Valuing the Flood Reduction Benefits of Marsh Restoration

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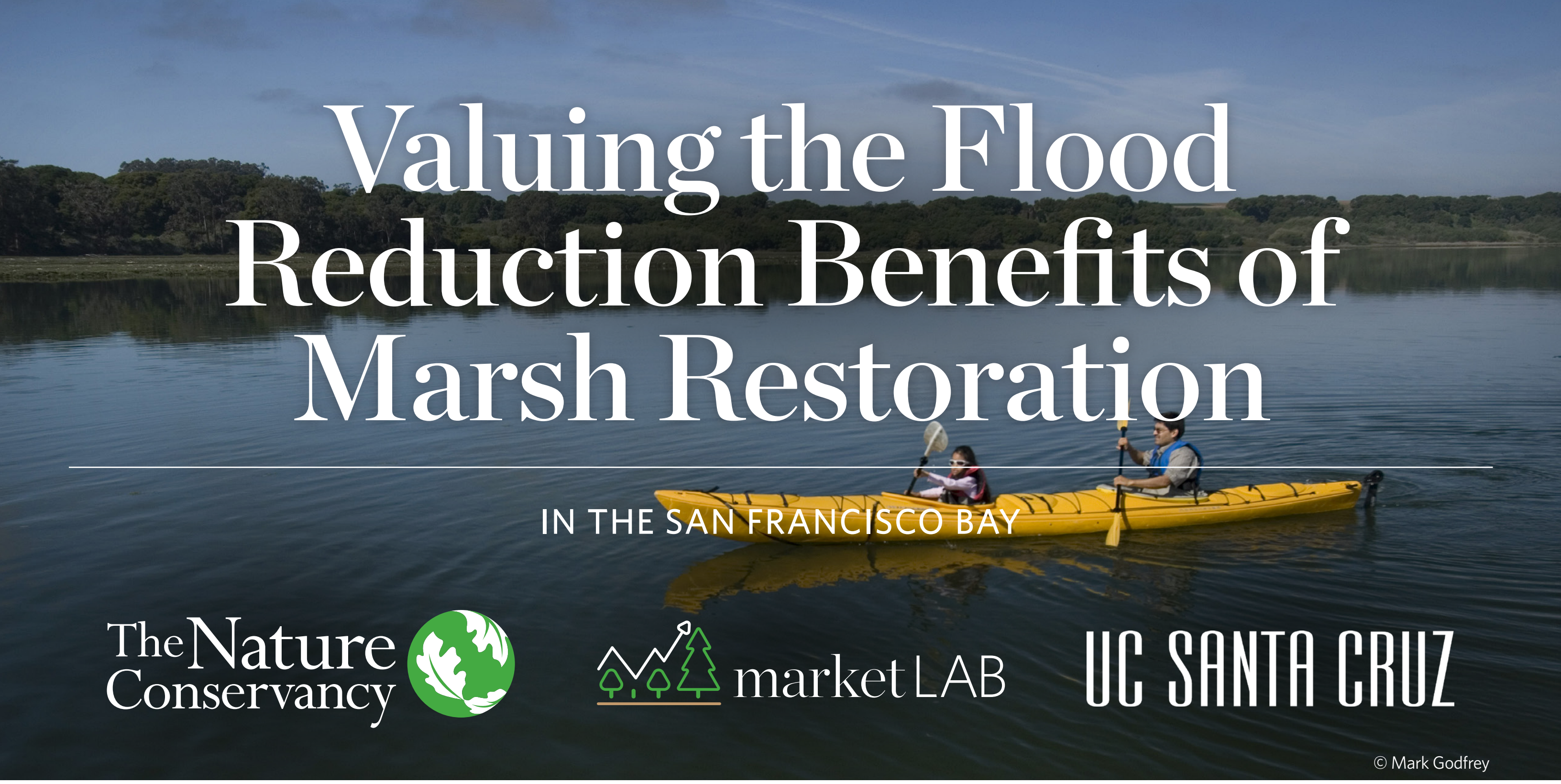

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INTRODUCTION

There is growing evidence for the beneficial role that wetlands can play in reducing flood risk, but in many urban estuaries, coastal development has resulted in dramatic habitat loss and fragmentation. In the past several decades, marsh restoration has emerged as a core management objective in the San Francisco Bay. The co-occurrence of high and increasing flood risk and opportunities for wetland management makes San Mateo County, California, well suited to serve as a study site for an investigation of the potential for marsh restoration as a nature-based flood defense. In this policy brief, we summarize the results of a high-resolution study to quantify the social and economic flood risk reduction benefits of salt marsh restoration currently and with climate-driven changes in storms and sea levels for the bay side of San Mateo County. We identify where stakeholder-identified potential salt marsh restoration could have the greatest socio-economic impacts in reducing flood risk and the role that habitat restoration may play in building community resilience to climate change.

The study summarized in this brief was initiated by the Protecting the Bay Working Group, a convening of stakeholders focused on coastal resilience with the shared objective of exploring opportunities for creative financing to enhance natural infrastructure in the San Francisco Bay in the face of climate change. To advance this objective, the Working Group first sought to fill a significant data gap by quantifying the extent to which salt marshes reduce flood risk in San Mateo County and the associated economic and social benefits.

