

terrestrial transition zone landform of East Bay, South Bay, and much of Suisun and northern San Pablo Bay (Petaluma, Napa, Schellville, Fairfield vicinity).

MUTH are also important because sea level may rise too quickly for the estuary's marshes to keep pace (Callaway et al 2007). If marsh sustainability models (Thorne et al., 2013; Strahlberg et al. 2011) and other models are correct, marshes appear to be at risk of losing important habitats (such as high marsh) and eventual permanent submergence unless they have room to migrate upslope (i.e. shift their spatial distribution landward as the Bay rises and expands). Therefore, broad expanses of gently sloping open space connected to the tidal zone should be conserved to prepare for this likelihood.

Ecological Functions

The functions and ecological services provided by MUTH are myriad and varied. In addition to providing unique habitats and corridors for plants and wildlife, and some opportunities for compatible human use, MUTH provide high elevation space to accommodate a rising estuary, mitigating for threats of climate change induced sea level rise. Functions specific to MUTH include:

1. **Wildlife Habitat:** The MUTH thought to provide critical supplementary functions for wildlife, such as movement corridors between habitats (summarized in Josselyn, 1983). MUTH can also provide wildlife resources, such as, for example, forage and nesting materials for salt marsh harvest mice during the winter when pickleweed and other salt marsh species are senesced.
2. **High Tide Refugia** for marsh-dependent species including threatened and endangered species such as the California Clapper Rail and the salt marsh harvest mouse: MUTH are used by threatened and endangered, special status and other marsh dwelling wildlife species for high tide refugia. These refuge areas are used by marsh-dwelling fauna during the occasional winter tides which swamp high marsh vegetation. As climate change produces more intense and frequent storm events, this zone will become more critical to the survival of these species. Prolonged flooding of marsh habitat as a result of climate change and sea level rise may increase predation of salt marsh harvest mice by predators, and increases the risk of mortality due to exposure or drowning. Mice and rails can move locally from flooded tidal marsh to emergent high ground or vegetation (USFWS 2013).
3. **Potential discharge zone for fluvial flooding:** Historically the alluvial fans and plains consisted of wet meadow, alkali meadow, vernal pool grasslands, riparian scrub, and freshwater marsh, where shallow groundwater emerged into this zone, or where seasonal flooding and overland flow was distributed (Baye, 2012). These hydrologic processes also replenished MUTH with sediment. Opportunities exist in some locations to mimic these historical processes by reconnecting rivers to MUTH, which can provide flood management and waste water treatment infrastructure by engineering “horizontal levees” (Bay Institute, 2013). However challenges remain as most rivers carry urban or agricultural runoff, which carry undesirable pollutants.

4. **Space for marsh migration:** Sea level rise rates may exceed marsh accretion capabilities, leading to marsh loss if they are not provided with the space to migrate upslope (USFWS 2013). In areas where adjacent land use allows for transgression of tidal marsh into higher elevations as sea level rises, these MUTH are where marsh migration could occur.

Threats

Although estimates of the loss of habitats at the Bay's margin are rare (one estimate exceeds 90% - Shellhammer, 1982), it has been disturbed enough to significantly degrade the functions provided to the tidal marsh ecosystem (Baye 2004). The result is that much of what was originally a healthy transition has been converted to the Artificial Dikes typology (Baye, 2012), which consists of steeply sloped levees. These artificial dikes have greatly diminished ecological functions. Artificial dikes and levees can also be a travel corridor for terrestrial predators, putting excessive pressures on sensitive marsh fauna (Giselle Block, USFWS, pers. com.). They are also inherently unstable, requiring more frequent maintenance.

Frequent maintenance disturbs MUTH plant communities, so they are especially susceptible to invasion by non-native plants. Weeds create poor Transitional habitat structure that facilitates predation by the many human associated predators (e.g. domestic cats, raccoons) on marsh dwelling wildlife. California Clapper Rails likely experience higher predation rates due to access by predators via roads, levees, and trails. Disturbance of nests can also reduce reproductive success. Reduced survival of adults, in particular during winter high tide events when weeds are in senescence and extreme high tides flood available marsh habitat and limit refugia, has been shown for California Clapper Rails (Overton, in press). Similarly, salt marsh harvest mice are subject to excessive predation pressure (USFWS 2013).

