Mapping the Transition Zone:

Integrating the Upper Boundary and Bay Margin Methods

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Background

Efforts to address the ecological and economic threats imposed by sea-level rise and other aspects of climate change have begun to focus on the estuarine–terrestrial transition zone (between tidal wetlands and local watersheds), or the "transition zone." The transition zone is an area that exists along the shoreline between tidal wetlands and uplands that includes areas of former marsh and low upland slopes. The transition zone is an important area of connection between the Bay and watersheds. It provides corridors of movement for wildlife, along with important habitat and protection for sensitive species. This same transition zone was developed and now supports human activities such as housing, recreation, transportation, commerce and industry. They provide a variety of ecosystem functions and services including high tide refugia, movement corridors, niche habitats, public access and recreation, carbon sequestration, flood detention, and sea level rise accommodation.

Ecological transitions are challenging to map because of the dynamic nature of the processes that result in variability over place and time. The challenge rests in the need to reconcile the complexity of the transition zone into practical maps that delineate the existing and projected future transition zone. These maps can provide scientists, planners, engineers, and community-based groups with better information to identify opportunities to protect and restore transition zones as part of the process of planning more resilient shorelines and prioritize protection and restoration actions and policies.

The San Francisco Estuary Partnership (SFEP) proposed to advance this task for the region by facilitating a technical working group ("Task Force") to develop a regional mapping methodology for existing and projected transition zones. The 2015 Baylands Habitat Goals Science Update ("Science Update") (Goals Project 2015) provides significant guidance on transition zone, and included a Science Foundation chapter on the estuarine-terrestrial transition zone as well as an appendix with further discussion of transition zone. The Science Update provided guidance on transition zone mapping, but did not resolve a comprehensive approach for multiple audiences and users of maps of the transition zone. The effort to map transition zones is supported in the Comprehensive Conservation and Management Plan or Estuary Blueprint (CCMP 2016). Action 4 of the CCMP, "Identify, protect and create transition zones " describes a series of tasks to support this work. The objectives of the Task Force were:

- Expand on the process laid out in the Science Update to identify information needs to address key management questions.
- Determine the key steps and decision points in mapping the transition zone.
- Integrate existing transition zone mapping methodologies and clarify uses for different audiences

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The Task Force met four times during the course of this process. The project team included Brian Fulfrost, and staff from the San Francisco Bay Joint Venture (SFBJV), San Francisco Estuary Institute (SFEI) and SFEP. The Task Force considered key management questions and map uses, as well as ideas for regional mapping methodology of existing and potential transition zone. Subsequent Task Force meetings considered the Science Update's recommended use of distinct and overlapping ecosystem-based subzones, key audiences, and review of existing (the Bay Margin) and emerging mapping (the Upper Boundary) methodologies. The work of the task force was to clarify and refine how these methodologies overlap, and how they are different so that intended users can better navigate the two approaches.

The Bay Margin mapping approach was developed by Fulfrost and Thomson (Thomson et al 2013; Fulfrost and Thomson 2015). This approach maps transition zone distributions based on tidal elevations and sea level rise and ranks them according to habitat function (including habitat connectivity, shape/width, and adjacency to development). However, there are different ways to define the transition zone depending on the ecosystem functions and services of interest. The Upper Boundary mapping approach was developed by SFEI to delineate an upper transition zone boundary that encompasses additional subzone functions and services (such as riparian flooding) identified in the Science Update to assist agencies in assessing development projects and developing adaptation plans. The Upper Boundary approach is being developed to complement and be used in addition to the Bay Margin method.

Defining a Transition Zone

The two transition zone mapping methodologies discussed in this document are based on slightly different definitions of the transition zone. The Bay Margin method defines the transition zone based on relation to tide zones: Estuarine-terrestrial transitional habitats occupy the boundary between land and sea, from the zone of regular flooding to the effective limit of tidal influence. They harbor a unique plant community, provide critical wildlife support to adjacent ecosystems, and play an important role in linking marine and terrestrial processes (Thomson et al, 2013). The Upper boundary method defines the transition zone based on processes and services: Estuarine-terrestrial transition zone (transition 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 (Goals Project 2015). The Upper Boundary methodology roughly estimates an area likely to encompass the majority of the ecosystem services identified in the Science Update report.

Ultimately, the Task Force came to the conclusion that combining the two mapping methods would enable a broad audience to both assess and plan for existing and future transition zone ecosystem needs as sea levels rise and development pressures along the bay-urban interface continue.

The goal of this document is to explain the differences and similarities between these approaches and lay the groundwork for a common methodology for when and how to use these approaches together in a comprehensive manner.

More broadly, the Task Force came to the conclusion that there are multiple valid ways to define the transition zone, and these different definitions lend themselves to different mapping methodologies. As more is learned about the transition zone, mapping methodologies are expected to evolve further. There is a need to further study the transition zone, to better understand how the transition zone differs between locations, and to better understand how different transition zone functions and services can be better supported.

Key Audiences

The transition zone is a dynamic area of the shoreline, and maps of the transition zone are used by planners, managers, community-based restoration groups and scientists. These users are often driven by different priorities (e.g., estuary restoration and conservation, flood control, endangered species protection, community needs) as well as different time and spatial scales (project level, city planning, regional planning, etc). This may lead to different mapping needs. Potential users of transition zone maps and mapping methodologies include:

- natural resource managers and land managers;
- local, state, and federal agencies;
- Restoration Authority;
- urban planners;
- special districts (flood control, parks, wastewater, etc);
- environmental non-profits; and
- community-based watershed and restoration groups.

Potential management applications of transition zone mapping include identifying what restoration and enhancement actions to prioritize, identifying what areas are most vulnerable or resilient to sea level rise, tracking change in transition zone extent over time, flood control, and prioritizing where to acquire land.

Table 1. Key Transition Zone Management Questions

Type of Organization	Example Organizations	Example Questions
Regulators	BCDC, Water Board, USFWS	● What is the minimum functional area for a transition zone? ● How does current/future t-zone fall within specific regulations and jurisdictions? ● Can project impacts be mitigated in adjacent transition zones
Planners	Cities, Counties, SCC, BCDC, Restoration Authority, SFEP	● How does the amount of transition zone habitat change over time? ● Where are the best places to acquire land for transition zone in the near term? ● What locations are best for mitigation? ● Do you prioritize areas for restoration that are adjacent to t-zone and vice versa? ● What functions and services do t-zones provide to surrounding natural and built environments? ● How do you prioritize restoration and enhancement of t-zones?
Land Managers	USFWS, NPS	● How much transition zone do you have on your property? ● How can you manage the t-zone for species ranges to shift over time? ● What tzone features are important for wildlife and can be mapped?
Funders	SCC	● How do you maximize benefits in t-zone for money spent?

