# Appendix A

# ADAPTATION STRATEGY COMPILATION

## Costs and Co-Benefits Table

| | Strategy Name | Habitat Impacts* | Other Co-Benefits | Costs | |
|---|---|---|---|---|---|
| | | | | Unit | $ |
| 1.1 | Seawall/Revetment | - | public safety | km | 37,000,000 (seawall)<br>22,000,000 (revetment)[1] |
| 1.2 | Elevate Bulkheads | - | public safety, recreation/tourism | km | 590,000 |
| 1.3 | Breakwaters, Artificial Reefs | 0 | recreation/tourism | km | 44,000,000 |
| 1.3 | Groins | - | public safety | km | 30,000,000 |
| 1.4 | Traditional Levee | - | public safety, recreation/tourism | km | 5,5000,000 |
| 1.5 | Pump Station | - | public safety | | 500,000 to 4,000,000 |
| 1.6 | Tidal Gate | - | public safety, recreation/tourism | ea | 1,000,000-2,000,000 |
| 2.1 | Beach Nourishment | 0 | recreation/tourism, aesthetic | acre | 500,000** |
| 2.2 | Dune Restoration/nourishment | 0 | recreation/tourism, aesthetic | acre | 200,000 |
| 2.3 | Beach Dewatering | 0 | recreation/tourism, aesthetic | | n/a |
| 2.4 | Offshore Bio-beds (sea-grass, oysters) | + | Public health, recreation/tourism, aesthetic, carbon sequestration, air quality, water quality | | n/a |
| 2.5 | Wetland enhancement | + | Public health, recreation/tourism, aesthetic, carbon sequestration, air | | Varies |

[1] ESA, 2016

| | Strategy Name | Habitat Impacts* | Other Co-Benefits | Costs | |
|---|---|---|---|---|---|
| | | | | Unit | $ |
| | | | quality, water quality, stormwater management | | |
| 2.6 | New wetland creation | + | Public health, recreation/tourism, aesthetic, carbon sequestration, air quality, water quality, stormwater management | acre | 20,000 |
| 2.7 | Horizontal levees | + | Public health, public safety, recreation/tourism, aesthetic, carbon sequestration, air quality, water quality, stormwater management | LF | 1,500 |
| 3.1 | Elevate buildings (flood zone) | 0 | Public safety, seismic safety, recreation/tourism, stormwater management | SF | 140 |
| 3.1 | Elevate buildings (wave zone) | 0 | Public safety, seismic safety, recreation/tourism, stormwater management | SF | 250[2] |
| 3.2 | Elevate roads (secondary) | - | Public safety, recreation/tourism, stormwater management | SF | 570 |
| 3.2 | Reconstruct roads | - | Public safety, recreation/tourism | LF | 280 |
| 3.3 | Raise grades | - | Public safety, seismic safety | High Costs - Varies | |

[2] ESA, 2016

| | Strategy Name | Habitat Impacts* | Other Co-Benefits | Costs | |
|---|---|---|---|---|---|
| | | | | Unit | $ |
| 3.4 | Floodproof buildings | 0 | Public health, public safety, recreation/tourism, aesthetic | Varies (see Retrofitting Options section pages 95-110) | |
| 3.5 | Floodable and floatable development | 0 | Public safety, recreation/tourism, aesthetic, stormwater management | building | 2,400,000 |
| 5.5.1 | Managed retreat/relocation | + | Public health, public safety, seismic safety, recreation/tourism, aesthetic, stormwater mgmt.. | varies | |
| 5.5.2 | Zoning and overlay zones | + | Public health, public safety, recreation/tourism, aesthetic | | |
| 5.5.3 | Setbacks for development | + | Public safety, recreation/tourism, aesthetic | | |
| 5.5.4 | Siting and design requirements | + | Public safety, recreation/tourism, aesthetic | | |
| 5.6.1 | Capital improvement programs | + | Public safety, seismic safety, recreation/tourism, aesthetic | | |
| 5.6.2 | Acquisition/buy-out | + | Public health, public safety, seismic safety, recreation/tourism, aesthetic | | |
| 5.6.3 | Conservation easements | + | Public health, public safety, seismic safety, recreation/tourism, aesthetic | | |
| 5.6.4 | Rolling easements | + | Public health, public safety, seismic safety, recreation/tourism, aesthetic | | |

| | Strategy Name | Habitat Impacts* | Other Co-Benefits | Costs | |
|---|---|---|---|---|---|
| | | | | Unit | $ |
| 5.7.1 | Transfer of development credit/rights | + | Public health, public safety, seismic safety, recreation/tourism, aesthetic | | |

*+ = positive impacts, 0 = neutral or unknown, - = negative impacts

**considers opportunistic source, could reach $830,000+ per acre if sand acquired traditionally

Co-Benefits considered: public health, public safety, seismic safety, recreation/tourism, aesthetic, carbon sequestration, air quality, water quality, stormwater management

Data Sources: Marin County Department of Public Works, Giacomimi Wetland Restoration, Waikiki Beach, Florida Fish and Wildlife Conservation, Caltrans, ESA, California Adaptation Planning Guide

# Appendix A) Adaptation Strategy Compilation

This section describes in conceptual terms a set of strategies to address the adaptation needs identified in Task 3.1. Adaptation strategies were gathered from a variety of sources including project consultants Environmental Science Associates (ESA), Marin County Department of Public Works[3] (DPW), AECOM, existing adaptation plans from other jurisdictions, and several guidance and research publications, such as the California Coastal Commission's (CCC) Sea Level Rise Guidance and Georgetown Climate Center (GCC) Adaptation Toolkit[4]. A summary table at the end of this narrative identifies environmental impacts, costs and co-benefits of each strategy.

## 1) Structural Measures: Protect

### 1.1) Seawalls and Revetments

Seawalls are vertical structures along a beach or bluff, used to protect structures from wave action as a course of last resort. A seawall works by absorbing or dissipating wave energy. They may be either gravity- or pile-supported structures. Seawalls can have a variety of face shapes. Seawalls and bulkheads are normally constructed of stone or concrete, however other materials can be used. Current seawall projects usually require design elements that allow the structure to resemble the natural environment in that area, in order to blend in with the existing geologic conditions.

Revetments provide protection to existing slopes affronting a threatened structure, and are constructed of a sturdy material such as stone. Similar in purpose to a seawall, revetments work by absorbing or dissipating wave energy. They are made up of: an armor layer--either stone or concrete rubble piled up or a carefully placed assortment of interlocking material which forms a geometric pattern, a filter layer --which provides for drainage, and retains the soil that lies beneath, and a toe--which adds stability at the bottom of the structure. Revetments are the most common coastal protection structure along the shore of Marin County, protecting homes in Bolinas and Seadrift. In comparison to seawalls, revetments tend to have greater visual impacts and require a larger footprint, which leads to a larger placement loss and impacts to public access. These structures can introduce active erosion effects which accelerate beach loss when beach width narrows and wave run-up frequently reaches the structure. As the beach disappears and sea level rises, wave run-up and overtopping will also worsen over the structure as the waves begin to discharge near or on the structure, which will require more frequent maintenance or reconstruction.

Both seawalls and revetments were found to have a negative net cost benefit as a result of high construction cost in past erosion mitigation study (ESA PWA 2012). In other words, the loss in recreational and habitat value was greater than the costs to build the seawall/revetment (ESA 2015).

- Negative environmental impact
- Moderate to high cost

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[3] Leventhal, Roger, P.E. "Richardson Bay Shoreline Study. Evaluation of Sea Level Rise Impacts and Adaptation Alternatives". August 2015.
[4] Grannis, Jessica. "Adaptation Tool Kit: Sea-level Rise and Coastal Land Use." Georgetown Climate Center. October 2011.

- Offers short-term protection against temporary flooding, storm surge and some sea level rise, but can increase wave run-up and overtopping (CDA, DPW AECOM 2015).

Pros:

- Seawalls can be built in a narrow right of way where other solutions may not fit (DPW 2015).
- Effective when built and maintained properly (DPW 2015).

Cons:

- Aesthetic Impacts. Seawalls tend to be built out of concrete. They are unsightly, and, depending on the design elevation, may impact views and even public access to the shoreline. These design considerations may be mitigated to a point, but any large-scale wall will have landscape-scale impacts (DPW 2015).
- Additional bolstering needed. The edges and footings of the walls require protection from direct shoreline erosion and loss of structural support. This is typically provided by ensuring sufficient land waterside of the wall or by adding rock rip-rap (described below) or wetlands to reduce wave impacts on the waterside edge of the wall (DPW 2015).
- Need for a contiguous structure. Any barrier structure (walls and levees) is only as strong as its weakest link. To be effective, barrier structures need to have a continuous boundary and be tied into higher ground at both ends to avoid flooding behind the barrier (DPW 2015).
- Barriers may isolate shoreline habitat from uplands (DPW 2015).
- Barriers do not address continued erosion at the shoreline, which may have to be controlled to prevent undermining of the barrier's foundation (DPW 2015).
- All barrier solutions (walls, gates, levees) have the potential for catastrophic failure if engineering factors of structural safety are exceeded during design events (DPW 2015).
- As sea level continues to rise, walls may need to be raised. Depending on the design height and construction method, at some point, the wall's foundation may become inadequate and need to be rebuilt or reinforced to remain effective (DPW 2015).
- Add info about loss of beach and recreational area – address physical loss from footprint of wall as well as passive erosion over time

Costs:

- $37 million/km seawall (ESA 2015)
  There are additional design costs for barrier walls. Typically, a geotechnical investigation will be needed to determine the quality of the soils and hence the costs for the wall. Other costs, such as right of way acquisition for private properties, also need to be included in estimates (DPW 2015).
- Also costs related to maintenance over time

## 1.2) Elevate bulkheads

Newly constructed or reinforced and raised bulkheads around waterfront facilities or neighborhoods would prevent increasing water levels (both during high tides and storms) from flooding the adjacent low-lying neighborhoods (ESA 2015).

Costs:

- $590,000/km (ESA 2015). Costs for these measures are from Environ and ESA PWA (2013), and assume the cost of raising bulkheads to equal 50% of new bulkheads.

## 1.3) Breakwaters, Artificial reefs and Groins

These large coastal engineering structures are often used in conjunction with large beach nourishment to retain sand. The retention structures essentially slow the rate of sand transport away from the nourishment area, thereby slowing the rate of beach width reduction. These solutions were found to net negative cost benefit in Southern Monterey Bay (ESA PWA 2012) primarily due to high construction cost.

Offshore breakwaters are considered the most effective because wave sheltering and diffraction reduces sand transport directly. Offshore Breakwaters consist of fill in the surf zone, typically quarry stone arranged in a mound that penetrates the water surface. The breakwaters dissipate incident wave energy and change the pattern of sand transport in their lee, thereby reducing the transport of sand from the nourished area. These structures are generally applicable where there is a firm seabed and the need to create a calm area free from wave energy (ESA 2015).

Offshore artificial reefs consist of fill in the surf zone that reduces the wave power reaching shore and changes the pattern of sand transport, thereby conceptually reducing transport of sand from the nourished area. Offshore reefs are considered less effective than offshore breakwaters because the wave sheltering is reduced by the low crest height which allows wave overtopping. Artificial reefs installed to act as submerged breakwaters have received increased attention in recent years as a means of shore stabilization and erosion control, primarily due to their low aesthetic impact and enhanced water exchange relative to traditional emergent breakwaters (Vicinanza et al., 2009) and the potential to enhance local surfing conditions (Ranasinghe & Turner, 2006).

Groins are structures that extend seaward from the shore. Groins are generally considered along stretches of coast with high net longshore sediment transport. In application, the groins are located to segment the beach and nourishments into compartments, thereby reducing the loss of sand to adjacent shores. Groins are considered the least effective because wave climate is not reduced and rip current formation causes offshore transport, bypassing and edge effects near the structures (ESA 2015).

- Neutral/moderate environmental impacts
- Moderate to high cost
- Offer medium-term protection against temporary flooding and wave impacts (CDA, DPW 2015).

Offshore structures can work in Bay and open coast but will become less effective over time as sea level rise. Future adaptation could raise crest elevation to sustain function over time.

Pros:

- Potential to improve conditions for surfing, fishing, boating and other recreation, potential safety and public access improvements (ESA PWA 2012)

Cons:

- Groins can create rip currents, which could be dangerous to beach users (ESA PWA 2012)

- Potential impacts to offshore bottom species, potential promotion of non-native species/ecosystems through conversion of sand bottom to rock reef (ESA PWA 2012)
- Potential aesthetic impacts

Cost:

- $44 million/km for emergent breakwater (ESA 2015)

## 1.4) Traditional Levee

Levees have been the standard practice for flood protection in riverine and estuarine environments. Where constrained by infrastructure or commercial/residential structures, raising existing levees may be an effective adaptation strategy, but the risk to assets behind levees and maintenance costs may increase as sea level rises. Leeves and dikes are earthen structures that can be built to any desired height but require more space then flood or seawalls. A typical levee can require at least 80 feet and likely more of right of way space from the inside toe of the levee to the outside toe of the levee.

- Negative environmental impact
- Moderate to high cost
- Medium-term protection against temporary flooding, storm surge, and some sea level rise, but can increase wave run-up and overtopping (CDA, DPW 2015).
- Levees are not a great option on the open coast due to high wave energy environment, need to armor levee slope. Levees could be used in tidally influenced creeks and rivers though.

Pros:

- Levee tops can be used for roads/trails when properly designed and can provide views of the bay from the levee top.
- Depending on the location of the borrow source (soil for fill placement) and right of way acquisition costs, costs will typically be somewhat less for levees than for seawalls, and levees are usually less likely to catastrophically fail since they typically erode from the top rather than fail completely.

Cons:

- Require a larger right of way for construction. The exact width of the right of way depends on the starting and ending elevations, levee top elevation, and side slopes. A minimum footprint area of 60 to 80 feet is required for a flood control levee, and depending on various factors, the actual right of way required may be much greater. The right of way requirement depends on existing ground slope and condition, but typical right of way requirements are larger than the minimum footprint, usually in the range of 80 to 100 feet from toe to toe. Levees may not be possible in areas where the right of way is too narrow. The top width of the levee needs to be wide enough so that the levee can be raised at a later date if sea level rise rates increase.
- Like most any other elevated, linear barrier structure, levees can block views from the land side, depending on the elevation of the adjacent ground. Depending on location, some vegetation can be planted to soften views provided levee integrity is not compromised.
- The edge of a steep levee may require protection from direct shoreline erosion and loss of structural support. This is typically provided by ensuring that there is sufficient land waterside of the wall or by bolstering the levee with rock

rip-rap (described below). An alternative approach is to enhance or create wetlands on the water side to reduce wave impacts naturally (the horizontal levee approach), or to build an experimental, engineered bay beach to inhibit erosion.
- Like flood/seawalls, levees require regular inspection and maintenance to maintain their flood protection benefits.

Costs:

- Levee costs can range from $200 to $1,000 or more per linear foot. A typical new levee costs in the range of $300 to $400/linear foot. Actual costs depend greatly on the amount of fill required and, most importantly, on the proximity of the fill borrow area and the degree of soil conditioning required for placement. (DPW 2014)
- $5.5 million/km levee (ESA 2015) assuming a clay levee with 3:1 side slopes and 20-foot top width. A 10 foot levee meeting these criteria would then occupy a footprint of 80 feet, not including setbacks.

## 1.5) Pump station

Pump stations are centralized locations where one or more large capacity pumps pump stormwater from behind a levee or wall to the bay or creek. A common secondary impact of coastal barriers such as levees and seawalls is that they impede gravity drainage of flood flows from the land. Therefore, stormwater pumping facilities are needed to move stormwater over or through the barriers to prevent flooding. Pump stations tend to be expensive to design, build, and maintain. In critical drainage areas, an on-site power generator may be needed to maintain pumping ability in the event of electrical power outages (DPW 2015).

Pros:

- Effective when working and designed properly (DPW 2015).

Cons:

- Very expensive—one of the highest costs per unit of -per-gallon alternatives (DPW 2015).
- Subject to power outages and complete loss of pumping capability (DPW 2015).
- Higher maintenance costs, especially in more saline environments (DPW 2015).

Costs:

- Pump station costs can vary greatly depending on the size of the pump station and generator. Typical costs for design and construction for pump stations can vary greatly but would start at $500,000 to $1MD for smaller pump stations up to several million (for this study we used up to $4M for larger pump stations). The annual costs for electricity to run pumps (depending on usage) and pump maintenance and repair can be upwards of $50,000 per year (highly variable) (DPW 2015).

## 1.6) Tidal Gate

High tide gates are used more frequently in other countries. These floating or controllable tide gate structures are usually built across creeks, rivers, and even major waterways to limit the impact of high tides by closing during high tide events. Various types of gate structures are available. At a scale appropriate for Tomales Bay, a tidal gate could reduce or replace the need to elevate roads and structures. ESA's estimate was taken from a past project (Environ and ESAPWA 2013) that considered a tide gate/lock for Hueneme Harbor (~690 feet wide), while Tomales bay is much wider even at its constriction points (~2500 feet at Dillon Beach and headland south) (ESA 2015).

- Negative environmental impact.
- Medium-term flood protection.
- Protect against temporary flooding, storm surge and some sea level rise (CDA, DPW 2015).

Pros:

- Can be effective when properly designed, built, and maintained (DPW 2015).
- Tide gates can potentially protect a significant length of upstream shoreline relative to the length of the tide gate. May be the only viable solution where right of way for other solutions cannot be obtained (DPW 2015).
- A properly designed tide gate can provide protection without major levees and seawall costs and right of way acquisitions (DPW 2015).

Cons:

- Very expensive to build and maintain, especially on the soft soils that likely exist at the creek crossings at Richardson Bay's edge. On soft soils, expensive pile support structures will need to be built to prevent settling of heavy tide gates. Gate systems that rise and fall with tides require sophisticated control systems and large maintenance budgets (DPW 2015).
- As the bay tide elevation increases, the gates will have to be closed more often to be effective, which could cause water quality issues and impacts to fish (DPW 2015).
- As the gates close more frequently, tidal marsh habitat will be lost as the frequency and depth of inundation increases and existing marshes are blocked from transgressing landward. Several threatened and endangered species would likely be affected as well as fish populations in the bay (DPW 2015).
- Once this barrier has been established and people expect this level of flood protection, it will be difficult to stop maintaining it and increasing its height and days of closure as sea level rises. This reliance is also known as "moral hazard," and the same concern applies to all barriers, such as walls and levees (DPW 2015).
- In the event that the barrier is breached, catastrophic failure could occur if floods exceed the gate design criteria (DPW 2015).

Costs:

- Costs for flood gates vary greatly by type, extent, and size. Small tide gates may cost tens of thousands of dollar, and larger gates can cost in the millions of dollars. A cost of $1M to $2M per structure for the mid-size tide gates for the two main creeks draining into Richardson Bay is a likely minimum cost. This does not account for any mitigation requested by the regulatory agencies (DPW 2015).
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## 2) Nonstructural Measures: Protect

The alternatives in this category tend to be focused either on enhancing sediment supply and accretion processes or reducing sediment losses, and reduce or limit flooding. Implementing mechanisms for these types of alternatives will likely require the involvement of a regional planning entity. In general, these measures replace eroded sand frequently and repeatedly. Nonstructural measures attempt to work with natural processes and systems to achieve engineering goals while also providing other benefits such as habitat (ESA 2015).

## 2.1) Beach nourishment

Beach nourishment refers to placement of sand to widen a beach. The beach then provides flood and erosion protection to the backshore. However, it is generally assumed that the beach will diminish with time, requiring "re-nourishment". As sea level rises, the frequency of required nourishment increases.

- Neutral/moderate environmental impacts.
- Moderate cost.
- Offer short- to medium-term protection against temporary flooding and storm surge (CDA, DPW 2015)

Pros:

- Beach Nourishment may be a viable short term solution in areas with low erosion rates (ESA 2015).

Cons:

- Potential problems with beach nourishment include the construction impact to people and beach ecology (generally considered a short term negative effect), and changes to shore conditions that may result from difficulty in finding sand with the desired grain sizes. The success of the nourishment depends on the volume of nourished material, the grain size, and the proximity or use of sand retention structures (ESA 2015).
- The long-term effectiveness of this measure at reducing erosion is doubtful (ESA 2015).

Costs:

- $500,000/acre (ESA 2015)
- Considered as an adaptation measure in Southern Monterey Bay (ESA PWA, 2012), Opportunistic Beach Nourishment uses sand that is extracted from a flood channel, debris basin, navigation channel, harbor area, a by-product of construction or other source, where the main reason for extracting the sand is not to use it for beach nourishment. Costs associated with Opportunistic sand can be low, especially when providing a cost savings to the entity providing the sediment source by avoiding or reducing transportation and disposal costs (ESA 2015).

## 2.2) Dune restoration/ nourishment

Dune restoration would include placement of sand, graded and planted to form back beach dunes. Beach nourishment is recognized as a natural way of mitigating backshore erosion as well as maintaining a wider beach through sacrificial erosion of the dunes. A variant includes placement of cobble (rounded rock) which is often naturally present as a lag deposit[5] below beaches in California. This strategy includes the dune enhancement activities below:

- Dune augmentation (adding sand to dunes to provide protection during storm events), especially to raise low-

[5] Lag deposit refers to coarser sediments that accumulate over time at lower elevations during periods of eroded beaches, and subsequently covered by sand after the beaches recover.

lying beach access paths to prevent flood waters from flowing into the neighborhoods behind the dunes.
- Ceasing any activity that adversely affects the sediment supply of the dunes.
- Ceasing beach grooming. This would encourage dune vegetation establishment and dune formation. Beach grooming removes driftwood and wrack and reduces vegetative growth and dune formation.
- Planting vegetation. Planting native dune vegetation, together with wind action, will help build up and stabilize dunes.
- Fencing off sensitive areas and creating dune walkways
- Informational signs and other outreach activities to educate about the importance of maintaining stable sand dunes (ESA 2015).

Pros:

- Habitat benefits for several bird species (DPW 2015).
- Promotes nature-based solutions as alternatives to more traditional engineering approaches (DPW 2015).

**Cons:**

- Does not protect against permanent sea level rise. As with beach nourishment, this strategy would require periodic sand replenishment (ESA 2015).

Costs:

- $200,000/acre (ESA 2015)

## 2.3) Beach Dewatering

Generally, beach dewatering involves the removal of water from the beach to increase the natural accretion processes. Dewatering works on the hypothesis that a dry beach face will improve wave swash infiltration and thus deposit sediment on the beach. In theory, the lowering of the beach face groundwater during a falling tide promotes a small incremental enhanced accretion during each swash over the dewatered beach and integrated over many waves cycles may result in significant accretion of sand (ESA 2015).

Pros:

- Depending on current ground water levels, this may be feasible in the short term to sustain the wastewater treatment efficacy of the existing wastewater leach fields in the Stinson/Seadrift neighborhood (ESA 2015).

Cons:

- Elevated groundwater levels will continue to worsen with sea level rise and beach dewatering will be ineffective or expensive. Given the experimental nature of “beach dewatering” and the limited potential time horizon for efficacy, ESA suggests that this measure be replaced with installation of storage tanks and pump out service as a replacement to the current leach fields (ESA 2015).

## 2.4) Offshore bio-beds

Living Shorelines projects use habitat restoration techniques to manage the shoreline, reduce coastal erosion, and maintain coastal processes while protecting, restoring, and creating natural habitat for aquatic flora and fauna. Such techniques enhance habitat values and increase connectivity of wetlands and deeper intertidal and subtidal lands, while providing some amount of shoreline protection. ESA is currently in monitoring the SF Bay Living Shorelines project. This pilot project is investigating the ideal configurations and size scales of oyster reefs and eelgrass beds for habitat enhancement. Oyster elements all consist of a hard oyster settlement substrate of some type placed onto a supporting structure. In past projects, a wooden pallet has been used to support oyster shell or other substrates, while this project uses a PVC base structure. Oyster bag mounds were then placed on the base as an oyster recruitment structure (other small test pilot cases use relatively inexpensive modular cement structures as the oyster substrate). Experimental treatment plots of 32 by 10 meters were constructed parallel to shore, approximately 250 m from the shore, with eelgrass beds later planted between the oyster structures using shoot transplants as well as buoy-deployed seeding. In addition to biological recruitment monitoring by others, ESA is actively monitoring the sedimentation behind these oyster reefs to evaluate the erosion protection efficacy (ESA 2015).

Oyster reefs are considered potential erosion and flood hazard mitigation measures where waves are small and weak enough to be dissipated by the limited reef structures. Hence, this measure is potentially viable only in estuarine areas such as Tomales Bay and Bolinas Lagoon (ESA 2015).

## 2.5) Wetland enhancement

In areas that were previously wetland habitat, the conversion back to wetlands through restoration and revegetation may provide additional buffering of storm surges, habitat and water quality improvement. Combined with managed retreat of the shoreline, transgression of wetlands upland would maintain valuable habitat. In areas where wave attack is small (Bolinas Lagoon, Tomales Bay, etc.), wetland creation and vegetation of the shoreline could be effective in limiting erosion of otherwise exposed road embankments (ESA 2015).

This adaptation alternative involves placing fill in a manner that enhances wetlands but may result in a conversion of wetlands type (i.e., from subtidal to mudflats or mudflats to tidal marsh). In general, wetlands enhancement is an acceptable and sometime preferable permitting option for regulatory agencies. Wetlands constructed to a higher elevation provide wave attenuation benefits while still providing habitat and ecological benefits. This option includes engineered fill placement through dredge sediment or mechanical fill placement with trucks (DPW 2015).

- Moderate to high cost
- Offer short- to medium-term protection against temporary flooding, storm surge, and wave impacts.
- Wetlands can reduce wave hazards in sheltered waters like the San Francisco Bay, but are not a viable solution on the open Pacific coast except in sheltered areas such as estuaries and lagoons. Also, wetlands will not prevent inundation of low-lying areas unless they are backed by a flood protection levee (CDA, DPW 2015).

Pros:

- Can provide both flood protection and ecological benefits.
- Can potentially reuse dredged sediment from local creeks to raise wetlands, while reducing ongoing creek sediment dredging costs.
- Meets ecological goals for integrating wetlands into a multi-objective project (i.e., horizontal levee approach) (DPW 2015).

Cons:

- Currently, it is difficult to obtain permits to fill the bay even to create wetlands, though there are efforts to change this
- Wetlands projects are complex to design and permit since they must accommodate habitat and flood protection needs.
- The effectiveness of wetland solutions will diminish with higher levels of sea level rise unless grades are raised as the wave dampening ability of tidal wetlands diminishes with increased water depth (DPW 2015).

Costs:

- Costs for wetlands enhancement vary greatly by scale and quantity/location of fill source.

## 2.6) New wetlands creation

Another approach to creating wetlands (usually preferred by permitting agencies) is to excavate soils from existing vacant uplands down to the appropriate grades to allow for either/both tidal or seasonal wetlands to form (DPW 2015).

Pros:

- Newly created wetlands could be used as potential mitigation (i.e., offset areas) for other shoreline impacts likely to occur under other alternative strategies (DPW 2015).

Cons:

- Reduces existing uplands along the shoreline. In areas with limited space available along the shoreline, retreating from the uplands edge may be difficult in some areas. Relocating existing land uses and structures may require negotiations and payments (DPW 2015).

Costs:

- Costs for wetlands excavation can be estimated per acre. Typical costs are $10,000 to $60,000 per acre, but the range can be highly variable (DPW 2015).
- $20,000/acre (ESA 2015).

## 2.7) Horizontal Levee

"Horizontal levees" are earthen levees with flatter side slopes towards the water's edge and use the wave attenuation benefits of expanded wetlands in front of the levee to reportedly reduce the top of levee crest elevation and thus levee height and costs. The full horizontal levee also involves use of treated wastewater to infiltrate through permeable layers to enhance wetlands vegetation and recreate natural processes.

- Low to neutral environmental impact, with co-benefits.
- Moderate to high cost
- Offer medium- to long-term protection against temporary flooding, storm surge and some sea level rise, and wave impacts.
- Wetlands can reduce wave hazards in sheltered waters, but are not a viable solution on the open Pacific coast except in sheltered areas such as estuaries and lagoons (CDA, DPW 2015).

Pros:

- Horizontal levee projects combine flood protection benefits with habitat benefits by maintaining or enhancing wetlands along the water side of the levee. Much discussed by bay scientists and environmental engineers as a viable approach to multi-objective flood protection (DPW 2015).

Cons:

- Significant wave attenuation across a tidal marsh requires a minimum width of several hundred feet. In many locations on Marin's coast, finding enough space to create more tidal marsh will be problematic. If enough marsh cannot be created, the final levee crest elevation may not be significantly lowered and the cost benefits achieved. However, the ecological and wave attenuation benefits of horizontal levees combined with the benefits of expanded wetlands should be considered an important adaptation approach when developing a comprehensive plan for sea level rise (DPW 2015).

Costs:

- Costs for importing and placing fill vary significantly depending on the location and quality of the borrow source of sediment. Horizontal levee construction costs may be approximately the same as described for more traditional levees above. The Bay Institute Report (Bay Institute 2013) assumed a cost of $25/cy for engineered fill and $15/cy for placing non-engineered fill to create wetlands on the water side of the proposed levee (DPW 2015).
- ESA previously worked on The South Bay Shoreline Study (USACE 2015) with the purpose to decrease tidal flood risk that exists for large areas of low-lying terrain protected by non-engineered dikes, restore tidal marsh habitat that was lost in the past creation of the salt ponds and maintain recreational opportunities. USACE provided costs for building an ecotone over an existing ground surface of about 0-2 feet NAVD. The slope extended from EL 5 to EL 16 at 30:1 to accommodate 5' of sea level rise and extending down to below the vegetation colonization elevation. Using USACE unit cost estimates, the ecotone was about $1,200-$1,400 per LF (roughly $4,000,000 to $4,500,000 per kilometer) or about $13 per CY assuming that delivery of the material to the site was free. For that study the cost of placement & hydroseeding was included. Container plantings, irrigation, and maintenance was not included in the cost estimates. Prior successful implementations of this concept have occurred at Warm Springs Marsh (south San Francisco Bay) and the Hamilton Wetlands Restoration Project (Novato, Marin County)[6].

# 3) Accommodate

## 3.1) Elevate buildings

An important adaptation approach is to elevate structures above coastal flooding elevations. This measure is consistent with FEMA guidelines. Note that unlike storm event flooding, sea level rise entails consistently recurring flooding that worsens over time as water levels rise. Elevating structures is only one aspect of this approach: associated utilities such as roadways, power, sewer, water, and electrical connections also need to raised or waterproofed to some extent to avoid damage. These costs should also be considered (DPW 2015).

As part of the Climate Ready Southern Monterey project, ESA developed unit cost estimates for elevating structures in both flood

[6] ESA PWA, 2013. Hamilton Wetland Restoration Project Breach and Completion Contract, Supplemental Design Documentation Report, Prepared for the US Army Corps of Engineers, April 19, 2013, ESA project number DWO1764.08.

zones and in wave impact zones where wave impact results in increased loads on the structure. Many homes and business structures along Tomales Bay, some already on piles, can be elevated to limit inundation with rising sea level (ESA 2015).

- Moderate environmental impact
- Moderate cost
- Offer short- to medium-term protection against temporary flooding. Elevating buildings is a viable option in the Bay and the open coast. On the open coast, shoreline retreat may expose building foundations to damage in future (CDA, DPW 2015).

Pros:

- Can be effective if done properly and associated utilities are also raised above future tidal flooding levels (DPW 2015).

Cons:

- Depending on the sea level rise scenario used, the possible elevation change can be significant. Redesigning and rebuilding structures and relocating utilities and infrastructure can be very expensive.
- Not all slab on-grade homes can be raised so might have to be demolished and rebuilt.
- Any structures and infrastructure not elevated would not be protected and still be subject to flooding (DPW 2015).
- Potential scenic, visual and community character impacs
-

Costs:

- Costs for raising structures will have to be determined based on the type and number of structures. A recent study estimated a typical cost for raising a single family house at approximately $50,000. Larger homes and commercial structures will cost significantly more to elevate. However, sea level rise, as opposed to riverine flooding, is a more permanent type of flooding and therefore, it would not be enough just to raise structures; the associated utilities and infrastructure, such as roads, would also have to be raised. These costs will depend on many factors and will be very significant (DPW 2015).
- $140/sf in flood zone, $250/sf in wave zone (ESA 2015)

## 3.2) Elevate or reconstruct roads

As part of the Climate Ready Southern Monterey project, ESA developed unit cost estimates for elevating roadways with bridges or trestles, as well as cost for reconstruction of a secondary roadway. These costs are provided in Table 1. Critical roadways designated for elevation through the vulnerability assessment could be improved by a combination of elevation by earth fill and armoring. Roads exposed to wave action on the coast will require heavier armoring, while waterfront roads along Bolinas Lagoon or Tomales Bay may be sufficiently armored with a lower cost revetment or combined with a fronting ecotone slope.

- Initial negative environmental impact. Could provide positive long term environmental impacts if designed to avoid the blocking of beaches/wetland inland migration.

Costs:

- $570/sf to elevate road on trestles, $280/sf to reconstruct secondary road (ESA 2015)

## 3.3) Raise grades (add fill to raise the ground elevation)

This alternative adds fill to raise the land surface above flooding elevations. This alternative requires large amounts of imported fill to raise site grades and thus would also require the subsequent rebuilding of the communities at the new higher elevations (i.e. buildings and all associated infrastructure). This alternative is a large engineering undertaking that to our understanding has been implemented in parts of Japan (also known as "super levees") (DPW 2015).

- High cost
- New road construction or elevation of an existing road have initial negative environmental impacts
- Medium- to long-term protection against temporary flooding and inundation (CDA, DPW 2015).

Pros:

- Once completed, raising the land surface would be a very effective and relatively low maintenance solution.
- Views from the new elevated land areas might be enhanced.
- Might allow for more modern design approaches for floodable developments with greenways and design approaches that combine natural with urban systems (DPW 2015).
- Designs could incorporate horizontal levees/living shorelines at the water's edge

Cons:

- Would take a large amount of fill as well as significant costs to rebuild the entire community at higher elevations.
- People in areas not elevated would have their views blocked by elevated areas.
- Would require complete agreement across all public entities and private homeowners and businesses. While super levees have been built in some areas of Europe/Japan, through consensus or eminent domain, the level of consensus needed to build them in the USA is more difficult to achieve. This approach may be more applicable as a longer-term planning goal if sea level rise cannot be managed using other approaches.
- This approach is potentially costly and how well it could be implemented is unknown. Also, associated levees would need to be stabilized, either with a natural sloping edge or perhaps an engineered structure such as a bulkhead or hardened levee face (see Category 1 engineered structures above).
- Added fill may be more vulnerable to seismic issues (DPW 2015).
- Could prevent beach and habitat migration.

Costs:

- Costs would be substantial. Structures within areas to be raised would have to be removed and abandoned or rebuilt at higher elevations. New infrastructure would have to be built, at substantial cost. Fill costs are always very difficult to estimate since they depend greatly on borrow source location and fill quality (DPW 2015).

## 3.4) Floodproof buildings

- Neutral/moderate environmental impact.

- Low- to moderate cost.
- Offer short- to medium-term protection against temporary flooding. Waterproofing could be a good option for buildings exposed to infrequent nuisance flooding (DPW 2015).

## 3.5) Floodable and floatable development

This approach involves rebuilding structures and associated infrastructure (the entire development) to adapt to sea level rise. Designs for creative floodable housing structures and communities that can withstand and accommodate flooding are being proposed for many locations around the world. Floodable development is a relatively new type of urban design for zones (or tiers) of areas and buildings where more or less flooding is allowed. The lower tiers would be designed for areas such as wetlands, parks, and open spaces that can handle more consistent flooding, moving up to areas and structures at higher elevations that are not designed to be flooded (DPW 2015).

- Neutral/moderate environmental impacts.
- Medium- to long-term protection against temporary flooding (CDA, DPW 2015).

Pros:

- As housing is rebuilt, there will be more opportunities to rebuild the housing stock in a way that adapts to sea level rise. Given the magnitude of sea level rise projections, floatable housing—house boats or floating communities—may be a viable solution for inhabiting low-lying areas adjacent to the bay that are subject to direct coastal flooding (DPW 2015).

Cons:

- Costs for redevelopment including utilities if not borne by private developers. Ultimately, may require rethinking the shoreline planning and density limitations and require community consensus as private development would likely result in increased development density (DPW 2015).
- Potential negative environmental impacts through occupying space that could potentially be open space and/or habitat.

Costs:

- Costs for this approach depend on the scale of the adaptation effort and construction requirements; costs can be estimated at 2,400,000 redevelopment costs could inform a more accurate estimation. Commonly, redevelopment costs are financed by private developers in exchange for market-based property income (DPW 2015).

# 4) Hybrid Shoreline Protection

Recent experience indicates that hybrid approaches that include a mix of adaptation measures may be the most practical in some situations. For example, the Ocean Beach Master Plan includes a hybrid approach in south Ocean Beach where prior development and erosion have resulted in an acute hazard to both built and natural assets. At this location, a low-height seawall is proposed but at a location established as far landward as possible which requires removal of roadway and parking within a managed retreat framework [3,6]. The plan also includes beach nourishment and dune

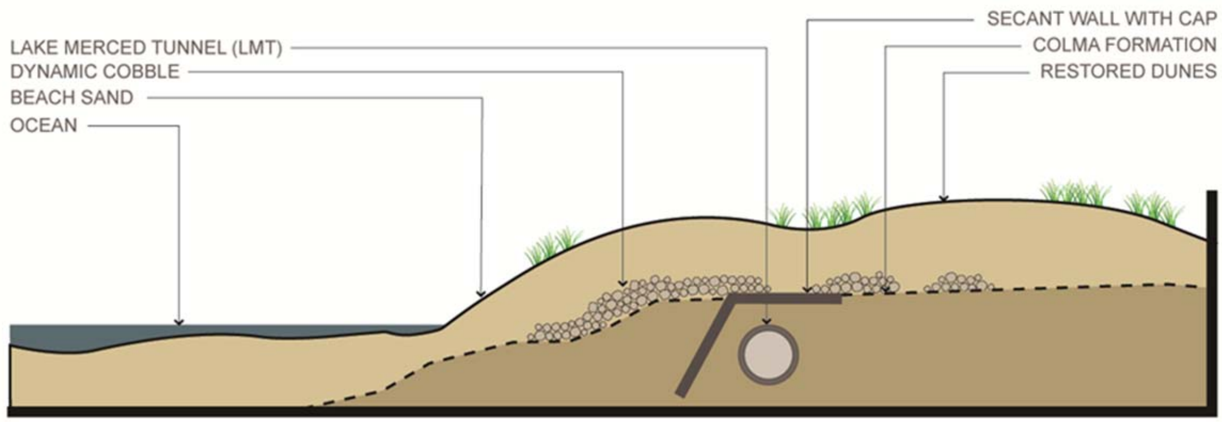


Figure 1: Conceptual cross section of the south Ocean Beach hybrid adaptation strategy which includes low-profile armoring as well as beach nourishment and dune construction in space presently occupied by rubble, parking and a roadway. Source, ESA PWA 2015.

construction, and includes adaptive management with revisions anticipated for higher sea level rises after 2050 (ESA 2015).

## 4.1) Characteristic Applications

### *Stinson Beach*

Stinson is currently a dune-backed beach, with either homes or park facilities built behind. It is a major recreational attraction, and thus preserving the beach should be a priority when developing adaptation strategies. We recommend in this case a hybrid solution. Initially, for low sea level rise amounts, dune enhancement on the back beach is recommended. A linear sand embankment would be constructed and planted, with the expectation that it would erode during large wave events, thereby dissipating wave power and providing sand to the beach. The "sacrificial" dune would be rebuilt as needed. Eventually, with greater sea level rise, we expect that it will not be practical to maintain a dune, and additional measures would be employed. There are several options. One option would combine a low profile seawall at the back of beach with a cobble toe that is then covered by sand, as well as continued sand placement. All measures would be installed as far landward as possible, and take advantage of any realignment of built assets (retreat). See Figure 1 for a conceptual cross section of this type of solution proposed for the Ocean Beach Master Plan (ESA 2015). A second alternative would include the Structural Modification measure, resulting in buildings being raised on piles and roads and utilities adjusted. This alternative would also benefit from managed retreat actions that remove built assets from the higher risk areas progressively over time and sea level rise. This alternative has the advantage of allowing shore migration while the first alternative will likely result in reduced beach width. Both alternatives have limited sustainability because large amounts of sea level rise will result in migration of the shore or high hazards if the shore is held in place (ESA 2015).

### *Seadrift*

Seadrift is currently a narrow beach with revetment armoring the backshore. Homes behind this structure will become increasingly vulnerable to coastal hazards with sea level rise. We anticipate that management measures may be difficult to implement owing to the high costs driven by existing property values and density of development. We recommend consideration of structural modification measures such as lifting homes on piling. Subsequently, as sea level rises, the sandy spit could be allowed to migrate north and the most seaward properties removed and potentially relocated on the lagoon side. Conceptually, natural wave overwash processes will maintain the spit and beaches, but move them north (ESA 2015).

### *Bolinas*

Steep eroding cliffs in Bolinas continue to jeopardize homes built at the cliff top.  If hard measures are taken along the cliffs in Bolinas, the beach can be expected to erode and eventually disappear, affecting recreational opportunities. Armoring to prevent bluff erosion is not recommended because it would result in loss of the fronting beaches over time, resulting in increased loadings and structural requirements, and the costs may outweigh the values of the properties. To maintain the beaches below, existing armoring can be removed and development removed or relocated in a managed retreat scenario. Easements and other land use policies are recommended to limit further construction and investment in the most hazardous areas. These easements would move (or "role") with bluff and shore erosion. Services such as utilities and roads would also be realigned in an orderly manner over time to limit costs and avoid catastrophic failure and hazardous conditions. Structural modification measures (e.g. pile foundations) as well as innovative management measures (e.g. conservation easements) could facilitate the overall retreat adaptation strategy (ESA 2015).

### *Eastshore, Inverness*

Within Tomales Bay, communities such as Marshall and Inverness are subject to rising sea level but may not experience as much erosion or wave hazards as other communities on the Pacific coast owing to the lower wave exposure in these relatively sheltered waters. Structural adaptation measures could be a viable adaptation strategy in these areas. Homes and other structures currently over water could be raised higher, and portions of roadways that are critical roads for emergency access should also be raised to maintain access at higher water levels. Horizontal levees may serve as practical measures where land use, space and habitat allow.  Realignment of development farther landward within a managed retreat context should be accomplished as much as possible in order to maintain no net loss of ecological function of coastal assets as well as limiting costs and increasing resilience. For example, the cost associated with structural modification is reduced if the structure is moved inland. An example of the analysis approach to assess these measures is the planning accomplished for the Cyprus Grove facility of Audubon Canyon Ranch (PWA, 2007) (ESA, 2015).

# 5) Governance

## 5.1) Regulatory Tools

### *Managed retreat/ relocation*

Managed retreat is a broad strategy that can encompass the use of all erosion mitigation measures while allowing long term shore recession over time, requiring the removal of structures and infrastructure, realignment of roads, etc. ESA has completed various projects in the past that implemented retreat of oceanfront development to restore beaches and shoreline habitat[7,8,9,10]. The cost of these managed retreat projects ranged from about $4.5 Million per acre of beach to $45 Million per acre: The lower value is associated with built assets that are public and limited (e.g. parking lot) while the higher value entails high-value utilities. The costs for retreat in areas consisting of private property are not well defined by this project data, but could be approximately estimated by assessing the value of the property, and the compensation mechanism (e.g. purchase, easement, etc.). One of the most difficult elements of this measure is uncertainty over who pays and who benefits, and quantification of benefits. Typically, this measure is part of a strategy that includes public cost to rebuild public infrastructure and compensate private property owners for their property net the costs associated with shore armoring (ESA 2015).

Although this may be the most straightforward method for protecting development that is under imminent or long-term threat of being damaged or destroyed, it is often assumed to be technically or financially infeasible. Often there is not sufficient space or land available for the structure to be relocated, and the property owner is often responsible for the full cost of the relocation. Accordingly, this approach has been most typically used for public property and by government agencies such as the California Department of Parks and Recreation in this region (ESA 2015).

In this approach, areas would be allowed to be flooded and possibly converted to occasionally flooded parklands/uplands and transition zone habitat, and, ultimately, as sea level rises, to coastal wetlands. These areas could potentially be used as mitigation for impacts to wetland areas. Structures and facilities in the planned retreat areas would be removed and potentially relocated. In other places like Louisiana, some residences within coastal areas have retreated due to the high cost of flood insurance and rebuilding (DPW 2015).

- Initial negative environmental impact through re-establishing development elsewhere, long-term positive impact.
- Long-term protection against all hazards. High benefit due to moving infrastructure out of floodplain. Could work for isolated assets (CDA, DPW 2015).

Pros:

- Ultimately provides reduced costs for flood protection (DPW 2015).

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[7] Philip Williams & Associates, Ltd. (PWA) PACIFICA STATE BEACH RESTORATION PHASE 1 Prepared for RRM Design Group and City of Pacifica, January 16, 2002, Amended May 22, 2002, PWA Ref. # 1547

[8] Philip Williams & Associates, Ltd. (PWA) SURFER'S POINT MANAGED SHORELINE RETREAT & ACCESS RESTORATION Preliminary Design Prepared for RRM Design Group and the City of Ventura, August 2, 2005 PWA Ref. # 1708.

[9] ESA, 2015. ESA,SPUR, Moffatt & Nichol, McMillen Jacobs Associates, AGS, Inc., Coastal Protection Measures & Management Strategy for South Ocean Beach, Ocean Beach Master Plan: Coastal Management Framework, Prepared for the CCSF Public Utilities Commission. Project D120925.00

[10] PWA 2008. Goleta Beach County Park, Park Reconfiguration Alternative, Prepared for The Coastal Fund at UCSB, Surfrider Foundation – Santa Barbara Chapter, Environmental Defense Center, Prepared by Philip Williams
& Associates, Ltd. November 24, 2008, PWA REF. #1940.00

- Numerous environmental, recreational and aesthetic/scenic benefits

Cons:

- Potential loss of properties, businesses, and housing as well as park and public use areas.
- Likely requires relocation of utilities for servicing built areas or remaining or rebuilt areas.
- While costs for retreat may be relatively low, costs for buying out property owners or for rebuilding structures and infrastructure elsewhere can be significant. Very limited—if any—space for rebuilding upslope exists in Marin County's coastal zone, so this approach is probably not a very feasible option (CDA, DPW 2015).

Costs:

- Costs for retreat from coastally flooded areas are typically lower then engineered protection, and if the retreated areas can be used as mitigation, they may also be useful in reducing costs for other alternatives. However, costs for buy-outs or rebuilding may be significant. The loss of some areas that have a lot of community usage may have impacts. This alternative may be useful when it is deemed that protecting these areas is beyond the likely means of the local community (DPW 2015).
- Costs for retreat are variable and depend on the costs for removal of existing structures if any, as well as any requirements for compensation and/or for relocation. As such, retreat from parklands would be less expensive than retreat from urbanized areas. Costs would also depend on the degree of environmental clean-up that would be required to return these lands to the tides or habitat areas (ESA 2015).

### *Zoning and Overlay Zones*

Areas that are particularly vulnerable to sea level rise impacts can be designated as hazard zones and specific regulations can be used to limit new development and/or encourage removal of existing development in such zones. Open areas can be designated as conservation zones in order to protect and provide upland areas for wetland and habitat migration or for additional agricultural land. The process for designating overlay zones could include the development of coastal flood maps that include areas that will be subject to wave action and flooding due to sea level rise. These maps may be able to rely upon existing flood maps, such as the FEMA Flood Insurance Rate Maps, for current flood areas and base conditions, but should be augmented to include future conditions, including sea level rise, likely to occur through the life of proposed new development (CCC 2015).

Changes in zoning and permitting to adapt to climate change can be implemented in conjunction with any and all alternatives (ESA 2015). Marin County could consider developing an overlay zone for sea level rise, with performance standards for structures within that zone (CDA 2015).

- Near to mid-term moderate environmental impact. Long-term positive environmental impact.
- Long-term protection against temporary flooding, inundation and erosion.
- High flood protection benefit due to moving infrastructure out of floodplain. Large scale retreat (or realignment) could be expensive depending on level of development and infrastructure present. (CDA and DPW 2015)

Pros:

- Zoning is a key part of any long-term planning effort and provides certainty and vision for the local community. (DPW 2015)
- Fits well within the planning horizon for sea level rise. Since this is a relatively slow moving disaster, we have an opportunity to implement these types of changes in time to inhibit the major impacts of sea level rise. (DPW 2015)

Cons:

- Zoning and ordinance changes are likely to face political opposition, and may lead to takings lawsuits (CDA 2015).

Costs:

- Low cost for municipality but transfers cost to property owners (CDA 2015).

### *Setbacks for development*

Ensure structures are set back far enough inland from the beach or bluff edge such that they will not be endangered by erosion (including sea level rise induced erosion) over the life of the structure, *without the use of a shoreline protective device*. When used to address future risk, setbacks are normally defined by a measurable distance from an identifiable location such as a bluff edge, line of vegetation, dune crest, or roadway. Establish general guidance and criteria for setbacks in LCPs that consider changes in retreat due to sea level rise. Require detailed, site-specific analyses through LCPs and CDPs to determine the size of the setback taking into consideration sea level rise and establish the expected life of the structure (for example, the time period over which the setback should be effective). (CCC Guidance)

### *Siting and Design Requirements*

Establish and implement standards for building siting and construction that avoid or minimize risks from flooding and erosion and increase resilience to extreme events within sea level rise hazard zones. Such standards should be included in LCPs as additional development controls in areas that are identified in the LCP as hazard areas, and applied in specific projects through a CDP.

- Low cost for municipality but transfers cost to property owners.
- Moderate environmental impact
- Protects against temporary flooding and some sea level rise (CDA, DPW 2015).

## 5.2) Spending Tools

### *Capital Improvement Programs (CIPs)*

Guide future investments in public infrastructure based on community needs and coastal hazards. Government agencies can use CIPs to site new infrastructure out of coastal hazard areas, discontinue maintenance and repair of infrastructure that is repetitively damaged, or relocate or retrofit existing infrastructure to be more resilient to sea level rise (GCC 2011).

### *Acquisition and Buy-out Programs*

Fee Simple Acquisition is the purchase of vacant or developed land in order to prevent or remove property from the danger of coastal hazards such as erosion. As an erosion avoidance measure, this technique would transfer the erosion risks from the current property owner to the group or entity willing to acquire the property. Normally, the Fee Simple Acquisition is done to remove the property from being developed and prevent the construction of buildings or other capital improvements that would eventually be in danger from erosion. Fee simple acquisition is not likely to be effective when the property is in public ownership. However, one hybrid approach could include a fee simple purchase followed by a lease or rent back option until the property becomes uninhabitable. This hybrid may enable public investment to recover some of the initial purchase cost (ESA 2015).

Costs:

- Cost of Fee Simple Acquisition is potentially high based on perception of developed land value, potential loss of tax revenues, and transfer of legacy burdens. For this alternative, it is typically assumed that parcels are purchased at Fair Market Value. Conceptually this is likely to require the highest upfront costs although the cost may be less when a parcel is threatened by erosion and the owner is considering constructing shoreline armor, rather than after the property is damaged (ESA 2015).

### *Conservation Easements*

A conservation easement is a legally enforceable agreement attached to the property deed between a landowner and a government agency or a non-profit organization that restricts development "for perpetuity" but allows the landowner to retain ownership of the land. Conservation easements can be applied to any coastal parcel, but typically where a large and or valuable parcel with environmentally sensitive elements exists, and the landowner is willing to enter into the agreement.

The cost of conservation easements depends on willingness of seller, costs associated with maintenance and monitoring of easements, as well as the implementing mechanism. In general, someone has to file, hold, and enforce a conservation easement on the sending parcel to ensure that future land use planning bodies cannot decide to allow development in the sending area. Either local government or a third party (e.g., an NGO) could hold the easement. Filing/management/enforcement of the easement can have costs. There may not be a public cost to acquire the easement if the easement is included as a condition to a coastal development permit for some related development activity. There may be administrative cost to filing, managing the holding of, and enforcing the easement, depending on whether the local government or a third party (e.g., an NGO) holds the easement. Also, there could be lost property tax revenue and altered property values (ESA 2015).

Conservation easements could be used as a tool to preserve lands that serve as flood buffers, habitat or migration corridors. Government agencies and citizens can work with land trust organizations to convert at-risk areas to open space. Similarly, existing open areas can be designated as conservation zones to protect and provide upland areas for wetland and habitat migration or for additional agricultural land. Work with these organizations to conduct monitoring activities.

### *Rolling Easements*

Rolling Easements are open space or conservation easements that move or ambulate with some identified reference feature, such as the Mean High Water line (MHW) for coastal properties. As the coast retreats the easement line migrates along with it, inland on a parcel, then any development is removed and becomes part of that easement. This approach ensures maintenance of beach width and protection of the natural shoreline by requiring humans to yield the right of way to naturally migrating shores. Rolling easements may be implemented by statute or, more typically, by specifying that a conservation easement "roll" or move landward as the shore erodes.

Rolling easements have both costs and benefits. More transaction costs can be anticipated in densely developed coastal areas. Like all easements, Rolling Easements will require some regular inspection and potential enforcement. There may not be a "cost" to acquiring the easement if the government prevails against a challenge on a public trust or related law theory, but such resolution may require litigation, which could involve significant legal costs. Alternatively, the functional rolling easement (in the form of a "no future armoring" policy) is implemented using a condition to a coastal development permit (CDP), and thus is considered "costless." Ultimately, the rolling easement could result in lost property tax revenue and decreased property values—but this is decades away. Also, one can assume there will be administrative costs associated with enforcing a rolling easement (ESA 2015).common

## 5.2) Tax and Market-based Tools

### *Transfer of Development Credit/Rights*

Transferable Development Credit (TDC) programs allow the transfer of the development rights from one parcel to another parcel. These programs are tools used by land use planners to direct development away from certain sensitive areas (source sites) and into areas that can better accommodate it (receiver sites). TDC, also known as Transferable Development Rights, could be applied where undeveloped sensitive or hazardous parcels exist (to transfer potential development from) and desirable areas to transfer potential development to are available. TDC programs are widespread throughout the country and vary based on local land use planning priorities and needs. While the design specifics are left to the discretion of a local government, in general a TDC program identifies source sites (from which a TDC is taken away) and receiver sites (to which a TDC is added). The owner of a source site can sell a TDC to the owner of a receiver site. The seller typically retains ownership of the "sending" property, but relinquishes the right to develop it, while the buyer is able to intensify development on the receiver site more than would otherwise be permitted under existing zoning. Source or sending sites may be sensitive land areas such as endangered species or wetlands habitat, or areas prone to coastal hazards such as erosion or landslides. Owners of source sites receive monetary compensation from the sale of the TDC and in the form of potentially smaller property taxes, while owners of receiver sites have assurance of future development rights on their site. TDC programs may provide a higher level of certainty over traditional zoning efforts because of the specificity of the amount and location of future development.

TDC programs do, however, require extensive planning and sustained implementation and enforcement over the long term. An integral key to success will be the willingness of the local community to participate in such a program, which will undoubtedly be linked to financial incentives made available. Some potential complications can occur if transfers are between jurisdictions, one jurisdiction could lose part of its tax base and also lose part of its developable land inventory. Some consideration of the net benefit to the community (e.g. tax receipts vs. required government services) may be needed. Other considerations could include access to services, water limitations, agricultural conversion and zoning changes (GCC 2011).

# Appendix B

# ESA MEMO -
# MARIN COUNTY
# COASTAL HAZARDS
# AND
# SLR ADAPTATION
# STRATEGIES

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# memorandum

date 4/28/2016

to Alex Westhoff, Jack Liebster, Lauren Armstrong

from James Jackson PE, Bob Battalio PE

copy Jeremy Lowe, SFEI (subcontractor)

subject Marin County Coastal Hazards and SLR Adaptation Strategies

## Purpose

This memo was developed after discussions with the County to highlight possible adaptation measures for communities at risk, further explore the cost, timing and implications of alternative strategies in a "Case Study" for Stinson-Seadrift beaches, and provide guidance regarding shoreline monitoring and triggers for adaptation strategies. Geographic areas covered in this memo are shown in Figure 1.

### Contents

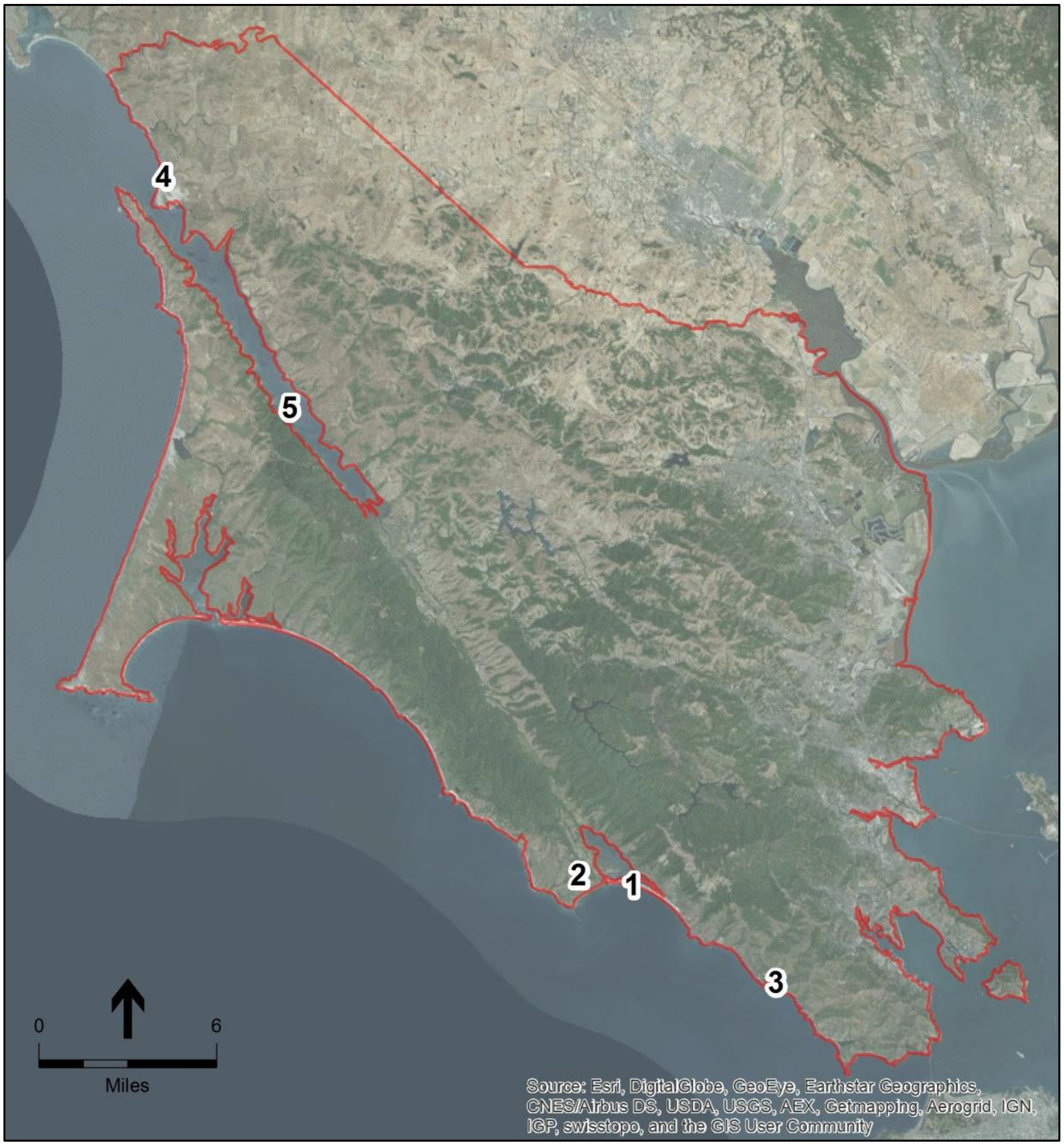


**Figure 1. Marin County border and geographic focus areas in this report: 1-Sinson/Seadrift, 2-Bolinas, 3-Muir Beach, 4-Dillon Beach, 5-Tomales Bay.**

# 1. Shoreline Erosion and Flooding Hazards

Sea level rise (SLR) increases the potential for erosion and should be considered for a full vulnerability assessment of coastal property and resources to future conditions. The increased rate of shoreline erosion with SLR in Northern California was previously modeled and mapped for the Pacific Institute study (PWA 2009), which included Marin County. For the present study, ESA utilized past model input data from the PI study to model and map coastal erosion amplified by the various SLR scenarios selected by Marin County with refined methods (ESA 2015a). This is the best available estimate of shoreline erosion that considers future SLR for Marin County. The OCOF (Our Coast Our Future) study (Ballard et al 2014) provides erosion hazards derived from USGS historic erosion rates, but does not consider increased erosion in response to SLR. The erosion data developed for the present study was used to assess existing and future hazards and asset vulnerability and is the basis for adaptation action triggers, explained in section 2. Triggers for Adaptation Actions.

In addition to amplifying erosion hazards, SLR will increase the extent of frequent (chronic) inundation in low lying areas and result in more severe storm (event) flooding. Adaptation measures should be tailored to the governing flood hazard mechanism (chronic or event), and will be initiated at determined trigger points which are discussed below.

# 2. Triggers for Adaptation Actions

Adaptation strategies should be in place when projected hazards surpass some pre-determined level of risk, either frequency or consequence. In this section, various erosion and flooding mechanisms are discussed to inform the County and its residents about potential trigger options to consider while deciding when to implement adaptation measures, such as nourish beaches and raise or relocate homes, roads and other infrastructure. The trigger type depends on the level of service the infrastructure provides (e.g. critical roadway versus park driveway) and what consequence (how deep/ far) and frequency (how often) of erosion or flooding impact is acceptable. The science behind both erosion and flooding triggers are described below, and professional judgement is needed to choose the appropriate trigger for specific assets. Each Community and the County will need to decide how to address future hazards, and therefore ESA's work is advisory only, and subject to revision based on additional information and further analysis.

## 2.1 Flooding

The following tide datums were compiled from the Point Reyes tide gauge (NOAA#9415020)[1], and could be used to develop triggers for sea level rise adaptation of different assets at risk:

**Mean High Water (MHW)** – A tidal datum. MHW is the average of all the high water heights observed over the National Tidal Datum Epoch (a 19 year period). MHW equals 5.1 feet (1.6 m) NAVD at Pt Reyes tide gauge. Inundation at MHW typically occurs 1-2 times per day and can last a few minutes to a few hours, depending on the tidal cycle. MHW is not necessarily exceeded every day.

**Extreme Monthly High Water (EMHW)** – A highest high water level that is reached once in a month. From existing monthly high water level records at the Pt Reyes tide gauge, EMHW is approximately 6.9 feet (2.1 m) NAVD.

**1-year Water Level** – Water level that is exceeded on average once every year, or has a 99% chance of being exceeded in any year. The 1-year water level is about 7.1 feet (2.2 m) NAVD, other recurrence interval flood levels are shown in Figure 2 in the MSL datum.

One could imagine choosing a different level of acceptable impact for a house compared to secondary roadway. For example, a road that is only used for recreation to access a beach park may tolerate flooding once a month but flooding every other day would limit access, so the EMHW could be chosen as a trigger for raising the road. On the other hand, a critical road such as Calle Del Arroyo in Stinson Beach that is the only access route to residences should have a higher level of acceptable impact so that it is operable for emergency situations. In this case, a greater level such as a 50-year or 100-year flood elevation could be used to set a trigger to initiate adaptation measures. For underground utilities such as gas and septic leach fields that are affected by high groundwater, the MHW level could be used to determine a trigger for adaptation as this is more likely to govern

[1] Accessed at http://tidesandcurrents.noaa.gov/datums.html?id=9415020

groundwater levels. Additional factors could play into the trigger selection such as infrastructure materials (pavement that degrades quicker under prolonged flooding versus a building that is floodable up to a certain depth). An additional freeboard of 1-2 feet may be added to the chosen tide datum to account for uncertainty and response time, and this “safety factor” or “buffer” may be increased to account for sea level rise over time.

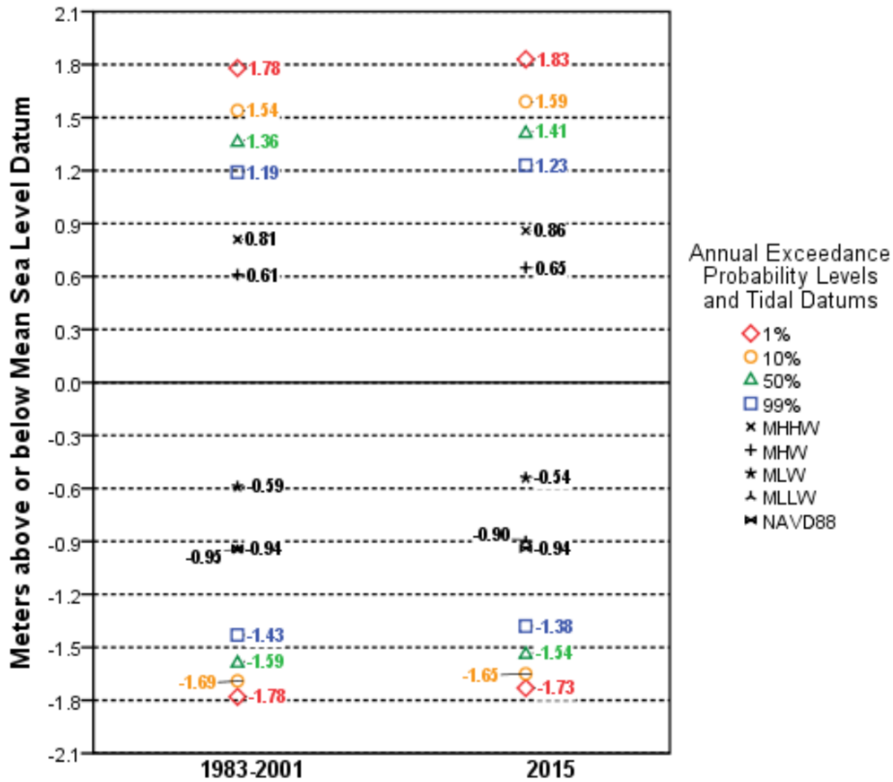


**Figure 2. Point Reyes tide gauge (NOAA#9415020) extreme water levels.**
**NOTE: to convert values to NAVD, add MSL = 0.94 m NAVD**

## 2.2 Erosion

Using data from past studies (PWA 2009), ESA developed erosion rates and storm erosion impact distances to evaluate vulnerability to beaches and waterfront property/infrastructure and are applied here to suggest a range of triggers to initiate adaptation measures. The geomorphic indicators for vulnerability of coastal property and infrastructure are the backshore (toe) elevation and the dry beach width which requires the tracking of shoreline position (Figure 3).

