Wave Impact Energy Along Levee Edges

Tidal marsh ecosystems, including mudflat habitats are known to provide flood protection to upland habitats and human infrastructure. With increasing rates of sea level rise, species and human infrastructure are increasingly vulnerable to flooding due to high tides and storm surges. Additionally, human created flood protection infrastructure such as levees may need to be repaired and/or enhanced to continue to provide flood protection in the face of increasing sea levels. However, existing tidal marsh habitat could provide natural flood protection lessening the investment needed for repairing or raising levees. Investments in enhancing or restoring tidal marsh ecosystems could provide habitat for wildlife as well as reducing the need for investments in other flood control infrastructure.

We used our models of tidal marsh elevation to estimate the erosion protection tidal marsh habitats are providing to levees at sites throughout the San Francisco Estuary. We conducted a review of existing research on marsh wave attenuation to assign values to the different vegetation classes. From the literature surveyed (Cooper, 2005; Houser and Hill, 2010; Knutson 1982; Kobayashi, 1993; Lee, 2004; Moller and Spencer, 2002; Moller *et al*, 1996; Moller *et al* 1999; Wayne, 1976), we came up with estimated attenuation values of 10% per meter for upland, 6% per meter for hi marsh, 3%per meter for mid marsh, 1% per meter for low marsh, 0.1% per meter for mudflats, and 0.001% per meter for subtidal/open water. To represent the uncertainty in this estimate, we created values for both higher-than-expected attenuation and lower-than-expected attenuation by doubling and halving those values, respectively.

We then created a least-cost path for waves from San Francisco Bay and major streams/rivers to reach sites along the coast. We used wave attenuation (i.e. wave travel cost) grids as the cost surface and the direction to the nearest open water as the horizontal factor to restrict wave movement to within 45 degrees of its direction of propagation. These additive path costs were then turned into estimated wave attenuation values by first dividing the cost to reach each pixel by the distance that pixel was from open water to get an average attenuation and then raising this value to the distance travelled to get the true, multiplicative effect of wave attenuation. Subtracting the wave attenuation values from one produced the wave retention grids, which show the percentage of a wave's initial energy (upon leaving open water) that remains upon reaching a given pixel.

2 Wave impact energy along levee edges

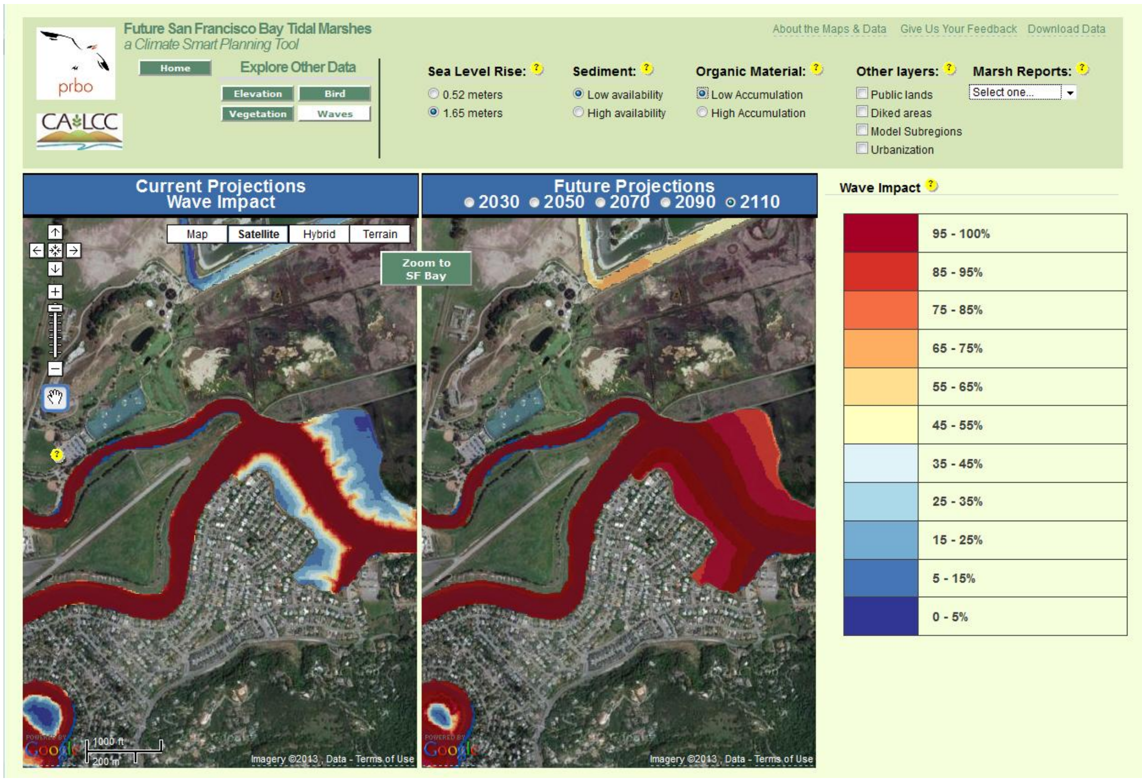

Figure 1 Wave retention, or the amount of wave energy remaining, for sites along Gallinas Creek for current conditions and for a high sea level rise/ low sediment scenario for 2110. Warmer colors indicate where greater wave energy remains. Blue colors show where tidal marsh habitat provides erosion protection to levees. In 2110, we project that the levee protecting the residential area behind Santa Venetia Marsh will be vulnerable to erosion due to wave exposure.