As noted above, most MUTH are now confined to the steep slopes of levees. While within the Transitional elevational range, they are not true MUTH as they do not transition to any significant upland habitat. Also noted above, transitional habitats are created by the intermixing of two adjacent habitats, so without them a transition is an artificial habitat that will require ongoing maintenance to sustain needed quality. Due to the extent of human development surrounding the estuary this is likely necessary, and therefore must be part of planning efforts.

In summary, MUTH need sufficient depth (marsh backshore to upland width) to provide adequate acreage for plant communities to be self-sufficient, and they must be tens of meters wide in order to minimize the impact of predation pressures (Block & Shellhammer, pers. com). For tidal marshes that do not contain high marsh, habitats on slopes above the marsh plain become even more important, as the only adequate high tide refugia during events that swamp all vegetation within the marsh plain. Furthermore, the Bay's margin (i.e. MUTH and adjacent upland open space) must provide adequate acreage for landward transgression of tidal marshes during rapid sea level rise (SLR) events that threaten to negatively impact marshes.

Mapping

Although there have been notable projects that have mapped the estuarine marsh throughout the Bay (e.g. SFEI, Point Blue, CalVeg), none have explicitly included transitional habitat either spatially or taxonomically. Parallel efforts to map uplands, most prominently the Conservation Lands Network, have

also not included transitions. Efforts to map transitional habitats should ideally be accomplished in parallel with efforts to map all the elements of the Estuary (as well as its adjacent terrestrial habitats).

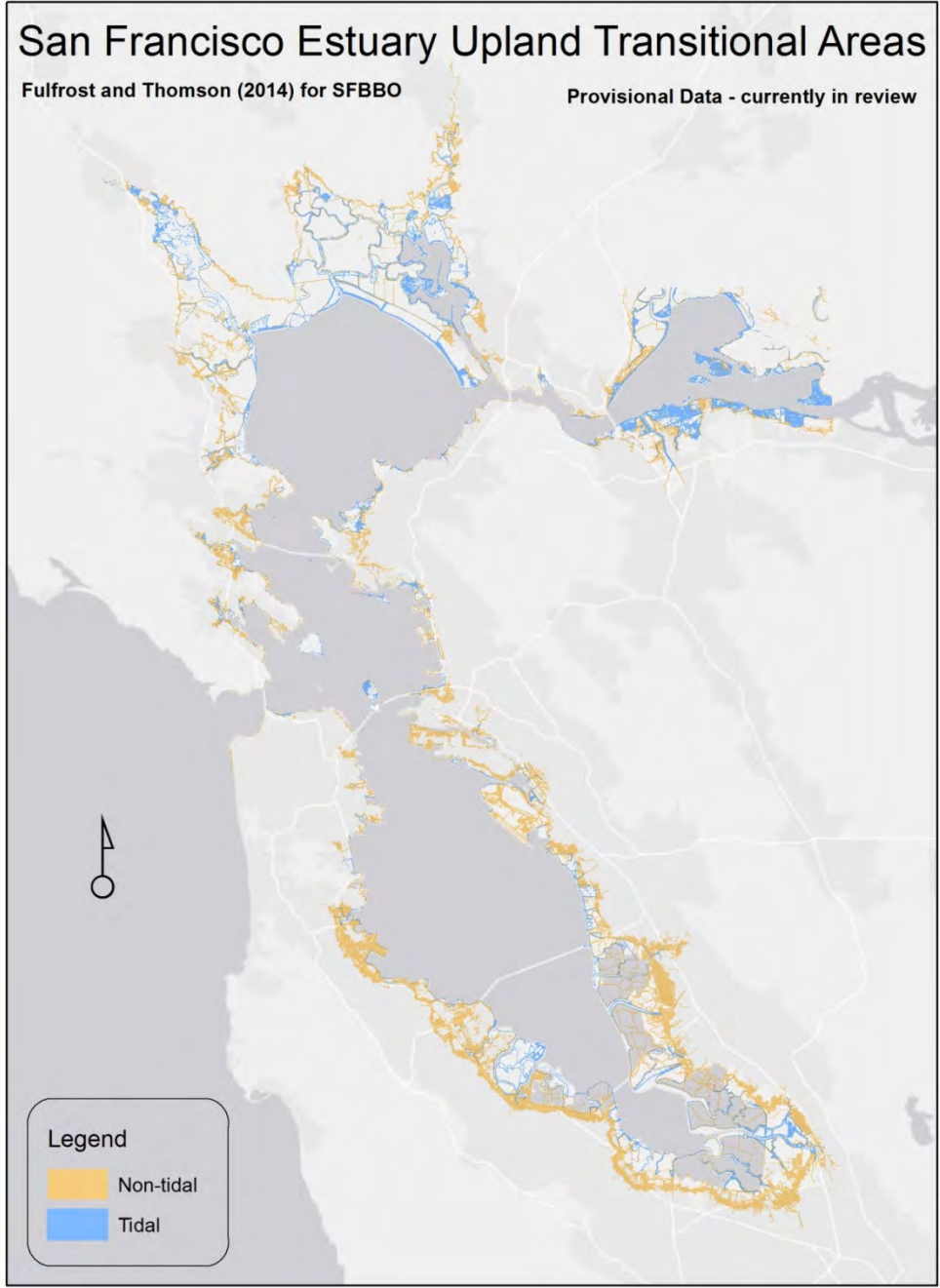
Mapping of MUTH is distinctive from other mapping efforts in the Bay because the boundaries of MUTH elevations are defined by tidal datums. Mapping current MUTH at a landscape scale as a means to assess quality and prioritize management actions for protection, restoration, and enhancement has been accomplished (Fulfrust and Thomson 2014). Maps of their distribution and extent are presented below based on provisional data. Mapping MUTH at a site specific level may further inform individual management decisions, and enable conservation and protection of this integral component of tidal marsh ecosystem. Mapping at this level may also provide empirical data on actual ecological process that form transitional habitats, and the ecological functions a given transition is (or is not) providing. Land managers can use GIS based mapping efforts described below to identify MUTH sites that provide the most potential improvement(s) to ecological function as well as provide potential marsh accommodation space in an era of sea level rise.