**Toe elevation (grade elevation at back beach)** – The location where the beach meets the back beach dune, cliff, or armoring structure. The toe elevation is compared to total water levels and used as an indicator of the amount of wave energy that could reach the back beach and cause erosion and overtopping. The deeper the water at the toe, the larger the waves that can reach the back beach. This elevation varies as the beach erodes in the winter/spring and accretes in the summer/fall. Extreme low values are an indication of exposure the backshore experiences during an extreme winter (such as this 2015-2016 El Niño), and are more likely to occur in the winter and spring, following erosion during winter storms.

**Dry beach and dune width** – The dry beach width functions as wave energy buffer for the backshore. Dry beach is defined as beach above Mean High Water (MHW), Mean Higher High Water (MHHW) or similar (beach berm). Wave run-up dissipates with distance traveled over a beach, and hence wider beaches result in lower run-up and less backshore erosion. Conversely, a narrow (or absent) fronting dry beach offers little protection to the backshore; more wave energy reaches the backshore which results in greater run-up, erosion of dunes and bluffs and high hydrodynamic loading on coastal armoring structures.

**Shoreline position** – The shoreline location provides a means of tracking shore changes and estimating the volume of sand in the beach. In combination with the back shore location, a dry beach width can be calculated. The shore line is typically defined as the elevation of Mean High Water (MHW), Mean Higher High Water (MHHW) or similar.

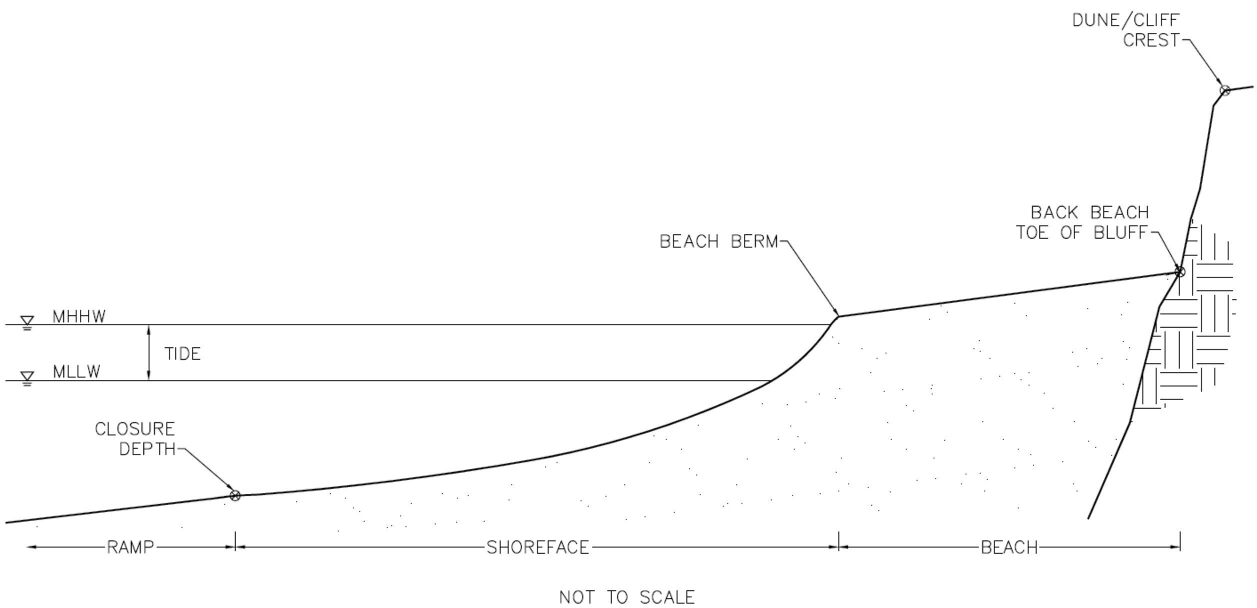


**Figure 3. Shoreline morphologic attributes.**

Dimensions of these geomorphic indicators vary depending on the location, and are influenced by wave exposure and littoral processes. In the case of an armored backshore (e.g. Seadrift) the beach elevation at the toe of structures will serve as an indication of the exposure of the structure to wave action. As the fronting shoreline recedes towards the structure with sea level rise, the beach will likely drop in elevation at the structure. This is because the structure is closer to the shoreline and experiences increased scour caused by the deeper and faster-moving wave run-up and reflection of wave energy by the structure. As the beach elevation drops at the toe of structure, more wave energy will reach the structure, resulting in increased run-up and overtopping and more rapid dropping of beach levels and degradation of the structure. To guide long term and emergency management activities, the following vulnerability triggers and potential actions are proposed:

<u>**Toe elevation**</u> – Thresholds for minimum toe elevations could be considered in two tiers:

- **Long term "maintenance" trigger** = Elevation to be determined, generally the elevation of the beach berm (break in slope) that typically occurs several feet above high tide, depending on wave exposure, at a particular location.

- Trigger action – increase monitoring frequency, evaluate resources at risk, consider actions (nourish, notify residents, etc).

- **Critical condition trigger** = Mean tide or sea level.
  - Trigger action – emergency nourishment, evaluate resources at risk, consider other actions.

**Beach width** – Thresholds for minimum beach width were considered for two tiers considering the seasonal variability of the beach profile and characteristic storm erosion:

- **Long term "maintenance" trigger** = A dry-beach width to be determined, but conceptually the width approximately equal to or greater than the typical summer-winter change plus an allowance for an extreme erosion event. Provisionally, this distance is about 85 feet (25 meters) at Stinson/Seadrift beaches, based on available estimates of storm erosion (ESA, 2015a). In some areas the beach is already very narrow and a smaller distance may be applicable: Provisionally, the erosion distance with an annual recurrence of 2 to 5 years was estimated to be 50 feet (15 meters) at Stinson/Seadrift beaches. A study on past seasonal beach width fluctuations along with future monitoring would further refine the selected trigger distance.
  - Trigger action – increase monitoring frequency, evaluate resources at risk, consider other actions (nourish, notify residents, etc).

- **Critical condition trigger** = When beach widths in the summer and fall are less than typical seasonal recession due to winter conditions, it is possible that the beach will narrow to the point of providing nearly no protection to the backshore if a severe storm or swell occurs. Monitoring surveys would inform this seasonal fluctuation distance along the beach (for examples in this report, we used 25 feet (15 m).
  - Trigger action – Sand placement in a berm or embankment shape to temporarily raise the backshore elevation and limit wave runup, absorb wave power as the sand erodes, and provide sand to the beach during erosion events. Consider other actions such as sand bags, blocking low areas that might be used for access but also provide a pathway for wave runup, and contingency preparation for evacuation and utility shutdown.

# 3. Timing of Adaptation Triggers

The timing of implementation for an adaptation measure depends on the lead time required to effectively plan, permit, design and construct that particular measure. Caltrans (2011) has published guidance on planning and development of project initiation documents. A previous study by GHD, ESA PWA and Trinity Associates (GHD 2014) identified and evaluated a range of adaptation options to address SLR vulnerabilities at four example locations in Northern California. For the GHD study, designs were developed to provide protection against a king tide (1-year tide) plus 1 foot, but were not specific about the initiation selection. For the present study, we propose an evolving assessment methodology that incorporates the latest SLR and climate change science and includes the following general outline:

- Determine acceptable trigger to be maintained for the useful life.
  - Flooding: the king tide + 1 ft, 10-yr tide elevation, or the Highest Astronomical Tide (HAT)[2] from NOAA estimates.

[2] The elevation of the highest predicted astronomical tide expected to occur at a specific tide station over the National Tidal Datum Epoch (NTDE). The NTDE is a specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean lower low water, etc.) for tidal datums. Additional information can be found at: https://tidesandcurrents.noaa.gov/datum_options.html

- Erosion: the inter-annual beach variation plus 5-year or 10-year storm buffer.

- Determine the planning/permitting/design/construction lead time required.
- Determine timing of impacts based on latest SLR projections. Decide SLR curve (or in Marin County's case, the SLR amount) to use based on resource needs. (single home could plan on Low-Med SLR curve, critical roads could plan on High SLR curve)
- Determine project start date by back-tracking from end of useful life with desired freeboard considering the applicable SLR amount and timing, include lead time for trigger.

For example, consider a critical roadway that will be lifted to maintain protection from the "trigger" 100-year tide (say 10-feet NAVD today) that is currently at 14 feet NAVD, and once constructed will be maintained for a useful life of 50 years. If the process time is determined to be 10 years and sea-level rise is 4 feet by 2090, the initiation for planning should start in 2030 so that the road is constructed by 2040 and can serve its 50-year useful life by the time the 100-year tide reaches 14 feet in 2090. This assumes we know the exact sea-level rise amount and timing, and that future storm conditions are consistent with historic record. While the uncertainty may be high for future predictions, a sufficient level of protection could be chosen to limit the risk of planning for too little SLR. This trigger-timing process could also be applied to shrinking beaches and backshore adaptation strategies with sea-level rise or stream bridge and culvert crossings with climate driven precipitation changes.

# 4. Shoreline Monitoring

Due to the uncertainty of future rates of SLR and thus anticipated shoreline response, it is important to monitor the shore into the future to properly assess vulnerability to coastal hazards. A shoreline monitoring program should include periodic transect surveys along reaches of concern to track the following beach attributes: shoreline position, toe elevation at the backshore, and dry beach width or dune width. These attributes are explained in section 2. Triggers for Adaptation Actions.

In the case of an armored backshore (e.g. Seadrift) monitoring the beach elevation at the toe of structures will indicate the exposure of the structure to wave action. As the fronting shoreline recedes towards the structure with sea-level rise, the beach will likely drop in elevation at the structure. This is because structure is closer to the shoreline, and experiences increased scour caused by the deeper and faster-moving wave run-up. As the beach elevation drops at the toe of structure, more wave energy will reach the structure, resulting in increased run-up and overtopping and more rapid degradation of the structure. To guide long term and emergency management activities, we propose that the following vulnerability triggers are monitored:

**Toe elevation** – monitor yearly for seasonal fluctuations (survey profile at end of summer when beach is highest and in late winter/early spring when beach is lowest) and after any significant coastal storm event. Thresholds for minimum toe elevations could be considered in two tiers:

- Long term "maintenance" trigger – Elevation to be determined, generally the elevation of the beach berm (break in slope) that typically occurs several feet above high tide, depending on wave exposure, at a particular location.
- Critical condition trigger – Mean tide or sea level.

**Dry beach width** – monitor yearly for seasonal fluctuations (late winter/early spring) and after any significant coastal storm event. Thresholds for minimum beach width could be considered in two tiers:

- Long term “maintenance” trigger – typical 2-5 year storm erosion distance plus buffer, equaling about 25 meters (83 feet) at Stinson/Seadrift beaches.
- Critical condition trigger – typical seasonal fluctuation distance, to be determined.

Residents that live within the FEMA V-Zone (with or without fronting armor structure) may consider actions to protect their home if the long term triggers for dry beach width (or toe elevation) are reached. Homes closest to the ocean are most vulnerable to wave loads, and would benefit the most from structural modification measures such as elevation. However, the homes farther inland may be lower due to the pre-existing grades, and may be more subject to deeper flooding that may persist after a wave overtopping event. Easkoot Creek is a separate hazard source and not considered here.

## 4.1 Monitoring Program Development

ESA is actively involved in two shoreline monitoring projects with plans that are applicable to Stinson-Seadrift beaches. The monitoring programs for both are outlined below as examples of what could be implemented at Stinson-Seadrift beaches. A complete monitoring program should be developed by a coastal engineer, and the descriptions below are for example purposes only. With each example project, a survey team of at least two individuals is dispatched to collect topographic data twice a year (late summer/early fall and late winter/early spring) to capture seasonal shore changes, as well as before and after a significant coastal storm event. Additionally, aerial surveys could be conducted to generate a continuous digital elevation model and orthoimagery for desktop analysis of structures and shoreline position.

We recommend that the County staff could “take over” monitoring after the plan is developed and approved, and a year of coordinated monitoring is accomplished. The County may still wish to have participation by coastal practitioners in the data assessments and reporting, especially if the reports are submitted to the Coastal Commission or other regulators and resource managers.

### 4.1.1 South Ocean Beach

The Ocean Beach Short-Term Erosion Protection Measures Project 2016-2021 Short-Term Monitoring Program (STMP) (ESA 2016) was developed as a multi-objective, multi-year effort to manage coastal hazards and provide public benefits associated with ecology and recreation. A key focus of this plan is the South Ocean Beach (SOB) area where the Lake Merced Transport tunnel, a 14-foot-diameter tunnel that is part of the City and County of San Francisco’s sewer system operated by the San Francisco Public Utilities Commission, is at risk of damage due to ongoing and forecasted coastal erosion. The monitoring program included a baseline data collection effort that established the reference for future monitoring surveys, and included the following elements: survey control points, trigger line, bluff crest, bluff toe, existing erosion control limits, wet-dry line on the beach, regularly spaced shore-normal profiles, photo point stations. The baseline conditions survey data for South Ocean Beach is shown in Figure 4. ESA is conducting the surveys, performing data analysis and preparing the reports.

Specified in the monitoring plan at South Ocean Beach, environmental data, including waves, tides, and meteorological conditions will be archived annually for each monitoring period to improve the understanding of the shore response to storm events and seasonal changes over the course of a year. Topographic surveys of the beach will occur at least twice per year, typically spring and fall. The topographic surveys will include aerial surveys and land surveys to collect information of the overall site and detailed elevation profiles at regularly spaced intervals along SOB. In addition to regular fall and spring surveys, the beach will be surveyed after a storm event to measure the response of the interventions to storm conditions. Approximate storm retreat amounts, scour depth, and other impacts will be quantified and applied to subsequent erosion control measure implementations. Erosion control measures that are implemented through STMP, including sandbag structures and sand placements, will be monitored. Shore protection structures existing prior to the STMP will be observed and conditions noted, but monitoring of these elements will be focused on the effects on the beach elevations and if the structures experience any major impacts. Shoreline position is largely a function of sediment supply and storm wave events. The shoreline position will be estimated through analysis of aerial and topographic surveys. The shoreline will be added to an existing database of digitized shorelines over time, and processed through publically available software used to estimate long-term and short-term shore change trends. Digital photographs will be collected at the marked GPS photo stations shown in Figure 4. Additional photographs will be taken at areas of concern or interest at the discretion of the field crew. The GPS location of additional photo stations will be recorded for future reoccupation. This STMP establishes a framework for evaluating shoreline conditions, will inform the need for immediate interventions, and sets forth a methodology for tracking and reporting shoreline changes over the next 5 years. In general, immediate-term actions will be recommended based on the findings of the baseline conditions assessment and other ongoing monitoring. A trigger distance associated with the long-term project was established in the OBMP. Setback distances between the bluff edge and the LMT will be measured along each profile during spring monitoring, fall monitoring, and post-storm event monitoring. Annual monitoring reports will be prepared to present data collected during fall, spring, and storm event surveys.

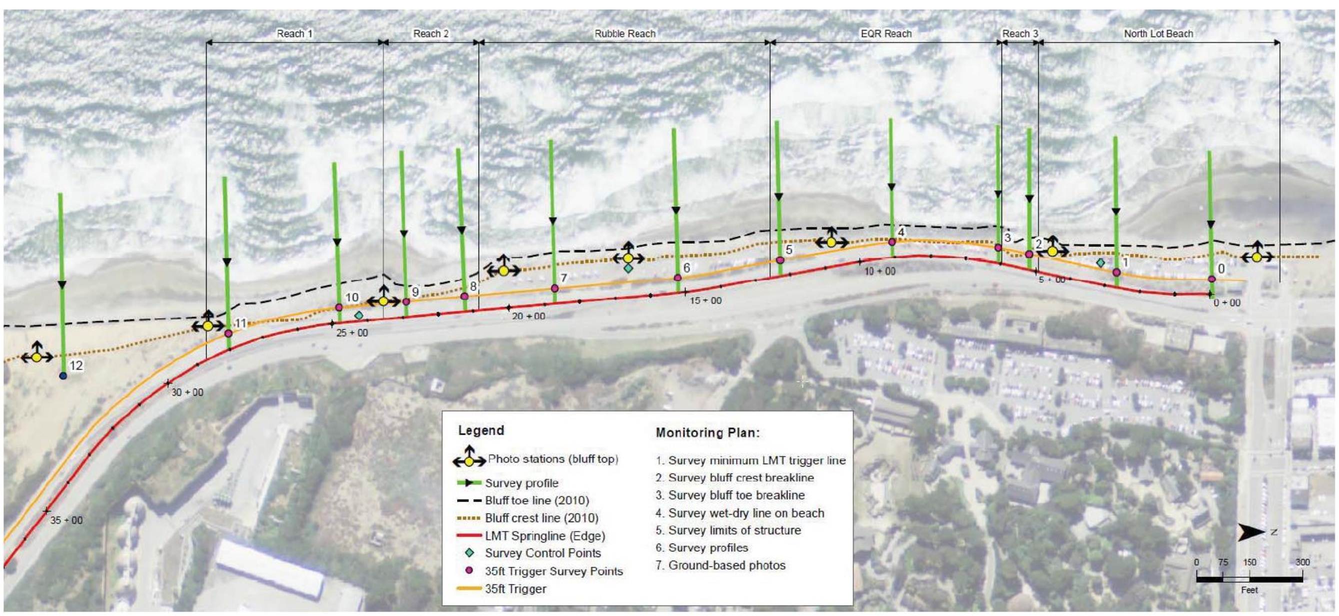


**Figure 4. Monitoring Plan Schematic at South Ocean Beach (source: ESA 2016).**

### 4.1.2 Surfer's Point Managed Retreat

ESA PWA (now ESA) designed and is responsible for the monitoring of project performance of the shoreline portion of a managed retreat project in which included the demolition and landward relocation of a parking lot and construction of about 2000 feet of a cobble berm and dune restoration (ESA PWA 2013). ESA was responsible for the collection of baseline conditions and identification of maintenance triggers to meet the special conditions under Coastal Development Permit (CDP) Number 4-05-148, which approved the placement of cobbles and other work along Surfer's Point, Ventura, CA. The project site is located immediately east or down drift of the mouth of the Ventura River. The monitoring program is similar to the SOB plan, and includes physical processes, topography and shoreline position. ESA conducted the first year monitoring and reporting; the city of Ventura is now performing the surveys while ESA performs the data analysis and reporting. Surfers Point differs from the SOB plan in that the City of Ventura is providing much of the monitoring with City staff, and the triggers are intended to maintain the shore for recreation and ecology rather than primarily infrastructure protection. Also, the SOB monitoring is a near-term plan pending implementation of the longer-term shore enhancement (hence focused on infrastructure), whereas Surfers Point is focused on long-term management of the implemented project.

This project, while designed as a managed retreat project, also considered potential maintenance activities to maintain the cobble berm and sand dunes. Maintenance triggers identified in the Monitoring Plan were as follows:

- Deflation of the cobble berm below 13.0 feet (NAVD88) within 40' from the path.
- Inland migration of the berm crest to within 40 feet of the bike path. To minimize disturbance to the project in consideration of sand on top of the berm crest, the cobble berm face defined here to be the frontal slope below the crest of the cobble berm, generally in between the elevations of 14' and 10' NAVD88 may be used as a proxy to estimate the location of the berm crest.

These triggers identified were intended to raise awareness of potential issues and serve as an early warning (~1-3 years) indicator of potential future problems to the project. Specifically, once these triggers are met there is an increasing urgency to initiate more detailed monitoring, stockpiling of cobbles and sand opportunistically, and planning for cobble and sand renourishment.

# 5. Adaptation Measures

Adaptation measures are types of actions that can be considered to mitigate coastal hazards driven by sea-level rise. Not all measures are appropriate for a particular location. A selected suite of measures can be considered an adaptation alternative strategy for a project or area; a few conceptual strategies are explored in the section 7. Adaptation Strategies Case Study: Stinson-Seadrift . To further help the County identify appropriate adaptation strategies, we developed descriptions of various measures including the functionality, feasibility, and relative cost (ESA 2015b). The adaptation measures are divided into the following categories: Land Use Planning, Non-Structural, Structural, and Hybrid. Many descriptions were drawn from past studies (ESA PWA 2012; TNC 2016).

To develop a focused case study of adaptation strategies for Seadrift-Stinson beaches, the following applicable measures were selected:

## 5.1 Beach and Dune Nourishment (Sand and Vegetation)

Beach nourishment refers to placement of sand to widen a beach. The beach then provides flood and erosion protection to the backshore. However, it is generally assumed that the beach will diminish with time, requiring "re-nourishment". As sea-level rises, the frequency of required nourishment increases because the rate of sand additions needed to build the beach up increases. Potential problems with beach nourishment include the construction impact to people and beach ecology (generally considered a short term negative effect), and changes to shore conditions that may result from difficulty in finding sand with the desired grain sizes. The success of the nourishment depends on the volume of nourished material, the grain size, and the proximity or use of sand retention structures.

Dune restoration would include placement of sand, graded and planted to form back beach dunes. Beach nourishment is recognized as a natural way of mitigating backshore erosion as well as maintaining a wider beach through sacrificial erosion of the dunes. A variant includes placement of cobble (Figure 5) which is often naturally present as a lag deposit[3] below beaches in California.

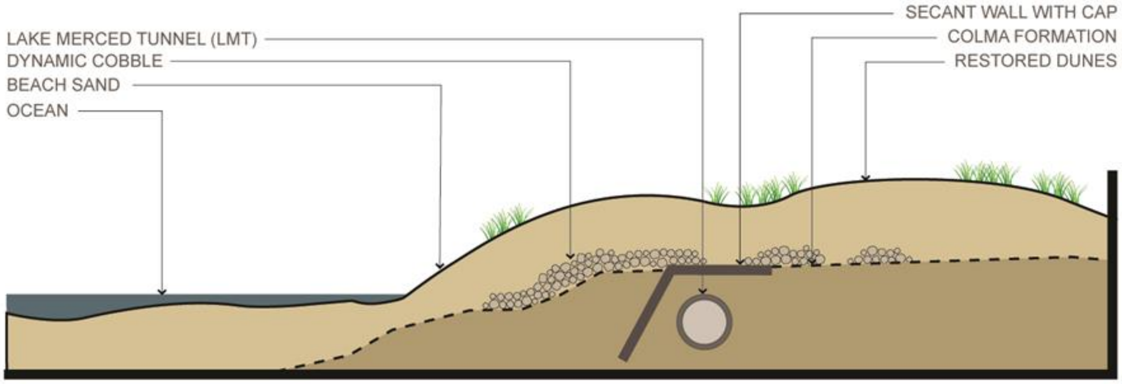


**Figure 5. Conceptual cross section of the south Ocean Beach hybrid adaptation strategy which includes low-profile armoring as well as beach nourishment and dune construction in space presently occupied by rubble, parking and a roadway. Source: ESA PWA 2015.**

## 5.2 Revetments

Revetments provide protection to existing slopes fronting a threatened structure, and are constructed of rock or concrete armor units. Similar in purpose to a seawall, revetments work by absorbing or dissipating wave energy. They are made up of: an armor layer--either rock or concrete rubble piled up or a carefully placed assortment of interlocking material which forms a geometric pattern, a filter layer --which provides for drainage, and retains the soil that lies beneath, and a toe--which adds stability at the bottom of the structure. Revetments are the most common coastal protection structure along the shores of Marin County, protecting homes in Bolinas and Seadrift. These structures can introduce active erosion effects which accelerate beach loss when beach width narrows and wave run-up frequently reaches the structure. As the beach lowers and sea-level rises, wave run-up and overtopping of the structure will also increase as the waves begin to break near or on the structure, which will require more frequent maintenance or reconstruction.

Revetments were found to have a negative net cost benefit as a result of high construction cost in past erosion mitigation study (ESA PWA 2012). In other words, the loss in recreational and habitat value was greater than the costs to build the seawall/revetment.

[3] Lag deposit refers to coarser sediments that accumulate over time at lower elevations during periods of eroded beaches, and subsequently covered by sand after the beaches recover.

## 5.3 Elevate Buildings

As part of the Climate Ready Southern Monterey project (TNC 2016), ESA developed unit cost estimates for elevating structures in both flood zones and in wave impact zones where wave impact results in increased loads on the structure. Many homes and business structures along Tomales Bay, some already on piles, can be elevated to limit inundation with rising sea level. This measure is considered for oceanfront homes along Stinson-Seadrift beaches.

# 6. Cost Estimates

ESA developed engineering cost estimates for a prior deliverable to Marin County (ESA 2015b) that cover a range of adaptation measures. The relevant estimates are recalled here with some updates to facilitate a case study of Stinson-Seadrift shoreline management. Most costs were developed for an economic evaluation of climate adaptation strategies in Southern Monterey Bay (SMB) (TNC 2016). The SMB costs were scaled to the area using city cost index conversion from Salinas to San Rafael (increase of 8%) from RSMeans (2014). Building from the TNC (2016) study, our analysis uses a 1% discount rate to calculate net present value of each adaptation alternative schedule, which is consistent with Arrow et al. (2014) and others. Engineering costs and specific considerations for each adaptation measure are presented below:

## 6.1 Beach and Dune Nourishment (optional low profile wall/cobble)

The cost of sand was estimated from $12 to $61 per cubic yard (CY). The lower value considers local opportunistic (free) sand is available. Considered as an adaptation measure in Southern Monterey Bay (ESA PWA, 2012), opportunistic beach nourishment uses sand that is extracted from a flood channel, debris basin, navigation channel, harbor area, a by-product of construction or other source, where the main reason for extracting the sand is not to use it for beach nourishment. Costs associated with Opportunistic sand can be low, especially when providing a cost savings to the entity providing the sediment source by avoiding or reducing transportation and disposal costs. In past studies (Environ & ESA PWA 2013; TNC 2016), opportunistic sources were readily available and were used in near term cost estimates. ESA has not evaluated the availability of opportunistic sand sources for the Stinson-Seadrift beaches, and thus assume a higher cost to import sand from external source. This cost assumes the sand is dredged from the central SF bay, trucked from San Francisco to Stinson, and spread by a bulldozer. This cost may be higher, especially in the future.

The actual cost of constructing a sand berm or other beach nourishment depends on factors not adequately defined and hence the estimated cost is a very approximate, order of magnitude estimate used on other studies (TNC 2016, ESA PWA & SPUR 2015). A key uncertainty is whether sand with adequate quality (grain size, sorting, clean) is readily available in the quantity desired, and can be economically delivered to the site with limited adverse effects. A similar action has been taken at Ocean Beach, San Francisco several times since 2000 and three times since 2012. The more recent actions use take sand from another part of Ocean Beach where the beach is abnormally wide. However, the relatively fine sand grain sizes are susceptible to wind-blown transport, which has posed challenges during windy periods. An engineering feasibility analysis is recommended to inform planning for Stinson/Seadrift beaches.

An alternative adaptation measure to a rock revetment, the low profile wall and cobble berm may be preferable owing to less wave reflection, flatter slopes, and easier walking under eroded conditions if the beach drops. This estimate was modified from the Ocean Beach Master Plan, and the cost equals $55M per mile ($34M per km). Considering construction of just the cobble berm that acts as a last defense behind a dune (no wall), the cost equals $8M per mile ($5M per km).

## 6.2 Revetments

The cost of a rock revetment equals $35M per mile ($22M per km). The functional life of a revetment is assumed to be 30 years as long as a positive beach width is maintained in front of the structure. Generally considered in past study (TNC 2016), 1 foot of sea-level rise could lead to failure within the designed lifetime, as the design storm for which a structure was built to withstand would likely be exceeded more frequently during the life of the structure. A diminished functional life of 20 years was applied to revetments once the fronting beach width disappeared in the TNC study, but this is beyond the level of detail in this conceptual study.

## 6.3 Elevate Buildings

Raising homes in the wave damage zone (FEMA V-zone) is assumed to equal $250 per square foot (SF). This estimate was previously reported (ESA 2015b), and does not assume a specific height of raising.

## 6.4 Disclaimer

The information provided herein was developed to provide a standard basis for comparison between different shore erosion mitigation measures for the benefit of coastal zone management discussions. The information provided herein is neither intended nor authorized for any other use and should not be used for any purpose without prior written approval by ESA.

These estimates do not explicitly include consideration of all possible costs, such as design, environmental review, permitting, construction administration, monitoring, property purchase and other costs. In particular, significant costs can be expected for sand mitigation fees for coastal armoring projects. Please note that in providing opinions of probably costs, ESA has no control over the actual costs at the time of construction. The actual cost of construction may be impacted by the availability of construction equipment and crews and fluctuation of supply prices at the time the work is bid. ESA makes no warranty, expressed or implied, as to the accuracy of such opinions as compared to bids or actual costs.

These estimates do not consider all possible benefits and costs including indirect, consequential, aesthetic and community health and well-being. Estimation of benefits is less certain than construction costs. Higher confidence is afforded recreational economics, while ecological values are inherently uncertain. ESA makes no warranty, expressed or implied, as to the accuracy of opinions of erosion rates. In particular, the erosion rates are not consistent with existing guidance on sea-level rise which would tend to increase the rates of erosion.

# 7. Adaptation Strategies Case Study: Stinson-Seadrift Beaches

Often, it is beneficial to consider a range of adaptation measures to form alternative strategies for evaluation, and selection of a preferred strategy, which may be a "hybrid" of the strategies initially selected for review. To illustrate this concept, ESA developed a diagram of an adaptation "solution space" in which many given strategies are possible and include a combination of hard or soft treatments and no action (Figure 6).

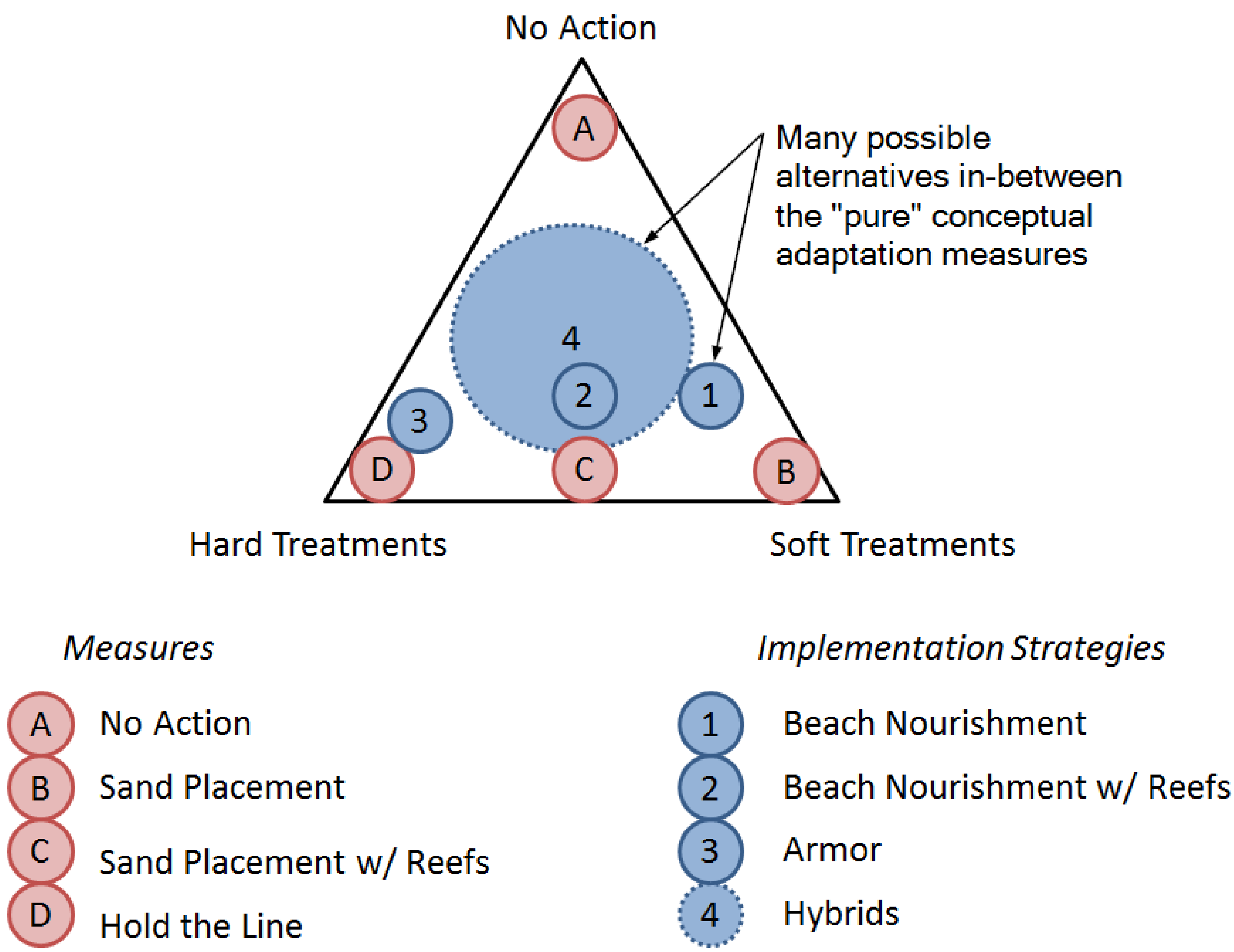


**Figure 6. Example Solution Space of Adaptation Strategies.**

ESA developed a conceptual set of adaptation strategies for the Stinson-Seadrift beaches (Figure 7), including conceptual timeline, relative ecological impact and order-of-magnitude cost estimates for comparison. The costs and maintenance schedules presented below are conceptual and are rough estimates for comparison of alternative options only. Conceptual adaptation strategies are discussed with respect to each study reach: Seadrift, Stinson, and the National Parks Service beaches.

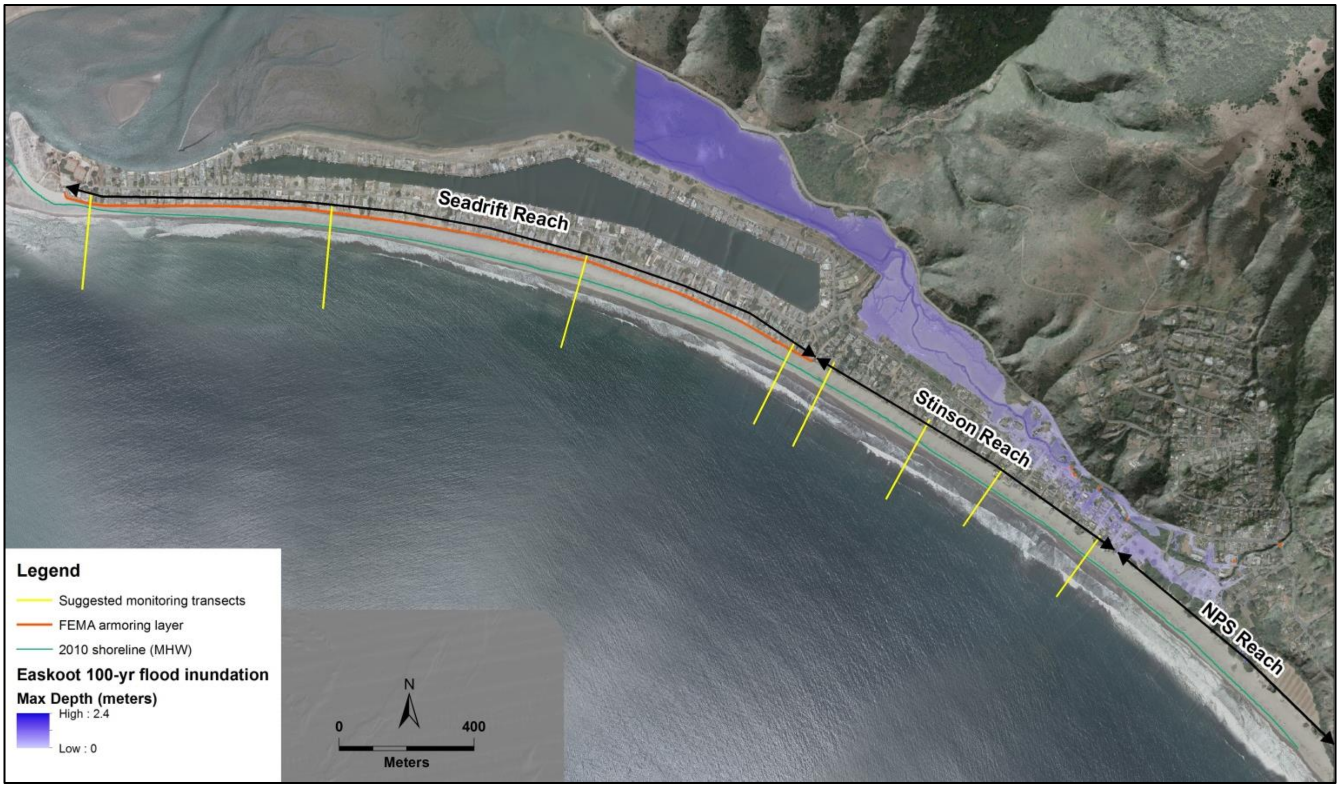


**Figure 7. Stinson-Seadrift case study reaches and suggested beach monitoring transect locations.**

Existing and projected future beach widths were determined for the Stinson and Seadrift beaches in the Geomorphic Response memo (ESA 2015a) and are presented in Table 1. The Stinson reach was updated to remove the National Parks beaches from the average width calculations. This timeline of reach-average beach widths was used to determine the initiation for beach nourishments considered in the case study adaptation strategies below. In reality, some locations may experience greater shoreline erosion than the reach average and may require attention; this nuance is not considered here. Where critical beach width is reached between the times in Table 1, the intermediate decade will be chosen to apply a beach nourishment.

**TABLE 1**
**EXISTING AND FUTURE BEACH WIDTHS WITH SEA-LEVEL RISE MIGRATION OF THE SHORE; NO NOURISHMENT.**

| | Beach Width (m) measured from MHW to backshore | | | | |
|---|---|---|---|---|---|
| **Reach** | **2010** | **2030** | **2050** | **2070** | **2100** |
| Seadrift | 38 | 29 | 14 | 0 | 0 |
| Stinson | 44 | 37 | 22 | 0 | 0 |

After the beach width from Table 1 reaches the critical trigger (see 2. Triggers for Adaptation Actions), future nourishments are assumed to take place every 30 years for the purpose of developing the adaptation strategies schedules, and are considered in each adaptation strategy. As the rate of sea-level rise increases in the future, the volume and frequency of beach nourishments will increase.

Generally, with any adaptation strategy and enough sea-level rise (by 2070 or 2100), the required amount of shoreline adaptation measures would be so intensive that homes would need to be raised. The trigger for this could be determined by the community and is debatable; but we suggest that once the protection devices required to limit wave overtopping are so high that they limit the view of oceanfront homes, focus is instead placed raising structures and modifying infrastructure accordingly. Sometime after 2100 (or sooner!) the first seaward row of homes would likely need to be abandoned or relocated.

The following adaptation strategies are conceptual level only. Further engineering analysis is required. This is just the start of a process that should be further developed with community input and other strategies may be possible that are not discussed here. The costs associated with each strategy below do not consider higher future costs of materials and labor. Sand in particular will likely become more expensive as it is a limited resource.

## 7.1 Seadrift Beach

Before homes were built along Seadrift Beach, it was a sand spit that shifted naturally depending on waves and sand delivery from the Bolinas lagoon watershed and elsewhere. In the absence of development, the spit would respond naturally to sea-level rise by migrating inland as the ocean encroaches on and erodes the front of the dunes while wind and wave run-up moves sand landward over the dunes and maintains the spit as it migrates north into the lagoon.

Approximately 7500 feet of rip rap revetment was placed in the late 80's in front of homes along Seadrift Beach after a storm eroded dunes and damaged homes (Griggs & Patsch 2005). A 2013 photograph taken of this revetment structure is shown in Figure 8. The existing beach at Seadrift is currently narrow with revetment armoring the backshore (Figure 7). Homes behind this structure will become increasingly vulnerable to coastal hazards with sea-level rise. We anticipate that management measures may be difficult to implement owing to the high costs driven by existing property values and density of development. We recommend consideration of structural modification measures such as lifting homes on piling. Subsequently, as sea-level rises, the sandy spit could be allowed to migrate north and the most seaward properties removed and potentially relocated on the lagoon side. Conceptually, natural wave overwash processes will maintain the spit and beaches, but move them north, and the development would migrate with the land.

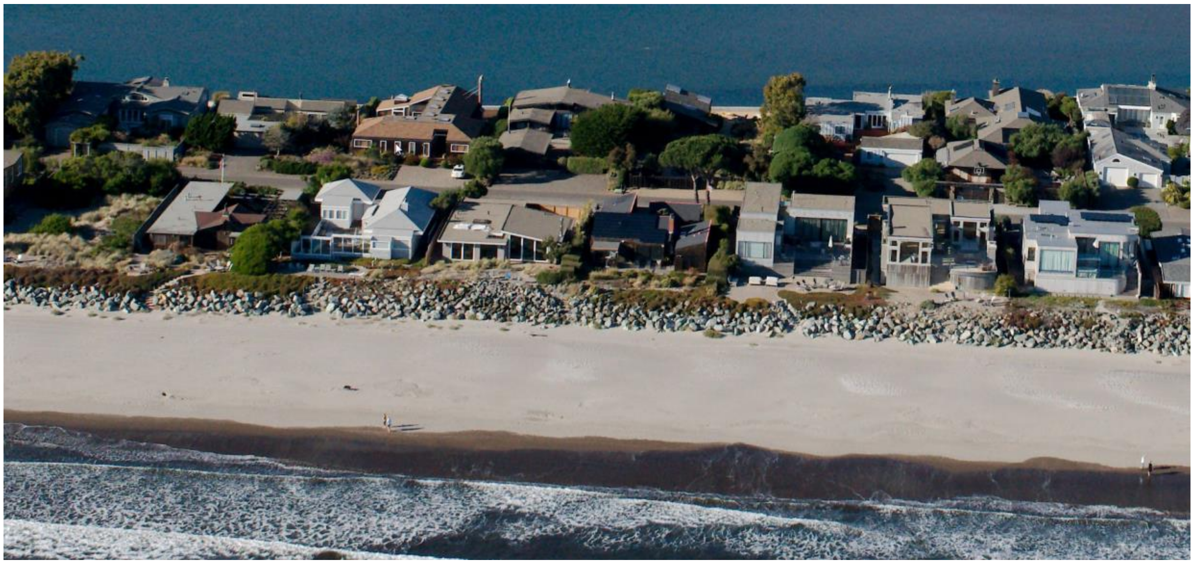

**Figure 8. Existing rock revetment fronting Seadrift homes. Source: californiacoastline.org (2013).**

### 7.1.1 Revetment

Strategies for sea-level rise adaptation at Seadrift Beach are somewhat limited in scope due to the existing revetment. For the purpose of the Seadrift adaptation strategy, ESA assumes that the revetment was maintained properly since its construction and applied the 30-year functional lifespan starting today. Maintenance is assumed to occur after each useful lifetime of 30 years; we estimate that **a revetment repair/upgrade of 7550 ft (2300 m) would cost roughly $51M.** As required to maintain the fronting beach along this reach, we estimate that a **50 ft (15 m) beach nourishment would cost roughly $24M**. The adaptation schedule includes maintenance/rebuilding of the revetment, beach nourishment for a protective buffer and recreation/habitat value, and ultimate relocation of homes, and is shown in Table 2. Every 30 years (2045, 2075), the existing revetment will require significant repair/upgrade. This maintenance cost could also be represented as a yearly cash flow, and may be a more effective approach but is not considered in this conceptual strategy. The beach is projected to surpass the critical trigger width at 2050, requiring a 50-ft (15 m) beach nourishment. This is repeated after 30 years in 2080. The appropriate frequency of future nourishments will likely be higher in reality. Once the required backshore modifications are so intensive the homes will need to be raised (assumed at 2100). At any time, a major erosion event may erode the beach to a dangerous condition requiring revetment repairs and or beach nourishment.

**TABLE 2**
**SEADRIFT BEACH REVETMENT ADAPTATION STRATEGY SCHEDULE.**

| Year | Cost | Note |
|---|---|---|
| 2015 | - | Assume existing revetment was adequately maintained |
| 2045 | $ 51,000,000 | Rebuild/upgrade revetment after 30-yr life |
| 2050 | $ 24,000,000 | Nourish 50 ft beach when beach drops below trigger |
| 2075 | $ 51,000,000 | Rebuild/upgrade revetment after 30-yr life |
| 2080 | $ 24,000,000 | Nourish 50 ft beach after 30 years |
| 2100 | $ 81,000,000 | raise homes in FEMA V-zone |
| **Total net present value (2015)** | **$ 130,000,000** | Assumes 1% discount rate |
| **anytime** | *$24,000,000* | *Emergency 50-ft beach nourishment if extreme storm erosion occurs; revetment repair not estimated* |

## 7.2 Stinson Beach

Stinson Beach is characterized by a combination of a dune-backed beach and armored homes that encroach upon the beach (Figure 7). It is a major recreational attraction, and thus preserving the beach should be a priority when developing adaptation strategies. We developed three adaptation strategies: armoring, beach and dune nourishment, and structural modification.

### 7.2.1 Armoring

Some community members expressed interest in extending revetment from Seadrift southeast to Calle De Pinos to protect homes along Stinson Beach. Drawing on cost estimates previously developed for Marin County (ESA 2015), we estimate that **a revetment extension of 3540 ft (1080 m) would cost around $24M**. The revetment could be built along the alignment of the existing dune face from Walla Vista to the residence at the end of Calle Del Embarcadero, and sand excavated for the revetment could be placed in front and on top of the revetment for aesthetic improvement, but additional sand may be required if complete burial of the revetment is desired. For the remaining stretch of homes from Calle Del Embarcadero to Calle De Pinos, a new revetment would have to occupy existing beach area, and sand would need to be imported to cover the structure and increase cost. This approach could limit erosion and wave run-up on homes in the near term. However, without increased maintenance of the revetment and fronting beach, long term sea-level rise will eventually overload the revetment as the fronting beach is eroded and waves damage and overtop the revetment. To remedy this, subsequent beach nourishments will be required to maintain a beach fronting the revetment. We assume portions of the Seadrift revetment currently have little or no fronting beach width, and can serve as an example of possible future conditions in Stinson Beach without continued beach nourishment. A shrinking beach will result in a loss of both recreational and ecological function at Stinson Beach as sea levels rise.

If a revetment extension is pursued, proper monitoring of the fronting beach and structure will be required to assess the integrity of the revetment and potential exposure to overloading during a coastal storm. The two indicators mentioned in the above 2. Triggers for Adaptation Actions section could be monitored: fronting dry beach width, and beach elevation at the toe of the revetment. For this example we considered the 50-foot (15 m) trigger for beach nourishment actions needed to protect the revetment from overloading.

For example, triggers and potential actions are listed below:

- Fronting beach width drops below 85 feet trigger distance
    - Beach nourishment or dune sand placement on the revetment.
        - Implications: temporary construction impact to people and ecology, cost ($2-11M for 50-ft beach widening along Stinson Beach)[4]
- Toe elevation at structure drops below threshold (MSL, beach berm elevation)
    - Beach nourishment or dune sand placement on the revetment.
        - Implications: temporary construction impact to people and ecology, cost ($2-11M for 50-ft wide beach along Stinson Beach)

[4] Cost range: low end is based on estimate of $12/cy sand assuming locally available source and small project; high end is based on offsite dredging and import ($61/cy).

By increasing the beach buffer or sacrificial material placed on/in front of the revetment, storm erosion and run-up could be reduced. This activity would be repeated after storm erosion events that expose the structure. For longer time horizons, beach nourishment will likely become cost prohibitive as available beach sands diminish and higher sea levels require more frequent nourishments. At this point, new adaptation measures such as managed retreat will need to be considered.

Utilizing cost estimates and beach width projections listed in this report, the Revetment strategy schedule for the Stinson Beach was developed (Table 3). It includes the initial revetment construction, assumes replacement/upgrade after 30-year life, and beach nourishments required to maintain a fronting beach of at least 50 ft (15 m). The revetment maintenance cost could also be represented as a yearly cash flow, and may be a more effective approach but is not considered in this conceptual strategy. The initial nourishment is determined from previous beach width calculations, subsequent nourishments are applied at 30 year interval. The appropriate frequency of future nourishments will likely be higher in reality. Once the required shoreline/backshore modifications are so intensive the homes will need to be raised (assumed at 2100). At any time, a major storm erosion event may erode the beach to a dangerous condition requiring revetment repairs and or beach nourishment.

**TABLE 3**
**COST SCHEDULE FOR REVETMENT ADAPTATION STRATEGY AT STINSON BEACH.**

| Year | Cost | Note |
|---|---|---|
| 2015 | $ 24,000,000 | Construct revetment along Stinson Beach |
| 2045 | $ 24,000,000 | Rebuild/upgrade revetment after 30-yr life |
| 2060 | $ 11,000,000 | Nourish 50 ft beach when beach drops below trigger |
| 2075 | $ 24,000,000 | Rebuild/upgrade revetment after 30-yr life |
| 2090 | $ 11,000,000 | Nourish 50 ft beach after 30 years |
| 2100 | $ 29,000,000 | raise homes in FEMA V-zone |
| **Total net present value (2015)** | **$ 80,000,000** | Assumes 1% discount rate |
| **anytime** | *$ 11,000,000* | *Emergency 50 ft beach nourishment if extreme storm erosion occurs; revetment repair not considered* |

### *7.2.1.1 Groins*

Not addressed in this strategy, groins are large coastal engineering structures that extend seaward from the shore used in conjunction with the large beach nourishment to retain sand. These retention structures essentially slow the rate of sand transport away from the nourishment area, thereby slowing the rate of beach width reduction. Groins are generally considered along stretches of coast with high net longshore sediment transport. In application, the groins are located to segment the beach and nourishments into compartments, thereby reducing the loss of sand to adjacent shores. Sand losses in the Stinson/Seadrift beaches will be dominated by offshore losses from storm-driven erosion as well as long term erosion and migration of the shoreline caused by sea-level rise. Because there is low longshore sand transport in the area, groins are not considered an appropriate solution for conditions at Stinson-Seadrift beaches.

### 7.2.2 Beach and Dune Nourishment

Beach and dune nourishment is an adaptation strategy that provides protection against coastal storm erosion while maintaining the natural habitat and geomorphic response mechanisms. Dune restoration would include placement of sand, graded and planted to form back beach dunes. A variant includes placement of cobble (rounded rock) which is often naturally present as a lag deposit[5] below beaches elsewhere in California. This strategy includes the dune enhancement activities below:

- Dune augmentation (adding sand to dunes to provide protection during storm events), especially to raise low-lying beach access paths to prevent flood waters from flowing into the neighborhoods behind the dunes.
- Ceasing any activity that adversely affects the sediment supply of the dunes.
- Ceasing beach grooming (if any). This would encourage dune vegetation establishment and dune formation. Beach grooming removes driftwood and wrack and reduces vegetative growth and dune formation.
- Planting vegetation. Planting native dune vegetation will help build up and stabilize wind-blown sand.
- Fencing off sensitive areas and creating dune walkways.
- Informational signs and other outreach activities to educate about the importance of maintaining stable sand dunes.

Dune restoration is a positive strategy in terms of appearance, ecology and recreation. ESA previously developed an approximate estimate for beach and dune nourishment that is listed in the 6. Cost Estimates section, as well as the construction of a cobble toe that is based on experience of such beaches and nourishments at Pacifica and Ventura (Figure 9). Along Stinson Beach (3450 ft) we estimate that a **13-ft tall, 50-ft wide dune nourishment would cost roughly $6M** while a **50-ft wide beach nourishment would cost roughly $11M**. A buried cobble berm could be designed at a sufficient elevation to limit excess erosion if the entire dune is sacrificed during a large storm. If constructed along the Stinson Beach (3540 feet) a **cobble berm would cost roughly $6M**. The dune and beach would need subsequent nourishment as necessary after extreme coastal erosion events. The beach is already squeezed along homes from Calle Del Embarcadero to Calle Del Pinos; beach conditions in late winter expose the armoring revetments/seawalls in front of existing homes along this stretch.

[5] Lag deposit refers to coarser sediments that accumulate over time at lower elevations during periods of eroded beaches, and subsequently covered by sand after the beaches recover.

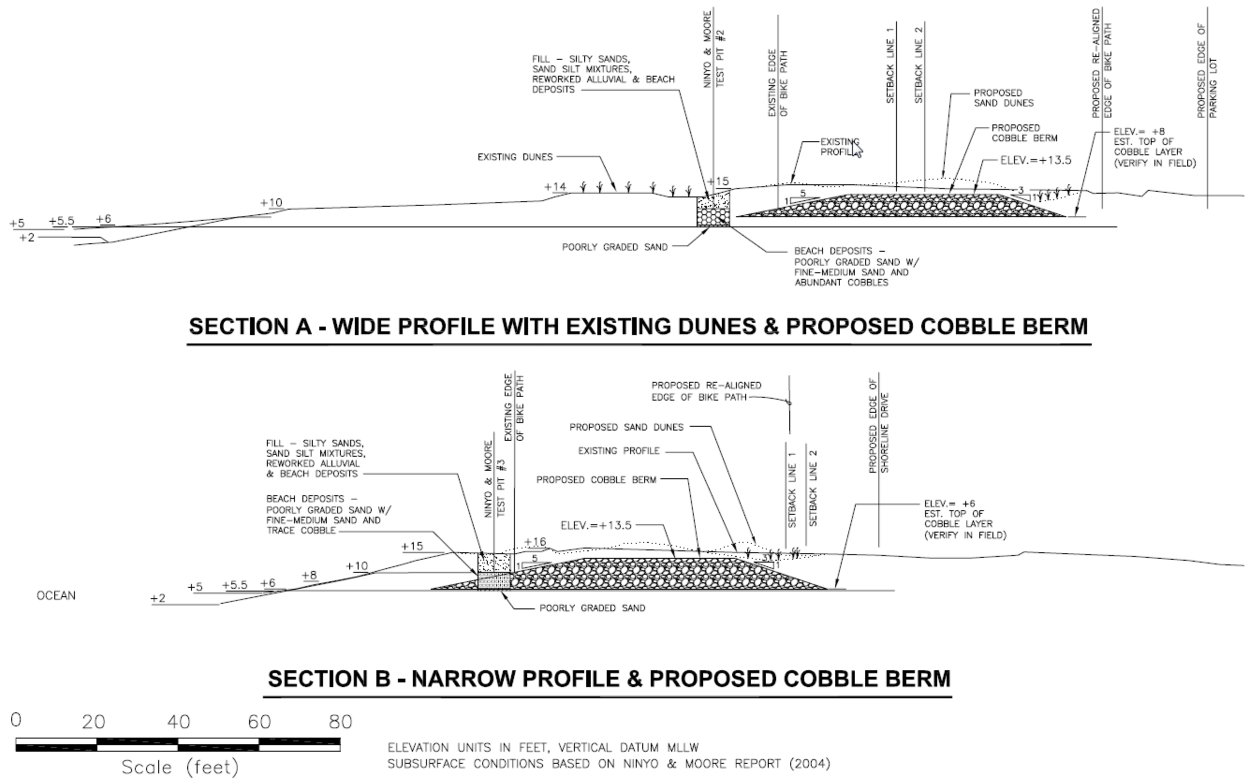


**Figure 9. Example section views of cobble berm and dune nourishment. Source: PWA (2005).**

Monitoring will play an important role in identifying the need for additional nourishments in the future, and could focus on the annual minimum beach width and dune width. The minimum dune width would provide an acceptable buffer for storm erosion (2- to 5-yr or more) as measured from the dune crest to the heel (inland limit). Estimated previously for Stinson Beach, the storm erosion buffer for a 2- to 5-year recurrence storm is 43-52 ft) respectively. Geomorphic triggers and potential actions are listed below:

- Maximum seasonal beach width (end of summer) drops below 50 feet trigger distance
    - Beach nourishment of affected reach
        - Implications: temporary construction impact to people and ecology, cost ($2-$11M for 50-ft wide beach along Stinson Beach)
- Dune width drops below 2-year storm buffer (50 ft) trigger distance
    - Replenish and revegetate dune system (build to at least 2-yr buffer)
        - Implications: temporary construction impact to people and ecology, cost about $1-$6M for 50-ft wide dune nourishment along Stinson Beach depending on local free sand availability ($6M cost assumes dredged and imported sand).

Utilizing cost and beach width estimates in this memo, the Beach and Dune Nourishment adaptation strategy schedule for Stinson Beach was developed (Table 4). Initially, a 50-ft wide, 13-ft tall dune would be constructed along the Stinson Beach. The width was based on the storm erosion distance, while the height was based on existing dunes at Stinson Beach. A cobble toe would be placed as landward as possible for the sub reach spanning Walla Vista to Calle Del Occidente where a natural dune exists; cobble would be placed immediately seaward of the homes in front of the dune line for the remaining stretch SE to Calle Del Pinos, and extend into gaps between homes. Dune sand would then be placed on top and seaward of the buried cobble berm. Since the initial dune nourishment would occupy existing beach, the trigger distance is reached more quickly requiring nourishment of the beach in 2040. Subsequent nourishments are applied on a 30-year interval. The appropriate frequency of future nourishments will likely be higher in reality. Once the required shoreline/backshore modifications are so intensive the homes will need to be raised (assumed at 2100). At any time a major storm erosion event may require beach nourishment. Beyond 2100, the first seaward row of homes will likely need relocation as they may be severely exposed.

**TABLE 4**
**COST SCHEDULE FOR BEACH/DUNE NOURISHMENT ADAPTATION STRATEGY AT STINSON BEACH.**

| Year | Cost | Note |
|---|---|---|
| 2015 | $ 12,000,000 | Nourish 50 ft dune with cobble toe (takes up 50 feet of existing beach) |
| 2040 | $ 11,000,000 | Nourish 50 ft beach when beach drops below trigger |
| 2070 | $ 11,000,000 | Nourish 50 ft beach after 30 years |
| 2100 | $ 40,000,000 | Nourish 50 ft beach after 30 years, raise homes in FEMA V-zone |
| **Total net present value (2015)** | **$ 44,000,000** | Assumes 1% discount rate |
| **anytime** | *$ 11,000,000* | *Emergency 50 ft beach nourishment if extreme storm erosion occurs; dune nourishment not considered(add $6M)* |

As sea-level rises, the frequency of required nourishment increases because the rate of sand addition needed to build the beach up increases unless the beach is allowed to retreat landward. Potential problems with beach nourishment include the construction impact to people and beach ecology (Peterson & Bishop 2005; Schlacher et al 2012), generally considered a short term negative effect, and changes to shore conditions that may result from difficulty in finding sand with the desired grain sizes. The success of the nourishment depends on the volume of nourished material, the grain size, and the proximity or use of sand retention structures.

Placement of sand typically provides a temporary benefit until the sand erodes and migrates away from the placement area. It is therefore important to consider the fate of the sand and implications of deposition in other areas. In general, increased sand supply is considered beneficial to most beach areas, but can be problematic at harbors and drain outlets. A site-specific study is required. The regional transport pattern attributed to the Pacific coast of Marin County is toward the south (Habel and Armstrong, 1978). Locally, the transport is primarily within the Bolinas Lagoon inlet mouth and broader Bolinas Bay (PWA, 2006). This implies that some of the placed sand may end up in Bolinas Lagoon and some may migrate southward toward Muir Beach. Whether the sand could be dredged and retrieved and recycled is not known, primarily due to the potential for impacts associated with dredging. However, with sea-level rise, increased sediment supply may be considered a net benefit in terms of mitigating rapid morphologic and ecological changes. If beach-sized material becomes available via construction or other activity, we recommend considering whether the material could be beneficially re-used on the Marin County beaches. More information can be found via the Coastal Sediment Management Workgroup (CSMW)[6].

6 Coastal Sediment Management Workgroup webpage, lasdt visitined April, 2016. http://www.dbw.ca.gov/csmw/

## 7.2.3 Structural Modification (Raise Homes)

Instead of constructing new revetment/dunes along the Calles, homes could be raised to limit wave run-up and erosion damages to homes as the dune is allowed to erode during coastal storms. Appling the cost estimate in this memo, to lift Stinson homes in the effective/preliminary FEMA V-Zone (89 individual structures identified in either zone), we estimate **the total cost would equal roughly $29M.** One advantage of raising homes over building a revetment is it allows limited migration and persistence of a fronting beach in the near term. If additional measures such as beach and dune nourishment are not taken in the future, the shoreline will continue to migrate past homes and potentially damage roads, infrastructure and even the homes if the pilings are undermined. There may also be challenges with height restrictions and other codes. Still, this option could be preferable to armoring in the sense that the back beach is allowed to evolve naturally. As the backshore migration approaches property lines, dunes could be replenished to improve the aesthetics and habitat function at the backshore, as well as limit future damages in areas that are eroded during storm events.

A quantitative trigger for dune/beach replenishment could be tied to estimated storm erosion mentioned above:

- Dune width fronting a home shrinks below the threshold distance (50 feet)
    - Beach/dune replenishment needed.
        - Implications: temporary construction impact to people and ecology, cost of about $3-17M for 50-ft wide dune and 50-ft beach along Stinson Beach.

Utilizing cost estimates and beach width projections listed in this report, the Structural Modification strategy for the Stinson Beach was developed (Table 5). Initially, homes in the effective/preliminary FEMA V-Zone (assuming no decrease in V-zone extents mapping) would be lifted. As the beach narrows with sea-level rise, beach nourishments will be needed to maintain a buffer to the backbeach as well as for recreation and ecological function. The first nourishment occurs at 2060 and again at 2090. The appropriate frequency of future nourishments will likely be higher in reality. At any time a major storm erosion event may require beach/dune nourishment. Beyond 2100, the first seaward row of homes will likely need relocation as they may be severely exposed.

**TABLE 5**
**COST SCHEDULE FOR STRUCTURAL MODIFICATION ADAPTATION STRATEGY AT STINSON BEACH.**

| Year | Cost | Note |
|---|---|---|
| 2015 | $ 29,000,000 | raise homes in FEMA V-zone |
| 2060 | $ 11,000,000 | Nourish 50 ft beach at Stinson when beach drops below trigger |
| 2090 | $ 11,000,000 | Nourish 50 ft beach after 30 years |
| **Total net present value (2015)** | **$ 41,000,000** | Assumes 1% discount rate |
| **anytime** | *$ 11,000,000* | *Emergency 50-ft beach nourishment if extreme storm erosion occurs, dune nourishment not considered (add $6M)* |

## 7.2.4 Easkoot Creek

In addition to the coastal hazards that affect the Stinson Beach area are fluvial flooding hazards from Easkoot Creek. A previous study (OEI 2014) identified strategies to managing the Creek for current and future flooding. One strategy consisted of raising Calle De Arroyo to limit fluvial flooding of homes seaward of the road. Three of the ten strategies included a flood bypass across the beach that would convey enough flow during a storm event to reduce flooding of the Calles and restore or enhance wetland habitat that once existed in the National Park Service's south parking lot. Our initial assessment is that these flood-management strategies are consistent with adaptation planning. The restoration of a lagoon wetland feature and overflow to the Pacific across the beach is particularly attractive as it reduces the need for structural modification of homes while provides ecological benefits in a sustainable manner, and is consistent with restoration of historic conditions, and may have a broader potential for funding.  Structural adaptation to use pile foundations and raise homes above flood levels is also potentially viable, and complementary to other strategies as well as responsive to coastal flooding. Further analysis is warranted to assess the preferred adaptation strategy(ies).

## 7.3 National Parks Service Beach

The remaining National Parks Service beach that extends southeast of Calle Del Pinos is backed by nourished dunes and parking/amentities (Figure 7). The area is low lying and once was a lagoon/pond, and is subject to flooding from Easkoot Creek (OEI 2014). Landward of the Parks land are county/city assets that will become at risk if the natural shoreline defenses are compromised. Adaptation alternative cost schedules were not developed for the National Parks Service beach. However, we anticipate that National Parks will not armor to protect the backshore, but instead facilitate the natural development of future habitat (Caffrey and Beavers 2013). NPS will likely employ a retreat strategy that may include maintaining the dunes/beach and reduce parking and amenities as the shore migrates inland with sea-level rise. Coordination may be required between Federal and Local jurisdictions in the future to ensure effective risk management of Stinson assets that exist inland of NPS land.

# 8. Additional areas of interest

ESA developed a broad review of strategies for Muir Beach, Bolinas, Dillon Beach, and Tomales Bay:

## 8.1 Muir Beach

Muir Beach is characterized by low lying floodplain surrounding Redwood Creek flanked by steep eroding bluffs. Homes built on the tops of bluffs will continue to be at risk as sea-level rise accelerates erosion of bluffs. Two management strategies were identified for the residences and infrastructure on these bluffs: protect or retreat.

There are a few general best management practices that should be followed to reduce erosion of the bluff top and face (Figure 10). Finding appropriate solutions to these processes depends on local subsurface conditions, geology, existing drainage patterns and are not prescribed here. Example solutions include subdrains to intercept and reroute groundwater flow from the bluff top, and underdrains to intercept groundwater before it reaches the bluff face. No solution is appropriate for all conditions/locations.