The amount of energy dissipated by a given marsh area depends not just on the marsh vegetation but on the energy of the wave itself: higher energy waves will lose more energy per meter than will lower energy waves. This is because many of the dissipative forces of marsh vegetation increase proportionally (within limits) to wave energy. Another consequence of this effect is that a 'fresh' wave just encountering the outer edge of a marsh will lose more energy in the first meter of the marsh than the second, more in the second than in the third, and so on and so forth. Most wave attenuation occurs on the outer edges of a marsh, with progressively smaller amounts being dissipated as a wave travels inwards. Therefore, a simple additive sum of attenuation values is insufficient: wave energy decay is best modeled exponentially (Cooper, 2005; Houser and Hill, 2010; Moller and Spencer 2002; Moller et al, 1999). We accounted for this by using the (additive) cost path only as an intermediate step by which we could determine the average attenuation per meter for a given wave path. We then produced a (multiplicative) attenuation value by raising the average to the distance the water had to travel to get there. Things are further simplified when the initial waves are likely to be very similar in height, as in the case of San Francisco Bay. This means that initial wave height can be ignored when calculating the wave attenuation, following the exponential wave decay model presented in Moller et al (1999).

To evaluate the effects of sea-level rise on levees and other shoreline structures, we extracted the estimated wave retention values along them for each attenuation and sea-level rise scenario. When wave retention values remain low at a site throughout the century, tidal marsh habitat is projected to continue to provide wave erosion protection. For example, we project that the Santa Venetia marsh will continue to protect existing levees from wave erosion in all scenarios throughout the century except in the high seal level rise/ low sediment scenario (Figure2). In that scenario, we project wave impacts will increase steadily from 2030 on as the marshes are unable to maintain current elevations with sea level rise (Figure 2). However, our models indicate that with sufficient sediment, Santa Venetia could continue to provide adequate wave protection suggesting sediment management could make this site more resilient to climate change.

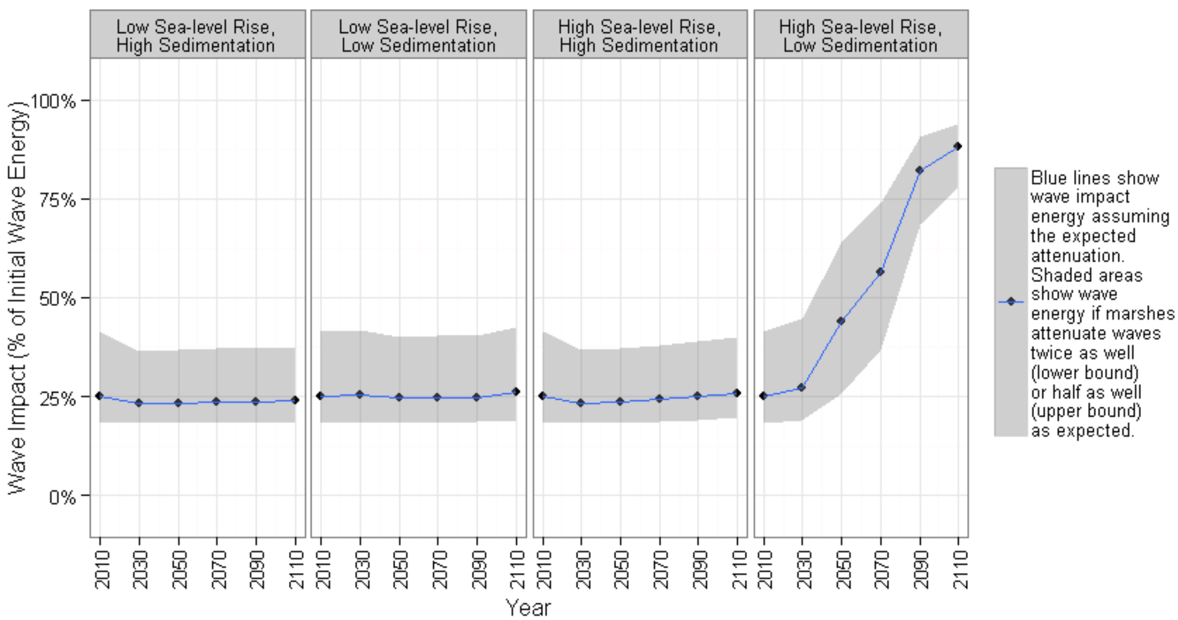

Figure 2. Wave retention (impact) estimated at Santa Venetia Marsh for four sea level rise/sediment scenarios. Higher wave retention means that tidal marshes are providing less protection for existing levees and the levees are more vulnerable to wave induced erosion.

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