KEY FINDINGS

- The **benefits of marsh restoration vary** across San Mateo County, based in a large part on locations of existing defenses (levees), marsh size and location, and social and economic assets.
- Overall, **marsh restoration decreases flooding**, but has stronger effects on flood depths than flood extents. By reducing flood extents, marsh restoration reduces the number of people who are impacted by flooding.
- With projected **sea level rise**, the benefits of marsh restoration increase, particularly around **Foster City** and **Redwood Shores**, as regional levees are increasingly overtopped.
- Under current conditions, the risk reduction afforded by 7,200 acres of marsh restoration **countywide** is over **$21 million**.
- The value of marsh restoration **countywide** increases five-fold to **$106 million** with just 0.5 meters of sea level rise and by a factor of more than 20 to **$499 million** with 1 meter of sea level rise.
- The marsh with the greatest potential restoration benefits per acre covers 36.3 acres near **San Francisco International Airport** and provides over **$350,000 per acre** in benefits under current conditions.
- With a 0.5-meter rise in sea level, the flood reduction benefits of marsh restoration near **San Francisco International Airport** increase to more than **$3.75 million per acre**.

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MARSH RESTORATION FOR RISK REDUCTION IN CALIFORNIA

US West Coast communities bordering low-lying estuarine environments, including Puget Sound, San Francisco Bay and smaller Southern California lagoons and estuaries, are highly vulnerable to flooding, resulting in substantial socio-economic exposure on the West Coast (Barnard et al. 2019). Recent research suggests that in California, 2 meters of sea level rise combined with a 100-year storm would affect 675,000 people (Barnard et al. 2019). The population bordering the San Francisco Bay ("the Bay Area") accounts for two-thirds of future flooding impacts in California, and the cost of raising Bay Area coastal protection structures to prepare for 2 meters of sea level rise could reach $450 billion (Hirschfeld and Hill 2017).

Within California, San Mateo County (Figures 1A and 1B) will have the most climate change induced flood exposure, with over $39 billion of infrastructure exposed to flooding, erosion and sea level rise through this century ("Hazard Reporting and Analytics (HERA)" 2017). Communities are already beginning to experience these impacts. San Mateo County's bay shoreline is highly altered and contains critical public infrastructure, including the San Francisco International Airport, terminals of two regional bridges, an interstate highway, major electricity conveyance infrastructure, the heart of the Silicon Valley technology industry and over 750,000 residents.

Levees are an essential component of flood control throughout the region (SFEI 2016). Much of the urban coast is built on historical wetlands that have been filled; wetlands were also drained to create ponds for industrial salt production (SFEI 1999). In San Mateo County, historical marsh habitat in the northern part of the county was filled and developed to create the communities of Foster City and Redwood Shores, while in the southern part of the county, historical marsh habitat was drained to create ponds for salt production. The result of this filling, diking and development of low elevation marshes is that 6% of the county's population and 10% of the county's total parcel values are likely to be flooded in a 1-meter and 100-year storm scenario (HERA 2017).

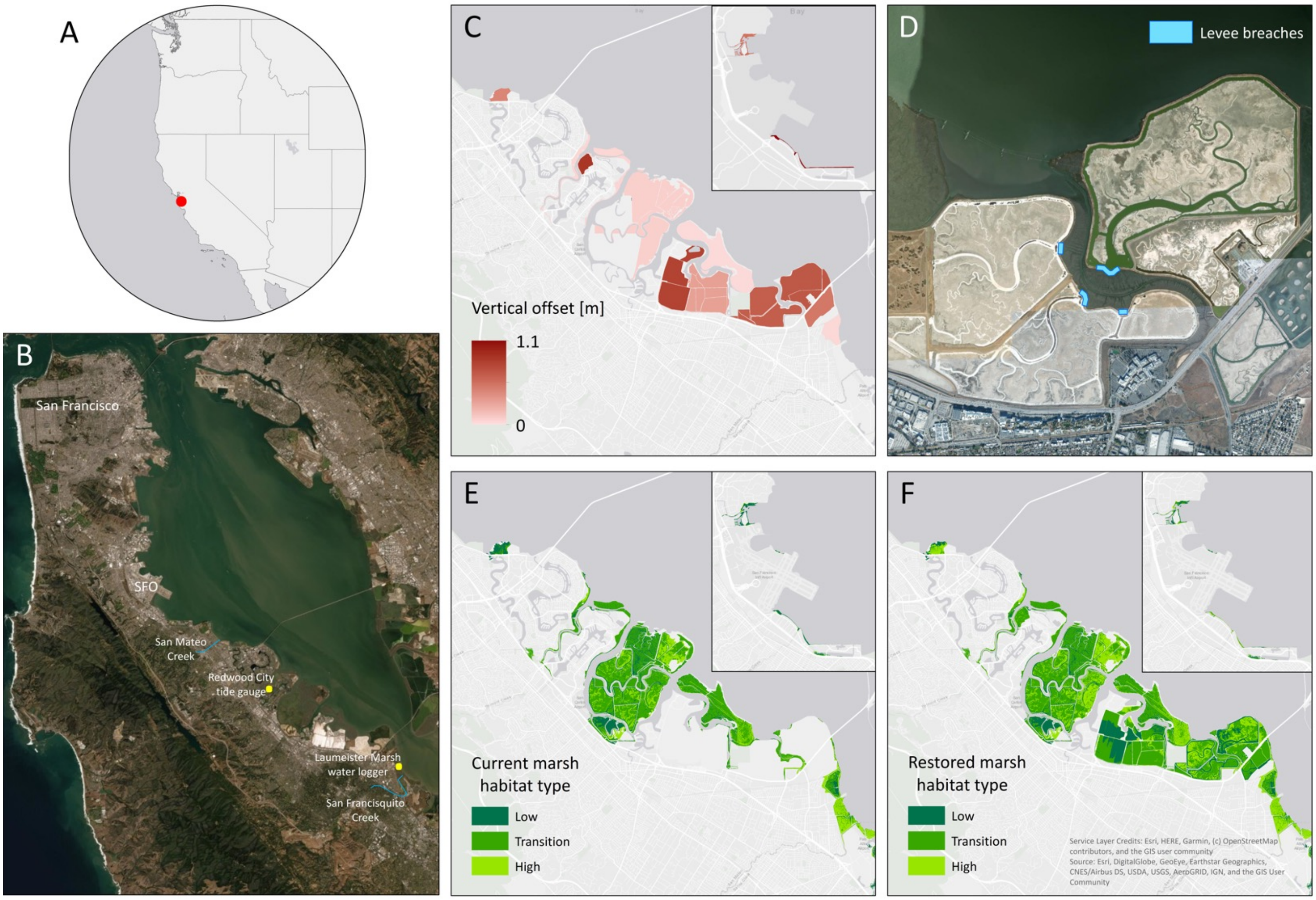
Many studies show that nature-based solutions, such as marsh restoration, provide significant benefits for flood risk reduction, but few quantify these benefits socially or economically. Even fewer studies assess the benefits of restoration scenarios, particularly under climate change (Gourevitch et al. 2020; Storlazzi et al. 2021; Martínez-García et al. 2022). Climate change is a pressing issue on coasts around the world, and assessments of the benefits of both natural and traditional "gray" infrastructure will need to account for these challenges. We address this need by rigorously assessing the flood risk reduction benefits of marsh restoration in San Mateo County under current and future climate conditions.

