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Stinson Beach Nature-Based Adaptation Feasibility Study

Study Memorandum 1

date	May 21, 2020
to	Leslie Lacko
cc	Jack Liebster, Bob Battalio, Michelle Orr
from	ESA Project Team
subject	Study Memorandum 1: Stinson Beach Existing Conditions Task 1 Deliverable for Stinson Beach Nature-Based Adaptation Feasibility Study (ESA Project D17009.00)

This memorandum presents the background literature and describes existing conditions at Stinson Beach for the Nature-Based Adaptation Feasibility Study (study). This is the deliverable for Task 1 of ESA's scope of work for the Marin County Community Development Agency (CDA).

This study memorandum is broken into the following sections:

1. Project Description, Goals and Objectives.
2. Literature Review
3. Study Reach Definitions
4. Ecological Characterization
5. Reference Sites
6. Shore Dynamics Characterization
7. Sediment Characterization

1. Project Description, Goals and Objectives

The study will assess the feasibility of a nature-based green infrastructure project at Stinson Beach (Federal) and Upton Beach Park (County) to develop a resilient beach and dune ecosystem that enhances existing habitats and public access, supports vibrant recreational opportunities for users of all socioeconomic circumstances, and provides flood and erosion protection for public and private assets against existing coastal hazards and future sea level rise. The nature-based project alternatives developed in this feasibility study will be compared to a traditional engineered shoreline protection approach. The project goal and objectives were confirmed during the project kickoff meeting between ESA and Marin CDA on October 8, 2019.

Project Goal: Assess the feasibility of a nature-based green infrastructure project at Stinson Beach to develop a resilient beach and dune ecosystem that enhances existing habitats and public access, supports vibrant recreational opportunities for users of all socioeconomic circumstances, and provides feasible flood and erosion protection for public and private assets against existing coastal hazards and future sea level rise under future scenarios consistent with state guidance for adaptation planning.

Project Objectives for this Study include the following:

1. Understand sediment transport along Stinson Beach's shore.
2. Characterize historical and modern shoreline change trends.
3. Identify sand sources and sand grain size at candidate sand source sites.
4. Assess the performance of nature-based adaptation alternatives relative to flood and erosion hazards at Stinson Beach.
5. Quantify expected life of nature-based adaptation alternatives for a range of SLR scenarios, and life-cycle costs (first cost and reconstruction after storms), in terms that inform feasibility as well as support a broader long-term adaptation plan.
6. Assess the performance of nature-based adaptation alternatives relative to evaluation criteria (design life analysis, geomorphic and coastal habitat benefits, environmental impacts, recreation, costs, regulatory considerations, storm/SLR protection levels, public access, constructability and possibly others), compared to a more traditional/engineered approach.
7. Support County staff in engaging local residents and beach users in the decision-making process through presenting and soliciting input on project alternatives.
8. Identify existing regulatory barriers to implementation and identify possible regulatory pathways.

The Project Goal and Objectives 1 to 3 are addressed throughout this existing conditions memorandum.

2. Literature Review

Several studies and reports were reviewed to inform existing and historic conditions at Stinson Beach as well as relevant example projects that may provide insight to this Feasibility Study. Notable studies and /reports are summarized below along with key information relevant to this Feasibility Study.

In 1984, the Pacific Northwest Laboratory investigated the damage from the winter storm of 1982-83 at Stinson Beach Park (NPS reach in this study), as well as its contributing physical processes, beach recovery, and shore protection measures feasibility to reduce future risk. This study was documented in the ***Investigation of Stinson Beach Park Storm Damage and Evaluation of Alternative Shore Protection Measures*** report (Ecker and Whelan, 1984). Over the winter of 1982-1983, the beach was almost completely eroded and wave run-up eroded the foredunes and flooded the backshore at Stinson Beach Park. The study summarized local wind and wave climate, including details on the various storms that occurred during the 1982-1983 winter. The largest 6-hour significant wave height of 25 feet (12.2 second period) was observed on January 26, 1983 at the Farallon Island wave gauge. Using the energy-flux-method-based program by Perry and Street (1969), this study estimated potential longshore sediment transport at Stinson Beach Park to equal about 310,000 cubic yards per year, directed almost exclusively to the northwest. The study evaluated shoreline protection alternatives for Stinson Beach Park in comparison to no action: foredune development/enhancement, riprap revetment and nearshore artificial seaweed beds. The lowest cost alternative was determined to be limited riprap revetments only around existing structures at Stinson Beach Park (lifeguard station, restrooms, parking lot).

In the ***Measuring Key Physical Processes in a California Lagoon*** paper (DeTemple et al., 2000), Philip Williams & Associates (PWA) conducted a data collection and analysis program at the Bolinas Lagoon as part of the USACE feasibility study for protection and restoration alternatives in the lagoon. A wide range of physical processes including tidal hydrology, tidal current, wave climate, and inlet channel morphology were measured during April-May and October-November of 1998. This study is one of several reports developed for the USACE.

The Bolinas Lagoon Ecosystem Restoration Feasibility Project was conducted in 2006 by PWA and WRA, Inc. for the Marin County Open Space District, to review the historical evolution and develop a 50-year projection evolution of Bolinas Lagoon and its habitats (PWA, 2006). Analysis of sediment cores collected in Bolinas Lagoon (Byrne et al., 2006) revealed that sediment accumulation has averaged approximately 43,000 CY/yr between 1906 and 2004, to which the littoral beach sands from Stinson Spit and silt eroded from the Bolinas Bluffs contributed about 33,000 CY/yr, and the alluvial processes contributed about 10,000 CY/yr.

O'Connor Environmental, Inc. (OEI) prepared the ***Stinson Beach Watershed Program Flood Study and Alternatives Assessment*** for the Marin County Flood Control and Water Conservation District in 2014 (OEI, 2014). The study examined existing creek and floodplain conditions of Easkoot Creek in the community of Stinson Beach with respect to peak storm runoff and long-term sediment deposition as well as SLR effects on these processes. Ten feasible alternatives that provide benefits for flood protection, habitat restoration and emergency access were assessed, among which Alternatives 9 and 4 that include dredging were shown to be more significant for flood mitigation. Dredged materials from the Easkoot Creek are a potential opportunistic source for use in the adaptation alternatives developed for the current study. OEI proposed removing 3,100 cubic yards of sediment from 2,300-foot reach of Easkoot Creek between Arenal Avenue and Calle del Arroyo and constructing supplemental sediment removal structures with a capacity of about 290 cubic yards.

A similar restoration project was conducted in 2016 at the Cardiff Beach **- *The Cardiff Beach Living Shoreline Project*** (Moffatt & Nichol, 2016), which aimed to develop a natural SLR adaptation approach to protect a vulnerable segment (2,900 feet) of Cardiff Beach by beneficially reusing export materials generated from the San Elijo Lagoon Restoration Project (SELRP) or another opportunistic sand source. The SELRP began in 2017 and through 2019 was estimated to yield ~one million CY of export material. Three alternatives were considered for Cardiff Beach living shoreline designs, including 1) exposed cobble dune (5,000 CY of sand + 15,000 CY of cobble), 2) sand dune (20,000 cy of sand), and 3) buried cobble under dune (10,000 CY of sand + 10,000 CY of cobble). While this report is not relevant to existing conditions at Stinson Beach, this project provides examples of adaptation measures that could be evaluated in this study. The constructed alternative included upgrade of existing rip rap to an engineered revetment, existing cobble reconfigured into a dune core, a sand dune created with native habitat, and pedestrian improvements created along HWY 101.

The Sonoma-Marin Coastal Regional Sediment Management Report was prepared by the Greater Farallones Association in 2018 (George et al. 2018). The Greater Farallones National Marine Sanctuary (GFNMS) led a process financially supported by the State of California to develop coastal sediment management recommendations for the Sonoma and Marin County outer coasts (340 miles, including Tomales Bay). This report summarized sediment sources and sinks in the study area from the literature and identified potential sediment sources for future coastal restoration activities. Key findings relevant to our study are summarized below.

- In the literature, sediment sources are not well constrained because of widespread data gaps. The largest individual sediment sources to the Sonoma-Marin coast include the Russian River (900,000 tons/yr, Milliman and Farnsworkth, 2011), Gualala River (270,000 tons/yr, Milliman and Farnsworkth, 2011), San Francisco Bay (1,200,00 tons/yr total export, Erikson et al., 2013), Cliffs such as Bolinas bluffs (5,100 tons/yr, Ritter, 1973) and slides such as the Lone Tree Slide (1,800,000 tons, Komar, 1998) after the 1989 Loma Prieta earthquake.

- Sediment sinks are only quantified in three areas in the literature, including Bodega Harbor (6,300 tons/yr, Conner et al., 2006), Tomales Bay (2,828 tons/year, Rooney and Smith, 1999), and Bolinas Lagoon (5,180 tons/yr, PWA, 2005). Two dams erected on the Russian river and culverts under Highway 1 and county roads that prevent free flow of sediment to the coast also function as sediment sinks.

- Potential sediment sources include dredged materials from San Francisco shipping Channel (about 300,00 CY/yr) currently placed near Ocean Beach, offshore sand deposits at the Bolinas Graben (volumes not provided), and accumulated sediment in Bolinas Lagoon.