Mapping ecological transitions is multi-faceted, as is the case with all dynamic ecological phenomena. Sources of variability are numerous and include the interactions of tidal and freshwater influences, underlying biotic and abiotic factors, and other ecological processes. Efforts to map transition zones for long term conservation and climate mitigation should focus on practical and mappable measures that best characterize the overall distribution and extent of MUTH, as well as assist in determining ecological functions needed and ecosystem services provided, by the tidal marsh ecosystem. Mapping at site specific and landscape scale are both critical for providing information for different management objectives.

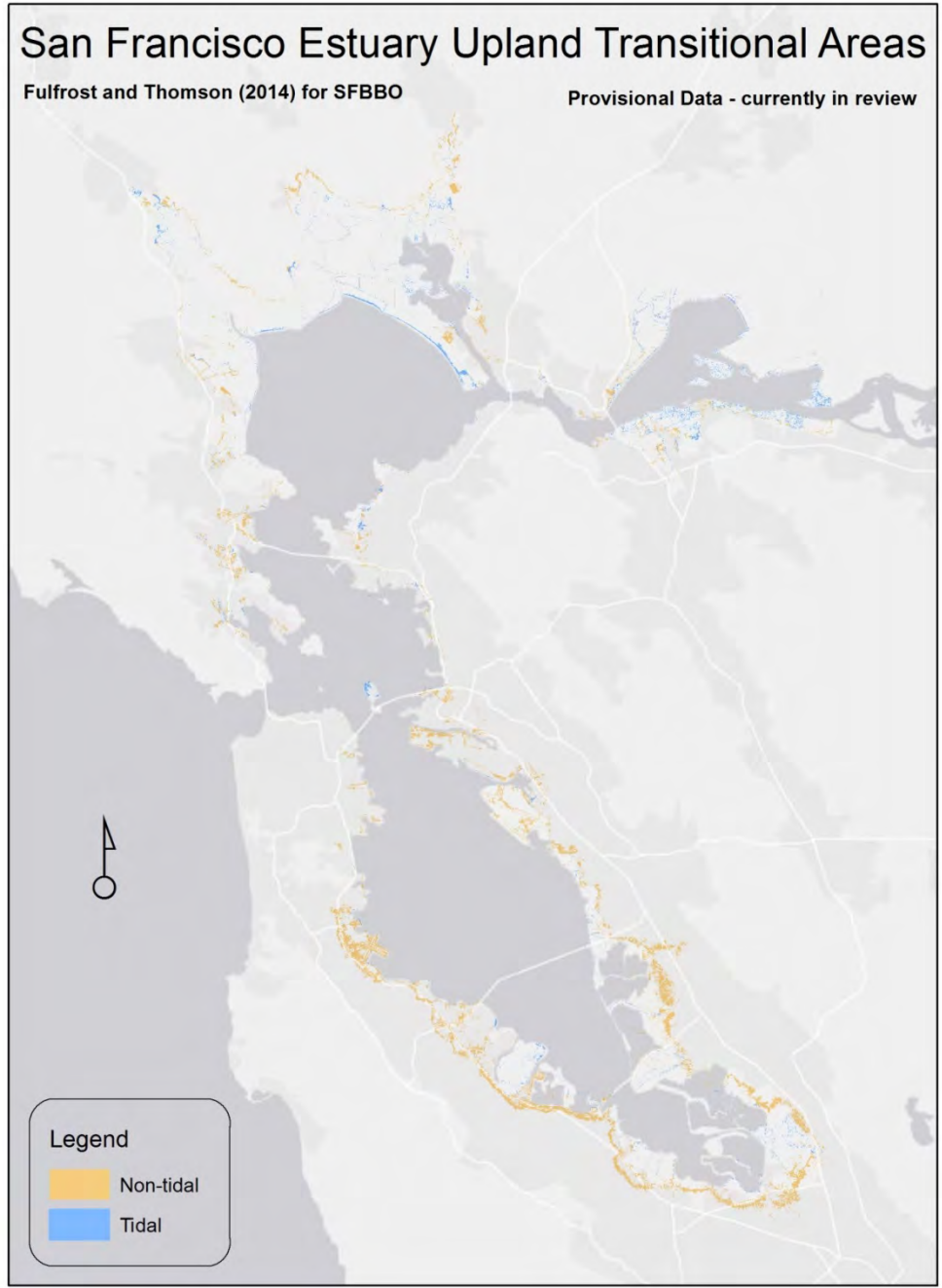
Landscape Scale Mapping

Goals of landscape level mapping efforts may be to identify overall MUTH abundance (distribution and extent), quality (using proxy metrics for measuring potential tidal marsh ecosystem function) and type (as determined historically). Landscape level mapping also provides the overall status of MUTH, and as a basis for decisions by ranking and prioritizing sites for protection, restoration or enhancement. Land managers can utilize these GIS based mapping efforts, to identify MUTH sites that provide the most potential improvement(s) to ecological function as well as provide potential marsh accommodation space in an era of sea level rise. It is also possible to use manual aerial photography interpretation (e.g. BAARI) or even field based surveys to map distribution. However, the time and expense required, often limits the ability to conduct these type of surveys across broad geographic areas. As a result, efforts to map distribution at the landscape level should focus on the use of GIS techniques, possibly supplemented by image based interpretation and field sampling (useful for validation of the GIS mapping and calibration of the proxy metrics).

Distribution Map of Tidal Marsh-Upland Transitional Land Surfaces
(sizes accentuated so small areas show up at this scale)



Extent Map of Tidal Marsh-Upland Transitional Land Surfaces
(sizes are to scale so small areas do not show up at this scale)



Site Specific Scale Mapping

On the other hand, the focus of site specific efforts may be to provide empirical data on actual ecological process that form transitional habitats, and the ecological functions a given transition is (or is not) providing. By utilizing mapping efforts at both scales, managers are provided measures of habitat “health” and resilience at both the planning and design scales. Consequently, efforts to enhance the overall functioning and resilience of MUTH, as an important component of the estuarine system in an era of marsh transgression, should incorporate both landscape and site specific mapping efforts.