METHODS

We coupled two commonly-used models to assess coastal flooding, Delft 3D Flexible Mesh (2022) and Simulating WAves Nearshore (SWAN, Booij et al. 1999). These models account for tides, steric changes in water level (i.e., storm surge), river discharge, wave setup and relative sea level rise; this model does not account for movement of water due to breaking waves. Marsh habitat locations were determined from the Bay Area Aquatic Resources Inventory (SFEI & Aquatic Science Center (ASC) 2015), and the location of flood control infrastructure was determined from the SFEI's Bay Shore Inventory (SFEI 2016). We simulated flooding driven from both the bay and associated creeks. The model was calibrated and validated by comparing modeled water-levels to measurements collected by the National Oceanic and Atmospheric Administration (NOAA) Redwood City Tide Gauge ("Tides and Currents" 2021) and by a water logger deployed in Laumeister Marsh during storms in 2010 and 2011 (Thorne et al. 2013). The simulated marsh restorations were developed in close collaboration with local flood managers and other stakeholders from San Mateo County and the Bay Area more broadly over a series of workshops, with the goal of developing plausible scenarios of marsh restoration to assess effects on flood risk in the study region. Storm water levels, wind and pressure time series were derived from Barnard et al. (2019). Creek flows for San Francisquito Creek were derived from Erikson et al. (2018), and creek flows for San Mateo Creek were determined by the same percentile of flow from the stream gauge as that from San Francisquito Creek, which is 20 kilometers away.

Sediment nourishment and re-vegetation were simulated by bringing restoration sites to an average elevation of 1 meter above mean sea level, which is a representative elevation of healthy regional marshes (Takekawa et al. 2013). The vertical offset applied to restoration sites is shown in Figure 1C. Marsh types were shifted accordingly, as shown in Figures 1E and 1F. The simulated restoration included breaching several levees surrounding salt ponds. We used satellite imagery and historical photography to determine locations for the breaches, as shown in Figure 1D. For the 0.5- and 1-meter sea level rise scenarios, vegetation zones were modified to represent the corresponding upslope shift of marsh vegetation zones caused by an increase in mean sea level. We used the most recently available data on marsh distribution, but this distribution is dynamic as there are ongoing impacts and management efforts. For example, some sections of the region's levee system have been breached since the SFEI Bayshore Inventory was published in 2016, and a section of Bair Island has been restored to marsh habitat from open water since the SFEI Bay Area Aquatic Inventory was published in 2015. We manually edited the datasets for marsh distribution and levee elevation based on stakeholder input to ensure the most up-to-date dataset for hydrodynamic modeling.

Figure 1. Methods used to develop marsh restoration scenarios



Subplot A shows the location of the study, and subplot B identifies key landmarks. Subplot C shows potential restoration sites identified by stakeholders through a series of workshops. The color of each site corresponds to the vertical offset applied to the site to simulate sediment nourishment, bringing each site to 1 meter above mean sea level. Subplot D shows levee breaches (in blue) across historical marsh channels to facilitate tidal connectivity in salt ponds. Subplots E and F show, respectively, current and restored marsh habitat types (low, transition and high marsh), which are determined by elevation relative to tidal data.

We used the Federal Emergency Management Agency's (FEMA's) Flood Assessment Structure Tool (FAST, Hazus 2021) to value flood risk and risk reduction from marsh restoration. We used the National Structure Inventory (NSI) (2019), which includes information on structure replacement cost, content cost, material type, basement type and number of floors for about 200,000 residential, commercial, industrial and public structures in San Mateo County (measured in 2021 $USD). NSI and the flood depth maps produced from the hydrodynamic model were used as inputs to FAST, which determines the appropriate depth-damage curve for each structure in the domain and the damage to each structure based on the provided flood depth. The difference in damage between habitat scenarios determines the avoided damages provided by marsh restoration.