The Natural Shoreline Infrastructure: Technical Guidance for the California Coast (TNC, 2018) provided guidance and design criteria crucial to inform natural shoreline infrastructure planning process, based on a more in-depth paper (Newkirk et al. 2018) from the California's Fourth Climate Change Assessment. This guidance discussed six Natural Shoreline Infrastructure Measures – Vegetated Sand Dunes, Cobble Berm, Marsh Sill, Tidal Bench, Oyster Reef, and Eelgrass Bed, among which the Vegetated Sand Dunes and Cobble Berm are suitable for our site at Stinson Beach. To implement the Vegetated Sand Dunes, the design parameters that need to be considered include seaward edge of the dune, landward limit of zone/space available for a dune field, and appropriate alongshore length. Key design parameters that should be determined for a Cobble Berm site include: alongshore length of constructed berm, crest elevation, slope and layer thickness and volumes. In addition to the space needed for constructing such features, space for lateral beach access and property boundaries must also be considered.

In 2014, the Marin County Community Development Agency (CDA) commenced "Collaboration: Sea-Level Marin Adaptation Response Team" (C-SMART) to develop adaptation solutions for West Marin. To date C-SMART has produced two major deliverables: the ***Marin Ocean Coast Sea Level Rise Vulnerability Assessment*** (2016) and ***Marin Ocean Coast Sea Level Rise Adaptation Report*** (2018) with the support of ESA. The Vulnerability Assessment used coastal flooding and erosion hazard maps produced by the US Geological Survey (USGS) and ESA, respectively, to determine exposure of the Stinson Community and other Pacific coast communities to sea-level rise. The Vulnerability Assessment concluded that 200 to 400 of Stinson Beach's homes may be exposed to flooding by 2030, potentially increasing to nearly 600 by the end of the century while beaches are vulnerable to coastal squeeze and may disappear by the end of the century. The Adaptation Report identified several conceptual alternatives for adaptation along the Pacific shoreline of Stinson Beach including nature based alternatives such as dune restoration that could have multiple benefits in providing habitat, recreation and flood protection. This Stinson Beach Nature-Based Adaptation Feasibility Study is part of CDA's continued efforts to develop innovative adaptation solutions for West Marin.

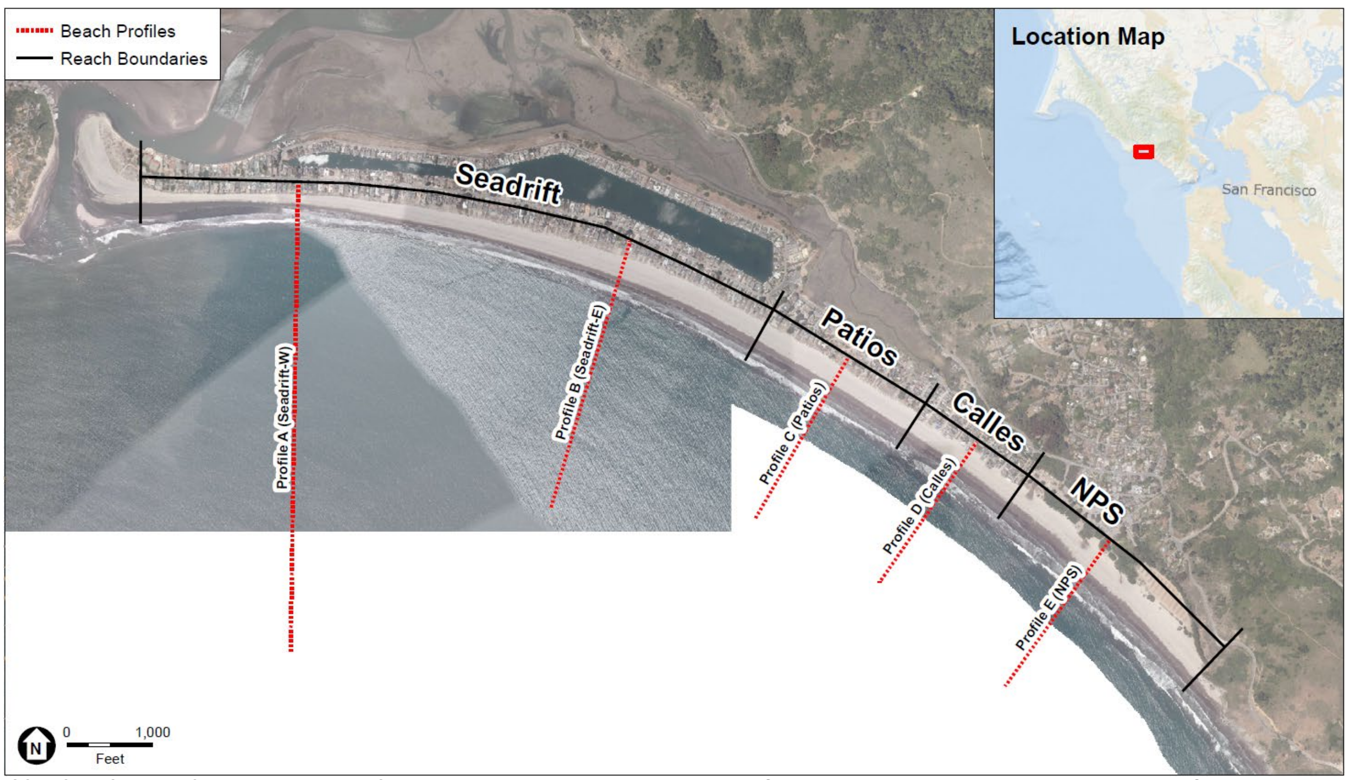
3. Study Reach Definitions

The Stinson-Seadrift study area was divided into four distinct reaches for the purposes of the study. The reaches span from the Bolinas Lagoon mouth at the north-west end to the Stinson Beach Boulders at the southeast end of the study area and are described below. Existing beach dimensions provided below are based on a topographic survey conducted on October 16, 2019. Beach width is defined as the distance from the MHW shoreline to the backshore (dune or armoring toe, or development). One characteristic profile was surveyed for each reach except for Seadrift which has two profiles. Figure 1 below shows the Stinson Beach study area with reaches, including nearby wave and wind gauge locations that were accessed for this analysis. Note the beach profiles extend offshore to approximately -35 feet NAVD to capture the full active beach profile. The location of this depth is further offshore at the Bolinas lagoon mouth (due to the sand shoal there, which forms from ebb tide sediment export from the lagoon) and closer to shore near the headlands on the east side of Stinson.

Large format plan figures of each study reach are provided in **Appendix A**.

Photos taken at each shore profile location are provided in **Appendix B**.

Representative shore elevation profiles for each reach are plotted in **Appendix C**.



SOURCE: ESA, Marin County 2018 Imagery, ESRI

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Figure 1
Stinson Beach Study Reaches

Reach 1: Seadrift – Lagoon mouth to Walla Vista (7,610 feet long). The backshore homes are currently armored with rock revetment shoreline protection structure that was constructed after the 1982-1983 winter. This shoreline protection structure is exposed along the western 3,800 feet and eastern 1,200 feet of shore, while the central portion of the structure is buried by sand with dune vegetation. The beach width in October 2019 ranged from approximately 50 to 250 feet, while the minimum documented beach width was 29 feet. The basemap for this reach is shown on Figures A-1 to A-3. Reach photos taken from the October 2019 shoreline and back of beach at each survey profile are shown on Figures B-1 and B-2. Noble Consultants (Noble et al 2007) has documented armoring conditions along Seadrift for the past few decades. After the 1983 El Nino, over 35,000 tons of rock riprap along the Seadrift shoreline for the protection of 125 property owners and residences, expanding upon an emergency structures built along the western and eastern portions of Seadrift during the 1978 and 1980 winters respectively. This structure was constructed to a 2.5:1 (horizontal: vertical) slope with a toe elevation of approximately +7 feet MLLW (Mean Lower Low Water) and a crest elevation of +17.5 feet MLLW. After 1998 El Nino, 5,500 tons of new stone was placed for repairs. An additional 3,000 tons were placed in 2004 and 700 tons of repair work was done in 2006. Due to the existing protection afforded by the rock revetment that spans the Seadrift Reach, the relative need for natural infrastructure is lower compared to the other study reaches.

Reach 2: Patios – Seadrift/Walla Vista to Calle Del Embarcadero/Occidente (2,080 feet long). This reach has the greatest width of beach and foredunes seaward of residential property. The beach width in October 2019 ranged from approximately 210 to 275 feet, while the minimum documented beach width was 73 feet. The basemap for this reach is shown on Figure A-4. Reach photos taken near the survey profile are shown on Figure B-3.

Reach 3: Calles – Calle Del Embarcadero/ Occidente to Calle Del Pinos (1,460 feet long). Homes closer to shore, encroaching on beach. The beach width in October 2019 ranged from approximately 240 to 295 feet, while the minimum documented beach width was 80 feet. The basemap for this reach is shown on Figure A-5. Reach photos taken from the October 2019 shoreline and back of beach on the survey profile are shown on Figures B-4.

Reach 4: NPS – Calle Del Pinos to Stinson boulders (3,040 feet long). National Park beach and dunes fronting parking. The beach width in October 2019 ranged from approximately 240 to 300 feet, while the minimum documented beach width was 56 feet. The basemap for this reach is shown on Figure A-6. Reach photos taken from the October 2019 shoreline and back of beach on the survey profile are shown on Figures B-5.

Representative beach profiles were surveyed by ESA and Merkel on October 16, 2019 to establish existing geometry and sediment characteristics (see Section 7). The opportunities and constraints for nature-based adaptation alternatives will depend on available space and backshore elevations along the study area. Table 1 lists documented beach widths for each reach since the 1920s; the greatest beach widths are typically observed in the fall and minimum widths occur in the late winter/spring. The beach width is defined as the distance between the backshore (toe of dune or armoring, or development edge) and the mean high water line (5.1 feet NAVD based on NOAA tide gauge 9415020 at Point Reyes). ESA timed the existing conditions topographic survey in October 2019 before the first winter storms occurred in order to document the widest beach conditions. The average minimum beach widths reported in Table 1 were determined by available LiDAR from April 1998, May 2010 and May 2016.