Site specific efforts move beyond distribution, quality and type and attempt to delve into the *processes* (physical, chemical, biological) that drive the formation of transition zones. These efforts are useful for “on the ground” design efforts. Site specific mapping techniques can quantify and determine empirically the ecological function, health and resilience of a given Transition within a local context. There is no current single accepted method for mapping Transition at the site specific scale. However, there have been some efforts to map transition zones at the site specific scale. This includes Tom Harvey's field studies in the 1970s where they utilized both (a) elevation in relation to tides and (b) the percentage of upland or wetland species (5%) to delineate MUTH.

Site specific efforts should attempt to empirically quantify MUTH function and resilience. It's also useful to understand the historical context for Transition, such as provided by Beller et al. (2013). Field based measures of areal extent (including mapping perimeter), elevation (using RTK GPS or other high precision measurements) length and extent of tidal inundation, and size (and condition) of adjacent habitats should be included in site specific surveys so as to provide in-situ measurements (and calibration) of landscape level mapping efforts. However to adequately assess ecosystem function, which provide a better understanding of health and resilience, such efforts should quantify and qualify the ecological functions (and services) that a given Transition is (or can be) providing. This includes actual linkages (or lack thereof) among estuarine, fluvial, and terrestrial processes, geomorphic conditions (soil, topography), as well as flora and faunal occurrence(s) and habitat quality.

Key Indicators for Mapping

A “working list” of habitat indicators were developed which were utilized to assess transitional habitat quality. These indicators were combined with threats, notably sea level rise, for ranking and prioritizing MUTH for protection or restoration. The indicators, and associated metrics, utilize commonly available GIS datasets including high resolution LIDAR, interpolated surfaces derived from NOAA tidal gauges, Land Use Land Cover (in this case the USDA's CalVeg) and National Hydrography Dataset (in this case BAARI). These spatial datasets are common and the processing techniques are mappable and repeatable and as such provide an excellent tool for assisting with the long term conservation and planning efforts within the SF Bay [See Fulfrost and Thomson 2014 for a more detailed discussion of methods, results and GIS datasets of current (and future) MUTH distribution]. Key indicators, and their associated ecological function(s), are summarized below:

Key indicators, and their associated ecological function(s), are summarized below:

1. *Elevation in relation to Tide (MHHW)*

MUTH are largely determined by the effective limit of tidal influence, which drives soil salinity, and the consequent distribution of flora. The topography of the land surfaces adjacent to the marsh modifies its lateral extent, but it is tidal variability that determines the distribution of flora. The cornerstone of mapping transition zones at the landscape level is empirical observations of transitional plant communities. Based on field data collected by Harvey et al. (1978), the lower elevation boundary is just above Mean Higher High Water (MHHW), and the upper elevation boundary is just above Highest Observed Water Level. These data were tied to modern geodetic elevations and then correlated to tidal datums. Fulfrost and Thomson (2014) utilized existing LIDAR (1-meter) and NOAA Tidal Gauges (71 stations) to develop surfaces of vertical elevation in relation to MHHW and HOWL. Despite subtle differences in elevation between the MUTH upper and lower elevation boundaries - and other complexities of tides that can make identification of its precise location difficult – these metrics provide highly accurate means for delineating MUTH at the landscape level. As MUTH are delineated primarily by their relation to a specific tidal range, it is the topography in this range that dictates their extent and character. Topography beyond the MUTH is also involved, particularly in relation to fluvial hydrology.

2. *Size, Shape, and Depth*

Ecological function (and habitat quality) of the tidal marsh ecosystem can be summarized at the landscape level using a number of well-known metrics from landscape ecology. These “patch metrics” serve as proxies for the function of plant community structure (and possible faunal use). Size (i.e. area) is easily calculated once transitional zones are stored as individual polygons in a GIS. Habitat quality based on “width” is a function of the tidal marsh width. Habitat depth was measured as “average” width (transitions within the SF Bay includes patches with very complex shapes) by dividing the surface area by the “maximum length” (the diameter of the smallest circumscribing circle). Narrow transitions (aka ecotones) are reportedly more easily hunted and may contribute to losses of sensitive species. Wide transitions (aka ecoclines – see *Sidebar on Terminology* below the Citations) provide more space for secretive fauna to hide from predators; they would also provide more area for larger, more contiguous habitat that usually contains healthier plant communities; and they are generally found on gentler slopes, which provide better abiotic conditions for vegetation. In addition to “width” the average shape (linear to compact) of transition zone patches was calculated using a variety of modified perimeter to area ratios (shape index, fractal dimension and ratio of patch area to area of smallest circumscribing circle). Shape is a proxy for edge-effects, which can impair both habitat quality and plant community stability. And overall size is likely the best indicator for suitability as marsh accommodation space during rapid SLR.