Economic benefits were calculated in present value terms, using discount rates of both 7% and 3% over 50 years.[1] We calculated a simple benefit cost ratio (BCR) for marsh restoration, comparing flood reduction benefits to restoration costs, both countywide and for a specific restoration scenario. A BCR greater than 1 indicates that a project's benefits exceed its construction costs. Applicants to FEMA's Building Resilient Infrastructure and Communities (BRIC) and Flood Mitigation Assistance grant programs must calculate a BCR, using approved methodologies, to assess a project's cost-effectiveness. FEMA's BCA (Benefit-Cost Analysis) Toolkit allows project proponents to include a number of additional precalculated co-benefits (e.g., recreation value), which would likely increase a project's benefits relative to our BCR, which focuses only on hazard mitigation benefits.

The social impacts of marsh restoration on flooding in San Mateo County were determined assuming the population across each census block-group was evenly distributed between residential buildings, and the population impacted was determined by whether a residential structure was flooded. Social vulnerability was determined by census block using the approach used by Bay Conservation and Development Commission (BCDC) et al. (2020).

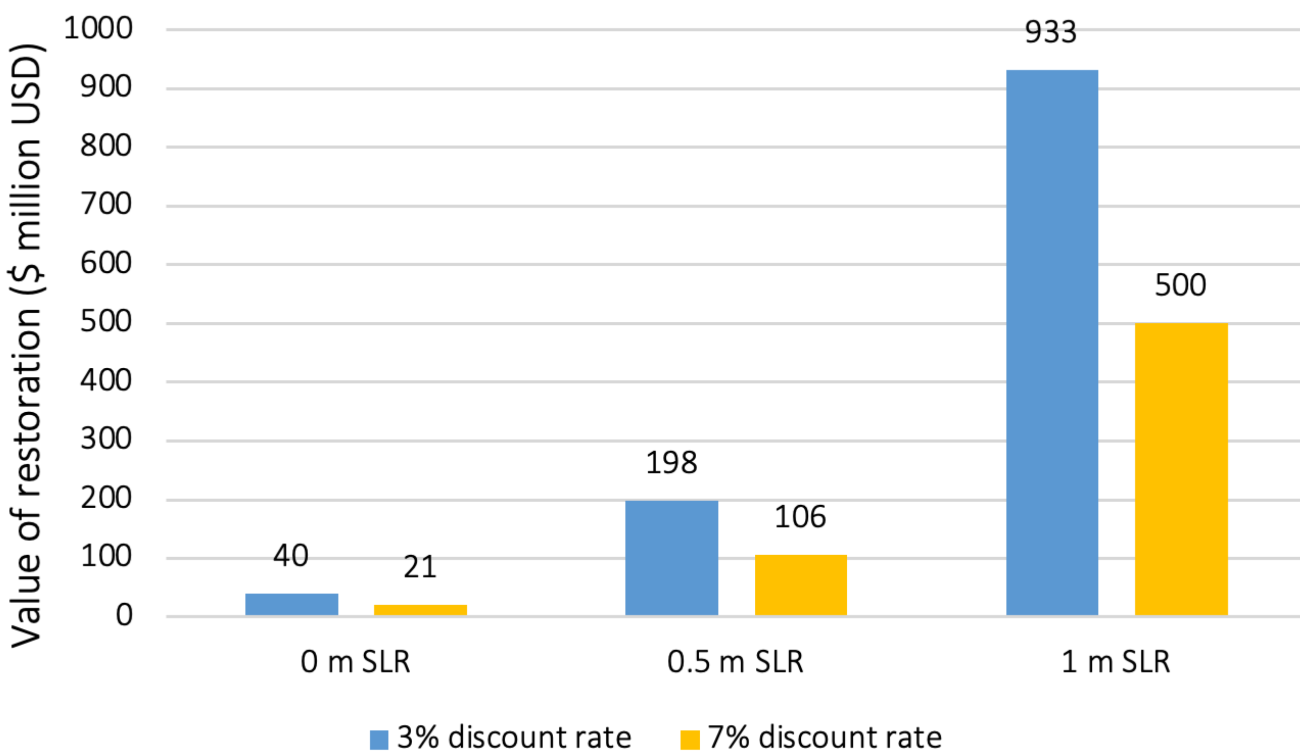
1 7% is the standard value used by the US Army Corps of Engineers, FEMA and other federal agencies. Studies suggest that lower discount rates, such as 4%, are more appropriate for public agencies that make long term, intergenerational investments (Schmidt and Mann 2019), since a lower discount rate more heavily weights future benefits. FEMA recently issued an alternative methodology that allows proponents of Hazard Mitigation Assistance grant programs to use a discount rate of 3% in the required Benefit Cost Analysis for mitigation that addresses climate change.

RESULTS

Overall, marsh restoration decreases flooding in San Mateo County, providing significant economic benefits. These benefits increase as sea levels rise. With 0 meters of sea level rise, 7,200 acres of marsh restoration produce a total present value benefit of $20 million with a 7% discount rate over 50 years. This value increases by a factor of 5, with 0.5 meters of sea level rise, to $106 million, and by a factor of more than 20, with 1 meter of sea level rise, to $500 million. With a 3% discount rate, which assigns greater value to future benefits, the flood protection benefits of marsh restoration nearly double to $40 million at 0 meters of sea level rise, $198 million with 0.5 meters of sea level rise and $933 million with 1 meter of sea level rise (Figure 2).

