Sea Level Rise Adaptation at the Corte Madera Baylands

May 30, 2013 Floodplain Management Association Meeting

One of the Bay Conservation and Development Commission (BCDC) primary planning initiatives is to help the region understand and adapt to sea level rise. This includes improving our understanding of how to increase resilience of both built and natural shorelines while protecting critical ecosystem and community services.

As part of this initiative the agency recognized a number of years ago that there was a significant gap in the understanding of the degree to which baylands (mudflats and marshes) protect coastal communities from flooding, and how this critical ecosystem service will change as sea level rises.

This project was conceived as an effort to fill this knowledge gap.

Mudflats and marshes provide flood risk reduction through wave attenuation

View looking north across the Corte Madera Baylands
Photo by John Callaway, USF

While we know both mudflats and marshes can reduce wave height and energy, there have only been a handful of data sets collected in San Francisco Bay that quantify the amount of wave attenuation they provide. In addition, prior research on wave attenuation has often treated mudflats and marshes separately.

This project was one of the first efforts in the Bay to quantify wave attenuation across the entire baylands system – including subtidal shallows, mudflat and marsh. This data set is key because it informs the discussion of how preserving, enhancing, and restoring baylands can reduce future investment in structural solutions to protect coastal communities from sea level rise.

Project purpose

1. How is wave attenuation at the Corte Madera Baylands sensitive to sea level rise?

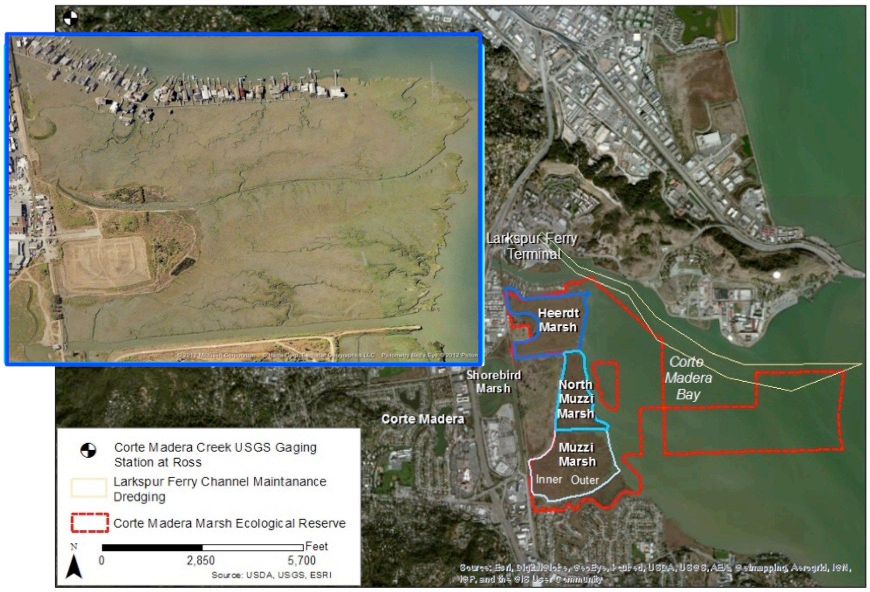
2. What management measures would improve the resilience of the Corte Madera Baylands to sea level rise and thereby maintain their ability to provide flood risk reduction?

The purpose of the project was two-fold:

1. Understand wave attenuation and how this flood risk reduction benefit will be sensitive to sea level rise

2. Investigate alternative management actions that could be taken to improve baylands resilience thereby maintaining wave attenuation benefits

Corte Madera study site



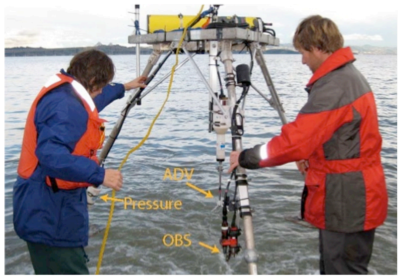
The study site is located just north of the Tiburon Peninsula in Central San Francisco Bay, Marin County. Corte Madera Creek flows past the northwest corner of the site into Corte Madera Bay. Larkspur Ferry Terminal sits at the mouth of Corte Madera Creek and since 1976 when operations began, ferries regularly through a channel which is dredged every 3-4 years.

The entire study site is within the Corte Madera Ecological Reserve managed by the CA DFW. The reserve is bounded by a flood risk management levee along the historic railroad alignment and surrounded by residential, commercial, and industrial development.

