that T-zone restoration is a new subject for many ecologists, engineers, and managers who will be involved in implementing T-zone restoration projects. The guidance is therefore fundamental. Given that there is relatively little experience with the restoration of the various T-zone types around the Bay, prescriptive recommendations are not possible. At this early stage of T-zone restoration science and engineering, pilot projects are needed to test various design concepts and management approaches. Additional management strategies may also be determined as mapping or other methods to delineate T-zones are developed or refined.

General Principles for Local Transition Zone Design and Management

This set of general principles should be considered at the beginning of any T-zone restoration or enhancement project, regardless of T-zone type.

<u>Emphasize Collaboration and Partnership.</u> All designs should be developed with an expert understanding of the permits needed to implement the designs, with input from all agencies responsible for any aspect of the T-zone, and with the ongoing advice and review of special interest groups and the public. To the degree possible, projects should be co-sponsored by multiple agencies.

<u>Identify the Target T-zone Type(s).</u> The first technical step in T-zone planning or restoration is to decide what type of T-zone is best suited to the restoration site. Most projects will only involve a single T-zone type. However, large projects might involve multiple types. Historical Ecology (HE) can guide the selection of the target T-zone type by revealing what type existed historically at or near the project site and might therefore still be suitable. The HE analysis can also reveal the site-specific form of the T-zone, including how and why the Sub-zones varied in width. The goal of HE evaluations is not necessarily to recreate the historical landscape but rather to reveal the site-specific T-zone types and their particular characteristics that could still be compatible with local controlling factors. HE can be invaluable for fully understanding the local restoration opportunities.

<u>Identify and Assess Dominant Local Physical and Biological Processes and Needed Expertise</u>. To the full extent possible, T-zone designs should accommodate the local physical and biological processes and

extreme events that are likely to control the target levels of selected T-zone services. Review the factors and processes controlling the formation and condition of different T-zone types (Figure 4.7 and accompanying text). Consider the likely effects of climate change on these factors and processes. While there are numerous processes acting on any T-zone, its form, structure, and services are usually controlled by a few dominant processes. When assembling a project design team, identify the particular scientific and engineering expertise required, based on the assessment of what natural or anthropogenic processes and events control the form, structure, and services of the site, now and into the future. For example, the design of a Levee T-zone that is likely to be at risk of wind-wave erosion should involve experts in coastal engineering, geomorphology, and ecology who can explore natural and artificial solutions to dissipate the wave energy. For the design of the Riverine T-zone, information about storm and annual hydrographs plus sediment loads is always important. The design team should therefore include a fluvial geomorphologist and hydrologist. Biological invasion by non-native plant species is a process of special concern for most restoration projects that requires the expertise of a botanist and/or restoration ecologist. T-zone projects typically require careful determination of both tidal elevations and geodetic elevations, and should therefore involve experts in these technical subjects.

<u>Evaluate Local Landscape Constraints</u>. Many T-zone designs must accommodate existing infrastructure and land uses that constrain the kinds or levels of ecosystem services that the T-zone can support. The design team must take into account any and all infrastructure above and below ground, plus rights-of-way, needs for emergency access, and the kinds and levels of existing recreational use. Ways to minimize constraints and conflicts through project design and timing should be explored. For example, the T-zone has conventionally been regarded as a suitable location for water lines, sewer lines, gas pipe lines and high-tension electrical power transmission lines. Much of this infrastructure obstructs any modification of the T-zone. The managers of this infrastructure typically charge restoration projects for its protection or realignment, which can greatly increase project costs. However, the costs can be reduced if the projects are planned to coincide with the replacement or repair of such infrastructure.

Mosquito control can be an essential and sometimes expensive aspect of T-zone management. Mosquito Abatement Districts typically advice project planners to consider natural processes of source control (e.g., wave action, tidal flushing, and predation), as well as water management and biological control as needed. The Districts may need to be compensated for ongoing mosquito control efforts. Public outreach and education will be needed to manage nuisance levels of mosquito production and associated health risks.

<u>Identify the Target Kinds and Levels of T-zone Services.</u> The steps outlined above provide the basis for exploring the kinds and levels of services that the T-zone should provide. Review the discussion on ecosystem services and their relationship to T-zone types and Sub-zones. Consider any local requirements to implement water quality control plans, habitat conservation plans, and recreation plans. The focus should be on what is needed, rather than what is simply desirable. Vet the decisions about services with the affected communities of people.

<u>Select the set of services that is most suitable for the target T-zone type.</u> Focus on achieving the few services that are most likely. Be conservative; while it is certainly possible that many services will be supported by the project, it is only likely to provide sustainably high levels for a few services. It will not usually be possible to quantify the target levels of all selected services. In fact, climate change increases the uncertainty of such quantifications. In general, physical services such as sea level rise accommodation, flood water storage, and erosion control are more easily quantified than biological or ecological services,

such as buffering and wildlife support. The selected levels and kinds of service must be consistent with the targeted type of T-zone, reference conditions, and the landscape constraints of the project site.