Marsh restoration costs are highly variable and project-specific, but for this analysis, we used $80,000 per acre (in 2021 USD; Bayraktarov et al. 2015), based on a review of salt marsh restoration costs in developed countries. Using this figure, the total cost of restoration countywide is around $576 million. Therefore, the benefits of flood protection alone exceed restoration costs once sea levels have risen 1 meter, using a 3% discount rate, resulting in a net benefit of $357 million and a BCR of 1.6. A BCR over 1 indicates that benefits exceed costs. In this context, flood protection benefits cover between 4% and 7% of marsh restoration costs under current conditions, which increases to between 87% and over 100% with 1 meter of sea level rise. Thus, investments made today in marsh restoration will provide increasing payoffs into a future with higher water levels. However, beyond flood protection, salt marshes have some of the highest per-acre rates of carbon sequestration (Mcleod et al. 2011), and they clean waters, provide fish and wildlife habitat and support recreation, among other benefits (Barbier et al. 2011).

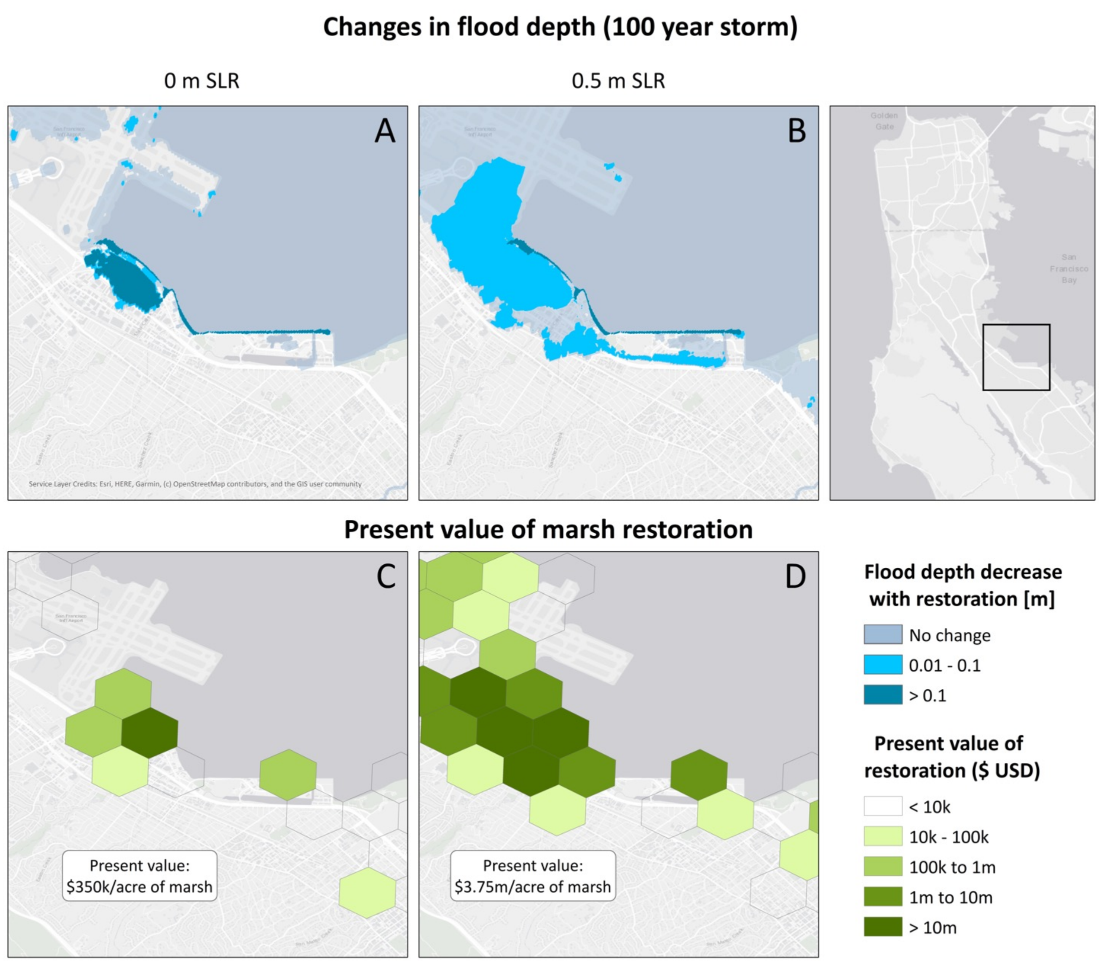
Figure 2. **Summary of total benefits (present value) of flood reduction provided by marsh restoration in San Mateo County under 3 different sea level rise scenarios.**



Present value is calculated for 7,200 acres assuming a 50-year lifespan, with discount rates of 3% and 7%.

While we have provided a county-wide estimate of potential marsh restoration flood risk reduction benefits, we know that these benefits vary greatly by location and that restoration can be targeted to deliver much higher benefits. For example, in our analyses we were able to identify that marsh restoration at a non-levee protected site near the San Francisco International Airport could deliver high benefits per acre. Flood depth reduction benefits are not always directly attributable to a specific restoration site due to complex hydrodynamics such as channels, creeks and sloughs. However, the restoration scenario south of the airport is an isolated fringing marsh, and in this case, we can directly attribute benefits to restoring the marsh. With 0 meters of sea level rise, the 36-acre restoration site produces flood protection benefits of $12.7 million total and $350,000 per acre, the greatest per-acre benefits in the county (using a 7% discount rate). The flood reduction benefits of marsh restoration in this area increase substantially with 0.5 meters of sea level rise to more than $135 million total and $3.75 million per acre (Figure 3).