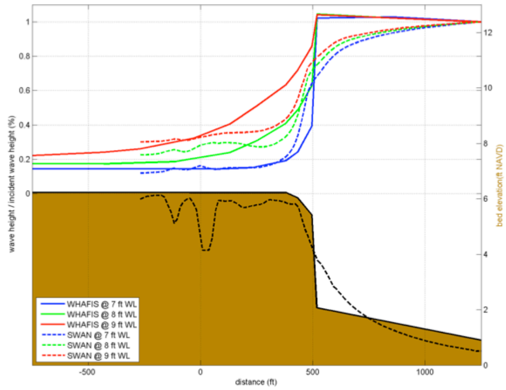
There are three distinct marshes within the reserve -- restored Muzzi Marsh, formerly diked North Muzzi Marsh, and Heerdt Marsh, which has never been diked or filled, closest to Corte Madera Creek.

Wave attenuation sensitivity analysis

Wave measurements

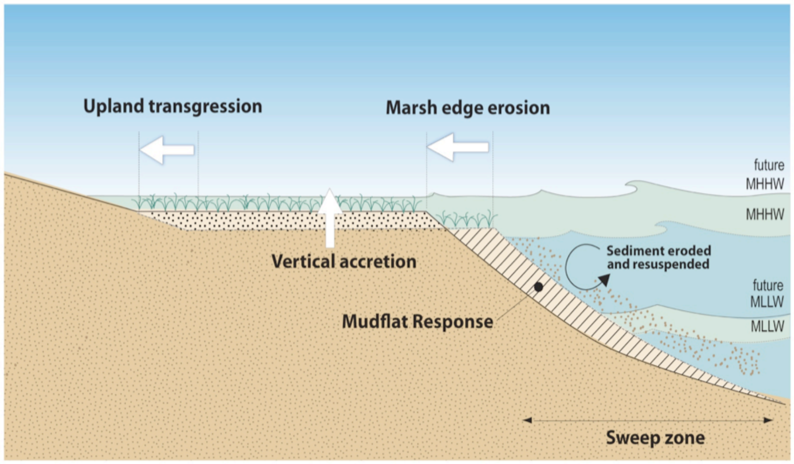


Wave modeling
(1-D WHAFIS, 2-D SWAN)



Working with the USGS, ESA PWA, and UNESCO-IHE (Delft), we investigated the sensitivity of wave attenuation to various parameters including water level, wave height, and vegetation conditions using both field measurements and wave modeling based on the 1-D WHAFIS and 2-D SWAN model.

Baylands geomorphic evolution



Wave attenuation sensitivity analysis helped us understand how flood risk reduction benefits will change as baylands evolve with sea level rise. Baylands evolution is closely related to the history of changing sea level. As sea level rises, marshes will be flooded more often. They respond by building upward and moving landward. However, if they can't evolve in a manner that keeps up with sea level rise and maintains marsh elevation relative to the tidal frame, increased flooding over the marsh will stress vegetation, reducing both sediment trapping potential and primary production.

As vegetation is stressed and begins to die, the marsh has even less of a chance of keeping up, leading to even greater flooding and further vegetation stress. This cycle leads to marsh habitat downshifts, e.g., from mid marsh to low marsh. Unless there is a significant increase in local suspended sediment concentrations, which could increase vertical accretion and the capacity of the marsh to maintain its elevation relative to rising sea level, this feedback loop will continue until there is total vegetative die off and the marsh converts to mudflat.

Wave attenuation is insensitive to vegetation species (pickleweed or cordgrass)


Photo courtesy of John Callaway, USF

When there is a downshift from mid marsh dominated by pickleweed to low marsh dominated by cordgrass, the modeling conducted for this project suggests that the change in vegetation alone won't significantly affect the amount of wave attenuation provided.

Wave attenuation is sensitive to elevation loss

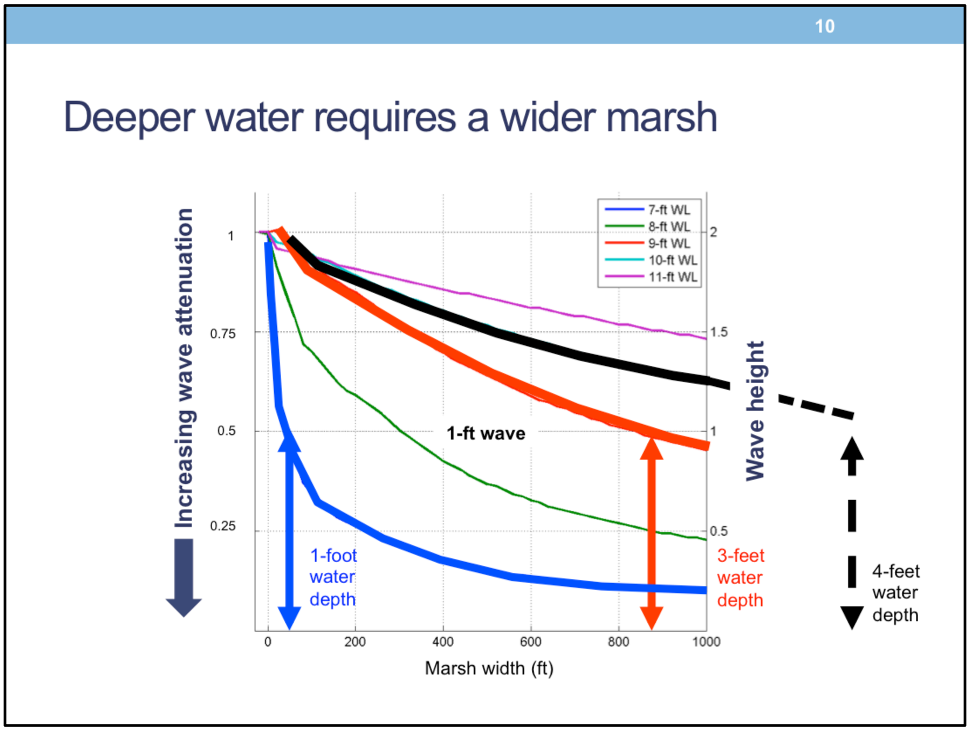
However, in reality, this downshifting involves not only a change in vegetation species, but a change (a loss) in marsh elevation as well. Field measurements and modeling confirm that this loss of marsh plain elevation will significantly affect wave attenuation because wave attenuation is largely determined by water depth.