		• Which t-zone projects should be funded?
Residents and Landowners	Residents, Chevron	• What complementary actions (dog walking, biking, etc) can be done in the t-zone?
Academia	UC Berkeley, Stanford	• How does the ecosystem function? • How do you improve estuarine/marsh health? • How much t-zone is needed to support different t-zone functions?
Non-profits	Save the Bay, Point Blue, TNC, SFBBO	• How can the t-zone support community engagement with bayland habitats?

Current state of transition zone mapping

Although there have been notable projects that have mapped the estuarine marsh throughout the Bay (e.g. SF Bay EcoAtlas, Point Blue, USDA CalVeg), up until recently 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).

(from BEGHU) 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. 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. The challenge is made more difficult by the need to resolve the complexity of the transition zone into a practical map that planners and managers can use to track local and regional changes in transition zone extent and condition, and to prioritize transition zone restoration and protection needs and opportunities (Fulfrost and Thomson 2013).

Only the Bay Margin method has been used to map transitions throughout SF, San Pablo and Suisun Bays. This work provided an inventory and ranked the "quality" of transition zone elevations (actual and potential; connected to the estuary or disconnected from it), now and under two SLR scenarios. The Upper Boundary method has been trialed in Southern California and can be further developed for the SF Bay Region.

Bay Margin Mapping Approach

Approach

The Bay Margin mapping methodology was created by Brian Fulfrost and Associates and the San Francisco Bay Bird Observatory. It is a decision support system (DSS) designed to assist land managers in identifying and prioritizing transitional geography (i.e. land surfaces with the proper elevation) based on their potential value to the protection and restoration of the San Francisco Bay Estuary. The DSS also allows the user to account for the landward migration of transitional habitats in response to projected sea level rise (SLR). For the purposes of tidal marsh ecosystem recovery in San Francisco Bay, critical habitats at the bay's margin are defined as those occurring between high marsh or the zone of regular flooding, through estuarine-terrestrial transitional habitats (transitions), and some portion of adjacent terrestrial habitats. Transitional zone distributions are mapped via tidal elevation modeling. Although the mapping methodology takes an "estuary up" approach, it characterizes transition zone as an area of dynamic interactions between adjacent habitat's processes (Kent et al 1997). The method also takes a forward thinking approach not only mapping the distribution of transition zone under two sea level rise scenarios (high 2050 and high 2100) but also by mapping non-tidal areas that fall within relevant tidal elevations for the present topography.

Current transition zone distributions (actual and potential) are then ranked according to a range of mappable metrics of habitat function, including linkages to both wetlands and uplands, landscape metrics (width, size and shape), and adjacency to development. Rankings are based on indicators of habitat function described in the attendent Transitional Zone Definition Report. The report characterizes the physical and biological properties of upland transitions with respect to the functions of the tidal marsh ecosystem, including: (a) wildlife habitat, high tide refugia for obligate fauna, discharge zone for fluvial flooding, and accommodation space for marsh migration. A list of habitat indicators based on these functions were utilized to map their distribution and assess their quality.

Status: Completed and in use. See Appendix A for more detail

Audiences and uses

The target audience for the Bay Margin method and decision support system is wide and varied. It includes estuarine managers (e.g USFWS, CDFW), resource and coastal management agencies (e.g.Water Board, BCDC, EPA, State Coastal Conservancy), non-profit conservation groups (e.g. Save the Bay, Point Blue, SFEI) , regional conservation planning and implementation collaboratives (SFEP, SFBJV), as well as city/county planners and flood districts.

The GIS datasets of both (a) current ranked transition zone (actual and potential) and (b) distributions of transition zone under two sea level rise scenarios (61cm and 167cm) can be used to meet multiple needs (from landscape to site specific scales). These include:

- inventory current transition zone elevation distributions and acreage (actual and potential),
- assist in identifying transition zone habitat goals (acreage and other),
- identify needs for obligate fauna for high tide refugia,
- identify and prioritize transition zone sites that provide the most potential improvements) to (or lack) ecological function, and
- identify and prioritize transition zone sites that provide potential marsh accommodation space.

The Bay Margin method has been considered or utilized by a variety of local individuals, groups, and agencies. The San Francisco Bay Joint Venture (SFBJV) Science Steering Committee (SSC) has recently adopted the use of the Bay Margin maps of current transition zone distribution to be used as a baseline to meet the needs of an element of their science program focused on tracking habitat change on the landscape. The SFBJV baseline maps will only include current transition zone locations that are both tidal and adjacent to an existing wetland. The remainder of potential transition zones (including SLR distributions) will be considered as a resource for identifying habitat acreage and condition goals. Additional modifications might be made to the rankings (e.g. including sites within and adjacent to agriculture as positive modifiers to habitat ranking) to best meet the SFBJV's goals.

Some examples of the ways the Bay Margin mapping approach have been applied include:

- Baseline inventory and monitoring program for the SFBJV Science Steering Committee
- To inform the transition zone planning group gathered by the Wetlands Regional Monitoring Program (CCC & EPA)
- Appendix in the Science Update Transition Zone report, focused on the needs of estuary managers, drafted by Thomson & Fulfrost with the help of scientists from USGS, USFWS, SFBJV, and others.
- The State Coastal Conservancy's South Bay Salt Pond Restoration Project management team has been using this work to inform their Phase II planning.
- The SFBJV also utilized the datasets to quantify transition zone within BEGHU planning units for their Climate Adaptation Decision Support (CADS) report.

Upper Boundary Mapping Approach

Approach

The Upper Boundary approach is a methodology for delineating a transition zone area that could potentially support a broad suite of transition zone ecosystem services, looking both from the estuary up and the watershed down. The method assumes a certain transition zone width is necessary to support different transition zone benefits. The method delineates an area where transition zone management, and support of the associated ecosystem services, should be considered when making land use planning and management decisions.

Land use is a major consideration in determining what can be done within this transition zone boundary. Although many developed areas are unlikely to be considered for habitat restoration, these areas may still support transition zone functions in other ways. For example, some land uses in developed areas (e.g., vacant lots, golf courses) may still provide some buffering functions. Actions taken in developed areas within this boundary can support wildlife movement (e.g., removal of barriers and planting of native vegetation in yards), and affect flood control (e.g., rain gardens and bioswales). Infrastructure realignment within these areas, to protect from increased flooding with climate change, may provide opportunities for transition zone restoration.

This method supports long term visioning that reconnects terrestrial and fluvial processes with estuarine processes to restore a wide range of ecosystem functions at the landscape level, to increase the resiliency of these functions to sea level rise and climate change. See Appendix B for more detail.