Figure 3. Flood reduction benefits for a 36-acre marsh restoration site south of San Francisco International Airport

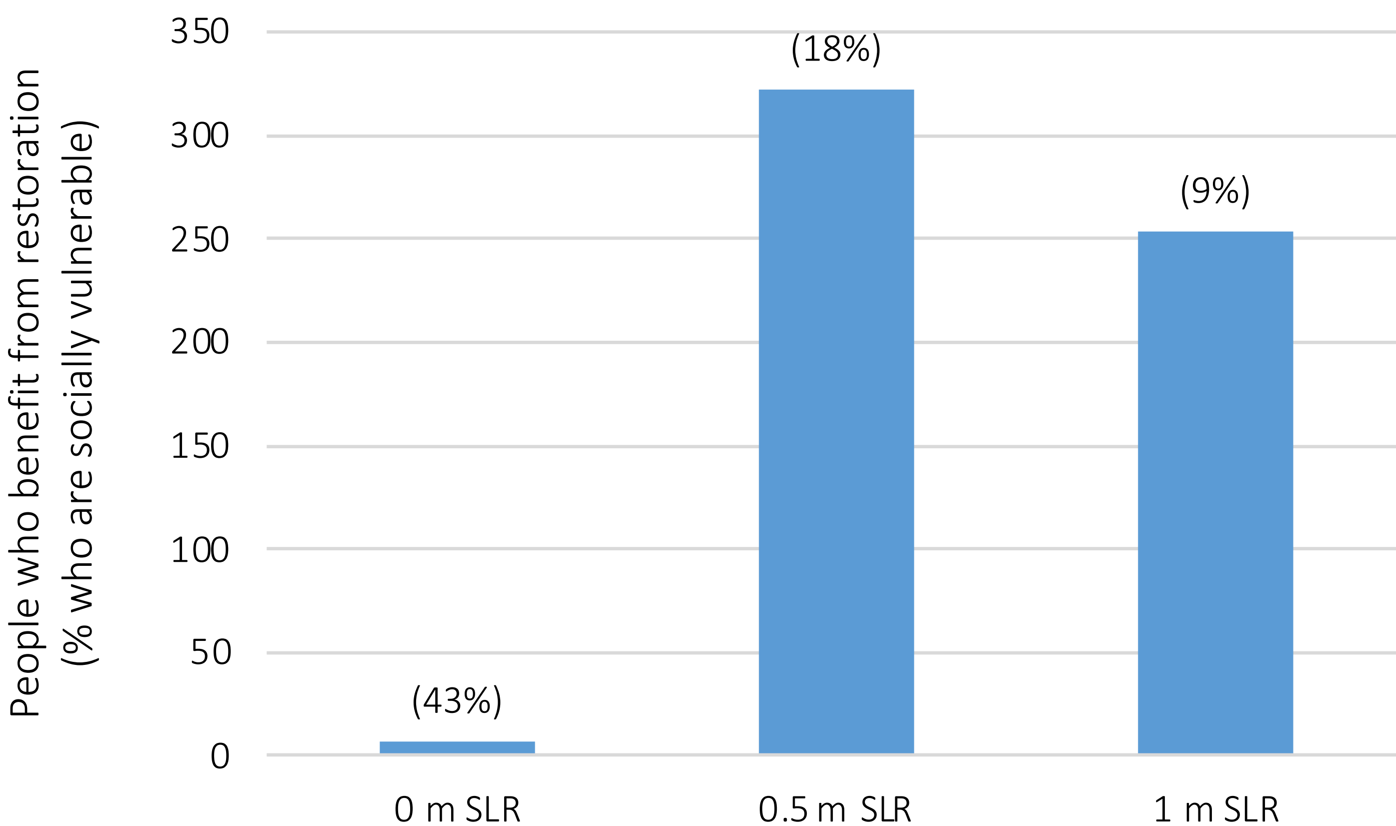


In the top row, reduction in flood heights during a 100-year storm due to habitat restoration with 0 meters of sea level rise in subplot A and 0.5 meters of sea level rise in subplot B. Shaded blue areas show flood extent of a 100-year storm with change in depth as a result of marsh restoration. In the bottom row, present value of marsh restoration with 0 meters of sea level rise in subplot C and 0.5 meters of sea level rise in subplot D. Darker green colors signify higher present values, and paler green colors signify lower present values of flood reduction benefits.

The per-acre present value benefit figure provides an estimate that can be used by planners and managers as a "break-even point" for restoration, indicating the level at which flood reduction benefits would equal costs. With restoration estimated to cost $80,000 per acre (in 2021 USD, Bayraktarov et al. 2015), marsh restoration in the 36-acre area south of the airport would yield a BCR greater than 4 under current conditions and greater than 40 under climate change with 0.5 meters of sea level rise. This restoration project would yield substantial benefits for hazard mitigation, highlighting that small marsh restorations can play an important role in reducing flood risk.