Identify and evaluate reference sites. These are examples of the type of T-zone selected for the project that exhibit the best achievable or least altered conditions. To the degree possible, the project should be designed to achieve the levels of selected ecosystem services evident among the reference sites, adjusted for immitigable landscape constraints. For some T-zone types, reference condition may no longer exist. In these cases, the reference conditions should be inferred from historical evidence.

Design the Sub-zones and Refine the Target Kinds and Levels of Service. At this stage of the project design, it should be possible to sketch the T-zone in plan-view and profile, such that the approximate widths, topography, elevations, and vegetation of each Sub-zone can be visualized. Engage appropriate experts in ecology, hydrology, and tidal elevation reckoning to review the drawings. Adjust the target kinds and levels of services as warranted based on the conceptual Sub-zone designs. Be realistic; do not plan to extract more kinds or levels of service than the site can realistically sustain. However, consider possible future expansion of the project, and aim for designs that do not diminish the possibility for such expansions.

Build a Conceptual Model. Use the results of the Historical Ecology analysis, the evaluation of site-specific controlling processes, and the evaluation of reference conditions to build a conceptual model of the likely cause-and-effect relationships among the controlling processes and the selected kinds and levels of ecosystem services. Explicitly identify basic assumptions that underlie the causal relationships. Use the model to identify key constraints and design attributes that are most likely to affect project success. The model should serve as a framework for estimating project timetables, costs, and risks. Update the model with new information as the project design evolves. Completion of the conceptual model can result in further modifications of the conceptual design of the project and the target services.

Engage the Community. Public outreach and education are vital to increasing the public awareness of the importance of the T-zone and to create the political will to support restoration and protection of the T-zone into the future.

Consider Relationships to Other Projects. This is a major step in the T-zone design process. Each new project should be considered in the context of other existing or intended projects. Of special concern are any other projects in the same landscape, meaning that they are likely to influence the levels and kinds of ecosystem services they can sustain. A practical initial approach to this analysis is to review whether the projects are likely to influence each other's hydrology, sedimentation, vegetation, or wildlife support. A proactive approach is to develop a conceptual plan of T-zone restoration for the entire landscape of the project. This is the best way to assure that all the projects that might eventually occur in the landscape work together to achieve the highest levels of the most diverse array of ecosystem services possible. This is also a way to develop long-term plans for minimizing landscape constraints.

Think ahead. Existing management practices might be modified to prepare future areas targeted for T-Zone restoration.

In agricultural lands, consider allowing the formation of farmed wetlands, creating ponded areas along the inboard toes of levees and at sumps, encouraging tall vegetation as wildlife habitat along fences, delaying spring harvests of hay and similar crops to protect breeding wildlife, using rotational grazing practices to encourage habitat diversity, providing livestock with water away from riparian areas, and fencing livestock from seasonal wetlands during wet periods.

In urban areas, consider establishing setbacks along watercourses that link tidal marshes to healthy riparian corridors, and disallowing fences (or requiring fences to be elevated off the ground) to enable wildlife movement through the built environment.

The landscape approach to T-zone design might involve realignment of existing elements of the project site. For example, consider locating heavy-use recreational trails at inland locations or at the landward edge of SZ3, such that human access is restricted from bayward areas of the T-zone that support sensitive wildlife.

It is important to understand the soil characteristics and geotechnical properties of imported materials used to create levees, berms, and other T-zone features. Several restoration projects in the past failed to consider the nature of imported materials or how their condition would change over time. In some cases the materials were too acidic or nutrient-poor to support healthy vegetation. In other cases, the materials lacked the correct geotechnical properties to withstand existing wave erosion.

Design for complexity. For example, consider creating topographic variability at multiple scales. At the large scale, consider grading multiple topographic benches or plains at different heights parallel to the backmarsh or riverine channel that together comprise a stepped gradient in the frequency and duration of tidal or riverine flooding. For small-scale variability, provide swales, hummocks, large woody debris, etc. The occurrence of large woody debris can be very beneficial to many species of wildlife. Designs that are too uniform in terms of their elevations and topographic relief will result in a T-zone that is ecologically simple and therefore less resilient than a more naturally complex T-zone. This guideline is often difficult to implement because most engineering and construction firms are not used to building complexity into their projects. Therefore, consider building projects on a time-and–materials basis with a qualified geomorphologist and ecologist in the field directing the contractor on the details of habitat construction.

Determine How to Measure Progress and Determine Success. A monitoring plan should focus on the minimum data necessary to maintain compliance with all permits and to assess the project's ecosystems services relative to their target levels. The monitoring should focus on what is happening and not why. Understanding the causes of the conditions observed is not necessary unless the conditions are unacceptable. Consider progress as the occurrence of conditions that are consistent with a trajectory of success, defined as achieving the target levels of service. Regularly report the status of the project to the public.