Audiences and uses

The Upper Boundary Methodology is particularly appropriate for regional planning and visioning, as it identifies an area where transition zone processes must be integrated with other land uses. This method is meant to be used by planners and regulators to encourage larger-scale and longer-term thinking about incorporating transition zone functions into shoreline planning. The transition zone is a contested zone with both ecological and urban functions. This methodology is NOT meant to suggest that everything within this boundary remain undeveloped. Rather, considering sea-level rise and transition zone function more holistically within these areas can help us develop better adaptive and multi-benefit shoreline solutions that improve both ecological and societal benefits over the long term.

Status: Draft methodology, currently being validated. Additional guidance for prioritizing actions in the delineated area is in development.

Comparison of the two approaches

As discussed above, the two methodologies are based on slightly different definitions, with the Bay Margin approach basing its definition on habitats and the Upper Boundary approach basing its definition on ecosystem services.

Both methodologies address a broad suite of ecosystem services and habitat functions. The Bay Margin methodology focuses on an initial need for obligate fauna and estuarine function, taking an estuary-up approach, while the Upper Boundary approach places an additional emphasis on landscape connectivity for upland wildlife and broad habitat gradients, adding a watershed-down perspective.

The two approaches potentially target different audiences by answering different management questions. The Bay Margin is currently being used to prioritize restoration decisions/land acquisition by the South Bay Salt Pond project, and for SFBJV monitoring to track changes in transition zone extent (and to potentially assess transition zone goals). The Upper Boundary approach is being used for the North Richmond shoreline, to help with community-based landscape visioning with consideration of ecosystem services. As these methods are further implemented and refined we will better understand how the two might be used together.

While these two methodologies have the potential to answer different management questions, we were unable to reach consensus around which questions were best answered by which method. Using the two methods together (see the next section) might be a good way to tease apart the best uses for each. The Bay Margin method has an explicit way for measuring habitat function that accounts for SLR and prioritizes sites for restoration potential using a ranking system.

Potential applications for the two methodologies include:

- Identifying areas for transition zone restoration actions,
- Prioritizing restoration actions,
- Identifying areas most vulnerable or resilient to sea level rise,
- Tracking change in transition zone extent over time,
- Prioritizing areas for land acquisition, and
- Informing shoreline planning in urban areas.

How the two current methods can work together

Long term estuarine management may be better informed by use of these two tools together, moving toward a more comprehensive “estuary up” and “watershed down” approach.

The Bay Margin approach has already been completed and was designed to meet the needs of resource managers and planners for both short term and long term planning by mapping and ranking transition zone distributions while considering long term processes like sea level rise.

The Upper Boundary approach can support landscape visioning for a future landscape looking from the watersheds down, to incorporate support for terrestrial wildlife near the bay, and broad habitat gradients.

Where the area delineated by the Upper Boundary method intersects with the Bay Margin method, the Bay Margin methodology could be used to prioritize restoration actions and areas in a way that connected with this landscape visioning approach.

The idea that the two methodological approaches to mapping transition zone are in fact complementary was born out of the Task Force. One participant said “I think there are multiple audiences who might focus on different components - depending on their goal. I could see the Restoration Authority actually needing both, so the users/stakeholders have something now, and by extending it to this ‘aspirational boundary’ they will then also be able to think even more long term, past even 167cm of SLR.”

The initial interest in mapping estuarine-upland transition zone comes from resource managers, agencies, and researchers involved with management and conservation of the estuary. However, in an era of sea level rise, climate change and land use pressure, the intended audience is growing to include urban planners, flood districts, water bureaus, among others. It became clearer to the Task Force and Project Group that the “estuary up” the “watershed down” approaches were not mutually exclusive, but in fact complementary. At the same time, the combination of a “practical” mapping method, that accounts for sea level rise, with a more “aspirational” landscape vision, that at least conceptually attempts to look at the connection between terrestrial and estuarine processes, does not limit either approach but enhances both.

As an example, resource managers and others involved with restoration can use the existing Bay Margin maps to identify the (actual and potential) distribution and functioning of transition zones now and under SLR, within their restoration areas. They can also use these datasets to help identify acreage and habitat goals (e.g. the SFBJV). However, by adding the Upper Boundary methodology (as another GIS layer) to the same map, a restoration practitioner will better be able to see how current (and future) transition zone distributions might connect to even longer term riparian/terrestrial processes. This comprehensive view could influence their criteria for restoring, enhancing, or protecting a transition zone. The same could be true for a water regulator looking down the watershed about decisions regarding (as an example) zoning of a riparian flood zone that could be connected to transition zone distributions that are already mapped.

As a result, the integration of both approaches into one decision support system is likely to provide better overall estuarine and terrestrial/riparian management and conservation. The combination of these two approaches enables users to address the management and conservation of transition zones to meet multiple goals, at a range of spatial (landscape to site specific) and temporal scales (current to SLR time horizons and to longer term landscape reconnections). Another advantage of the combined approach is when exploring both datasets at the landscape level, a user can see the distribution and functioning of (actual and potential) transition zone (now and under SLR) using the existing landscape while also looking at potential transition zone in a visionary landscape that reconnects terrestrial and estuarine processes.

Next steps

This white paper reviews the current state of transition zone mapping methods and includes evidence that a combined approach provides an enhanced approach to all potential audiences. An additional section of the white paper, could outline the practical step of how the two approaches could be used together. A simple first step of implementing the combined approach is to package (and/or link) together the GIS datasets from both methods.

More long term, we envision a possible next step is to generate an online GIS tool, that enables users to visualize and query both approaches (as either an integrated layer or as two separate layers). Users would then be able to to envision the transitional zone within the landscape at a range of spatial and temporal scales.

Appendix A: Bay Margin Methodology

Introduction and Background

Upland transitional habitats found along the margin of estuaries are critical to tidal marsh ecosystems. However the status, distribution and extent of these habitats is generally not well understood. Land managers and estuarine planners require an understanding of these habitats to make proper choices regarding the conservation of estuaries. With the support of the USFWS Coastal Program and the State Coastal Conservancy, we developed a GIS based Decision Support System (DSS) to describe and map the distribution and extent of potential tidal marsh-upland transitional habitats (aka ecotones) and rank their value to tidal marsh ecosystem conservation. Rankings are based on indicators of habitat function described in our transitional zone definition report. The DSS is designed to assist land managers in prioritizing transitional geography (i.e. land surfaces with the proper elevation) based on their potential value to the protection and restoration of the San Francisco Bay Estuary. The DSS also allows the user to account for the landward migration of transitional habitats in response to projected sea level rise (SLR).

Estuarine-Terrestrial Transitional Habitats (hereafter “transitions”) are defined as follows:

Estuarine-terrestrial transitional habitats occupy the boundary between land and sea, from the zone of regular flooding to the effective limit of tidal influence. They harbor a unique plant community, provide critical wildlife support to adjacent ecosystems, and play an important role in linking marine and terrestrial processes (Thomson et al, 2013).