3. *Adjacent Habitats and Hydrologic Connectivity*

The value of a given transition zone is a factor of adjacent habitats. Transitional plant communities are a product of blending of the two adjacent stands of vegetation. So a transition bordered by development will be doubly impaired, both by the known impacts of development on sensitive habitats and the fact there is no upland habitat of any quality to mix with the tidal high marsh species and create a high quality transitional plant community. Adjacent habitats can be mapped using standard high resolution (30 meter or better pixels) land cover datasets (e.g. C-CAP and CalVeg) even at broad taxonomic scales –

as long as they differentiate between 'wetland' and 'upland'. In the SF Bay, land cover datasets from USDA were supplemented with the Bay Area Aquatic Resource Inventory (BAARI), to differentiate tidal and freshwater marshes. Although tidal hydrology is the primary driver of the distribution and extent of transitions, upland hydrology (riverine, incipient rainfall, surface runoff, and vadose zone) likely exerts significant influence on the plant community (i.e. ave. 26" rainfall in the North Bay selects for grasslands; ave 13" rainfall in the South Bay selects for forb-lands). Therefore, hydrologic connectivity also plays a role in both habitat type and quality.

Although not explicitly an ecological indicator, land use within a potential transition zone, provides a key proxy for determining habitat "quality" (and therefore ecological function) and its concurrent potential for restoration and protection. As an example, a potential transition zone that is identified using the 3 indicators listed above, could currently be within a developed land use (e.g. residential commercial or industrial) severely limiting its potential to service ecological function. Land use data at the parcel level, along with tax assessor information regarding land (and improvement) values, can better assist land managers in making decisions about the costs and benefits of protecting and restoring a given parcel to improve ecological functioning now (as transition zone) and into the future (as marsh accommodation space).

4. *Plant Community Composition and Structure*

Habitat quality is directly related to plant community composition, expressed by levels of native species diversity, and composition of their physical stature and seasonal growth patterns. Hypotheses based on marsh faunal habitat requirements in the tidal marshes are used to guide the use of historic local plant species when creating communities that can provide needed structure. The development of more inclusive habitat structure guidelines using the needs of other Transitional species (salt marsh wandering shrew, Burrowing Owl, Short-Eared Owl, Horned Lark, Savannah Sparrow, SF Common Yellowthroat, Marsh Wren, White and/or Golden-crowned Sparrows, White-tailed Kites, among other migrant birds) is still needed (D. Thomson & A. Jaramillo - SFBBO, pers. com.).

5. *Faunal Occurrences*

Data on direct observations of faunal use of MUTH are lacking. Radio telemetry studies of California Clapper Rail use of MUTH are being planned to provide some empirical data (C. Overton – USGS, pers. com.). However trapping of salt marsh harvest mice in MUTH is almost unthinkable given the threat of flooding risk needed to force them into this zone. Indeed, the only publication of secretive marsh faunal use of MUTH is a note in Zedler (Tidal Marsh Restoration Handbook – CRC Press, 2000) entitled "Ecotones in coastal wetland restoration" by Matt James, which relied upon observations of the signs of rodent use (scat, trails, etc.).

Additional metrics useful for evaluating ETTZ quality and type, that can be mapped at the landscape level (where adequate data is available), include:

6. Soils and Topography (slope/topographic diversity) - used to predict habitat type
7. Landscape Context Metrics - used to better understand overall *connectivity* and *fragmentation*

Management actions/recommendations

Management guidance (Bay Goals 2000) and the USFWS Recovery Plan for Tidal Marsh Ecosystems of Northern and Central California (USFWS, 2013) note that MUTH are a crucial component of the ecosystem, and requires as much attention as tidal marsh. Some of these recommendations are addressed further below:

Mapping

Efforts to map transitional habitats should ideally be accomplished in parallel with efforts to map all the elements of the estuary (as well as its adjacent terrestrial habitats). Landscape level mapping as well as site-specific mapping are both needed. Historical mapping of MUTH are also useful for understanding their likely past characteristics and locations.