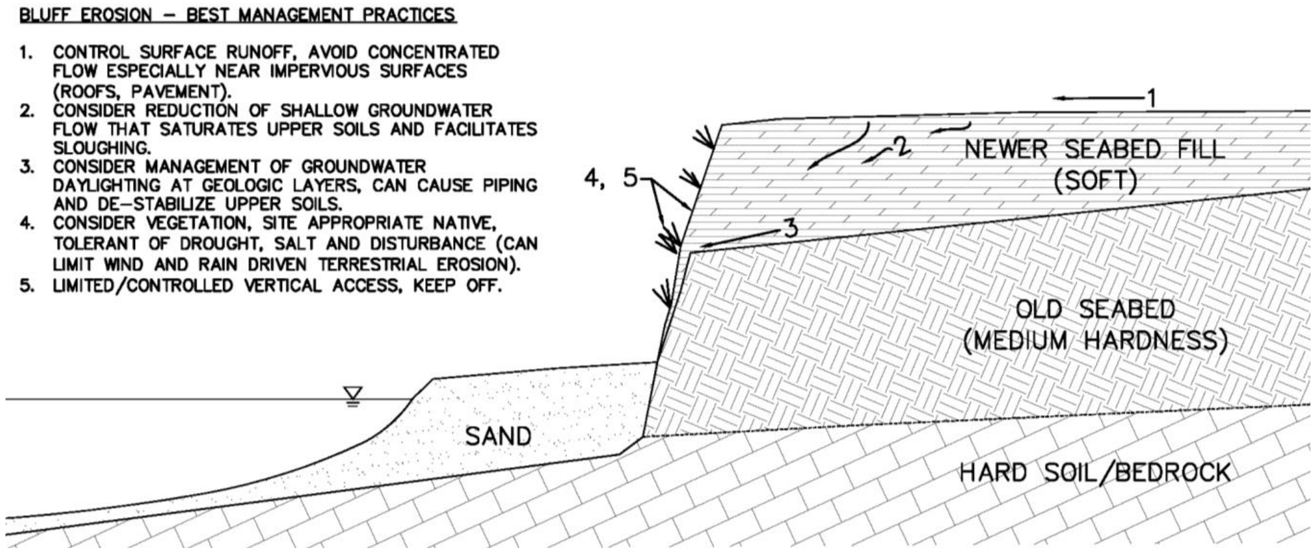


**Figure 10. Bluff erosion best management practices.**

## 8.1.1 Protect

**Beach and Dune Restoration**: Dune restoration may not be an effective solution for protecting blufftop homes at Muir Beach, as the beach is already squeezed or absent in front of the bluff toe and sand placed for dune creation would likely not last. Additionally, nourishments would not affect the erosion processes at the bluff top.

**Armoring**: Some armoring structures are already in place at the bluff toe fronting homes at Muir Beach. If designed properly, this solution could be effective in limiting erosion of the bluff face, but will result in less sediment delivery to the beach, lead to local scour at the toe of structure and ultimately lead to rapid degradation and failure of the structure. Furthermore, toe revetment may not prevent additional erosion of the upper bluff face. Armoring requires maintenance and sea-level rise will result in increased loadings that will likely require reconstruction: Therefore, armoring may not be a sustainable approach.

In addition to protection strategies that address erosion of the toe, elements of drainage control, disturbance avoidance, vegetation management and slope stabilization could be employed to limit (but not completely prevent) erosion of the bluff top and face. These elements are discussed in the following Managed Retreat section.

## 8.1.2 Managed Retreat of Bluff Top

Removal or relocation of structures and infrastructure from the bluff top and allowing erosion would result in greater preservation of the natural beach system than armoring the toe. Eroding bluffs will continue to supply sand to the beach, in turn increasing the buffer the beach provides from wave action on the bluff toe. Given the costs associated with purchasing property, and the costs associated with degradation followed by abandonment, a planned retreat, realignment or landward redevelopment strategy may be preferred. Such a strategy may include one or more of the following elements:

- Drainage control: Limited surface and shallow subsurface drainage to the bluff edge and face that can cause local erosion and slope failures;
- Disturbance avoidance: Limit access, especially uncontrolled vertical access which may destabilize the bluff and pose a safety hazard;

- Vegetation management: Identify preferred vegetation for bluff stability and other criteria;
- Slope stabilization: There are a range of surficial and shallow stabilization techniques which may slow the pace and extent of bluff recession. Such measures are particularly valuable in the interim until a longer-term retreat strategy can be negotiated. Larger structures such as walls can be included, but use of such structures should be linked to a commitment to remove them as part of the retreat strategy;
- Structure Modification and Relocation: In some cases, a structure can be moved landward or otherwise modified to allow for bluff recession.
- Land use measures: In addition to purchasing property, there are alternative measures that may be effective. Conservation easements and redevelopment restrictions can prevent increased damage risk. Transfer-of-development-credits can facilitate relocation of the development function. Rolling easements, development restrictions, and reverse-mortgage-buyouts are other approaches which may facilitate a fair and orderly adaptation.
- Eminent Domain. The public can potentially take private property for public use such as maintaining natural shores, following the payment of just compensation to the owner of that property.

## 8.2 Bolinas

Bolinas is vulnerable to sea-level rise in a few locations: beachfront and blufftop homes along the open coast as well as homes and infrastructure along Wharf Rd. To maintain the beaches below bluffs, existing armoring can be removed and development removed or relocated in a managed retreat scenario. Easements and other land use policies are recommended to limit further construction and investment in existing most hazardous areas and also limit long-term investment in areas that will have hazards in the future. These easements would move (or "roll") with bluff and shore erosion. Utilities and roads would also be realigned over time to limit costs and avoid catastrophic failure and hazardous conditions. Structural modification measures (e.g. pile foundations) as well as innovative management measures (e.g. conservation easements) could facilitate the overall retreat adaptation strategy. Marin County requested input from ESA on adaptation measures listed in following subsections.


**Figure 11. Bolinas 2010 bluff edge segmented by Pacific Institute (PWA 2009) study blocks.**

### 8.2.1 Armoring

Homes built at the top of steep eroding cliffs in Bolinas will always be in jeopardy. Existing hazards are apparent from the rock revetment and seawalls presently built in front of homes and along bluff toes in the area. If further armoring measures are taken along the cliffs in Bolinas, the supply of sediment from the cliffs to the beach will be cut off and the beach can be expected to erode and eventually disappear, affecting recreational opportunities and ecological function. Armoring to prevent bluff erosion is not recommended because it would result in loss of the fronting beaches over time which will result in increased loadings and structural requirements. Additionally, the overall costs may outweigh the values of the properties.

### 8.2.2 Nature based

Beach nourishment could provide short term benefits of maintaining a beach for ecology and recreation services and reducing wave run-up on seawalls and bluffs along the south facing shores of Bolinas west of the Bolinas Lagoon mouth. In the long term, beach nourishment will become more expensive as sand sources are limited and the amount of sand required increases with sea-level rise.

Inside the lagoon mouth along Wharf Rd, nature based strategies to managing SLR may be difficult to implement. This would require an evaluation of how the lagoon mouth is likely to evolve, how it interacts with the lagoon and the cliffs and what opportunities or constraints this might create. The lagoon mouth configuration and slough channel along Wharf Rd are hurdles to implementing an adaptation measure such as a horizontal levee. The slough channel would need to be realigned, which would limit boat access from Wharf Rd homes. However, land east of Olema Bolinas Rd could be used to develop a horizontal levee system to adapt to higher sea levels in the future. Beach nourishment and horizontal levee are only two of several nature-based adaptation strategies.

### 8.2.3 Accommodate

To maintain existing boat access at Wharf Rd, higher sea levels could be accommodated by elevating homes and Wharf Rd. By including proper stormwater features such as flap gates, an elevated Wharf Road could also protect the low lying neighborhood behind it.

### 8.2.4 Culverts vs Causeways at Shoreline Hwy

Shoreline Hwy along Bolinas Lagoon will be impacted by SLR. As precipitation patterns shift with climate change to more flashy storms, culverts on many streams will need to be upgraded to convey higher peak flows. This requires either larger culverts or raising the roadway on piles to allow conveyance of storm runoff. In the context of sea-level rise, a piled causeway design could provide further ecological benefit by allowing migration of habitat under the roadway and upland.

### 8.2.5 Bluff top best management practices (BMPs)

Bluff erosion in Bolinas will likely accelerate with sea-level rise. To avoid risk of damage, setback distances have been specified by different entities. The Marin County Local Coastal Program Unit I states:

> *The Coastal Commission in its Interpretive Guidelines for Marin County recommends a minimum setback of 150 feet from the blufftop for new construction. This setback is based on a retreat rate of 3 feet per year multiplied by an economic life expectancy for a structure of 50 years. The also require a geologic investigation and report for all blufftop development.*

*The Environmental Hazards Element of the Marin Countywide Plan calls for adherence to the guidelines adopted by the Coastal Commission. The Bolinas Community Plan recommends a variable setback. From Little Mesa to Duxbury Reef, they recommend an 80 foot (two feet per year times 40 years) setback and from Duxbury Reef to Point Reyes National Seashore, they recommend a setback of 120 feet (three feet per year times 40 years). This is based on an economic life expectancy of 40 years for a structure and the retreat rates indicated in parenthesis.*

The Bolinas Gridded Mesa Plan (1985) presents similar bluff rates in the context of construction setbacks:

*Differential rates of bluff retreat necessitate differential construction setbacks. Setbacks should be considered on a site specific basis. The Local Coastal Program setback of 150' and the Bolinas Community Plan figure of 120' discussed during the planning process were based on the formula: setback = life expectancy of structure (50 yrs., I 00 yrs., 150 yrs.) x rate of retreat + safety factor (45'). (Rate of retreat figures and the safety factor are based upon studies done for the California Division of Mines and Geology in 1977 by David L. Wagner, Geology For Planning In Western Marin County, California.) Since the two Mesa bluff areas are different, separate bluff retreat rates are considered as follows:*

*Between Overlook and Duxbury Point:*
*50 yrs x 2'/yr + 45' (safety factor) = 145'*
*I 00 yrs x 2'/yr + 45' (safety factor) = 245'*
*150 yrs x 2'/yr + 45' (safety factor)= 345'*

*Between Duxbury Point and Poplar Road:*
*50 yrs x 2.5'/yr + 45' (safety factor)= 170'*
*100 yrs x 2.5'/yr + 45' (safety factor)= 295'*
*150 yrs x 2.5'/yr + 45' (safety factor) = 415'*

*Because cliff erosion is episodic, not constant, it is difficult to estimate the position of the cliff for any given year in the future. Building life expectancy is highly variable. The setback formula was used by the Mesa Plan Resource Group to determine the zone a long both bluffs where no new construction should occur.*

Current thinking on blufftop setbacks in Marin County is summarized here from the latest Local Coastal Program Amendment:

***C-EH-5 Blufftop and Shoreline Erosion Hazards***

***Blufftop Erosion.*** *Ensure that new blufftop development, is safe from bluff retreat and other coastal hazards without a reliance on shoreline protective devices. Except as provided for by Policies C-EH-7, C-EH-15, and C-EH-16 new development shall be set back from the bluff edge a sufficient distance to ensure its stability and structural integrity for a minimum of 50 years and to eliminate the need for shoreline protective devices. A coastal hazards analysis shall evaluate the effect of erosion, geologic and other hazards at the site to ensure structural integrity for a minimum of ~~100 years~~ 50 years. The coastal hazards analysis shall include a quantitative slope stability analysis demonstrating a minimum factor of safety against sliding of 1.5 (static) or 1.2 (pseudostatic, k=0.15 or determined through analysis by the geotechnical engineer). Safety and stability must be demonstrated for the predicted position of the bluff following bluff recession over at least ~~100 years~~ 50 years. The predicted bluff position shall be evaluated considering not only historical bluff retreat data, but also acceleration of bluff retreat due to continued and accelerated sea-level rise, and other climate impacts. According to potential sea-level rise estimates prepared and adopted by the County of Marin for use in coastal hazards analyses.*

To support the County's Vulnerability Assessment, ESA produced bluff erosion hazard zones for both projected historic rates and amplified rates from sea level rise (ESA 2015a). These rates and buffers are summarized and compared against the above suggested values in Table 6 below. Setbacks are specified for each planning timeframe; ESA setbacks are referenced to 2010 conditions. Corresponding erosion rates are reported for historic and 2100 accelerated conditions from the Pacific Institute (PI) study (PWA 2009) that consider High SLR. The ESA setbacks for each reach were determined using the average erosion rate plus one or two standard deviations within each reach. It is helpful to think about the average and standard deviations of erosion rates as the likelihood of exceedance; the average plus two standard deviations describes a setback that is not likely to be exceeded (around 2% of locations / times), whereas adding one standard deviation indicates exceedance may occur around 15% of the locations / times, and use of the average (no additional standard deviation) indicates the distance could be exceeded at about 50% of the locations / times. Thus, there is uncertainty in all estimates of future erosion distances and selection of the distances can be affected by tolerance for risk such as loss of property or infrastructure. The risk acceptance and corresponding setback should be determined by county planners or other local entities. Note that improved methodologies used in more recent SLR hazard mapping studies suggest that the PI study may over predict accelerated erosion rates with SLR. Also note that the ESA-computed rates for the sub reaches in Table 6 are average values; localized erosion rates can be higher depending on geology, potential for landslides/block failures etc. Alongside the ESA computed setback distances are ranges of erosion rates, rate factor of safety (FOS) and equivalent rates for comparison against the recommended rates from past guidance.

**TABLE 6**
**BOLINAS OPEN COAST BLUFF EROSION SETBACKS CONSIDERING VARIOUS GUIDELINES.**

| Erosion Buffers and Rates | 40 yrs (2050) | 50 yrs (2060) | 100 yrs (2110) | 150 yrs (2160) | Erosion Rate (R) | FOS (+X StDev) | Equivalent Rate (R+FOS) |
|---|---|---|---|---|---|---|---|
| **Coastal Commission Interpretive Guidelines for Marin County:** | | | | | | | |
| Minimum setback for new construction: | (120 ft) | 150 ft | (300 ft) | (450 ft) | **3 ft/yr** | - | - |
| **Environmental Hazards Element of the Marin Countywide Plan:** | | | | | | | |
| Little Mesa to Duxbury Reef | 80 ft | (100 ft) | (200 ft) | (300 ft) | **2 ft/yr** | - | - |
| Duxbury Reef to Point Reyes | 120 ft | (150 ft) | (300 ft) | (450 ft) | **3 ft/yr** | - | - |
| **Bolinas Gridded Mesa Plan (1985):** | | | | | | | |
| Overlook to Duxbury Point | - | 145 ft | 245 ft | 345 ft | **2 ft/yr (+45 ft)** | - | - |
| Duxbury Point to Poplar Road | - | 170 ft | 295 ft | 415 ft | **2.5 ft/yr (+45 ft)** | - | - |
| **ESA - considering only USGS historic (1929-1998) erosion rates:** | | | | | | | |
| Little Mesa to Duxbury Reef **(+1 StDev)** | 116 ft | 145 ft | 290 ft | 435 ft | 1.5 ft/yr | 1.4 ft/yr | **2.9 ft/yr** |
| Duxbury Point to Poplar Road **(+1 StDev)** | 80 ft | 100 ft | 200 ft | 300 ft | 1.3 ft/yr | 0.7 ft/yr | **2 ft/yr** |
| Little Mesa to Duxbury Reef **(+2 StDev)** | 172 ft | 215 ft | 430 ft | 645 ft | 1.5 ft/yr | 2.8 ft/yr | **4.3 ft/yr** |
| Duxbury Point to Poplar Road **(+2 StDev)** | 108 ft | 135 ft | 270 ft | 405 ft | 1.3 ft/yr | 1.4 ft/yr | **2.7 ft/yr** |
| **ESA - considering accelerated erosion rates due to SLR (PWA 2009):** | | | | | | | |
| Little Mesa to Duxbury Reef **(+1 StDev)** | 212 ft | 160 ft | 475 ft* | N/A | 1.5-4.3 ft/yr** | 1.1-3.1 ft/yr** | **2.6-7.3 ft/yr**** |
| Duxbury Point to Poplar Road **(+1 StDev)** | 82 ft | 104 ft | 228 ft* | N/A | 1.3-1.5 ft/yr** | 0.7-0.9 ft/yr** | **2.0-2.6 ft/yr**** |
| Little Mesa to Duxbury Reef **(+2 StDev)** | 171 ft | 225 ft | 671 ft* | N/A | 1.5-4.3 ft/yr** | 2.2-6.2 ft/yr** | **3.7-10.5 ft/yr**** |
| Duxbury Point to Poplar Road **(+2 StDev)** | 110 ft | 140 ft | 309 ft* | N/A | 1.3-1.5 ft/yr** | 1.4-1.8 ft/yr** | **2.7-3.3 ft/yr**** |

*Extrapolated to 2110 using 2100 rate
**Range: historic to SLR-amplified rate at 2100

We recommend that setbacks for development and planning in Bolinas (and elsewhere) use a minimum 50 year analysis timeframe and apply SLR-accelerated erosion rates with a factor of safety (1-2 standard deviations of the erosion rate, with an additional block failure/landslide offset where applicable). Site specific evaluation of erosion rates is recommended; the average values reported in Table 6 could be considered as a minimum.

**New Construction:** Setback that considers long term erosion plus accelerated erosion due to sea-level rise (sea-level rise rate to be determined by County) plus factor of safety that includes erosion variability and/or landslides/block failure widths where applicable. For the example of a new structure near Ocean Pkwy with a structure life of 50 years, this setback could be 225 feet (50 year offset from average erosion plus 2 StDev from Table 6).

**Existing Structures (planning trigger):** Local studies are required to assess local geologic conditions and characteristic block failure (or landslide) widths. Generally, a planning timeframe could be established that determines a distance set by long term plus accelerated erosion and a factor of safety. For example, assume it takes 5 years for permitting/planning to remove or relocate a structure at Ocean Pkwy: using a near term retreat rate of 3.7 feet per year (average plus 2 StDev from Table 6) and a 45 foot block failure factor, the trigger distance (from structure to bluff edge) to start planning would be 64 feet (3.7 ft/yr times 5 years = 18.5 feet, plus 45 feet).

## 8.3 Dillon Beach

### 8.3.1 Dune restoration

Dune enhancement would improve the existing conditions along Dillon Beach. The area is fronted by a vegetated dune that protects the trailer park and access roads from wave run-up, although past aerial imagery shows the dune width fronting the trailer park has eroded 50% in the last few years in some locations. The Lawson's Landing trailer park location as well as the dunes fronting Dillon Beach parking lot are good candidates for dune enhancement in the near term. With future sea-level rise and monitoring of dune erosion, critical areas may be identified that warrant dune replenishment.

### 8.3.2 Retreat

In the near term, most of the trailer park and access roads appear to be well protected by the existing dunes. As dune face erodes, infrastructure could be removed before it is impacted. By allowing the dunes to erode naturally, sand is supplied to the beach in the process and the natural beach function is maintained.

## 8.4 Eastshore/Tomales

The main hazard within Tomales Bay is tidal flooding. As sea-level rises, both regular tides and coastal storm surges will inundate greater areas. Many homes are built over the water that will become increasingly at risk as these flooding hazards worsen. One possible adaptation for affected buildings and roads is to raise on pilings or by placing fill. Aside from rising water levels, local wind waves pose a risk to some homes and roads, although not as extreme as on the open coast. Due to the limited fetch in Tomales Bay, natural features such as offshore bio-beds (oyster reefs, sea grasses) can be used to limit wave impacts on shoreline development in some areas. Shown in Figure 12, the bathymetry in Tomales Bay is the limiting factor on where these measures can be applied. Both oyster reefs and sea grass beds require relatively shallow water, while much of central Tomales Bay is deep.

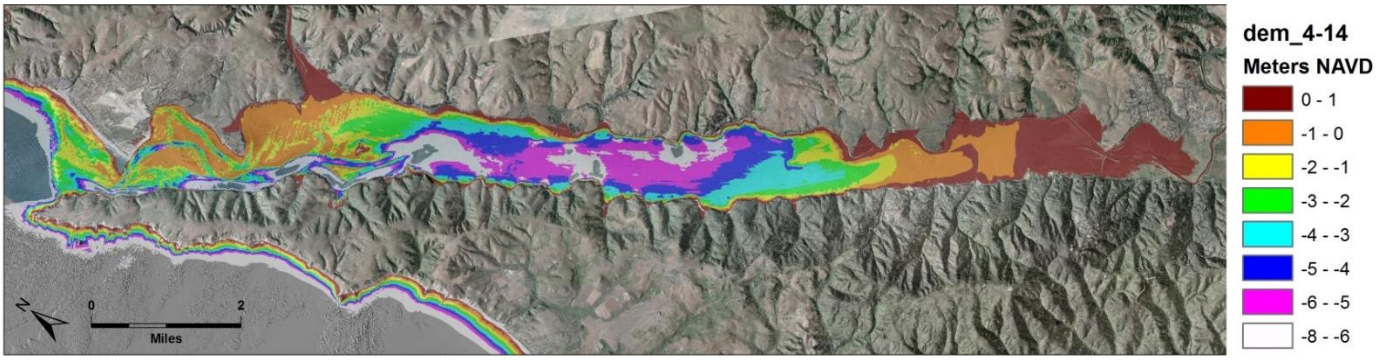


**Figure 12. Bathymetry in Tomales Bay, DEM source: USGS (Foxgrover & Barnard 2012).**

## 8.4.1 Offshore Bio-beds (Oysters, Sea-grass, Kelp)

Oyster reefs are considered potential erosion and flood hazard mitigation measures where waves are small and weak enough to be dissipated by the limited reef structures. Hence, this measure is potentially viable in estuarine areas such as Tomales Bay. Oyster reef elements can consist of a hard oyster settlement substrate of some type placed onto a supporting structure. In past projects, a wooden pallet or PVC base structure has been used to support oyster shell or other substrates. Oster bag mounds are then placed on the base as an oyster recruitment structure, other small test pilot cases use relatively inexpensive modular cement structures as the oyster substrate.

As pointed out at a recent meeting of the Eastshore Planning Group, oyster reefs may not be a viable solution to erosion and flooding hazards in Eastshore due to the deeper bay in the area. However, other areas may be suitable for oyster reefs as a nature-based erosion mitigation alternative to shoreline revetment. In the absence of detailed bathymetric data in Tomales Bay, the Digital Elevation Model (DEM) utilized in the OCOF hazard mapping study was used to identify potential areas where relatively shallow slopes exist near human development. These areas mostly occur along the Inverness shoreline and Millerton. A detailed feasibility analysis should be conducted to fully understand the possible opportunities and constrains to using oyster reefs in Tomales Bay.

Also studied in the SF Bay Living Shorelines study, eelgrass beds are another possible means of wave energy attenuation. Various studies have examined wave attenuation from sea grasses in low-energy environments (Bradley & Houser 2009; Fonseca & Calahan 1992; Wu & Cox 2015). Similarly to oyster reefs, seagrass beds require shallow water among other factors to flourish, and are thus limited in applicability to wide shallow areas in Tomales Bay.

## 8.4.2 Elevating Structures

There is obvious interest in a community-wide approach to elevating homes along the Bay. In the past, residents got together to develop a community-wide septic system and therefore have a good model for community collaboration. Such a program could be set a good precedent, support economies of scale (making it cheaper for individual homeowners) and be competitive for state grants and other funding sources. Depending on community desires, the timing of elevating structures could be determined by a chosen acceptable level of protection against monthly high water (EMHW) or greater (1-year or 10-year flood), as explained in section 2. Triggers for Adaptation Actions.

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# Appendix C

# ADAPTATION POLL RESULTS

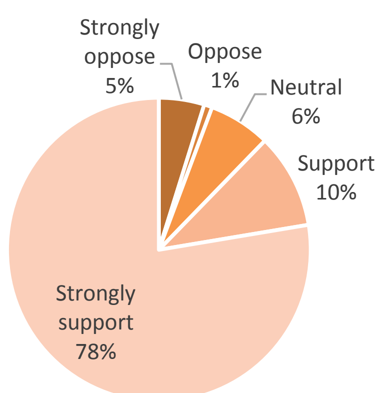
# West Marin Adaptation Poll Results

Collaboration: Sea-level Marin Adaptation Response Team (C-SMART) January 2016

Over 200 people participated in the West Marin Sea Level Rise Adaptation Poll between November 2015 and January 2016, helping Marin County Community Development Agency understand which adaptation strategies might receive the most public support in the future. (Numbers in parentheses after comments indicate the number of respondents who made a particular comment.)

## Policy questions for coastal hazard areas

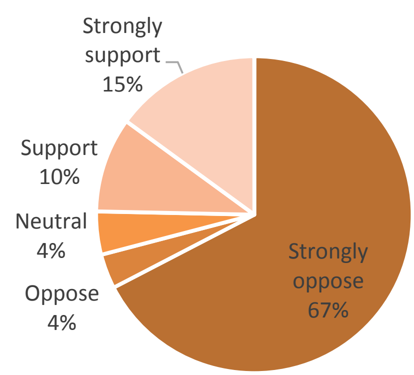
1. **Planning timeframes for construction standards in hazard zones should take into consideration the life expectancy of the structure or development being proposed.** *For example, should construction standards and permits for private residential or commercial use be evaluated on a different timeframe from plans for major public facilities (such as a fire station, Highway 1 or a new bridge)?*




**Question 1 Comments:**

- Planning timeframes for single family homes should not exceed the existing 50-year standard (5).
- Residential should not be required to last as long as public infrastructure.
- This should be more specific; private residences shouldn't have construction shut down for hazards that may be 50+ years away, even if that might be appropriate for a hospital or fire station.

2. **Require a sea level rise hazards analysis as part of a Coastal Development Permit for new projects on vacant land or for projects that expand the size of existing development.** *Landowners would be required to: 1) Establish the projected sea level rise range for the proposed project's planning horizon; 2) Determine how physical impacts from sea level rise may constrain the project site, including erosion, structural and geologic stability, flooding and inundation; 3) Determine how the project may impact coastal resources, considering the influence of sea level rise upon the landscape and impacts of adaptation strategies that may be used over the lifetime of the project; and 4) Identify alternatives to avoid resource impacts and minimize risks throughout the expected life of the development.*



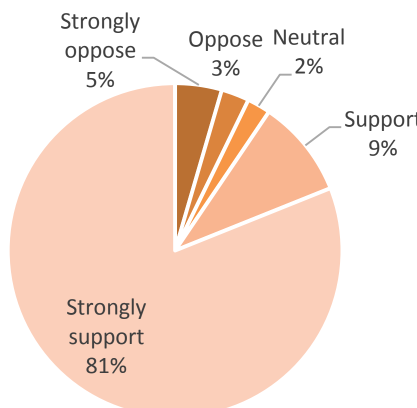

**Question 2 Comments:**

- New requirements should not make it more difficult to develop in ways that protect our homes from hazards. (5)

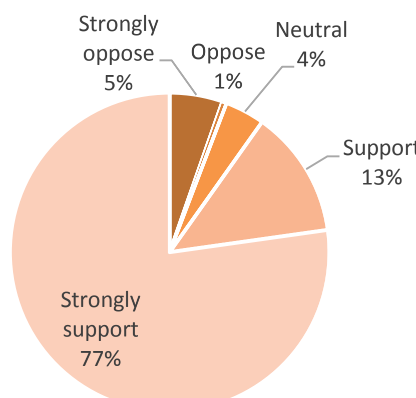
- Reasonable standards should allow for improvement/expansion of existing homes.
- Nobody knows how bad sea level rise will be.
- Given the wide variability in projections for sea level rise, a site-specific hazards analysis would provide little useful information at great expense; effectively prohibiting any development.
- The County should map out these hazards for homeowners as is done for earthquakes in Alquist-Prieto zones. It shouldn't be the burden or responsibility of the homeowner to determine what sea level rise will be in their area in 100 years. (3)
- Enough studies have been done. Requiring every resident to pay for their own study is overly-taxing and an unreasonable burden.
- Support analysis for new projects on vacant land, but oppose it (don't see need for) on expanding existing development.
- Yes, when the expansion is more than 35% of the existing development. (2)
- Generally, support but scope must be controlled. Similar though to the analysis in the city that informs owners of land quality.
- As long as it's a simple analysis, not CEQA scale.

3. **Allow waivers or seek a Categorical Exclusion for projects in coastal hazard areas, including structures in the 100-year floodplain, that meet the following standards:**

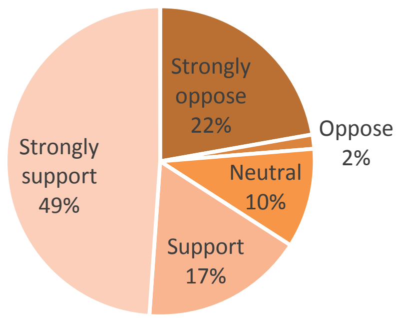
   a. *Alterations to existing structures that consist of interior or exterior renovations/ remodeling or the replacement of structural components (such wall, floor, and roof framing and cladding or foundation components) that do not alter the existing building footprint or increase the height, bulk or floor area of the structure.*




   b. *Projects that meet safety standards, which may include breakaway walls, flood vents and elevation.*



*c. Structures elevated to meet or exceed FEMA standards by up to 3 feet, result in up to 10% additional floor area[1], and do not exceed the current building height limit.*

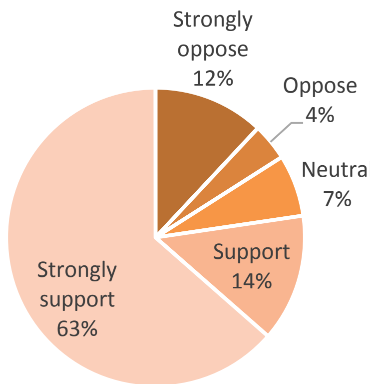



**Question 3 Comments:**

- Proposal C should be eliminated. Policies that permit safe development and hazard areas should be encouraged. (8)
- Seems like we should want to permit safe development in hazard areas. I do not understand how to vote on "c". Need clarity on whether question applies to remodels or new development. This question is very confusing. (4)
- We need to be able to protect our homes. We live directly on the water. With housing costs rising this is our only choice. We need to protect our homes from rising water.
- For a and c, support WHERE THE INCREASE IS LESS THAN 35%. In c allow 10-15% increase in building height to accommodate elevation of floor level.
- For a and c: allow improvement/ expansion of up to 50% and allow for some greater height to accommodate raised floor levels.
- On c there should also be some exemption or at least streamlined variance process for homes that have to exceed the current height limit if they are being built to meet FEMA standards or otherwise to resist flooding.
- C is too vague. We need to be able to expand/enhance our homes beyond 10% additional floor area. No one wants to pay $100k to raise a 600 sq. ft. shack that is in poor repair or worse, have to build new at the same size for $500k!
- Setting general standards and then providing more streamlined processing based on those standards strikes me as a good idea.
- Support if it's possible to indemnify permitting agencies and neighbors.
- As a property owner of a tiny cottage, determining expansion percentages (10%) without giving considerations to overall TOTAL home size and TOTAL lot size seems like very bizarre and arbitrary planning code. So neighbors that have already expanded to 2100 square feet in 1985 can add another 210 square feet, but I can only add 70 sf, even though my lot is larger?
- I think generally, homeowners in Stinson want to be able to have and let their neighbors have reasonable renovations for existing structures. The questions of new development on a vacant lot is a hot button that would bring different responses.
- We want Malibu exclusions. We will rebuild without FEMA $$. Note that max FEMA allows is $250k, costs 7-8k per year and deductible is $25-100k. Terrible "insurance". Maybe ok in Gulf but not here.

[1] The certified Marin County Local Coastal Program identifies additions resulting in an increase of less than ten percent of the internal floor area of an existing structure as exempt from a Coastal Development Permit. (Sections 22.56.050I and 22.56.055I carry out California Public Resources Code Section 30610).

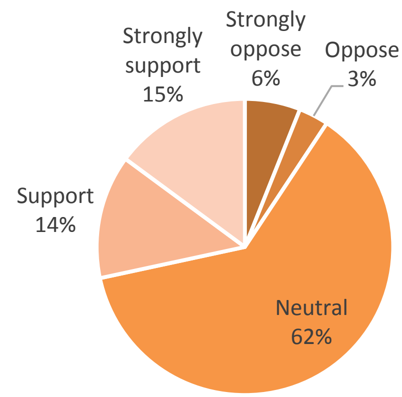
4. **Raise building height limits in coastal hazard areas to allow for adaptation to sea level rise.** *If strict height limits are maintained, some landowners may need to construct flat roofs or seek a variance to exceed the maximum height. Raising building height limits may affect views, but may also allow for greater design flexibility.*




**Question 4 Comments:**

- Raising height limits would have minimal view impacts from public roads along Stinson Beach. (5)
- Allow 10-15% increase in building height to accommodate elevation of floor level. (2)
- As sea levels rise, so should building height limits.
- This seems likely a reasonable and measured approach to adaptation. It can be implemented relatively rapidly and on a parcel by parcel basis as and when sea level conditions change. It's the very essence of adaptive management.
- This should be done in some combination of raised limits and exemptions (preferable) or variances (less preferable) for building above height limits when it is done for safety reasons in hazard zones.
- Depends on impact to existing buildings and community.

5. **Encourage the creation of local self-funded assessment districts to manage common hazard risks.** *Local assessment districts, such as County Service Areas, Hazard Abatement Districts or similar neighborhood-level entities, could enable communities to pool resources to obtain insurance coverage, conduct a community coastal hazards analysis, and fund local risk reduction and adaptation measures (e.g. raising private roads).*




**Question 5 Comments:**

- Need more information about how such districts would work to be able to answer this question. (10)
- Seems reasonable to require some level of local participation in managing costs of common hazard risks. Encouraging local districts would also let the local community decide what investments in hazard mitigation it is willing to make rather than having it imposed (or disallowed) by a regional or statewide entity. Local involvement is a big plus.
- Generally supportive but only if these are "voluntary" and follow existing local district organization, for instance in Stinson Beach the SBVA or Seadrift HOA.

- FEMA and the County task force studies are there to be used and should be used. The local community does not have the resources to do better and there is more risk of local political intervention.

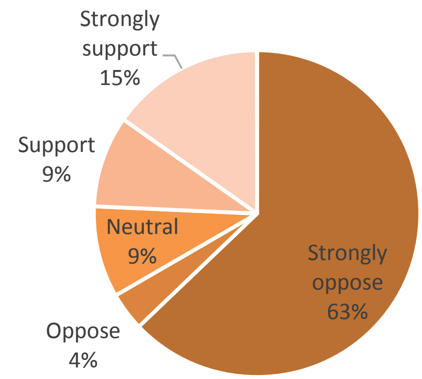
- What is the other option? Is this similar to what parts of Marshall does for its septic and water systems? They seem to work very well.

- I can't envision working class population being able to afford this. I think It discriminates against working people.

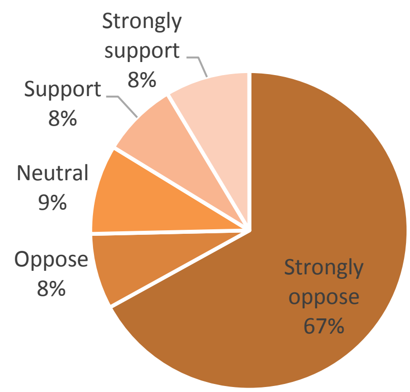
- For information, but they shouldn't control the owners' rights in their building and remodel projects. As long as they meet building requirements, owners should be able to do as they wish. Committee should also not have the power to delay construction whatsoever. Only to inform and recommend but frankly, if owners are meeting code, that's their right. Unless this committee can represent the interests of the community to influence policy that restricts owners unlawfully or unreasonably.

6. **Establish a managed retreat program.** *Purchase properties vulnerable to coastal hazards. Structures are typically demolished or relocated. The property would be restored to a natural state and used for open space or recreation. Lands of lesser habitat value and hazard vulnerability could be rezoned or made available in exchange for properties in hazard areas, along with equitable financing arrangements.*

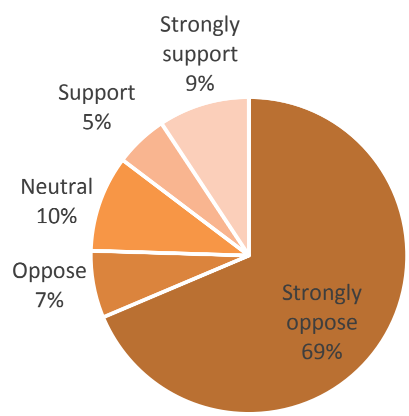
*a. Acquire vacant vulnerable properties.*



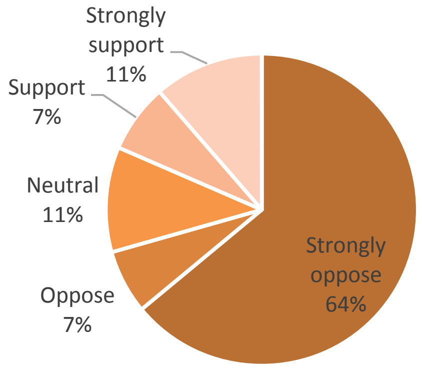

*b. Acquire developed vulnerable properties before damage occurs.*



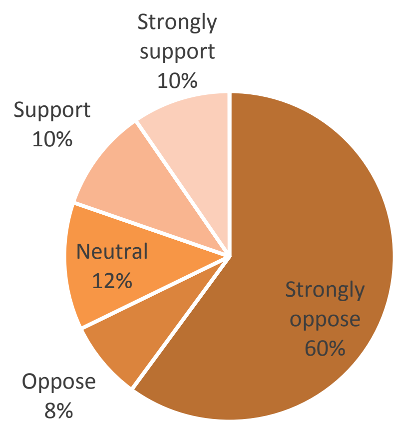

*c. Acquire developed vulnerable properties only after significant destruction by storms or high tides.*



*d. Explore the feasibility of a public parkland exchange program that encourages landowners to move out of hazardous areas.*




*e. Identify and make available (eg. through rezoning) land outside the hazard areas to allow owners of vulnerable properties to relocate nearby.*




**Question 6 Comments:**

- No County policies should be created to comply our homes need to be abandoned. (10)
- This is too heady, remote, and overwhelming to think about. I can't imagine how such programs would be implemented. Far-fetched.
- We would appreciate it if the County of Marin would leave us alone. We are old enough and smart enough to deal with the problems.
- Managed retreat is not a realistic nor desirable policy for Stinson in the short to medium term.
- This is a constitutionally questionable effort and likely to be wildly expensive if market prices are paid for taken property.
- Who will be paying to "acquire"? Where's the money coming from? Vulnerable houses won't be worth anything. (6)
- Funding for acquiring property is very unlikely! Deny rebuilding in demolished properties.
- Strongly disagree with managed retreat. It is one thing to restrict new development in sea rise hazard areas, it is quite another to basically move existing and longstanding development out of these areas. Finding a way to protect and adapt should be the first priority.
- Tricky item: Must be done so that is "just-in-time" in case projections on sea level rise that are flawed don't induce unneeded dislocation. Also, purchases should be structured to not reward owners who poured money in to their property with full warning of the dangers.
- I am against because wording is unclear. Would the purchase be mandatory? Or always a homeowner's option? Only with the concurrence and approval of the owner and NOT as an eminent domain activity.
- This seems like an overreach of government to suggest property owners

must be forced to abandon with unclear compensation.

- 6e ("relocate nearby"): "Where? Rezone Open Space land?"

- Not happy about Park lands being used for private houses. I would strongly support if this didn't mean developing public parkland. If it does, I'm not sure.

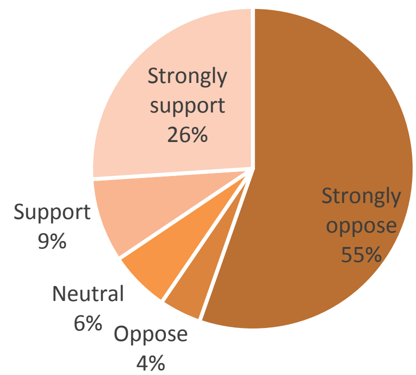
- Work with community Land Trusts to acquire multi-family and generational buildings.

- This seems draconian, extraordinarily expensive and premature. County policies should allow for an "adaptive" incremental approach as the actual effects of climate change and sea level rise become apparent.

- Revisit plans after 10 years so more history can be developed.

- I strongly support creative use of resources with an eye to preventing or addressing problems of expected sea rise and flooding for properties that are going to be affected or which have been affected. Allowing land in higher elevation to relocate for those who are facing loss may be a workable option I would support but a lot of work would need to be done to make that happen. What is not clear is who pays for the damaged or high risk land and would it be market value or how would reimbursement be determined. This is a community that wouldn't vote Measure A, remember? But for the feds it may be a cheaper thing than the FEMA insurance reimbursements over time. It may make for good long-term policy to clear the lots away that are most at risk.

7. **Prioritize adaptation options that protect, enhance, and maximize protection of coastal resources and public access.** *Give full consideration to innovative nature-based approaches such as living shoreline techniques.*




**Question 7 Comments:**

- Text does not acknowledge property owner rights provided for by the Coastal Act. (6)

- This appears reasonable, but what about property owner rights? (2)

- "Nature-based" and "Living shoreline" sound reasonable but are a bit nebulous. I think this could be done in conjunction with graduated building adaptations.

- This is the only solution. Work with Nature, not against.

- Yes, more cost effective and durable (2).

- Increase dunes and/or beach area by augmenting or adding plants/sand – Protect new sewer/water/utility lines with new building or BIG renovations.

- Wait until the "living shoreline" experiments on the east coast have survived a few storms.

- In a vacuum? How does this interface with the fact that homes and businesses exist in these areas?

- Currently developed property is more important to protect.

- The problem with Policy 7 is that it fails to take into account the comparative costs and benefits of other options.

**8. Please provide any other suggestions for policy initiatives to address sea level rise in Marin County.**

- We support reasonable policies that allow property owners to develop in ways that protect against sea level rise. (75)

- Please try to help property owners without making it harder to develop or taking steps which violate their rights. Government should help - not create a burden. Give property owners options that they can elect to implement to protect their property and assets against a rise in sea level. (2)

- Any mandates on property must adhere to the laws of land ownership, and rights of land ownership.

- Existing residents should be allowed to structurally upgrade and do interior renovation – empty land may need to be treated differently.

- I think we should allow people to expand/enhance if they tick a box that says they will not seek funds for repairs/rebuilding from FEMA. In other words- "I am willing to take on the financial risk of destruction, but I want a second bathroom in exchange for that risk."

- Continued community meetings to raise awareness of possible or probable damage to currently owned parcels. Frequent neighborhood meetings that inform, collaborate, and plan. Have information and community dialogue at Countywide libraries.

- Study how to alert us of tsunamis.

- I am not into the 3-30' rise in ocean levels in the next 10 to 85 years.

- Do not move sand. It is temporary, expensive, useless.

- I would like to see a focus on green infrastructure, barrier wetland restoration and other ways to adapt through ecological enhancement.

- Prioritize planning for alternative public infrastructure (roads, power, water) to continue service to residents whose properties are near but not directly affected by sea level rise.

- County and State should prioritize raising low sections of roads over 10 and 20 years to reduce traffic stops due to high tides.

- I support a wait & see attitude. I see information that supports a much smaller change than some are proposing.

- Sea level rise is real and policies should provide for sensible management of property in areas most likely to be affected.

- Please try to avoid causing decline in property values. Be sensitive to the need for balance – preparation is prudent, but let's not impose too much expense too quickly. Also, please try to explain the connection between the work you are doing, and what is required to get and keep flood insurance. If there could be coordination with flood insurance requirements, that would be good.

- Require realtors to give written opinions on ocean rise (and varied papers reference – I am aware not all think same issues about timeline etc.

- There is a balance to be maintained, Local, state and federal governments should allow development on a reasonable basis, but remove the subsidies to those who build in risk areas – no federal insurance for example or subsidies to rebuild.

- FEMA should be consulted on all policy making creation. Although states make policy, they make it to fit FEMA regulations. This without them saying what policy should be, of course.

- Short term goals make sense 0-20 years. Long term is too uncertain, range of 25cm-100cm, 75 years, to make firm long term rules.

- The County and the Coastal Commission should develop objective criteria to identify public and private properties that are seriously threatened by sea level rise, king tides, and storm risks. For such properties, their significant environmental impacts already exist. Therefore, specific remedies (such as elevating structures) that do not in themselves have additional serious environmental impacts should be determined, widely publicized, and allowed. Those specific remedies should be permitted without requiring extensive bureaucratic regulation -- e.g., property owners should be required to do no more than give notice to the agency and permit a summary subsequent inspection.

- County loan programs to raise buildings above the floodplain and pay back on property taxes or on sale of property. (Revolving fund.)

- One size fits all policies that don't allow property owners to have a say in what happens to them can create unintended problems.

- The lenders involved in financing the houses threatened by sea level rise will develop initiatives to protect themselves as will homeowners. The citizens don't need the County's best efforts at telling them how to protect their real estate investments. For most of us it is our single biggest investment so we are paying attention.

- I'm very appreciative of this effort to engage citizens and residents.

- Dredge Easkoot Creek regularly to make homes less vulnerable. (2)

- Sea Level rise is one issue but there are continuing flooding issues that are not from sea level rise alone. The issue with the Creek flooding continues and Measure A should be brought back again I believe with continued effort. The water wants to flow out to the ocean across the parking lot the feds now control rather than only out to the lagoon. I believe there should be a way added so that in winter the water from the hills can get out to the ocean without having to travel through Stinson Beach lowlands and putting at risk so many homes and streets for flooding. A big pipe bypass that could be turned on and off could take some of the water in heavy winter flows out to the ocean while being turned off in summer months so water will flow through the usual route to the lagoon for the wildlife and riparian benefits. Community information meetings and distribution of sea rise and flood maps are excellent actions I applaud. Mailings to inform property owners and residents are helpful.

## STINSON BEACH

The first set of numbers refer to locations on maps, and the numbers in **red** indicate how many poll respondents expressed support for the strategy. *Entities in blue italics represent POTENTIAL implementing agents or funding sources.*

| | Near-term | Medium-term | Long-term |
|---|---|---|---|
| Protect | 1) Restore and enhance dunes. *Local assessment district.* **28/ 33%**<br>2) Place sand on beaches. *Local assessment district.* **23/ 27%**<br>3) Enhance living shoreline on lagoon side for temporary flood protection. *Local assessment district, Government grants.* **28/ 33%**<br>4) Maintain existing seawalls and revetments throughout community. *Landowners.* **86/ 100%** | 5) Construct low-profile sand-covered seawall from end of existing Seadrift revetment toward southeast end of beach. *Local assessment district.* **32/ 37%**<br>6) Continue to place sand on beaches. *Local assessment district*. **18/ 21%**<br>7) Construct artificial reef or other offshore structure to minimize wave and erosion damage. *Local assessment district.* **11/ 13%** | 8) Continue to place sand on beaches. *Local assessment district*. **17/ 20%** |
| Accommodate | 9) Elevate red buildings impacted in the near-term. *Landowners.* **10/ 12%**<br>10) Flood proof red buildings. *Landowners.* **9/ 10%**<br>11) Update substandard septic systems to meet code. *Landowners.* **29/ 34%**<br>12) Continue to retrofit water meter connections. *Landowners.* **24/ 28%**<br>13) Elevate Calle del Arroyo. *County, local assessment district.* **81/ 94%**<br>14) Elevate private roads in Calles and Patios. *Local assessment district.* **20/ 23%** | 15) Elevate orange buildings and utilities (impacted in the medium-term). *Landowners.* **7**<br>16) As needed, abandon leach fields and convert septic tanks to holding vessels. *Landowners.* **13**<br>17) Elevate Shoreline Hwy. along Bolinas lagoon. *State.* **70**<br>18) Realign Shoreline Hwy. along Bolinas lagoon. *State.* **19**<br>19) Develop boardwalk access to elevated buildings in the Calles and Patios. *Local assessment district.* **4** | 20) Elevate roads that are subject to flooding. *Local assessment district.* **17/ 20%**<br>21) Develop community wastewater system. *Local service providers, Local assessment district.* **8/ 9%** |
| Retreat | 22) Relocate critical facilities such as fire station and/or emergency generator. *Local service providers, County.* **29/ 34%**<br>• See options in the "Policy Questions for Coastal Hazard Areas" section. | 23) Relocate red buildings. *Landowners.* **8/ 9%**<br>24) Remove shoreline protective devices that limit inland migration of beach. *Landowners.* **2/ 2%**<br>25) Remove development that limits inland migration of beach. *Landowners.* **2/ 2%** | 26) Relocate orange buildings. *Landowners.* **1/ 1%** |
| Other | • I support landowner Accommodation options that are non-mandatory and encouraged by permit waivers. (30)<br>• #13.: Needed now"; #21.: "This is a good idea regardless of sea level rise." #s23 & 26: "Where?"<br>• Continue to execute on and prioritize the Bolinas Lagoon Restoration Project!<br>• Can the shoreline be enhanced or adapted to collect large amounts of seawater on a more permanent basis?<br>• 16. & 21.: "Tier/separate disposal/dispersal systems for black water and gray water to reduce costs."; 7.: "?"<br>• Allow for the development of small scale desalination plants. Dredge Easkoot Creek and the bypass uptown.<br>• 6. & 8.: "Waste of money! Sand gone almost every winter."; 21.: "Wildly expensive / very unlikely again…"; 22.: [Changes "Relocate" to:] "Elevate"; 24.: "No, bad idea!"; 25.: "Funding!"<br>• I cannot afford local assessment or homeowner stuff.<br>• 5.-7.: "every time we mess with nature on beaches --i.e., east coast–nothing good comes of it"; 15.: "too expensive"; 16.: Have "holding vessels" ever been tried on a beach town? Where, when, & did it work? 18.: "way too expensive if you do this how about an elevated wooden boardwalk for bikers over edge of lagoon"; 23.-25. "none of these"; 26.: "no".<br>• I like the natural approach.<br>• I don't support the government doing any of these. | | |

## BOLINAS

The first set of numbers refer to locations on maps, and the numbers in **red** indicate how many poll respondents expressed support for the strategy. *Entities in blue italics represent POTENTIAL implementing agents or funding sources.*

| | Near-term | Medium-term | Long-term |
|---|---|---|---|
| Protect | 1) Maintain existing revetments, seawalls, and levees. *Landowners, local assessment district.* **2/ 40%**<br>2) Protect bluffs with armoring. *Local assessment district.* **2/ 40%**<br>3) Place sand on beaches. *Local assessment district.* **2/ 40%** | 4) Continue to place sand on beaches. *Local assessment district.* **3/ 60%**<br>5) Create oyster reef in Bolinas Lagoon. *Government grants.* **3/ 60%** | 6) Install wall around sewage lift station entrance. *Local service provider.* **5/ 100%** |
| Accommodate | 7) Elevate red buildings and utilities impacted in the near-term. *Landowners.* **1/ 20%**<br>8) Flood proof red buildings. *Landowners.* **1/ 20%**<br>9) Elevate bridge over Pine Gulch Creek. *County.* **2/ 40%**<br>10) Elevate Wharf Rd. *County.* **3/ 60%**<br>11) Acquire agricultural land for wetland restoration. *County, land trust.* **2/ 40%** | 12) Elevate orange buildings and utilities impacted in the medium-term. *Landowners.* **2/ 40%**<br>13) Flood proof orange buildings. *Landowners.* **0**<br>14) Elevate Olema-Bolinas Road. *County.* **1/ 20%**<br>15) Increase height of opening enclosures and pedestals for above ground equipment. *Local service provider*. **2/40%**<br>16) Realign Bob Stewart Trail at exposed segments. *County, State.* **2/40%** | 17) Elevate yellow buildings impacted in the long-term. *Landowners.* **0**<br>18) Flood proof yellow buildings. *Landowners.* **0**<br>19) Acquire land to develop alternative route from Big Mesa to Horseshoe Hill Road. *County.* **1/20%** |
| Retreat | • See options in the "Policy Questions for Entire Coastal Zone" section. | 20) Relocate red buildings. *Landowners.* **2/40%**<br>21) Remove shoreline protective devices that limit inland migration of beach. *Landowners.* **2/40%**<br>22) Remove development that limits inland migration of beaches. *Landowners.* **3/60%**<br>23) Relocate coastal access points. *County, State.* **2/40%**<br>24) Relocate sewage lift station to upland location. *Local service provider.* **2 /40%**<br>25) Realign section of Shoreline Hwy. along lagoon (would require cutting into bluffs and stabilizing them). *State.* **2/40%** | 26) Relocate orange buildings. *Landowners.* **1 /20%**<br>27) Remove structures that inhibit sediment supply to marshes and beaches. *Landowners.* **1/20%** |
| Other | • Section of PRS to Olema. Relocate Hwy 1 eastward into the nearby hills. We would also gain valuable tons of earth used in elevating other sections of Highway.<br>• Replace and enhance seawall & groins to protect beach cliffs. Allow coastal permits to protect beach property. Lower costs permits & speed process like you did for Surfer's Overlook. Remove sediment from the lagoon & clear trees from Kent Island and debris from lagoon. | | |

## INVERNESS

The first set of numbers refer to locations on maps, and the numbers in **red** indicate how many poll respondents expressed support for the strategy. *Entities in blue italics represent POTENTIAL implementing agents or funding sources.*

| | ***Near-term*** | ***Medium-term*** | ***Long-term*** |
|---|---|---|---|
| **Protect** | 1) Restore/ enhance wetlands along Tomales Bay. *Local assessment district, State, Government grants.* **6/100%**<br>2) Create oyster reef in Tomales Bay. *Local assessment district, State, Government grant.* **2/33%** | 3) Construct horizontal levee along Tomales Bay. *Local assessment district, State, Government grant.* **0**<br>4) Convert affected segments of Sir Francis Drake Blvd. to levee (also protects water pipeline in Inverness Park and downtown. *County, local service providers.* **4/67%** | 5) Armor/ convert additional segments of Shoreline Hwy. or Sir Francis Drake Blvd. to levee. *County, local service providers.* **3/50%** |
| **Accommodate** | 6) Elevate red buildings and utilities impacted in the near-term. *Landowners.* **4/67%**<br>7) Flood proof red buildings. *Landowners.* **3/50%**<br>8) Permit houseboats. *County, State.* **0**<br>9) Update old septic systems. *Landowners.* **5/83%** | 10) Elevate orange buildings and utilities impacted in the medium-term. *Landowners.* **3/50%**<br>11) Flood proof orange buildings. *Landowners.* **2/33%**<br>12) Elevate Shoreline Hwy. *State.* **4/67%**<br>13) Develop community wastewater system. *Local service provider, local assessment district.* **3/50%** | 14) Elevate yellow buildings impacted in the long-term. *Landowners.* **3/50%**<br>15) Flood proof yellow buildings. *Landowners.* **2/33%**<br>16) Create moorings for boats when marinas are inundated. *State, County* **3/50%** |
| **Retreat** | • See options in the "Policy Questions for Entire Coastal Zone" section. | 17) Relocate red buildings. *Landowners.* **3/50%**<br>18) Relocate coastal access points. *County, State.* **4/67%**<br>19) Remove shoreline protective devices that limit inland migration of beaches and wetlands. *Landowners.* **4/67%**<br>20) Remove development that limits inland migration of beaches and marshes. *Landowners.* **1/17%**<br>21) Realign affected segments of Sir Francis Drake Blvd. along Tomales Bay. *State.* **3/50%** | 22) Relocate orange buildings. *Landowners.* **3/50%**<br>23) Remove structures that inhibit sediment supply to marshes and beaches. *Landowners.* **4/67%** |
| **Other** | • 10: "only with financial assistance"<br>• 6: "maybe …"<br>• Project: "Bring back ferry from Pt. Reyes to Inverness" | | |

## POINT REYES STATION

The first set of numbers refer to locations on maps, and the numbers in **red** indicate how many poll respondents expressed support for the strategy. *Entities in blue italics represent POTENTIAL implementing agents or funding sources.*

| | ***Near-term*** | ***Medium-term*** | ***Long-term*** |
|---|---|---|---|
| **Protect** | 1) Restore/ enhance wetlands along Tomales Bay. *Government grants.* **13/100%**<br>2) Armor segments of Shoreline Hwy prone to flooding in near-term. *County, State.* **7/54%** | 3) Horizontal levee along Tomales Bay *Local assessment district, Government grant.* **2/15%**<br>4) Armor segments of Shoreline Hwy prone to flooding in medium-term. *County, State.* **7/54%** | 5) Armor road segments of Shoreline Hwy. or Sir Francis Drake Blvd. prone to flooding in long-term. *County, State.* **5/38%** |
| **Accommodate** | 6) Elevate Green Bridge on Shoreline Hwy. *State.* **11/85%** | 7) Elevate affected segments of Shoreline Hwy. *State.* **9/69%**<br>8) Elevate Sir Francis Drake Blvd. with pipeline below. *County, NMWD.* **8/62%** | 9) Elevate yellow buildings. *Landowners.* **7/54%**<br>10) Flood proof yellow buildings *Landowners.* **2/15%** |
| **Retreat** | • See options in the "Policy Questions for Entire Coastal Zone" section. | 11) Relocate red buildings. *Landowners.* **3/23%**<br>12) Relocate coastal access points *County, State.* **6/46%**<br>13) Realign affected segments of Shoreline Hwy. *State.* **5/38%** | 14) Relocate orange buildings *Landowners.* **2/15%**<br>15) Relocate Gallagher well upstream *Local service provider.* **8/62%**<br>16) Remove shoreline protective devices that limit inland migration of beaches and wetlands. *Landowners.* **6/46%**<br>17) Remove development that limits inland migration of beaches and marshes. *Landowners.* **8/62%** |
| **Other** | • Close Levee Road when necessary. | | |

## EAST SHORE

The first set of numbers refer to locations on maps, and the numbers in **red** indicate how many poll respondents expressed support for the strategy. *Entities in blue italics represent POTENTIAL implementing agents or funding sources.*

| | Near-term | Medium-term | Long-term |
|---|---|---|---|
| Protect | 1) Restore/ enhance wetlands along Tomales Bay. *Government grants.* **5/100%**<br>2) Create oyster reef along Tomales Bay. *Government grant.* **3/60%** | 3) Construct horizontal levee along Tomales Bay. *Local assessment district, Government grant*. **2/40%**<br>4) Armor segments of Shoreline Hwy prone to flooding in the medium-term. *State.* **5/100%** | 5) Armor segments of Shoreline Hwy prone to flooding in the long-term. *State.* **5/100%** |
| Accommodate | 6) Elevate red buildings and utilities impacted in the near-term. *Landowners.* **4/80%**<br>7) Flood proof red buildings. *Landowners.* **3/60%**<br>8) Permit houseboats. *County, State.* **1/20%**<br>9) Update old septic systems. *Landowners.* **0** | 10) Elevate orange buildings and utilities impacted in the medium-term. *Landowners.* **2/40%**<br>11) Flood proof orange buildings. *Landowners.* **2/40%**<br>12) Elevate affected roads, including Shoreline Highway at Walker Creek. *State.* **5/100%**<br>13) Improve coastal access facility or trail to account for sea level rise. *County, State.* **5/100%** | 14) Elevate yellow buildings. *Landowners.* **2/40%**<br>15) Flood proof yellow buildings. *Landowners.* **2/40%**<br>16) Create moorings for boats when marinas are inundated. *State, County.* **3/60%** |
| Retreat | 17) Relocate shoreline wells and septic leach fields to the east of Shoreline Hwy. *Landowners, County (ongoing).* **5/100%**<br>• See options in the "Policy Questions for Entire Coastal Zone" section. | 18) Relocate red buildings. *Landowners.* **2/40%**<br>19) Relocate coastal access points. *County, State.* **3/60%**<br>20) Realign affected segments of Shoreline Hwy. *State.* **3/60%**<br>21) Relocate critical facilities. *Local service providers, County.* **5/100%** | 22) Relocate orange buildings. *Landowners.* **2/40%** |
| Other | | | |

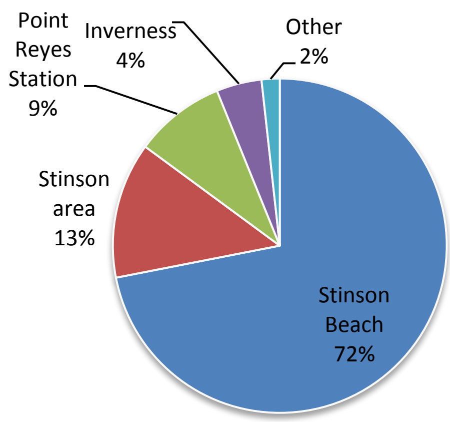
## DILLON BEACH

The first set of numbers refer to locations on maps, and the numbers in **red** indicate how many poll respondents expressed support for the strategy. *Entities in blue italics represent POTENTIAL implementing agents or funding sources.*

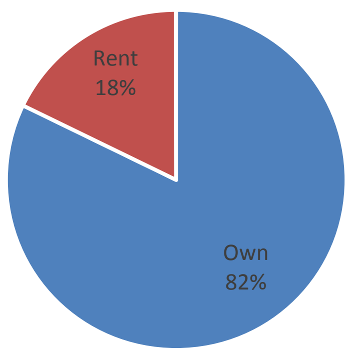
| | ***Near-term*** | ***Medium-term*** | ***Long-term*** |
|---|---|---|---|
| **Protect** | N/A | D2) Maintain sand dunes with sand placement and revegetation*Landowner, government grants.* **2/100%** | D7) Continue to maintain sand dunes with sand placement and revegetation *Landowner, government grants.* **2/100%** |
| **Accommodate** | N/A | D3) Elevate orange buildings and utilities impacted in the medium-term. *Landowners.* **1/50%**<br>D4) Flood proof orange buildings. *Landowners.* **1/50%** | N/A |
| **Retreat** | D1) Relocate well along Dillon Creek at Bay Dr. inland. *Local service providers.* **2/100%**<br>• See options in the "Policy Questions for Entire Coastal Zone" section. | D5) Relocate red buildings. *Landowners.* **0**<br>D6) Relocate sewage pump inland. *Local service providers.* **1/50%** | D8) Relocate orange buildings. *Landowners.* **1/50%**<br>D9) Relocate parking lot. *Landowners.* **2/100%** |
| **Other** | As the owner of the home in the village's northwestern-most corner, it's been my joy to see that the Klines have allowed the natural dunes to return horizontal to the surf at the north end of the beach. This must be continued. Formerly, the Lawsons had scraped the entire area flat for parking. Those natural, vegetated dunes are our most important erosion control for our homes on the bluff above. | | |

# Evaluation and Participant Information

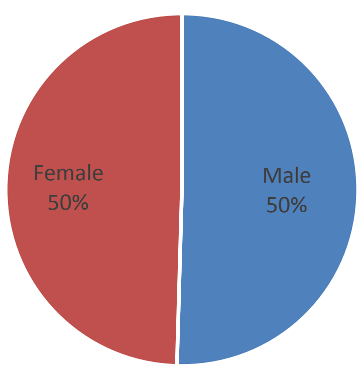
1. Where do you live?