The project team, led by lead ecologist, David Thomson, conducted an extensive literature review on the ecology of estuarine-terrestrial transition zone (herein referred to as Transitions). This focused on the functions that Transitions play in tidal marsh ecosystem function. David reviewed both broader scientific literature as well as local applied science reports that helped to document the ecosystem function of Transitions as well as historic distribution within SF Bay. At the same, David convened an advisory group of regional experts including specialists in estuarine ecology, obligate fauna and conservation management with input from our USFWS funder (John Klochak). One focus of the definition and characterization development was the importance of Transitions for obligate fauna, specifically Salt Marsh Harvest Mouse (SMHM) and Ridgeway’s Rail (RWRA), as well as its importance in overall estuarine function. The advisory group included Dr Bibit Traut, the only known ecologists to have written on estuarine function of transitions, Dr Howard Shellhammer, the premier scientist studying SMHM, Dr Corey Overton, who at the time was studying the ecology of Ridgeway's rails, as well as Dr Laura Valoppi, lead scientist for the South bay Salt Pond Restoration Project, which is in the process to restoring more than 15,000 acres of ex-salt ponds to functioning estuarine habitats. We also included a floral palette for restoring Transitions within SF bay as an attachment to the technical document. It's difficult to precisely characterize the historic flora of Transitions, but would be a mix of local estuarine and upland species.

The result of both the literature/document review and interviews with the advisory committee resulted in a technical document that both defined and characterized Transitions with regards to functions required by obligate fauna and aspects of tidal marsh ecosystem resiliency to climate change. Within this document, Transitions were characterized by a number of indicators of "Transitional habitat function" from which metric were derived for evaluating those particular indicators. These included both biotic (eg habitat structure) and abiotic (eg patch width, size and shape) elements. These indicators and metrics were utilized in remaining stages of the project to identify, map and rank Transitional patches throughout the estuary. With the help of tidal marsh ecosystem specialists throughout the region we drafted a thorough description of tidal marsh-terrestrial transition zones. This document contains a detailed characterization of of the physical and biological properties of transition zones with respect to the functions of the tidal marsh ecosystem and needs for obligate fauna. A list of habitat indicators were developed based on these functions and utilized to map their distribution and assess their quality. These indicators were then combined with threats, notably sea level rise, for ranking and prioritizing TZH for protection or restoration.

The DSS includes 3 major components:

(1) a technical report that describes and characterizes transitional habitat based on how it can support the ecological functions of the tidal marsh ecosystem;

(2) GIS models (shapefile) of ranked (potential) current transitional habitats based on site specific indicators of patch "quality" for conservation value and restoration potential; and

(3) GIS models (as rasters) of the (a) current and future (b) 61cm SLR (2050) and (c) 167cm SLR (2100) distribution of transitional habitat patches, based on documented tidal elevations, at the landscape level for the entire SF Bay.

The toolkit is designed to help managers allocate limited resources on site prioritization, alternative/scenario evaluation, and includes considerations for the influence of future climate change (ie SLR) and land-use scenarios. GIS users can filter sites based not only on the sum total ranking but also user defined criteria (eg undeveloped, tidal, habitat adjacency, etc.) for individual metrics or sets of metrics.

All components of the estuarine-upland transizione zone decision suport system are hosted on the california climate commons (see http://climate.calcommons.org/dataset/san-francisco-bay-estuarine-terrestrial-transitional-zone-decision-support-system) and Data Basin (see https://databasin.org/articles/c5f4d540073247189709a144ebd49d7c)

Mapping Methodology

The transitional zone is largely determined by the extent of the tidal zone, the salinity of the soil, and the consequent distribution of flora. The first component of the transitional zone decision support was to map the potential transitional zone based on tidal and elevation constraints. Metrics based on indicators of habitat functions were then mapped using best available GIS datasets. Index values (positive and negative) were created for all metrics in order to rank each transition polygon according to habitat quality. The ranks can be used to identify the restoration, enhancement or protection potential of each transition zone. Indicators values were summed into a combined index representing potential value to tidal marsh ecosystem management. Both potential existing transitional patches ("levee on") and potential accommodation space ("levee off") were assigned index values.

Processing Steps

Step #1: Tidal Elevations

The transitional zone is largely determined by the extent of the tidal zone, the salinity of the soil, and the consequent distribution of flora. The first component of the transitional zone decision support was to map the potential transitional zone based on tidal and elevation constraints. The resulting landscape-scale transitional topography maps show their current distribution and extent. The few still connected to the estuary are termed “existing transitions”; those disconnected by water control structures (such as levees) are termed “potential transitions”. These transitions, when viewed with the distribution and extent of tidal marshes can help managers visualize where they are lacking (i.e. requiring creation) and where they are plentiful (i.e. requiring protection). Transition zones were also mapped according to two Sea Level Rise time horizons (“high” 2050 = 61cm; “high 2100 = 167cm) identified by the National Research Council (NRC 2012), in order to predict likely changes in distribution and extent through time.

The width of transitional habitat is largely determined by the extent of the irregularly-flooded tidal zone, which modifies the salinity of the soil, and the consequent distribution of flora. The first component of the transitional zone decision support was to map the potential transitional zone based on tidal and elevation constraints. High resolution Lidar (1 meter) was combined with tidal rasters created from NOAA tidal gauge datasets. Two tidal rasters (converted to NAVD88) were generated from the tidal gauges data to assist with mapping the lower and upper limits of Transitions: (1) interpolated surface of MHHW (using ~ 40 tidal gauges) and (2) a trend surface of the difference between MHHW and HOWL (using around ~16 tidal gauges) to account for tidal variability on the upper boundary of transition zone throughout the estuary. The Lidar elevation data was merged with the MHHW surface in ArcGIS so elevation represented elevation relative to MHHW for the entire SF Bay. The “range” of potential Transitions was identified as .31 meters above MHHW as the lower limit to HOWL + .27 meters as the upper limit. This tidal range was used because it conformed to work mapping transition zone tidal ranges by Tom Harvey () and predictive modeling of marshes by Point Blue. Raster output from the tidal elevation model of transition zones was converted to vector polygons, simplified and adjacent polygons were merged. Final raster results were divided into “tidal and nontidal based on “levee on” (tidal) and “levee off” (nontidal) boundaries provided by PRBO (see Step #4 below).

Potential tidal elevations modeled to predict Transitions using this approach were ground truthed using a mapping grade GPS. There was a high degree of correlation between the location and distribution of predicted Transitions and field based characteristics of these locations. Sites were visited in south, central and north bays. The majority of these sites were slightly overlapping and above high marsh and slightly overlapping with upland (where existing) as anticipated. The majority (although not all) of potential Transitions in the south bay exist on levee flanks. Certain sites, such as within San Pablo Bay National Wildlife Refuge along Sears Point Rd in the north bay, seemed slightly shifted off from expectations (on top of levees as supposed to flanks). This could be due to georeferencing issues of Lidar or the precisions of tidal models. Predicted distributions of Transitions were also checked in the lab using high resolution imagery (Ikonos - June, 2011 and Google Earth - various) and also showed a high degree of correlation with expected tidal elevation that were identified as corresponding to Transitions. In addition to mapping the current distribution of Transitions based in tidal elevation, we also successfully mapped the distribution of Transitions under two Sea Level Rise scenarios for 2050 and 2100 (61 cm and 167 cm).