Wave attenuation is sensitive to vegetation loss

Photo courtesy of John Callaway, USF

If the marsh continues to downshift, e.g., from low marsh to mudflat, water depths will further increase and there will be a complete loss of vegetation. These changes will result in even less wave attenuation because there’s deeper water and because there’s no vegetation dissipating wave energy.

The SWAN modeling found that at extreme water levels (10-ft NAVD88), wave attenuation over a marsh without vegetation is on the order of half as much as the case with vegetation.



Our modeling results make the case that a high, wide marsh is needed to preserve flood risk reduction benefits. Along the x-axis is marsh width and along the y-axis is wave attenuation. The colored lines represent various total water levels, in this example, where each stillwater level is coupled with a 2-foot incident wave height.

The marsh plain at Corte Madera is at roughly 6 feet, so a 7-foot water level means there is about one foot of water over the marsh. At this shallow water depth, a narrow marsh can provide significant wave attenuation. Deeper water over the marsh, for instance during a 100-year water level of 9 feet, requires a wider marsh to provide the same flood risk reduction benefit – in this case, reduction of the wave to approximately a 1-foot height.

If the marsh can not keep up with sea level rise, then water depth effectively increases. So, if the marsh loses a foot of elevation (e.g., shifting from high to mid, or mid to low marsh), wave attenuation for a 9-foot water level will behave like a 10-foot water level and and an even wider marsh will be needed to achieve the same reduction of wave height.

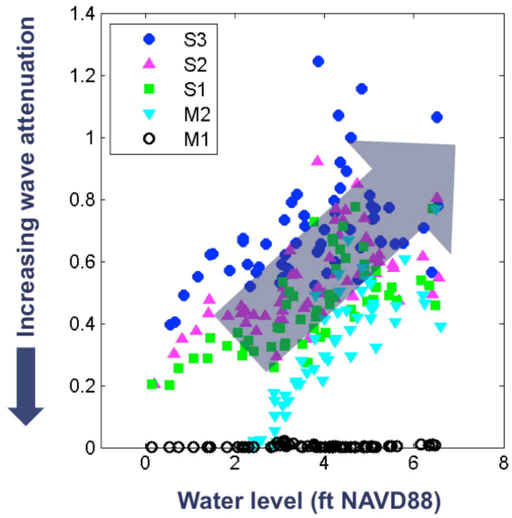
Wave attenuation is more sensitive to water level than wave height

Incident wave height (ft)	Marsh width in feet to reduce incident wave height to 1 ft		
	7-ft WL	8-ft WL	9-ft WL
2	40	300	840
3	50	320	980

Large waves and high water levels don't always co-occur.

We also did this same analysis with a 3-foot incident wave height. This table shows some of the results to emphasize that wave attenuation is more sensitive to water level than wave height. For example, at the 7-foot water level (spring tide), the width of marsh to reduce the incident wave to a 1-foot wave height are almost the same for either the 2- or 3-foot incident wave height. Whereas, at the 2-foot incident wave height, the width of marsh to reduce the incident wave to a 1-foot wave height is much greater for the 8-foot (2-year return period) than the 7-foot water level.

Deeper water diminishes mudflat muscle



As waves travel through shallow water, they break when they reach a limiting depth and lose energy to friction between the water and the sediment along the bottom. Then, at high water levels, such as during storms that occur at high tides, waves flood the marsh and attenuate via the same process of depth-limited breaking, but because there's vegetation rather than a bare bottom, they also lose energy to friction between the water and the vegetation along the marsh plain.