Flora

The Bay's margin should be comprised mainly of plant communities dominated by native species in order to provide the functions needed by tidal marsh fauna (D. Thomson – SFBBO, unpublished observations). Native plant diversity is critical to proper function (Traut 2005), and impacts to these habitats have reduced their diversity, and hence their function. There is a host of plant species that once thrived in these habitats, and may have played a role in providing functions to the tidal marsh ecosystem (as indicated in Table 1.3, Bay Goals 2000). MUTH are the intergradation of two adjacent plant communities (Kent et al 1997), so they require adjacent terrestrial plant communities of reasonable quality to be self-sufficient (i.e. not require active management). Plant cover must be entire (or nearly so) throughout the year, and reach above one-third of a meter in height (which remains emergent through the highest tides) so that small marsh mammals and secretive marsh birds can find cover from predation. Vegetation must also provide adequate forage for marsh fauna (Shellhammer, pers. com.). These recommendations could be improved with the addition of other faunal habitat requirements as they become available from primary research into the species listed above.

f) Requirements of tidal marsh fauna for cover, forage, and other needs

1) Escape Cover Structure - similar to tidal marsh structure (a hypothesis)

Ex. salt marsh harvest mouse: 1-2' high, dense cover of pickleweed with saltgrass and gumplant nearby (in marsh plain) 1) Forage Species - pickleweeds and other marsh species in the warm season; cool season grasses in the winter

2) Other Needs – e.g. grasses for nesting materials – cool season grasses (such as creeping wildrye, *Elymus triticoides*) are predominantly located in the transitions and adjacent uplands

Protection/Conservation

MUTH gets referred to as a “buffer” for tidal marsh habitat in parts of Chapter 4, but is itself a unique habitat essential to overall tidal marsh ecosystem function and resilience. Buffers should be established and managed around MUTH to protect it from degradation by human influences, invasive infestations

and predators. Considering the need for good upland habitat adjacent to the transitions for plant community stability and future marsh migration, it seems more prudent to consider the adjacent uplands as potential habitat buffer zones.

During tidal marsh migration MUTH will also transgress upslope as tidal marshes move landward with rising sea level. Wherever possible, adjacent lands need to be protected for this upward transition to occur over the long term. Forward thinking will be key here, as open space or lightly developed land is relatively rare surrounding the estuary. Furthermore, because transitional habitats are a mixture of adjacent habitats, a self-sustaining amount of adjacent uplands should be restored and conserved (i.e. protected by or as a buffer beyond MUTH) to ensure these habitats are able to function, as well as provide crucial habitat needed by marsh fauna that move beyond MUTH, such as the salt marsh harvest mouse (H. Shellhammer & R. Duke – HT Harvey, pers. com.).

Restoration

MUTH must be incorporated into marsh restoration projects where topography exists, or projects need to create gradually sloping lands bayward where restricted by levees and development. For design purposes, MUTH should be at least 10s of meters deep for current habitat needs to hundreds deep for SLR adaptation (*Shellhammer* pers. Com. in Thomson, 2013). Significant populations of many transitional plant species are rare throughout the region, so active vegetation management is required to recreate historic communities, and may continue to be needed until they attain adequate distributions to self-propagate and compete well with exotic species, or perpetually in cases where there is not enough space for adjacent upland habitat.

Acquisition

Acquire all undeveloped land that currently lies within this elevation range, as this is where marsh transgression will occur with SLR. There are not many opportunities to do so, but MUTH maps such as Fulfrost and Thomson (2014) will help identify opportunities. There would have to be great efforts made to reconnect the Bay with its historic upland transitions, as they are currently cut off from the tides by dikes, salt ponds and other levees. There would also have to be quick action to ensure current planning projects (ex. the USACE Shoreline Study) and other development does not create new barriers to conservation of the tidal marsh ecosystem. Furthermore, as the dynamics of this process are currently unknown, research needs to occur that improves our understanding of this so we can prepare these accommodation spaces and improve their conservation value as climate adaptations.