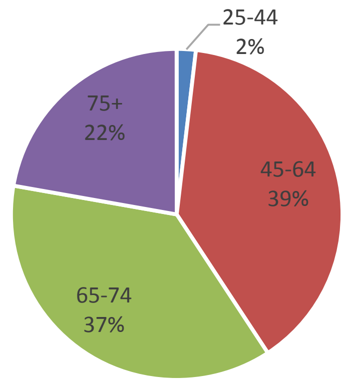

2. Do you own or rent your home?



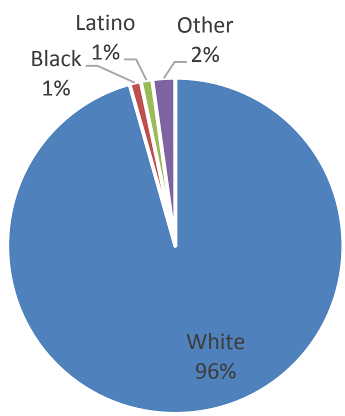

3. What is your gender?



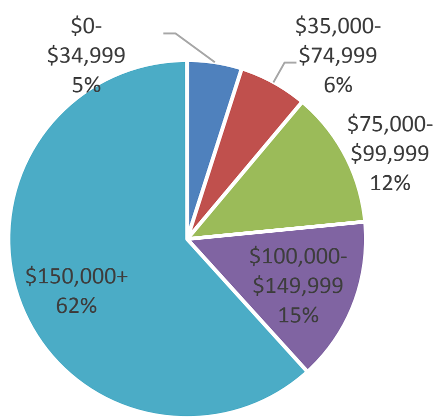

4. What is your age bracket?




5. What is your race/ethnicity?

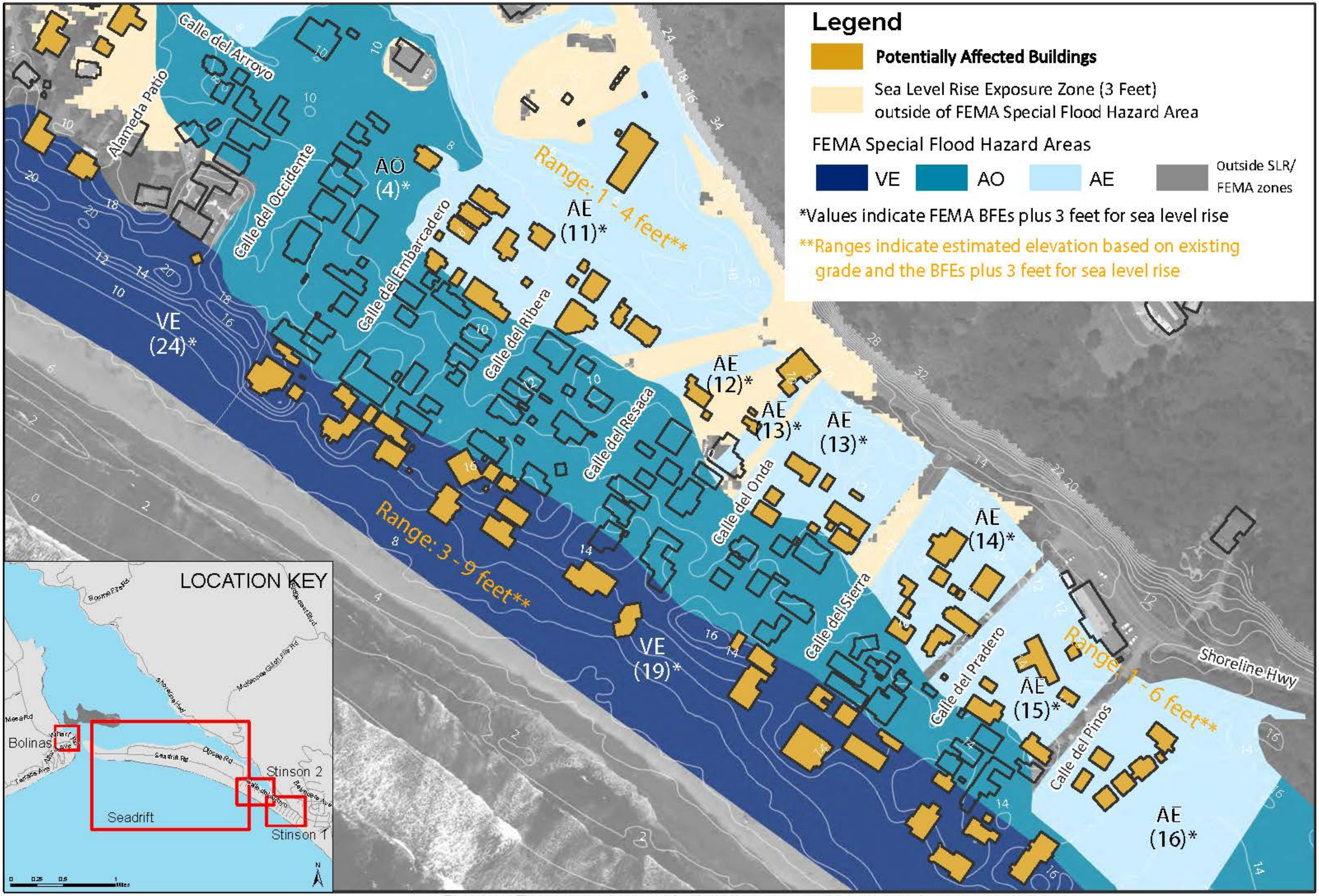



6. What is your household income?



# Appendix D

# POTENTIAL SEA LEVEL RISE MAPS

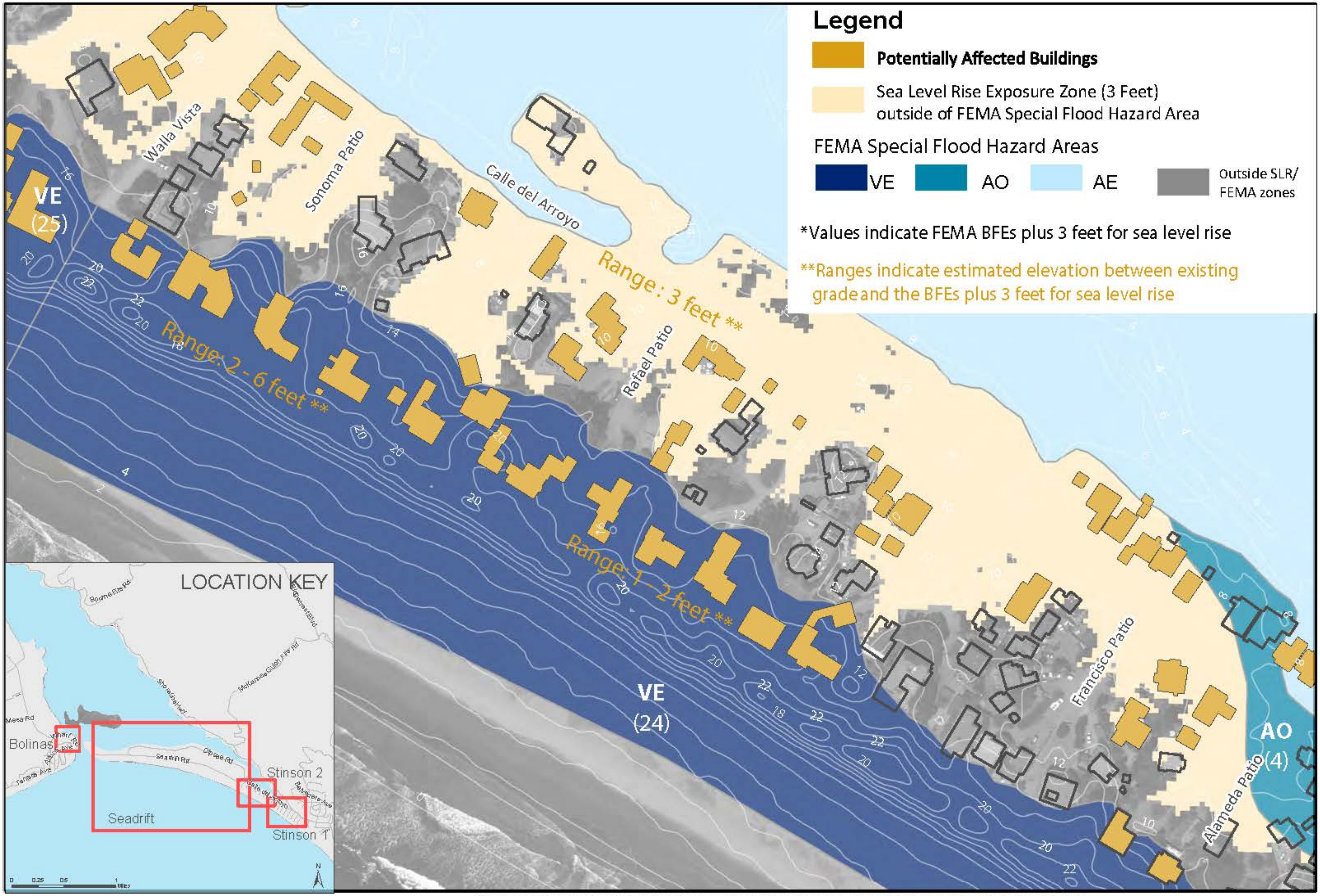



Disclaimer: This map was developed for illustrative purposes and can be used as a resource to help identify potential hazardous areas and affected buildings. Marin County, and data providers here in, make no warranties of the accuracy or completeness of maps. The maps have not been adopted by the Marin County Board of Supervisors. Source: Federal Emergency Management Agency (FEMA) Preliminary Flood Insurance Rate Map (FIRM) 2015, Our Coast Our Future, Marin Map.

Marin County Community Development Agency, July 2016

# Stinson 1

Potential Sea Level Rise




0 250 500 Feet

N

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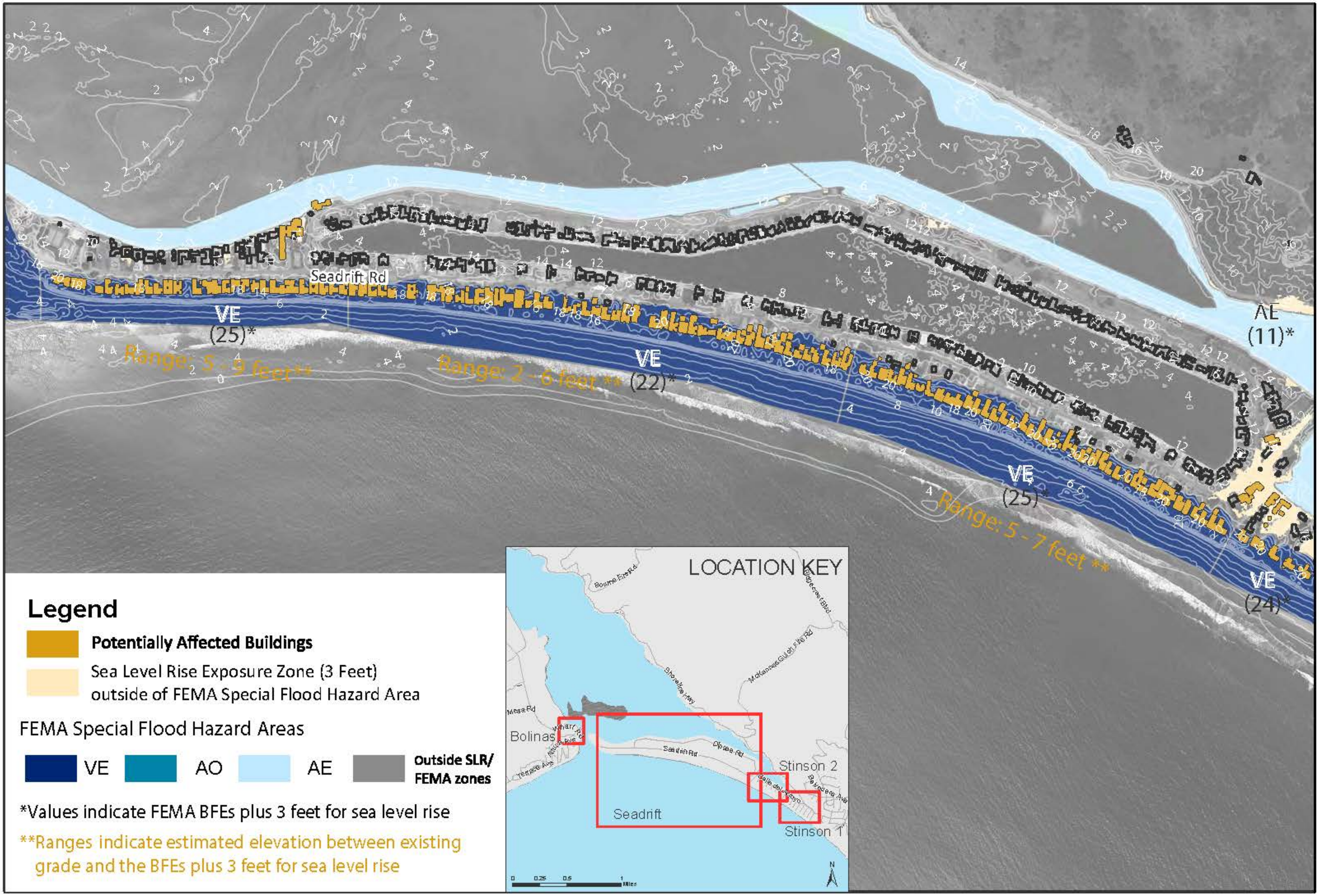
Marin County Community Development Agency, July 2016

# Stinson 2

Potential Sea Level Rise




0 0.25 0.5 Miles

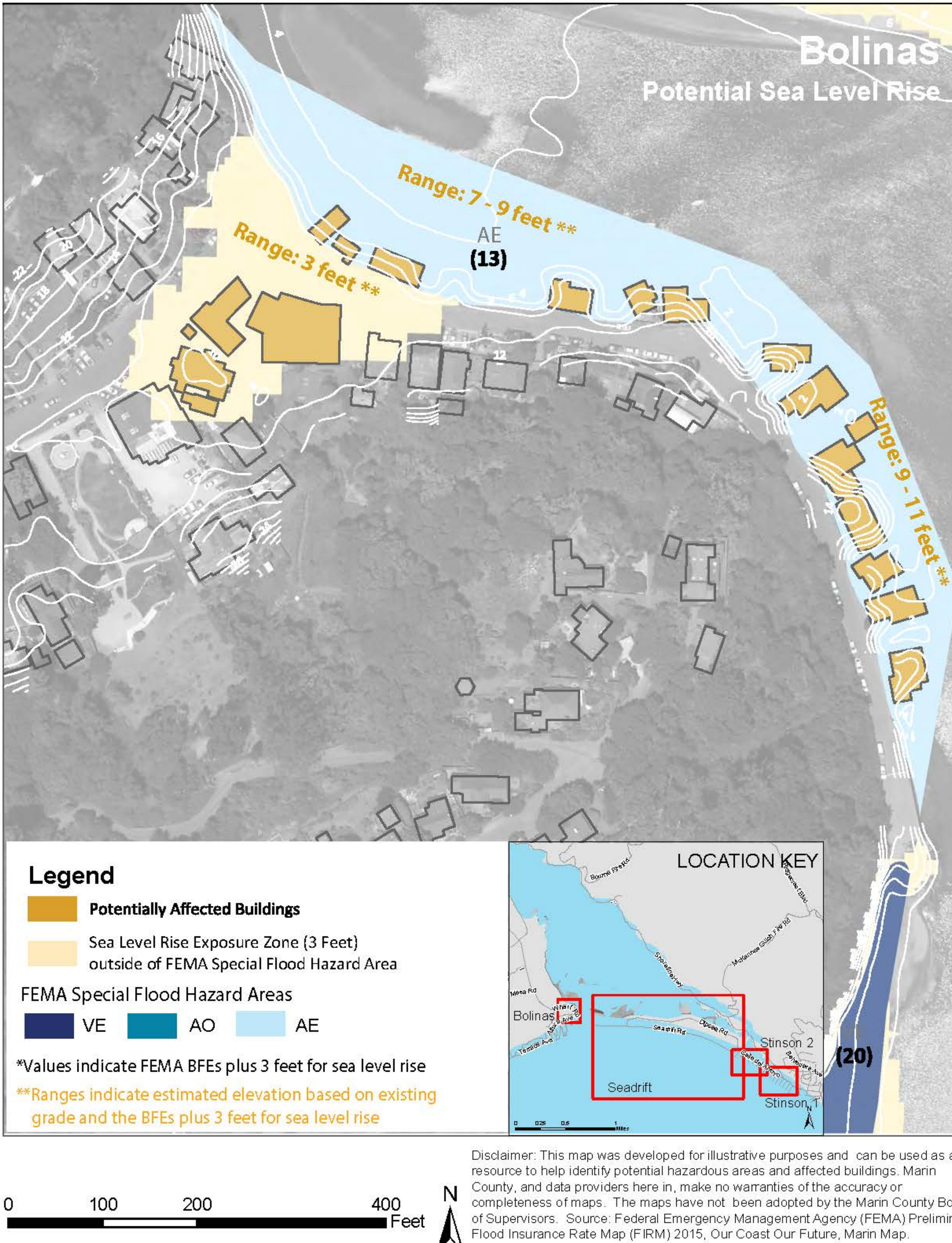
N

Disclaimer: This map was developed for illustrative purposes and can be used as a resource to help identify potential hazardous areas and affected buildings. Marin County, and data providers here in, make no warranties of the accuracy or completeness of maps. The maps have not been adopted by the Marin County Board of Supervisors. Source: Federal Emergency Management Agency (FEMA) Preliminary Flood Insurance Rate Map (FIRM) 2015, Our Coast Our Future, Marin Map.

Marin County Community Development Agency, July 2016

# Seadrift

Potential Sea Level Rise

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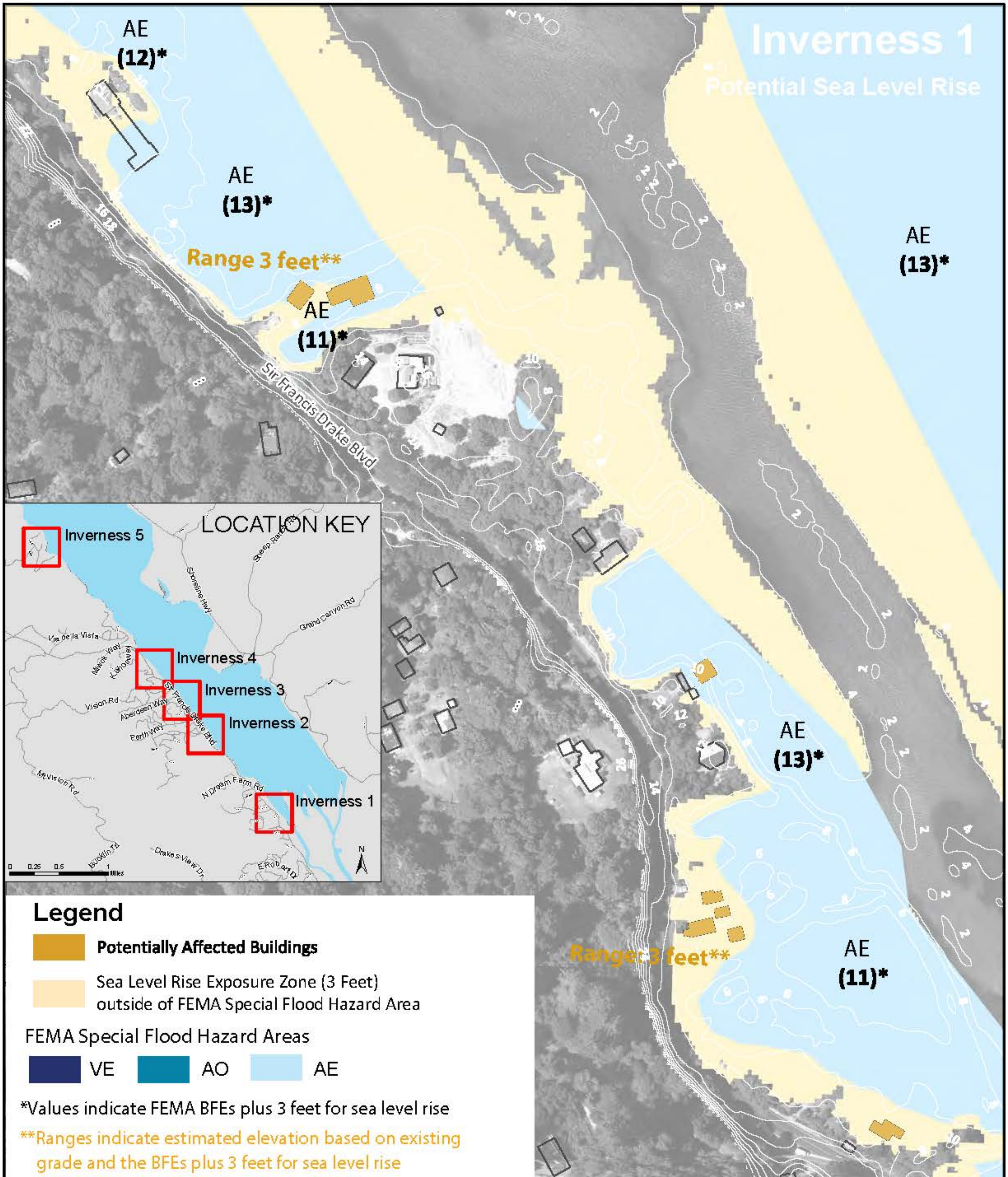


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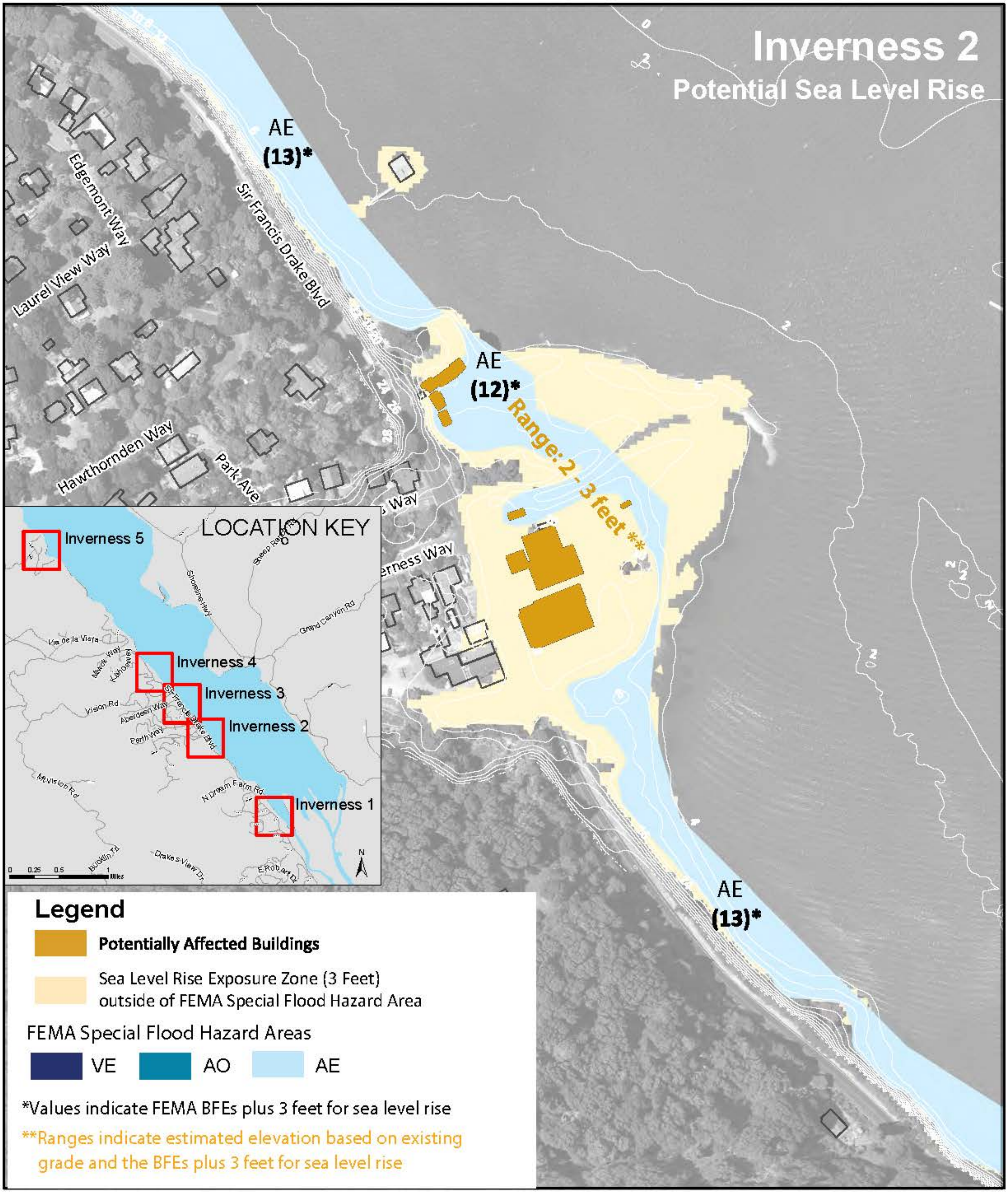


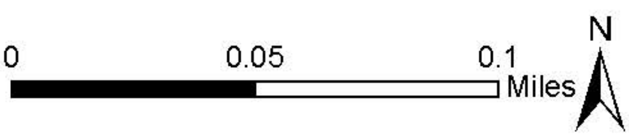


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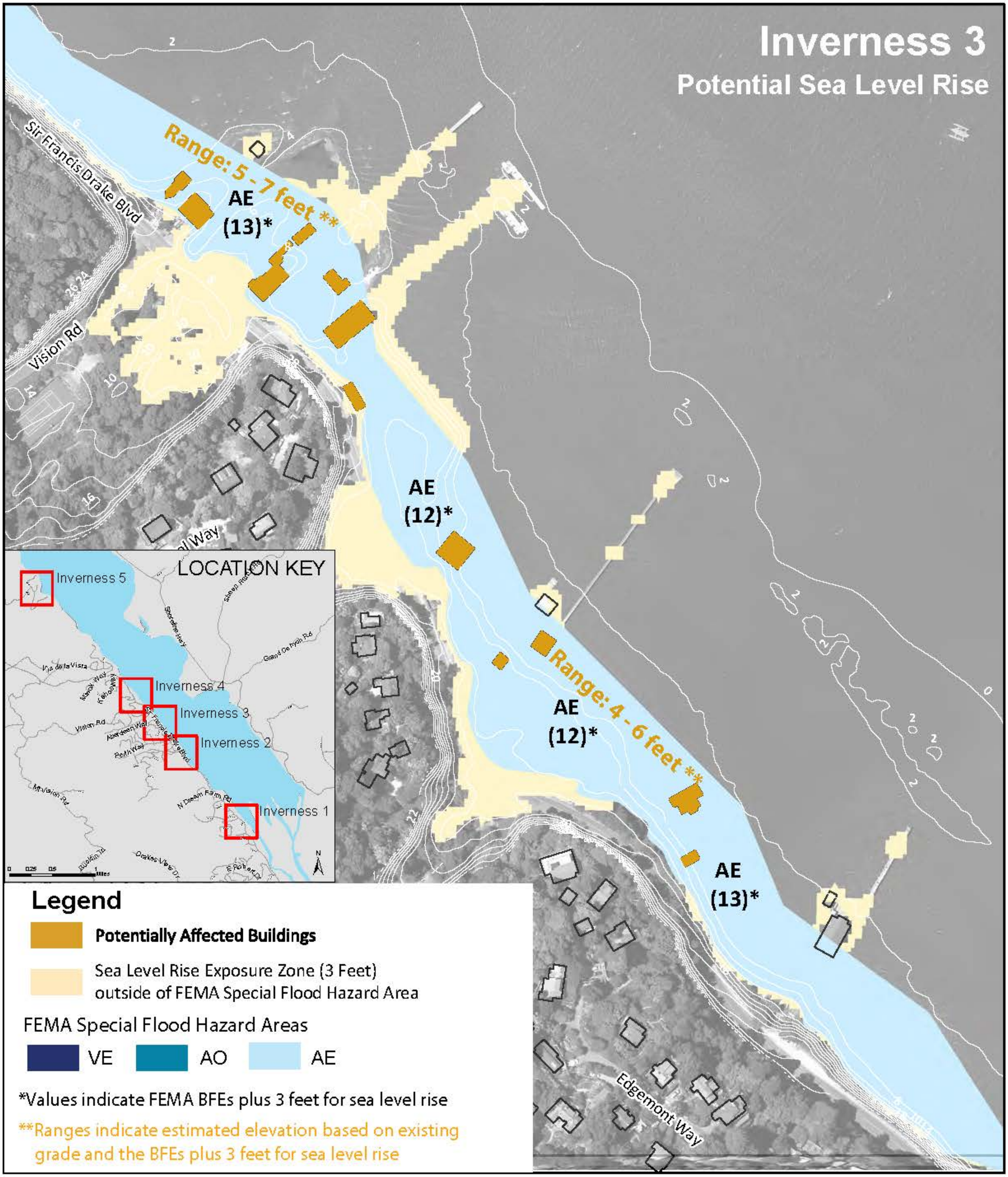


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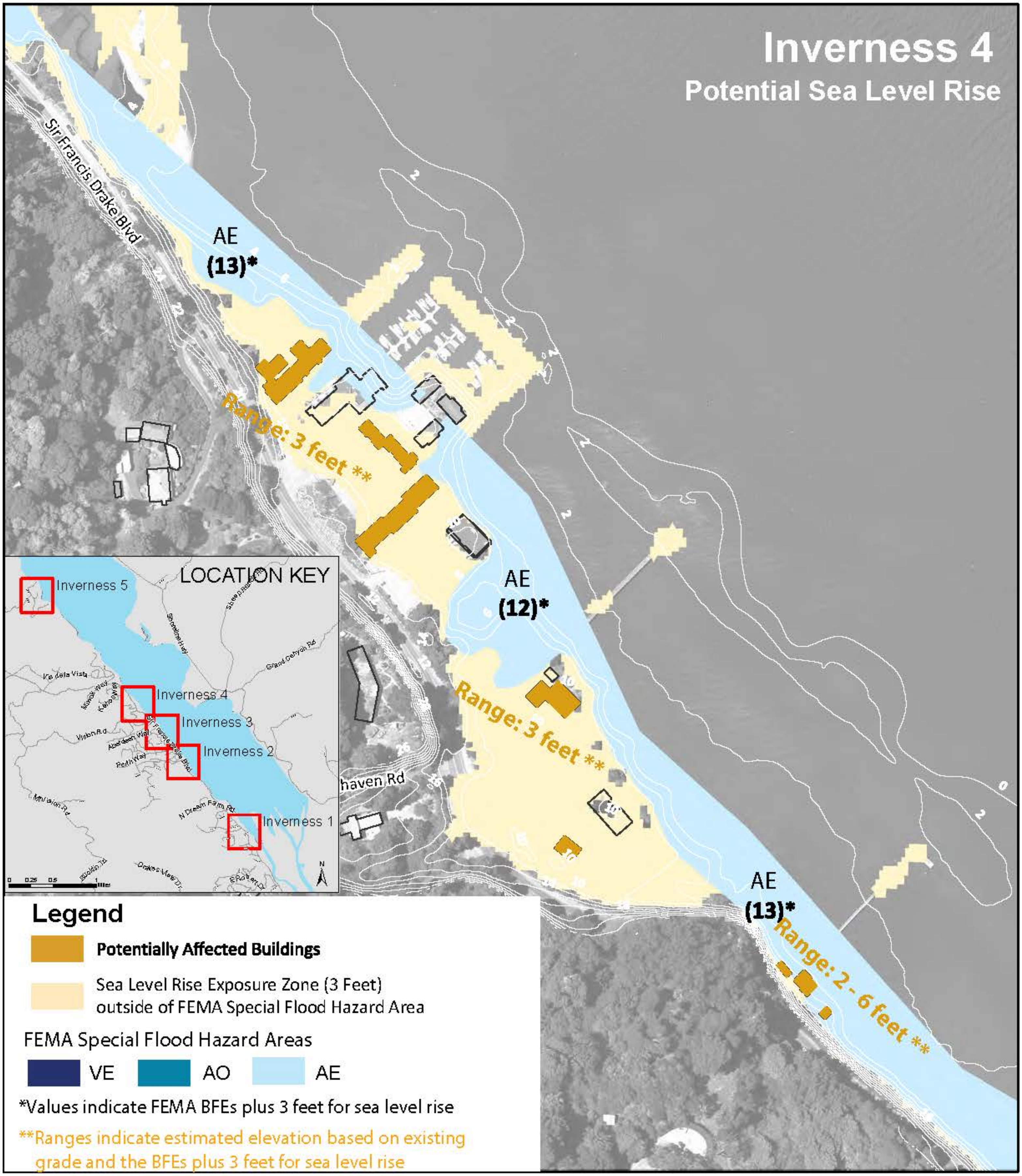


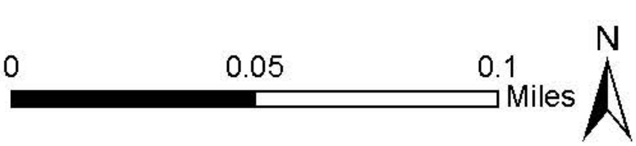


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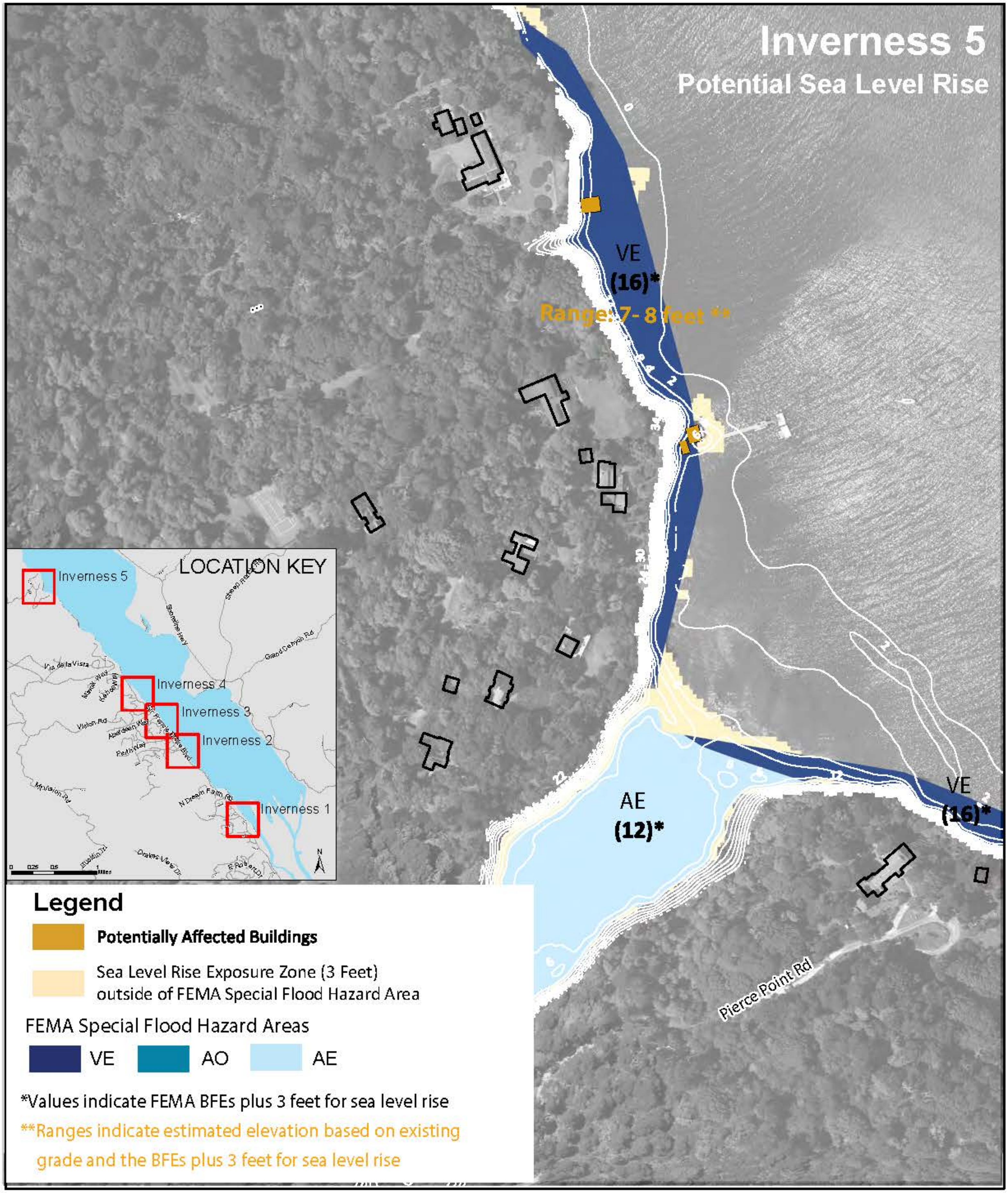


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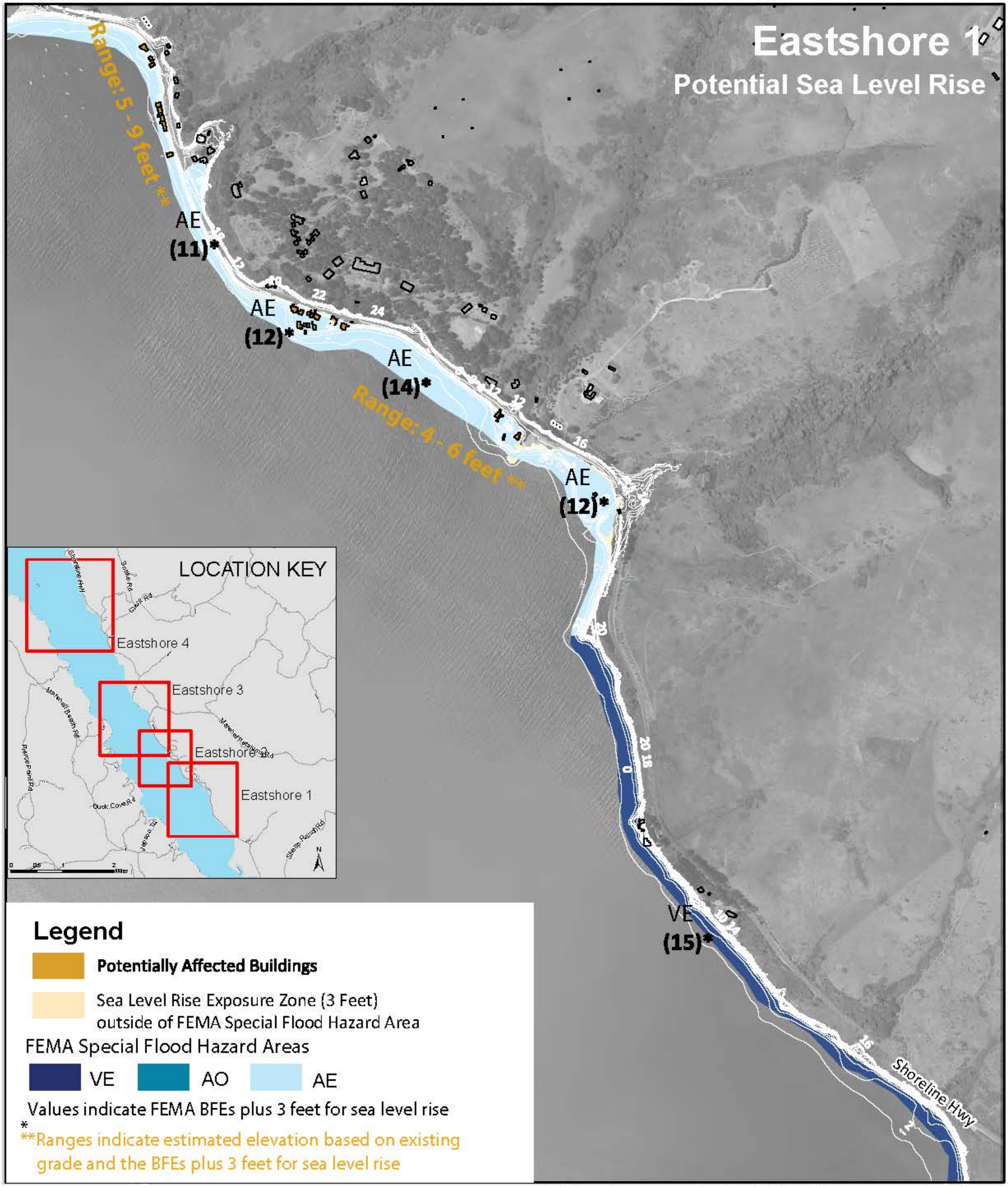


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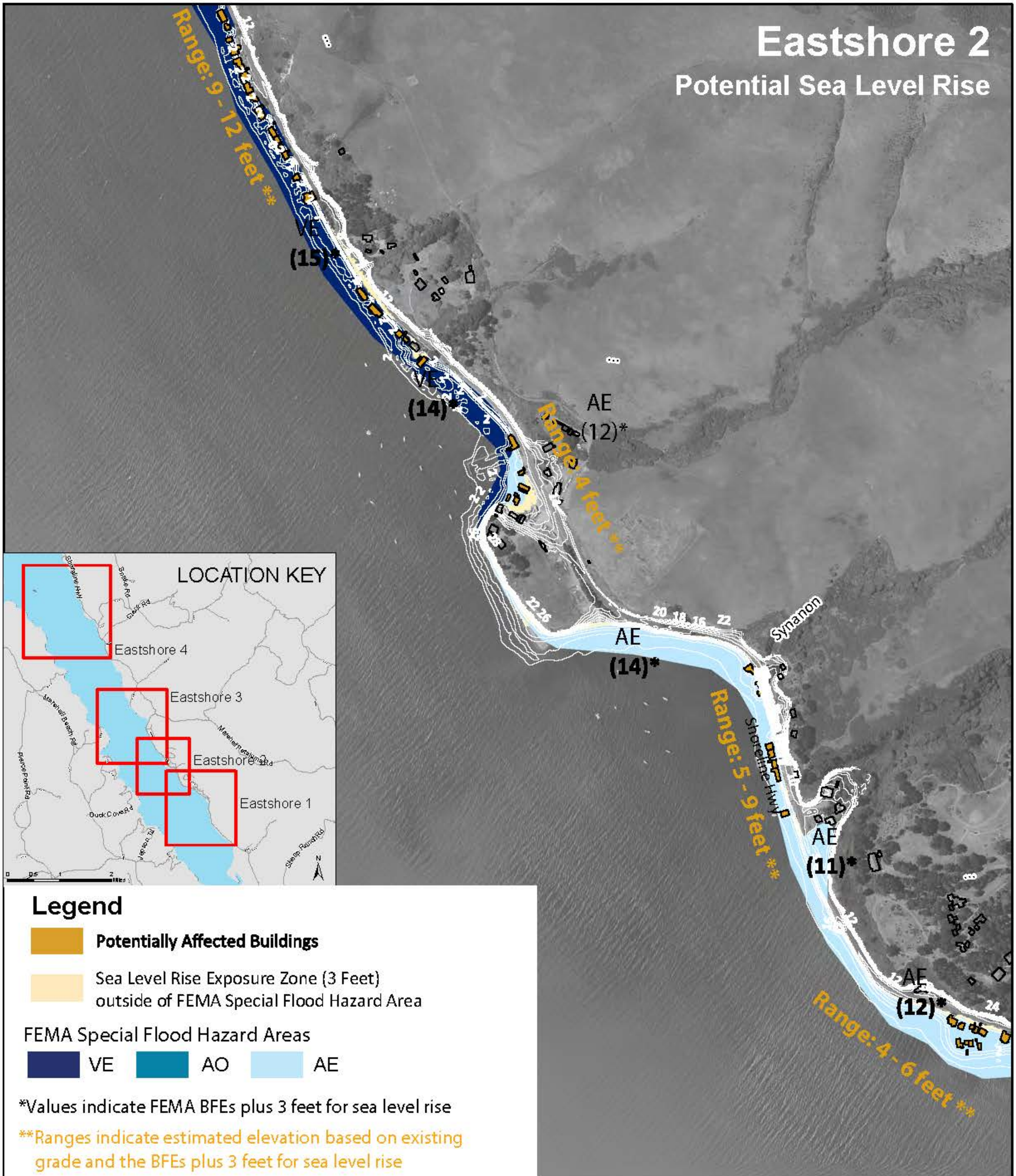


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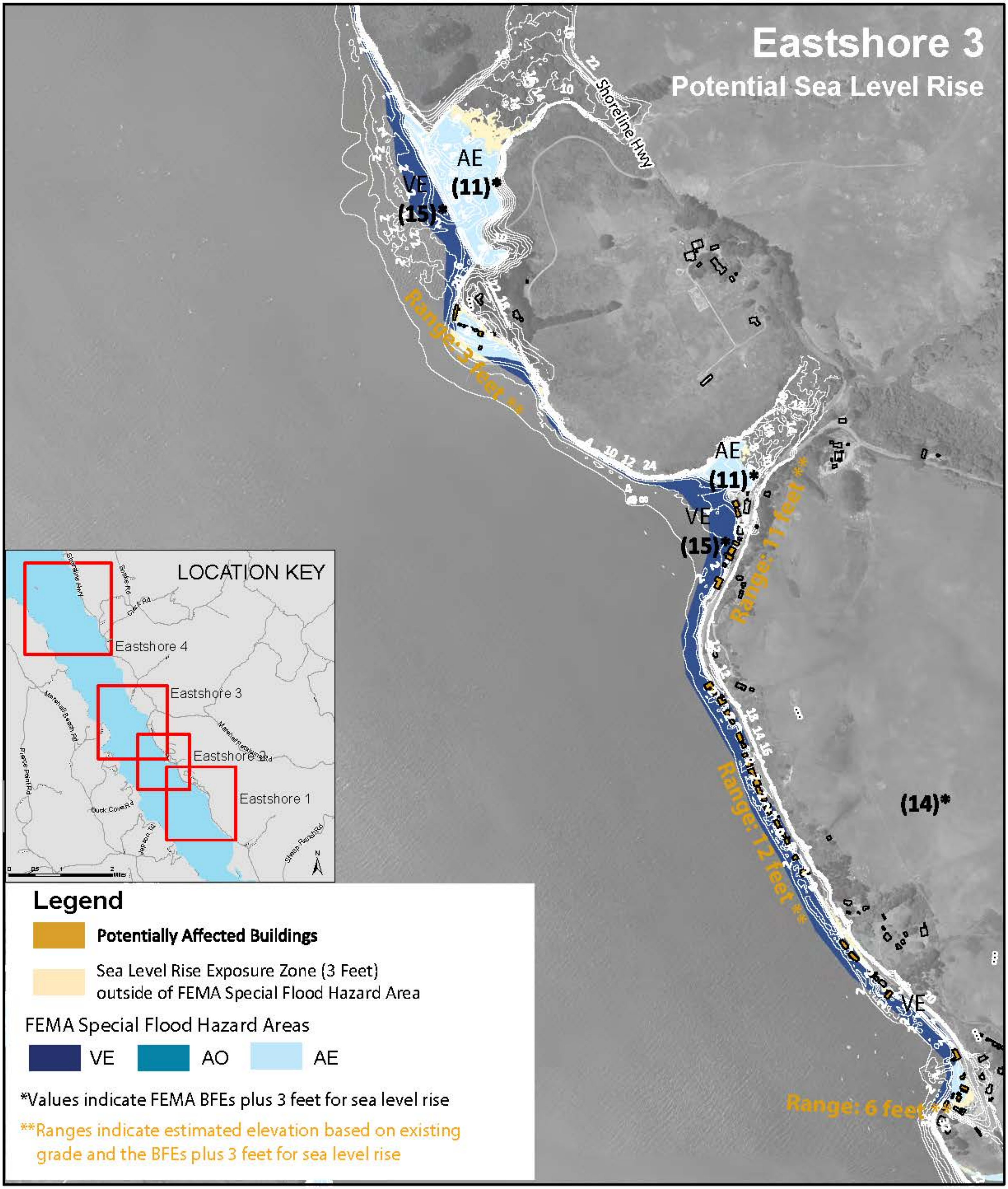


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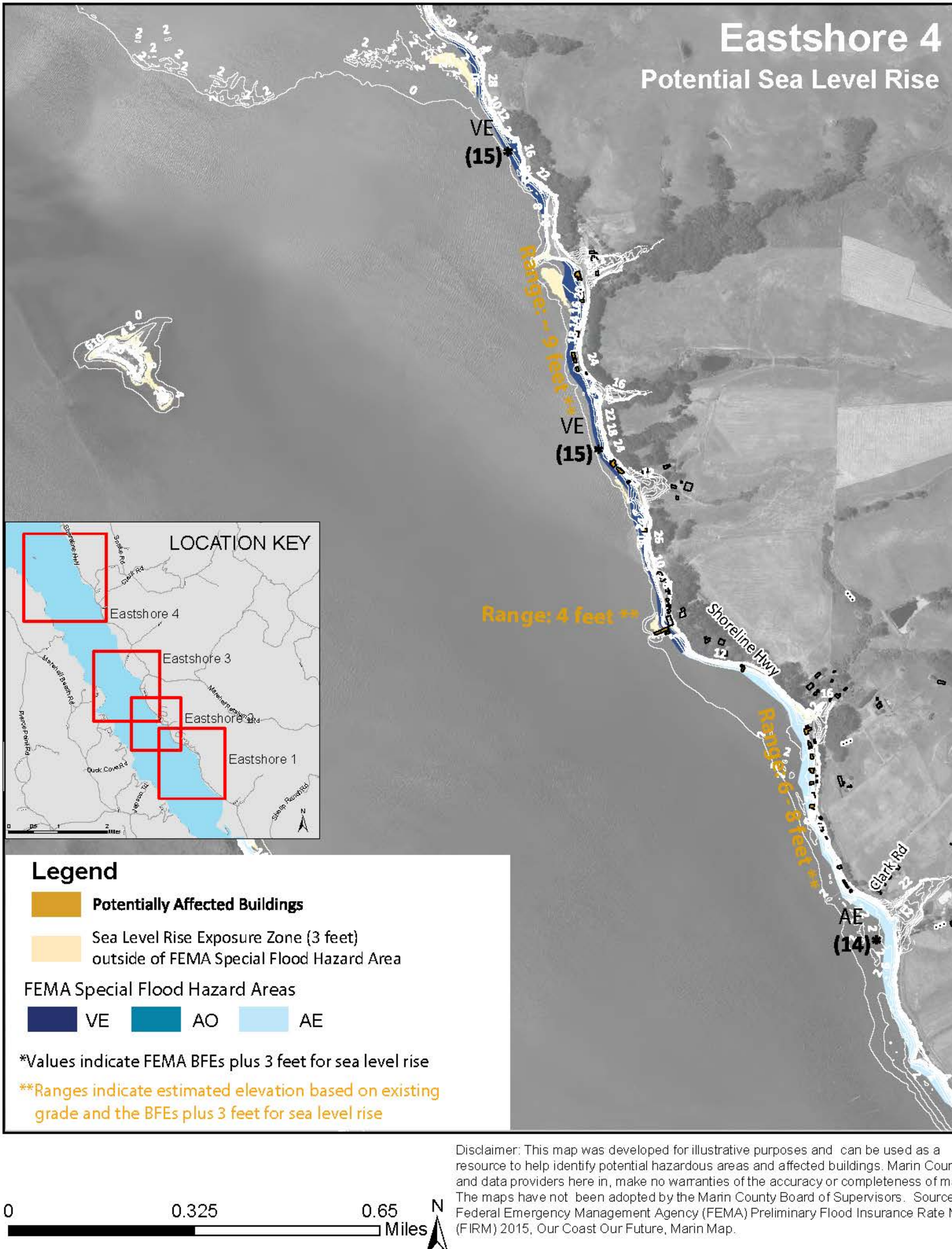


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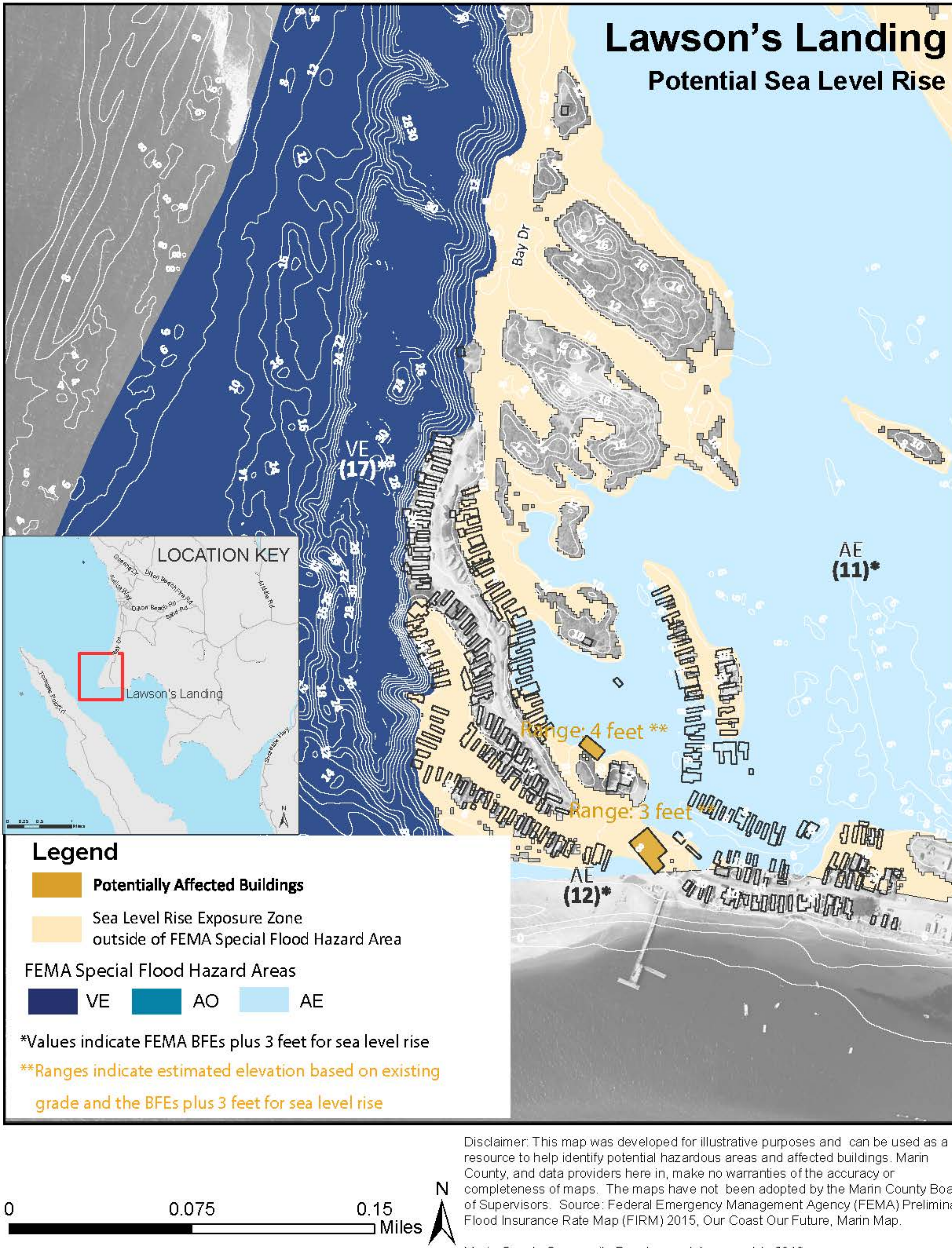


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Marin County Community Development Agency, July 2016

# Appendix E

# CLIMATE-SMART ADAPTION FOR NORTH-CENTRAL CALIFORNIA COASTAL HABITS

# Climate-Smart Adaptation for North-central California Coastal Habitats

Report of the Climate-Smart Adaptation Working Group of the Greater Farallones National Marine Sanctuary Advisory Council

Editor: Sara Hutto

March 2016

**Report Citation**

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**Cover photos**

(left) Bolinas Lagoon seawall, Eric Hartge, Center for Ocean Solutions, (right) Rocky intertidal at Point Arena, David Ledig, BLM/California Coastal National Monument, (bottom): Rodeo Beach, NPS

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National Marine Sanctuaries
Greater Farallones

CA LCC

Farallones Marine Sanctuary Association
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Debbie Aseltine-Neilson, California Department of Fish and Wildlife
Kate Bimrose, Greater Farallones Association
Marlene Finley, San Mateo County
Joel Gerwein, California State Coastal Conservancy
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Jaime Jahncke, Point Blue Conservation Science; GFNMS Advisory Council
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Jack Liebster, Marin County
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## Table of Contents

# Executive Summary

The North-central California coast and ocean is a globally significant and extraordinarily productive marine and coastal ecosystem that boasts an array of local, state and federal protected areas and other managed lands. Despite this richness and attention to conservation, this region is still vulnerable to the effects of climate change. The Greater Farallones National Marine Sanctuary Advisory Council (Council) convened the multi-agency Climate-Smart Adaptation Working Group (Working Group) in response to the need to develop climate-smart adaptation strategies to enable coastal and marine resource managers to respond to, plan, and manage for the impacts of climate change. Working Group members sought to provide strategies to help ensure long-term viability of the species and habitats natural resource agencies are mandated to protect, and the public values. Building on Phase 1 of the Greater Farallones National Marine Sanctuary's Climate-Smart Adaptation Project that assessed vulnerability to climate and non-climate stressors for select species, habitats, and ecosystem services, the Working Group undertook a yearlong multi-agency process to develop the climate-smart adaptation strategies presented in this report. The strategies were presented to the Council for discussion, modification, and approval, and forwarded to the Sanctuary Superintendent for consideration in current or future adaptation planning efforts.

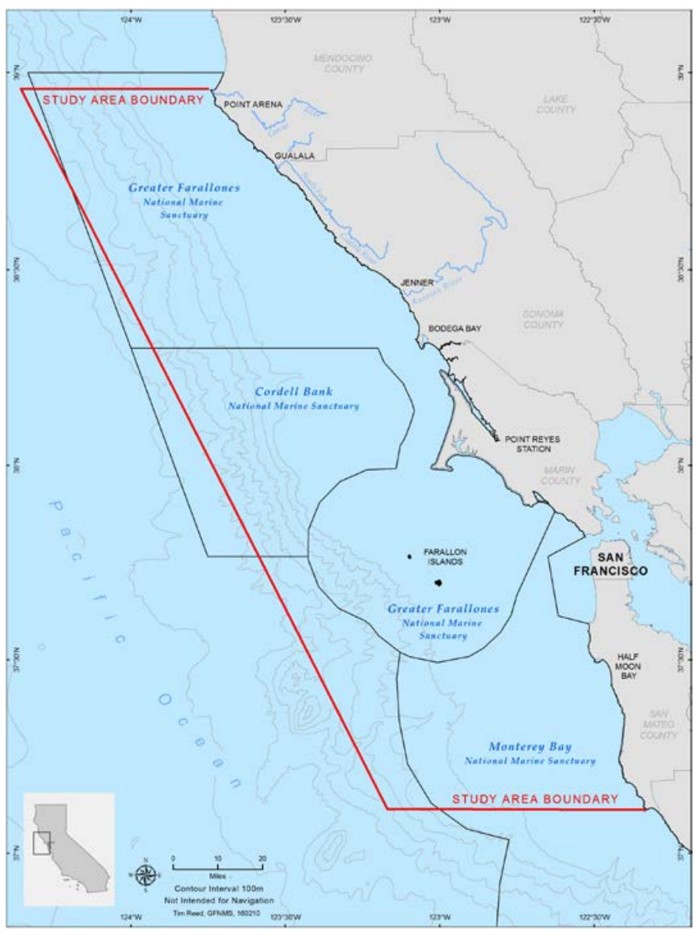
The Council Working Group developed 50 priority strategies and 28 lower priority strategies in 10 categories, including Alleviate Climate Impacts, Manage Dynamic Conditions, Promote Education, Protect and Restore Habitat, Limit Human Disturbance, Address Invasive Species, Promote Landward Migration, Invest in Science Needs, Protect Species, and Manage Water Quality. Strategies were also characterized in terms of timeframe, location, strategic management action, stressor addressed, key partners and required resources.

While there is much work on tropical marine adaptation action, temperate regions to date have had many fewer resources. The Council Working Group's contribution aims to turn this tide and begin a wave of implementation of climate-smart temperate coastal and marine management.

## Introduction

Project Background

The North-central California coast and ocean is a globally significant, extraordinarily diverse and productive marine and coastal ecosystem that is home to abundant wildlife, valuable fisheries, two national marine sanctuaries, two national parks, a national wildlife refuge, a national monument, multiple state parks and state marine protected areas, and two international RAMSAR estuaries. This coastal region is a treasured resource of the San Francisco Bay Area's seven million residents that rely on this unique marine ecosystem for their livelihoods and recreation. Significant coastal areas, including Tomales Bay, Bolinas Lagoon, Fitzgerald Marine Reserve, Point Reyes Headland, Drakes Estero, Pescadero Marsh, Duxbury Reef and the Farallon Islands, support a diversity of habitats, including eelgrass beds, intertidal rocky benches, sand and mud flats, salt and freshwater marshes, and extensive beaches and dunes. These habitats also provide numerous ecosystem services such as carbon storage, flood and erosion protection, and improved water quality. Offshore islands, rocks, and coastal cliffs provide critical nesting, haul-out, and roosting areas for the largest concentrations of seabirds and marine mammals on the West Coast outside of Alaska.




Natural resource managers realize the imminent threats of climate change to the health, sustainability, and ecosystem function of the special coastal and ocean places they protect, yet the capacity to develop appropriate management options to prepare for and respond to a changing environment are limited (Gregg *et al.* 2011). Adaptation planning techniques and processes are well developed, but there is a lack of application of these methods for marine systems (Gregg *et al.* 2011). The Greater Farallones National Marine Sanctuary Advisory Council (Council) convened the multi-agency Climate-Smart Adaptation Working Group (Working Group) in response to this need to develop climate-smart adaptation strategies to enable coastal and marine resource managers to respond to, plan, and manage for the impacts of climate change to habitats, species, and ecosystem services within the North-central California coast and ocean (Figure 1). Specifically, project partners seek to integrate climate-smart adaptation into existing management frameworks, and provide guidance to help ensure long-term viability of the species and habitats natural resource agencies are mandated to protect and the public values.

This effort builds from Phase 1 of the Greater Farallones National Marine Sanctuary (Sanctuary)'s Climate-Smart Adaptation Project that assessed vulnerability to climate and non-climate stressors for select species, habitats, and ecosystem services in the region through two decision-support workshops (Hutto *et al.* 2015 and available here). The climate-smart adaptation strategies presented in this report are a result of a yearlong multi-agency process to develop management responses to the vulnerabilities identified in Phase 1. These strategies will be presented to the council for acceptance, and then forwarded to the Sanctuary Superintendent as well as other coastal resource management agencies in the region, such as National Park Service, U.S. Fish and Wildlife Service, Bureau of Land Management, California State Parks, California Department of Fish and Wildlife and Counties of San Mateo, San Francisco, Marin and Sonoma, for consideration in their current or future adaptation planning efforts.

Working Group Goal:
*Develop and prioritize climate-smart adaptive management strategies that can be feasibly implemented by managers to reduce the vulnerability of select focal resources, while considering a range of plausible future climate scenarios for the region.*

Working Group Objectives:

1) From the focal resources assessed in Phase 1 (available here), select those that should be the focus of adaption planning.
2) Develop distinct, plausible future climate scenarios for the region to serve as a framework for adaptation planning (Appendix A).
3) Based on the vulnerability assessments, develop issue statements and management goals for focal habitats (page 5).
4) Develop adaptive management strategies for each habitat under all climate scenarios.
5) Finalize and prioritize management strategies across habitats (pages 10-31).

## Methods

Working group authority

Working groups are established under the Council, whose purpose is to provide community and interagency stakeholder advice to the Sanctuary Superintendent on a variety of Sanctuary management issues. The Council can establish working groups for specific purposes or topics that need focused attention that cannot otherwise be accomplished by the full Council. Working groups may be composed of members of the Council and persons outside the Council, be chaired by a primary member of the Council, and shall function under the purview of the Council. The opinions and findings of a working group and the Council do not necessarily reflect the position of the Sanctuary, the National Oceanic and Atmospheric Administration, or the agencies and organizations working group members represent.

Working group process

At the August 2014 meeting of the council, project staff presented the results of the vulnerability assessment from Phase 1 of the Climate-Smart Adaptation Project (Hutto *et al.* 2015), and requested the formation of a working group to develop and prioritize management actions in response. The Council voted to convene this working group and selected Anne Morkill, USFWS, as working group chair. In December 2014, based on expertise and jurisdictional boundaries, representatives from local, state, and federal agencies, non-profit organizations, and academic institutions were invited to serve on the Climate-Smart Adaptation Working Group. The Working Group was staffed and advised by representatives from the Sanctuary, as well as members of the scientific and conservation community in order to provide invaluable information used during the working group's deliberations, enabling the group to formulate practicable strategies. The Working Group held five meetings from April through December 2015 in Oakland, as well as numerous conference calls and online collaborations. This document is the result of those efforts.

Meeting summaries

*Scenario Planning (April 22, 2015)*

At their first meeting, Working Group members discussed the results of the vulnerability assessment and selected the resources they would consider in adaptation planning. The group decided to plan for the three most vulnerable habitats in the region (as identified in the Phase 1 vulnerability assessment):

- Beaches and dunes,
- Rocky intertidal, and
- Outer coast estuaries,

with the understanding that benefits from the adaptation strategies would extend to the vulnerable species and ecosystem services associated with these habitats. Cliffs were also included in association with beaches/dunes habitat due to the importance of this habitat to nesting seabirds. Sam Veloz, staff to the Working Group, led members through a scenario planning exercise, using the vulnerability assessment results and the Scenario Planning for Climate Change Adaptation guide (Moore *et al.* 2013). Scenario planning is a successful and flexible approach to incorporate climate uncertainty into decision making to develop adaptation actions for multiple, plausible climate futures, and is especially useful when critical drivers of change are highly uncertain and cannot be controlled (Moore *et al.* 2013). Members evaluated drivers of change that were identified in Phase 1 as contributors to focal resource vulnerability and ranked those drivers by their relative uncertainty (in future direction and magnitude of change) and importance to management decisions. The Working Group selected the three most uncertain/impactful drivers of change (precipitation, wave action, and upwelling), and from those created 12 potential climate futures for the study region. The group discussed the implications of the three scenario drivers to each of the habitats of interest and did an initial brainstorming session of likely management responses to these drivers of change. They were not able to pare the 12 scenarios down to a more manageable number, so they tasked staff to work with technical advisors John Largier and Andy Gunther to determine how best to move forward with identifying four distinct and robust climate scenarios from the initial 12 proposed scenarios.

*Refining Scenarios and Developing Management Goals (May 27, 2015)*
At their second meeting, the Working Group heard an update from Sam Veloz regarding the development of four final climate scenarios for the region, from the original 12 proposed by the group. Sam presented a “straw man” proposal from John Largier to develop four scenarios from the drivers of upwelling and run-off. The Working Group discussed these new drivers and approved of the resulting scenarios, then developed titles and headlines to describe these future scenarios and the impact they may have on the North-central California coast and ocean region. Four Working Group members volunteered to help staff write up summaries for each scenario (Appendix A) in preparation for the group’s next meeting. Lara Hansen, staff to the Working Group, gave a presentation regarding adaptation planning and discussed the process and methodology for successful development of adaptation strategies.

Based on interest and expertise, Working Group members organized into habitat teams for the remainder of the meeting to develop the following management goals for each habitat:

- Beaches and Dunes: Maintain functional stability and protect and enhance the ecological integrity of the beach and dune environment both under present and future conditions.
- Cliffs: Protect existing cliff habitat from accelerated degradation.
- Rocky Intertidal: Ensure that viable and ecologically functioning rocky intertidal habitat remains present in the study region.
- Outer Coast Estuaries: Optimize physical and biological function and processes of outer coast estuaries under present and future conditions.