TABLE 1
RECENT BEACH GEOMETRY FOR STUDY REACHES

Reach	Name	Length (feet)	**October 2019 Average Beach Width, feet** [with range per reach]*	**1920-2019 Average Minimum Beach Width, feet** [with range per reach]*	October 2019 Average Beach Berm Elevation, feet NAVD	October 2019 Intertidal Slope, from MLLW to MHHW
1	Seadrift	**7,610**	**156** [47 to 243]	**71** [26 to 127]	10.3	2.4 to 2.5%
2	Patios	**2,080**	**250** [210 to 274]	**102** [73 to 128]	9.3	2.4%
3	Calles	**1,460**	**267** [242 to 295]	**104** [80 to 142]	9.0	2.5%
4	NPS	**3,040**	**264** [241 to 298]	**130** [56 to 197]	9.5	2.4%
All	-	**14,190**	**205** [47 to 298]	**92** [29 to 197]	9.8	2.5%

** Averages and ranges of beach width are based on 50-foot spaced transects along the study shoreline.*

4. Ecological Characterization

Existing and historical ecological conditions along the Stinson Beach study area were studied to inform the development and evaluation of nature-based adaptation alternatives. Site ecology (wildlife and vegetation) is linked to physical characteristics such as beach width and elevation, sediment grain size, etc. By understanding these physical-ecological links, future shoreline projections can be related to existing ecology functions and to evaluate the ecological implications for shoreline adaptation alternatives. This section presents an overview of available historical information about the natural topography and vegetation at Stinson Beach prior to residential development (early 20th century) followed by discussions for onshore and offshore ecological conditions as observed in Fall and Winter of 2019 by the ESA team.

4.1. Historical Foredune and Backshore Conditions at Stinson Beach

The natural features we hope to utilize for coastal adaptation at Stinson Beach evolve over long time periods. The historical conditions of Stinson Beach before significant development were studied to develop an understanding of the natural evolution of the beach-foredune spit that is Stinson Beach. The historic conditions provide an indication of the natural maintenance potential of implemented nature-based adaptation measures. The photograph below provided by the Stinson Beach Historical Society shows an undeveloped sand spit in 1910.

Stinson Beach circa 1910, showing undeveloped sand spit. (Stinson Beach Historical Society)

Primary sources of information on Stinson beach and foredune morphology, landforms, and dynamics include descriptive geomorphic and vegetation accounts by W.S. Cooper's monograph of California coastal dunes, and interpretation of historical photographs. Cooper (1967) provided only brief descriptive accounts of Stinson Beach as having "rudimentary" dune development, like Doran Beach, based on his coastal California dune surveys of the 1930s. This description is consistent with the historical early 20th century photographic images of Stinson Beach showing most of the spit supporting a wide geomorphically young washover terrace dotted with relatively uniform distribution of low-relief vegetated dune mounds across the entire barrier beach profile. The early 20th century Stinson Beach dune field exhibited no traces of older remnant dune vegetation or landforms, indicating the area is a frequently overtopped and experiences limited natural dune accretion.

Stinson Beach was affected by subsidence of the eastern side of the San Andreas Fault in Bolinas Lagoon following the 1906 earthquake: wave overtopping of the spit became frequent and apparently widespread after the earthquake (Lawson 1908:81-82). Plate 6B of the "California Earthquake of April 18 1906" (Lawson 1908) shows a view of Stinson Beach from Wharf Road in Bolinas immediately after the earthquake. Seadrift appears to be a low, wide uniform overtopped terrace, which would be expected if co-seismic subsidence lowered the spit and thus it's elevation threshold for storm wave overtopping. Geologist G.K. Gilbert (a pioneer in barrier spit geomorphology) recorded his own and local resident observations of Stinson Beach's change in wave overtopping frequency following the 1906 earthquake:

> The overflow of the spit by waves during the past winter had washed a considerable amount of sand down the north slope, and this sand suffocated large tracts of Salicornia and other plants…[quantified estimated subsidence of adjacent McKinnon Island of 10 inches] appears sufficient to account for the overwashing of the spit, (G.K. Gilbert, in Lawson 1908:83)
>
> Various residents are of opinion that the sand-spit, except at its extreme western end, is lower than formerly. A lady who has lived at Dipsea Inn several years states that before the earthquake the spit was overtopped by waves only during storms with heavy winds, but that since the earthquake waves frequently wash over it. It will be observed that all this testimony, with the single exception of Mr. Morse's observation of water-levels near his house, tends to show a general sinking of the land east of the fault, and a general rising of that to west of it. (G.K. Gilbert, in Lawson 1908:82)

The Stinson-Seadrift spit is situated above the San Andreas fault which passes under the western end of Seadrift and northwards up Bolinas Lagoon. Thus the Stinson spit may be subject to future subsidence during earthquakes along the fault.

Looking down Bolinas Lagoon and Bay toward the Golden Gate, village of Bolinas in foreground (H.W.F.). Plate 6 B. Andrew C. Lawson, The California Earthquake of April 18, 1906. Report of The State Earthquake Investigation Commission. Carnegie Institution of Washington Publication No. 87, Volume I, Part I.

The east/west fault scarp uplift and subsidence pattern that rejuvenated Stinson Beach by wave overtopping was marked by a visible, measurable transient fault scarp boundary on “Pepper Island” (original name of Kent Island) and its adjacent lagoon flats of Bolinas Lagoon. Gilbert and botanist W.S. Jepson (Lawson 1908) made direct measurements of transient fault scarps on “Pepper Island” sands and muds following the earthquake, estimating an average of 1 ft (up to 1.5 ft) subsidence on the NE side of the fault (Lawson 1908:72). Recent sediment cores (Reidy and Byrne 2006) indicate significant net co-seismic subsidence of the lagoon flats up to 2.7 m during the last two millennia of the late Holocene (after AD 400), unevenly balanced by tidal and fluvial sedimentation during gradual sea level rise.

Therefore, the geomorphic evolution of the dune field at Stinson Beach during the 20th century should be interpreted as sequential, gradual stages in long-term recovery following abrupt seismic subsidence of the spit and intensification of wave overtopping. The limited foredune growth that occurred by the time of post-War residential development (1950s) suggests that even under relatively slow sea level rise during the 20th century and favorably wide backshore conditions, Stinson Beach dune building rates are relatively slow compared with west-facing Pacific dune fields oriented onshore to dominant westerly winds (e.g. Dillon Beach, Ocean Beach). Previous earthquakes documented in 1695 and 1776 north of the Golden Gate suggest a shorter, time interval (130–210 yr) between major earthquakes here than has been previously documented (Hall and Niemi 2008).

The extreme eastern end of Stinson Beach, where back-barrier wetlands where non-tidal freshwater pond, swamp (riparian woodland), and marsh, were apparently not impacted by wave overtopping following the 1906 earthquake, and persisted in historical photographs of the 20th century (see below) until most of them were drained and filled. Significant repeated storm wave overtopping of seawater there would likely have caused persistent brackish wetland conditions and associated dieback of salt-sensitive freshwater riparian scrub or woodland dominants, such as willow, waxmyrtle, and red alder. Well-developed, steep foredunes and anomalous wetland dune scrub vegetation were evident in the east end of the spit, where the backbarrier wetlands formed a freshwater non-tidal “lagoon” or dune pond, instead of the tidal lagoon salt marsh. This area corresponds with the approximate location of the modern County Park and GGNRA shoreline and backbarrier parking lots (referred to as NPS reach in this study), where wetland scrub foredunes and emergent groundwater exist today (see historic T-Sheet below).

View west from hills above NPS Reach showing historic lagoon in foreground in the location of the existing dirt parking lot. (Stinson Beach Historical Society)

Marram (European beachgrass; Ammophila arenaria) was first collected from “Bolinas Lagoon” in 1931, and subsequent multiple herbarium collections from the 1930s-1940s at Stinson Beach indicate that this was the “Bolinas” locality. Marram was introduced to San Francisco and extensively established to form stabilized large mobile dune systems in the 1870s, and Stinson Beach is the nearest backshore dune habitat north of San Francisco. All west Marin dune localities north of Bolinas had established significant marram cover by the 1930s (Cooper 1967). It is very likely that marram dominated foredune geomorphic processes and topography of Stinson Beach during the entire 20th century, prior to residential development.

The T-sheet excerpts in Figure 2 below show the extent of fill and development along the sand spit in the 20th century. Development along the western spit backshore were constructed in low foredune areas that experience frequent wave overtopping as well as periodic subsidence as a result of fault activity on the San Andreas fault that passes below the west end of Seadrift. At the eastern end of the spit, development occupies much of what was once a wetland and lagoon complex sustained by freshwater overflows from Easkoot Creek and saltwater from wave overtopping and tides in Bolinas Lagoon.