At present sea levels, most people in San Mateo County already receive protection benefits from levees; hence the protection benefits from marsh restoration are small, although concentrated in more socially vulnerable census blocks. With sea level rise, the population protected increases, but with this increase, the share of vulnerable populations benefiting from restoration decreases (Figure 4). Restoration protects people through complex interactions between water levels, levee height and location of residences, so this pattern is not linear with sea level rise. While socially vulnerable census block groups are also vulnerable to flooding with sea level rise, damage becomes widespread, and the effect of restoration is more focused in less vulnerable communities as sea levels rise.

Figure 4. **Summary of people protected from flooding due to marsh restoration under 3 different sea level rise scenarios.**



Total people protected is shown with the blue bars, and the percentage of people protected in census blocks ranked high or highest social vulnerability is shown in parentheses. Restoration protects people through complex interactions between water levels, levee height, and location of residences, so this pattern is not linear with sea level rise.

LOOKING AHEAD

This policy brief has summarized research showing that marsh restoration has an important role to play in building resilience to sea level rise and storm-driven flooding, in addition to providing community and ecosystem co-benefits. While restoration can meaningfully reduce flood risk to people and property in San Mateo County and the San Francisco Bay Area, it is only part of a set of hybrid solutions needed to provide sufficient flood protection. Furthermore, flood protection is only one of many benefits that salt marshes provide, such as carbon sequestration, fish and wildlife habitat, improved water and air quality and recreation. This first-of-its-kind valuation of marsh restoration benefits has the potential to advance the protection and restoration of this important form of natural infrastructure in San Mateo County, the California county with the greatest exposure to sea level rise, via the following pathways:

- **Restoration project design**

  Marsh restoration does not reduce flood risk evenly across the landscape—some locations in San Mateo County would benefit more than others, as demonstrated by the restoration scenario south of the San Francisco International Airport where shorelines are currently protected mainly by riprap. The detailed flood model developed in this study evaluates the risk of flooding with and without salt marshes at a local scale, a tool that can be highly useful for the planning and design phases of marsh restoration projects in San Mateo County.

Flood insurance applications

The Protecting the Bay Working Group explored the potential for marshes in the San Francisco Bay to reduce insurance premium pricing by reducing the risk of flooding and associated property damage. A key barrier to this exploration was the lack of available science that quantified the risk reduction of marshes across the landscape. This study has effectively filled this data gap, and a key next step will be to explore potential applications with both the insurance industry and FEMA's National Flood Insurance Program (NFIP). FEMA's Community Rating Strategy, a voluntary program where community investments in flood risk reduction, such as preserving open space, result in discounted premiums for NFIP policyholders, may serve as an analog. There is also the potential to incorporate the modeling of salt marshes into industry risk models used for pricing private flood insurance products, providing a more detailed assessment of the flood risk reduction benefits of salt marshes and potentially, premium reductions.

Investment in marshes

Monetizing the flood risk reduction benefits of salt marshes has the potential to help identify where funds for hazard mitigation, disaster recovery and/or climate adaptation would be most cost-effective. The additional quantification of benefits may focus greater investments in restoration projects throughout San Mateo County by further building the case that project benefits outweigh the costs. Such benefit-cost analyses may be used to bolster applications for public investments, such as through FEMA's BRIC grant program or Regional Measure AA, which provides approximately $500 million for marsh restoration throughout the San Francisco Bay. Private property owners along the Bay may be motivated to invest in salt marshes if they directly benefit from reduced flood risk, in addition to co-benefits such as recreation and habitat protection.

Going forward, TNC and the UCSC Center for Coastal Climate Resilience will continue to collaborate in building the evidence base for flood risk reduction by salt marshes, with the goal of unlocking additional investments in marsh protection and restoration. This policy brief focuses on quantifying the benefits of salt marshes in reducing levee overtopping in San Mateo County, the first phase of a project that the Protecting the Bay Working Group initiated. A second phase of this work, funded by the California Ocean Protection Council, will quantify the extent to which marshes in San Mateo County reduce the risk of levee failure by mitigating wave attack and run-up. This second phase aims to advance discussions around investments in hybrid flood mitigation, such as horizontal levees, which may be one solution to building greater coastal resilience in the decades ahead.

A primary goal going forward will be to explore these pathways and determine the opportunities for leveraging the value of salt marshes for flood protection to expand their protection and restoration in San Mateo County and the San Francisco Bay more broadly, which has historically relied on gray infrastructure, such as levees. Wetlands play a valuable role in reducing flood risk, and marsh restoration can, therefore, be an important tool for increasing community resilience through nature-based flood defense.

As climate change progresses, and sea level rise and flooding put communities at increasing risk, protecting and restoring wetlands can ameliorate the social and economic impacts to coastal communities in San Mateo County and beyond. While this study was focused on a single county, and site-specific conditions, our approach may be applied to a diverse array of communities in estuaries worldwide. Quantifying the benefits of nature-based solutions such as salt marsh restoration will allow for greater opportunities for incorporating them into a holistic set of climate resilience investments.

REFERENCES

Barbier, Edward B., Sally D. Hacker, Chris Kennedy, Evamaria W. Koch, Adrian C. Stier, and Brian R. Silliman. 2011. "The Value of Estuarine and Coastal Ecosystem Services." Ecological Monographs 81 (2): 169–93. https://doi.org/10.1890/10-1510.1.