During the study period from January 22 – March 23, 2010, waves were moderate – representative of typical winter conditions. Waves were always largest offshore at DP, smallest on the mudflat near the marsh edge at M2, and essentially non-existent within the marsh at M1. While we did not observe significant wave activity over the marsh, we measured significant wave attenuation over the shallows and mudflats of Corte Madera Bay. On average, they reduced wave heights by 66%. This plot shows water level on the x-axis and wave attenuation on the y-axis for each of the wave measurement stations in Corte Madera Bay. If mudflats cannot keep up with sea level rise, then water depth effectively increases and wave attenuation decreases. So, if the mudflat erodes a foot, wave attenuation at a 5-foot water level behaves like a 6-foot water level, resulting in less wave height and energy reduction, and possibly more shoreline erosion.

Suite of management measures

1. Reduce nearshore wave energy
2. Stabilize with coarse beach
3. Recharge mudflat and marsh
4. Improve sediment pathways
5. Enhance sediment trapping
6. Increase transition zone
7. Realign levees

Living Shorelines
Photo courtesy of California Coastal Conservancy

So, to preserve wave attenuation benefits (and other ecosystem services) it makes sense to maintain a high, wide mudflat and marsh. The question is, how best to do so.

For this project we considered seven management measures that would improve baylands resilience to sea level rise by enhancing the mudflat and marsh's natural ability to move upward or landward.

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Benefits and constraints
Implementation details
Examples (natural/constructed)

For the seven management measures investigated, we provided a general discussion of the benefits and constraints, implementation details, and natural/constructed examples.

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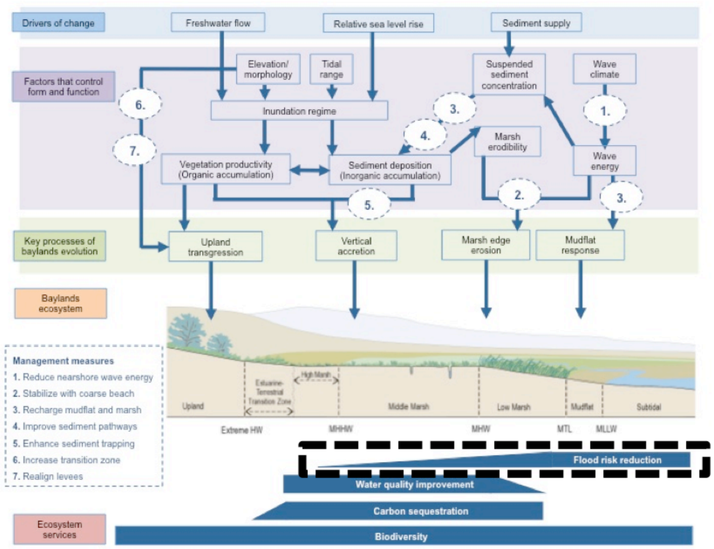
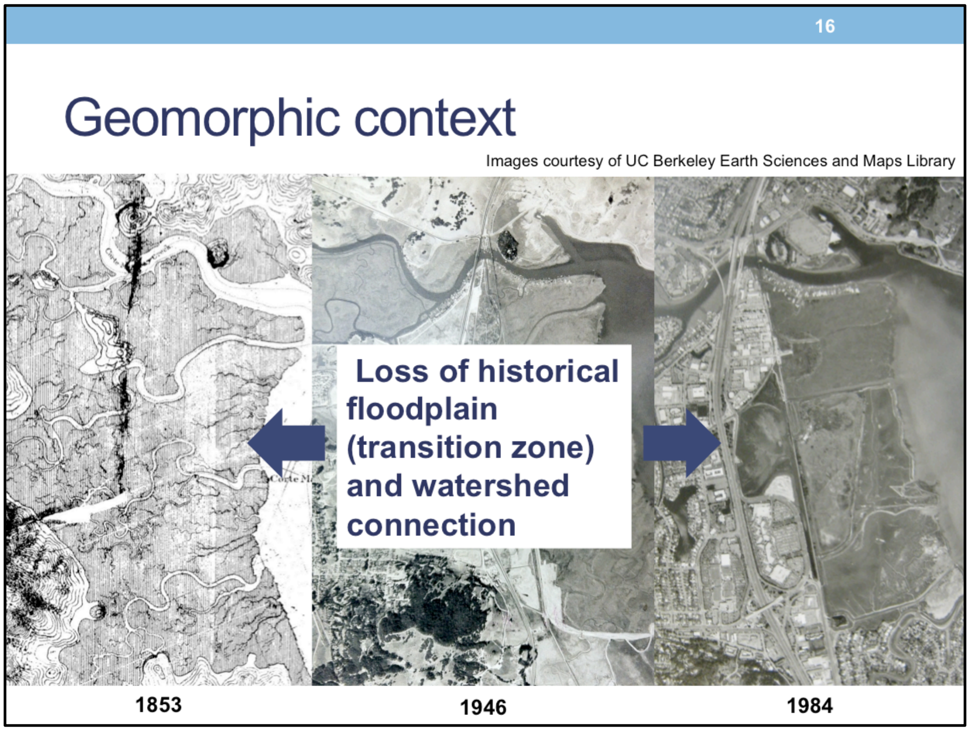
Selection process



To decide which measures were most appropriate at the Corte Madera Baylands to protect the ecosystem service benefit we were focused on – flood risk reduction – we developed a conceptual geomorphic model that can be applied elsewhere around the Bay. Measures were selected based on the opportunities and constraints at the site and formed the project's conceptual sea level rise adaptation strategy.