SOURCE: USGS 1897 and 1993 Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 2
Excerpts of US Geological Survey T-Sheets 1897 (Tamalpais, top) and 1993 (Bolinas, bottom),

4.2 Onshore Characterization

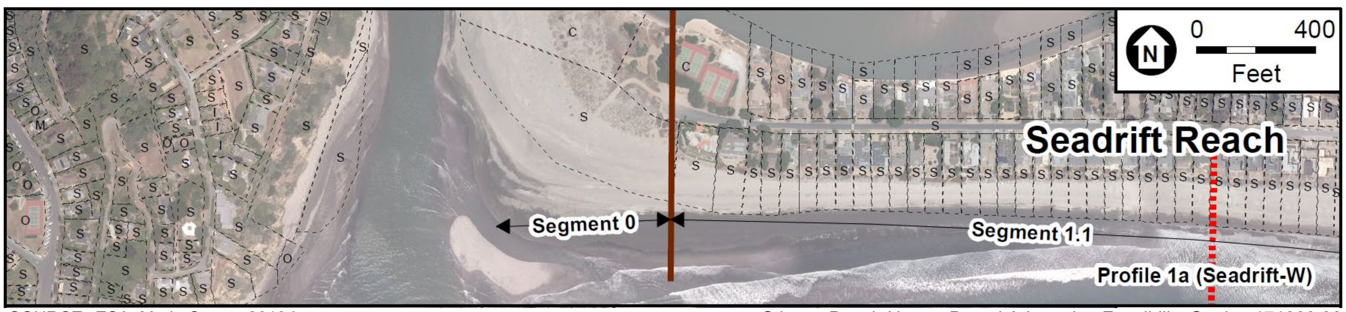
Onshore beach and foredune conditions at Stinson Beach were surveyed by Dr. Peter Baye on December 20, 2019. The description in the following subsections draw from observations made during this survey as well as prior observations made over the past decade. The main focus of the beach and dune assessment is on indicators of ecological and geomorphic interactions between (a) wave and wind transport of sand, (b) beach and foredune vegetation, and (c) patterns and processes of short-term and long-term erosion and deposition, and backshore (beach and dune) landforms resulting from their interactions. The assessment is presented as continuous segments that comprise the coast. Reaches defined fort this study align with and are represented by one or more ecological segments

4.2.1. Shoreline Segments

The artificially filled and developed Stinson Beach shoreline today has distinct segments with high contrasts in the development of existing foredunes, and backshore beach space available for either incipient ("embryo") foredunes or post-storm recovery of scarped (wave-cut) foredune profiles. For description purposes, the shoreline was classified based on the seaward extent of residential structures and presence of a shore armoring structure or continuous sand beach-foredune backshore transition. Based on these criteria, review of aerial photography, and field observations, 8 distinct shoreline segments were identified along Stinson Beach from the Bolinas Lagoon mouth to the eastern end of the spit at the Stinson Boulders. These segments are described below within the context of the shoreline reaches defined for this feasibility study.

Seadrift Reach

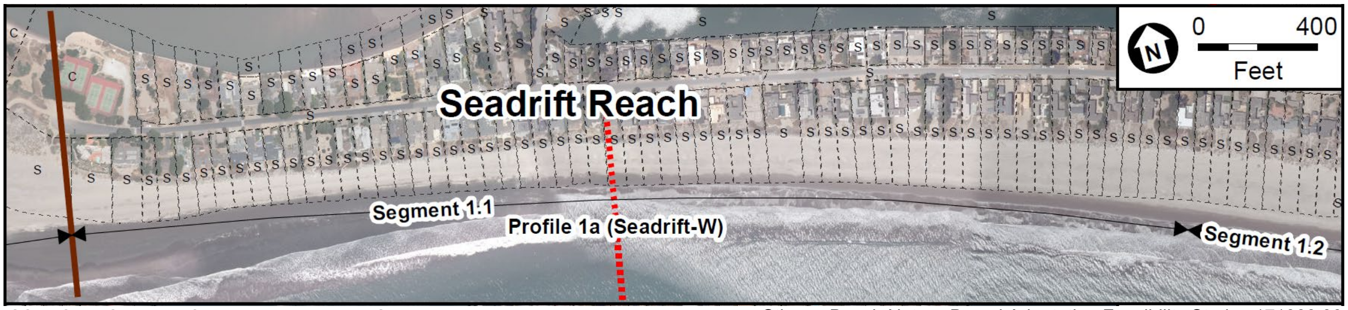
Segment 0 (Figure 3): Beyond the west end of the Seadrift reach is the end of the Seadrift spit. The area is a low foredune terrace and that borders the Bolinas Lagoon tidal inlet. This low-relief foredune terrace is dominated by a non-native marram (European beachgrass, Ammophila arenaria), with patches of native foredune and beach vegetation including beach wildrye (American dunegrass, Leymus mollis; syn. Elymus mollis). Due to forces from tidal currents from the lagoon mouth and waves, this area to cycles of erosion and recovery of the sandy spit and sandbars (as shown in Figure 3), but the foredunes have likely experienced infrequent wave overtopping given its sheltered position relative to the overall shoreline.



SOURCE: ESA, Marin County 2018 Imagery
Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 3
Shore Segment 0

Segment 1.1 (Figure 4): Approximately 60 oceanfront lots at the west end of Seadrift are armored by a rock revetment and the beach profile was essentially a low tide terrace (bar and trough inshore) and narrow intertidal beach face up to the toe of the revetment. There was wave reflection off the revetment at mid-tide, and little or no backshore berm profile in the vicinity at the time of the visit. The base of the concrete/rock stairways within the revetment ranged from 0 to 5 feet above the intertidal beach face, indicating significant long-term loss of beach backshore elevation. This segment has essentially no significant remaining foredunes, and no geomorphic space for them either now (December 2019) or in any season in any year shown in recent aerial photographs in Google Earth. This suggests that utilizing foredunes as natural infrastructure in this reach may not be feasible, especially without the space to construct them.



SOURCE: ESA, Marin County 2018 Imagery, ESRI

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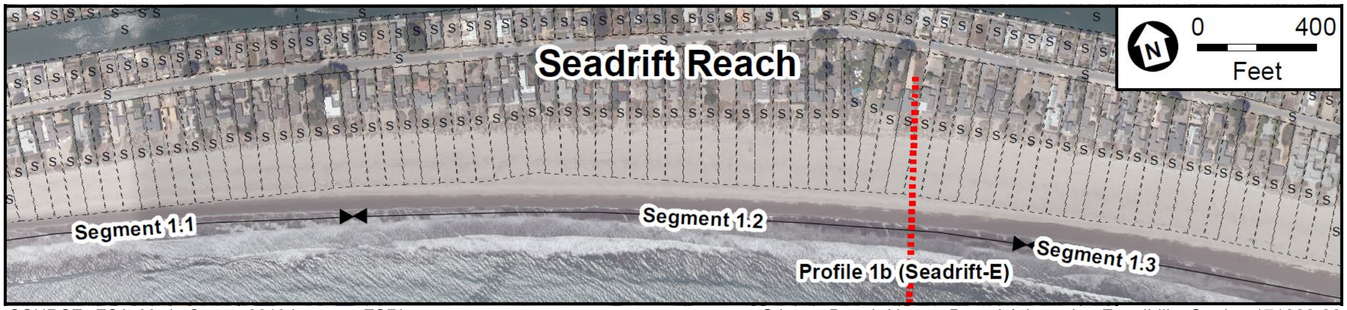
Figure 4
Seadrift Reach - Shore Segment 1.1

Western rock revetment in Seadrift reach, December 20, 2019. Intertidal beach face is revealed at low tide, the surf zone reaches the revetment at high tide with no backshore. An apparent foreshore trough with visible longshore currents lies close inshore near the beach face. (P. Baye)

Segment 1.2 (Figure 5): Along the central foredunes of the Seadrift reach (~2,300 feet), the rock revetment is completely buried along approximately 38 oceanfront lots. This segment is characterized by low and apparently relict and stabilized foredunes with persistent decaying leaf litter at the surface, with minimal indicators of recent (1-2 years) wind-driven sand accretion, and many indicators of recent net erosion (scarped dune faces and exposure of older vegetation at the scarp crest). Homes are landward of the foredunes. This segment has a wider beach than Segment 1.1, which could provide space to construct foredunes as natural infrastructure. However, the existing rock revetment that spans the Seadrift reach provides some backshore protection and reduces the relative need for additional protective infrastructure at Seadrift in the near term compared to the eastern reaches.



SOURCE: ESA, Marin County 2018 Imagery, ESRI

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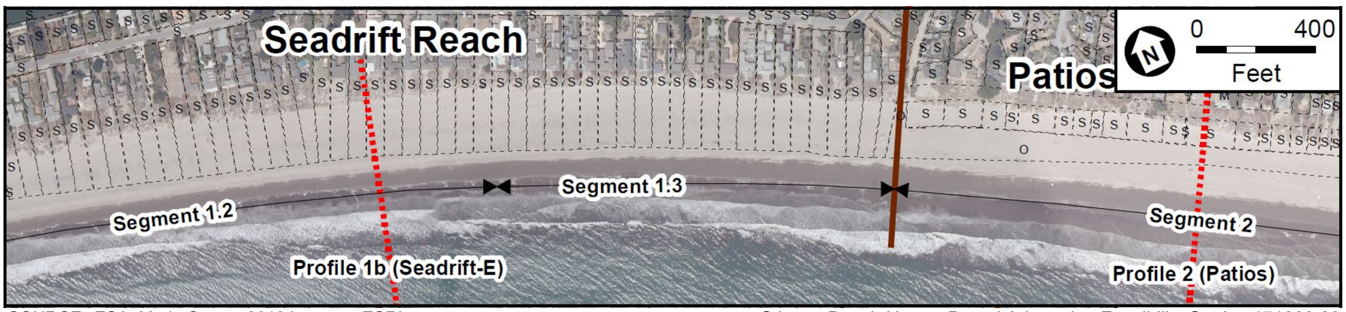
Figure 5
Seadrift Reach - Shore Segment 1.2