Summary

MUTH is an important component of the tidal marsh system of San Francisco Bay. Vast acreages of historical MUTH have been replaced with steep sloped levees and dikes, which has resulted in the loss of this important habitat. With the extensive tidal marsh restorations being undertaken throughout the Bay, there is an opportunity, an imperative one, to include restoration, enhancement and recreation of the MUTH as a component of marsh restoration.

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SIDEBAR on TERMINOLOGY

Transitional Habitat Terms – D. Thomson

An important part of describing anything is agreeing upon terms and their meaning to help ensure the intent of writing is understood. A local vernacular for habitats at the bay's margin developed over the years that does not conform to common scientific usage. There are quite a few local references to all such habitats as "upland ecotone" (Collins and Grossinger, 2004), fewer refer to them all as "transition zone" (Josselyn, 1983), and one simply called them the "upper zones of marshes" (Shellhammer, 1982). Some are concerned that the use of a local vernacular or changing the terminology so it conforms may create confusion and interfere with this report's use. The intent of this sidebar is to ensure readers understand this portion of the report's terminology, regardless of their background.

Ecotone - this term may have been coined by Clements in 1901, or at least by Livingston in 1903, and has since been defined by Kent et al. (1997) as "... a zone of relatively rapid change between two plant communities and a dynamic zone of interaction..."

Ecocline - this concept was first proposed by Whittaker in 1960 as "coenocline" and has since been defined by Kent et al. (1997) as "... a more gradual gradient of vegetation change between two plant communities corresponding to a progressive spatial change in one or more underlying environmental or biotic factor(s)..."

Mosaic - this term was introduced by Whittaker (1953) as part of his climax pattern hypothesis: "a pattern of intergrading communities corresponding to a pattern of environmental gradients". Kent et al. (1997) state that "... most, if not all, transitional areas contain a degree of mosaicking..." so this should be considered a characteristic of the other two terms.

Transitional Area - this term is recommended as a general transitional habitat term (Kent et al. 1997). It contains the ecotone/ecocline/mosaic concepts defined above.

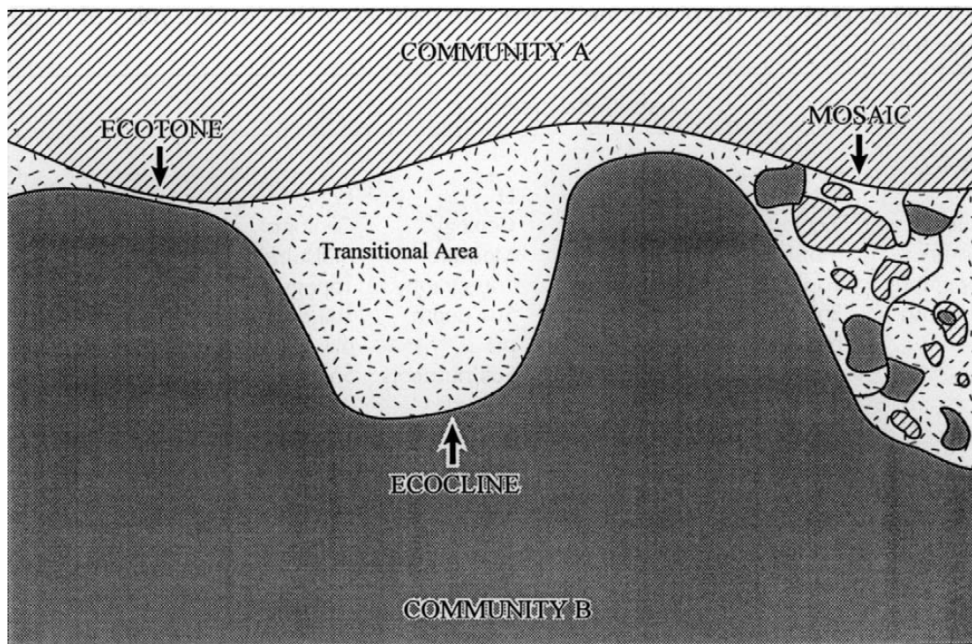


Figure 7 The linear nature of transitional areas demonstrating the varying widths of ecotones and ecoclines with mosaicing superimposed upon them

From Kent et al. (1997) depicting the terms.