SUMMARY

The objectives of this chapter are to define and describe the estuarine-terrestrial transition zone of San Francisco Bay, hereafter termed the "T-zone", and to provide science-based guidance for conserving its ecological services in the context of climate change and especially sea level rise.

Efforts to address the ecological and economic threats imposed by sea level rise have begun to focus on the T-zone. There is a growing awareness that its design and management can help mitigate these threats. The T-zone can provide space for the Bay to expand without creating unacceptable flood hazards and without completely losing the ecological services of the baylands. Many historical cultural resources are associated with the T-zone, and it provides important recreational opportunities, while providing critical habitat for wildlife.

The T-zone is defined as:

> *the area of existing and predicted future interactions among tidal and terrestrial or fluvial processes that result in mosaics of habitat types, assemblages of plant and animal species, and sets of ecosystem services that are distinct from those of adjoining estuarine, riverine, or terrestrial ecosystems.*

The T-zone does not have a fixed width. It varies in width from place-to-place and over time. In the landward direction, the width of the T-zone is affected by the vertical range of the tide, the slope of the land, and the locations of built structures that control the upstream or landward movement of tidal water. In the bayward direction, the width of the T-zone depends on the volume of terrestrial runoff entering the baylands. The T-zone only includes the areas of intertidal vegetation that are measurably influenced by terrestrial runoff and other freshwater discharges. It only includes diked baylands that serve to store terrestrial flood waters or that represent future space to accommodate sea level rise.

The width of the T-zone also varies based on the kinds of ecosystem services it provides. For example, a broader T-zone is needed to provide refuge from high tide for marsh wildlife than if such refuge is not provided, and a broader T-zone is needed to accommodate sea level rise for the next century than for the next half-century.

The functional relationship between the T-zone and local watersheds should be emphasized. Most of the inorganic sediment that accounts for the formation and persistence of the tidal marshes is derived from local watersheds. The freshwater runoff from local watersheds creates salinity gradients through the baylands that greatly increase the overall biodiversity of the region. Many wildlife species, including birds of prey and salmon, move between the Bay and local watersheds through the baylands. The Bay and its local watersheds are linked together by the baylands, and the mechanisms of this linkage are the workings of the T-zone.

Seven T-zone types have been identified based on their formative processes. In aggregate, the seven types represent the full range of historical and existing T-zone conditions for the Bay. Each type of T-zone consists of 2-4 sub-zones that provide different suite of services. The kinds and levels of service provided by the T-zone can be controlled to some degree through design and management of the sub-zones.

At this time, there is no regional map of the T-zone as defined here. A regional T-zone map is needed to identify and track restoration opportunities, to assess the relative effects of restoration and ambient climate change, and to evaluate the efficacy of state and federal policies for protecting the T-zone. Local maps are needed to inform restoration design. The optimal mapping approach will probably involve estimating the extent of each type of T-zone and the width of their sub-zones, such that the map can inform the restoration and management of specific ecosystem services.

There are three main drivers of T-zone change: climate, geology, and land use. They operate through a complex network of interacting factors. Of these three drivers, only land use can be managed to achieve target kinds and levels of T-zone services. In this regard, land use includes any activity by people that alters the topography or elevation of the land, or that affects the abundance, quality, and distribution of surface waters.

If nothing is done to protect and restore the T-zone, its ecosystem services will decline. There will be a lack of space to accommodate sea level rise, more shoreline erosion due to waves and ship wakes, increased biological invasion of the bayshore due to increased disturbance, increased risk of river and creek flooding due to upstream migration of high tides, and increased fragmentation of the T-zone ecosystem due to its compression against the built environment. Without intervention to prevent or minimize these impacts, they are likely to become increasingly severe as the climate continues to change and the Bay continues to rise.

The T-zone presents difficult management challenges because of the need to balance demands for ecosystem services requiring different management practices with limited resources. Meeting the challenges requires ongoing coordination among agencies at all levels of government. However, with abundant technical support, the conflicts among T-zone management objectives can be mitigated through T-zone design. At this early stage of T-zone restoration science and engineering, pilot projects are needed to test various design concepts. In general, each restoration project should engage the public in a process to set ecosystem service goals for the t-zone type that best fits the restoration site, based on an operational understanding of the formative processes, local constraints, and future opportunities for further restoration. T-zone restoration projects should be planned in a landscape or sub-regional context, such that positive synergies among the projects can be maximized.

Methods to assess the existing and restored T-zone should be standardized, such that projects can be compared to each other and to background or ambient conditions over time. Information about the location and status of T-zone restoration projects should be readily available online, and the overall condition and prognosis of the T-zone throughout the region should be regularly explained to the public.

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