Central Seadrift foredune segment, typical profile with a relatively wide backshore, persistent drift-lines (potential embryo foredunes) and a foredune scarp with extensive recovery of perennial vegetation and slight but significant sand accretion on the seaward slope. December 20, 2019. This profile indicates some backshore persistence over winter for more than 1 year. (P. Baye)

Segment 1.3 (Figure 6): Along the eastern end of Seadrift reach, approximately 22 oceanfront lots have relict foredunes with exposed rock revetment. Homes are landward of the revetment and relict foredunes. The foredune vegetation in most of this segment is apparently sand-starved, erosional at the seaward face (scarped dune faces are prevalent), and dominated by marram, iceplant and various ornamental landscaping specimens. The west end of this segment, however, exhibited the greatest sand accretion (a precursor to foredune formation) and widest backshore areas near its west end. Some of the eastern boulder revetment had been buried by marram-vegetated foredunes accreted to the height of the revetment in past years, burying and obscuring the revetment but has been recently re-exposed by erosion. Relatively young marram foredunes in some locations are perched on the revetment, protected from wave erosion below. However, there is no indication of recent (1 year or older) backshore vegetation seaward of the revetment. This inconsistent pattern suggests alternation between complete erosion of the backshore, and phases of temporary beach recovery and sand accretion, with trapping of sand in the only persistent perennial vegetation perched atop and protected by the revetment. In other words, the only geomorphic space apparently available for persistent foredunes is that which is provided behind the rock revetment given the current range of shoreline positions. In summary, this segment also has a wide beach that could accommodate the construction of foredunes as natural infrastructure. However, the existing rock revetment that spans the Seadrift reach provides some backshore protection and reduces the relative need for additional protective infrastructure at Seadrift in the near term compared to the eastern reaches.



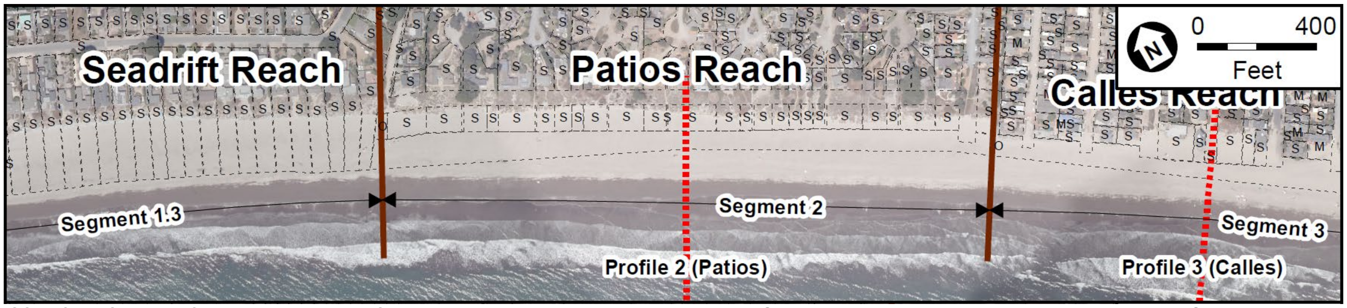
SOURCE: ESA, Marin County 2018 Imagery, ESRI
Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 6
Seadrift Reach - Shore Segment 1.3

Eastern end of Seadrift rock revetment, December 20, 2019. The boulder revetment here varies between exposed boulders with recent unvegetated wind-deposited sand ramps (SE-oriented) and mixed marram foredunes perched in the revetment, partially eroded or persistent. This profile indicates alternation between severe erosion to the revetment, and episodes of backshore beach and dune accretion. There is currently no significant annual or perennial beach vegetation in the backshore seaward of the revetment. (P. Baye)

Patios Reach

Segment 2 (Figure 7): The Patios reach is comprised of foredunes and a wide beach. West of Calle del Embarcadero (Calle del Occidentale) to Walla Vista are relict foredunes seaward of homes. Relict foredunes here exhibit strong long-term and short-term (recent) erosion indicators, and no indicators of recent significant wind-driven sand accretion.



SOURCE: ESA, Marin County 2018 Imagery, ESRI

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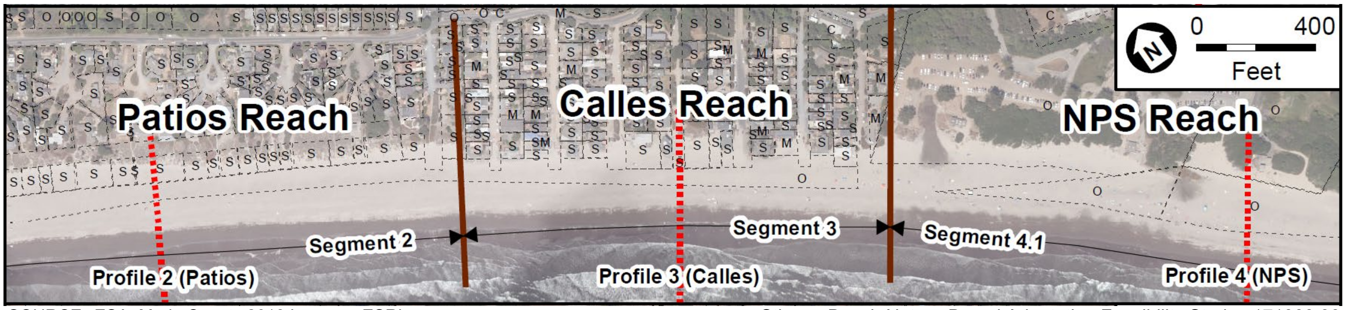
Figure 7
Patios Reach - Shore Segment 2

Patios reach, December 20, 2019. All foredunes exhibit "sand-starved" persistent linear scarps, with exposed older graying marram leaf litter at the sand surface. There is no sand burial of attached, matted gray leaf litter, no tapered mounds of wind-blown sand around vegetation patches (sand shadows) in the scarp or above its crest. There is no significant annual or perennial backshore vegetation seaward of the scarp. (P. Baye)

Calles Reach

Segment 3 (Figure 8): The Calles reach is primarily beach-top residential. The extreme eastern lots along County roads (Calle del Embarcadero to Calle del Pinos) project seaward of the adjacent foredune lines and backshore beach zones, located directly over (pile-supported homes) or on (seawall-protected homes) the beach, with recent swash lines landward of the structures. The setback older homes between them also appear to be positioned seaward of the nearby willow scrub foredunes of the NPS Reach to the east (See Leymus mollis account below).



SOURCE: ESA, Marin County 2018 Imagery, ESRI

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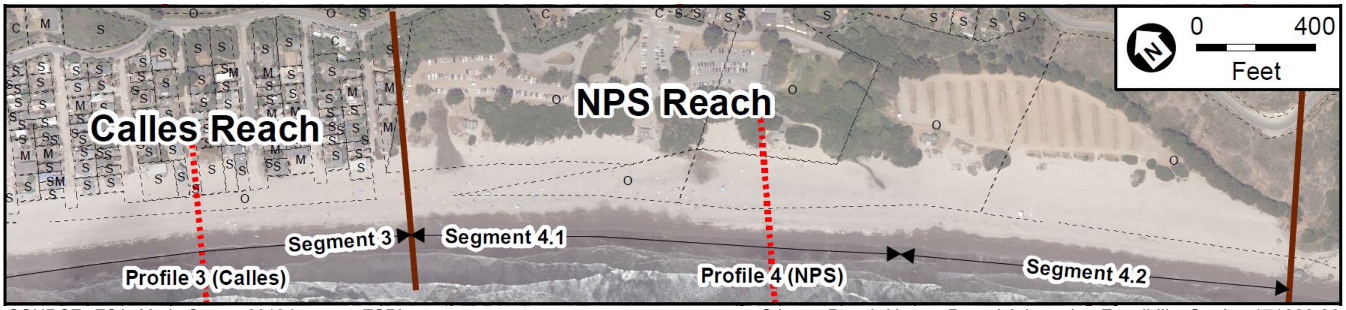
Figure 8
Calles Reach - Shore Segment 3

Calles reach, December 20, 2019. Homes are located on the active foreshore and backshore (swash zones of fair-weather and storm beach profiles); eroded foredunes, where they persist, are landward and between the prominent homes. (P. Baye)

NPS Reach

Segment 4.1 (Figure 9): The National Park Service Reach backshore is comprised of freshwater wetland scrub foredunes influenced by seep and distributary channels including Easkoot Creek.