Step #2: Habitat Quality

Each transition zone polygon identified was then ranked according to a series of 7 metrics representing the indicators of habitat quality (Thomson, D., et al 2013; Fulfrost, B., Thomson, D., 2015).

A major use of the characterization report was to identify indicators of habitat "quality" and function, that could be used to map and rank the restoration potential of Transition. We identified the 3 most salient (and practical) indicators to be used in our GIS based suitability model. These included: (1) Transition width - 30 meters was identified as a minimum width for functional habitat; (2) Transition Shape and Size - areas with more core area were determined to provide better overall habitat function (especially for wildlife) and a minimum area of 900 m2 (based on the 30 m width) was used as threshold of adequate habitat size ; and (3) adjacent habitat (or development) - habitat connectivity was identified as a major influence on habitat function and as a result we ranked transition zones positively according to their adjacency to wetlands (tidal and freshwater) and uplands.

These 3 Indicators of habitat function identified in the definition document were converted into the following 7 metrics:

Patch Metrics (width, size and shape)

Once the polygons were simplified and combined, patch metrics were calculated for each potential transitional zone polygon. These include:

Area (of transition zone patch)

- with >= 900m2 used as a threshold for determination of highest index values

- not a metric unto itself but used as a weighting for determination of index values for width and shape

Mean Width

- with >= 30m used as a threshold for determination of highest index values
- calculated as surface area / maximum length (diameter of smallest circumscribing circle) weighted y area of polygon
- values range from -10 to 30

Shape

- linear to compact with the more compact being given higher index scores
- Measured by minimum bounding circle and weighted by area of polygon
- values range from -10 to 10

Adjacent Habitat

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 ideally between tidal wetlands and uplands in this case. At the same 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 were mapped using standard high resolution (30 meter or better pixels) land cover datasets (CalVeg) at broad taxonomic scales – as long as they differentiate between 'wetland' and 'upland'.

Adjacent Tidal Wetland

- measured as the size of adjacent tidal wetlands weighted by the length of the shared boundary
- Values range from 0 to 40

Adjacent Freshwater Wetland

- measured as the size of adjacent freshwater wetlands weighted by the length of the shared boundary

- values range from 0 to 10

Adjacent Upland

- measured as the size of adjacent upland land cover weighted by the length of the shared boundary
- values range from 0 to 30

Adjacent Urban Area

- measured as the size of adjacent urbanized land cover and weighted by the length of the shared boundary (index values are negative)
- values range from 0 to 30

Adjacent Agricultural

- measured as the size of adjacent agricultural land cover and weighted by the length of the shared boundary
- values range from -15 to 0

The (a) proportion of shared boundary for adjacent land cover(s); and (b) area (i.e. size) of these same adjacent land covers were quantified in ArcGIS for each transitional polygon "patch". Land cover types that were used in the rankings included: tidal wetland, terrestrial wetland, urban, "upland", and agriculture . Transitional patches adjacent to both wetland and uplands were given the highest positive indicator values while patches adjacent to urban(and to a lesser degree agricultural) land cover were given negative indicator values. Indicator values for adjacent land cover assigned to transitional patches were weighted based on both the proportion (>= 50% of shared boundary given the highest weight) and area (>=50 acres of landcover given the highest value). We used land cover data from the USDA's CalVeg database.

Step #3: Development (within polygon)

The percentage of each transition zone polygon that was "developed"was measured using urban land use classes from NOAA's C-CAP database. Polygons with larger undeveloped areas were given higher values for this metric.

Information about land use(s) designations assist land managers in determining the feasibility for restoring or protecting potential transitional parcels - geographic unit utilized by land managers and planners. Although we did not use the land use designations at the parcel level in our ranking system, we did identify the APN ID(s) associated with each transition zone.

Step #4: Tidal or Non Tidal
Each transition zone polygon was identified as either being within a tidal (50 points) or non tidal (25 points) location using a mask provided by Point Blue. Non tidal areas were also mapped and ranked in order to account of potential marsh migration and restoration potential.

Step #5 : Final Rankings
Rankings of restoration value (and categories from extremely low to high) are assigned relative to all the potential transition sites mapped within the study area. The final restoration index values (restidx) was calculated as:

(a) sum of the 7 metric indices (100+ points) +
+
(b) development index (50 points)
+
(c) tidal (50 points) or non-tidal (25 points) index

Step #6: Protection Status

Although not used in the rankings, we calculated the area of each transition zone polygon that was within a protected area using the California Protected Area Database (CPAD). The "protindex" field contain the percentage of the area (as a fraction of 1) that is within a protected area.

Step #7: Sea Level Rise Scenarios

In order to account for projected sea level rise (SLR), we mapped the tidal distributions of transition zone under two SLR scenarios. The scenarios were taken from the high 2050 (61cm) and high 2100 (167cm) projections from the National Research Council (NRC 2012). The resulting two additional GIS layers are provided to assist users, in conjunction with the GIS layer of ranked current distributions, to account for the landward migration of transitional habitats in response to projected sea level rise. Transition zone distributions under these two scenarios were created by simply adding 61 cm and 167 cm respectively to the current modeled tidal distributions (ie they are 'bathtub' models).

Note: GIS users can filter sites based not only on the sum total ranking but also user defined criteria (eg, % of transition zone within protected area, undeveloped, tidal, habitat adjacency, etc.) for individual metrics or sets of metrics.

Data Sources: NOAA (C-CAP), CDFW (CalVeg), NOAA/USGS (2m Lidar), NOAA (tides and currents), ABAG/MTC (parcel land use), SFEI (BAARI), GreenInfo (CPAD), Point Blue (tidal/non-tidal mask)

Results and Discussion

During the development of the GIS based suitability model to rank Transitional patches according to their potential for restoration or protection, it became clear as we interacted with the wider scientific and conservation community, was the type of action (restoration, enhancement or protection) varied greatly. Certain locations where the Transitions were poor and ranked very low, required the creation of Transitions (i.e. “needed area”) while certain Transitional patches which ranked very high might need restoration or perhaps just enhancement. As a result, our criteria and mapping efforts utilized the criteria to prioritize Transitional patches for restoration and not protection. These patches were identified as “within or outside” of a protected area but not ranked separately.

Although the movement of transitions away from the estuary was predicted, Fulfrost and Thomson's research found that the extent (i.e. acreage) of transitions will diminish over time because the tidal elevation required for transitions zone decrease as slopes generally increase with distance from the estuary (see table and graphs below). Simply put there will be less acreage of upland transitional habitat in the future surrounding the estuary.