*Adaptation Planning (September 15, 2015)*
After a summer hiatus, the Working Group came together for the third time to begin adaptation planning, using the scenarios and management goals they had developed at previous meetings and resources developed by staff to aid in the process. The scenarios that were approved at the May meeting were detailed by Working Group volunteers and staff over the summer, and the habitat-level impacts of these scenarios were presented and discussed. The remainder of the meeting was spent in habitat teams, developing management strategies in response to the four climate scenarios. The goal of the scenarios was to encourage Working Group members to move past uncertainty in future conditions to develop adaptation strategies. In general, the habitat teams realized that good strategies will make sense regardless of which scenario may occur in the future and were not at all constrained by uncertainty in their planning exercise. The scenarios were helpful to visualize potential future impacts but ultimately were not needed by the Working Group after this meeting. Adaptation planning resources available to the Working Group during this and subsequent meetings included a summary table of marine and coastal adaptation strategies being implemented across the United States (sourced from the Climate Adaptation Knowledge Exchange) and regional maps detailing jurisdictional boundaries to facilitate spatially informed adaptation planning.

*Adaptation Strategy Development (October 16, 2015)*
At their fourth meeting, the Working Group continued the development of management strategies in their habitat teams. The teams focused on providing as much detail to the strategies as possible, and brainstormed new and innovative responses to climate impacts. At the end of the day, all teams reported back to the large group and agreed that a conference call for each habitat team would be needed in order to finish the development of their recommendations. These conference calls took place in November.

*Adaptation Strategy Prioritization (December 3, 2015)*
At their final meeting, the Working Group spent an hour in their habitat teams to address any additional information needs for the strategies and to analyze any that may be combined or removed from the final list. The teams then underwent a prioritization exercise, using the following criteria to rank the strategies in order of priority:

1) Consistency with project goal (protect and maintain healthy ecosystems by enhancing the resilience of resources) and individual habitat goals;
2) Co-benefits (e.g., to infrastructure, economy, recreation);
3) Consistency with existing laws and policies;
4) Feasibility (cost and institutional capacity);
5) Efficacy in reducing identified vulnerabilities;
6) Climate-Smart:
    - Addresses near-term and long-term changes
    - Robust to uncertainty (i.e., applies to multiple scenarios)

- Minimal carbon footprint
- Adaptive and flexible, can respond to change
- Avoids maladaptation and unintended consequences
- Provides mitigation benefit (sequesters carbon)

7) Urgency (i.e., needs to be implemented or started soon in order to see benefits)

Habitat teams presented their highest priority strategies back to the large group (those ranking 2.5 or higher on a 1-3 scale), and the group identified overlapping and conflicting strategies across habitats and asked questions of other habitat teams. The Working Group decided to include all final strategies in their report, but to highlight those that were identified as "high priority" through this prioritization process. There was some discussion regarding process and a timeline for next steps for the Working Group to finalize their management strategies and final report to the Council.

*Council Meeting (March 2, 2016)*

At the conclusion of the working group's meetings, staff and the Working Group chair prepared the strategies and drafted a report for Council review and approval at their March 2nd meeting. At this meeting, the Council reviewed each individual strategy, provided edits and revisions, and voted on the strategies by approach category with the following motion:

> The GFNMS Advisory Council recommends the sanctuary consider the "[insert approach category]" strategies identified for the sanctuary, and for the strategies identified for other agencies, the Council recommends that the sanctuary superintendent forward them to the appropriate agency.

Those final strategies are included in this report, and a content-protected excel file is attached as Appendix D.

## Potential Management Strategies

Potential management strategies developed by the Working Group are presented by overall approach. Strategies that identify the Sanctuary as a key partner are highlighted and listed first under each approach category. Within these groupings, strategies are then listed by the timeframe indicated, with near-term strategies listed first. Priority management strategies are listed in the first table, with the remaining, non-priority strategies following in a second table. The non-priority strategies may still be potential adaptation actions to consider based on different management needs and goals. In addition, these actions may become more feasible and effective in the future if uncertainties are addressed via research. Appendices B and C include descriptions of key terms and agency designations found throughout the strategies. Strategies are also included in Appendix D as a sortable, content-protected excel file to enable users to sort by column and search by key word. Appendix E presents successful case studies of coastal and marine adaptation, compiled by EcoAdapt. It is the intent of the Working Group to provide these potential management strategies as a reference for management agencies in the region to reduce the vulnerability and increase the resilience of coastal habitats in response to increasing impacts from a changing climate. This also presents an opportunity for agencies and organizations to share, communicate, and collaborate to assess, improve and implement these strategies.

These strategies do not represent the entirety of what can be implemented to reduce vulnerability of coastal resources and do not provide detailed recommendations for individual projects. These strategies represent the ideas generated through a diverse and collaborative effort to identify potential actions that could be taken by natural resource management agencies to address climate change. Application of these strategies will require additional legal and methodological considerations by the implementing agency on a case-by-case basis. It is ultimately the Council's decision to convey these strategies as recommendations to the Sanctuary Superintendent for consideration. These strategies do not necessarily represent the positions of affiliated agencies or organizations, have not been vetted by those organizations, and reflect the opinions and ideas of the Working Group members themselves.

The Working Group recommends that regional partners consider the following as they view and reference this effort:
1) All strategies should be implemented with metrics for monitoring and evaluation of efficacy.
2) Some strategies identify new or novel ideas that either have not been tested or have not been tested in the context recommended; therefore, these ideas may require a demonstration project and/or research on viability and the mechanism for implementation.
3) Some strategies are more general in nature or are presented in a simplified context. These will require additional detail depending on the agency and location of implementation.
4) Sanctuary staff should ensure that the correct implementing agencies are identified for each strategy, and make these strategies available to all agencies identified.

Table Legend

*Approach:* The general method for reducing habitat vulnerability and the descriptive identifier for the type of strategy.

*Strategic Management Action:* The implementable and specific action to be taken to accomplish the approach (e.g. restrict public access through signage, closure zones, and enforcement in order to protect sensitive habitat).

*Spatial or site-specific details:* If applicable and possible, the strategy includes potential locations for strategy implementation (i.e. Bolinas Lagoon), and/or spatial characteristics for which the strategy would be appropriate (i.e. sediment-starved estuaries).

*Timeframe:* Immediate (implement as soon as possible), near-term (by 2025), mid-term (by 2050), long-term (by 2100)

*Stressor(s) addressed:* Of the stressors addressed by the Climate Change Vulnerability Assessment Report (Hutto *et al.* 2015), the major climate or non-climate stressors that are being targeted and alleviated by this strategy. See “Climate Factors for the Study Region” on page 12 of the Assessment Report for description of climate stressors, and the methodology section on page 17 for non-climate stressors.

*Key partners:* All agencies, organizations, academic institutions and others that would need to be part of successful implementation. Some strategies indicate the ideal lead for implementation.

*Required resources:* The resources required for implementation, including staffing, funding, information, collaboration, and community or political support.

*Notes:* Any additional details that do not directly fit in the other columns, including methodology details, potential interactions with other habitat types, potential conflicts, consequences, benefits of the strategy, and required cooperation.

Priority Strategies (highlighting indicates strategies identified for Sanctuary implementation)

**Manage Dynamic Conditions**: strategies that are responsive and adaptive to changing conditions

| Ref # | Strategic Management Action | Spatial or site-specific details | Time-frame | Stressor(s) addressed | Key Partners | Required Resources | Notes | Habitat |
|---|---|---|---|---|---|---|---|---|
| 1 | Add or relocate sediment to areas that are sediment-starved in estuaries and wetlands to help keep pace with sea level rise. | Sediment-starved areas in estuaries, or where needed. | Near-term | sea level rise, sediment supply | Sanctuary in partnership with Army Corps of Engineers and other sediment suppliers. | May be able to use dredge materials. There must be a process to ensure quality sediment is used. Incorporate into a larger, watershed-specific sediment management strategy. CCC permit or federal consistency review. | Creates/maintains habitat area and function in the face of sea level rise. Potential issues with TMDLs. | estuaries |
| 2 | In areas dominated by grey infrastructure, identify potential demonstration sites for green infrastructure projects and/or other "active management" projects; implement and evaluate effectiveness to inform future efforts across the region.<br><br>Potential project options include:<br>- Use wastewater treatment plants to supply fully treated and advanced wastewater for estuaries where benefit can be demonstrated.<br>- Build a horizontal levee in threatened part of sanctuary (e.g., estuary that is flood-prone or needs additional habitat)<br>- Install bioswales near areas dominated by infrastructure/roads<br>- Install rain gardens with soil layers engineered to help stormwater infiltrate underlying layers of soil<br>-Find ways to allow larger passage for high flow events | Site-specific: location and method/project will be determined by issues in each specific estuary<br><br>Prioritize estuaries currently impacted by flooding/storms, and in locations where the project could have co-benefits for other systems or human communities | Near-term | precipitation, sea level rise, coastal erosion, wave action | Sanctuary and estuary managers (possibly Marin County Parks, State Parks, NPS, Sonoma County Parks) in partnership with universities. | Funding required for initial project implementation as well as monitoring after implementation - consider NSF and foundations. Monitoring framework. CCC permit or federal consistency review. | There are many unknowns in how to manage for estuaries; this action will test different strategies and help innovate management, with the goal of helping sustain estuary habitat. Could have negative impacts (e.g., loss of tidal mudflat habitat). Need to balance risks | estuaries |
| 3 | To the extent practicable, reduce or modify armoring that exacerbates erosion; replace or enhance with natural material to create sloped, transitional habitat (e.g., artificial reef or dune). If armoring can't be removed and replaced, implement living shoreline techniques in conjunction with new construction/repairs. | Potential locations: Bolinas Lagoon (on lagoon side of the spit), Seadrift on Stinson Beach, Tomales Bay, Sonoma County along Hwy 1, Russian River | Mid-term | overwater/under water structures, roads/armoring, coastal erosion | Sanctuary and estuary managers (possibly Marin County Parks, State Parks, NPS, Sonoma County Parks) in partnership with communities. | Education and outreach, CCC permit or federal consistency review. | Reduces erosion (problem for Bolinas Lagoon), creates habitat for estuary movement. May be perceived by the community as a loss of flood protection. | estuaries |
| 4 | Let go of pocket beaches that can't retreat, and do not intervene with management actions. | Those that can't be nourished or retreat. | Long-term | coastal erosion, sea level rise | CCC (LCP plan approval), Sanctuary, NPS | Public outreach will be required to explain inaction. | | beaches/ dunes |

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| 5 | For sediment-heavy estuaries, conduct instream and upstream restoration work to reduce sediment delivery and flash floods. Activities could include:<br>- restore impaired and incised creeks - add large woody debris<br>- reconnect creeks to floodplain<br>- restore incised creeks by raising elevation to allow overflows/sediment deposition<br>- dechannelize upstream segments<br>- restore stream complexity<br>- remove old road crossings and legacy roads, parking lots and other sediment sources<br>- plant vegetation (e.g., drought/heat tolerant native species)<br>- incentivize best land management practices that enhance soil health and decrease runoff and erosion (e.g., rotate land uses on agricultural upland properties, plant drought-tolerant natives, forest management)<br>- build retention ponds/catchments that can be used for upland water management opportunities<br>**For all activities listed, note that environmental conditions (e.g. storms, flooding, erosion, drought, SLR) can shift areas within estuaries between sediment-starved and sediment-heavy, so this action will need to be dynamic and respond to changing estuary conditions in the future. | Potential locations: areas within Pescadero Marsh, Bolinas Lagoon, San Gregorio, Tomales Bay, Drakes Estero. | Near-term | sediment supply, turbidity, land use change | Land owners (NRCS, Resource Conservation District, local cities and counties), SWRCB (TMDL info), Coastal Conservancy, upland managers, NPS for Drake's Estero. | Site-specific research to avoid invasive species introduction (vegetation management, impact assessments). Education and outreach will be needed to gain public buy-in, as footprint to restore the floodplain may be large, and may endanger houses and infrastructure. CCC permit or federal consistency review. | May alter habitat in upland areas. Could cause stream vs. estuary conflicts. Land owner/infrastructure challenges. Helps trap sediment/paces sediment release, enhancing estuary function. Enhances wetland filtering characteristics. Supports water infiltration and percolation. May benefit freshwater wetlands. Can help mitigate marine debris associated with storms. | estuaries |
| 6 | Encourage a climate-smart response to erosion events that smother the rocky intertidal by developing a diagnostic decision support tool so management agencies know how to respond to either 1) recover the habitat by removing material, 2) leave material and encourage surfgrass growth or 3) leave material and take the opportunity for creation of a new beach. Have the knowledge to take advantage of the new situation due to erosion events. Ideally would have some options with the ultimate goal of leveraging resources to provide the best response. | There are proximal (cliff failure) and more distant (debris flow from coastal watersheds) sources of sediment - to address more distant sources, focus on the largest coastal watersheds (Garcia, Gualala and Russian Rivers, Pescadero and Gazos Creeks) with soils, topography, etc. that are likeliest to yield the greatest amount of debris flows. To address more proximal causes (cliff failure), identify slide-prone areas and pursue cliff failure prevention (see strategy 16). | Near-term | coastal erosion, wave action, precipitation | USGS | Requires modeling done by USGS scientists. | For distance sources of sediment, this action also requires watershed management efforts to reduce devastating impacts of wildfires that remove extensive vegetation and result in debris flows that are more likely and larger. | rocky intertidal |
| 7 | Maintain streamflow to mitigate estuarine temperature increases and salinity changes. Activities to help maintain streamflow could include:<br>- upland water management (e.g., implement best management practices)<br>- dam releases<br>- upland restoration<br>- building and using water retention ponds (land owners draw water from ponds rather than stream) | Smaller estuaries and estuaries with closed bars.<br>Potential location: Esteros de San Antonio and Americano. | Near-term (as needed) | temperature, mixing/stratification, precipitation, oxygen, pH, salinity | Regulatory agencies, CDFW, Resource Conservation District, NPS, land owners, local water supply and flood control agencies | Education/outreach: communicate how water use impacts estuary function and other habitats; Collaboration: can potentially coordinate with/build off regulation of instream flows. CCC permit or federal consistency review. | Consider the balance of human water supply (agriculture and residential) vs. ecosystem needs. Sediment supply/transport may increase; which may not benefit sediment-heavy estuaries. Moderating temperature may help mitigate algal blooms. | estuaries |

**Promote Education**: strategies that address the need to educate the community

| Ref # | Strategic Management Action | Spatial or site-specific details | Time-frame | Stressor(s) addressed | Key Partners | Required Resources | Notes | Habitat |
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| 8 | Develop a comprehensive education/outreach plan to address all of the 10 categories of strategy approaches in this report, including: partnerships with environmental ed orgs, schools and other public entities, social media and other communication strategies, interpretive signage and collaboration with other agencies and public entities to create a goal for climate literacy. | Region-wide | Near-term | all | Sanctuary | | | all |
| 9 | Enhance education programs (including marsh and tidepool education and interpretation programs) through training and guidance to communicate the implications of climate change and the exacerbating stressor of trampling and recreation on coastal habitats. Target existing programs (e.g. Duxbury and Fitzgerald Marine Reserves) and identify other highly-visited areas that need attention from volunteer docents. Docents should all have a common training core that includes climate change impacts and the exacerbating stressor of trampling and recreation on intertidal habitats, as well as tidepool etiquette and safety and the impact that impaired safety will have on natural resources. (i.e. boat groundings and the impact of emergency response). Strategies could include SLR visualizations and clean-ups. | Highly visited beaches, estuaries and tidepools. | Near-term | recreation/trampling | Sanctuary as the lead, in partnership with California Academy of Sciences, local cities and counties, NPS visitor center, Marine Mammal Center, Headlands Institute, State Parks, education programs and schools. | Existing docent programs. Funding and staff required to produce materials, curricula and trainings. | Effect on public access, public opinion. Opportunities for environmental education. Could link to Marin and San Mateo Counties YESS program and other school curricula | all |

**Protect and Restore Habitat**: strategies that focus on protecting and restoring habitat or key ecosystem processes

| Ref # | Strategic Management Action | Spatial or site-specific details | Time-frame | Stressor(s) addressed | Key Partners | Required Resources | Notes | Habitat |
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| 10 | Remove or modify structures that disrupt the delivery of sediment via long-shore sediment transport (jetties, breakwaters, storm and wastewater discharge pipes), and coastal and near-shore structures that contribute to erosion. Prioritize areas that are already impacted by these structures, and remove where possible. If the structure cannot be removed, then enable for managed retreat (for bluffs to feed the beach as sea level rises) and support beach nourishment to allow for beach expansion. | Potential locations: Pillar Point jetty which disrupts the delivery of sediment to surfer's beach in Half Moon Bay, areas along the Bolinas Lagoon shoreline where structures can be modified or living shorelines can be implemented, Oceanside Water Pollution Control Plant (including the westside transport box and Lake Merced Tunnel) and the Great Highway that impact Ocean Beach in San Francisco, structures that impact Fort Funston. Narrow road culvert at Schooner Bay, Drakes | Mid-term | coastal erosion, sediment supply and movement, wave action, wind, precipitation, overwater/underwater structures, sea level rise | Structure removal - Army Corps of Engineers, San Mateo County Harbor District, CCC, Sanctuary; Managed retreat - Caltrans, City of Half Moon Bay, CCC; Beach nourishment - Sanctuary, MBNMS, CCC, Army Corps of Engineers, SFPUC, Daly City, other local governments, Coastal Sediment Management Workgroup, Ocean Beach Master Plan, NPS. | Army Corps of Engineers staff, time and funds; CCC permit; political and local will. Living shorelines may need to be used to replace artificial structures and may require regulatory oversight through restoration - also may not be feasible on exposed outer coast beaches. Specific to the Pillar Point jetty: a feasibility study is near completion, and environmental impact review will be required regardless of the final action (though beach nourishment may only need an assessment). The MBNMS management plan may ned to be updated for longer term beach nourishment. A living shoreline to replace structure removal may require | The Pillar Point jetty is causing the erosion of surfer's beach, but the negative consequences of removing this structure may be too great for the community (in which case, managed retreat and beach nourishment should be implemented). This strategy protects and encourages expansion of sandy beach habitat, restores sediment influx, protects dune systems and infrastructure inland of beach, enhances recreational value, improves public access, prevents the impact of flooded infrastructure to natural system, reduces | beaches/ dunes |

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| | | Estero. | | | | regulatory oversight through restoration. | further risk of erosion adjacent to the problem erosion areas, and allows coastal systems to respond naturally. This strategy may also result in changes to shoreline erosion, e.g. accelerate where shoreline is currently protected and decreased where currently accelerated. | |
| 11 | Create local and regional sediment management plans for full range of the sanctuary that are climate informed. | Exist: S. Monterey Bay, Santa Cruz, San Francisco (littoral cell internal draft is under review); still needed for: Marin, Sonoma, S. San Mateo County, San Francisco (central bay) | Immediate | coastal erosion, sediment supply and movement, wave action, wind | Army Corps of Engineers, Coastal Sediment Management Workgroup, State Parks, BCDC, local flood control districts, NMFS, CDFW, CCC, NPS, local cities and counties | Funding and staff | | all |
| 12 | Restrict and direct human access on cliff base, face and top; including motorized transport. | Devil's slide (though this impact may be ameliorated by the tunnel), Jenner, Bolinas. | Immediate | coastal erosion, sea level rise, wave action, recreation, road/armoring | NPS, State Parks, BLM, local land trusts | Installation of fencing and signage; enforcement. Local governments can plan for restrictions to public access in their LCPs.CCC would need to approve signage and LCP updates. With consideration to Article 1, Section 25 of California Constitution that guarantees access to fishing grounds for citizens. | | cliffs |
| 13 | Monitor dredge materials to be used for beach restoration or expansion for contaminants, make sure existing regulatory mechanisms control for contaminant exposure and take into account interaction with additional stresses form climate change (e.g. temperature, dilution concentrations, pH) | Region-wide | Immediate | dredging | SWRCB, RWQCB, EPA, Army Corps of Engineers | Requires sediment/sand testing/approval by RWQCBs. Report out at the San Francisco Bay Long Term Management Strategy (LTMS) meetings. POC: Brian Ross, EPA. CCC permit or federal consistency review. | | beaches/ dunes |
| 14 | In the aftermath of a spill of oil or other contaminant, ensure that restoration of affected areas takes into account climate considerations (type of restoration, location of restoration, what should actually be restored based on climate envelope modeling to predict what species will likely become dominant). Oil spill restoration plans need to explicitly account for climate impacts on restoration of affected sites. | | Near-term | pollution (oil spills) | CDFW OSPR, NOAA Restoration Office, NPS, USFWS, CCC | Collaboration of the responsible party with Federal, State of California, and tribal trustee agencies. Climate change modeling. | This recommendation is applicable to all habitats and affected areas. | all |
| 15 | Identify and purchase 1) cliff lands that are less likely to erode to provide enduring cliff habitat and public access, and 2) lands behind cliffs to allow for landward migration of cliff habitat. | | Near-term | coastal erosion, sea level rise, land use change | State Parks, USGS, TNC, local land trusts, counties and cities, academic institutions | Funding, staff, research to identify cliffs less susceptible to erosion. | | cliffs |
| 16 | Stabilize cliffs through revegetation (with native, climate appropriate species) and natural netting (e.g. jute, not chain-link fence). Design any hardening methods to take into account ecosystem needs (e.g. seabird nesting). | Places experiencing vegetation loss through social trails or other means (social trails are | Near-term | coastal erosion, sea level rise, wave action | California Conservation Corps, California Native Plant Society, | Appropriate species that will persist in the context of future change, permits. | | cliffs |

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| | | paths not created by the land manager, but created by people walking repeatedly through a particular area to create a worn path) | | | Caltrans, land owners/managers (public and private) | | | |
| 17 | In restoration projects, use native, drought tolerant and heat resistant species or strains that fulfill ecological function of beach and dune processes. | Any location where restoration is proposed. | Near to mid-term | invasive and problematic species, air temperature | NPS, State Parks, land owners, National Audubon Society, California Conservation Corps, friends and stewards programs of the seashores and parks, Point Blue (use STRAW program's plant palette modified for dunes/beaches), CCC (through permit conditions or LCPs), local governments, Surfrider Foundation. | Create database of useful species to fill this niche (similar tool created for the Bayland Ecosystem Habitat Goals Update), source/supplier, staff and money, consider paleo/historic record to ID plants that thrived under previously similar conditions) | | beaches/ dunes |
| 18 | Restore and/or create high marsh/upland transitional vegetation, wetland habitat, and deltas in areas that are flood-prone for multiple purposes: to accommodate landward marsh migration, to provide refuge habitat for marsh and upland species during high tide events, and to provide flood protection | Undeveloped upland areas adjacent to marshes and flood prone areas adjacent to estuaries, including Bolinas Lagoon north end and east side drainages. | Near-term: acquire habitat Long-term: restoration activity | temperature, sea level rise | Land owners in partnership with Land Acquisition Funds, National Audubon Society, NPS | Identify transitional wetland habitat using regional estuary modeling and inventories, and obtain land by coordinating with land acquisition action. CCC permit or federal consistency review. | Tradeoff with existing habitat: may require some modifications. May restrict grazing opportunities. Provides habitat for the threatened and endemic red-legged frog. Creates refuge habitat from temperature and high water events. | estuaries |
| 19 | Construct/augment coastal dunes. Remove/relocate shoreward constraints to dune movement and evolutions. | Many coastal locations (e.g. Stinson Beach, North and South beach of PRNS). | Mid to long-term | coastal erosion, wave action, sediment supply and movement | NPS, local governments | CCC permit or federal consistency review. | Impacts to recreation and visitor facilities through managed retreat and dune/wetland restoration. Shoreline recreation may be preserved but facilities may require relocation to offsite with shuttle to access beach. Would provide added protection to the town of Stinson Beach from SLR. | beaches/ dunes |
| 20 | Protect beaches in order to protect cliffs (see beach strategies: 4, 8-11, 13, 14, 17, 19, 22, 23, 25-27, 29, 32-39, 42, 44, 45, 49, 50, 54, 59, 60, 62, 66-71, 75, 76, 78). | | | coastal erosion, sea level rise, wave action | | | | cliffs |

**Limit Human Disturbance**: strategies that restrict or reduce access to sensitive habitats to limit disturbance and enhance resilience

| Ref # | Strategic Management Action | Spatial or site-specific details | Time-frame | Stressor(s) addressed | Key Partners | Required Resources | Notes | Habitat |
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| 21 | Restrict human access to critical rocky intertidal areas. The type of access to rocky intertidal ecosystems that seemed | Critical habitat in the study region that | Near-term | recreation/trampling | CCC in partnership with Sanctuary, | CCC review of LCP updates or other plans. | Effect on public access, public opinion. Species | rocky intertidal |

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| | appropriate in the 1960s may not be as appropriate now based on current knowledge of the increasing impact of people on these changing and likely more fragile ecosystems. | deserves protection from human impact: important larval source, highly visited, highly impacted. | | | CDFW, NPS, Coastal Conservancy, local governments in their LCP updates. | | populations might continue to improve under additional protections against human disturbance. | |
| 22 | With the expectation that climate change impacts (such as those from storm activity and sea level rise) will reduce or cause major marine mammal haul-outs and seabird nesting sites to change, monitor and identify new locations of major marine mammal haul-outs and seabird nesting sites (see strategy 43) and provide protections for those locations. Reduce human disturbance, especially during times of heavy surf and inundation that will reduce availability of these habitats. Protect from major sources of disturbance from land, air and sea when appropriate, either as Special Closures, low overflight regulation zones or land-based closures. For example, NPS creates seasonal closure depending on the location of new elephant seal colonies and exposure to storm surf. | Historical areas - Pescadero Rocks, Bean Hollow, etc. Proritize the locations with the largest amount of disturbance to the largest breeding sites. Fitzgerald Marine Reserve already has this protection (cones are put out when mammals are present, and rangers are present), Pillar Point haulout has no protection. Spatially identify where these sites are and if there are new areas that will need protection due to SLR if used by marine mammals. | Near-term onward | wave action, recreation/trampling | CDFW - for vessel-based impacts, BLM, NPS, or USFWS for land-based impacts, Sanctuary or NPS for air-based and water-based impacts. Partners include: State Parks, NPS, county and city parks, Marine Mammal Center, Sanctuary (Beach Watch), MARINe, universities, Seabird Protection Network, CCC permit conditions for signage. | Public education (staffing for education and enforcement and resources like ropes and signs, interpretive materials). Provide spotting scopes for people to see mammals/seabirds up close. Better coordination amongst organizations and agencies to report new haulout areas, changing uses, etc. Landscape design of observation points, most protective to mammals and best vantage point. | SLR and storminess will flood haul out locations, especially during pupping season which overlaps with upwelling season – this may cause concentration of haul outs to fewer locations (erosion of north-facing beaches). Species conservation planning for marine mammals. Safety of boaters and pilots need to be considered. | all |
| 23 | Minimize access through dunes to protect dune stability. | Highly visited beaches that require access through dunes. | Near-term | coastal erosion, sea level rise, wave action, recreation | CCC, NPS, local cities and counties | | LCP policies and permit conditions are potential ways to implement this management action | beaches/ dunes |

**Address Invasive Species**: strategies that address the impact of invasive species on habitat resilience

| Ref # | Strategic Management Action | Spatial or site-specific details | Time-frame | Stressor(s) addressed | Key Partners | Required Resources | Notes | Habitat |
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| 24 | Prevent non-native invasive species establishment (aquatic and terrestrial) in estuaries. Potential activities to prevent establishment include:<br>- plant natives (e.g., in disturbed areas)<br>- remove invasive species that are near/adjacent to estuaries that have the potential to invade (e.g., invasive tunicate, green crabs). | Region-wide | Near-term | invasive & other problematic species, sediment supply | Sanctuary in partnership with National Aquatic Invasive Species Group, SF Estuary Partnership, SF Estuary Institute, and other relevant estuary management agencies (CDFW, NPS, Marin County Parks). | Need an understanding of what species may invade the area, monitoring and maintenance, collaboration on education and outreach - work with local community and other management agencies to mitigate introductions and enhance participation. CCC approval of permits and LCP updates. | This action specifically prevents establishment (as compared to removing invasives that are already established) | estuaries |
| 25 | Update the definition of introduced/invasive/non-native aquatic and terrestrial species for Sanctuary management. An example for aquatic species may be that if it is a California Current species, it should be managed as a native, and expansions into the study area should be considered a migration or expansion. | Throughout study region. | Near-term | invasive & other problematic species, sediment supply | Sanctuary and relevant species management agencies | Specific definition might want to be revised by local experts - may want to re-word and change from California Current designated in this strategy and incorporate terrestrial species. Take into consideration the definition provided by the National | | all |

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| | | | | | | Aquatic Nuisance Species Task Force and the Western Regional Panel. | | |
| 26 | Enhance/establish the detection and monitoring of species changes (southern species moving north, northern species moving out and invasive species moving in) via a novel rapid assessment program. Something similar to Reef Check, partner with PISCO and MARINe (currently monitoring sites two times per year, needs to be more frequent and in more locations). Engage land managers (such as PRNS, CDFW, Sanctuary via LiMPETS) to leverage pre-existing efforts to detect and monitor. Create a uniformity of practice across the region. | Existing sampling sites (e.g. MARINe), especially those that are less disturbed, urban/more disturbed sites like Fitzgerald and Duxbury where volunteers and visitors can be engaged. Leverage citizen science networks and programs. | Near-term | invasive & other problematic species, sediment supply | MARINe, CDFW (base off of existing protocols for community assessments), Sanctuary should lead the effort if it is determined a novel program is warranted. NPS. | Monitoring programs, volunteer removal programs; outreach to corporations, schools, communities to volunteer. Protocols for identifying invasive species as well as the response - trigger criteria to launch a rapid response. Permit for collection of novel identified organisms. Funding will be needed. Build capacity through citizen science training (e.g. LiMPETS). | Check with Pete Raimondi on existing efforts (biodiversity plots) and consider altering this recommendation for better continuity and support. | all |
| 27 | Rapid response of non-native invasive species removal following detection to protect natural systems (e.g., control invasives via: manual removal, flooding, fire in transition zones; reestablish natives). | Region-wide with focus on National Parks (GGNRA, PRNS), State Parks, and private lands | Near-term | invasive & other problematic species | Sanctuary, NPS, State Parks, land owners, National Audubon Society, California Conservation Corps, friends and stewards programs of the seashores and parks | Build and use volunteer base for manual projects. Will require monitoring and maintenance. Education and outreach with community, visitors, management agencies. Funding. CCC approval of permits and LCP updates. | Rare plants and snowy plovers may benefit, but need to mitigate for increased depredation of plover chicks. Where European beachgrass and iceplant are pervasive, removal cannot be accomplished and sustained by volunteers or heavy equipment. May mitigate range expansions with warmer water. Helps restore sediment and hydrological movement. Volunteer engagement can enhance education/outreach efforts. Disturbance associated with removal could create habitat/opportunity for other invasives. | all |
| 28 | Remove non-native invasive plants (e.g. jubata grass) that undermine cliff integrity, and where appropriate, replant with natives or drought-/heat- tolerant species that support cliff structure. | Cliff habitat throughout study region. | Near-term | invasive & other problematic species | NPS, State Parks, CalTrans, local counties | Training, funds, CCC approval of permits and LCP updates. | Similar to actions for strategy 15 "Stabilize cliffs through revegetation" | cliffs |

**Promote Landward Migration**: strategies that enhance the ability for habitat to migrate landward in response to sea level rise (SLR) and storms

| Ref # | Strategic Management Action | Spatial or site-specific details | Time-frame | Stressor(s) addressed | Key Partners | Required Resources | Notes | Habitat |
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| 29 | To the extent practicable, remove/redesign roads in locations that act as barriers to natural expansion of habitats. Prioritize roads that are already impacted by high tides and start with those immediately. Always remove roads where possible; if not possible, redesign the road.<br><br>Steps to accomlish this action in a changing climate include:<br>1) Identify areas that: A) are critical for estuary expansion and that have roads that impede estuary migration, and B) have roads vulnerable to sea level rise, flooding, other climate impacts<br>2) Develop Rapid Climate-Ready Response plans: develop plans that will allow for road removal/redesign in case of a disaster (e.g., road is wiped out in a flood)<br>3a) Post-disaster (flooding/road failure): implement the Rapid Climate-Ready Response plan to move/redesign road to a enhance future resilience<br>3b) If road is not impacted by climate change/extreme events, remove/redesign the road as available during standard maintenace schedule timeframes (i.e., when the opportunity arises to replace/redesign the road, take it) | Potential project locations:<br>1) Highway 1 along the east shore of Tomales Bay<br>2) North end of the Bolinas "Y"<br>3) Highway 1 at Pescadero Marsh<br>4) Sir Francis Drake Blvd near Drakes Estero (re-route or re-design)<br>5) Pescadero Creek Road<br>6) Highway 1 at Surfer's Beach in Half Moon Bay<br>7) Great Highway at Ocean Beach in San Francisco<br>8) Dillon Beach to Lawson's Landing | 1) Long-term<br>2) Near-term (higher urgency)<br>3) Long-term<br>4) Near-term (higher urgency)<br>5) Near-term: assessment; Long-term: implementation<br>6) - 8) Mid to long-term | sea level rise, roads/armoring | "Local governments can plan for road relocation in their LCP updates.<br>1) A state agency should be identified to organize implementation in partnership with Caltrans, Sanctuary, CCC, County of Marin, and NPS.<br>2) Marin County Parks, County of Marin, Sanctuary, NPS<br>3) Caltrans, San Mateo County, CCC, State Parks, scientists<br>4) NPS and San Mateo County, CCC, USCG (need facility access), private ranching community, farm bureau<br>5) San Mateo County, NMFS, CDFW, Pescadero Fire Station (currently working on moving their flood-vulnerable facility)<br>6) Caltrans, City of Half Moon Bay, CCC<br>7) Caltrans, City of San Francisco, CCC<br>8) Caltrans, Marin County, CCC" | 1) Do not anticipate the need for policy change in order to implement. Post-disaster planning might need to interface with local hazard mitigation plans.<br>2) Likely requires permit and environmental impact review; Needs project coordinator and adequate resources for assessments; Funding; Do not anticipate the need for policy change in order to implement. CCC approval of the plan, especially if elements are in the LCP update.<br>3) Need a place to move Hwy 1<br>5) Funding: partners can help leverage funding | Creates space and facilitates estuary movement in response to SLR, reducing vulnerability to flooding. Facilitates water and sediment movement throughout the estuary, improving hydrologic function. Improves connectivity between upland and lagoon habitats, with positive impacts on riparian and nursery habitat.<br>Site specific benefits and consequences:<br>1) Provides more areas for eelgrass restoration in Tomales Bay. Reduces flood risks for human communities and infrastructure, enhancing long-term resilience. Also improves driver safety and traffic flow. Potential conflicts with tourism, transportation, infrastructure needs, etc. Road redesign may be the only feasible alternative since it is Highway 1. May need a causeway or reroute over the hills to the east at various locations.<br>2) Provides transitional habitat in an estuary where most of the edges are hardened. Road removal may cause loss of non-native and native species in habitat on other side of the road with unintended consequences; however, this area will eventually be inundated anyway. Transportation conflicts: | all |

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| | | | | | | | | local residents, tourists. Part of Marin County's sea level rise project - this action supports local efforts.<br>3) May improve dynamism of marsh morphology - Hwy 1 has low point near marsh, estuary bar is fixed under Hwy 1 bridge and can't move around, which likely affects marsh morphology. However, no records show the historical outlet so it is unknown how marsh morphology may change. Societal impacts of moving road: directing it toward a small town, tourism/recreation, safety routes, etc. Could negatively impact marsh depending on design.<br>4) This road (culvert/bridge) is at the pinch point at the head of Drakes Estero, and floods every winter. Would allow connectivity of habitats on each side of road, and prevent costly infrastructure maintenance. May be able to link to county program: San Mateo is identifying all roads vulnerable to SLR and affected by flooding. There are communities on each side of road; may affect access.<br>5) Road is at head of marsh and floods frequently because channel is filled with sediment. Could provide additional wetland habitat. County is moving fire station (Pescadero Fire Station Replacement Project) and looking at options for the road. There is an opportunity to leverage projects for multiple benefits. | |

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| 30 | For roads that can't be raised/moved, or in conjunction with raising/moving roads, look for opportunities to create functional habitat (e.g., replace hard/grey infrastructure such as rip-rap with living shorelines and migration space) | Region-wide Potential location: install a horizontal levee at Bolinas Lagoon/Hwy 1 | Bolinas Lagoon: Mid-term Region-wide: long-term, leverage opportunities when they exist | sea level rise, overwater/underwater structures, roads/armoring | Caltrans, Sanctuary, Army Corps of Engineers, RWQCB, NPS (GGNRA and PRNS), Sonoma County Parks, State Parks, land owners | Capitalize on natural destruction events, rebuild smarter. CalTrans would likely need policy adjustments (repair vs. rebuild); develop pre-planned response to road failures; revise planning horizons. CCC approval of a plan. | Creates functional habitat and space in areas that can't be moved/expanded. Short-term impacts to existing species/vegetation with habitat modification (e.g., may need to fill part of lagoon to create sloped transitional habitat). | estuaries |
| 31 | For locations identified as having coastal area available for developing new rocky intertidal habitat (see strategy 43), allow cliffs to erode to create new habitat. Discourage the creation of seawalls that would inhibit cliff erosion. | Create unfettered sea-to-land linkages for new habitat development. Where possible maintain the thread-like habitat continuity of rocky intertidal habitat north to south - avoid where possible large stretches of total inundation of rocky intertidal habitat. If design is possible, create new habitats that are less powerfully affected by storm damage, i.e., is there "wiggle room" to design new habitats that will be resilient to increasing storm surges. | Long-term | sea level rise | Sanctuary, NOAA Restoration Office, USGS, local cities and counties, land owners | Excellent marine geomorphologists, oceanographers, CCC federal consistency review. | May require efforts to clean up contamination sites, remove infrastructure at risk to provide adequate setbacks for development of new habitat - would link to efforts to control or manage coastal cliff erosion; intersects with intertidal species conservation strategies. | rocky intertidal |
| 32 | Explore legal and economic mechanisms to encourage coastal habitat protection in exchange for something analogous to an agricultural tax credit (e.g. coastal protection tax credit or transfer of development rights). | | Near-term | coastal erosion, sea level rise, wave action, roads/armoring | CCC, local cities and counties, land owners | May need state legislature. | LCP policies and permit conditions are potential ways to implement this management action | beaches/ dunes |
| 33 | Exclude development in critical habitat areas and areas of potential habitat expansion through various policy changes. Exclusion language should be integrated into policies for retrofitting existing buildings, new construction, and rebuilding post-disaster. Add sea level rise conditions to general plans and local coastal plan updates. | | Near-term | sea level rise, coastal erosion | CCC, Coastal Conservancy, local cities and counties, Center for Ocean Solutions (policy guidance), Georgetown Law Center, State Attorney General (legal guidance), UCLA Model Ordinance project (policy guidance) | Education and outreach: make changes amenable/understandable by the public. If needed, explore and investigate opportunities for how exclusion has been accomplished elsewhere (e.g., along the Napa River, other floodplain examples), and confer with groups with expertise in this realm (e.g., Nature Conservancy, Coastal Conservancy). Capitalize on large natural disasters - prevent vulnerable re-building that would negatively affect estuary migration. | Prevents construction/retrofits that can impede estuary migration. Prevents building construction that could fall into estuary habitat in the future. Public opinion may be hard to change. In long-term, benefits counties, cities, and homeowners: saves money by preventing the construction of structures vulnerable to SLR and flooding. | all |

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| 34 | Prioritize locations, purchase or redesignate available land for inland movement of beach and dune habitat, using Open Space/Conservation Easements | Any site that is vulnerable to SLR and has potential to move inland. | Near to long-term | coastal erosion, sea level rise, wave action | CCC, local cities, counties and land trusts, Coastal Conservancy, land owners, State Parks, NPS, State Lands, BLM, TNC, Caltrans, FEMA (through Hazard Mitigation Plans), Army Corps of Engineers | Spatial prioritization, funding, knowledge of sediment circulation and supply | Might be in conflict with adjacent land management that is trying to abate SLR | beaches/dunes |
| 35 | Move or remove infrastructure that blocks or impedes habitat migration, or presents a potential risk of contamination to critical habitats, including utilities (e.g. power lines, sewer pipes), buildings, roads, or agriculture endeavors. | Places where lifetime of structure is ending or structure is creating a coastal hazard. Will likely be similar locations as road removal/redesign; all projects involving Hwy 1. | Near-term and long-term | sea level rise, overwater/underwater structures, coastal erosion | CCC, local cities, counties and land trusts, Local Coastal Programs, Coastal Conservancy, relevant utilities agencies and/or project lead of other barrier removal projects. | Planning for infrastructure relocation can be part of a local government's LCP update. | Deals with multiple obstructions at same time (co-benefits, leverage projects); facilitates estuary expansion. Availability of utility services | all |
| 36 | Work with counties to zone for protection of dunes and cliffs (setbacks, buffers, moratoria, elevate structures, designate areas of special biological interest for protection) to reflect changing coastal conditions | | Mid-term | coastal erosion, sea level rise, wave action, roads/armoring | CCC, State Lands, local cities and counties | | LCP policies and permit conditions are potential ways to implement this management action | beaches/ dunes |
| 37 | Consider the removal of seawalls (including rip rap) and make associated modifications to support retreat. | Where appropriate. | Mid to long-term | coastal erosion, sea level rise, roads/armoring | Caltrans, City of Half Moon Bay, CCC, Marin County, homeowner's associations (if applicable), NPS, local cities and counties. | Caltrans staff and time, funding (increase gas tax in San Mateo County), create sustainable development community with transit hub | | beaches/ dunes |
| 38 | Assess the need to move or modify visitor facilities, pavement, and parking lots. | Visitor facilities (visitor centers, kiosks, bathrooms, signage, trails and parking lots) | Depends upon timing of impact | coastal erosion, sea level rise, roads/armoring | NPS, State Parks, CCC, local cities and counties | Funds, permits, staff time | | beaches/ dunes |

## **Invest in Science Needs**: strategies that call for increased research to inform management

| Ref # | Strategic Management Action | Spatial or site-specific details | Time-frame | Stressor(s) addressed | Key Partners | Required Resources | Notes | Habitat |
|---|---|---|---|---|---|---|---|---|
| 39 | Develop a systematic research and science agenda to inform climate-smart adaptation. | | Near-term | | OST and NOAA. | | | all |
| 40 | Conduct regional inventory and modeling to identify how existing estuaries may change and identify potential areas for estuary expansion; use this information to set regional adaptation priorities. This effort includes:<br>- completing current estuary inventory<br>- identifying values of different estuaries (e.g., estuary harbors endangered species [or those that may become so], has valuable wilderness character, soundscapes, landscapes, lightscapes, pinniped breeding sites and haulouts, salmon | Study region | Immediate | sea level rise, precipitation, overwater/underwater structures, roads/armoring, coastal erosion | Sanctuary to convene a regional partnership of numerous land management agencies, scientists and funders. See "required resources" for a listing of partners that need to be involved. | Funding: variety of sources/joint venture (NOAA, NPS, Stanford Natural Capital Project, Universities/Academics, Federal Highways, foundations)<br><br>Modeling: leverage current | Identifies how estuaries may change, and areas ripe for estuary expansion. Can be used to inform locations of all other adaptation actions, and helps prioritize sites for action. Short-term benefits: can identify where short-term | estuaries |

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| | habitat, etc.]<br>- identifying where future estuary habitat may move<br>- better understanding how habitat types may change, and<br>- better understanding and modeling system dynamics, and how they may change (e.g., how tidal prism may change)<br><br>If possible:<br>- Model entire region, utilizing current information/regional efforts and modeled future changes to identify net changes to estuaries<br>- If not, model specific sites of management interest<br>- If really limited, look only at the information we currently have (e.g., OCOF model) rather than conducting new modeling | | | | . | data from existing regional efforts and combine with new modeling. Will need someone to lead data aggregation, plus someone to model (consider Point Blue and/or USGS)<br>Data/models that should be used:<br>- current estuary inventories from various management agencies/groups; combine these to make a regional inventory, and standardize/expand on detail collected for each estuary (e.g., key species, services provided, estuary values, etc.)<br>- OCOF: use to identify what areas will be flooded; combine with salt water intrusion modeling, riverine flooding modeling (e.g., FEMA flood maps). Build in uncertainty by using max/worst case scenario projections<br>- pollutant hotspots (critical to know if polluted area will be inundated; get data from EPA and regional/local environmental health agencies)<br>- historic/archeological resources (NPS, State parks, counties)<br>- sediment availability (identify if each estuary requires more/less sediment)<br>- location of berms/levees/existing infrastructure/armoring<br>- demonstration projects/lessons learned from regional projects (e.g., Muir Beach, Giacomini, South Bay Salt Ponds)<br><br>Can create a decision matrix to go along with this process to facilitate future updates/repetitions. | measures are needed/feasible and identify opportunities to leverage resources with other groups and activities. Long-term benefits: guides prioritization of projects, can identify short-term actions within longer-term processes. | |
| 41 | Capitalize on natural extreme events to increase monitoring and knowledge of estuary processes and climate change impacts to inform adaptive management (e.g., monitor impacts of projected El Nino, study closed/open estuaries) | Study region | Near-term | precipitation, wave action, coastal erosion, turbidity, salinity, sea level rise, pH | Sanctuary, CDFW and OST. Relevant land owners (e.g. NPS) to lead monitoring on individual sites. | May require a Sanctuary staff member to lead data management and acquisition. Need rapid response monitoring teams ready to deploy (in case of extreme | Can help inform adaptive management and help mitigate negative impacts of extreme events in the future by better understanding natural | estuaries |

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| | | | | | | events). Need a standardized monitoring framework across sites; need to identify what Sanctuary wants to monitor for. Base locations on sites identified through monitoring and inventory action. Gather input from other groups (Bay Area Climate Change Consortium, CA LCC, agency partners). There are several estuaries that contain MPAs so it would be good to link the MPA monitoring efforts to other monitoring efforts for estuaries in the region. | processes. Builds knowledge to inform adaptive management. Can be used to increase education/outreach and public engagement. | |
| 42 | Determine the source of sediment for vulnerable beaches in order to improve sediment supply processes. | Wherever sediment patterns are vulnerable and uncertain | Near to mid-term | coastal erosion, sediment supply and movement, wave action, wind | Sanctuary, Coastal Conservancy (for funding), academic institutions, NPS, USGS, Army Corps of Engineers, Coastal Sediment Management Workgroup | Researchers, funding | Implications for estuary management and cliff erosion. Possible counteracting sources (e.g. cliff erosion and long-shore current counteract). | beaches/ dunes |
| 43 | Identify future viable locations for rocky intertidal habitat migration inland either through modeling or known information (how do rocky intertidal areas form, and would there be available rock inland for habitat migration? Is there rock under the cliff bluffs or under the sand?). Identify future viable locations for seabird and marine mammal breeding sites and haul-outs. | TBD through modeling analyses and site analyses. Some modeling has been done at PRNS for elephant seals. | Long-term | sea level rise | USGS, universities. | Modeling, interagency collaboration of Federal, State, County, and municipal governments; regional planning - perhaps along the lines of planning zones used in Area Contingency Plans; Army Corps of Engineers might have very useful expertise | This strategy informs the implementation of strategies 22 and 31. This activity intersects with intertidal species conservation strategies. | rocky intertidal |

## **Protect Species**: strategies that directly protect species rather than habitats

| Ref # | Strategic Management Action | Spatial or site-specific details | Time-frame | Stressor(s) addressed | Key Partners | Required Resources | Notes | Habitat |
|---|---|---|---|---|---|---|---|---|
| 44 | Designate, expand, and increase enforcement of resource management areas to enhance and support special protections for target species in the context of climate change. | Study region | Near-term | coastal erosion, sea level rise, temperature, precipitation | CDFW, NOAA OLE, BLM, USFWS, NPS, State Parks, relevant land managers | California Coastal Commission permitting | | beaches/ dunes |

## **Manage Water Quality**: strategies that improve water quality to enhance habitat resilience

| Ref # | Strategic Management Action | Spatial or site-specific details | Time-frame | Stressor(s) addressed | Key Partners | Required Resources | Notes | Habitat |
|---|---|---|---|---|---|---|---|---|
| 45 | Improve storm water management by reducing combined sewer overflow events. | Ocean Beach, Fort Funston, Pacifica, other locations with combined sewer overflow | Near-term | precipitation, coastal erosion | SFPUC or Public Works, CCC for review of permit or LCP updates. | Funding for infrastructure improvements and/or replacements | Improves water quality | beaches/ dunes |

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| 46 | Capture and redirect storm water away from cliff face into better infiltration systems to reduce erosion and avoid landslides. | | Near-term | pollution, precipitation | Local cities and counties, SWRCB, CCC | Hydrology information, funding for contracts to regrade/swales/etc, local permits | | cliffs |
| 47 | To prevent algal blooms, Regional Water Quality Control Boards that manage TMDLs for nutrients should consider stricter prohibitions for effluent flows of excessive fertilizer to address stressors of excessive nutrients at low flow times into the ocean, a situation likely to get worse with climate change. See publication: http://pubs.acs.org/doi/pdf/10.1021/acs.est.5b00909. | San Francisco Bay (Napa and Sonoma rivers have TMDLs for nutrients which are now under consideration for delisting), Walker Creek and Tomales Bay (mercury and pathogens only, not nutrients), and Russian (phosphorus in the Laguna de Santa Rosa) rivers all have water quality impairments for nutrients. TMDLs are under development for Fitzgerald Marine Reserve (for bacteria) and for Pescadero Marsh/Butano Creek (sediment). | Near-term (higher urgency) | pollution, oxygen, stratification | RWQCB, SWRCB, California Farm Bureau, Natural Resources Conservation Service. | Local Resource Conservation Districts. Sanctuary to help track water quality changes through monitoring (ACCESS cruises) with partners (Point Blue). | Decrease the possibility of negative impacts due to blooms smothering the intertidal (macro) and changing water quality (micro). Planning to reduce debris flows from storms, efforts to reduce mercury input into coastal waters | rocky intertidal |
| 48 | Take a watershed approach for rocky intertidal areas near estuary mouths, streams, etc. to limit sediment and improve water quality entering from the watershed:<br>1) Watershed managers and regional water quality control boards should enforce TMDLs with forestry operations, municipalities, agriculture, etc. to limit sediment coming down into the intertidal area.<br>2) Incorporate climate considerations into formulation of TMDLs in specific locations (see site specific category) to respond to predicted climate change impacts on outflows of sediment, toxins and nutrients. | Potential project locations:<br>1) Garcia River estuary next to Point Arena intertidal reefs. Farmland and forestry operations upstream.<br>2) Gualala River next to Gualala Point. Logging and land recently purchased as conservation lands.<br>3) Russian River with rocky intertidal both north and south of estuary mouth. Mercury-rich sediments from mines upstream. Forthcoming inclusion of Lake Mendocino and Lake Sonoma in the Statewide Reservoir Mercury TMDL.<br>4) Pescadero Creek with rocky intertidal area just south of estuary.<br>5) Gazos Creek with Ano Nuevo just south. Timber logging upstream. | Near-term | coastal erosion, precipitation, land use change | For all potential projects: SWRCB and RWQCBs, local cities and counties, relevant forestry, farming, mining, logging operations upstream. Additional:<br>2) Gualala River Watershed Council, Friends of Gualala River<br>3) Russian River Watershed Association, Russian River Watershed Protection Committee | Collaboration among rocky intertidal managers (BLM, CDFW, State Parks, Sanctuary) and RWQCBs. Need to secure immobilization of pollutants as the disturbance regimes along coastlines, coastal rivers and streams, and uplands intensify. CCC review of plans. | Negative impact on sediment-starved estuaries. Note that San Francisco Bay and Tomales Bay have TMDLs for mercury. | rocky intertidal |

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| 49 | Improve storm water management by creating bioswales and other urban run-off reduction tools (e.g. permeable pavement, street trees/catchment/storage). | Pacifica/Linda Mar Beach, San Francisco, Half Moon Bay and other San Mateo County Unincorporated Areas, all highway locations in the five county area | Near to mid-term | precipitation, coastal erosion | Local cities and counties, Friends of the Urban Forest, California Conservation Corps, The Arbor Day Foundation, CCC (in permit conditions or LCPs), ASBS funding | Wetland vegetation, saplings, staff or volunteers | Improves water quality, and reduces beach erosion | beaches/ dunes |
| 50 | Improve storm water management by reducing agricultural (croplands and livestock) run-off (buffer strips). | San Mateo County, Lawson's Landing, Sonoma County, Tomales Bay | Near to mid-term | precipitation, sediment supply and movement | Resource Conservation Districts, SWRCB, CCC (in permit conditions or LCPs) | Grants and conservation easements for private landowners | Improves water quality | beaches/ dunes |

Additional Strategies (lower priority)

**Alleviate Climate Impacts**: strategies that directly reduce the impact of climate stressors

| Ref # | Strategic Management Action | Spatial or site-specific details | Time-frame | Stressor(s) addressed | Key Partners | Required Resources | Notes | Habitat |
|---|---|---|---|---|---|---|---|---|
| 51 | Restore and enhance lower intertidal mussel beds and algae, including sea palms (a species identified as vulnerable), to buffer from storm activity by enhancing structural roughness (physical/structural resistance) to lessen impacts of storms on intertidal zones. | Consider the evolving (new) subtidal and intertidal zones | Near-term onward | wave action | Sanctuary and landowners (NPS, CDFW, State Parks, State Lands Commission) in partnership with NGOs to get funding | Marine and coastal habitat restoration ecologists; monitoring to address efficacy. CCC permit or federal consistency review. | Facilitates species colonization and recovery from disturbance due to an increase in ocean wave energy that may destabilize and transform intertidal habitats. | rocky intertidal |
| 52 | Restore subtidal kelp forests to attenuate waves and buffer from enhanced storm activity. | Select locations that do not currently have kelp but have appropriate conditions for kelp settlement and growth (good light and water quality, little turbidity). | Near-term onward | wave action, coastal erosion | Sanctuary in partnership with NPS, Bodega Marine Lab and UCSC. NGOs and Coastal Conservancy for funding. | Monitoring to address efficacy. CCC permit or federal consistency review. | Reduces ocean wave energy in subtidal habitats as a further step to reduce energy impacts in the intertidal zone - to modulate the intensity, frequency, and duration of storm impacts. Reduces sediment and turbidity in the intertidal. Creates habitat for subtidal systems that supports objectives for rocky intertidal ecosystems. Need to balance with any commercial programs for kelp collection. Learn from Southern California efforts. Seek funding for a research project at Bodega Marine Lab. | rocky intertidal |
| 53 | Restore and enhance surfgrass *(Phyllospadix)* and algal species to act as aqueous canopies and provide shading to reduce temperatures and reduce evaporation in tide pools. | Prioritize intertidal reefs that are most vulnerable to prolonged exposure and heat stress. Potential locations include: Tomales Bay headwaters, Point Reyes Headland, Palomarin, Pescadero State Beach, San Gregorio State Beach, Fitzgerald Marine Reserve, Año Nuevo State Park, Pigeon Point, and Pillar Point for *Phyllospadix scouleri*, and Moss Beach for *P. torreyi* (see calflora.org for more information on species distributions). | Long-term | air temperature, sea surface temperature, salinity | Sanctuary in partnership with NMFS, Coastal Conservancy, CDFW, NPS, other agencies that manage marine resources, and NGOs to assist with funding | CCC permit or federal consistency review. | Additional benefit is carbon sequestration and local mitigation of the impacts of ocean acidification provided by surfgrass restoration. | rocky intertidal |

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| 54 | Diminish heat stress by testing the efficacy of shade delivery systems (including nest umbrellas/boxes/tents and revegetation) or encouraging animals to nest in more protected areas. | Farallon Islands, critical nesting sites | Near-term | temperature, precipitation | USFWS, Point Blue, State Parks, CDFW, NMFS, NPS, relevant coastal land owners and managers | Determine need for seal pup thermal protection; California Coastal Commission permitting | Make out of solar fabric for ancillary power production (e.g. fans if needed). Create possible user experience/education tie-in, such as renting similar umbrellas to beach users. | all |

**Manage Dynamic Conditions**: strategies that are responsive and adaptive to changing conditions

| Ref # | Strategic Management Action | Spatial or site-specific details | Time-frame | Stressor(s) addressed | Key Partners | Required Resources | Notes | Habitat |
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| 55 | Manage the bar:<br>- create a breach if estuary closes and conditions are detrimental to estuarine species or resources of interest<br>- actively close the bar if estuary is open and conditions are detrimental to estuarine species or resources of interest | Site specific: will largely depend on estuary condition (e.g., breach may be required in case of restricted passage or poor water quality; closure may be required to capture necessary freshwater outflow or to protect from marine pollutants)<br><br>Potential areas for breach: Bolinas Lagoon (although natural closure may be unlikely with sea level rise), Pescadero Marsh, Russian River, Muir Beach, San Gregorio, Tunitas Creek, Pomponio, Rodeo Lagoon, Gazos Creek, steelhead or salmon bearing streams that have restricted passage<br><br>Potential areas for closure: Nursery grounds (e.g., Russian River - salmon), or in case of pollutants (e.g., done at Rodeo Lagoon in the past to protect from oil spill) | As conditions require. | precipitation, oxygen, pH, water temperature, salinity, turbidity, currents/mixing /stratification, temperature | Partnership with land owners, County (equipment/staff), Sanctuary, regulatory agencies, Coastal Commission, community support.<br><br>Lead agency may be different if species of concern isn't a key commercial or T/E species, or depending on who wants the action done | Need to first accomplish in the near-term the policy/permitting framework (programmatic permits required for each system; must be very site-specific and lay groundwork for approval ahead of time) and a better understanding of individual system dynamics to identify when this management action would be beneficial/harmful. Will also require agency coordination (esp. related to breach timing). Funding needed to monitor impacts and cover permit costs. | Creating a breach may ameliorate stagnant water impacts, poor water quality, limited passage (anadromous fish [juveniles/adults], recreation, other biota) and promote hydrologic and sediment transport. May cause earlier opening in the future, and could affect marsh accretion and water chemistry (methyl mercury production). May provide positive education opportunity around resource values, and may benefit certain human communities that believe the septic system doesn't function when estuary is closed. May also help prevent algal blooms by moderating temperature.<br><br>Closing the bar may capture freshwater and protect/maintain related freshwater habitats, including nursery grounds, when runoff is pulsed. May reduce recreational use/access and/or become stagnant and smelly. Could cause loss of sediment (depending on how it's done), shorebird foraging habitat/subtidal habitat, haulouts, cordgrass, and mud organisms (due to | estuaries |

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| | | | | | | | anaerobic conditions). | |
| 56 | Reconsider sediment requirements and stream management mandates to ensure sustainable sediment delivery to estuaries. Activities could include:<br>- conduct sediment study for each estuary site to determine if estuary is sediment-starved or keeping pace with sea level rise<br>- recommend that sediment management plans be climate-informed | Region-wide, but prioritize sediment-starved areas within estuaries.<br>Potential location: Tomales Bay | Near-term | sediment supply, coastal erosion, sea level rise | Army Corps of Engineers in partnership with Coastal Sediment Management Working Group, CA State Sediment Master Plan, other sediment management and planning efforts. Coordination with SWRCBs for TMDLs. NPS. | Expand existing groups/efforts to look at estuaries. Utilize existing monitoring data from NPS, USGS, and gather high resolution data for sites of interest. | Could benefit beach systems. Enhancing sediment delivery may not be possible if streams harbor sensitive species (e.g., salmonids). | estuaries |

**Protect and Restore Habitat**: strategies that focus on protecting and restoring habitat or key ecosystem processes

| Ref # | Strategic Management Action | Spatial or site-specific details | Time-frame | Stressor(s) addressed | Key Partners | Required Resources | Notes | Habitat |
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| 57 | Protect and promote eelgrass growth; protect existing beds and restore areas that have been adversely affected by human activities, such as aquaculture operations, moorings or other infrastructure. | Potential locations: Tomales Bay, Esteros de San Antonio and Americano, Bolinas Lagoon, Drakes Estero. | Immediate | pH, overwater/underwater structures, temperature | CDFW, California Fish and Game Commission, State Lands, Sanctuary, NPS | Requires funding, enforcement to protect current beds from degradation and to protect restored areas, and education and outreach. CCC permit or federal consistency review. | Enhances nursery grounds. May help regional carbon sequestration. Economic benefits (oyster farming). Need to work with oyster companies to reduce light blockage and other damage from anchors, racks, floats. | estuaries |
| 58 | Remove overgrowth of macroalgae (ulva blooms) from rocky intertidal habitat as they occur. | Areas impacted by major overgrowth. | Immediate | pollution, oxygen | Sanctuary | Permitting | Potential impacts to the intertidal area due to trampling and harvest - needs to be done in a way that does not impact resources (consider only free-floating harvest by vessel). Separate approach (Water Quality Management strategy) focuses on reducing pollutants from estuaries and run-off. | rocky intertidal |
| 59 | Beach nourishment | Potential locations: Ocean Beach: middle and southern reaches, Stinson Beach, Inverness, East Shore, Dillon Beach, Lawson's Landing, Salmon Creek, Jenner, Half Moon Bay, Surfer's Beach, pocket beaches on Farallon Islands, Point Arena, Manchester State Park, Gualala Point | Near to mid-term | coastal erosion, sediment supply and movement, wave action, wind | City of San Francisco, Army Corps of Engineers, NPS, State Parks, USFWS, SPUR, USGS, SFPUC, CCC, Sanctuary, local harbor districts, cities, and counties, Coastal Sediment Management Workgroup | Sand, money, staff, federal permit, CCC permit or federal consistency review. | Implications for beach and benthic invertebrates. Forestalls beach hardening to maintain habitat. Potential to establish dune vegetation. Carbon emissions from implementation may be significant. Impact to surfing uncertain. Consider where sediment source is blocked by dam | beaches/ dunes |

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| | | Regional Park, other locations as identified in the draft San Francisco Regional Sediment Management Plan | | | | | or otherwise. Apply for both human and wildlife access. Preserves/prolongs beach habitat values, as well as public recreation and access. | |
| 60 | Install beach sediment traps (add good jetties, giant fine mesh nets, sand flume cells) to accumulate sediment where needed. | Cliff-backed beaches, pocket beaches, high erosion beaches. | Long-term or emergency measure | coastal erosion, sediment supply and movement, wave action, wind | Caltrans, Army Corps of Engineers, CCC, State Lands, Sanctuary, landowners/managers | Spatial assessment, feasibility and efficacy studies, permits. Take into account wildlife impacts. | Wave energy generation. Artificial habitat created on structures. | beaches/ dunes |
| 61 | Restrict livestock access to cliff top, including rotational grazing plans. | Hwy 1 north of Jenner; Sonoma and Marin Counties | Immediate | coastal erosion, sea level rise, land use change | NPS, TNC, local counties and land trusts, private land owners | Agreement with ranchers, resource conservation districts | | cliffs |
| 62 | Evaluate and remove or modify barriers to riverine flow and sediment supply (dams, bridges, culverts, and flood-control gates) to allow for greater sediment transport to beaches and estuaries. | Throughout region, including dams on rivers draining to SF Bay, water district dams - Lagunitas Creek, Russian River, Gualala, Walker Creek. Focus upstream of sediment-starved estuaries and beaches. | Near to long-term | sediment supply and movement, precipitation, overwater/underwater structures, sea level rise, coastal erosion | Army Corps of Engineers, BLM, Resource Conservation District, Bureau of Reclamation, DWR, Coastal Commission, watershed organizations and water districts, partnerships with dam managers. | Funding, support from upstream/downstream communities, will require impact studies | Restores natural sediment regimes to help with accretion; helps hydrology and water movement; promotes healthy function; improves beach access; possible trade-off in current discharge rates; possible tie-in to salmon access. Potential negative impacts of dam removal: shifts in open water habitat, water supply and storage, hydrological regime (increased water and uncontrolled flooding), contaminant loads, upstream habitat, recreational access, change in timing of availability of water. | beaches/ dunes and estuaries |
| 63 | Engineer marshlands to enhance water flow and balance sediment transport. Activities could include sinuous channelization. | Apply to restoration projects; flood-prone estuaries; sediment-heavy estuaries; archaeological sites/past development sites (i.e., where erosion may be an issue) | Long-term | sediment supply, sea level rise, oxygen, temperature | Local counties, ranches, Resource Conservation District, NMFS (salmonids), CDFW (fairy shrimp) | Planning, coordination, and knowledge: channelization has been done at Giacomini - could use similar resources. CCC permit or federal consistency review. | Pollutant mobilization (e.g., mercury - Walker Creek), short-term impacts to existing species/vegetation with habitat modification. May moderate temperature which may help mitigate algal blooms. | estuaries |
| 64 | If a barrier is required to protect human infrastructure, determine the most beneficial material to use and the best design to encourage rocky intertidal species to colonize and/or migrate landward. This is not a recommendation to create new barriers, and should only be implemented where totally necessary, or the barrier is already in place and opportunities exist to refashion the barrier / infrastructure in a way that promotes a simultaneous habitat use with the barrier. | Only in locations where a barrier is necessary. | Long-term | armoring, coastal erosion, wave action, sea level rise | CCC and local counties and cities, academic institutions, Army Corps of Engineers | Resources to identify best design to use for armoring, working with CCC to allow for different armoring materials and designs. Working with local universities on engineering. | Potential interactions with nearby beaches with sediment movement based on oceanographic conditions. The littoral zone – doing work on sediment movement in San Mateo/SC counties. | rocky intertidal |

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| 65 | Protect cliffs from erosion to protect rocky intertidal habitat from smothering (see cliff protection strategies: 8, 9, 11, 12, 14-16, 20, 22, 25-29, 33, 35, 39, 46, 54, 61,69). | | | | | | | rocky intertidal |

**Limit Human Disturbance**: strategies that restrict or reduce access to sensitive habitats to limit disturbance and enhance resilience

| Ref # | Strategic Management Action | Spatial or site-specific details | Time-frame | Stressor(s) addressed | Key Partners | Required Resources | Notes | Habitat |
|---|---|---|---|---|---|---|---|---|
| 66 | Prepare for increased beach use in the event that climate change results in dryer, sunnier weather, including managing traffic, litter, visitor services, etc. | throughout region | Near-term | recreation, temperature, coastal erosion, sea level rise | State Parks, NPS, State and County Departments of Public Health, volunteer groups (such as Save Our Shores, Pacifica Beach Coalition) | Organize volunteers for beach clean-ups, funding. | Build new infrastructure (e.g. bathrooms) to accommodate more visitors. Increase schedule of litter clean up. | beaches/ dunes |
| 67 | Manage pet beach experience/access (leashes, locations) | Known haul out, nesting and restoration sites, shorebird wintering sites | Near-term | recreation, temperature, coastal erosion | State Parks, NPS, BLM, County Parks, Municipal Parks | Increased signage and enforcement, CCC permit or federal consistency review. | | beaches/ dunes |
| 68 | Manage or control density and distribution of beach users if beaches become too impacted by high visitation, while respecting the public's right to access the coast. | Highly visited beaches. | Near-term | recreation, temperature, coastal erosion, sea level rise | State Parks, NPS, BLM, County Parks, Municipal Parks, CCC (permit conditions or LCPs) | Funding, staffing, consider reservation system (see Point Lobos example), signage, outreach, enforcement, CCC permit or federal consistency review. | Seasonal closures may be more effective and efficient. | beaches/ dunes |

**Promote Landward Migration**: strategies that enhance the ability for habitat to migrate landward in response to sea level rise (SLR) and storms

| Ref # | Strategic Management Action | Spatial or site-specific details | Time-frame | Stressor(s) addressed | Key Partners | Required Resources | Notes | Habitat |
|---|---|---|---|---|---|---|---|---|
| 69 | Provide incentives for people to voluntarily relocate in areas that were, or could be, sensitive habitat, or where development reduces habitat resilience:<br>- Incentivize managed retreat if space is available<br>- Initiate and practice land trading (e.g., trade less valuable park land for private land that is vulnerable to flooding and that currently blocks habitat migration)<br>- Purchase land, when possible, to facilitate habitat migration | Areas where habitats are impaired and can't migrate, infrastructure is projected to be inundated anyway, and/or areas where barrier removal would improve habitat function or resilience. | Near-term: land acquisition Long-term: land trading, but start laying policy foundation now | sea level rise, coastal erosion, precipitation | Agencies that own or abut land, land owners, NPS, Army Corps of Engineers, local cities, counties and land trusts, Resource Conservation Districts | Funding via joint venture with many groups, maybe insurance companies. Will need tradeable land. Policy changes may be required (e.g., congressional change to allow trading of NPS lands). Education and outreach will be critical to gain public support; utilize regional modeling to show current land owners why moving is the smartest financial decision. If needed, explore and investigate opportunities for how this has been accomplished elsewhere and confer with groups with expertise in this realm. Golden Gate and Point Reyes (NPS) have already acquired estuary-adjacent parcels that have come up for sale (NPS has a lands acquisition program). | Removes structures that are going to be destroyed by flooding and/or structures that could fall into the Sanctuary. Provides habitat/room for estuaries to expand. Land trading may affect other terrestrial habitats (i.e., may allow for construction in new areas). Can combine with removing non-functional infrastructure (e.g., eliminate old berms and flood levees). Will likely face public opposition, but there are long-term benefits to human community: structures will eventually be destroyed by flooding, cheaper to move the infrastructure now. | all |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 70 | Create a Transfer of Development Rights program in areas needing protection to reflect changing coastal conditions. In hazard areas or sensitive habitat areas that will be threatened by SLR over time, transfer development rights from vacant lots not suitable for development to other locations in the jurisdiction | | Mid-term | coastal erosion, sea level rise, wave action | CCC, local cities and counties | | LCP policies and permit conditions are potential ways to implement this management action | beaches/ dunes |
| 71 | Work with County general plans and coastal zone LCPs to consider development in anticipation of sea level rise. | | Mid to long-term | coastal erosion, sea level rise, wave action, roads/armoring | CCC, local cities and counties | Could be accomplished with a state level statute | | beaches/ dunes |

**Invest in Science Needs**: strategies that call for increased research to inform management

| Ref # | Strategic Management Action | Spatial or site-specific details | Time-frame | Stressor(s) addressed | Key Partners | Required Resources | Notes | Habitat |
|---|---|---|---|---|---|---|---|---|
| 72 | Promote estuarine research to enhance eelgrass restoration efforts. Major research questions may include:<br>- Eelgrass distribution: why is there no eelgrass in Bolinas and Pescadero?<br>- Do salinity and turbidity affect eelgrass establishment and persistence? | Study region | Near-term | salinity, turbidity, pH, temperature | Sanctuary, academic institutions, oyster companies | Knowledge: look at case studies from San Diego area, east coast and Gulf coast, San Francisco Bay research, Drakes Estero research to document recovery by CDFW. | Helps inform eelgrass restoration efforts, which enhances estuary habitat, and may enhance regional carbon sequestration efforts. Economic benefits (oyster farming) | estuaries |
| 73 | Pursue and encourage research in OA-mitigation methods including the restoration and expansion of photosynthesizers (kelp, surfgrass) to locally mitigate the impacts of OA and sequester carbon). Sanctuary should seek partnerships with technical experts who wish to establish experimental treatment plots to test these mitigation techniques. | Establish experimental treatment plots that test the effectiveness of management measures based on scientific expertise | Near-term | pH | Sanctuary (support from CDFW, State Parks, NPS, BLM, local counties) | Sea Grant funding to research institutions, CCC approval and permits for test plots. | Strategy would likely stabilize species populations, and facilitate habitat creation for new assemblages of intertidal communities whose species are shifting their range as the result of climate change impacts. | rocky intertidal |
| 74 | Better understand climate impacts on larval dispersal to ensure that larval source locations are effectively protected within the MPA system and are able to reach various intertidal areas (inside and outside MPAs). Investigate larval dispersal of key species and how this relates to distances among MPAs. Also consider important areas that are not currently designated MPAs. | All MPAs in the study region and additional important rocky intertidal areas. | Near-term | currents/mixing | CDFW in partnership with researchers and OST. | | Strategy would address decreased larval density due to increased turbulence of the water column (reduced survival) and increased offshore advection of larvae due to increased wind. | rocky intertidal |

**Protect Species**: strategies that directly protect species rather than habitats

| Ref # | Strategic Management Action | Spatial or site-specific details | Time-frame | Stressor(s) addressed | Key Partners | Required Resources | Notes | Habitat |
|---|---|---|---|---|---|---|---|---|
| 75 | Augment haul-out and nesting sites: floating haul outs, larger buoys, artificial offshore floating structures | Study region | Near to mid-term | coastal erosion, sea level rise | USFWS, NMFS, USCG, Sanctuary, NPS, State Parks, County Parks, CDFW, Boating and Waterways, Marine Mammal Center | California Coastal Commission permitting | Possible benefit - wave energy generation | beaches/ dunes |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 76 | Support animal rescue and rehabilitation services. | Study region | Near-term | temperature, precipitation | Marine Mammal Center, NOAA MMPA , USFWS, USGS Western Ecological Research Center, MBARI, Point Blue, NPS. | | | beaches/ dunes |
| 77 | Incorporate climate change into fisheries management to address the impact of ocean acidification and climate stressors. Exact strategy would depend on how specific species are being impacted. Monitoring to track impacts and effectiveness of regulations will be needed. | Extend protection from harvest in the rocky intertidal to the mean high-tide line next to marine protected areas (state and fed) where feasible. Maintain seamless consistency in degree of protection/mgmt. | Near-term – actions already in place | pH, harvest | NMFS, CDFW, State Parks and County Parks, NPS. | Increased monitoring of harvested OA-sensitive species (mussels, abalone) with triggers or thresholds. Increased funds for CDFW wardens and Parks Rangers to patrol and check permits. Requires public education and cooperation – outreach and stewardship. Monitoring teams to detect effectiveness of regulations (tie-in with Ocean Science and Marine Reserve System monitoring) | Would provide greater benefit to rocky intertidal community by increasing/maintaining biomass of species and surface roughness (maintaining functional habitat). | rocky intertidal |

## **Manage Water Quality**: strategies that improve water quality to enhance habitat resilience

| Ref # | Strategic Management Action | Spatial or site-specific details | Time-frame | Stressor(s) addressed | Key Partners | Required Resources | Notes | Habitat |
|---|---|---|---|---|---|---|---|---|
| 78 | Manage for flash flood and high flow events that might adversely affect existing and new vegetation by increasing absorption and decreasing runoff. Strategies may include: improve culverts, pumps, tide gates, bridges, stream management, increased use of permeable pavement and increased absorption opportunity, all communities require rain barrels. | Locations prone to flooding: Stinson Beach, Muir Beach, Lagunitas Creek, Hwy 1 in many locations | Near to mid-term | precipitation, coastal erosion | Caltrans, local cities and counties, Flood control districts, FEMA, California Office of Emergency Services, CCC (in permit conditions or LCPs), NPS | flood maps, money, community will | Sediment deposition, salmon habitat impacts from flood control actions. | beaches/ dunes |

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## Appendix A. Climate Scenario Summaries

The climate scenario summaries are based on best professional judgement and assessment of potential future conditions in the region. These summaries were developed as a tool for working group members in this planning process and are not meant to advise or guide future planning efforts.