SOURCE: ESA, Marin County 2018 Imagery, ESRI

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Figure 9
NPS Reach - Shore Segment 4.1

Very distinct and regionally rare wetland scrub foredunes (effectively small precipitation dune ridges; Cooper 1967) occur locally between the Calles and the west end of the National Park Service (GGNRA) overflow parking lot, where high groundwater emerges seasonally at the surface as perennial backshore beach seeps. This is one of the only examples of freshwater wetland-dominated foredunes left on the Central California coast. This segment also contains two seasonal stream distributary mouths connected to Easkoot Creek and Stinson Beach. The eastern small stream mouth breaches the stabilized wetland foredune ridge and drains a disconnected floodplain backwater swamp thicket landward of the wetland-vegetated foredune. The backdune wetland consists of freshwater riparian scrub and marsh dominated by willows (Salix lasiolepis, Salix spp.), waxmyrtle (Morella californica), sedges (Carex obnupta, Scirpus microcarpus), rushes (Juncus lescurii), and many freshwater marsh forb species, including water-parsnip (Oenanthe sarmentosa). This wetland foredune is apparently a descendent of the original backdune pond (freshwater lagoon) at the spit's eastern end, either a remnant of the original complex or reassembled from it. The western seasonal stream mouth drains an intermittent overflow distributary channel (bank breach) of Easkoot Creek through an unstabilized public pathway to the beach. The foredune vegetation itself consists of an older salt spray wind-flagged willow-waxmyrtle thicket that traps a dune precipitation ridge, and a younger low marsh-foredune terrace composed of mixed freshwater and brackish marsh vegetation, including coast bulrush (Schoenoplectus pungens), saltgrass (Distichlis spicata), and Vancouver wildrye (Leymus xvancouverensis). The younger marsh-foredunes alternate between accretion and erosion among years. The backshore in the wetland foredune zone is often eroded down to a seasonal stream channel (down to intertidal foreshore) saturated to the surface with freshwater (emergent groundwater). A lens of stream gravel, or wave-reworked stream gravel, sometimes outcrops in the backshore where seep-fed rill erosion and wave erosion expose it. The buried backshore gravels are likely a mechanism of efficient shallow subsurface freshwater discharge from backdune to beach. Little long-term net foredune growth has been observed here since 2011. Storm wave run-up appears to cyclically remove accreted foredune sand where the beach is perennially saturated with shallow groundwater.

Some of the willow-dominated foredunes near the west end of this segment have their seaward faces trampled down to bare sand, which destabilizes the dune face, and also makes it more conducive to vertical growth and landward retreat by enabling efficient onshore sand transport by wind and waves from the beach to the crest. The lack of trampling on the shaded, brushy landward slope maintains sand trapping capacity there, at least currently.

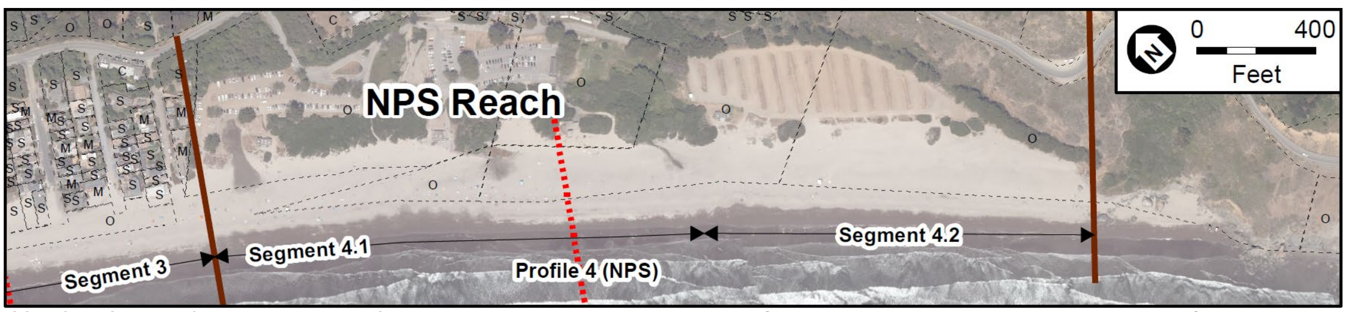
Freshwater marsh vegetation and riparian scrub vegetation dominate foredune area associated with high emergent groundwater (freshwater seeps) between the backdunes and backshore beach. June 17, 2011 (left; willow-waxmyrtle scrub and rush marsh) and April 2, 2013 (right; Vancouver wildrye). (P. Baye)

A perennial to seasonal freshwater channel draining the backdune wetlands supports dominant freshwater marsh vegetation in the foredunes, including broadleaf cattail (Typha latifolia), coast bulrush (Schoenoplectus pungens) and salt rush (Juncus lescurii), excluding typical terrestrial foredune vegetation. This is one of the only examples of freshwater wetland-dominated foredunes left on the Central California coast. April 3, 2015. (P. Baye)

Freshwater seeps and emergent groundwater can dominate the entire backshore profile in wet years with high groundwater, saturating the beach from the toe of the willow-waxmyrtle wetland foredune to the intertidal zone. Seep/spring erosion rills and wave erosion (intensified wave backwash in saturated sand) locally expose outcrops of buried stream gravels. March 6, 2014. (P. Baye)

Seasonal freshwater stream discharge from the willow-waxmyrtle wetland foredunes saturates the backshore and foreshore beach below the stabilized stream mouth breach in the foredunes. March 6, 2014. (P. Baye)

Segment 4.2 (Figure 10): Along the GGNRA overflow parking lot, the backshore is comprised of semi-artificial foredunes. This feature serves as a local example of foredune creation at Stinson Beach that could be evaluated for this study, as it shows the greatest signs of natural foredune accretion of all the shore segments.



SOURCE: ESA, Marin County 2018 Imagery, ESRI

Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 10
NPS Reach - Shore Segment 4.2

The east end of the sand spit supports a semi-natural foredune that is partially derived from occasional (or past) maintenance removal of blown foredune sand from the unpaved GGNRA overflow parking lot, and placement of mixed dune sand and parking lot soil/gravel (spoils) in berms at the edge of the parking lot's seaward roadway. The segments of spoil berms become linear nuclei for new foredunes as they become vegetated with a mix of roadside weeds (dependent on soil admixture enriching nutrient-poor, moisture-poor dune sand) and native and non-native foredune plants (dispersed by storm waves and tidal litter on the seaward side). The berm vegetation subsequently traps and accretes dune sand, and evolves into naturalized linear foredune ridges. The degree of naturalization of the berms to foredunes depends on the extent of sand burial. The landward sides of the berms generally have more surface exposure of mixed soil/sand, and support high proportions of weeds, especially ripgut brome (*Bromus diandrus*). The seaward and crest slopes tend to be thickly covered with accreted dune sand, and support one of the largest colonies of perennial pink sand verbena (taxonomically intermediate, variable population, close to the rare *Abronia umbellata* var. *breviflora*, introgressant with *A. umbellata* var. *umbellata*). The associated foredune species here include scattered colonies of Vancouver wildrye (*Leymus* x*vancouverensis*), beach-bur (*Ambrosia chamissonis*), and yellow sand-verbena (*Abronia latifolia*). Isolated willows also occur in this area, indicating shallow seasonal freshwater groundwater, but less so than the freshwater marsh-dominated foredunes in Segment 4.1.

This easternmost foredune segment contains the richest source of native foredune species populations on the sand spit, and has the strongest indicators of frequent significant onshore transport of wind-blown sand. It also rarely exhibits wave-eroded foredune scarps, in contrast with the rest of Stinson Beach. These distinctive features correspond with the beach orientation, profile, and sand texture at the east end of the sand spit: wide, dissipative low tide terrace and beach face dominated by finer (medium) sand, a wide backshore (provides a dry sand fetch), and orientation of the shoreline with greater exposure to westerly onshore winds.

Graded berms of mixed blown sand and parking lot "dirt" fill (gravel, soil, angular pebbles) are placed at the seaward edge of the overflow parking lot, develop sand-trapping vegetation, and become mantled with accreted dune sand. Sept 20, 2013. (P. Baye)

The landward slopes of the eastern berm-nucleated foredunes often have thin or no accretion of dune sand, and expose mixed sand/soil spoils at the surface, which support annual weed-dominated vegetation, mixed with native foredune plants. April 17, 2015. (P. Baye)

The accreted dune sand on berm-nucleated foredune crests inhibits dominance of annual weedy grasses, and selects for prevalence of native foredune vegetation. The eastern-most Stinson Beach shoreline is oriented with greater exposure to dominant westerly winds compared with central and western shorelines of the spit, and has a wide backshore with finer (medium) sand. These interactions promote vigorous growth of native foredune vegetation. April 5, 2013 (left) and April 17, 2015 (right). (P. Baye)

Perennial colonies of pink sand-verbena (Abronia umbellata) occur extensively in the berm-nucleated foredunes bordering the overflow parking lot. June 17, 2011. (P. Baye)

4.2.2. Vegetation and drift-lines

Existing vegetation observed in December 2019 is further elaborated upon in this section to provide context for nature-based approaches utilizing dune vegetation. The vascular plant species richness (number of species) and diversity (evenness of species' relative abundance) in the study area foredune and beach (high tide beach; backshore) were very low compared with Kent Island's west beach and the proximal end (GGNRA) of Stinson Beach. The dominant and most frequent plant in the foredune zone in all Stinson Beach shoreline segments was marram (European beachgrass; *Ammophila arenaria*), occurring throughout in naturalized populations, and probably some planted ones as well. The next most frequent and locally abundant plant in foredunes and on boulder revetments was iceplant (*Carpobrotus chilensis*, *C. edulis* x *chilensis*). One native foredune plant, beach wildrye, occur in small, sparse colonies in a few foredune locations, some evidently planted recently, but most apparently naturally established. Sea-rocket (*Cakile maritima*), a ubiquitous introduced annual or short-lived perennial forb on sand beaches of Central Coast region, was infrequent. Most of the native foredune and beach flora present at Kent Island, GGNRA Stinson Beach (East), was either absent or rare and not detected. Other cultivated, non-native ornamental plants were present in the foredune zone, probably as a result of foredune scarp erosion and retreat landward into older plantings (e.g., Monterey cypress, *Hesperocyparis macrocarpa*; acacia or green wattle, *Acacia decurrens*) that were originally farther landward from the shoreline.