This project serves to demonstrate the kind of information and process that can be used to develop a conceptual sea level rise adaptation strategy at other locations. As I will discuss, the strategy will depend on both the site geomorphology and the ecosystem services selected to protect.



First, a good understanding of the geomorphic context of the site is needed to select management measures. We reviewed historical imagery and maps to understand how the site responded to past changes, which helped us understand how it may evolve in the future.

For example, in 1853, the site contained extensive tidal marshes and sloughs. By 1946, these tidal marshes were filled for development and dissected by roads. By 1984, the historic floodplain was permanently lost and the once meandering Corte Madera Creek was disconnected from the adjacent marshes.

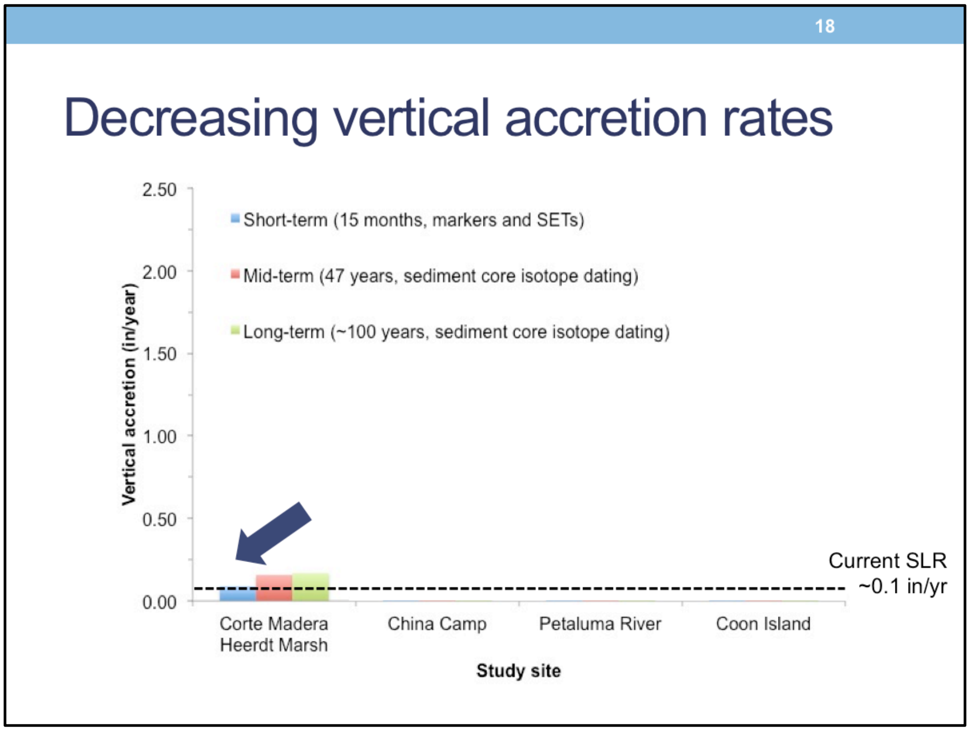
Historic mudflat and marsh edge erosion

1. Mudflat has generally been eroding (1855 – 2010), except during the early 1900s (hydraulic-mining sediment)
2. Marsh edge has eroded on average 485 feet (1853 – 2006)
3. Cause of marsh erosion uncertain – tidal/wave action, sediment supply, biological activity, etc.

Additionally, while land use around the Corte Madera Baylands was changing over the last 150 years, so did the mudflat and marsh edge.