**Scenario Summary**

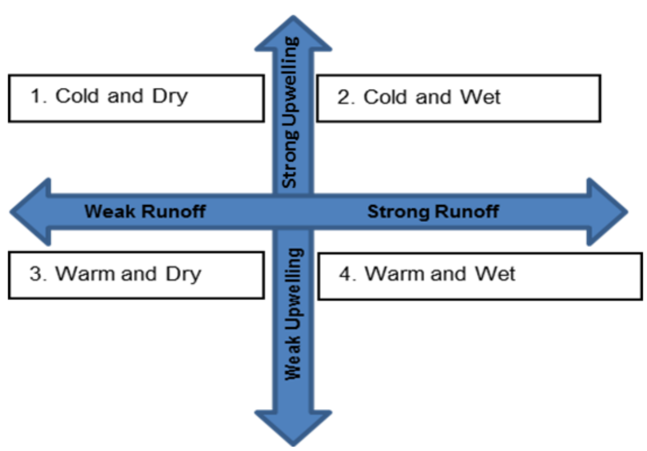
Working with the assumption that sea level is rising (as there is no realistic scenario of falling sea level) and that oceans are becoming more acidic, this leads to a set of four scenarios based on whether upwelling increases or decreases and whether freshwater runoff from land increases or decreases. There is high uncertainty about changes in the upwelling and runoff scenarios and also these two seasonal phenomena are foundational factors accounting for the character and changes in California marine environments. The future may bring colder or warmer spring/summer/fall waters depending on upwelling and it may bring either wetter or drier winters.

**Scenario Drivers**

Runoff: Runoff is a general term referring to the impacts of flooding that occur with storms of greater magnitude and/or higher frequency than occur currently. With increasing precipitation we expect to see greater runoff from rivers and storm drains into coastal waters. Additionally, we expect higher waves and southerly winds that are consistent with high precipitation storms that could increase coastal flooding.

Upwelling: Changes in the frequency or intensity of north winds are expected to have impacts on upwelling patterns. North winds drive upwelling of cold enriched waters and thus control exposure to low pH, low dissolved oxygen (DO) and high nitrate concentration; also rough spring/summer seas, cold air temperatures, and fog are associated with upwelling.

Sea level: Increases in sea level are expected to change the extent and distribution of intertidal habitats. Sea level rise (SLR) combines with waves and winds to increase coastal flooding and erosion.




Ocean acidification (OA): Changes in carbon dioxide levels in the ocean from atmospheric sources are expected to lead to changes in the acidification of the ocean waters. Changes in ocean pH may be regionally/locally mitigated or enhanced by changes in upwelling, runoff and organic/nutrient loading of runoff.

Upwelling/ sea level rise interaction:
Increased upwelling (north winds) and decreased winter storms (south winds) both result in lower sea levels. North winds lower sea level by up to 20-30cm and absence of south winds is absence of setup by 30-50cm; therefore, SLR is mitigated in both seasons. Decreased upwelling results in higher sea levels in spring/summer and increased south winds results in higher sea levels in winter, so SLR is enhanced in both seasons. In both cases, during big wave events, the sea level can be held up by another 30cm, which would lead to more inundation. Greatest impacts will be observed at spring tide, but tides should change negligibly with climate change.

**Detailed Scenario Descriptions**

**1) Cold and Dry** (weaker runoff with drier winters, stronger upwelling with colder summers)

Scenario narrative
Strong north winds in spring and summer drive upwelling, with high nutrient flux to the euphotic zone supporting productive bays and coastal waters – with increased upwelling, phytoplankton blooms will occur farther offshore in open coastal waters due to offshore transport, leaving nearshore systems less productive with impacts on birds, whales and out-migrating salmon. But waters that are entrained and retained in bays will fuel enhanced productivity in sheltered waters and fixed kelp forests will do better with more nutrients and more light (no shading by phytoplankton), supporting the communities that feed in these habitats. Stronger upwelling will bring low oxygen/high $CO_2$ water from greater depths, which will enhance the OA trend, thus impacting many bivalve larvae/juveniles, larval fish, and some zooplankton. Hypoxic events on the shelf will be more frequent and more severe, leading to benthic mortality (e.g., Dungeness crab). Cold and windy coasts through summer will impact fishing (most recreational and some commercial boats won't go out for salmon) and may impact tourism (due to cold/unpleasant conditions). However, the cool conditions may provide refuge from inland heat leading to increased tourism from inland areas. More fog in summer because of temperature differential between coastal cool waters and inland heat. Fog will be persistent and coastal areas will benefit from reduced heat and precipitation.

In winter, runoff is weaker than previously and occurs in a shorter season. The flushing of estuaries and bays does not occur (some small bar-built estuaries stay closed all winter, trending towards coastal lakes/marshes), allowing for buildup of organic material and increasing hypoxic events (e.g., Pescadero Lagoon). The absence of large plumes from San Francisco Bay and Russian River associated with rain and snow melt deplete the mud belts on the shelf and benthic communities are impacted. Without winter south winds and freshwater plumes, there is a reduction in northward currents and larval dispersal patterns change with loss of some coastal species due to southward "washout" – this is aggravated by stronger northerly winds and southward transport during upwelling. An absence of plumes and little stratification in the Gulf of the Farallones results in deep mixing, which limits light for primary production. In the absence of winter storms, upwelling occurs earlier in spring, leading to more productivity in spring and summer (winter primes summer). Also many people will enjoy fishing (crabs) and recreation (beaching, kayaking, etc.) – the mild sunny days in winter along the coast will become well known and draw in many seasonal visitors for beaching and boating. In summer, more foggy days may result in reduced number of people at beaches. With reduced southerly storm waves in winter and increased northerly waves during upwelling, accelerated erosion of north-facing beaches may occur. Though coastal retreat is generally anticipated across scenarios due to SLR, south-facing beaches in this scenario may experience less erosion relative to the other scenarios.

Habitat Impacts

Beaches and dunes:

- Reduced tourism in summer due to cold and fog may have economic impacts on communities; however, more tourists from the Central Valley may escape the heat on the coast perhaps offsetting tourism losses due to poor weather. Even so, drier, mild conditions early in winter/spring will offer good conditions.
- Erosion of north facing beaches and decreased erosion of south facing beaches. Much of the study area open coast is generally south facing, so in general this change could lead to decreased beach erosion, relative to the other scenarios.
- In south-facing dune systems, dune wetlands may receive reduced winter rain and undergo fewer dune blowouts/wave overtopping due to decreased erosion.
- North facing dune systems may suffer increased erosion.
- Rough summer conditions may lead to increased rescues of abalone divers, kayakers and other vessels.

Outer coast estuaries:

- Potentially severe impacts to salmonids from prolonged closure of creek mouths, less freshwater input, low lagoon water levels, and reduced nearshore productivity. However, reduced winter storms may be beneficial to salmonids because fewer juveniles will be washed out early due to lack of winter refugia.
- Increased OA will impact many invertebrate and fish populations, commercial oyster growers, sport and commercial crab fishery, and potentially other key species at the base of the food web.
- Reduced sediment transport from coastal watersheds could decrease the total area of mudflat habitat within the study region.

Rocky intertidal:

- Increased OA will impact many invertebrate and fish populations, commercial oyster growers, sport and commercial crab fishery, and potentially key species at the base of the food web.
- Rough summer conditions increase emergency rescues of abalone divers.
- Nearshore algae, cyanobacteria, and vascular marine plants (surfgrass) might benefit from the increased $HCO_2$ (acidic) environment. OA effects on seagrasses and marine macroalgae. Prevalence of surfgrasses influence tide pool temperatures and promote diversity of native invertebrate species. Temperature and community consequences of the loss of foundation species: surfgrass (*Phyllospadix* spp. Hooker) in tidepools.

**2) Cold and Wet** (increased runoff with wetter winters, stronger upwelling with foggier summers)

Scenario Narrative

Beaches and cliffs erode during winter storms, but without rebuilding through deposition during summer due to local high-frequency waves. In the winter, strong winds associated with cold fronts are more frequent. These storms bring increased runoff from local watersheds and the San Francisco Bay and delta (Bay). Relatively warmer winters with less snow in the Sierras increases winter runoff from the Bay and an earlier, more even plume of winter rainwater from the Bay and other coastal rivers.

Strong north winds in spring and summer drive upwelling, with high nutrient fluxes supporting productive bays and sheltered coastal waters – but in open shelf waters phytoplankton blooms occur farther offshore due to offshore transport, leaving nearshore systems less productive with impact on birds, whales and out-migrating salmon. But fixed kelp does well, as does the community that feeds on it. Cold and windy coasts through summer impact fishing and tourism.

Due to high runoff, the seasonal timing of the transition to upwelling doesn't change much from current conditions. Increased freshwater from winter runoff leads to lower salinity in bays and along the outer coast where freshwater plumes extend. Ocean water is drawn into bays and brings high-nutrient/relatively hypoxic/OA effects into bays. Higher winds and large storms in winter lead to greater movement of sand on beaches and dunes. In the winter, winds associated with storms tend to be from the south potentially facilitating northern transport of planktonic species. Winter outflow from the Bay will travel as far north as Point Arena leading to a decrease in salinity within the region, particularly. Small creek mouths in coastal watersheds will stay open longer in the summer, facilitating the movement of nutrients and biogenic material to nearshore environments but also potentially contaminants.

Because of greater frequencies of storms, there is a greater chance that storms will occur during extreme high tides (king tides) increasing the likelihood of coastal flooding. Coastal erosion, particularly on coastal cliffs, barrier beaches (Stinson Beach), and estuaries will increase which will increase turbidity of nearshore waters.

<u>Habitat Impacts</u>

Beaches and dunes:

- Nearshore productivity will decrease, limiting success of some nesting seabirds and other nearshore species.
- Despite increases in offshore primary productivity, birds, seals, and other beach species may not benefit and be under stress: increased erosion from storms will reduce current shoreline habitat for roosting and breeding. As storm wave directions change to the south, southward facing beaches may be more affected.
- Increased erosion of coastal cliff areas – public hazards. Potential temporary loss of pocket beaches along the cliff backed coast. Depending on cliff composition, pocket beaches may reform over time.
- Back-beach and inland flood occurrences will increase, altering habitats, vegetation, and adjacent coastal infrastructure more frequently.
    - Possible benefits to species like tidewater goby.
    - Back dune ponds form during wet winter events which may benefit species such as winter waterbirds and shorebirds.
    - Flood waters may mobilize and spread pollutants and HABs more widely.
- Sunny beach days throughout the year will not be as prevalent, and public-use space on the coast will decrease, displacing recreation impacts to recreation areas further inland.

Outer coast estuaries:

- Lower salinity may affect the success of some estuarine species such as eelgrass and *Gracilaria* algae.
- Seasonal decreases in primary productivity in some areas (Bay) reduces success of many species - alters food web.
- Increased access for salmonids in streams and sustained waters in streams carries over into summer. Pacific Herring benefit from increased freshwater runoff and suffer during drought conditions.
- May get increase of hypoxic events due to increased nutrients/deep-water intrusion – however, increased storms and runoff – hypoxic events may be more localized and dependent on circulation.
- Increased flooding will put stress on vegetation/marshes and their habitat specialists (e.g., Black Rail, Ridgeway's Rail) and infrastructure.

Rocky intertidal:

- Rocky intertidal may see decrease in primary productivity with impact to many species and ecosystems in those areas.
- Possible benefit from cool, foggy summers that prevent desiccation.
- Increases in mixing and currents from storms may increase invasive species.
- Increased storms damage/remove kelp-forest canopies: changes to kelp-dependent food webs and removal of some habitats.
- Increases in flooding/waves may put pressure on sessile species.
- Increased freshwater in tide pools may negatively affect surfgrass.
- Increased erosion of adjacent cliff areas – public hazards and burying of habitat.

General/regional impacts:

- Sport fishing may increase in offshore areas due to increases productivity leading to more boat traffic in general.
- U.S. Coast Guard use increases (accidents, spills, illegal activities).
- Fisheries management - may need to review and update limits/permits -- different approaches between nearshore/Bay and offshore fisheries.
- Surfing conditions improve in winter - but conditions also get more hazardous.
- Overall decrease in summer-time beach tourism due to fog - impacts to local communities' economies, utilities use.
    - Alternatively, residents of the Central Valley seeking heat relief may flock to coastal areas.
    - Local chambers of commerce/businesses may promote off-season tourism/other attractions.

**3) Warm and Dry** (less runoff with drier winters, weaker upwelling with warmer summers)

Scenario Narrative

The decrease of winds will cause less upwelling leading to fewer nutrients and less primary production. However, there will be less movement of nutrients offshore than in the high upwelling scenarios. So offshore productivity declines while the productivity in nearshore systems increases. Decreased offshore primary productivity is likely to lead to a decrease in reproductive success for seabirds. The higher acidity waters that are brought to the surface are processed quickly so less of an increase in acidity. Sea surface temperatures will be warmer than historically. We will see a decrease in localized hypoxic events, but HABs may be more prevalent inshore.

Less runoff means less stratification in nearshore and smaller inputs of biogenic materials and contaminants. Less runoff leads to higher salinity particularly in estuaries. Creek mouths will be closed longer potentially reducing water quality in those creeks and their lagoons. Fewer storm events leads to more offshore stratification because there is less mixing.

Habitat Impacts

Beaches and dunes:

- Greater build-up of beaches with fewer winter storms and less windy days.
- Increased public use of beach.

Outer coast estuaries:

- Salinity levels may rise due to less water exchange as well as less freshwater input.
  - May affect growth and survival of organisms.
- Likely seasonal decreases in dissolved oxygen due to increasing sea surface temperature (SST) and salinity levels leading to pockets of hypoxia.
  - Hypoxic events to increase due to creek mouth closures.
- Creek mouth closures - decrease in water quality conditions and stagnation.
- Harmful algal blooms may be more prevalent in estuaries because of stagnation and warmer water. Also, potential for dieoff of water birds due to botulism.
- Pacific Herring and salmonid productivity declines due to less runoff of freshwater and mixing of estuaries.

Rocky intertidal:

- Warmer SST, decrease in winds, and less fog likely to increase thermal stress on rocky intertidal.
- Tidepools likely to suffer greater number of days with increased temperature, both mobile and sessile organisms will be subject to thermal stress.
  - Will affect larval and early stages of some subtidal/pelagic fish that recruit to intertidal.
- Disease transmission and toxic algal blooms likely to impact rocky intertidal communities/species more intensively.
- Invasive species - a decrease in winds and water movement may inhibit species migration, however, warmer SST may allow for introduction of new species or expanded range of existing non-natives.
- Decrease in upwelling and wind movement is likely to affect recruitment to rocky intertidal although this may vary spatially.
  - Likely to also affect food web (predator size and abundance both decrease).

**4) Warm and Wet** (stronger runoff with wetter winters, weaker upwelling with warmer summers)

<u>Scenario Narrative</u>
Strong runoff due to increased winter storms leads to an increase in biogenic material into coastal waters. Decreases in upwelling results in less offshore transport, lower offshore productivity and higher pelagic productivity. However, if inputs (biogenic material and inorganic nutrients from terrestrial runoff) are extremely high, hypoxia below plumes could increase, leading to the emergence of dead zones near plumes. Stratification will increase during winter months with increasing runoff events; however, this will also be disrupted by large storm events that will mix waters with large wind waves. Higher runoff will lead to lower salinity, particularly in estuaries. Outside of the rainy season stratification decreases. Sea surface temperatures will be warmer year-round.

Southern winds during winter storms will facilitate northern transport. The lower spring and summer northern winds may result in a longer period during which northern transport is facilitated. Spring transition period may be delayed due to lower spring northern winds causing a mismatch for food webs. Coastal erosion and flooding are likely in winter months due to wet winters. Water quality in pelagic areas decreases with increased turbidity and increases locally in toxic contaminants.

<u>Late Fall/Winter:</u>

- Coastal areas experience periods of intensified storm activity, particularly from the south and south-west, with at least some activity due to the type of atmospheric "river" known as "the pineapple express."
- Boosted rainfall increases inland erosion, flooding, and runoff, and larger waves and swells driven by strong southern and southwest winds increase disturbance along the coast, particularly on south- and southwest-facing coastlines.
- Freshwater runoff increases the amount of biogenic and contaminant material transported from land into the estuaries and nearshore habitats and can generate plumes of silty, less salty water that stretches for miles from river mouths. During storms and under windy conditions, the plumes mix with ocean waters resulting in increases in turbidity, and concentrated nutrients and contaminants in coastal and offshore waters.
- Increased nutrients fuel water column and benthic environments, although turbid waters limit photosynthetic activity.
- In between storms, the plumes and adjacent ocean waters can experience warming with less mixing and may eventually stratify, resulting in localized plankton blooms in upper waters and hypoxic conditions in deeper waters.
- Strong southern and southwest winds, as well as freshwater runoff, will accentuate northern currents, resulting in a dominance of northward transport. Southern and

southwest winds, as well as large storm waves, can increase sea level, leading to more inundation of coastal areas and alteration of immersion times of rocky intertidal zones.

Spring/Summer/Early Fall:

- Coastal areas experience warm stratified waters and light winds but there is an increased potential for more southern moisture and tropical storm influence (note increased thunderstorm activity during the summer of 2015 and "atmospheric river-like" extension from Hurricane Guillermo on August 4th and 5th 2015).
- The decrease in northerly winds means less upwelling in spring and summer with the upwelled water being warmer and containing fewer nutrients. Declines in upwelling leads to lower productivity, particularly within offshore waters. If winds die down and upwelled waters become stratified, then localized plankton blooms can occur.
- Since the upwelled water is from shallower depths, the increases in ocean acidity and decreases in dissolved oxygen are not as substantial as those associated with deeper upwelled waters; as a consequence, pulses of increased acidic water are less common and hypoxic events on the shelf are rare.
- Reduced upwelling also results in higher sea levels in spring and summer, which enhances the levels seen during spring tides and the increases associated with climate change.
- The number of foggy days also may be reduced with fog burning off more quickly.
- The hotter days in non-coastal areas and the calm conditions along the coast bring more visitors to the area to visit the beaches and rocky intertidal areas, explore and enjoy the nearshore coastal waters, or go fishing for southern species that are becoming more common (including pelagic species such as tunas and nearshore species such as California barracuda).

Multiple Year: Several climate oscillations will likely amplify or dampen the effect of this scenario. The Pacific Decadal Oscillation (PDO) fluctuates between a warm and cool phase, each of which may persist over several decades, with its primary signature most evident in the North Pacific. The El Nino/Southern Oscillation also has a warm (El Niño) and cool (La Niña) state that typically persist 6-18 months, with its primary signature most evident in the Pacific Ocean tropics. During a PDO warm phase with a strong El Niño event, the conditions described above could be amplified while conditions could be dampened during a PDO cold phase with a strong La Niña event.

Habitat Impacts

Beaches and dunes:

- Due to the predominant southern winds, south-facing beaches will be impacted more by storm swells and waves and will tend to have less sand than northern beaches.

- Likewise, dunes along south facing coastal shores will be impacted more by storm waves and winds than those along north facing coastal shores.
- Coastal strand width will be reduced due to increased sea level from both southern winds and decreased upwelling (in addition to sea level rise from climate change), particularly during winter storms and spring tides.
- Wrack on beaches (from terrestrial sources, sea grasses, and drift algae) will increase during winter, decrease during summer.
- Due to high disturbance in winter, reduced wrack in summer, and reduced plankton productivity in spring/summer, beach productivity likely will be reduced which could impact shore bird populations.
- Beaches may be periodically closed during winter due to increased contaminants from rivers.

Outer coast estuaries:

- Increased mixing within estuaries during winter months could result from increased freshwater flows due to higher runoff, increased saltwater flows due to larger swells and waves plus enhanced sea levels, and increased winds, tidal mixing, and density gradients.
- Large runoff events will move sediments and woody debris into the estuaries.
- Large runoff events will widen channels between the estuaries and the ocean, and will scour out estuaries, moving sediments from the estuaries into the ocean.
- Scouring may also impact important estuarine habitats such as eel grass beds.
- Increased sea level from both southern winds and decreased upwelling (in addition to sea level rise from climate change) will inundate estuarine habitats, particularly during winter storms and spring tides.
- Decreased mixing (and increased stratification) within estuaries during summer and early fall months could result from decreased freshwater flows (warmer storms = less snow pack) and calm water conditions offshore (less ocean flow into the estuaries) although sea levels will be enhanced.

Rocky intertidal:

- During winter months, rocky intertidal areas along southern shores will be disturbed more by large storm swell and waves than those along northern shores (since most storms will be from the south or south-west). On other hand, the areas along northern shores could more likely be buried by sand than those along southern shores.
- During winter months, rocky intertidal areas close to estuary mouths will likely experience lower salinity, more turbid waters for longer periods of time. There is also the potential for increased exposure to contaminants transported from terrestrial sources.
- Increased sea level from both southern winds and decreased upwelling (in addition to sea level rise), particularly during winter storms and spring tides, will expose some rocky

intertidal habitats to longer periods of submersion, and will likely submerge, on a more frequent basis, high intertidal habitats that rarely experience any inundation.

- Warm, less productive waters mean less food for rocky intertidal filter feeders. Localized plankton blooms resulting from nutrient –enhanced waters that become stratified (e.g. upwelled waters in spring and summer, or increased nutrient concentrations from runoff) may occur, but also may contain high concentrations of harmful algal species. The toxins from these planktonic algae accumulate up the food chain and can be lethal to top predators such as birds and mammals.
- Increased exposure to warmer air temperatures and potentially drier air conditions (from reduced presence of fog) during low tides, and warmer ocean temperatures during high tides could impact species populations and community structure.
- Water temperatures in tide pools might rise – causing a shift in species composition. Also, drier coastal conditions might increase the frequency of fires along the coast. Then, in the subsequent rainy winter, erosion transport could bring increased nutrients, carbon, and debris into the rocky intertidal (and estuarine) zones.
- Calm, warm conditions may result in more human activity along the coastal zone and thus more disturbances to the rocky intertidal habitats.

Nearshore:

- Reduction of offshore marine water productivity results in decreased forage populations which impact sea bird production and juvenile marine mammal survival.
- Warm, stratified waters with fewer nutrients in the summer and larger swells and waves from southern storms in the winter reduce kelp biomass and impact kelp-associated communities. Warm, less productive waters also mean less food for nearshore filter feeders. Localized plankton blooms resulting from nutrient enhanced waters that become stratified (e.g. upwelled waters in spring and summer, or increased nutrient concentrations from runoff) may occur, but also may contain high concentrations of harmful algal species. The toxins from these planktonic algae accumulate up the food chain and can be lethal to top predators such as birds and mammals.
- With warmer waters and a dominance of northward transport, southern species become more common. Species that reproduce better in cooler waters (e.g. certain species of rockfish) become less common.
- Calm, warm conditions lead to more fishing within nearshore waters.

## Appendix B. Commonly used terms and acronyms

*Bioswales* - stormwater runoff conveyance systems that provide an alternative to storm sewers. They can absorb low flows or carry runoff from heavy rains to storm sewer inlets or directly to surface waters. Bioswales improve water quality by infiltrating the first flush of storm water runoff and filtering the large storm flows they convey[1].

*Climate-smart* - The intentional and deliberate consideration of climate change in natural resource management, realized through adopting forward-looking goals and explicitly linking strategies to key climate impacts and vulnerabilities[2].

*Ecosystem service* – any positive benefit that wildlife or ecosystems provide to people.

*Grey infrastructure* – manmade, engineered components of a system, including (but not limited to) seawalls, riprap, roads, levees, culverts.

*Horizontal Levee* – a term coined by The Bay Institute, this refers to a novel levee concept that uses vegetation on a gradual slope to protect from storm surge and waves instead of a vertical wall. It incorporates a brackish marsh that functions as a self-maintaining levee, building in elevation as plant root systems expand. It accelerates vertical growth of the marsh plain in order to keep pace with sea level rise[3].

*Introduced species* – a species (including any of its biological material capable of propagation) that is non-native to the ecosystem(s) protected by the sanctuary; or any organisms into which genetic matter from another species has been transferred in order that the host organism acquires the genetic traits of the transferred genes[4].

*Invasive species* – a species that is 1) non-native to the ecosystem under consideration and 2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health[5].

*Living shoreline* – a natural alternative to hardened shorelines to protect from erosion and storm surge, living shorelines may include beaches and dunes, oyster reefs, or vegetation.

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[1] Natural Resources Conservation Service: www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_029251.pdf
[2] Stein, B.A., P. Glick, N. Edelson, and A. Staudt (eds.). 2014. Climate-Smart Conservation: Putting Adaptation Principles into Practice. National Wildlife Federation, Washington, D.C.
[3] The Bay Institute. 2013. Analysis of the Costs and Benefits of Using Tidal Marsh Restoration as a Sea Level Rise Adaptation Strategy in San Francisco Bay.
[4] GFNMS Management Plan
[5] Presidential Executive Order 13112 (February 1999)

*LCP* – Local Coastal Program, a planning tool used by local governments to guide development in the coastal zone, in partnership with the Coastal Commission.

*OA* – Ocean Acidification, the process by which uptake of carbon dioxide from the atmosphere causes a decrease in seawater pH.

*Rolling easements* - a legally enforceable expectation that the shore or human access along the shore can migrate inland instead of being squeezed between an advancing sea and a fixed property line or physical structure. The term refers to a broad collection of legal options, many of which do not involve easements. Usually, a rolling easement would be either (a) a law that prohibits shore protection or (b) a property right to ensure that wetlands, beaches, barrier islands, or access along the shore moves inland with the natural retreat of the shore[6].

*TMDL* – total maximum daily load, a regulatory term in the U.S. Clean Water Act, describing a value of the maximum amount of a pollutant that a body of water can receive while still meeting water quality standards.

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[6] Titus, J.G. 2011. Rolling Easements. Climate-ready estuaries program. www.epa.gov/sites/production/files/documents/rollingeasementsprimer.pdf

## Appendix C. Agency Designations

BCDC – Bay Conservation and Development Commission
BLM – Bureau of Land Management
Caltrans – California Department of Transportation
CCC – California Coastal Commission
CDFW – California Department of Fish and Wildlife
Coastal Conservancy – California State Coastal Conservancy
DWR – Department of Water Resources
EPA – Environmental Protection Agency
FEMA – Federal Emergency Management Agency
GGNRA – Golden Gate National Recreation Area
LiMPETS – Long-term Monitoring Program and Experiential Training for Students
MARINe – Multi-Agency Rocky Intertidal Network
MBNMS – Monterey Bay National Marine Sanctuary
NMFS – National Marine Fisheries Service
NOAA – National Oceanic and Atmospheric Administration
NPS – National Park Service
NRCS – Natural Resources Conservation Service
OSPR – Oil Spill Prevention and Response
OST – Ocean Science Trust
Point Blue – Point Blue Conservation Science
PISCO – Partnership for Interdisciplinary Studies of Coastal Oceans
PRNS – Point Reyes National Seashore
RCD – Resource Conservation District
RWQCB – Regional Water Quality Control Board (North Coast and San Francisco Bay)
Sanctuary – Greater Farallones National Marine Sanctuary
SFPUC – San Francisco Public Utilities Commission
State Lands – California State Lands Commission
State Parks – California Department of Parks and Recreation
SWRCB – State Water Resources Control Board
TNC – The Nature Conservancy
UCSC – University of California, Santa Cruz
USCG – United States Coast Guard
USFWS – United States Fish and Wildlife Service

## Appendix D. Strategy List

Attached to this report is a content-protected and sortable excel file of all strategies developed by the Working Group. This file was requested by the Working Group as a means for agencies to sort the strategies by column and search by key word, while retaining protected content. The search and sort properties of this file do not work on Mac computers.

# Appendix F

# POINT BLUE CONSERVATION SCIENCE FINAL REPORT

Point Blue Report

# Natural resource vulnerabilities, potential adaptation strategies, and monitoring framework for Marin County's outer coast sea level rise vulnerability assessment

**January 2017, Final Report**

**Prepared for the Marin County Community Development Agency**

Conservation science for a healthy planet

3820 Cypress Drive, #11 Petaluma, CA 94954

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pointblue.org

# Natural resource vulnerabilities, potential adaptation strategies, and monitoring framework for Marin County's outer coast sea level rise vulnerability assessment

**January 2017, Final Report**

**Point Blue Conservation Science**

M. Hayden, S. Veloz, L. Salas, D. Jongsomjit, N. Nur

**Prepared for the Marin County Community Development Agency**

## Suggested Citation

Point Blue Conservation Science. 2016. Natural resource vulnerabilities, potential adaptation strategies, and monitoring framework for Marin County's outer coast sea level rise vulnerability assessment. Prepared for the Marin County Community Development Agency.

**Point Blue Conservation Science –** Point Blue's 140 staff and seasonal scientists conserve birds, other wildlife, and ecosystems through science, partnerships, and outreach. We have been assessing changes in our environment and advancing conservation since our founding as Point Reyes Bird Observatory in 1965. Visit Point Blue on the web www.pointblue.org.

**Cover photo credit:** Cory Gregory

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## PURPOSE AND SCOPE

This assessment was intended to assist Marin County in identifying site-specific vulnerability of natural resource assets to sea level rise and coastal erosion, to provide nature-based adaptation strategy suggestions to address identified natural resource vulnerabilities, and to provide a framework for monitoring of potential strategies. The goal was to further inform Marin County's sea level rise vulnerability assessment for the outer coast (C-SMART). Our analysis was limited to available geospatial data of mapped natural resource assets and existing modeling of projected hazards including (1) flood extent and depth from the Our Coast, Our Future project, (2) marsh elevation capital projections (projected evolution of estuary habitat) completed by ESA (2015), and (3) beach/cliff erosion projections for select areas also completed by ESA (2015).

Natural resource assets analyzed include:

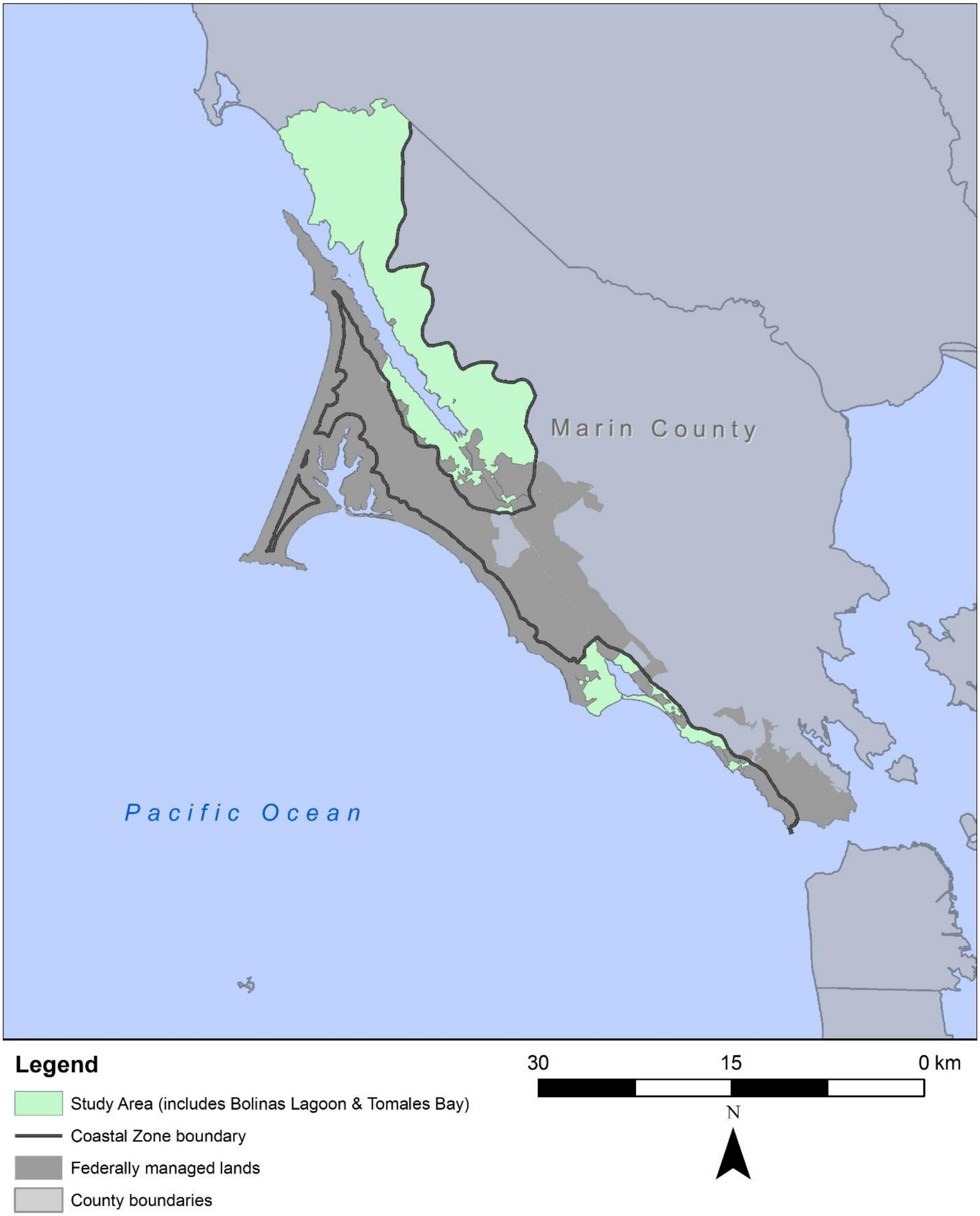
- Habitat - based on land cover from NOAA's Coastal Change Analysis Program
- Terrestrial state- and federally-listed species
- Tidal marsh bird indicator species (response to projected estuary evolution)
- Eelgrass beds
- Mammal haul-outs
- Seabird colonies

If a natural resource asset was not included, this is likely a reflection of lack of appropriate geospatial data and should not be assumed to mean it bears no risk. This is particularly true for aquatic species. For example, no spatial data were available for wild oyster or mussel beds. Certain aquatic species such as fish (i.e., coho salmon, longfin smelt, and tidewater goby) were not assessed given lack of modeling that appropriately reflects projected future habitat shifts.

## STUDY AREA

The study area encompasses non-federal lands within Marin County's Coastal Zone boundary and areas immediately offshore (Figure 1), including Tomales Bay and Bolinas Lagoon. Federal lands were not included because Marin County has no jurisdictional authority. In some cases (e.g., listed species), federal lands were included for context and this is noted accordingly.

**Figure 1**. Study region extent.



## SUMMARY OF VULNERABILITIES

There are three key regions within the study area that have natural resource assets at risk: Dillon Beach, Tomales Bay, and Bolinas Lagoon/Sea Drift. Table 1 presents a summary of the natural resource assets that are particularly at risk, based on our limited analysis. For most assets, the vulnerability will be mediated depending on the availability of upslope accommodation space and the ability of the asset to migrate in pace with sea level rise. For example, Bolinas Lagoon is an important estuary but is topographically confined. The lack of upland accommodation space makes vegetated marsh habitat particularly at risk from sea level rise.

**Table 1.** Summary of key natural resource vulnerabilities.

| **Region** | **Dillon Beach** | **Tomales Bay** | **Bolinas Lagoon/Beach** |
|---|---|---|---|
| **Natural Resource Assets Particularly at Risk** | • Beach/dune habitat<br>• Critical habitat for the endangered Western Snowy Plover<br>• Last remaining natural population of Showy Rancheria Clover | • Eelgrass beds<br>• Two large estuary complexes with associated plants and wildlife<br>• Pinniped haul-out sites | • Vegetated marsh habitat<br>• Pinniped haul-out sites<br>• Western Snowy Plover habitat |
| **Primary Hazards and Vulnerabilities** | • Coastal erosion and/or inundation from sea level rise | • Permanent inundation from sea level rise or changes in wave exposure, with potentially limited upslope accommodation space | • Permanent inundation from sea level rise or changes in wave exposure.<br>• Lagoon is topographically confined so upland accommodation space severely limited<br>• Beach erosion |

# NATURAL RESOURCE VULNERABILITY ASSESSMENT

## Natural land cover

Natural lands within the study area are predominately grassland and other upland vegetation types (Table 2). These upland types are projected to be minimally affected (≤ 1%) by inundation from sea level rise (Table 2), reflecting the steep topography of much of Marin's outer coast. Habitats at the land-water interface (e.g., beaches and coastal wetlands) are most exposed to potential inundation resulting from sea level rise. While the total spatial extent of these habitats is small relative to upland types, they tend to support a disproportionate number of endemic species (e.g., tidewater goby, black rail) and high species diversity (Hutto et al. 2015). The Unconsolidated Shore cover class includes sandy beach-dune habitat at Dillon and Stinson/Seadrift beaches, as well as rocky shoreline between Rocky Point and Slide Ranch. Tidal, higher salinity wetland types (Estuarine cover classes) are concentrated around Bolinas Lagoon and the deltas of Lagunitas and Walker creeks in Tomales Bay. Freshwater (Palustrine) wetland types are concentrated around creeks draining into Bolinas Lagoon and the eastern side of Tomales Bay. Approximately 1/3 of habitats at the land-water interface are projected to be inundated with 200cm of sea level rise (Table 2). The potential site-specific effects of this on key species is discussed in more detail below.

**Table 2.** Total area of natural land classes within the study area, and percent of this total projected to be inundated by various sea level rise scenarios. Source data: 2010 C-CAP land cover and sea level rise flood extent projections from OCOF. Developed and agricultural land cover classes were excluded from analysis.

| Land cover class | Total Area ($km^2$) | Sea Level Rise | | | |
|---|---|---|---|---|---|
| | | 25cm | 50cm | 100cm | 200cm |
| Unconsolidated Shore | 3.3 | 4.8% | 11.1% | 20.0% | 27.9% |
| Estuarine Emergent Wetland | 3.9 | 8.6% | 12.9% | 15.0% | 19.9% |
| Estuarine Scrub/Shrub Wetland | 0.4 | 6.8% | 12.9% | 23.8% | 41.3% |
| Palustrine Emergent Wetland | 3.8 | 5.1% | 10.7% | 17.3% | 38.5% |
| Palustrine Scrub/Shrub Wetland | 1.4 | 5.2% | 8.8% | 16.8% | 32.1% |
| Palustrine Forested Wetland | 0.7 | 0.6% | 2.6% | 6.5% | 12.4% |
| Grassland | 109.0 | 0.0% | 0.2% | 0.4% | 0.8% |
| Scrub/Shrub | 28.8 | 0.1% | 0.3% | 0.6% | 1.1% |
| Deciduous Forest | 4.9 | 0.0% | 0.0% | 0.1% | 0.1% |
| Evergreen Forest | 20.0 | 0.0% | 0.0% | 0.0% | 0.1% |
| Mixed Forest | 9.9 | 0.1% | 0.1% | 0.2% | 0.6% |
| Bare Land | 0.9 | 3.2% | 4.6% | 7.8% | 14.8% |

## Critical habitat for federally listed species

We assessed the potential impact of sea level rise and shoreline erosion on critical habitat for the four terrestrial federally-listed species with designated critical habitat within the study area: western snowy plover (*Charadrius alexandrinus nivosus*), yellow larkspur (*Delphinium luteum*), marbled murrelet (*Brachyramphus marmoratus*), and California red-legged frog (*Rana aurora draytonii*). Critical habitat for federally listed threatened or endangered species is designated by the U.S. Fish and Wildlife Service.

Critical habitat includes "geographic areas occupied by the species at the time it was listed, and contain the physical or biological features that are essential to the conservation of endangered and threatened species and that may need special management or protection. Critical habitat may also include areas that were not occupied by the species at the time of listing but are essential to its conservation" (USFWS 2016). For western snowy plover, we also included information on wintering habitat at Bolinas Lagoon/Seadrift Beach from shorebird monitoring conducted by Point Blue (L. Stenzel, pers. comm).

To assess potential exposure of critical habitat to inundation resulting from sea level rise, we overlaid vector shapefiles of critical habitat with sea level rise flood extent projections from the OCOF project. We assessed 25, 50, 100, and 200cm sea level rise scenarios, then calculated the total cumulative (i.e., highest SLR includes any lower SLR) percent area flooded for each scenario. We excluded critical habitat areas currently prone to flooding (baseline) using the 0cm sea level rise scenario from OCOF.

To assess potential exposure of critical habitat to shoreline erosion, we overlaid vector shapefiles of critical habitat with vector shapefiles of shore erosion hazard zones developed by Environmental Science Associates (ESA). These zones represent the potential extent of erosion for a given site and time horizon/sea level rise. We assessed shore erosion impacts at 2010 (0 SLR baseline), 2030 (25 cm SLR), 2050 (50 cm SLR), 2100 low scenario (100 cm SLR), and 2100 high scenario (200 cm SLR), then calculated the total cumulative (highest SLR includes any lower SLR) percent area impacted for each scenario. We excluded baseline flooding using the 0cm sea level rise scenario from OCOF.

Western snowy plover (*Charadrius alexandrinus nivosus*) is a small, wading shorebird that nests in coastal beach-dune habitat. Those found in Marin County are part of the federally threatened Pacific Coast population that includes approximately 28 nesting areas from Washington State south to the Mexican border (USFWS Recovery Plan). A total of 1.5 $km^2$ of federally designated critical habitat occurs within the Marin County Coastal Zone (including federal lands), and 50-58% of that will potentially be exposed to inundation, erosion, or both from projected sea level rise of 200cm by 2100 (Table 3 and Table 4). Federally designated critical habitat in the study area occurs along Dillon Beach at the mouth of Tomales Bay (Figure 2) and supports over-wintering habitat. Though not federally designated, additional wintering habitat exists along Seadrift Beach and on intertidal mudflats within Bolinas Lagoon, currently supporting a population of approximately 40 birds (L. Stenzel, Point Blue Conservation Science, pers. comm., January 2017). This additional area is <u>not</u> included in area summaries provided in Tables 3 or 4.

**Table 3.** Total area of federally designated critical habitat for terrestrial, federally-listed species within the Coastal Zone of Marin County, and the percentage of that habitat projected to be inundated under various sea level rise scenarios (source: OCOF). Percentages are cumulative (higher SLR includes areas flooded at lower SLR scenarios).

| | **Western snowy plover** | **Yellow larkspur** | **Marbled murrelet** | **California red-legged frog** |
|---|---|---|---|---|
| Area above current MHW* | 1.53 $km^2$ | 4.57 $km^2$ | 14.21 $km^2$ | 108.28 $km^2$ |
| 25cm | 6.4% | 1.0% | 0.3% | 0.7% |
| 50cm | 15.3% | 2.7% | 0.5% | 1.4% |
| 100cm | 33.9% | 4.5% | 0.9% | 2.1% |
| 200cm | 49.7% | 9.6% | 1.4% | 3.6% |

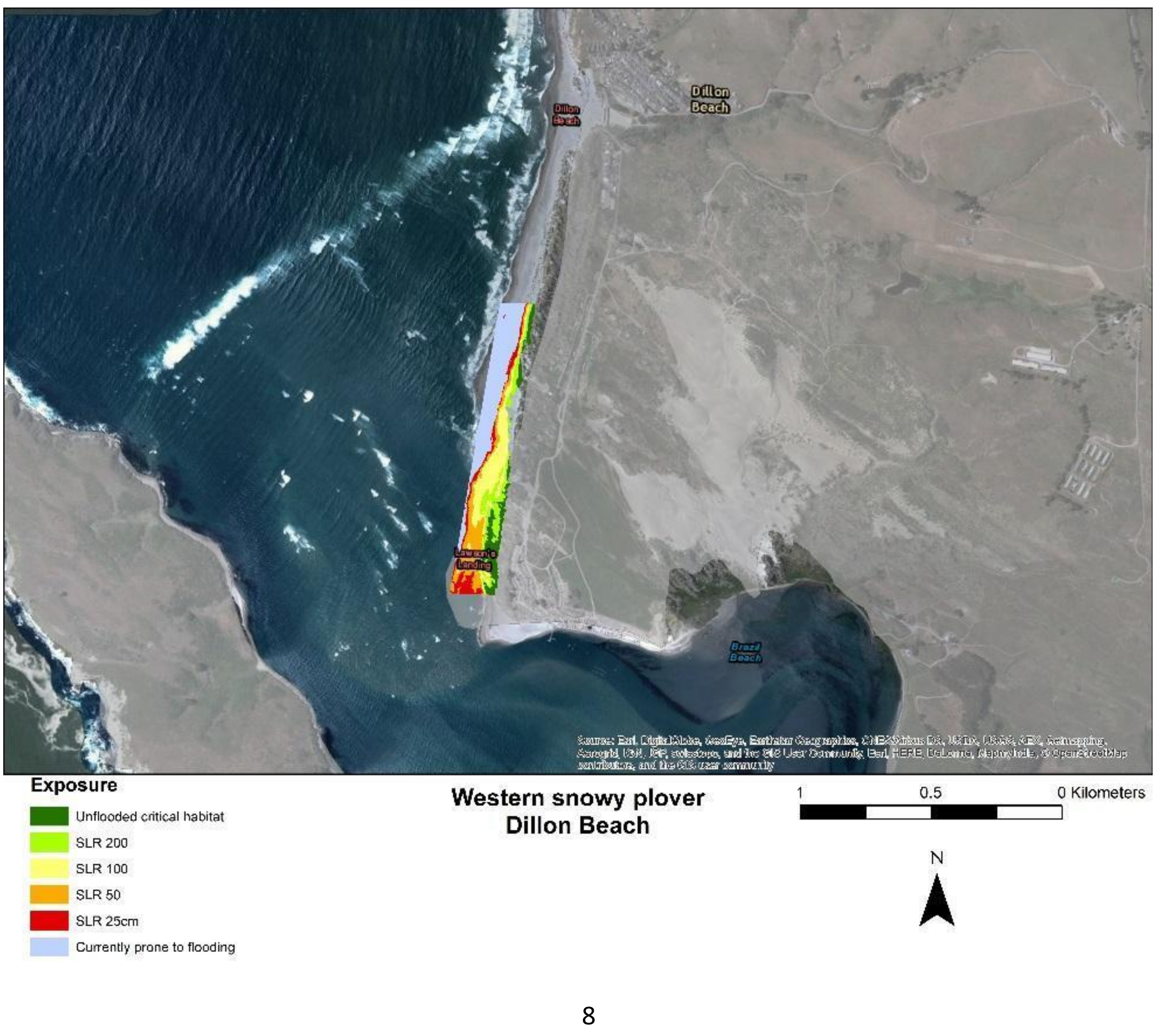
*Calculated based on 0 SLR scenario from OCOF data.

**Table 4.** Total area of federally designated critical habitat for terrestrial, federally-listed species within the Coastal Zone of Marin County, and the percentage of that habitat within shoreline erosion hazard zones at different time horizons, based on erosion modeling by ESA (2015). Approximate sea level rise scenarios corresponding to time horizon are included in parentheses. Percentages are cumulative (higher SLR includes areas flooded at lower SLR scenarios).

| | Western snowy plover | Yellow larkspur | Marbled murrelet | California red-legged frog |
|---|---|---|---|---|
| Area above current MHW* | 1.53 $km^2$ | 4.57 $km^2$ | 14.21 $km^2$ | 108.28 $km^2$ |
| 2030 (~25cm SLR) | 3.3% | 0% | 0% | 0% |
| 2050 (~50cm SLR) | 12.9% | 0% | 0% | 0% |
| 2100 low (~100cm SLR) | 23.7% | 0% | 0% | 0% |
| 2100 high (~200cm SLR) | 42.1% | 0% | 0% | 0% |
| No erosion hazard | 57.9% | 100% | 100% | 100% |

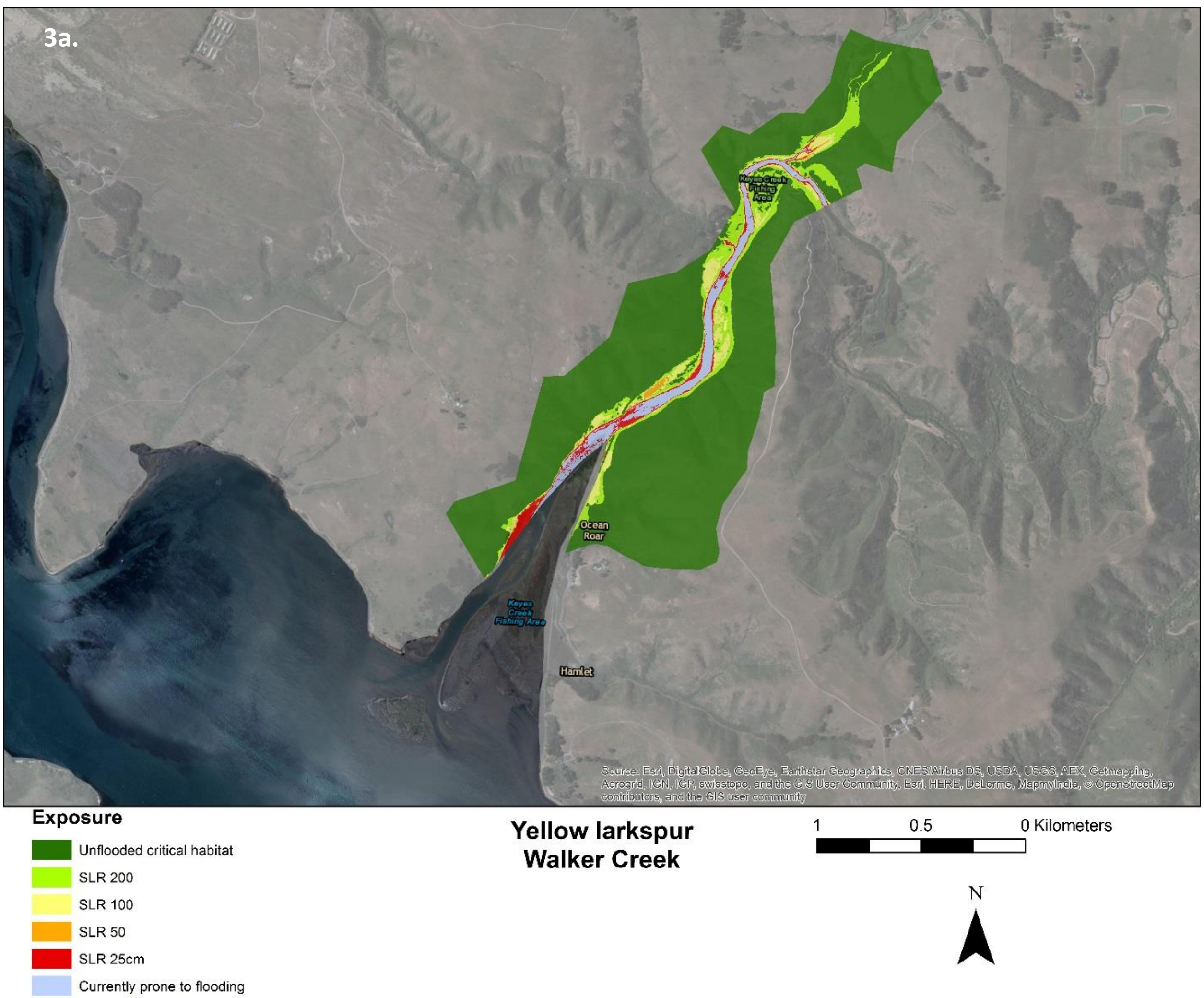
*Calculated based on 0 SLR scenario from OCOF data.

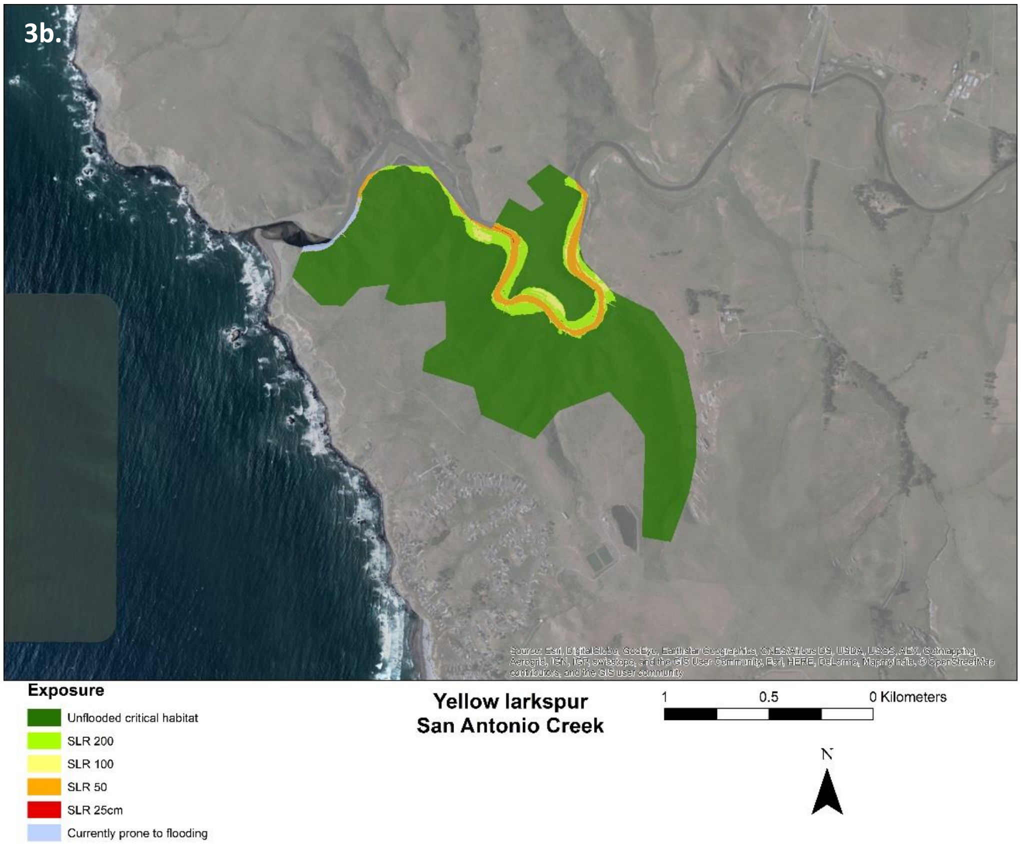
**Figure 2.** Federally-designated critical habitat for western snowy plover within the study area along Dillon Beach, at the mouth of Tomales Bay. It is vulnerable to both inundation from sea level rise and coastal erosion (not shown).

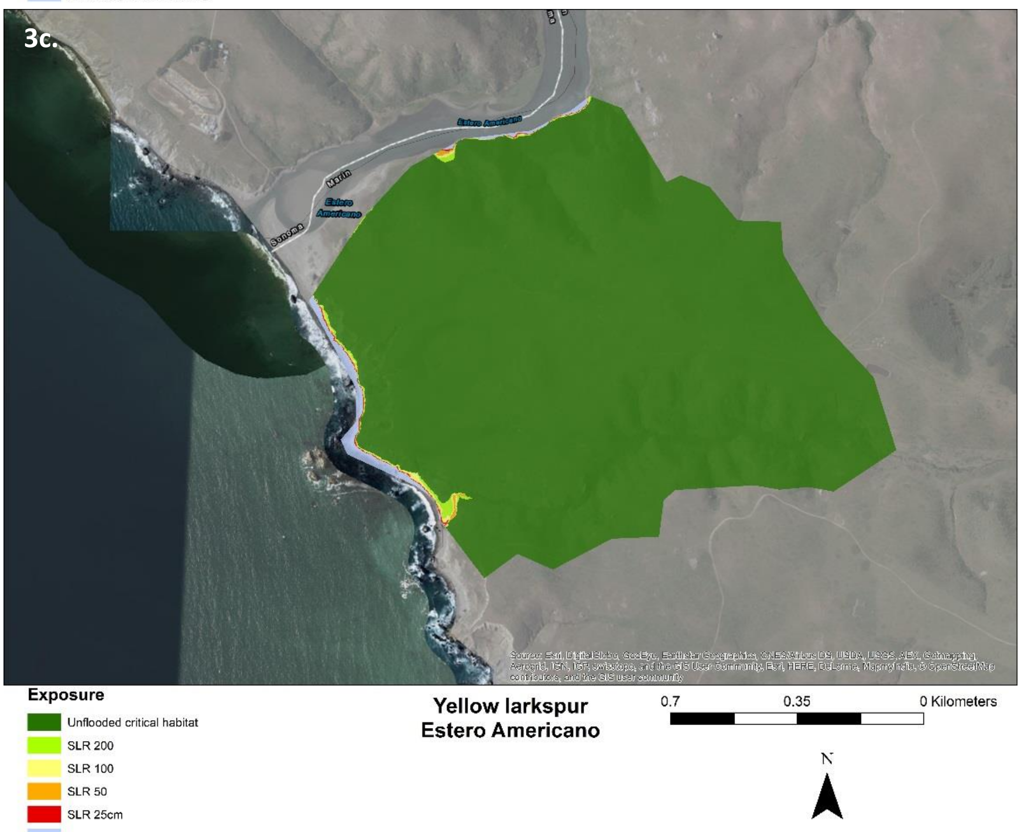


Yellow larkspur (*Delphinium luteum*) is a perennial herb in the buttercup (Ranunculaceae) family. Historically, it occurred in rocky areas of coastal grassland or coastal scrub in northwestern Marin and southwestern Sonoma counties, at elevations ranging from sea level to about 100 meters (USFWS 2011a). Within the study area, approximately 4.6 $km^2$ of critical habitat has been designated around Esteros Americano and San Antonio in Bodega Bay, and Walker Creek in Tomales Bay (Figure 3). Approximately 10% of designated critical habitat is potentially exposed to inundation with 200cm of SLR (Table 3). However, suitable habitat is typically on steeper slopes of coastal grassland and scrub and may not occur in lowland areas projected to be inundated. According to ESA modeling, none of the designated critical habitat falls within shore erosion hazard zones (Table 4).