***Cakile maritima* (sea-rocket)**. The common pioneer non-native beach weed, sea-rocket (*Cakile maritima*) is frequent on all West Marin beaches that are not severely trampled or eroded and wave-overtopped during the growing season. At Stinson Beach, however, *Cakile* was almost absent from the beach except along the foredunes in the center of Seadrift Reach and western terminal spit (Segment 0). Along the Patios reach, it was present only within the foredune scarp (near-vertical eroded slope), apparently where wave run-up deposited seeds. *Cakile's* significance here is as an indicator of beach erosion and disturbance, and potential for foredune succession, rather than a weed management issue per se. (*Cakile* is not a beach weed management priority, since it seldom conflicts with native beach plants). *Cakile* colonies indicate the zone where ecological succession can proceed between storm drift-lines (containing seeds, vegetative propagules, and organic debris), new and accreting foredunes can occur. Thus, *Cakile* is a useful feasibility indicator and zonal indicator for where embryo foredunes may be established. The extreme scarcity of this prolific pioneer colonizer of beach drift-lines at Stinson suggests that the beach profile space available for backshore deposits of seeds and drift-lines in winter, where they can be left undisturbed by waves or trampling during the subsequent growing season, is highly constrained under existing conditions. Even in highly trampled urban beaches like Ocean Beach, San Francisco, *Cakile* colonies are common except where the beach is graded.

Two factors are likely to contribute significantly to the extremely limited abundance and distribution of *Cakile* at Stinson Beach. First, the diffuse, intensive human trampling pressure along the beach is high because of the continuous distribution of residential access along the beach. Typically, beach trampling tapers rapidly from concentrated points of access, such as parking lots or boardwalks, so that reduction of beach vegetation is limited to the immediate access area. Related to the diffuse, intensive beach trampling pattern is the general compression of the backshore between high tide lines and either steep erosional foredune scarps or steep shoreline armoring. The "coastal squeeze" of the backshore likely confines wave run-up during high tides and high swell episodes, such that the highest, most landward drift-line colonies of *Cakile* (and other beach pioneer plant colonies initiated in winter) are subject to saltwater flooding and wave disturbance (erosion, burial) during the summer growing season. The presence of *Cakile*, in association with some native foredune species such as beach wildrye (*Leymus mollis*) in the central Seadrift Reach, where a low-angle foredune gradient occurs at the landward end of the beach profile instead of armoring or a steep scarp, suggests that beach steepness and width limit pioneer establishment of beach and foredune vegetation in most shoreline reaches of Stinson Beach.

Native beach and foredune plants.

There is a small native flora beach and foredune plants native to the Central Coast, which have been present at Stinson Beach since the earliest botanical locations for "Bolinas Bay" (19^{th} century) and "Stinson Beach" (1930s and later) were recorded. The Consortium of California Herbarium and Calflora were searched for the following species, which are still present at Kent Island and the GGNRA shoreline at east Stinson Beach, as well as the Doran Beach reference system (Bodega Bay).

> *Abronia latifolia* (yellow sand-verbena). Not found along any Stinson Beach shoreline segment. Infrequent as a pioneer in beach drift-lines, common in foredunes of West Marin where marram is not dominant. No local source populations are known.

Abronia umbellata (intermediate between *A. u*. var. *umbellata* and the rare *A. u*. var. *breviflora*; Marin-Sonoma populations from the same locality have been treated as both). Colonies are present along the eastern GGNRA beach reach, and at southwest Kent Island, where they rapidly expanded spontaneously during the restoration project there, after 2012. A. *umbellata* may be present at the western spit terminus, but it is apparently absent along the residential shorefront.

Ambrosia chamissonis (beach-bur). This species was not observed along armored or foredune-scarped residential shoreline segments of Stinson Beach. This is the most common native perennial pioneer beach and foredune forb in the Central Coast region. It may occur in the central foredune reach, but was not detected during winter (leafless or nearly so). Large colonies would have been detectible. It is present at Kent Island, GGNRA Stinson Beach, and at the western spit terminus, so local propagules (seeds; buoyant drifting dry fruits) are present in the littoral cell.

Atriplex leucophylla (whiteleaf saltbush). This is the most common and widespread native pioneer beach plant of the Central California coast. It is present at Kent Island, and at Limantour Spit, but it was not found along the residential shoreline segments of Stinson Beach. It would be expected to occur among *Cakile* in drift-lines of the backshore, but not in accreting foredunes.

Leymus mollis (beach wildrye) and *L. xvancouveresis* (Vancouver wildrye). Sparse colonies of *L. mollis* occur at about three locations in the central foredune reach, and more colonies occur at the western spit terminus foredunes. Compared with foredune colonies at Limantour Spit and Abbott's Lagoon in Point Reyes, the *L. mollis* at Stinson Beach backshore and seaward foredunes appears to grow at significantly lower density, and with shorter shoots. Environmental factors that may influence the lower density, height, and vigor of Stinson Beach *L. mollis* may include sand grain size (slightly coarser sand, lower moisture availability), low rates of organic drift-line debris deposition (nutrient, moisture retention capacity), and beach elevation relative to the fresh-brackish groundwater table surface elevation (high groundwater seaward of perched, non-tidal Abbott's Lagoon, and at low elevations near washover flats composed of medium sand at western Limantour Spit). The significance of the relatively low height and density of naturalized, unmanaged *L. mollis* at Stinson Beach foredunes is its role in generating sufficient surface roughness to trap wind-blown sand. Sparse, low shoot canopies of dune grasses are less efficient at trapping wind-blown sand than taller, denser shoot canopies.

One set-back residence on a lot at the eastern beach-top residential reach has a recently planted (about 1-2 yr) stand of *L. mollis* on what appears to be a low constructed sand bank (image below). The vegetated low (2-3 ft high above backshore) bank appears to be highly wind-sheltered by the adjacent lots with structures placed seaward, on or over the beach. The vegetated bank appears to be eroding at the seaward edge, and exhibits no sand accretion patterns on top.

The natural hybrid *L. xvancoverensis* occurs at both Kent Island (co-occuring with *L. mollis*) and in the vicinity of freshwater seep-influenced willow thicket foredunes at the GGNRA Stinson Beach, but it was not observed in the residential Stinson Beach shorefront. In the absence of high groundwater or finer sand, it would be expected to grow and spread less vigorously than *L. mollis*. *L. mollis* shoot canopy density and height can be increased by addition of nutrient-rich macroalgal (kelp) tidal litter in the backshore, over spreading root zones.

Beach wildrye was apparently planted on sand embankments placed in front of set-back residences within the Calles reach. The sand embankments and wildrye are mostly eroding by undercutting from wave action. (P. Baye)

Vancouver wildrye grows in both "marshy" foredunes (freshwater seep-influenced foredunes near high groundwater and wetland scrub) and well-drained accreting foredunes along the GGNRA overflow parking shore, where it often associated with pink sand-verbena (2011-2015). (P. Baye)

Non-native dune-building vegetation

Marram (marram grass, European beachgrass; *Ammophila arenaria*) is globally the most efficient dune-building grass of temperate zone coastal dunes. Its capacity to build and stabilize mobile dunes is a function of its extreme high tolerance to sand burial, high rates of growth and lateral spread despite high burial rates, and its ability to develop vigorous, dense, tall, upright stands of flexible, strong shoots that tolerate high wind-stress and sand abrasion.

High vigor of marram grass depends on periodic burial by sand accretion; in the absence of annual sand accretion, marram stands decline in density (number of shoots per unit area) and vigor (shoot size and growth rate), increase in mortality, and accumulate decaying leaf litter. The accumulation of decaying marram leaf litter at the base of shoots, at the sand surface, is a reliable indicator of recent dune surface stability, and the absence of significant sand accretion. Leaf litter more than one year old begins to disintegrate and turn from straw to gray in hue.

With the exception of the foredunes in the central Seadrift reach, all marram stands at foredune crests and even within scarps exhibited abundant accumulation of gray leaf litter at the dune surface. This indicates surface stability or slight surface erosion of foredunes and scarps for at least the past year. Minimal sand- buried litter was observed in the seaward zones of the central foredune reach. This key observation is consistent with local short-term geomorphic indicators of very low-level wind-driven sand accretion: little or no development of sand shadows in the lee of plants or other wind-obstacles (driftwood, debris, etc.) in the backshore.

Typically, back beach ramp accretion resumes during episodes of onshore winds above the threshold velocity for wind transport of sand, weeks or months after foredune scarp erosion by storm wave run-up. Sand deposition in the scarp/ramp profile initially occurs at the toe of the scarp face and slumping blocks of marram, and then proceeds up to the foredune crest as the back-beach sand ramp profile fills in. Only minor sand shadows and limited development of wind-driven sand ramps were observed in the central Seadrift and Patios reaches (maximum estimated local sand burial depth during the 2019 growing season less than 5-10 cm). For comparison, Doran Beach foredune marram was inspected on the same day as Stinson. The clear signature of recent SE onshore wind deposition of sand in foredune and embryo foredune marram was evident at all shoreline segments of Doran Beach except the farthest eastern end (where the backshore is extremely narrow, and sand is coarser). Both Doran and Stinson foredune marram experienced the same basic coastal winds this past year (growing season), but Stinson foredune marram exhibits almost no accretion, while Doran exhibits low to moderate accretion (burying basal marram leaf litter) in the seaward foredune slope.