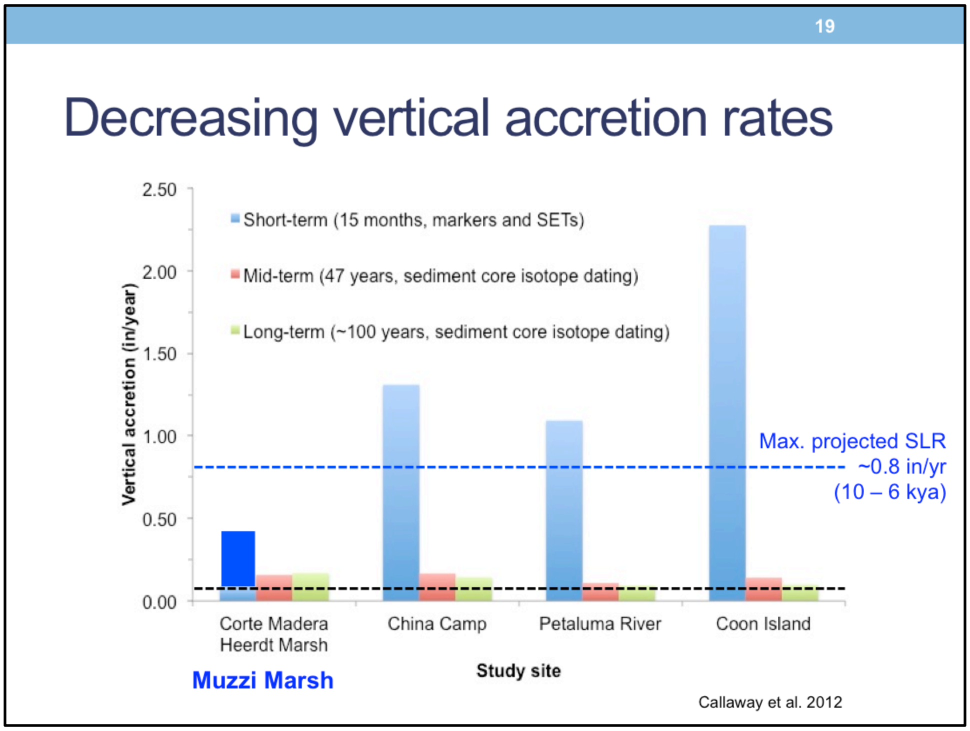
The mudflat and marsh edge have been eroding. The precise cause of erosion is uncertain and is likely due to a combination of factors.

Decreasing vertical accretion rates



In addition to reviewing historic records, we also worked with John Callaway at USF to measure vertical accretion for two of the three marshes in the project site. These measurements are key since for marshes to keep pace they will need to accrete at at least the same rate as sea level is rising.

What we found is that the Corte Madera marshes are currently keeping pace, but measurements at the historic Heerdt Marsh suggest that vertical accretion rates have been decreasing over time – with long-term accretion rates higher then mid- or short-term rates.



This finding is especially obvious in comparison to accretion rates at other marshes, where vertical accretion is highest over the short term, before the effects of compaction/decomposition.

At the Corte Madera Baylands, restored Muzzi Marsh was measured to be accreting faster than historic Heerdt Marsh. This is likely the case because Muzzi Marsh is at a lower elevation then Heerdt. This finding suggests the Corte Madera marshes can keep up with some amount of sea level rise, but the question still remains how much.

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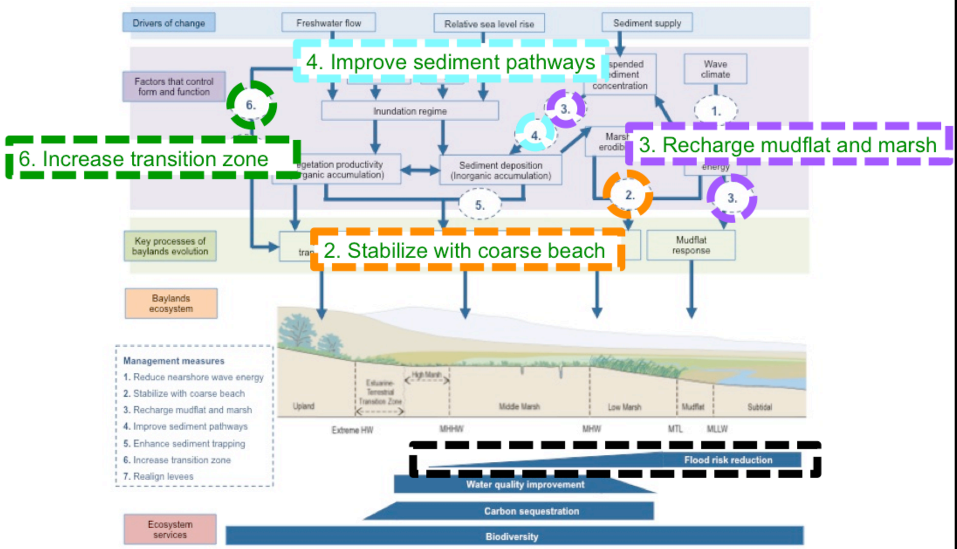
Selection process



Regional marsh sustainability models predict that the Corte Madera tidal marshes will convert to mudflat as sea level rise accelerates towards the end of century.

Decreasing vertical accretion rates, mudflat and marsh erosion, the lost connection between the creek and the marsh, and nearby sediment sinks such as the dredged ferry channel suggest the system is sediment-limited.