**Figure 3.** Overlap between yellow larkspur critical habitat and sea level rise inundation scenarios at (a) Walker Creek, (b) Estero San Antonio, and (c) Estero Americano.




3b.
Exposure
Unflooded critical habitat
SLR 200
SLR 100
SLR 50
SLR 25cm
Currently prone to flooding
Yellow larkspur
San Antonio Creek
1
0.5
0 Kilometers
N


3c.
Estero Americano
Marin
Sonoma
Exposure
Unflooded critical habitat
SLR 200
SLR 100
SLR 50
SLR 25cm
Currently prone to flooding
Yellow larkspur
Estero Americano
0.7
0.35
0 Kilometers
N

Reflecting their less coastally-dependent habitat requirements, potential exposure of critical habitat to inundation for the remaining two species (California red-legged frog and marbled murrelet) is small (<4% at highest SLR scenario) relative to the larger total habitat available within the Coastal Zone of Marin County (Table 3). Neither is subject to erosion hazard (Table 4).

## Other listed species

To identify other state- or federally-listed, terrestrial species potentially subject to inundation or erosion hazards within the study area, we reviewed mapped records from the California Natural Diversity Database (CNDDB) provided by Marin County (2016) and the latest species reports for federally listed species available from the USFWS ECOS database (https://ecos.fws.gov/ecp/). Of the 13 listed species potentially affected by 200 cm of sea level rise within the study area (source: C-SMART draft vulnerability assessment Table 29), 4 have designated critical habitat and were analyzed previously above, and 7 have been extirpated or occur only on federal lands managed by the Point Reyes National Sea Shore or Golden Gate National Recreation Area (Appendix A). The remaining two species likely to occur within the sea level rise or coastal erosion hazard zones are showy rancheria clover (*Trifolium amoenum*) and Ridgway's rail (*Rallus longirostris obsoletus*), formerly known as the California clapper rail.

Showy rancheria clover (*Trifolium amoenum*) is an annual herb in the pea (Fabaceae) family. It typically occurs in coastal bluff habitat. Historically it ranged from Mendocino County south through the western Bay Area counties. The last known remaining natural population occurs within the study area, on a private, developed bluff property in the town of Dillon Beach. According to ESA cliff retreat modeling and the location information provided by CNDDB records, this population is vulnerable to current and projected cliff erosion.

Potential vulnerability of Ridgway's rail was analyzed as part of *Projected Marsh Bird Response to Estuary Evolution* below.

## Projected marsh bird response to estuary evolution

ESA (2015) modeled the evolution of coastal wetlands within the study area for five estuary regions: Bolinas Lagoon, Walker Creek, Point Reyes Station, Marshall, and Inverness. Based on assumptions of marsh sediment accretion and sea level rise, ESA modeled elevation capital, or standardized marsh elevation, and translated that in to approximate habitat types based on their elevation relative to the tidal prism. Projected habitat shifts based on this modeling are reported in Tables 5–8.

In general marsh habitats decline linearly in area from baseline conditions as sea level rise increases (Tables 5–8) while the area of subtidal and intertidal mudflats increase (Tables 5 and 8). Notable exceptions to this are the area of mid marsh habitat, which increases from baseline conditions with 25 cm of sea level rise across all sites, and 50 cm of sea level rise at Bolinas and Marshall. However, as sea level rise increases to 100 cm, the area of mid marsh habitat at all sites declines below baseline levels (Tables 5–8). Additionally, the models project an increase in the area of low marsh habitat with increasing sea level rise between 0 and 50 cm at Walker and Point Reyes Station, followed by declining area at higher sea level rise scenarios. At Marshall, the area of low marsh habitat increases with increasing sea levels up to 100 cm, and then declines at 200 cm (Table 6).

We selected three species of tidal marsh birds as indicators of overall tidal marsh ecosystem quality. Ridgway's rail is a federally endangered species that has been observed in tidal marshes along Marin County's outer coast, but we know of no observations of the species breeding within the study region. Black rail is a California Threatened species and is known to occur within the study area. Three sub-species of tidal marsh song sparrow occur within tidal marshes of the San Francisco Bay and are all California Species of Special Concern. Tidal marsh song sparrow are common in the tidal marshes of Marin's outer coast and these populations do not have special status, but the species does prefer different aspects of the tidal marsh ecosystem than the rail species. Together the three species serve as good indicators of heterogeneous, high quality tidal marsh ecosystems.

We used statistical models modified from Veloz et al. (2013), which correlate counts of marsh birds with the percentage of high marsh, mid marsh and low marsh habitat surrounding point counts (50 m radius), to predict an index of potential abundance of Black rail, Ridgway's rail and song sparrow. We did not have data on the occurrence and abundance of the tidal marsh species on the outer coast with which to calibrate our models so we used data from the San Francisco Bay Estuary (Veloz et al. 2013). We should note that these models did not include many of the variables that were included in previous modeling efforts (Veloz et. 2013) because covariate data were not available on the outer coast. Therefore the models are likely to be an imprecise estimate of abundance for each of the species. However, the models do give an indication of trends in abundance due to projected changes in marsh habitat with sea level rise (Tables 5-8). With sufficient data the precision of the models could be improved. It is important to note that the models we report on provide estimates of the <u>potential</u> number of individuals of each species that could occur at each marsh. However, other non-habitat factors likely further limit the number of individuals that can occur at a site. So we emphasize that the numbers we report should only be taken as an index of habitat quality rather than interpreting the values as the actual numbers of individuals at a site.

We found that for all three tidal marsh species, marshes in Bolinas Lagoon, Walker and Point Reyes Station regions could support > 94% of the predicted baseline (2010) populations within the study area for each species (Table 9). Our modelling indicates that the Point Reyes Station marshes could support the greatest proportion of each species population as compared to other regions, followed by Bolinas and then Walker (Table 9).

To estimate vulnerability to sea level rise, we examined the percent change in the regional populations for each species relative to the predicted 2010 baseline. We excluded Marshall and Inverness from our analysis since the predicted populations at these sites were extremely small and a small change in predicted populations could result in a large percent change.

We project that both black rail and Ridgway's rail will experience similar population change patterns across all scenarios and sites (Figure 4). With 25 cm of sea level rise we project population declines from 2010 levels for both rail species and a great increase from 2010 levels with 50 cm of sea level rise (Figure

4). We project the populations of both rail species to return to 2010 levels with 100 cm of sea level rise. With 200 cm of sea level rise we project either stable populations or declines below 2010 levels with greatest declines expected at Bolinas (Figure 4). We project similar patterns for song sparrows as for the rail species. The main difference in patterns in the projections between the rails and song sparrows is in our projections at Walker where we project dramatic declines in song sparrow populations below 2010 levels with 100 cm of sea level rise and then increases from 2010 levels with 200 cm of sea level rise.

The resulting patterns of tidal marsh bird population changes cannot be directly interpreted from the projected changes of marsh habitat in Tables 5-8. For example, there is no clear pattern that explains what is causing the models to project an increase in bird populations between 25 and 50 cm of sea level rise for most species/site combinations (Figure 4). The difference between the 25 cm and 50 cm scenarios are that mid marsh habitat makes up a greater proportion of the total marsh acreage in the 25 cm scenario suggesting that the bird species we examined are sensitive to the relative mix of habitats. Still, the patterns could also reflect the spatial clumping of habitats that are missed by the site level summaries provided in Tables 5-8. For example, the same amount of the three different types of marsh habitat can result in different numbers of tidal marsh bird individuals depending on the actual spatial configuration of the marsh habitat.

**Table 5.** Area (acres) of marsh habitats at Bolinas Lagoon under current conditions and five sea level rise scenarios. From ESA 2015.

| **Bolinas Lagoon** | **Area in acres** | | | | |
|---|---|---|---|---|---|
| **Habitat type (6.8 mm/yr sedimentation)** | **Baseline** | **Scenarios 1 & 2** | **Scenario 3** | **Scenario 4** | **Scenario 5** |
| | **0 cm SLR (2010)** | **25 cm SLR (2030)** | **50 cm SLR (2050)** | **100 cm SLR (2100 low)** | **200 cm SLR (2100 high)** |
| Transition zone | 128.8 | 122.6 | 117.8 | 107.3 | 65.8 |
| High salt marsh | 164.2 | 95.3 | 47.7 | 42.4 | 27.3 |
| Mid salt marsh | 34.7 | 75.8 | 42.4 | 14.3 | 9.4 |
| Low salt marsh | 429.6 | 327.7 | 305.3 | 235.6 | 67.4 |
| Intertidal mudflats | 386.6 | 497.4 | 580.7 | 600.1 | 126.1 |
| Subtidal | 67.8 | 105.5 | 142.0 | 253.2 | 1025.8 |

**Table 6.** Area (acres) of marsh habitats at Walker Creek under current conditions and five sea level rise scenarios. From ESA 2015.

| **Walker Creek** | **Area in acres** | | | | |
|---|---|---|---|---|---|
| **Habitat type (1.5 mm/yr sedimentation)** | **Baseline** | **Scenarios 1 & 2** | **Scenario 3** | **Scenario 4** | **Scenario 5** |
| | **0 cm SLR (2010)** | **25 cm SLR (2030)** | **50 cm SLR (2050)** | **100 cm SLR (2100 low)** | **200 cm SLR (2100 high)** |
| Transition zone | 51.9 | 62.8 | 69.0 | 77.3 | 71.7 |
| High salt marsh | 47.7 | 20.8 | 12.6 | 17.1 | 24.3 |
| Mid salt marsh | 26.4 | 30.9 | 13.6 | 6.6 | 13.5 |
| Low salt marsh | 42.6 | 49.4 | 69.7 | 46.6 | 35.6 |

*Note: ESA data only included vegetated marsh zones at this site (no subtidal or intertidal)

**Table 7.** Area (acres) of marsh habitats in the Point Reyes Station area under current conditions and five sea level rise scenarios. From ESA 2015.

| **Pt Reyes Station** | **Area in acres** | | | | |
|---|---|---|---|---|---|
| **Habitat type (1.5 mm/yr sedimentation)** | **Baseline** | **Scenarios 1 & 2** | **Scenario 3** | **Scenario 4** | **Scenario 5** |
| | **0 cm SLR (2010)** | **25 cm SLR (2030)** | **50 cm SLR (2050)** | **100 cm SLR (2100 low)** | **200 cm SLR (2100 high)** |
| Transition zone | 232.9 | 235.3 | 228.4 | 195.8 | 128.0 |
| High salt marsh | 255.0 | 83.8 | 72.7 | 80.9 | 54.6 |
| Mid salt marsh | 124.5 | 201.1 | 44.5 | 38.0 | 35.8 |
| Low salt marsh | 298.1 | 309.4 | 400.8 | 247.0 | 121.2 |

*Note: ESA data only included vegetated marsh zones at this site (no subtidal or intertidal)

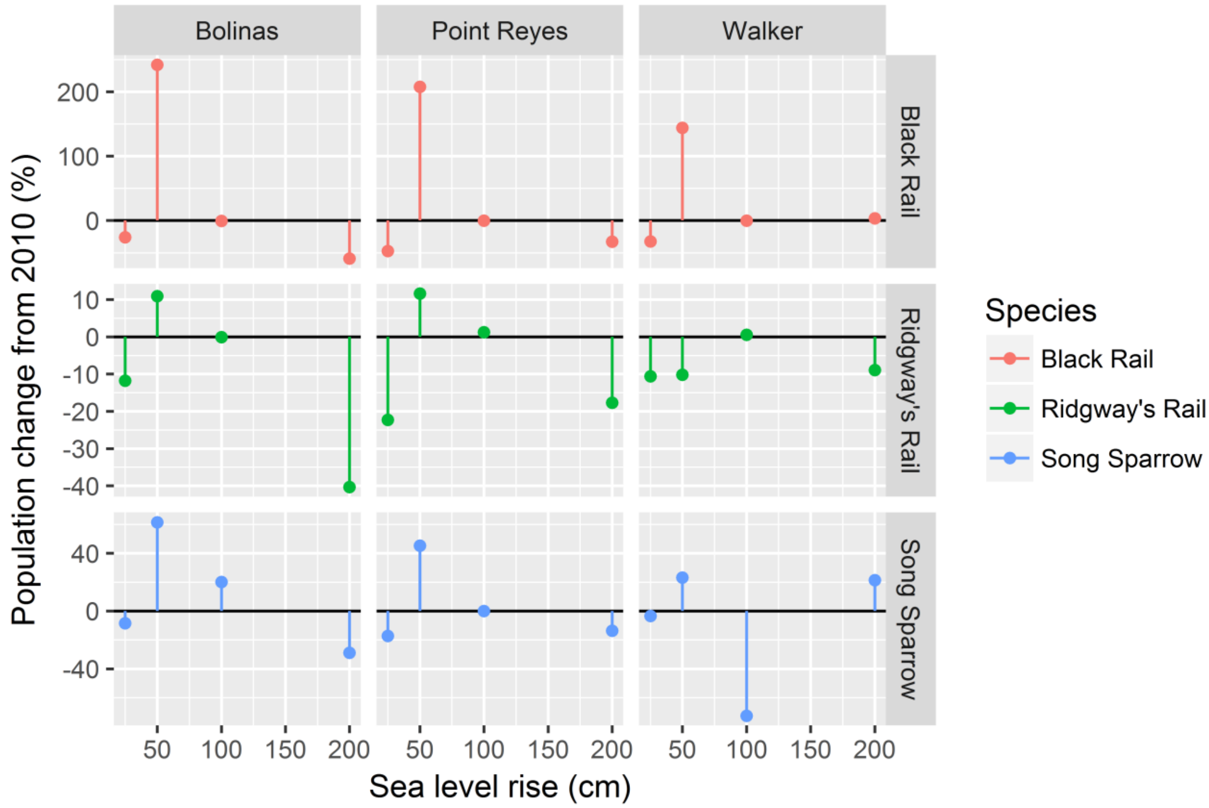
**Table 8.** Area (acres) of marsh habitats in the Marshall area under current conditions and five sea level rise scenarios. From ESA 2015.

| **Marshall Area** | **Area in acres** | | | | |
|---|---|---|---|---|---|
| **Habitat type (1.5 mm/yr sedimentation)** | **Baseline** | **Scenarios 1 & 2** | **Scenario 3** | **Scenario 4** | **Scenario 5** |
| | **0 cm SLR (2010)** | **25 cm SLR (2030)** | **50 cm SLR (2050)** | **100 cm SLR (2100 low)** | **200 cm SLR (2100 high)** |
| Transition zone | 6.8 | 7.3 | 8.2 | 9.2 | 8.3 |
| High salt marsh | 4.8 | 3.5 | 2.1 | 2.1 | 3.5 |
| Mid salt marsh | 0.8 | 2.5 | 2.3 | 1.0 | 1.6 |
| Low salt marsh | 1.4 | 1.9 | 4.1 | 5.9 | 3.6 |
| Intertidal mudflats | 1.2 | 1.6 | 2.1 | 2.8 | 7.5 |
| Subtidal | na | na | 0.0 | 1.0 | 4.4 |

**Table 9.** Predicted percent of Marin County outer coast 2010 potential population of Black Rail, Ridgway's Rail and Song Sparrow within different regions of the outer coast.

| **Region** | **Black Rail** | **Ridgway's Rail** | **Song Sparrow** |
|---|---|---|---|
| Bolinas | 35.3 | 36.0 | 34.1 |
| Walker | 11.2 | 16.0 | 17.3 |
| Point Reyes | 51.1 | 45.0 | 43.6 |
| Marshall | 1.2 | 1.0 | 1.3 |
| Inverness | 1.2 | 2.5 | 2.7 |

**Figure 4.** Projected percent change in population size from estimated (2010) baseline at Bolinas, Point Reyes and Walker for Black Rail, Ridgway's Rail and Song Sparrow. The black horizontal line indicates where there is no change from estimated 2010 levels.




## Eelgrass

Eelgrass is a marine aquatic plant that grows in sheltered waters in the shallow subtidal or intertidal zone. Eelgrass beds are highly productive, provide important nursery grounds for fish, sequester carbon, and provide for coastal defense by decreasing erosion and resuspension of sediment (Duarte 2002). Light availability is a primary driver of growth for plants. Thus, eelgrass bed depth limits are strongly controlled by light penetration through the water column (Duarte et al. 2016), which is in turn a function of depth and turbidity. To examine the potential impact of sea level rise on eelgrass within the study area, we assumed that turbidity remains unchanged from present, and focused on how depth within the existing footprint of eelgrass beds is projected to change with increasing sea level.

Eelgrass spatial distribution within the study area was limited to Tomales Bay, as delineated by a multi-source vector shapefile developed by the California Department of Fish and Wildlife for its Marine Life Protection Act process. To assess potential changes in water depth within these eelgrass areas, we used a raster bathymetry layer together with raster water surface elevation layers developed for the OCOF project. Initial depths were defined by taking the difference between the bathymetry layer and the water surface elevation layer with 0cm of sea level rise. Projected changes in depth were defined by taking the difference between bathymetry and water surface elevation at 25, 50, 100, and 200cm of sea level rise.  To assess projected changes within the existing footprint of eelgrass habitat, we summarized mapped eelgrass area by quartile depth values based on initial depth and applied these to each of the potential future depths.

Existing mapped eelgrass habitat covers 946 $km^2$ of the floor of Tomales Bay, and occurs at an approximate depth range of 0.2 to 17 m below the water surface, with a median value of 2.6m (Figure 5). Sea level rise results in an increase in water depth above the existing area of eelgrass habitat, pushing existing habitat to the deeper limits that currently support eelgrass within Tomales Bay. With 100 cm of SLR, almost 70% of existing eelgrass habitat is projected to be within the deepest quartile currently supporting eelgrass in Tomales Bay (> 3.3m), and a very small fraction of the area (<0.01%) begins to be outside the range of current depths. With 200 cm of SLR, almost all existing habitat is projected to be within the deepest quartile. While these deeper areas could, theoretically, continue to support eelgrass, they would be susceptible to even a small increase in turbidity, which also limits light penetration.

We emphasize that this is a very simplistic analysis and that eelgrass extent is highly dynamic and variable from year to year (e.g., San Francisco Estuary Partnership 2015). We do not have a clear understanding of how turbidity within the study area may change over time, which can factor heavily into the depth limit of light penetration. Additionally, we recognize that while water depth within the existing footprint of eelgrass may become too deep to support eelgrass in the future as a result of sea level rise, existing eelgrass may be able to migrate landward and colonize shallower waters, thus the total area of eelgrass may remain unchanged. Projecting future habitat suitability requires a better understanding of the combined influence of light availability, substrate conditions, water quality (e.g., salinity, temperature), and disturbance events (Duarte 2002).

**Figure 5.** Eelgrass suitable habitat on the Marin County outer coast for a suite of sea level rise scenarios.

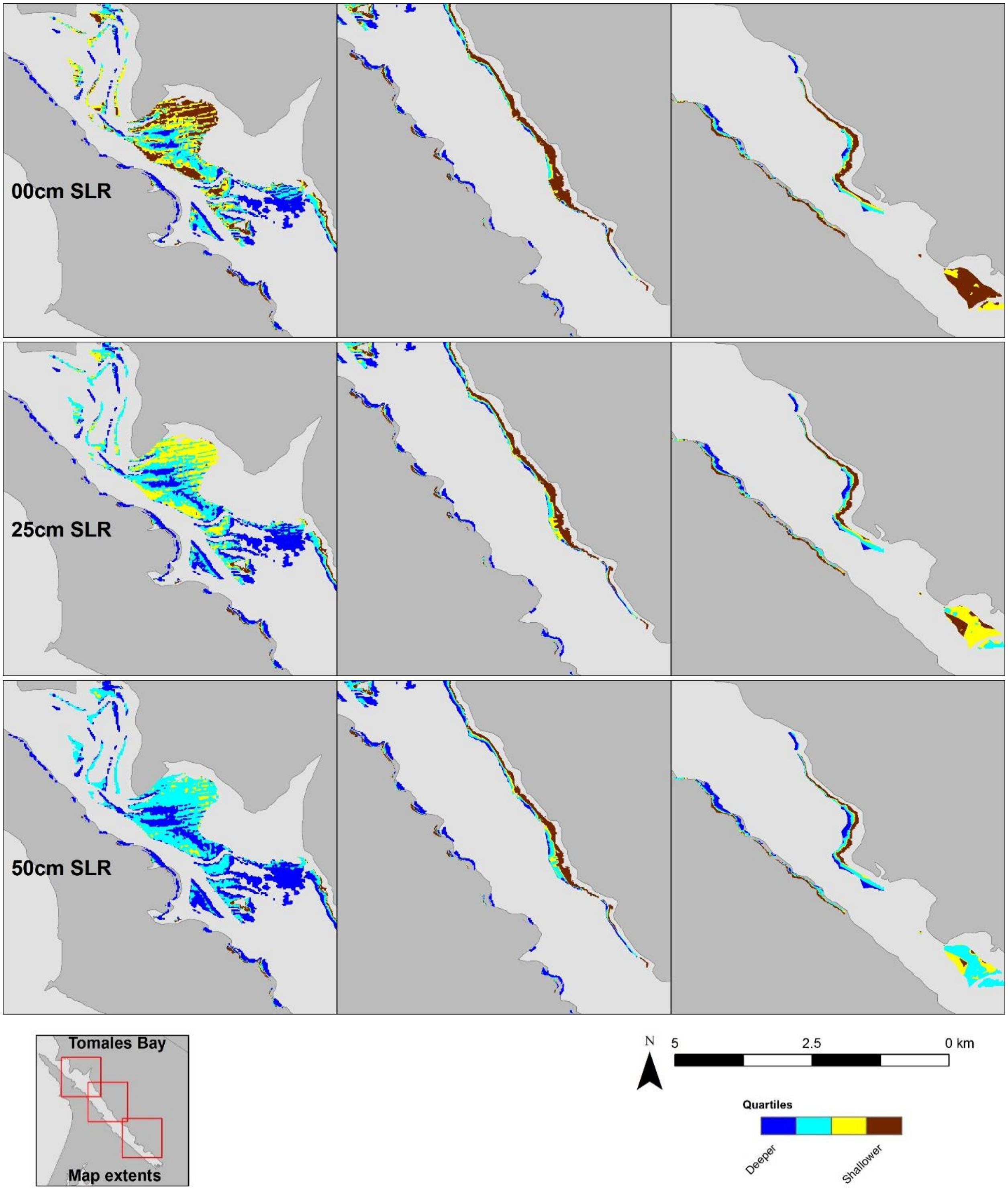
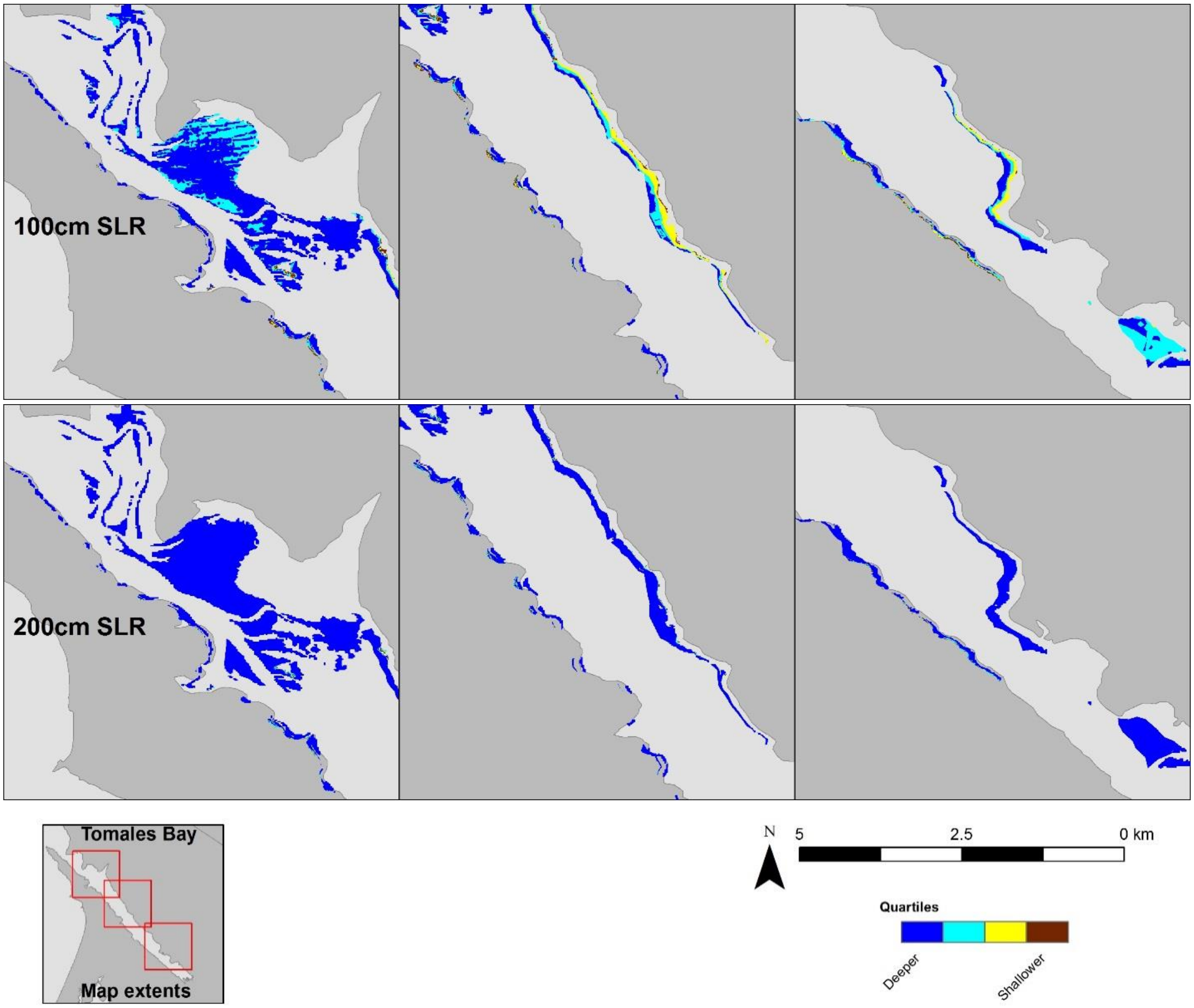


**Figure 5 (continued).** Eelgrass suitable habitat on the Marin County outer coast for a suite of sea level rise scenarios.



## Pinniped haul outs

In Marin County, sandy beaches where northern elephant seals, Pacific harbor seals, and California sea lions haul out to shore are at-risk areas due to sea level rise (Nur and Herbold 2015; San Francisco Estuary Partnership 2015). These seals and sea lions use these beaches to form colonies for only a few months of each year to give birth, breed, and molt. As sea level rises, access to beaches may become limited.

Previous work indicates that the sea level rise vulnerability of pinniped haul out sites is based on site elevation characteristics and exposure to larger waves (Funayama, 2013). We do not have detailed enough information about the inundation duration at haul out sites to adequately model the vulnerability of haul out sites to sea level rise. However, we used OCOF data to examine the distribution of water elevation and wave height projections at pinniped haul out sites along the Marin County shoreline as a coarse assessment of vulnerabilities to sea level rise. The water elevation projections increase linearly with sea level rise at pinniped sites as these areas are directly connected to open waters and lack barriers to mitigate sea level rise increases.

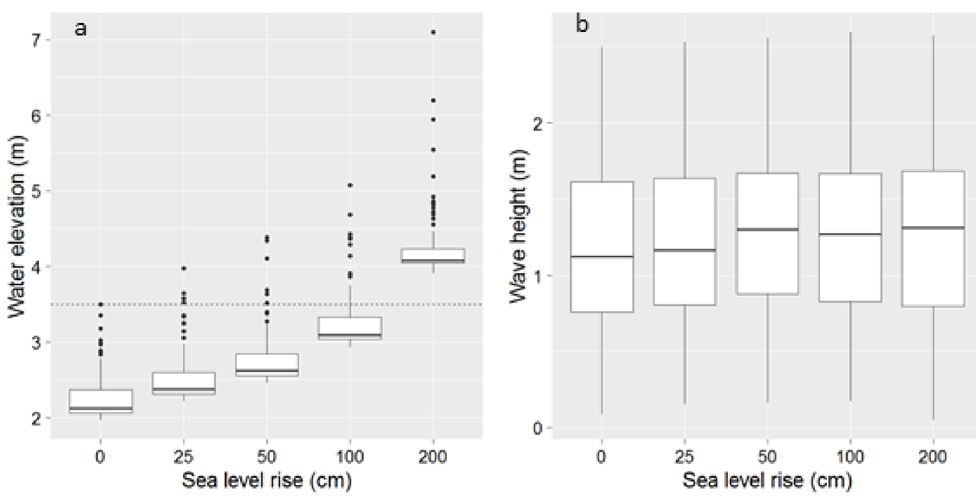



**Figure 6.** Boxplots from the modeled water elevation (a) and wave height (b) at 163 pinniped haul out locations. Each box shows the mean and distribution of each variable for each scenario of sea-level rise scenario. The line in the middle of each box is the median value (50% quantile) of the data for each scenario. The upper and lower hinges (box corners) correspond to the 25th and 75th percentile of the data respectively (first and third quartile). The whiskers extend to the highest and lowest values that are 1.5 times the distance between the box hinges (inter-quartile range). Values beyond the whiskers are considered outliers and are plotted as points. The dashed horizontal line in (a) indicates the maximum water elevation with current sea-level.

Under current conditions (0 SLR) we find a relatively wide range of water elevations at pinniped haul out locations along the Marin County shoreline (1.9 – 3.5 m, Figure 6a). The water elevation at most haul out sites remains within the range of current water elevations through the 50 cm of sea level rise scenario (Figure 6a). However, the models project the water elevation to shift from the low end of the 0 cm sea level rise scenario to the upper quartile (Figure 6a). With 100 cm of sea level rise, water elevations at current haul out sites begin to exceed the maximum water elevations of haul out sites without sea level rise (Figure 6a). With 200 cm of sea level, all of the haul out locations are projected to have water elevations well above the maximum found at current sea levels (Figure 6a).

Wave heights at haul out locations are not projected to change significantly across the sea level rise scenarios considered (Figure 6b). We can see a small increase in the median wave heights at haul out locations with 50 cm of sea level rise and above as compared to 0 – 25 cm of sea level rise, but overall wave heights remain relatively unchanged (Figure 6b).

## Seabird colonies

There are 16 seabird nesting colonies on cliffs or offshore rocks within the Coastal Zone of Marin County (USFWS 2012). Of those, 12 are located on federal lands (PRNS or GGNRA), which are outside of the study area. Three of the remaining 4 seabird colonies are on actively eroding cliff faces (Appendix B), and one is on a large offshore rock. The cliff top above the colony at Dillon Beach Rocks is privately owned, but there was no visible infrastructure that appears to be at risk from continued cliff retreat, so the risk of armoring appears low. The cliff top above the colony from Stinson Beach to Rocky Point is owned by State Parks. The Steep Ravine Environmental Campground and Highway One are within projected cliff erosion hazard zones on this stretch of coast, in some areas as soon as 2030. In the future, these assets may be protected with armoring that could impact the seabird colony.

It should be noted that these are all relatively small colonies in terms of population size. Within the North-Central MLPA region, located between Point Arena and Pigeon Point, there are approximately 70 breeding colonies (USFWS 2011b). However, 94% of the population of breeding seabirds (all species combined) is concentrated on the Farallon Islands or the Point Reyes Headlands. The four colonies within the study area support less than $1/10^{th}$ of one percent of the population (Appendix B).

## ADAPTATION STRATEGIES

**Table 10.** Potential nature-based adaptation strategies to address identified site-specific natural resource vulnerabilities, referenced strategies from the GFNMS Climate-Smart Adaptation for the North-Central California Coast project, and relevant case study examples gathered as part of our Natural Infrastructure project for California's 4th Climate Assessment.

| Location | Natural Resource Vulnerability | Nature-based Adaptation Options | Applicable GFNMS strategy # | Case study example |
|---|---|---|---|---|
| Tomales Bay | | | | |
| Eelgrass beds | Eelgrass: deeper water = decreased light penetration, leads to poorer growth/survival; narrow, linear patches adjacent to steep upslope topography are particularly at risk due to lack of adjacent accommodation space | Accommodation: map potential for landward transgression and protect potential transition habitat; given significant eelgrass beds near Walker Creek delta, this may be a particularly good location to consider integrating a complete subtidal to upland transition continuum (see Walker Creek delta) | 29, 57 | SF Bay Living Shorelines Project |
| | | Assisted migration: as water rises, monitor trends in eelgrass extent; possibly plant in shallower water to kick-start colonization of areas available for landward transgression | 57 | SF Bay Living Shorelines Project |
| | | Minimize non-climate stressors: restore areas lost from moorings, minimize disturbance to existing beds, monitor changes in turbidity | 57 | SF Bay Living Shorelines Project |
| Walker Creek Delta | Tidal marsh habitat: delta has expanded rapidly in recent decades due to watershed erosion (ESA 2015); There is potential for landward migration into transition/upland habitat until 2050/50cm SLR. However, with low sediment supply by 2050/50cm SLR, most existing mid- and high-marsh areas have transitioned to low-marsh, and elevation capital that might support mid- and high-marsh is constrained by | Near-term = accommodation: Consider need for additional transition habitat; Remove potential barriers to landward migration: Highway 1 bridge. Identify ownership of and acquire potential transition zones upstream of current marsh footprint | 18, 29, 35, other landward migration approaches | |
| | | Long-term = sediment augmentation: If high value resources/functions present, assess and consider augmenting sediment to allow for accretion of marsh within its existing footprint. | 1, 11, 56 | Seal Beach https://www.fws.gov/refuge/seal_beach/what_we_do/resource_management/Sediment_Pilot_Project.html |

| | | | | |
|---|---|---|---|---|
| | steeper topography. There is significant loss of vegetated marsh at higher SLR rates. | Minimize non-climate stressors: e.g., invasive species | 24, 25, 26 | |
| | Yellow larkspur: 10% of designated critical habitat in study area projected to be inundated under 200cm SLR scenario; however, suitable habitat is typically steeper slopes of coastal grassland and scrub and may not occur in lowland areas projected to be inundated | Confirm suitable habitat, monitor for species presence, assisted migration: Confirm presence of suitable habitat within the 200cm SLR projected inundation zone, which occurs in the lowland/riparian area of designated critical habitat. If suitable habitat exists, monitor for presence of species. If populations are present, consider assisted migration to locations further upslope. | | |
| Inverness | Tidal marsh habitat: low sediment supply, accommodation space severely restricted by topography and developed upslope land use. Near-term (2030) loss of marsh habitat significant. | Accommodation: Consider need for additional transition habitat; Remove potential barriers for landward migration: development and roads around intersections of Sir Francis Drake/Inverness Way and Sir Francis Drake/Vision Rd. | 18, 29, 35, other landward migration approaches | |
| | | Allow for loss: unless there are high value resources or functions provided, consider allowing for loss of this marsh and prioritizing action on more significant areas of intact habitat immediately south (Pt Reyes Station/Lagunitas Creek delta) | 4 | |
| | | Sediment augmentation: If high value resources/functions present, assess and consider augmenting sediment to allow for accretion of marsh within its existing footprint. | 1, 11, 56 | Seal Beach |
| Point Reyes Station (Lagunitas Creek delta) | Tidal marsh habitat: low sediment supply, accommodation space restricted by topography and developed upslope land use – especially to the east and west. Near-term (2030) loss of marsh habitat significant. | Accommodation: Allow for habitat transition especially in the area of existing low topography to the south on existing protected areas along Bear Valley Road (includes Giacomini Wetland | 18, 29, 35, other landward migration approaches | |

| | | | | |
|---|---|---|---|---|
| | | Restoration area). Investigate ownership beyond Giacomini Wetland footprint (e.g., along Olema Creek).<br><br>Remove or improve potential barriers for hydrologic connectivity and landward migration:<br>Sir Francis Drake Blvd between Inverness Park and Pt. Reyes Station, Bear Valley Road and Highway 1 | | |
| | | <u>Sediment augmentation:</u> Consider augmenting sediment to allow for accretion of marsh within its existing footprint (e.g., Giacomini Wetland Restoration footprint). This may be necessary in the near-term as accommodation space is acquired/designed. | 1, 11, 56 | Seal Beach |
| Marshall | <u>Tidal marsh:</u> assuming Tomales Bay average sediment supply of 1.6mm/yr, marsh will drown in place but has ample upland transition accommodation space (ESA 2015), most of which appears to already be protected | <u>Accommodation:</u><br>Allow for habitat transition Remove potential barriers for landward migration;<br><br>Ownership is either Audubon Canyon ranch (Cypress Grove Preserve) or GGNRA<br><br>Longer-term there is coastal squeeze and the southern piece runs up against Highway 1 though there appears to be additional valley bottom available on the other side for continued transgression | 29, 35, 38 | |
| Bodega Bay | | | | |
| Esteros Americano and San Antonio | <u>Yellow larkspur:</u> 10% of designated critical habitat in study area projected to be inundated under 200cm SLR scenario; however, suitable habitat is typically steeper slopes of coastal grassland and scrub and may not occur in lowland areas projected to be inundated | <u>Confirm suitable habitat, monitor for species presence, assisted migration:</u> Confirm presence of suitable habitat within the 200cm SLR projected inundation zone, which occurs in the lowland/riparian area of designated critical habitat. If suitable habitat exists, monitor for presence of species. If populations are | | |

| | | | | |
|---|---|---|---|---|
| | | present, consider assisted migration to locations further upslope. | | |
| Dillon Beach | Beach/dune habitat: At risk from both inundation and coastal erosion | Accommodation and natural infrastructure: Determine if topography and land use/infrastructure allows for inland movement of beach/dune habitat. | 19, 32, 34, 36, and other Landward Migration approaches | Surfer's Point Managed Retreat Project |
| | | Natural Infrastructure: Dune restoration for coastal defense | 19 | Humboldt Bay dune restoration (https://www.fws.gov/refuge/Humboldt_Bay/wildlife_and_habitat/DunesRestoration.html) Cardiff State Beach Living Shoreline Project http://scc.ca.gov/webmaster/ftp/pdf/sccbb/2015/1503/20150326Board08_Cardiff_State_Beach.pdf) |
| | | Beach nourishment Explore potential ecological cost/benefit of beach nourishment | 42, 59, 60 | Imperial Beach |
| | Western snowy plover: projected loss of designated critical habitat from SLR inundation and coastal erosion | In addition to adaptation strategies for beach/dune habitat (above) – minimize other non-climate related stressors such as human and pet disturbance (recreational visitors) | 23, 44, 66, 67, 68 | |
| | Showy Rancheria clover: last known remaining natural population on a private, developed bluff property; population is vulnerable to current and projected cliff erosion. | Stabilize cliff through revegetation | 16 | |
| | | Assisted migration: Consider assisted migration to locations further upslope. | | Experimental populations have been reintroduced at Pt Reyes NS[1] |
| Bolinas/Stinson to Muir Beach | | | | |
| Bolinas Lagoon | Tidal marsh habitat: accommodation space severely restricted by topography. Near-term | Sediment: Engage with the Bolinas Lagoon Restoration Project to ensure planning includes future SLR | | |

[1] https://www.fws.gov/endangered/news/bulletin-spring2009/showy-indian-clover.html

| | | | | |
|---|---|---|---|---|
| | (2030) loss of high marsh habitat significant (~40%). Lagoon projected to become primarily subtidal with 2m of SLR, with only 17% of vegetated marsh remaining. | conditions. Effort involves Marin County Open Space District, PRNS, GFNMS, GGNRA, and others. It has an active program of technical studies, planning, management, and restoration with particular emphasis on sediment supply and transport and the interaction with flooding and habitat evolution. | | |
| | | Accommodation and habitat enhancement: Accommodation space is very limited, allow where possible and include habitat enhancement features where barriers can't be moved (e.g., consider horizontal levees) | | |
| Bolinas Lagoon/Seadrift Beach | Western snowy plover: projected loss of habitat from SLR inundation and coastal erosion | See adaptation strategies for Dillon Beach and Bolinas Lagoon(above) – In addition, minimize other non-climate related stressors such as human and pet disturbance (recreational visitors) | 23, 44, 66, 67, 68 | |
| Stinson Beach to Rocky Point | Seabird colony: Cliff top owned by State Parks. Campground and highway are within the projected cliff erosion hazard zones. In the future, these assets may be protected with armoring that could impact the seabird colony. | Accommodation: Allow for cliff retreat by avoiding armoring and encouraging managed retreat of Highway One and the Steep Ravine Environmental Campground along this stretch of coast | 15, 20, 38 and other Landward Migration approaches | Surfer's Point Managed Retreat http://www.surferspoint.org/ |
| | | Minimize non-climate stressors that exacerbate erosion: Human access and livestock grazing, stabilize degraded areas through revegetation | 12, 16, 61 | |

## MONITORING FRAMEWORK

Here we summarize the main steps that we recommend taking to establish a monitoring program to detect the impacts of climate change and management actions on natural resources. In Appendix C we provide more details and case studies to illustrate our recommendations.

Monitoring for climate change impacts and adaptation actions implies challenges of collecting and interpreting data from disparate sources, covering large spatial scales, and with the expectation to detect very small gradual changes that are happening throughout a long (relative to usual scope of monitoring programs) period of time. There is also no certainty on the rate of environmental change over time. Therefore, a strong inference approach is recommended that uses the monitoring data to learn not just about the status, but also the causes of impact on wildlife and plant populations, and the effects of management actions on these. This approach calls for the establishment of *a priori* hypotheses about how and why climate change affects habitats and populations, and how management actions alter these effects. Designing a strong-inference monitoring program to understand the impacts of climate change and adaptation actions includes the following steps:

- Postulate hypotheses of habitat change, based on scenarios and literature, of how habitats will evolve in response to climate change.
- Design the monitoring programs to measure hypothesized changes
- Identify indicator species for selected habitats, and set tentative population parameter goals based on current status and knowledge of the species.
- Design the monitoring program to estimate the population parameter, and determine the extent and intensity of sampling required to achieve the monitoring goals, including sources of data, precision in parameter estimation, and costs
- Review costs vs expected probability of monitoring goals to choose final indicator species, monitoring targets, data sources, survey effort, and costs

### Hypotheses of future change

Successful climate adaptation will require developing hypotheses of how natural resources will be impacted by future change. As was done for the vulnerability assessment for this report, literature, observational data, models and expert opinion can be combined to develop models for how ecosystems will evolve with climate change leading to the identification of potentially vulnerable sites, habitats or species.

### Monitoring ecosystem change

Many of the impacts we project from climate change are uncertain and/or we do not expect them to occur at the far end of our planning horizons. In those cases where we do project near term changes or impacts, we recommend monitoring habitat changes so that initial changes of habitat conditions can be detected early. If multiple future scenarios were considered in the vulnerability assessment, ecosystem monitoring will give an indication of what scenario best represents the realized conditions and which adaptation actions are thus most appropriate to begin enacting. This strong inference-learning approach also sheds light on the mechanisms whereby changes in the environment are affecting the target species. This knowledge is fundamental for the design of effective adaptation actions.

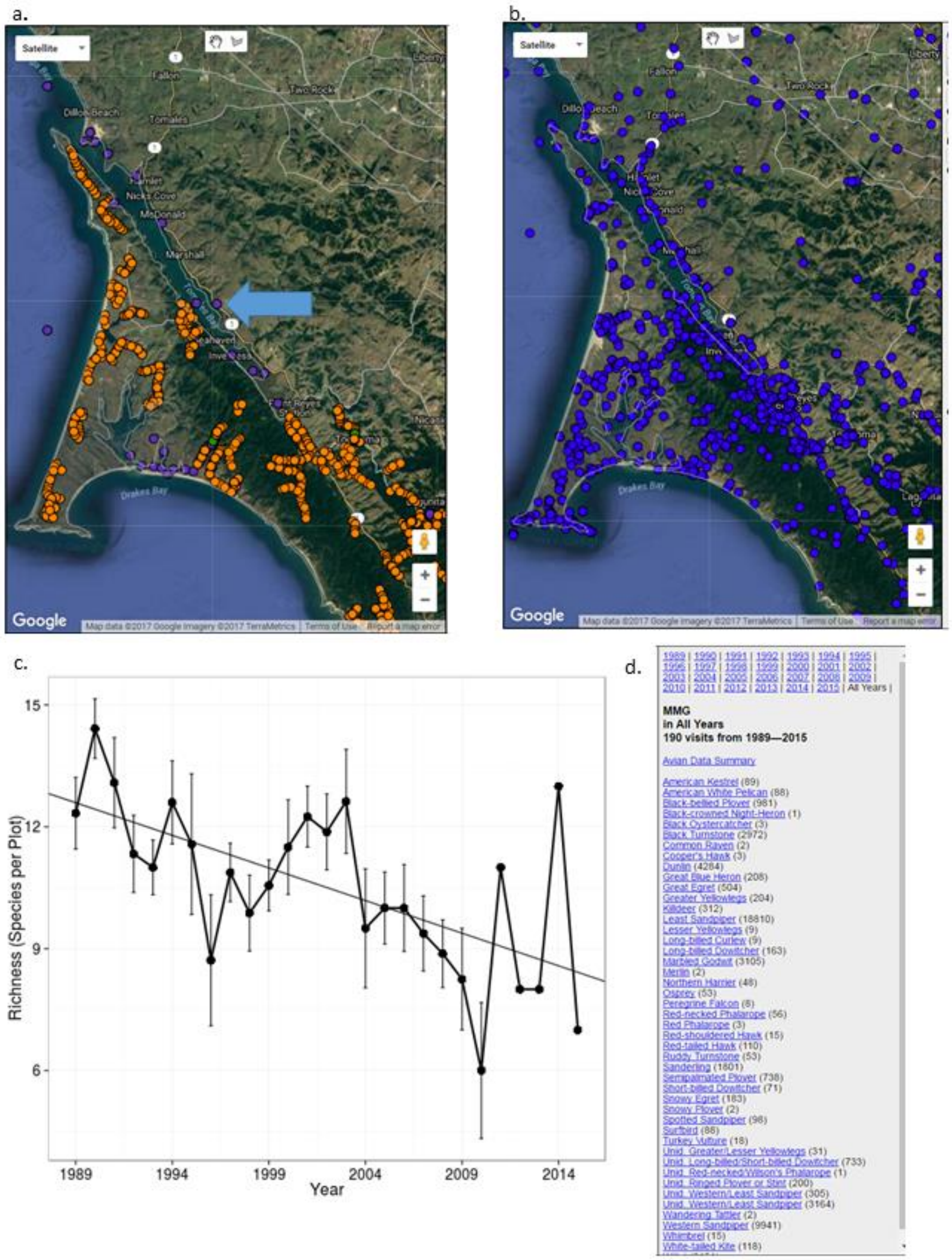
## Target species population trends

We recommend that specific trends in population levels for species are set to be used as indicators of response to both environmental change and management action. Indicator species should typically be selected based on outcomes from vulnerability assessments but also based on their sensitivity to environmental changes. More sensitive species should provide earlier indications of responses to environmental change. Year to year variation in the abundance of individuals within species can confound detection of population level changes. By analyzing trends over time, however, we can more effectively determine when important population level changes are occurring.

Additionally we recommend that monitoring should be focused on specific population parameters. Ideally this might include monitoring important demographic parameters such as adult survival or the nesting success of birds. However, with more limited resources monitoring could also focus on breeding season population numbers. The population parameters selected should be chosen based on their influence on population trends and our ability to manage them. Additionally, we recommend that specific hypotheses for how management actions will affect population parameters should be identified while setting targets. Adaptive management may be necessary if the system ends up responding in unanticipated ways.

We recommend that for wetland habitats on the outer coast of Marin County, monitoring programs should focus on birds as indicators of habitat quality. Birds are relatively easy to monitor with well-established monitoring protocols and are sensitive to habitat changes. In addition, Point Blue has existing long term monitoring data sets on birds in Tomales Bay and adjacent riparian areas that could be used to establish the basis of monitoring programs (Figure 7). Furthermore, ebird observations represent a continually growing source of citizen science data that will increasingly inform future monitoring programs (Figure 7b).

**Figure 7.** Point Blue point count (orange points), area search (light purple points) and banding stations (a) and eBird (dark purpl, b) in Tamales Bay. The blue arrow in (a) indicates a point where data are summarized by trends in species richness (c) and by the number of individuals of each species observed across all surveys (d).



## Design monitoring program

We recommend that the monitoring program should be designed using a rigorous statistical foundation based on statistical power analysis to determine the amount of sampling required to detect changes and to control for potential confounding factors (Nur et al. 1999). Where possible we also recommend that monitoring programs take advantage of multiple sources of existing data including data from standard monitoring programs as well as observations from citizen scientists. Additionally the monitoring program should be designed so that impacts from management actions can be detected, with a desired probability level, while accounting for other confounding factors such as inter-annual variation in population numbers.

We further recommend that the monitoring program should be structured as part of a learning model. The monitoring data should be analyzed periodically to determine if hypotheses concerning scenarios of environmental change and management actions are supported. If not, then new models and hypotheses should be established and additional management actions should be considered that conform to new hypotheses. The learning model will lead to more efficient management as actions that are not achieving results can be modified and future efforts can focus on actions that have been shown to achieve program targets.

## Evaluate monitoring costs relative to goals

Final decisions about which species and parameters to monitor, what sampling effort and what types of data to collect should be based on considerations of costs and goals. There will normally be a tradeoff between the level of resources invested in monitoring vs. the probability that the monitoring will accurately detect the status of monitoring targets. Furthermore, there are likely to be tradeoffs in the accuracy and precision of the data when using professional biologists to collect data rather than relying on citizen science data. Since many impacts from climate change will occur relatively slowly over decadal time scales, the ability to sustain long term monitoring programs must be included in cost considerations. We expect that methods to integrate monitoring data from multiple sources will continue to improve enabling the greater use of citizen science data in conjunction with standardized surveys so that the quality is not greatly sacrificed as costs are reduced.

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## APPENDIX A - ADDITIONAL INFORMATION ON LISTED SPECIES

**Table A-1.** Additional information on special-status species listed as potentially vulnerable in Marin C-SMART Draft Vulnerability Assessment Table 29, indicating whether and why they were included for further analysis in the report above.

| **Common Name** | **Scientific Name** | **Included in analysis?** | **Habitat** | **Location info for Marin County** | **source** |
|---|---|---|---|---|---|
| Ridgeway's rail (Clapper rail) | *Rallus longirostris obsoletus* | YES - analysis based on ESA estuary elevation capital | tidal salt and brackish marsh | suitable habitat exists in Tomales Bay (unknown if actually breeding there); bolinas possible transient birds | https://ecos.fws.gov/docs/five_year_review/doc4150.pdf |
| marbled murrelet | *Brachyramphus marmoratus* | YES - analysis based on mapped critical habitat | | see critical habitat maps | USFWS |
| western snowy plover | *Charadrius alexandrinus nivosus* | YES - analysis based on mapped critical habitat | beach/dune | see critical habitat maps | USFWS |
| California red-legged frog | *Rana aurora draytonii* | YES - analysis based on mapped critical habitat | | see critical habitat maps | USFWS |
| yellow/golden larkspur | *Delphinium luteum* | YES - analysis based on mapped critical habitat | | see critical habitat maps | USFWS |
| showy rancheria clover | *Trifolium amoenum* | YES - analysis based on CNDDB occurrence record | coastal bluff scrub | Dillon Beach is only remaining natural population | http://ecos.fws.gov/docs/five_year_review/doc4018.pdf |
| Baker's larkspur | *Delphinium bakeri* | no (pop extirpated) | one broad area reported touched by upriver flooding | reported 1923 and presumed extirpated at time of listing | U.S. Fish and Wildlife Service. 2015. Recovery Plan for Baker's Larkspur (Delphinium bakeri). U.S. Fish and Wildlife Service, Pacific Southwest Region, Sacramento, California. vi + 37 pp. |
| beach layia | *Layia carnosa* | no (PRNS only) | coastal dune | all within Pt Reyes NS | https://www.fws.gov/arcata/es/plants/beachlayia/documents/Signed%20beach%20layia%205yr%20review_2012.pdf |

| Common Name | Scientific Name | Included in analysis? | Habitat | Location info for Marin County | source |
|---|---|---|---|---|---|
| Sonoma shortawn foxtail/ Sonoma alopecurus | *Alopecurus aequalis* var. *sonomensis* | no (PRNS only) | freshwater marshes and swamps and riparian scrub | likely only PRNS | https://ecos.fws.gov/docs/five_year_review/doc3898.pdf |
| Sonoma spineflower | *Chorizanthe valida* | no (PRNS only) | sandy coastal grassland | The species is restricted to a single natural population and a single reintroduced population at Point Reyes National Seashore (PRNS) in Marin County, California | http://ecos.fws.gov/docs/five_year_review/doc3558.pdf |
| Tiburon paintbrush | *Castilleja affinis* ssp. *neglecta* | no (GGNRA only) | serpentine bunchgrass | 5 Marin County populations: occur only on GGNRA land and on Tiburon peninsula (inside Bay) | https://ecos.fws.gov/docs/five_year_review/doc4019.pdf |
| Tidestrom's lupine | *Lupinus tidestromii* | no (PRNS only) | partially stabilized coastal dune | The population at Dillon Beach in Marin County has since been extirpated (S. Lynch, Monk & Assoc., pers. comm. 2008). | https://ecos.fws.gov/docs/five_year_review/doc3210.pdf |
| San Bruno elfin butterfly | *Callophrys mossii bayensis* | no (San Mateo county only) | short-statured coastal scrub and grassland | All known locations are restricted to San Mateo County, California, | https://ecos.fws.gov/docs/five_year_review/doc3216.pdf |

## APPENDIX B - SEABIRD COLONY VULNERABILITY

**Table B-1.** Summary of potential vulnerability of seabird colonies on non-federal lands within the study area. The North-Central coast breeding seabird population extends from Point Arena to Pigeon Point.
PECO = pelagic cormorant; BLOY = black oystercatcher; WEGU = western gull; PIGU = pigeon guillemot

| **Colony name** | **Species** | **Percent of North-Central coast breeding seabird population** | **Habitat/ condition** | **Top of cliff ownership*** | **Existing infrastructure that may lead to armoring** |
|---|---|---|---|---|---|
| Sonoma-Marin County Line | PECO<br>BLOY | 0.003 | NA | | unknown |
| Dillon Beach Rocks | PECO<br>BLOY<br>WEGU<br>PIGU | 0.004 | actively eroding cliff, cliff retreat projected to continue | Private<br>*Note: offshore rocks are National Monument (BLM)* | None obvious |
| Stinson Beach to Rocky Point | BLOY<br>WEGU | 0.0008 | actively eroding cliff, cliff retreat projected to continue | State Parks | Highway 1, Steep Ravine Environmental Campground |
| Gull Rock | PECO<br>BLOY<br>WEGU<br>PIGU | 0.08 | offhsore rock - tall/steep, inundation minimal even at 2m SLR | likely State Parks | None (uninhabited offshore rock) |

NA = lacking clear location information, cannot assess hazard

*Ownership source data: California Protected Areas Database 2016

Cliff retreat: from ESA 2015 modeling

Seabird source data: USFWS. 2012. 2011-2012 breeding population estimates for seabirds breeding in the MLPA's North Central Coast Region of California. Database compiled from multiple sources by G.J. McChesney, U.S. Fish and Wildlife Service, San Francisco Bay National Wildlife Refuge Complex, Fremont, CA.

Percent of population from Point Arena to Pigeon Point: source data from USFWS 2011 breeding surveys for the North-Central Coast MLPA, http://oceanspaces.org/data/north-central-coast-seabird-colony-and-foraging-studies-seabird-breeding-population-sizes-2010

# APPENDIX C - DEVELOPING A CLIMATE ADAPTATION MONITORING PROGRAM

## Considerations of survey design

Simultaneous with the implementation of climate-smart nature-based adaptation solutions, the County of Marin will establish the foundation for evaluation of management actions. This evaluation is necessary to understand the success of adaptation actions under projected climate change scenarios. It requires more than a depiction of trends or rates of change. Three sets of questions are of particular interest:

1. Under what conditions will the populations of indicator species require management action? Can specific parameter values, i.e., trigger points or thresholds be identified? The specific definition of trigger points, including the parameters of interest, will help define the type and intensity of monitoring required.

2. Under which future scenarios should Marin County implement actions to ensure a species or habitat adapts to climate change? The understanding of the possible scenarios, and how they may affect the indicator species, will help identify if and when to act proactively and to prevent irreparable losses as well as to meet goals of maintaining or recovering species populations.

3. Which climate adaptation management actions are most effective for each species or habitat where action is needed? Due to uncertainties in our knowledge, it is important that we frequently evaluate and adjust our management actions to ensure they are most effective in helping wildlife, plants, and their habitats to adapt.

We note that the objective of designing a monitoring program is primarily to understand rates and causes of change with some level of precision and accuracy, to evaluate or modify management actions, and to identify what further actions are needed, if any. It is possible to use population abundance as a target, but this has notable drawbacks. Populations oscillate in numbers (or range sizes) every year. It is unclear if a target population level has been reached if the number changes the next year (Figure C-1). Also, there is no gain in the understanding of the processes driving the observed numbers. The use of trends and hypothetical mechanisms of change as targets implies multi-year knowledge of the behavior of natural populations, over the short- and long-term, thus more robustly reflecting their status (Nur et al. 1999, Nur et al. 2015, Nur and Herbold 2015). The relationship between trends in abundance and ecological mechanisms sheds light on the causes of population changes.

Clarifying the causes of change is a paramount motivation for the design of monitoring programs for impacts of climate change. It is one of the three most important and distinct considerations between these long-term programs and the conventional approach to monitoring wildlife (see e.g., Nur et al. 2015). It is unreasonable to practice judicious trial and error, waiting 30 years to figure out if initial hypotheses and assumptions about the nature and magnitude of change still hold, and whether we took the most appropriate management decisions. Rather, a scientific approach with strong inference should be used to constantly evaluate competing hypotheses and adjust management actions along the way. The other considerations unique to monitoring for climate change relate to the broad spatial scale and decades-long nature of the monitoring project. There will be changes in the technologies used to capture and maintain data, with data sources that may emerge or disappear throughout the course of the monitoring program. So the monitoring program is ideally designed to use a variety of data sources, be relatively inexpensive, and adaptable to ensure it continues to deliver actionable results.

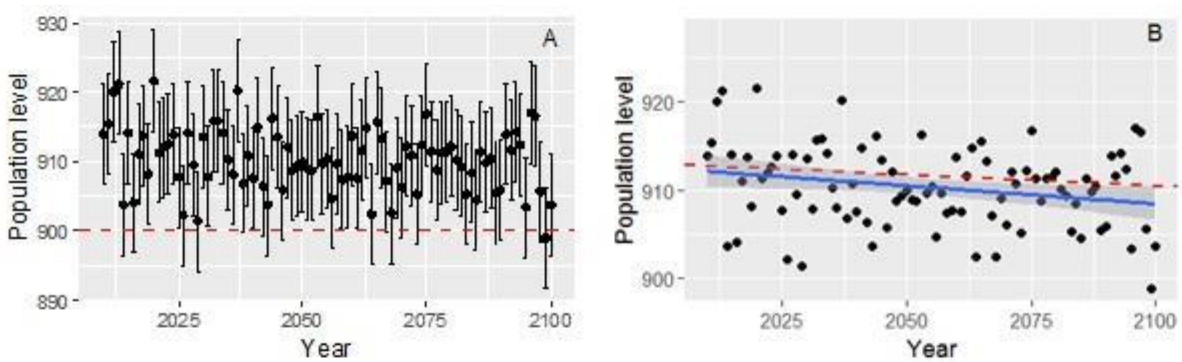



**Figure C-1.** Using population numbers vs trends as monitoring goals. Panel A shows the density estimates of a hypothetical population. The red line indicates a population target: if the population reaches that level, adaptation strategies are considered to fail. Given the interannual variability in the data, it is unclear when the population reached that point and thus, if the management actions are effective. Panel B shows the same dataset with the trend target (red dashed line), the estimated trend (blue line), and the error in estimation (light blue shaded area). The estimated trend is clearly below the confidence interval of the target by mid-century.

With the goal of determining long term rates and causes of change, of habitats and critical species, a trade-off is commonly encountered between precision in estimation and the required (and costly) survey effort. It is perhaps desirable to use relatively cheap and abundant data, such as citizen-science or remote-sensing data that are collected persistently over time. However, these usually have high levels of imprecision (spatial and temporal), often limiting confidence in information content. On the other hand, controlled-effort, well-randomized survey designs controlling for observer and other sources of error, such as is the goal in standard research practice, may be too expensive to encompass all areas of interest over a sufficiently long time period.

A third alternative is to use a mixture of both types of data. The smaller and more precise research-type surveys may be used to accurately estimate the more sensitive and critical information and the large and cheap datasets used to estimate less sensitive parameters. Here we propose that this combined approach be considered for monitoring selected taxa, though for some species the professionally trained surveyors will be required. Regardless of the approach, the design should be based on a rigorous statistical foundation, using statistical power analysis to detect the targeted changes to determine the amount of sampling required to understand changes and the impacts of management actions, as well as to control for potential confounding factors (Nur et al. 1999).

To determine which are the most effective adaptation management actions and how to adaptively manage actions requires an understanding of the species' response to change in available habitat, habitat characteristics and other factors related to climate change (Nur and Herbold 2015). For example, a change in habitat may result in a different carrying capacity, perhaps because the change altered the shape of the habitat, thus resulting in positive or negative trends in density of individuals. It may also result in a more volatile density, for example, a change that makes the population more susceptible to effects of weather on survival or productivity that will result in higher variance in trends, and consequently an increase in the probability of local population extinctions. Such examples are described in detail in the Bayland Ecosystem Habitat Goals Update Report (Goals Project 2015, Nur and Herbold 2015). Figure C-2 shows the expected responses of four marshbird species to changes in marshes due to sea level rise in the San Francisco Bay. Each line in the figure represents a different population path depending on the scenario. The various ways in which population parameters (mean or variance in trend values, mean or variance in probability of a pre-determined outcome) represent a set of hypotheses on how the indicator species may respond to changes in the environment. Adaptation management actions may be based on this knowledge, and their effectiveness tested in terms of the response they elicit in wildlife populations as measured through those population parameters.

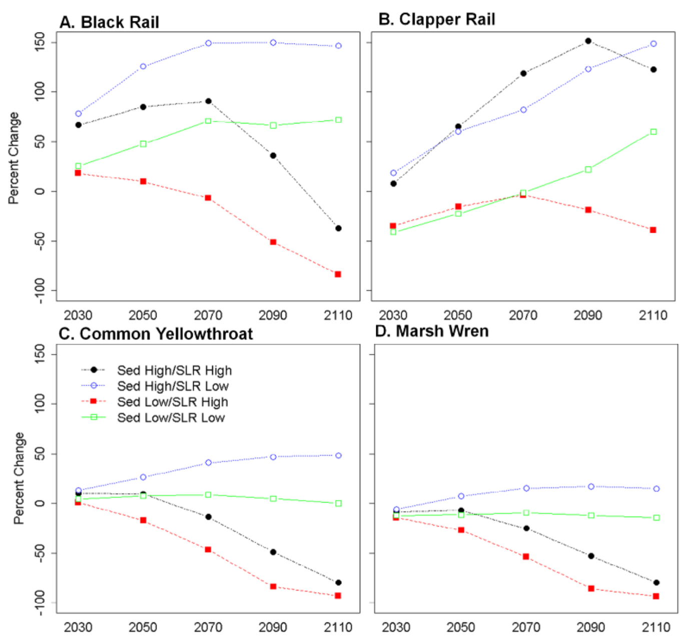



**Figure C-2.** The projected percent change from predicted 2010 abundance of Black Rail (A), Clapper Rail (B), Common Yellowthroat (C), and Marsh Wren (D) for each combination of the sediment/sea-level rise scenarios. Adapted from Veloz et al. 2013.

The hypotheses as depicted above imply metrics measured on a time scale. We usually speak of some percent change in suitable habitat within certain time frame. We also consider population change with respect to time. When predicting into the future we can project future population trends with respect to time (e.g., Nur et al. 2007), but we do not know how much time it will take for a certain amount of change in habitat to happen.  However, climate change models provide multiple metrics against which to measure change. It is possible, perhaps also desirable, to understand habitat changes in relation to amount of sea level rise, or temperature change, or other climate change metrics. These relationships may help identify the most important drivers of change in wildlife and plant populations. That said, animal and plant populations operate on generational time scales of a few years to decades, and so habitat change thresholds (and perhaps targets) need to be scaled accordingly and incorporated into time-specific monitoring and evaluation.

As more monitoring data are collected, analyses may then reveal more support for one competing hypothesis vs the others with regard to habitat change, and more support for one hypothesis over the others on how the population of the indicator species responds to these changes. The velocity of change is critically important to animal and plant populations.  A 50% loss of habitat over 25 years is of much greater concern, and its impacts must be able to be detected by a monitoring program, compared to a 50% loss of habit over 75 years.

## Setting initial indicator species, monitoring parameters, and monitoring goals

Management goals are usually set to maintain or increase population levels of a particular species, and of the critical habitat the species depend upon. In the context of climate change adaptation planning, population vulnerabilities should have been identified through a vulnerability assessment and a monitoring goal will be to identify whether adaptation actions reduce population vulnerabilities. Though it may be feasible to directly measure the trends in habitat availability, these measurements provide limited information about processes that maintain or alter the amount of habitat, or if the ecological services are being preserved.