Existing transitions (i.e. connected to the estuary) are projected to be eliminated by SLR around 2100, so they must either be created through filling the estuary or levees moved to reconnect potential transitions to the estuary. Creating transitions requires filling the estuary, converting lower elevation habitats into higher ones in preparation for future sea levels. Identifying which is more feasible, massive earthwork projects or moving levees and purchasing large tracts of land, will require landscape scale planning projects. Our DSS would provide useful information to such a project, but is primarily designed to help managers identify where their resources will provide the greatest impact.

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Appendix B: "Upper boundary" transition zone mapping methodology

Introduction

As defined by the Bayland Habitat Goals Update, the estuarine-terrestrial transition zone (transition 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.

Conceptually, the transition zone spans from the upper reaches of land that is influenced by the tides, up to an area of land that is not currently influenced by tides, but may be in the near future with sea level rise. The upper boundary of the transition zone transitions into upland with a lower boundary that transitions into intertidal wetlands . The type of transition zone (determined by the slope, hydrology, soils and vegetation) can affect the transition zone width.

The location of the transition zone moves over time as tidal marshes move with changing sea level. In areas with low gradient slopes, today's transition zone may become tomorrow's marsh. As rates of sea level rise increase, marsh migration may not be able to offset marsh loss without ensuring adequate sediment supply and other conditions that promote marsh growth. A better understanding of existing and predicted transition zone locations and ecosystem services offer opportunities for transition zone planning, restoration, and management actions.

This appendix describes a method for defining an upper boundary for the estuarine-terrestrial transition zone (transition zone). This boundary can be used to determine how far up-watershed to look in order to plan for transition zone management in a proactive way. It encourages large-scale and long time horizon planning. For the methodology described here the boundary can be defined for different time periods by using different sea-level rise projects. This methodology is meant to help managers, scientists and decision-makers think through how restoration and management actions within a region might fit together to sustain transition zone habitats and processes in the coming decades.

In many parts of the Bay Area this transition zone upper boundary methodology will delineate a transition zone area that encompasses both developed and undeveloped land (Figure 1). Land use is a major consideration in determining what can be done within the transition zone boundary. Although many developed areas are unlikely to be considered for habitat restoration, these areas may still support transition zone functions in other ways. For example, some land uses in developed areas (e.g., vacant lots, golf courses) may still provide some buffering functions. Actions taken in developed areas within this boundary can support wildlife movement (e.g., removal of barriers and planting of native vegetation in yards), and affect flood control (e.g., rain gardens and bioswales). Infrastructure realignment within these areas, to protect from increased flooding with climate change, may provide opportunities for transition zone restoration.

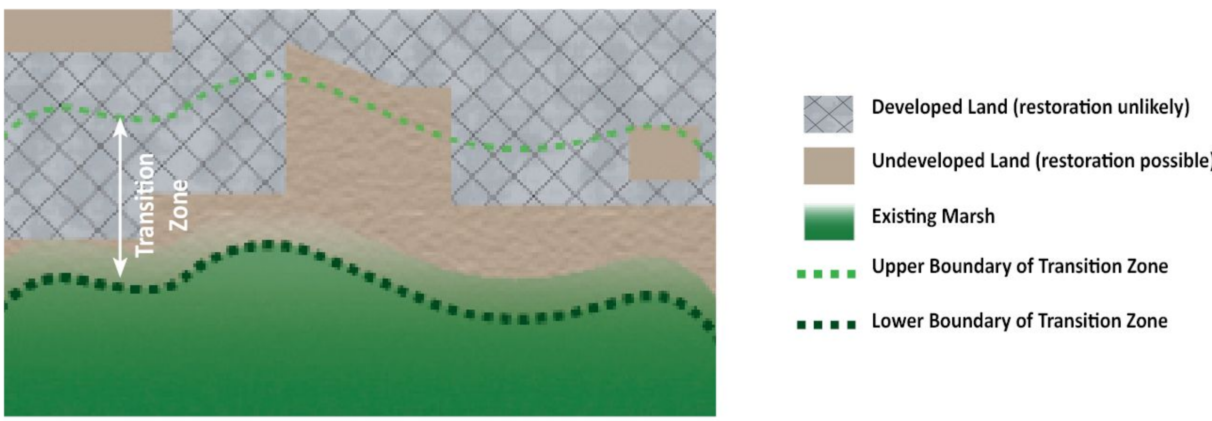

Figure 1. The transition zone, as defined by this methodology, can include both developed and undeveloped lands. While restoration is unlikely in developed areas, actions taken in these areas can still support t-zone functions.

Transition zone functions and services

The transition zone provides many important ecosystem services, as outlined in Bayland Ecosystem Habitat Goals Update (Science Update; Goals Project 2015). This methodology considers the benefits that the transition zone provides to terrestrial wildlife and terrestrial processes, as well as wetland species and processes, taking both a “bay up” and “watershed down” approach. The list of ecosystem services used for this effort is modified from Science Update, with a focus on those ecosystem services most relevant to defining the upper boundary.

Buffering is one of the important ecosystem services that the transition zone provides. There is some regulatory guidance for defining a buffer around wetlands. For tidal marshes this regulatory buffer will overlap with part or all of the transition zone, depending on the site. This buffer may or may not include other important transition zone functions, depending on its condition.

For many of the functions that the transition zone provides for terrestrial wildlife (e.g., climate refugia , movement corridors for broad suite of native species) there is still a lot that is unknown about the extent and condition necessary to provide meaningful levels of support.

Transition zones provide critical support to tidal marsh species such as the Ridgeway's rail and salt marsh harvest mouse by providing areas to escape flood events. Upland predators use the transition zone to access the marsh for food. High densities of marsh vertebrates in the transition zone during flood events provide opportunities for native predators such as herons and egrets. The transition zone can also attract non-native and nuisance predators such as red foxes, rats and feral cats. While wider transition zones may be better at keeping out non-native species, the degree to which they support less desirable species likely depends on how the transition zone is managed.

The transition zone facilitates wildlife movement in other ways as well. The Conservation Lands Network recognizes the importance of the Baylands, including the transition zone, as a wildlife corridor in highly urbanized areas. This is likely important in other urbanized estuarine systems as well. These wildlife movement corridors can be important for daily movements, seasonal habitat shifts, and juvenile dispersal of both marsh and upland species.

The 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. For some species, the transition zone may be critically important as a place for adaptations to changes in habitat conditions caused by sea level rise (Science Update, Chapter 4).

The transition zone contributes to a complex mosaic of bayland habitat types that increase the local diversity and abundance of plant and animal species across landscapes at a regional scale. Historically this included freshwater wetlands, alkali wetlands, and willow groves. As described for San Diego lagoons historically "extensive freshwater/brackish wetland complexes were present at the back edge of each estuary, creating a gradual transition zone between estuarine and upland habitat types that in some cases extended several miles inland."