Measures included in the conceptual sea level rise strategy were therefore those that could proactively address a limited sediment supply, an eroding marsh edge, and a lack of room to migrate landward as sea level rise outpaces vertical accretion towards the end of the century. I'll walk through the four measures which we selected for Corte Madera to improve its resilience. Restoration practitioners have solid experience with some of these, while others are still in the conceptual phase.

Stabilize with coarse beach


Photo courtesy of Peter Baye

Natural beach at Outer Bair Island

Constructed beach at Aramburu Island

Stabilizing the marsh edge with a coarse beach, like that which naturally occurs at Outer Bair Island, could decrease marsh edge erosion and provide wave attenuation across a gradual slope rather than a steep scarp. The coarse beach is dynamic and could also roll landward as sea level rises. Aramburu Island is the best example of a restoration project constructing this type of system in the Bay and the results of this pilot project will certainly inform the restoration community. In reviewing the Aramburu project, we found that it will be important to consider specific site conditions and tailor the measure to each site, e.g., investigate the nearest source of coarse material and evaluate whether construction involves terrestrial or marine equipment.

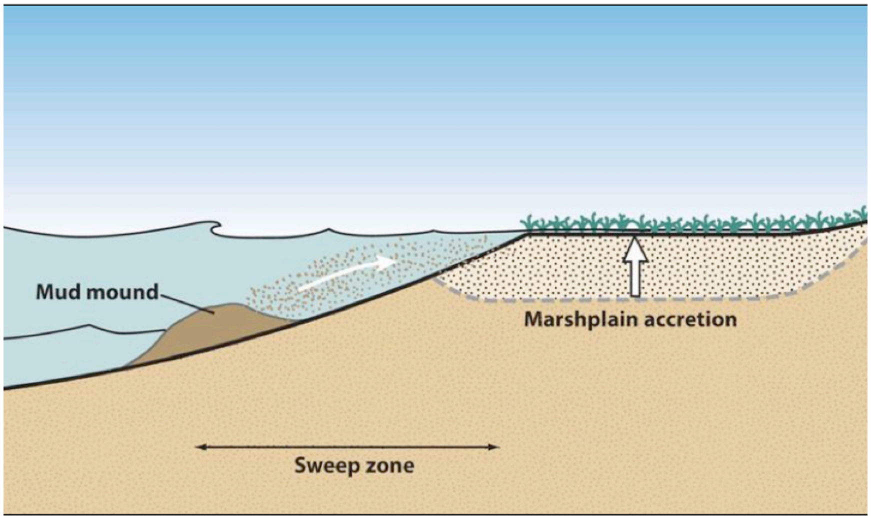
Improve sediment pathways
(channel network density/sidecast levees)

