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Wave attenuation across a tidal marsh in San Francisco Bay

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ABSTRACT

Wave attenuation is a central process in the mechanics of a healthy salt marsh. Understanding how wave attenuation varies with vegetation and hydrodynamic conditions informs models of other marsh processes that are a function of wave energy (*e.g.* sediment transport) and allows for the incorporation of marshes into coastal protection plans. Here, we examine the evolution of wave height across a tidal salt marsh in San Francisco Bay. Instruments were deployed along a cross-shore transect, starting on the mudflat and crossing through zones dominated by *Spartina foliosa* and *Salicornia pacifica*. This dataset is the first to quantify wave attenuation for these vegetation species, which are abundant in the intertidal zone of California estuaries. Measurements were collected in the summer and winter to assess seasonal variation in wave attenuation. Calculated drag coefficients of *S. foliosa* and *S. pacifica* were similar, indicating equal amounts of vegetation would lead to similar energy dissipation; however, *S. pacifica* has much greater biomass close to the bed (<20 cm) and retains biomass throughout the year, and therefore, it causes more total attenuation. *S. foliosa* dies back in the winter, and waves often grow across this section of the marsh. For both vegetation types, attenuation was greatest for low water depths, when the vegetation was emergent. For both seasons, attenuation rates across *S. pacifica* were the highest and were greater than published attenuation rates across similar (*Spartina alterniflora*) salt marshes for the comparable depths. These results can inform designs for marsh restorations and management plans in San Francisco Bay and other estuaries containing these species.

1. Introduction

Marshes, and tidal salt marshes in particular, are gaining recognition as critical elements in sustainable shoreline protection (Spalding et al., 2014a, 2014b; Narayan et al., 2016a; Narayan et al., 2016b; Green Infrastructure Effectiveness Database, 2017; Vuik et al., 2016). They contribute to coastal resiliency not only by attenuating wave energy in large storms (Gedan et al., 2011; Möller et al., 2014), but also by maintaining the existence of coastal land (Kirwan et al., 2016), supporting fisheries (Boesch and Turner, 1984; MacKenzie and Dionne, 2008), sequestering carbon (Ouyang and Lee, 2014), and removing contaminants (Dhir et al., 2009; Windham et al., 2003). These benefits directly contribute to the sustainability of the growing populations in coastal regions (Sutton-Grier et al., 2015). With this recognition, there are many ongoing projects to preserve existing salt marshes, restore former marshes, and create hybrids of natural and engineered structures (Pontee et al., 2016). These projects require an understanding of the underpinning processes that lead to marsh sustainability. One key process is wave attenuation.

Marsh plants attenuate wave energy via frictional drag. This drag has an impact on the overall wave evolution to a greater or lesser degree depending on vegetation and hydrodynamic characteristics (*e.g.* storm track and speed (Wamsley et al., 2010) and vegetation patchiness (Temmerman et al., 2012)). Understanding how attenuation changes with these conditions informs our understanding of other marsh processes that are influenced by wave energy, such as sediment transport and deposition. Lower wave energy can create conditions conducive to sediment trapping and settling, which is critical to marsh survival. Wave attenuation across marshes has been studied in both the field and laboratory. Tables containing aggregated results can be found in Paquier et al. (2016), Guannel et al. (2015), and Gedan et al. (2011).

It is well established that marshes attenuate wave energy, but the degree of attenuation can greatly vary. Pinsky et al. (2013) reprocessed data from nine field studies on marshes using a uniform method. The calculated drag coefficient (C_D), which is a measure of attenuation, ranged from 0.5 to 30 for similar hydrodynamic conditions. This

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variability is in part due to the presence of different vegetation species and location-specific conditions (*e.g.* tidal range, offshore bathymetry, bed characteristics). Cooper (2005) lists 23 factors that influence wave attenuation, many of which varied across the marshes in Pinsky's analysis. The ways that these factors combine in a location drive the spatial and temporal patterns of marsh effects on waves. Therefore, local measurements focusing on sites of interest are necessary for effective resource management and shoreline protection.

In this study, we measured wave attenuation in a tidal salt marsh in San Francisco Bay. The most abundant salt marsh species present are *Salicornia pacifica* (pickleweed) and *Spartina foliosa* (Pacific cordgrass) (Baye, 2012). *S. pacifica* and *S. foliosa* are morphologically different; *S. foliosa* is rod-like, while *S. pacifica* is shorter and highly branched (*i.e.* more shrub-like). The existing wave attenuation literature has focused heavily on *Spartina alterniflora* (smooth cordgrass), as it is dominant along the east coast of the U.S. and the Gulf of Mexico (*e.g.* (Knutson et al., 1982) in the field and (Anderson and Smith, 2014) in a flume). *S. foliosa* is distinct from *S. alterniflora* mainly because it is shorter and has less leaf production (Callaway and Josselyn, 1992). We also examined the seasonal variation in wave attenuation. Both *S. pacifica* and *S. foliosa* are perennial species; however, the aboveground biomass of *S. foliosa* dies back in the winter months, while *S. pacifica* retains aboveground biomass year-round.

