**The barriers of Venice**

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**Storm surge barriers can protect against coastal flooding. Observations from the Venice Lagoon in Italy show that the operation of these types of barriers must be carefully tuned to avoid inhibiting sedimentation and compromising marsh resilience to sea-level rise.**

Known as “The City of Water*”*, Veniceis an extraordinary human achievement built within a fragile lagoon system. Flooding has always been an endemic feature in the lagoon, but the threat is being exacerbated by ongoing sea-level rise. A system of storm surge barriers - known as Mo.S.E. (an acronym for Experimental Electromechanical Module) – has recently become operational and is programmed to close during extreme surges in order to keep the city and its cultural landscape dry [1, 2] (Figure 1). Though these barriers are critical for protecting the city from flood damage, storm surges also play an important and positive role for the lagoon’s salt marshes. Storm energy resuspends sediments that are delivered to the marsh surface during surge-induced flooding, helping the marsh maintain its vertical elevation and resist the impacts of sea-level rise, like enhanced erosion and vegetation drowning [3-5]. Writing in *Nature Geoscience*, Tognin *et al.* [6] use observations from the Venice Lagoon to show that the activation of storm-surge barriers can substantially hinder sediment accumulation on the salt marsh, potentially reducing the capability of this environment to vertically accrete and survive the consequences of sea level rise.

Salt marshes are important natural ecosystems which are valued for their coastal protection services, capability to uptake atmospheric carbon, filter pollutants and as a habitat for many species [7]. The resilience of salt marshes to sea-level rise depends on local hydrodynamics and sediment availability, which in turn can be influenced by coastal management practices [8-10]. Storm surge barrier installation is a tempting, if expensive, intervention in lagoons or estuaries in which strategically placed barriers can protect large stretches of coastline susceptible to flooding.  In the case of the Mo.S.E. system, the gates are filled with water and rest on their housing caissons when inactive; to rise the gates, compressed air is introduced inside them. The gates remain operational for the duration of the high-water event after which they are filled again with water to sink down [1, 2].

Tognin *et al.* conducted an in-depth investigation of how sedimentation on salt marshes in the Venice Lagoon responded to fair weather or stormy conditions and how the intermittent closing of the barriers modified these fluxes. They did this by measuring sediment accumulation on three salt marshes every month for over two years (from October 2018 to January 2021) -  spanning the time when the barriers started to be used to regulate flooding in October 2020.They found that the sediment accumulation on salt marshes was much lower when the surge barriers were operational.

The sediment accumulation observations collected in the salt marshes were combined with a model for coastal flooding and the impact of flood management practices in the Venice Lagoon. Tognin *et al.* found that, on average for their study sites and study period, the operation of storm surge barriers decreased the annual mean vertical sediment build up in the marsh by 26 to 30%. In the flood-regulated model scenarios they tested, the surge barriers were only closed for around 70 hours per year throughout their study period. The gates were closed during storm-dominated conditions, however, and these are the critical times that would otherwise deliver significant amounts of suspended sediments to replenish the marsh. Even though closures were temporally limited over the course of the year, the ensuing reduction in water levels and sediment deliveries were perfectly timed to yield into a significant decline in annual sediment accretion. Indeed, based on observations without operational barriers, more than 70% of the sediment accumulation on the marsh surface was caused by storms, even though just 25% of the period was storm-dominated .

Timing is critical in efforts to preserve both the rich history of Venice and the climatically and ecologically important salt marshes that surround the City of Water. Tognin *et al.* conclude that a holistic approach is needed for conservation of both the built and natural environment. The authors suggest mitigation strategies to ensure the essential delivery of sediments to the marsh: by only triggering the closure of barriers at higher activation thresholds, through diversification of protection interventions within the lagoon***,*** or through using river diversions or artificial sediment deliveries to shore up sedimentation in the lagoon.

The consequences of climate change can lead to difficult trade-offs when it comes to protecting human society and the built environment versus the natural systems and their environmentally important processes. Tognin *et al.* have highlighted these impacts and provided considerations to work towards a holistic coastal protection approach. Coastal management choices impact the hydrodynamics and sediment transport of coastal areas, and using observations and modelled scenarios can reveal their intricacies and enable optimized choices with fewer negative trade-offs.

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**Figure 1**: An aerial view of the Venice Lagoon and the narrow barrier islands that protect the city from the storm surges from the Adriatic Sea below. Tognin et al. [6] used observations and models to assess how storm surge barriers impact sediment accumulation in the adjacent salt marshes.