Fill in Corte Madera tidal marshes

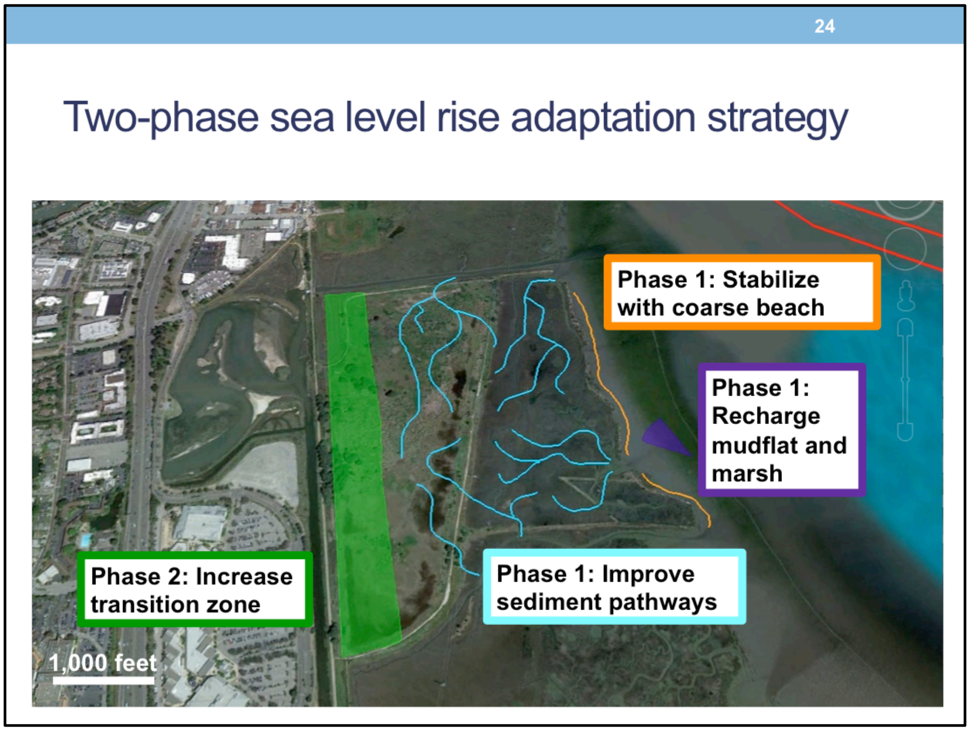
Natural levees at China Camp

Many of the high marsh channel networks have been filled. Increasing the density and complexity of channel networks would help sediment move to back of the marsh, thereby increasing vertical accretion. One co-benefit of this measure is that material excavated from the channels can be sidecast to emulate natural levees. Improving sediment pathways is a measure that restoration practitioners in the region have experience with, particularly when restoring diked, subsided marshes to tidal action, and their knowledge will make this measure easier to design.

Recharge mudflat and marsh



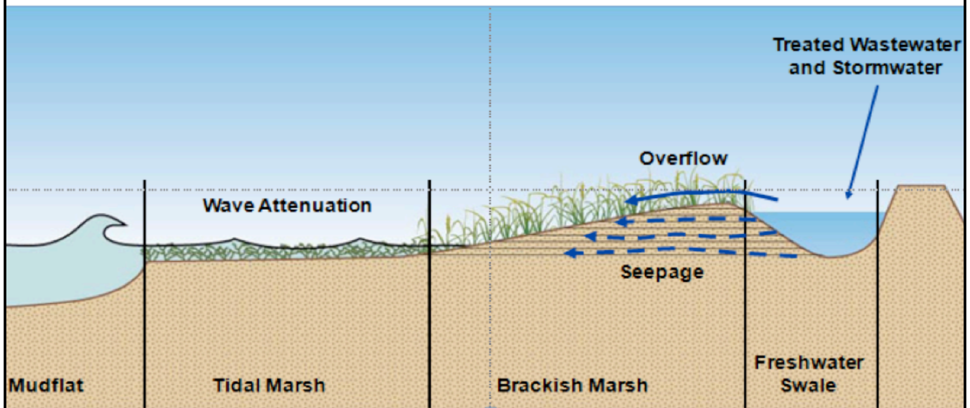
Recharging the mudflat and marsh involves placing sediment as close to the marsh as possible and letting natural sediment transport processes move the material onto the marsh. The goal of this measure is to increase local sediment availability, potentially using material from nearby sources to reduce overall costs. In a sediment-limited system, such as at the Corte Madera Baylands, increasing the local supply of sediment to the marsh could help to increase vertical accretion. While mudflats serve as a natural analog for this measure (i.e., the sweep zone is a natural source of sediment to the marsh), there is limited information about the feasibility of this measure in the Bay, and additional research – modeling to understand how to optimize placement, consideration of smothering impacts, operational analysis to see if there are efficient ways to move relatively small amounts of sediment to mudflats relatively frequently, and perhaps pilot testing – will be necessary before it can be implemented as a measure to improve resilience.



We developed a conceptual sea level rise adaptation strategy for each of the distinct tidal marshes at Corte Madera – they are similar but take advantage of the opportunities and constraints we found at each marsh. This is the strategy for North Muzzi Marsh.

The first phase involves the 3 measures I just described. These measures are targeted at improving the resilience of the existing marsh through mid-century. The second phase prepares the back of the marsh so that it has space to migrate landward when sea level rise outpaces vertical accretion toward the end of the century.

Increase transition zone



This last measure would involve creating a gentle slope at the back of the marsh similar to the floodplain that historically ringed the site. Taking advantages of conditions at this site, stormwater from the adjacent detention basin could be diverted to seep through the constructed slope, supporting development of a brackish marsh and possibly providing water quality co-benefits.

Conclusions

1. Wave attenuation is sensitive to sea level rise and management measures that maintain a high, wide marsh and mudflat are needed to preserve flood risk reduction benefits
2. To select measures, know your site (geomorphic context, shoreline change, sediment availability, etc.)
3. More regional research is needed to quantify wave attenuation over the marsh, to better understand sediment transport processes, and to integrate baylands management into coastal zone hazard mitigation planning

Conclusions

Proactive management will be needed to maintain wave attenuation benefits as sea level rises

Developing an adaptation strategy will require you to know your site both its current status and its history, in order to take advantage of natural processes

We are well on our way of building a knowledge base for improving baylands resilience to sea level rise. Not only this project I just presented but other regional efforts such as the Baylands Habitat Goals Update, the good research of academics and federal agencies, and the ongoing and diligent restoration planning around the region are all helping us better understand how we can protect the Bay and the services and values it provides into the future.

This project was funded by the US EPA through San Francisco Estuary Partnership with generous contributions from Marin County, USGS, UNESCO-IHE, USF and others. This project is the culmination of a number of scientific studies conducted by the project research team and other leading experts on these issues in the region.

Questions?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climate_change/WetlandAdapt.shtml