Table 1. Ecosystem services and functions, as grouped in Science Update report

Buffering	Pollution Control
	Non-native Invasion Control
	Erosion Control
Flood Risk Management	
Sea Level Rise Accommodation	
Biological Diversity	Wildlife Refuge and Predation
	Wildlife and Plant Movement
	Evolutionary Adaptation
	Landscape Complexity

Methodology Details

For this effort it is helpful to think about different types of transition zones because of the space requirements for different ecosystem services they can provide. Different management opportunities and priorities present themselves within different transition zone types. Here we suggest different methods to determine the inland extent of the transition zone based on the Science Update transition zone typologies. A) Bluff or Cliff, B) Hillslope, Fan, Valley or Plain, and C) Riverine or Stream. Because we are interested in delineating an "outer boundary" we focus on those transition zone types that go furthest upslope-watershed. Separate methodologies for delineating the outer boundary for these three transition zone types are detailed below.

Defining a lower boundary for all transition zone types

Focusing on a transition zone width means defining a lower transition zone boundary before we can define an upper transition zone boundary. For present conditions we use the same lower boundary as Fulfrost and Thompson (MHHW + 0.31 m). To incorporate SLR for different periods we used our "our coast our future" projections for flooding extent as our lower boundary for the transition zone.

Upper boundary definitions by transition zone type

Determining the Upper Boundary for Hillslope transition zones

Hillslope, Fan, Valley or Plain (hereafter, hillslope) transition zones span gradual slopes that provide opportunities to support wide habitat gradients, biological diversity, and landscape complexity. These transition zones are also important for accommodating sea-level rise and allowing marshes to migrate upslope. For defining an outer boundary for transition zone planning we focus on biodiversity support and assume that other ecosystem services associated with hillslope transition zones (e.g. buffering) would fall within a boundary set by these functions.

Supporting biological diversity within the transition zone includes 1) providing areas for wildlife refuge and predation, 2) facilitating wildlife movement, 3) supporting areas important for evolutionary adaptation, and 4) contributing to landscape complexity (Goals Project 2015). How exactly the transition zone supports biodiversity can vary significantly by site, and is influenced by elevation, slope, soils, vegetation, and land use. To develop a coarse transition zone delineation method that would be broadly applicable across sites we focused on determining a transition zone width that would likely provide enough area for key ecological processes such as dispersal and adaptation to occur.

Table 1 shows a summary of widths over which these ecosystem services would be expected to occur. Most of the biological diversity support functions associated with the transition zone are captured within a range of tens to hundreds of meters, as shown below. To capture these functions to a high degree, without using the most extreme distances, we recommend a transition zone width of 500m. This number is a best estimate based on available studies. More research on how the transition zone supports different functions, and how transition zones vary across different locations, is needed. As further research is done this methodology is expected to evolve.

Table 1. Summary of values from the literature which informed our methodology

Ecosystem Service	Width/Measurement	Notes and References
Wildlife refuge	20-50m	Collins et al 2007

Wildlife foraging and predation	150m	Distance of ground squirrels that forage in the marsh occasionally, Collins et al, 2007
Wildlife and plant movement	10-400m	Based on a variety of movement corridor values from the literature, including, on the upper end, Alexander et al., 2016
Evolutionary adaptation	50m - 500m	Gradients likely to support evolutionary adaptation (e.g., Collins and Collins 2007) likely play out on a scale of tens to hundreds of meters
Landscape complexity	50-1000m	transition zone associated habitats could extend hundreds of meters historically, Beller et al 2013

Mapping Guidance

- Determine MHHW plus 0.31m to determine lower end of transition zone –OR- use flooding extents associated with SLR projections of interest
- Add 500m out from lower end of transition zone to determine “outer boundary”.
- Overlap land use layer to identify undeveloped areas that could be restored or conserved to support transition zone habitats.

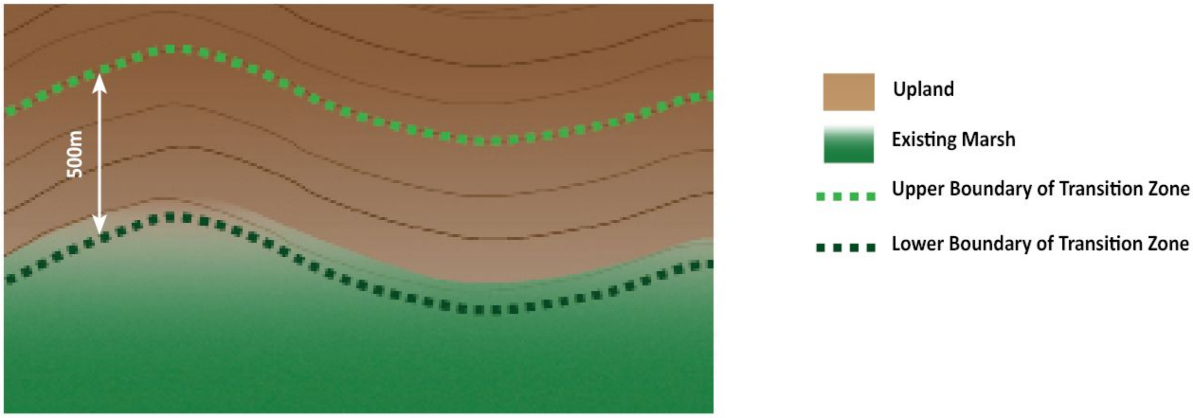

Figure 2. For hillslope t-zones, the lower transition zone boundary is determined in relation to MHHW and the upper t-zone boundary is defined as being 500m upslope from the lower t-zone boundary.

Outer Boundary for Riverine/Stream transition zone

Riverine transition zones transition between fluvial and tidal processes and conditions. The inland extent of tidal influence within streams, called the “head of tide”, is primarily a function of the stream bed gradient, with lower gradient streams having head of tide locations that can be miles inland from the shoreline. This transition zone area can be important for floodwater storage and retention, as well as supporting a unique assemblage of plant and wildlife species. To define the outer transition zone boundary, both tidal and fluvial flooding need to be considered along with wildlife support functions. For tidal flooding, HOWL for current conditions and sea-level rise projections for future conditions is used. We then add additional space (20m) beyond that tidal flooding extent to allow wildlife space to escape flooding and enough width to support riparian habitat for wildlife. For fluvial flooding, the 50-yr flood extent downstream of head of tide (i.e., the 50-yr flood on top of the tidal water in the channel) is used.

Ecosystem Services	Width/Measurement	Notes and References
Flood Control	Flooding for 50yr storm event	Likely high flooding within a relevant management time horizon
Wildlife refuge	20m	Guidance for flood refuge in Collins et al 2007

Mapping Guidance

- Model extent of tidal and fluvial flooding using RIPZET, FEMA maps, or other available data layers and tools.
- Add 50m width beyond extent of flooding.