The goal of this paper is to provide a first look at the wave attenuation and its seasonal variation across vegetated marshes in San Francisco Bay. We investigated how wave attenuation varies as waves progress through the different vegetation zones, as well as how it varies within the zones under different hydrodynamic conditions. We calculated bulk drag coefficients and exponential decay constants to differentiate mechanisms of dissipation. Finally, we discuss the results in the context of projected sea-level rise.

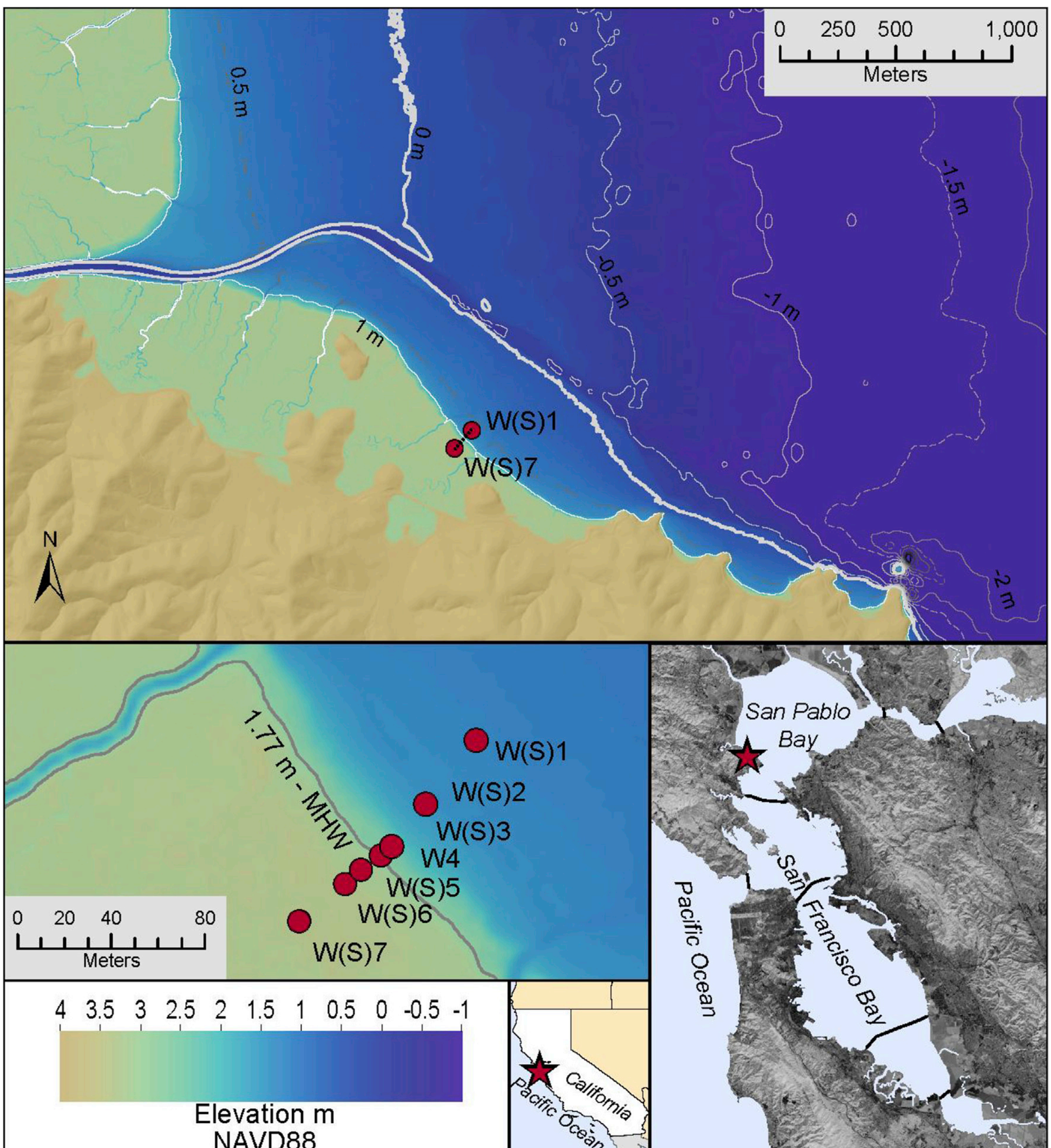

Fig. 1. Bathymetry of San Pablo Bay with the stations of the cross-shore transect. Inset in lower right shows San Pablo Bay and China Camp State Park (star) within the San Francisco Bay system.