Barnard, Patrick L, Li H Erikson, Amy C Foxgrover, Juliette A Finzi Hart, Patrick Limber, Andrea C O Neill, Maarten Van Ormondt, et al. 2019. "Dynamic Flood Modeling Essential to Assess the Coastal Impacts of Climate Change." Nature Scientific Reports 9. https://doi.org/10.1038/s41598-019-40742-z.

Bayraktarov, Elisa, Megan Irene Saunders, Sabah Abdullah, Morena Mills, Jutta Beher, Hugh P. Possingham, Peter J. Mumby, and Catherine E. Lovelock. 2015. "The Cost and Feasibility of Marine Coastal Restoration." Ecological Applications 26 (4): 1055–74. https://doi.org/10.1890/15-1077.1.

BCDC, Caltrans, MTC, ABAG, and BARC. 2020. "Adapting to Rising Tides Bay Area, Regional Sea Level Rise Vulnerability and Adaptation Study," no. March: 205. http://www.adaptingtorisingtides.org/project/art-bay-area/.

Booij, N., R. C. Ris, and L. H. Holthuijsen. 1999. "A Third-Generation Wave Model for Coastal Regions 1. Model Description and Validation." Journal of Geophysical Research: Oceans 104 (C4): 7649–66. https://doi.org/10.1029/98JC02622.

"Delft3D Flexible Mesh." 2022. Deltares. https://www.deltares.nl/en/software/delft3d-flexible-mesh-suite/.

Erikson, Li H., Andrea C. O'Neill, and Patrick L. Barnard. 2018. "Estimating Fluvial Discharges Coincident with 21st Century Coastal Storms Modeled with CoSMoS." Journal of Coastal Research 85: 791–95. https://doi.org/10.2112/si85-159.1.

Gourevitch, Jesse D., Nitin K. Singh, Josh Minot, Kristin B. Raub, Donna M. Rizzo, Beverley C. Wemple, and Taylor H. Ricketts. 2020. "Spatial Targeting of Floodplain Restoration to Equitably Mitigate Flood Risk." Global Environmental Change 61 (December 2019): 102050. https://doi.org/10.1016/j.gloenvcha.2020.102050.

"Hazard Reporting and Analytics (HERA)." 2017. https://www.usgs.gov/apps/hera/.

Hazus. 2021. "Hazus Flood Assessment Structure Tool." Federal Emergency Management Agency. https://github.com/nhrap-hazus/FAST.

Hirschfeld, Daniella, and Kristina E. Hill. 2017. "Choosing a Future Shoreline for the San Francisco Bay: Strategic Coastal Adaptation Insights from Cost Estimation." Journal of Marine Science and Engineering 5 (3): 42. https://doi.org/10.3390/jmse5030042.

Martínez-García, Víctor, José M. Martínez-Paz, and Francisco Alcon. 2022. "The Economic Value of Flood Risk Regulation by Agroecosystems at Semiarid Areas." Agricultural Water Management 266 (October 2021). https://doi.org/10.1016/j.agwat.2022.107565.

Mcleod, Elizabeth, Gail L Chmura, Steven Bouillon, Rodney Salm, Mats Björk, Carlos M Duarte, Catherine E Lovelock, William H Schlesinger, and Brian R Silliman. 2011. "A Blueprint for Blue Carbon : Toward an Improved Understanding of the Role of Vegetated Coastal Habitats in Sequestering CO 2 In a Nutshell :" https://doi.org/10.1890/110004.

"National Structure Inventory." 2019. US Army Corps of Engineers. https://www.hec.usace.army.mil/confluence/nsidocs.

San Francisco Estuary Institute (SFEI). 1999. "Historical Baylands GIS Dataset." Richmond, CA.———. 2016. "No Title." San Francisco Bay Shore Inventory: Mapping for Sea Level Rise Planning GIS Data. 2016. http://www.sfei.org/projects/SFBayShoreInventory.

San Francisco Estuary Institute & Aquatic Science Center (SFEI ASC). 2015. "Bay Area Aquatic Resource Inventory (BAARI) Version 2 GIS Data." 2015. http://desktop.arcgis.com/en/arcmap/10.3/manage-data/tables/calculating-area-length-and-other-geometric-properties.htm.

Schmidt, Rowan, and Alyssa Mann. 2019. "Stress Testing the BCA Toolkit with Nature-Based Solutions : Observations and Recommendations for FEMA," 1–37.

Storlazzi, C.D., Reguero, B.G., Cumming, K.A., Cole, A.D., Shope, J.B., Gaido L., C., Viehman, T.S., Nickel, B.A., and Beck, M.W. 2021. "Rigorously Valuing the Potential Coastal Hazard Risk Reduction Provided by Coral Reef Restoration in Florida and Puerto Rico." U.S. Geological Survey, 1–24.

Takekawa, J Y, K M Thorne, K J Buffington, K A Spragens, K M Swanson, J Z Drexler, D H Schoellhamer, C T Overton, and M L Casazza. 2013. "Final Report for Sea-Level Rise Response Modeling for San Francisco Bay Estuary Tidal Marshes." U.S. Geological Survey Open File Report 2012-1081, 161.

Thorne, Karen, Kevin Buffington, Kathleen Swanson, and John Takekawa. 2013. "Storm Episodes and Climate Change Implications for Tidal Marshes in the San Francisco Bay Estuary, California, USA." The International Journal of Climate Change: Impacts and Responses 4 (4): 169–90. https://doi.org/10.18848/1835-7156/cgp/v04i04/37200.

"Tides and Currents." 2021. NOAA.

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