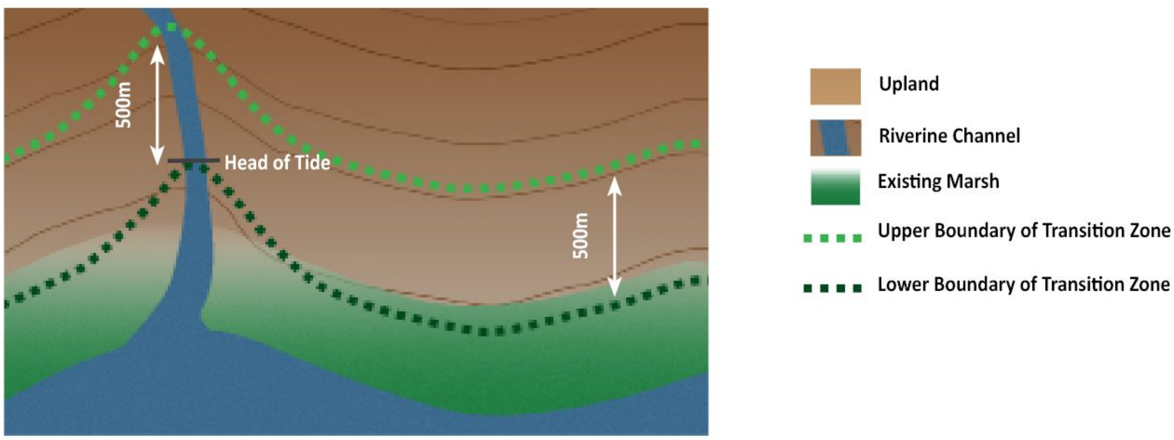

Figure 2. For riverine t-zones, this methodology adjusts the Cliff/Bluff

For cliff/bluff transition zones, the area at the top of the bluff is unlikely to provide the same flood control, habitat gradient, and movement corridor benefits as hillslope transition zones. Therefore we focus on erosion control to determine the extent of the transition zone, as this ecosystem service is more critical for these systems.

The area important for erosion varies greatly by system and rate of retreat, making it difficult to determine a broad width appropriate across systems. Here we use 50m.

Ecosystem Services	Width/Measurement
Erosion control	50m

Mapping Guidance:

- Extend upper transition zone boundary 50m beyond the top of the bluff/cliff

- If the change in slope that marked the start of the bluff/cliff is more than 250m from the lower extent of the transition zone (as defined for hillslope transition zone above) then the transition zone should be determined using the hillslope method.

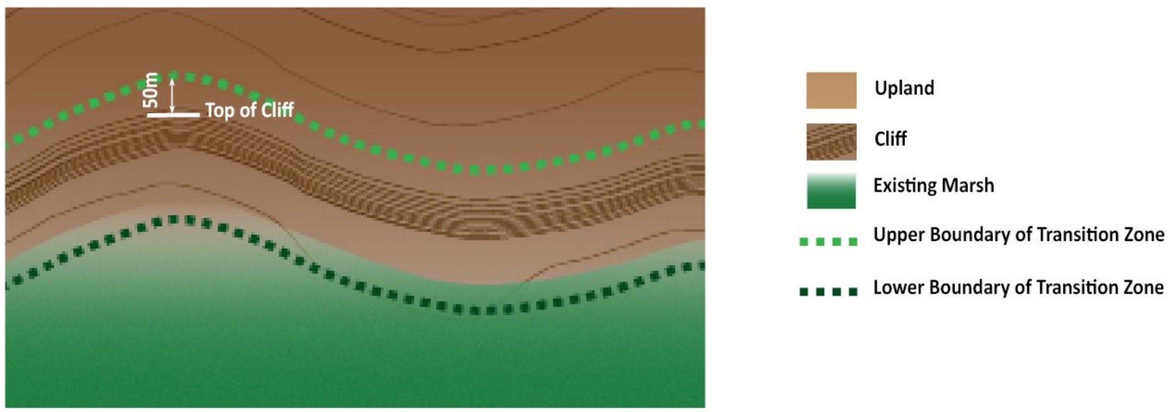

Figure 4. For cliff and bluff t-zones the upper boundary of the transition zone is defined as extending 50m from the top of the cliff.

Guidance for planning within the transition zone boundary

The transition zone “upper boundary” delineation method outlined in this document identifies an area within which transition zone management, and support of associated ecosystem services, should be considered when making land use planning and management decisions. This method is meant to be a quick yet robust way to delineate an inland extent of the transition zone that considers climate change, within which more site-specific considerations (including constraints of developed lands) will be addressed. The approach is meant to be used by planners and regulators to encourage larger-scale and longer-term thinking about incorporating transition zone functions into shoreline planning. The transition zone is a contested zone with both ecological and urban functions. This methodology is NOT meant to suggest that everything within this boundary remain undeveloped. Rather, considering sea-level rise and transition zone function more holistically within these areas can help us develop better adaptive and multi-benefit shoreline solutions that improve both ecological and societal benefits over the long term.

Considering Landscape Resilience

The Landscape Resilience Framework (Beller et al., 2015) developed a set of 7 principles that should be considered when trying to achieve ecological resilience at a landscape scale. These principles can help guide actions within this transition zone boundary. More specific guidance for what might be recommended within this transition zone boundary will be provided based on the area-specific work underway for Richmond and Southern California in other documents.

Below are questions meant as an example on how to asses transition zone considerations using the by landscape resilience principles:

<u>Setting:</u> What habitat types characterized the transition zone in this area historically? Based on how landscape has changed, and projected future changes, are historical habitats still appropriate? What constraints and opportunities result from expected changes in land use and development?

<u>Process:</u> Does conservation/management in this area support conditions that allow marsh migration? Sediment transport to support marsh accretion? Do restoration and management actions match current and projected groundwater conditions? Extent of tidal and fluvial flooding?

<u>Connectivity:</u> How far apart are areas supporting transition zone habitats and processes? Are they close enough to each other and to the marsh to support the services of interest (e.g. wildlife movement, marsh migration?

<u>Diversity:</u> What different types of transition zone habitats are appropriate in this area?

<u>Redundancy:</u> Are there multiple areas where support for critical species and processes is being provided?

<u>Scale:</u> What is the total amount of transition zone habitat conserved/restored within an area, and is this a large enough scale to support the species and processes of interest?

<u>People:</u> Community engagement in transition zone planning is critical, as the shoreline often supports important societal and economic benefits, in addition to ecological benefits. Some of the proposed actions that would provide biological diversity support (e.g., upland habitat restoration) would provide other societal benefits as well (e.g., recreation, flood protection).

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