Finally, the choice of indicator species is of paramount importance (e.g., San Francisco Estuary Partnership 2015). Often critical changes in habitats and ecosystem services are difficult to detect and require costly survey methods. Indicator species may exist that are sensitive to changes that would reflect on habitat quality and ecosystem services. A good indicator species is such that it can be monitored with relative ease, cost-effectively, and is also sufficiently sensitive to changes as to inform on the status of the habitat.

## Identifying data sources and parameter variances for designing a monitoring program

To summarize, the successful monitoring program depends on the appropriate choice of monitoring targets, with desirable and attainable probability of detecting them through cost-effective survey methods of good indicator species. An initial feasibility study using existing and perhaps new data could be used to determine which species, targets and survey effort to use to ensure some level of confidence in reaching the monitoring objectives.

Understanding the data sources is paramount to designing an effective monitoring program. The most important initial consideration is that the monitoring of climate change impacts and adaptation actions will span a long period of time and encompass large areas. Thus, data sources will likely be varied, collected with different degrees of error, and ideally using inexpensive methods. As a consequence, there may be a relatively large uncertainty in the estimate of monitoring parameters (e.g., trends in abundance) at any given time. For example, if we are estimating trends in abundance of an indicator species in relation to sea level rise, we should expect a small trend. If collected with inaccurate methods, the trend estimate will have large variance. The probability of detecting the small trend using parameter estimates with high variance is low at best.

Answering the question about the effectiveness of a management action also requires an understanding of the variance in the appropriate population parameter, and what may be determining such variation. For example, the loss in density of a marsh bird species may be due to the shape of marshes changing with sea level rise, perhaps causing more exposure of birds or their nests to predators (Liu et al. 2012). An adaptation action may be to enhance marsh edges to reduce predation, and the metric of impact may be survival estimates for nests or individuals. In order to determine how much sampling is required to assess the impact of our management actions, we must have some knowledge of the variance in estimation of the survival probabilities in relation to survey intensity.

Since the probability of achieving a monitoring objective is dependent upon the variance in parameter estimation, a thorough review should be done *a priori* of potential data sources, data collection methods, and variance estimates from these data using standard statistical power analysis methods before deciding on specific indicator species, data sources, monitoring parameters, and monitoring targets. This review should take into consideration the cost of data acquisition at the levels needed to attain the desired probability of detecting the monitoring targets.

## Monitoring as a learning model

Monitoring information should be collected not only to determine if monitoring targets are being reached through judicious trial and error, but also why or why not. The relationship between monitoring parameters and climate change covariates will provide insights about the reasons for the current status of wildlife populations. These types of analyses test hypotheses about the functional response of the indicator species to the climate change, management actions, or other environmental change (Nur and Herbold 2015). Similarly, data on habitat changes provide insights about hypotheses on how climate or management actions affect these habitats. The knowledge gained from testing competing hypotheses on the effects of climate change or prior management actions are valuable in the design and implementation of future management actions.

Setting several competing hypotheses *a priori* enables the use of strong inference approaches to understand the ways populations are affected, and thereby guide the development and choice of effective management actions. Management decisions may be made in one of several ways. For example, they may be based on the best supported hypothesis (e.g., that sea level rise is altering the shape of marshes, because marsh shape shows the strongest relationship with trend in abundance, and this trend may be the result of higher exposure of nests to predation, therefore management actions may be directed at reducing nest predation), or on a weighted average of all hypotheses (e.g., a combination of more-or-less equally important factors determines the observed trends, so a variety of management actions may be implemented, or choose actions that address more than one factor affecting the population), or on a risk aversion plan (e.g., some effects are well known and some are unknown but potentially impactful, yet actions are taken on the suspected, potentially most impactful factors even if not well understood).

Whatever the management decisions, new hypotheses of population response may be drawn over time, against which future data may or may not lend support. The rejection or lack of support for some hypotheses also reveals the important drivers of population change, helping make better management decision over time. More effective management actions and better metrics lead to increased probability of achieving monitoring objectives.

## Monitoring marshes through bird indicator species

Birds are unique among wildlife for a variety of reasons. They are easy to count and relatively cheap to monitor; there is a large contingent of “citizen scientists” (volunteers willing to go out, count birds, and record their findings in online databases); and there is a wide variety of adaptation strategies among birds that reflect various ecological functions of the habitats where they are found. Not surprisingly, birds are the most frequent study subjects among wildlife species. Several species live in coastal marshes in Marin County and can act as potential indicator species of marsh quality. Here we use marsh bird species inhabiting coastal marshes subject to tidal action as an example to illustrate how a monitoring plan may be devised that helps develop effective management actions over time.

Figure C-2 above shows several possible paths for populations of marshbirds into the future. We note that each path depicted for each species is a hypothesis about the climate change scenario expected, and about how the species will react to it in terms of numbers or density. Similar scenarios must be developed for any other species of management interest.

Trends in density may be a metric to help understand the type of climate change impact, so a monitoring scheme should be designed to ascertain which future path the population is following (Nur et al. 1999). However, other metrics may be more appropriate to understand why and how the population is responding to climate change, and whether management actions are effective. For example, in Figure C-2 some paths point to a decline in densities into the future for Marsh Wren. As a hypothesis, we may postulate that this is due to an increase in mudflats and loss of low-elevation marshes that provide nesting grounds. So, population numbers during the breeding season or productivity estimates may provide a more effective metric for testing this hypothesis and the effect of any management actions based on it.

Estimating productivity of the species requires labor-intensive mist-netting with variance in parameter estimates in relation to survey intensity. Counting breeding populations may be done at much lower cost and with the use of citizen scientist participation to cover large areas. The estimate of breeding populations will have variance that can be reduced with more survey intensity. With this information at hand, we can set monitoring targets: maintaining long-term productivity at no less than 90% of current level, or no less than 85% of the current estimate of birds per hectare during the breeding season, for example by the year 2030.

The variance estimates permit statistical calculation of the amount of sampling required to have 80% chance of detecting these trends. By doubling (for example) the mist-netting effort, or increasing the breeding bird survey effort by 50% both targets may be achieved. Critically, however, the increase in cost associated with doubling mist-netting effort far exceeds the increased cost of breeding bird surveys, because of the need to train and certify technicians to properly collect the mist-netting data. The breeding bird surveys are much more cost-effective. Importantly, mist-netting may still be used to provide evidence of current trends. The impact of management actions is estimated similarly. A goal is set about the amount of change expected in the appropriate metric. Estimates of variance around the metric then permit the estimation of the amount of sampling required to reach the monitoring objective to ascertain the effectiveness of the management action.

## Climate adaptation monitoring example

Figure C-3 below describes a specific hypothetical management example for the Giacomini marsh in Marin County, where a species of marsh bird may be impacted. The figure illustrates a hypothetical program with the goal of ensuring populations of California Black Rail (BLRA) are adapted to climate change in the Giacomini marsh. Projections are made of expected changes in marsh area under different sea level rise scenarios (see Figure C-3 below). The first programmatic decision, based on these projections, is to evaluate the possible impacts of alternative management actions, and decide on which to implement. This triggers the monitoring of the threatened population. Further decisions must be made about the monitoring targets and objectives to determine which one of the future projections may ensue, given the actions taken. This evaluation involves costs related to different targets, methodologies, and amount of survey effort, related to the monitoring objectives chosen (e.g., 80% chance of detecting a 5% trend in Black Rail abundance).

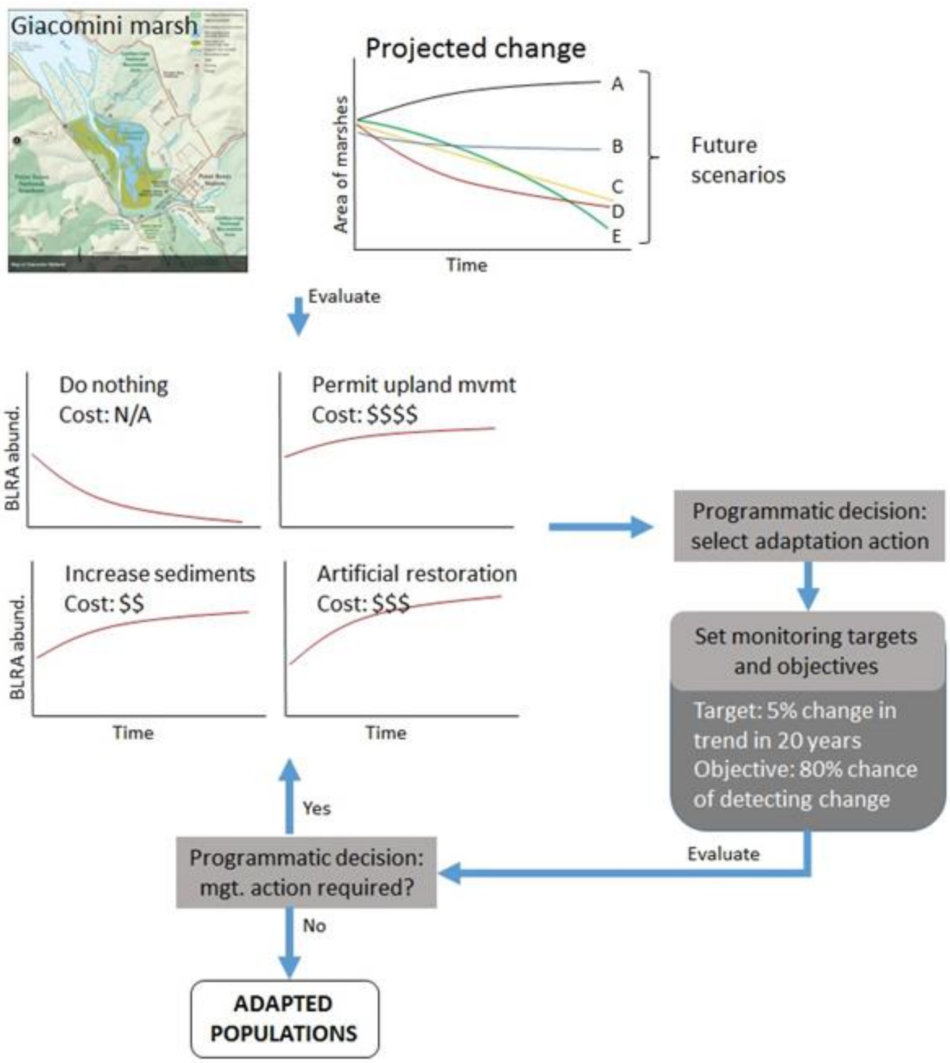



**Figure C-3.** Designing a Black Rail monitoring program for a hypothetical example of impacts to the Olema and Giacomini marshes.

Monitoring is conducted, and the results trigger the second programmatic decision: which one of the future scenarios is best supported by the data and does it merit additional adaptation actions? Strong-inference hypothesis testing reveals that scenario D, where initial loss of Black Rail numbers is high and then less pronounced, is the best supported by the data, and that management actions were not sufficient. Analyses also reveal that the most likely cause is loss of low elevation marshes. These results then trigger a new programmatic decision and a new iteration of the learning process until effective actions have been taken and there is enough confidence that the Black rail population in the Giacomini marsh will successfully adapt to the future conditions.

It is important to note that the multiple sites potentially impacted will differ in how they respond to climate change under various scenarios. This is likely due to different mechanisms operating at each site. For example, other marshes in Tomales Bay may maintain the total marsh area but change in shape, and the impact on bird populations may be due to higher exposure of rails to predators or invasive plant species. Consequently, different adaptation strategies may be implemented at some sites and not others (or to varying degrees), with different costs and expected impacts. Therefore, trade-offs may exist also across sites about where, what, and to what degree should actions be implemented. This is another type of programmatic decision not depicted in Figure C-3 above.

Lastly, one of the most effective adaptation measures for climate change is the buffering of populations with high numbers. This action may be considered for areas where, for example, marsh restorations are possible now, and likely to be successful despite sea level rise (e.g., where they are expected to accrete to some degree and cope with the change). Boosting population numbers now may help the species cope with losses later on. As with other management decisions, monitoring targets and objectives should be put in place to ensure the restorations are effective.

## Monitoring marine mammal haul out habitats

Depending on the sea level rise scenario, a set of possible changes in beach availability may ensue (Figure C-4A). Accordingly, a set of possible effects on seal/sea lion populations may be observed in response to the available amount of beach habitat (Figure C-4B). Estimating the number of seals or sea lions breeding in haul out locations through direct counts requires surveying that can be done repeatedly within a breeding season. Some areas of difficult access may require more expensive survey methods, such as boat surveys, aerial surveys, or the use of drones. Alternatively, a more costly mark-recapture program may be implemented to track the survival and productivity of individual females.

Monitoring goals can be set, for example, to ensure that a trend of 5% per year over 10 years in the number of male or female seals/sea lions can be detected with some confidence level during the breeding season in the haul out beaches. So, adaptation management actions (such as restoring or creating artificial beaches) may be taken in an attempt to increase male or female occupation of haul out sites. Monitoring targets can be set to achieve 80% or more confidence in detecting the 5% trend in occupation by female seals/sea lions in managed beaches. The targets can be estimated with knowledge of how variance in counts relates to survey effort.

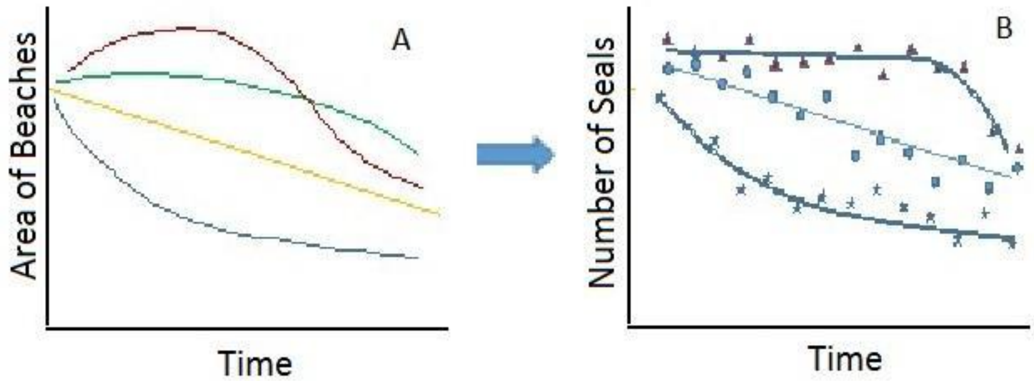



**Figure C-4.** A - Hypothetical change in area of haul out beaches with sea level rise for marine mammals in Marin County. Each line represents a different response scenario, due to a combination of sea level scenarios and beach accretion. B – Hypothetical responses in numbers of seals to the loss of haul out beach areas.

Alternatively, productivity and survival of females can be considered in population dynamic models that integrate other climate change impacts (e.g., warming of waters, changes in prey availability) to understand the impact of the loss of beach habitat on seal/sea lion populations. Variance around survival and productivity estimates permit the estimation of the amount of tagging and re-sighting effort needed to detect a change in 5% for each survival or productivity parameter for females within 10 years. Management actions can then be understood in terms of their expected impact on these population dynamics parameters, with monitoring objectives based on these projected impacts.

## Brief considerations about a monitoring information management framework.

Assuming that the goal is to maintain or improve on the current status of wildlife and plant populations, the monitoring plan requires three types of information to be used every time an evaluation of population status is requested. First, it requires the count data from the indicator species. Second, it requires covariate information about each specific survey. For example, surveyors often collect weather and other environmental data that vary across locations, dates within a year, and throughout years. This information should also relate to the projected impacts from climate change and sea level rise. Third, it requires covariate information that relates the observed changes to the management actions. For example, typical survey designs in ecological studies call for spatial and/or temporal stratification of the surveys to permit contrasts before and after, and/or between control and impact locations; the so-called "BACI" designs: before-after-control-impact. Though these three types of data will be used toward the same goals, they may not be collected by the same institutions, or maintained using the same information management systems. Hence, an ideal monitoring information management framework must be capable of integrating different sources of data, with considerations about their longevity and reliability, level of description, and about the means to combine the data for the goals of an effective monitoring program that is expected to last decades.

Regarding the longevity, concerns are not only about repositories planned to last decades, if not indefinitely. These repositories must be adaptable to the expected changes in the data collection methods (not just the techniques, but the frequency of collection), data management technologies (description and preservation), personnel, etc. The sources of data, as briefly described above, are collected using different instruments, methods, and precision levels that will change with time. Monitoring contractors change over time, and there is always flux in personnel within institutions. Thus, the design of a long-term monitoring information management framework should take into consideration the use of stable repositories that are adaptable to the changing technologies used to collect, describe, and maintain the data, and the changing schedules of data collection.

Lastly, transparency and objectivity should also be desirable features of a monitoring information management system. All the data, analysis code and algorithms should be made openly available for third-party scrutiny.

## Looking forward

Our goal is to project future trends, not just look backwards. The insights we will obtain through the type of monitoring program described here will allow us to project future trends, given environmental change.  Subsequent data collection and analysis will allow us to improve our insights regarding what are the critical factors affecting populations and their trends, and thus improve our ability to project future trends and ensure robust and resilient wildlife populations

# Appendix G

# ADAPTATION PLAN PASSPORT SUMMARY RESULTS

## Marin County Community Development Agency
## Collaboration: Sea-level Marin Adaptation Response Team (C-SMART)
## Adaptation Plan Passport Results Summary

In summer 2017, Marin County Community Development Agency (CDA) launched the ***Collaboration Sea Level Marin Adaptation Response Team (C-SMART) Adaptation Plan Passport***. The objective of this passport was to seek input from community members to inform next steps the County could take to address sea level rise in West Marin. As C-SMART Phase 1, including the Vulnerability Assessment and Adaptation Report, is anticipated to conclude in September 2017, CDA staff are developing a Phase II work program with direction from the Marin County Supervisors. Thus public input is critical to ensure next steps reflect local interest.

While previous C-SMART passports and surveys focused on the ***where*** and ***what*** of adaptation, this passport sought to understand the ***how.*** Participants were asked to give a High, Medium, or Low ranking to 11 different possible next step options spanning four categories: site scale improvements, community scale planning, continued partnerships and public education. Space was also provided for participants to comment on each ranking. Additionally, space was provided for additional options that participants felt were important for staff and elected officials to consider as possible next steps. Participants were also asked demographic questions to help staff understand community representation.

Passport options were modified from Next Steps in the ***Public Review Draft Marin Coast Sea Level Rise Adaptation Report.*** These next steps are ideas that have arisen through the C-SMART process to date. The options could be initiated with existing CDA staff time, but do not suggest County financial commitment. Passport results will be shared at the 8/1/17 Marin County Board of Supervisors C-SMART workshop.

The passport was shared with local community members through both traditional outreach and social media including:

- Hard Copies at Public Workshops (6/8/17 in Point Reyes Station and 6/14/17 in Stinson Beach)
- Hard Copies at June 2017 East Shore Planning Group Meeting (per request)
- Online Survey Monkey shared via:
    - Marin sea level rise website and email list (4,000+ email addresses)
    - Announcement in Point Reyes Light
    - Marin County Sea Level Rise Facebook page
    - West Marin Next Door (400+ people who live in West Marin)

***A total of 83 passports were completed!*** Summary results are as follows.

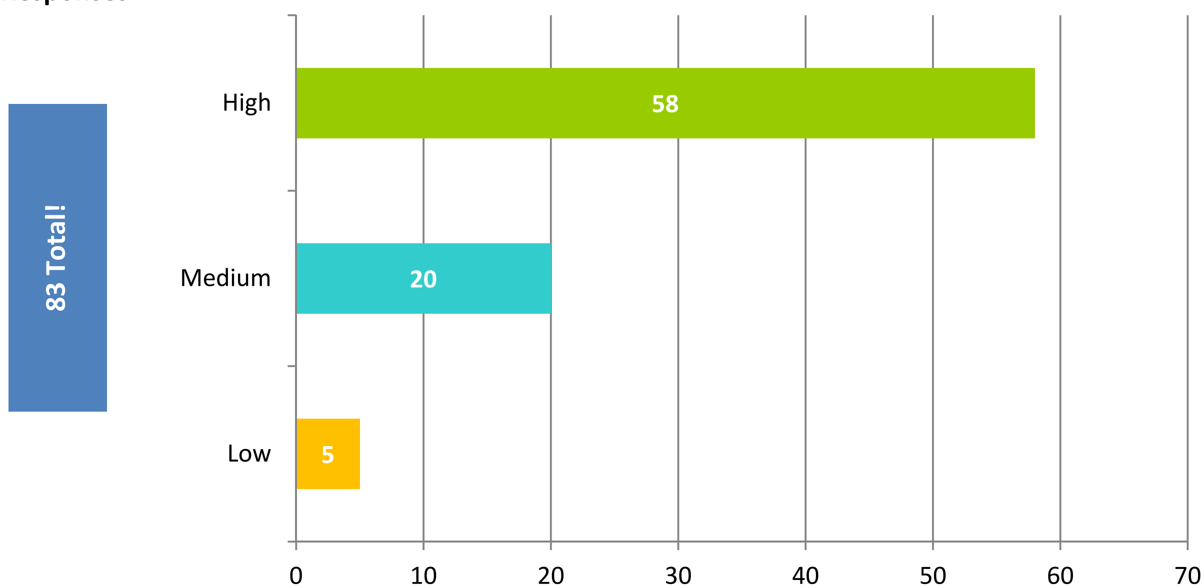
## Site Scale Improvements

**Option 1**

----- Develop a "**Homeowner's Guide to Preparing for Sea Level Rise**" to help property owners navigate regulatory system and funding opportunities to elevate or otherwise retrofit homes to accommodate sea level rise and storms. Topics could cover:

- County permitting process
- Coastal Permit Development requirements
- Agency Compliance (FEMA, California Coastal Commission, etc.)
- Potential estimated building elevation increase

**Responses**




**Comments**

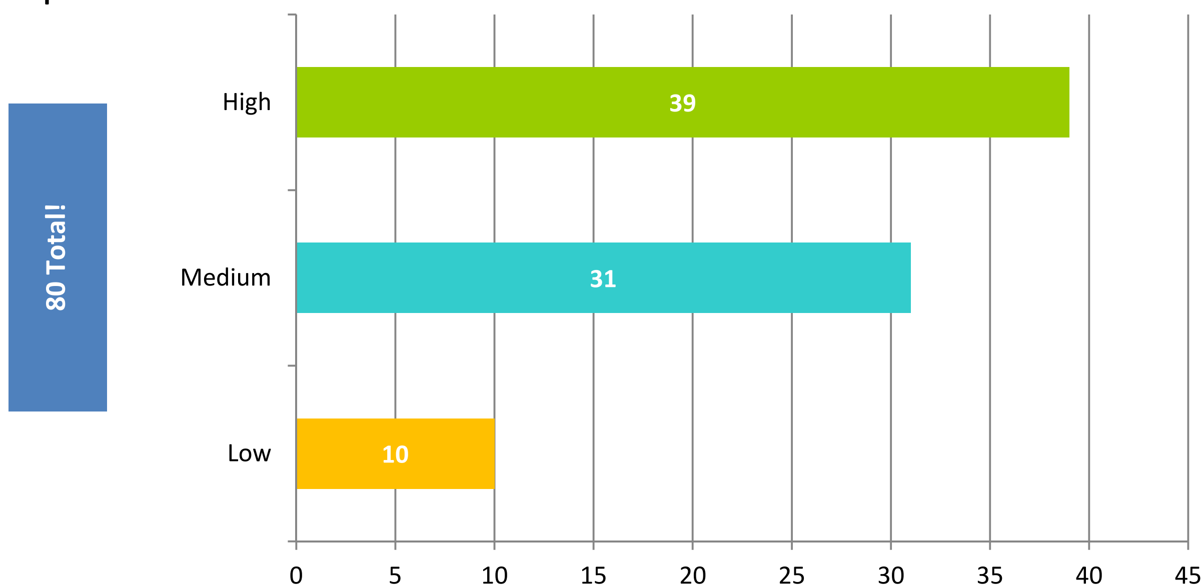
- Real estate disclosure statements
- Send them out by mail
- Sea level rise is B.S.
- Along with a list of other resources to help homeowners navigate the process and possibly list best practices
- Could be helpful to contactors for implementation. Possible savings on community-grouping of activities
- Limit to properties where flooding may occur / 3 feet of sea level rise
- Citizens need to be assured that government will NOT be part of the problem through excess regulations/requirements
- Should happen regardless for transparency
- Currently a lot of confusion on what is permissible, when permits are required, when waivers/exclusions can be sought. Would be helpful for County website and distributed to the community via architects, contractors and realtors

## Site Scale Improvements

**Option 2**

----- Develop and distribute technical information and guidance on **home retrofitting options** which could include elevation, wet/dry floodproofing, flood gates, drainage improvements, amphibiation, etc.

**Responses**




**Comments**

- Homeowners will rely on professionals
- Liberals still trying to regulate the world! Leave us alone!
- If the technical guidance is consistent with agency rules and accepted/embraced by the preponderance of contractors, this could be higher priority
- These may be expensive and costs need to be included. Some homes are not worth protecting
- Related to option #1
- Good in the short term, but I wonder about a waste of money for these interim steps. Why spend the money and then move/modify again?
- Limit to homes vulnerable to 3' sea level rise

## Site Scale Improvements

**Option 3**
----- Other Ideas – site scale improvements

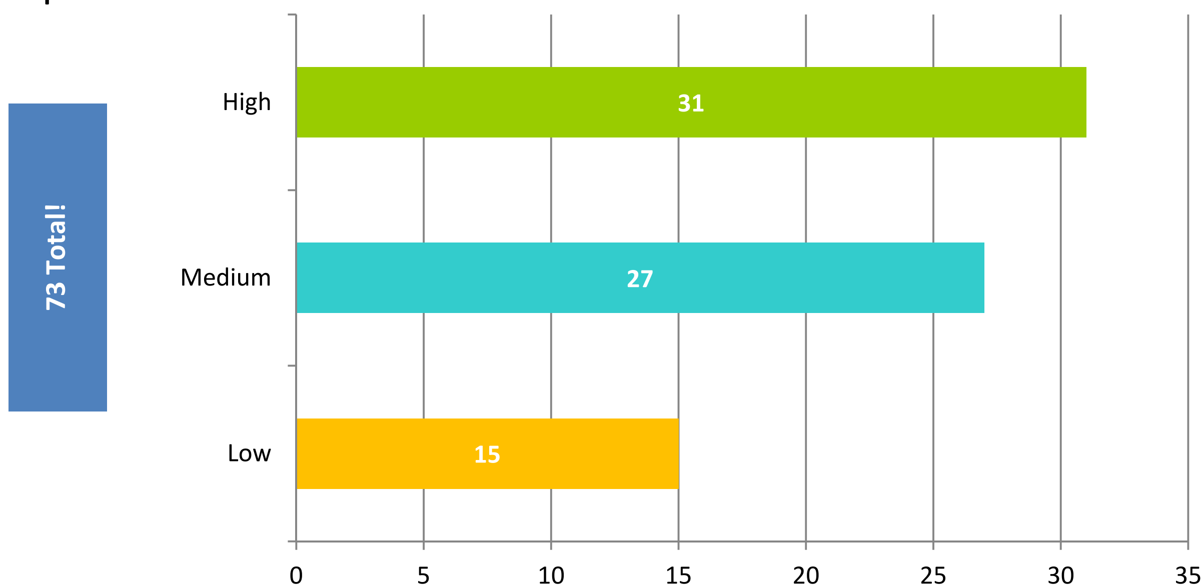
**Comments** (Individual responses, not tabulated)
- Staff time is probably best served by "more technical" planning type efforts. Guides and options would be helpful and maybe the staff could serve as a guide to direct individuals. Ultimately workshops with agency and industry reps could be helpful. Maybe this effort could work with community scale planning?
- Site elevation (home elevation), septic elevation, plumbing, reinforcement of stream banks.
- Consolidate projects. Look into grants
- Waste water systems – retrofit or replace with community system
- Programatic permitting, avoid duplicity, clearing house for homeowners/property owners
- Streamline permit process. Forget the past, think about the future and get it done!!!!
- More local meetings in beach/coastal community. Greater publicity/outreach
- Address required changes to infrastructure (roads, utilities, waste water)
- Stop meddling!
- Protect the rights of the existing network of protection that already exists and allow property owners to improve and maintain it.
- Tidal wetland enhancements, restoration and vegetation carbon capture

## Community Scale Planning

**Option 4**

----- Develop a **subcommittee** with Marin County BOS representation and community/local agency representatives to prioritize C-SMART next steps.

**Responses**




**Comments**

- More government? No!
- Community/local agency representatives have to have direct experience with coastal living in recent years, in the area of study
- This is very important to help maintain momentum on this project
- Too many acronyms here. Subcommittee should have authority to retain consultants
- BOS have to be responsible, knowledgeable and keep leadership roles. Committees can become too politicized.
- Seems that those who are most impacted – residents – should define priorities with government buy in
- Only viable if/when there is a LCP resolution. Once resolved this is a medium priority.

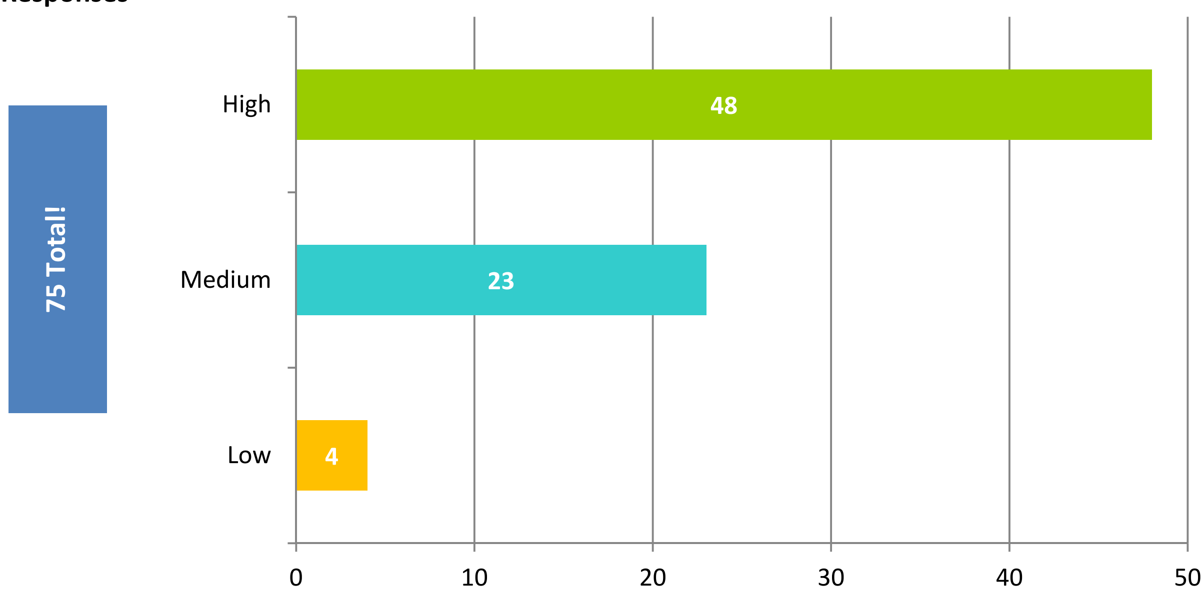
## Community Scale Planning

**Option 5**

----- Initiate **Community Plans for Adapting to Coastal Hazards** (Community PATCHs) in conjunction with community members and asset managers for smaller scale planning centered around vulnerable assets of community wide importance.

- Identify subarea boundaries for prioritization, possibly based on timing, area of impact, costs, equity, environment, economy, etc.
- Develop planning timeframes around the point at which flooding creates recurring significant problems
- Evaluate adaptation alternatives with cost estimates in more detail, which may include armoring, elevation, realignment, etc.

**Responses**




**Comments**

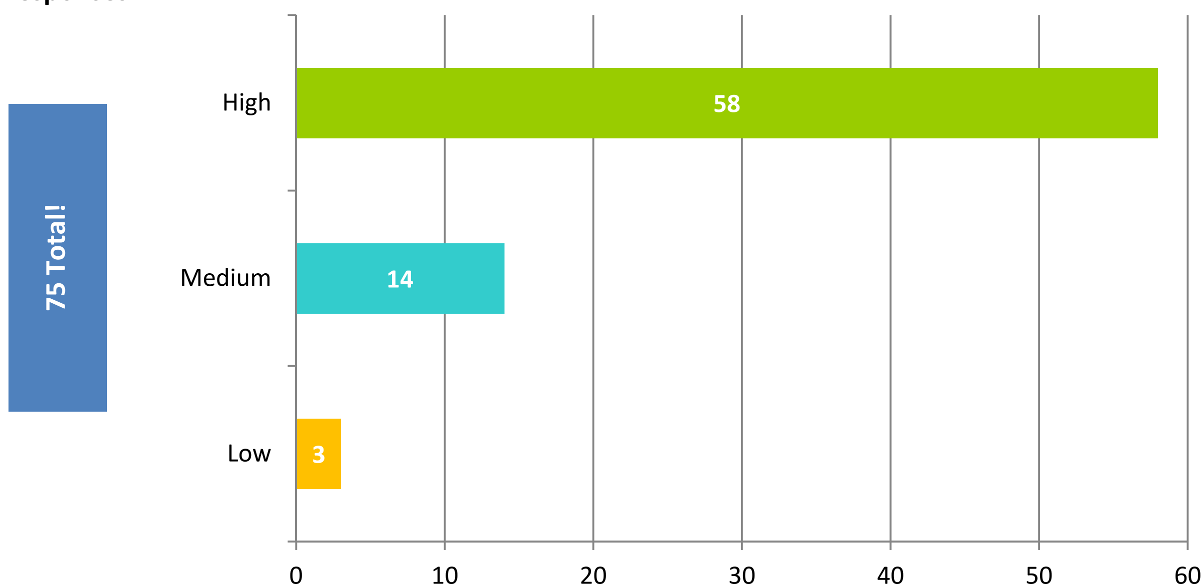
- Roads and Septic prioritize
- More B.S.
- The most important issue is the transportation system, which means the low lying roadways (i.e. Highway 1 around the Bolinas Lagoon)
- Asset managers? Very different timelines/objectives from homeowners
- Include shoreline retreat and tidal wetland restoration as a strategy
- Need technical help and knowledge
- Could be extremely valuable for near term flooding problems on our roads

## Community Scale Planning

**Option 6**

----- Consider sea level rise in capital improvement projects (roads, utilities, armoring, etc.) including both incremental repairs and maintenance, and new projects. Develop financing matrix for identifying possible funding sources including federal and state grants, local assessment districts, philanthropic resources, and public-private partnerships

**Responses**




**Comments**

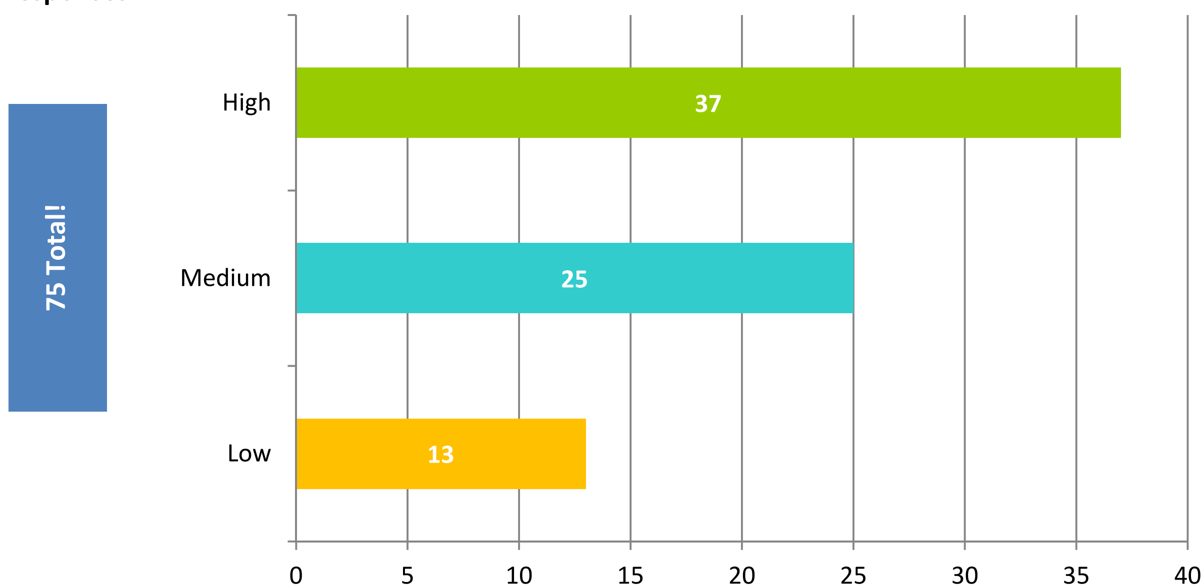
- Levee road (on Sire Francis Drake) flooded several times this past winter with rain and king tides and will be worse with sea level rise. Also Inverness store/downtown Inverness.
- More B.S.
- Promote new technologies as part of our new reality, like energy from solar, turning sewage into drinking water (toilet to tap), water production from solar panels, etc.
- More holistic approach
- Action to find funding sources will be critical
- Absolutely critical. If you're in a hole stop digging. Create ordinances that bar governmental future bailouts/emergency payments if strong guidelines/laws have not been followed on all prior new construction and major renovations.

## Community Scale Planning

**Option 7**

----- Evaluate **land use planning, zoning and legal frameworks** for addressing sea level rise which could include height limits, construction standards, and post-storm prohibitions. Such options could be integrated in the Local Coastal Plan Implementation Program and Marin Countywide Plan update.

**Responses**




**Comments**

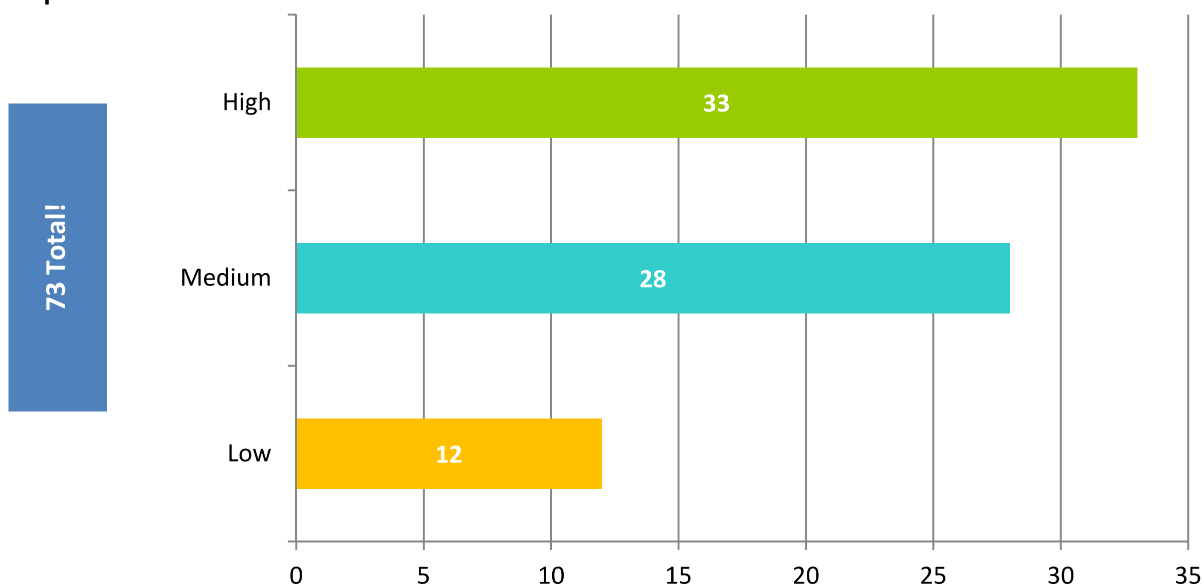
- Should be a separate focus
- While protecting the existing community fabric and organic framework in place now.
- Also very important for systemic mitigation
- I have severe flooding on my property, but I will not engage with sea level rise planning until there is CEQA reform or CEQA exemptions for public safety projects
- Focus on critical issues (low lying properties and erosion), not an excuse to increase regulations
- This could be a nightmare and effectively stall all new development…probably a good thing… but it would also stall attempts to retrofit… a bad thing… both due to weirdness at Coastal Commission…
- Should be "implement" rather than "evaluate"… This has immediate impact on property values – needs a really sound legal framework
- Appalling to me how little environmental hazards have been considered for some construction. More attention to environmental protections and more training for staff in decision making/advisory roles
- Early to include standards in regulatory documents without consensus on what fixes are needed
- Absolutely critical. If you're in a hole stop digging. Create ordinance that bars governmental future bailouts/emergency payments if strong guidelines/laws have not been followed on all prior new construction and major renovations.

## Community Scale Planning

**Option 8**

----- Consider sea level rise resiliency in the next update of the Marin Countywide Plan as a basis for developing countywide policies and programs.

**Responses**




**Comments**

- More B.S
- Very important though another substantial impediment to speedy MCP update

## Community Scale Planning

**Option 9**

----- Other Ideas – Community Scale Planning

**Comments** (Individual responses, not tabulated)

- Very High! Federal/state scale basis, like resource conservation districts, federal standards and $, local control and implementation
- Map and evaluate public trust boundaries, plan for public access
- Looking for more ways to expand government?
- Communities should be encouraged to work with the county to formulate and implement these proposals
- CEQA reform is vital. Conservation extremist groups block all sensible things due to CEQA. They block bike infrastructure, dredging, levees, public transit, public projects to address sea level rise
- Provide good estimates of sea level rise/flooding by year
- Provide demonstration projects; look at architectural solutions outside of U.S.
- Find grant and other sources of funding for large scale improvements

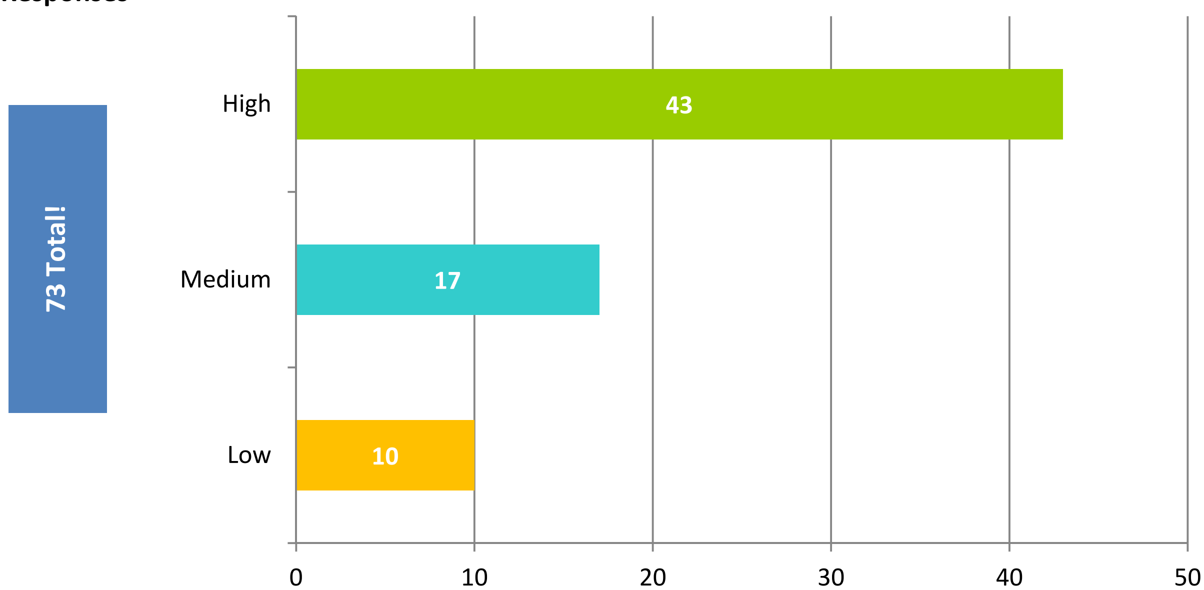
## Continued Partnerships

**Option 10**

----- Develop an **interagency sea level rise task force** with membership including County Supervisor and agencies who oversee West Marin assets (transportation, utilities, public lands, natural resources, etc.). Participants could include:

• Caltrans, MTC and TAM for transportation planning support
• National Park Service/Golden Gate National Recreation Area/CA Department of Parks and Recreation/Marin County Parks
• PG&E and local service providers to discuss utility adaptation

**Responses**




**Comments**

- Good luck! / Sure! Let's get everyone in the world involved / Prescription for bureaucratic paralysis / too broad, won't result in action
- We need progressive thinking individuals in this subject and majority of these agencies have not shown forward vision so far
- A task force could succeed with mandated completion date and leader with decision making authority
- Interactions with community groups will also be essential and critical
- Scary because this feels like it will force a one-size-fits-all solution, and that's not going to work best
- Golden Gate Transit, Water District (NMWD & MWD), telephone companies, cable companies, sewer and water treatment, and underground facilities and utilities
- A no brainer
- Get GFA/NOAA involved to spur Caltrans action on Highway 1. That worked for past flood control

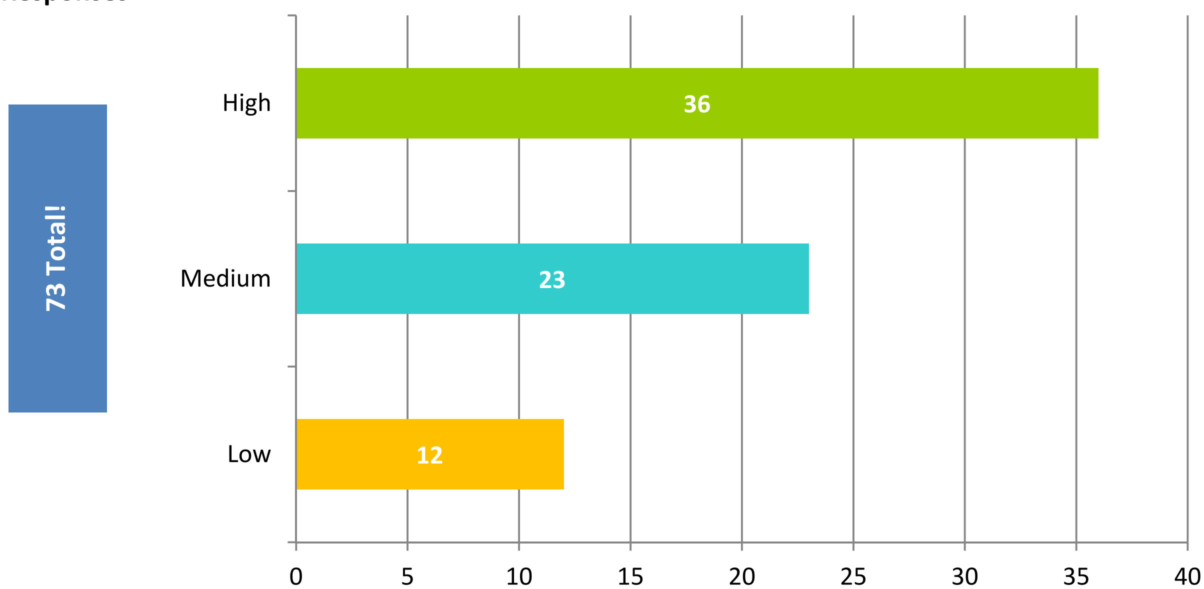
## Continued Partnerships

**Option 11**

----- Continue to work with the Sonoma/Marin County Sediment Management Working Group to assist with the development of a **Regional Sediment Management Plan** to

- encourage beneficial reuse of available, non-polluted sediment resources;
- restore and maintain coastal beaches;
- reduce shoreline erosion and coastal storm damages; and
- sustain recreation, tourism, public safety and access

**Responses**




**Comments**

- Gulf of the Farallones, Jack in rep
- Very important to build relationships
- General studies like this fail at the site level
- Very important for long term flooding mitigation and resources sustainability
- CEQA reform will be necessary for almost all of the good ideas proposed in this survey to work
- What does this mean? That sea level rise will bring more sediment or move sediment around more? Either way a lot of beach front uses will be unsustainable

## Continued Partnership

**Option 12**

----- Other Ideas – Continued Partnerships

**Comments** (Individual responses, not tabulated)

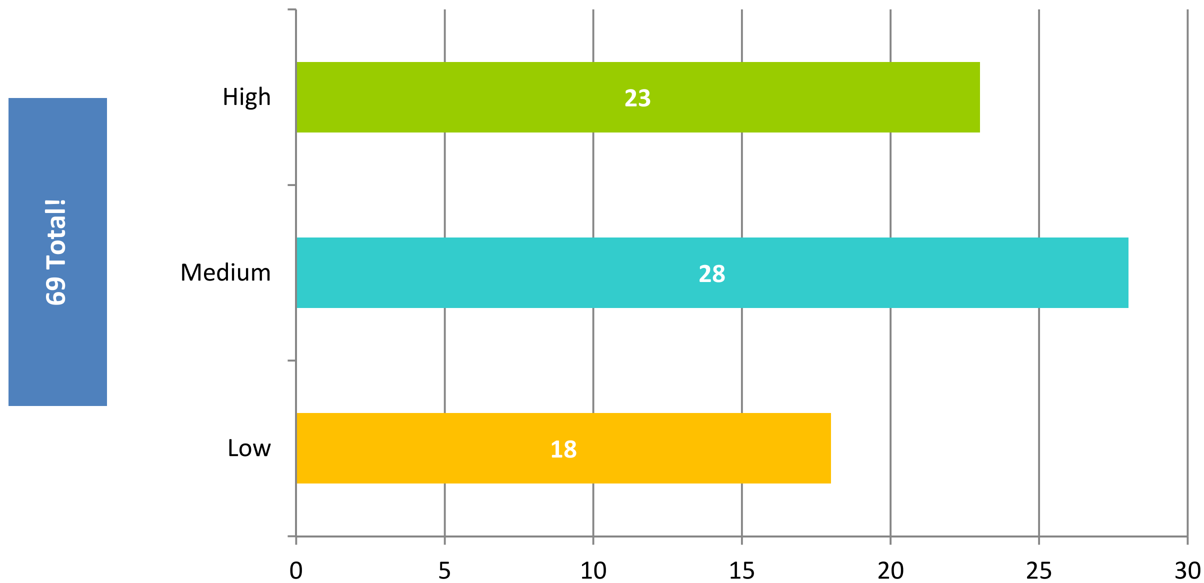
- Use partnerships with education systems/student to help with monitoring and mitigation options
- Most important is to allow local residents to adapt to changing conditions without interference from agencies with more allowance for strategic decisions. Important to realize that we want community to continue and not to undue damage. Trust the people that live here!
- Fund raisins to prepare for all these inevitable outcomes – home loss/relocation, community emergency solutions for housing transitions. Be sure that people who are continuing to build or remodel in zones that will see the rise are going to need to go beyond current 3 ft. Suggestions for FEMA
- Coordinate with Caltrans and other agencies. How to get these agencies to move quickly and in a coordinated way? How do we pay for this?
- Engage local housing bodies : Community Land Association of West Marin and Bolinas Community Land Trust in long term planning
- East Shore issues to have substantial East shore representation, including East Shore Planning Group
- Cooperation between community groups and governmental agencies is an absolute requirement
- I beg Marin Board of Supervisors to support state level CEQA reform and/or apply for CEQA exemption to critical public safety and green transportation projects. I consider planning for sea level rise to be a public safety project. Marin has clueless extremists who abuse CEQA to do things like prevent flood detention basins on the basis of aesthetics or minor impacts to endangered species
- Engage Marin Resource Conservation District, Marin Conservation Corps and UC Extension service in shoreline land management planning and restoration

## Public Education

**Option 13**

----- Establish a **citizen's science monitoring program** for community members to gather data on West Marin sea level rise impacts which could include measuring beach widths, documenting king tides and flooding, and monitoring wetlands.

**Responses**




**Comments**

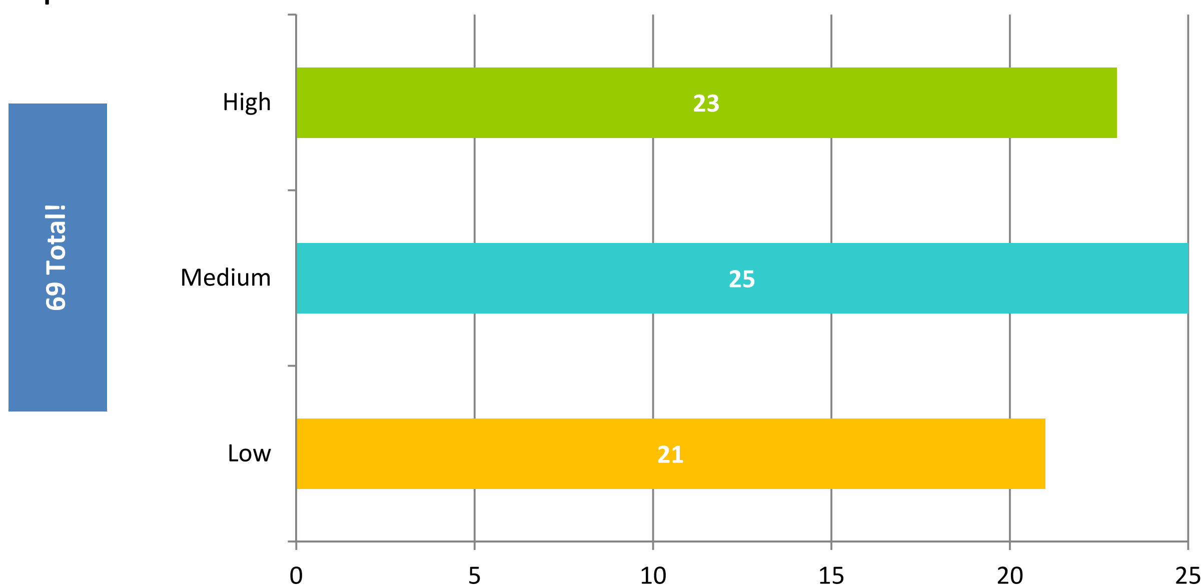
- Get real
- Too little, too late
- This should be handled by the County, not volunteers!
- Why not have existing groups do through own programs (Beach Watch, Point Blue, PRNS, GGNRA, etc.)
- Useful, but this data is available via remote sensing under existing frameworks

## Public Education

**Option 14**

----- Continue to pursue funding and partnerships to formalize a sea level rise **public education** program for high school students.

**Responses**




**Comments**

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- Too little, too late
- This should be handled by the County, not volunteers!
- Why not have existing groups do through own programs (Beach Watch, Point Blue, PRNS, GGNRA, etc.)
- Useful, but this data is available via remote sensing under existing frameworks

# Public Education

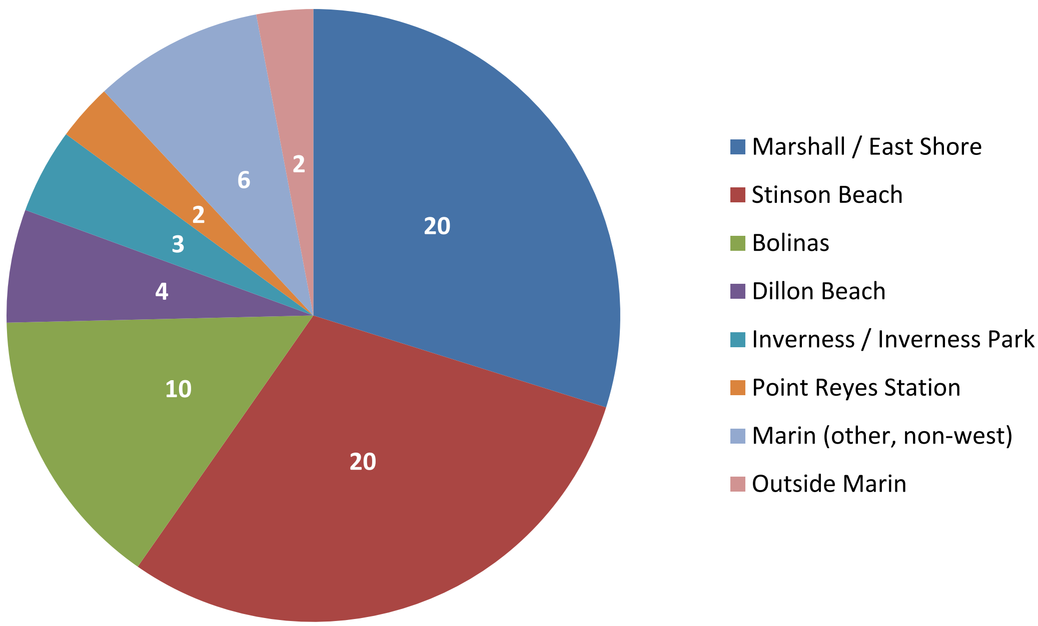
**Option 15**
----- Other Ideas – Public Education

**Comments** (Individual responses, not tabulated)

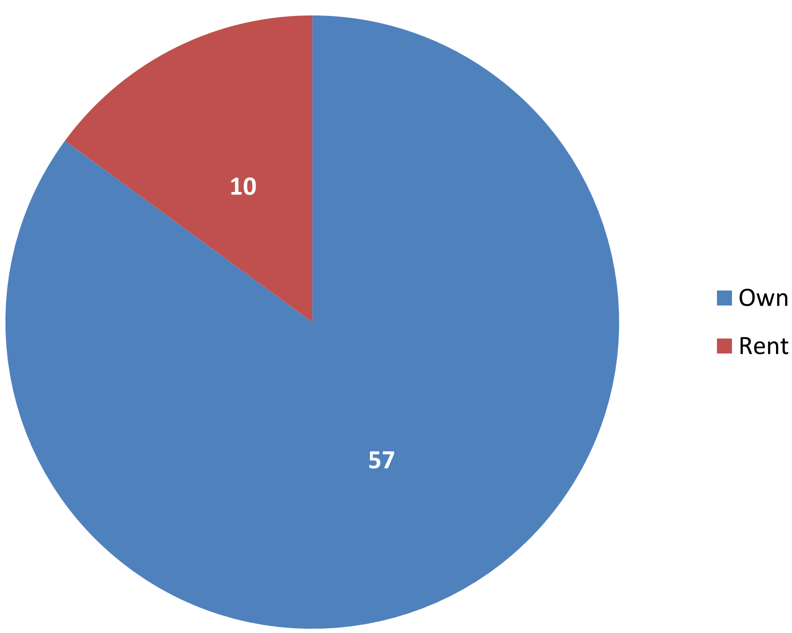
- Rather than develop a Marin County product, explore other areas for established programs. No need to duplicate
- Work out cost – who is going to subsidize Army Corps and FEMA? Can we do it as a whole package, blanked proposal/common engineer? Involve Coastal Commission and environmental groups like EAC. Outside groups must recognize our communities are important and must be protected
- Encourage a marine science program at local schools that can utilize this new normal as a significant useful monitoring devise. High school marine biology classes – connected with Bodega Marine labs
- Please just get on with it! And allow varied responses by CA coastal geography to prevail – one size does not fit all!
- Is there a way to show in time increments (say every 5 years) where we are in sea level rise – is it occurring more quickly or more slowly?
- Liberals looking to warp young minds
- Provide up to date local maps with sea level rise projections including different storm return periods, etc. This should be web-based (Google-Earth overlay?) and easy to use and access, with all appropriate source information and disclaimers included
- Of course

## Demographics

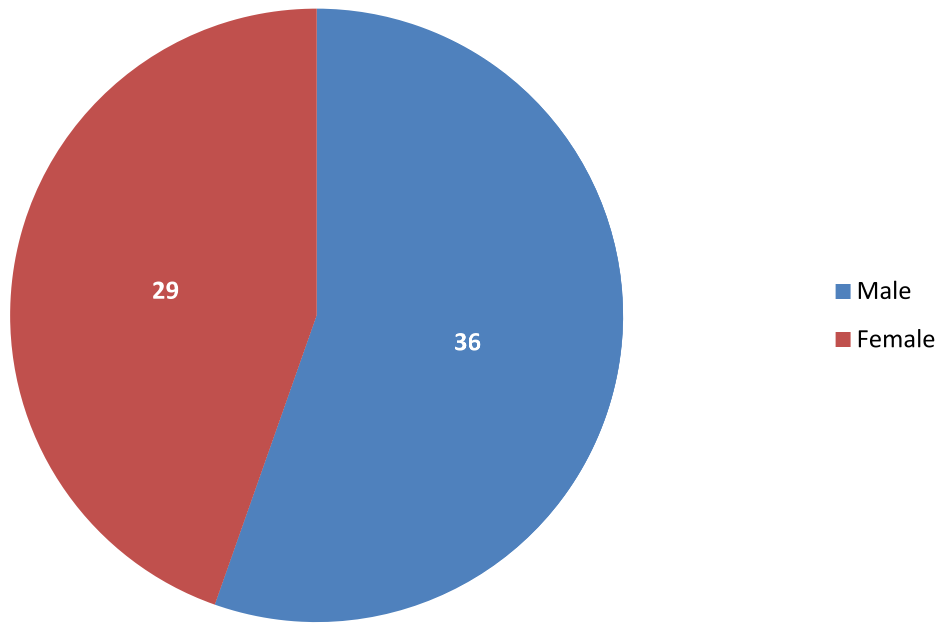
### What community do you live in?



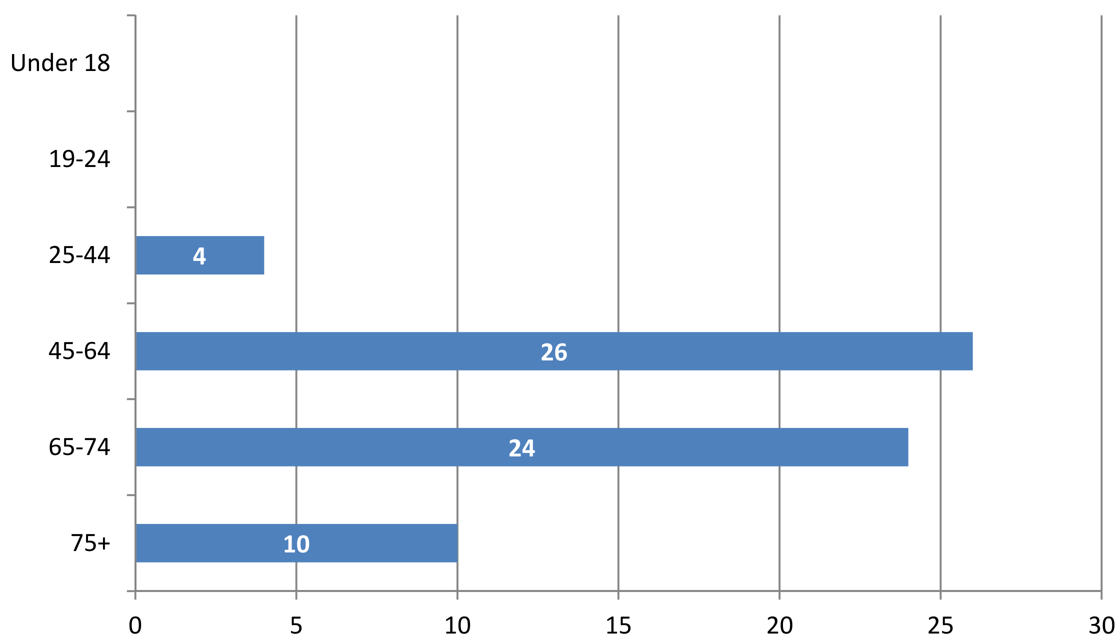

### Do you own or rent?



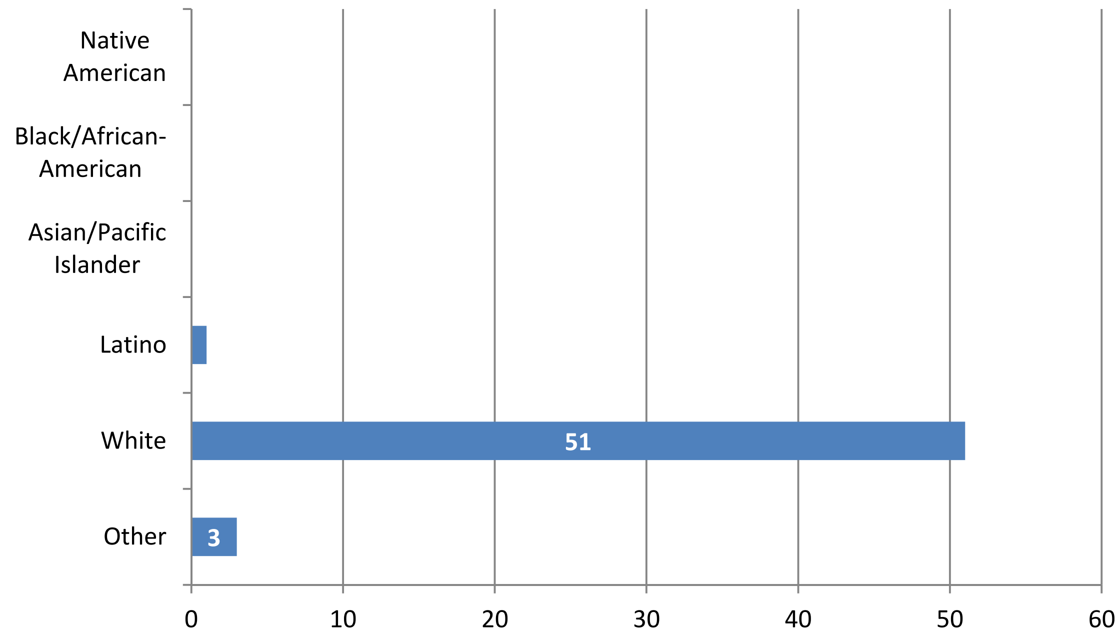
**Gender?**




**Age Bracket?**



**Race/Ethnicity?**




**Annual household income?**