Foredunes at Patios Reach, marram-dominated foredune scarps exhibit minimal post-storm recovery of vegetation and wind-driven ramp sand accretion; exposed roots, leaf litter unburied by sand dominate the surface of the slope, and there is almost no vegetative regeneration seaward of the scarp toe. December 20, 2019. (P. Baye)

Marram represents the upper limit of potential shoot height and density in the foredune vegetation canopy (maximum sand trapping capacity of vegetation canopy). All other native vegetation canopies would have somewhat lower sand-trapping capacity. Differences in sand-trapping capacity between marram and native foredune canopies are less significant at very low levels of onshore wind sand transport and vertical accretion rates. At low levels of onshore sand transport, marram tends to trap blown sand narrowly at the seaward edge of the dense canopy, forming a steep, narrow foredune ridge. Beach wildrye mixed with other species tends to trap onshore blown sand over a wider, gently sloping zone.

Iceplant (*Carpobrotus chilensis* and hybrids with *C. edulis*). Mats of iceplant are established in patches on some eroded foredunes and segments of boulder revetments. Iceplant has a low, flat leaf canopy and slow shoot emergence rates following sand burial; it builds low, broad mounded foredunes at slow rates, because the canopy saturates with sand at low levels of deposition. No iceplant mats were observed with accreted sand, and all iceplant mats exhibited retained old gray leaf litter (unburied) in the canopy. Iceplant apparently has no significant recent role in trapping wind-blown sand along residential shorefront lots at Stinson Beach. Iceplant vigor was usually low (reddish leaves, sparse growth) where it was rooted in interstitial soil or sand fill among boulders in revetments.

Iceplant occurs in scattered patches along eroding foredune scarps, interspersed with marram, or in single-species stands. Patios foredunes, December 20, 2019. (P. Baye)

4.2.3. Wildlife

Wildlife at Stinson Beach primarily consists of invertebrates that live on or under the sand surface, shorebirds and the occasional fish or sea mammal nearshore. This section provides a background on shorebird occurrence and beach ecology in the Stinson Beach region and describes recent shorebird observations.

Pacific Coast sandy beaches provide important habitat for shorebirds for migration and wintering and also provide breeding habitat for a few species. Sandy beaches are shaped by waves and vary by slope, width and sand grain size as a result. These characteristics influence the macroinvertebrate community and wider flatter beaches tend to have greater abundance and diversity of macroinvertebrates. Another factor that contributes to beach macroinvertebrate community is the presence of kelp wrack. Consequently, robust invertebrate community supports a greater abundance and diversity of shorebirds. The two most abundant shorebirds on sandy beaches are sandpipers and plovers.

Shorebird Occurrence and Beach Ecology in the Stinson Beach Region

The best available information on the ecological relationships between shorebird occurrence and sandy beach characteristics in the Stinson Beach region comes from the North-Central Marine Protected Area baseline characterization, conducted in 2010 and 2011 (Nielsen et al. 2013). Stinson Beach was not included in the more detailed assessment, but the covered adjacent beaches in the region that included Limantour Beach and Drakes Beach. However, it should be noted that, unlike Limantour and Drakes Beaches, most of the Stinson Beach backshore is developed and the beach is heavily used by humans, reducing the quality of the sandy beach habitat at Stinson for shorebirds. Another important factor affecting patterns of shorebird occurrence at Stinson is the very close proximity of Bolinas Lagoon, a 445 hectare seasonal estuary, which supports a large diversity and abundance of migratory and wintering shorebirds (Stenzel and Page 2018).

Shorebird abundance on sandy beaches in the region peaks in spring and fall, coinciding with migration periods (Nielsen et al. 2013). The most abundant species on sandy beaches in the region are Sanderling, Marbled Godwit and Willet (see Table 2 for species names and mean monthly abundance per kilometer of beach). Sanderling alone account for more than 50% of all shorebird numbers and this numerical dominance by Sanderling is consistent with other studies of sandy beaches in California (Hubbard and Dugan 2003, Neuman et al. 2005, Neuman et al. 2008, Nielsen et al. 2017). The highest maximum and mean densities of shorebirds per kilometer of beach in the region occurred at nearby Drakes and Limantour beaches (maxima of 125-153 shorebirds per km, mean of 25-39 shorebirds per km, respectively; Nielsen et al. 2013). Overall species richness was linked to habitat heterogeneity and proximity to wetlands. A small number of surveys conducted on Stinson Beach over the past decade for the Pacific Flyway Shorebird Survey indicate that Sanderling and Whimbrel are less common there than would be expected based on regional MPA data and patterns at other California beaches (Point Blue unpublished data), probably due to high levels of human-caused disturbance.

TABLE 2
THE TEN MOST ABUNDANT SANDY BEACH SHOREBIRD SPECIES[1] IN THE NORTH-CENTRAL MPA BASELINE STUDY REGION (ADAPTED FROM NIELSEN ET AL. 2013)

Common name	Latin name	Mean monthly abundance per kilometer of beach
Sanderling	*Calidris alba*	11.4
Marbled Godwit	*Limosa fedoa*	3.2
Willet	*Catoptrophorous semipalmatus*	1.6
Western Snowy Plover	*Charadrius nivosus nivosus*	1.0
Killdeer	*Charadrius vociferus*	0.8
Whimbrel	*Numenius phaeopus*	0.6
Black Oystercatcher	*Haematopus bachmani*	0.5
Black Turnstone	*Arenaria melanocephala*	0.3
Semipalmated Plover	*Charadrius semipalmatus*	0.2
Black-bellied Plover	*Pluvialis squatarola*	0.2
All Shorebird Species		20.1

[1] The other species observed included Ruddy Turnstone (Arenaria interpres), Western Sandpiper (Calidris mauri), Spotted Sandpiper (Actitis macularia), and Surfbird (Aphriza virgata)

See **Appendix I** for additional information on shorebirds at Stinson Beach.

Ecological Relationships with Physical Beach Characteristics

The physical characteristics of Stinson Beach, and Limantour and Drakes beaches measured by Nielsen et al (2013) are similar; all three sites are morphodynamically intermediate, meaning they are exposed to waves of 3+ feet, exhibit relatively small sand grain sizes (less than 0.26 mm), are sloped at around ~5% and have wide beach backshores (>240 feet). At Limantour and Drakes beaches, eelgrass is the dominant type of beach-cast wrack in terms of percent cover but kelp wrack are more abundant.

In the region at large, shorebird abundance is correlated with abundance and species richness of macroinvertebrates and macroinvertebrate biomass and diversity is highest at Limantour and Drakes beaches (Nielsen et al. 2013). Thus it is not surprising that the highest numbers of shorebirds in the region also occurs at these beaches. Based on the similarity between the physical characteristics of Stinson Beach and Limantour and Drakes beaches, the patterns of shorebird occurrence at these nearby beaches can be used as a general baseline estimate for Stinson Beach. However, the reduced habitat quality at Stinson resulting from development and high levels of human use must also be taken into account.

In addition to the physical and biological factors mentioned above, many other factors influence shorebird abundance and distribution on Pacific Coast sandy beaches, including tidal state and landscape features and human activity. For example, proximity to wetlands has been shown to influence shorebird abundance and species richness on other Pacific Coast beaches (Colwell and Sundeen 2000, Neuman et al. 2008, Lafferty et al. 2013). Stinson Beach is adjacent to Bolinas Lagoon and this proximity likely influences both species diversity and overall abundance of shorebirds using the beach. Tidal state strongly influences patterns of shorebird behavior and habitat use in estuarine and wetland systems, with most shorebirds foraging on mudflats at low tides when prey availability peaks. On sandy beaches the influence of tide on patterns of occurrence, behavior, and habitat use is less well-studied and the findings are inconsistent among studies. Stinson Beach has high levels of recreational use resulting in a high level of foot traffic and the physical landform has been altered to include areas of hardened and developed shoreline in all but the Patios Reach. These human-caused alterations of the landscape have likely reduced the quality of the sandy beach habitat for shorebirds.

Shorebird Nesting

The federally threatened Western Snowy Plover and the Killdeer are the two primary shorebird species that nest on sandy beaches in the region and are likely to nest along Stinson Beach or at the lagoon side of the north spit of Stinson Beach. Both species are sparsely distributed on beaches in the region and they are less abundant than other sandy beach shorebird species (Nielsen et al. 2013). There is a small nesting population of Snowy Plovers (<60) at nearby Point Reyes National Seashore, where nesting occurs primarily on the north and south sections of the Great Beach (Press et al. 2019). Plovers have nested at Limantour Beach since at least the 1970s (Point Blue unpubl. data) and have nested in some but not all of the past five years (Lau and Press 2019). At Stinson Beach, Snowy Plovers have nested at the northern tip of the spit in two of the past three years (one nest in 2017, two nests in 2018) and along the Seadrift section in 2013 (Point Blue unpubl. data). Historically, Snowy Plovers have occasionally nested on the sandy southern shore of Kent Island within Bolinas Lagoon (Point Blue unpubl. data). It is unlikely that Snowy Plovers nest along the more highly traversed eastern reaches of Stinson Beach.

Recent Shorebird Observations at Stinson Beach and Project Implications

Shorebirds were observed during the December 2019 visit in low numbers (a few dozen) along the outer edge of the swash zone at mid-tide, along the lower beach face. Whimbrels and western sandpipers were the most frequent shorebirds, and a few willets were present. One significant shorebird observation was the presence of at least 6 (possibly 8) western snowy plovers moving between the moist upper and lower beach face, in a zone about 200 feet wide along the Patios Reach. The plovers alternated between foraging movements along the lower beach face, and resting in human footprint depressions along the upper beach face, near but below the narrow dry backshore. The most recent high tide swash lines wetted the upper foreshore within about 5 to 10 feet of the foredune toe. The presence of wintering snowy plovers may be expected at similar locations where relatively wide backshore beach areas are present. At Doran Beach, also during a low tide the same day, over 30 western snowy plovers were similarly distributed (foraging in the lower beach face and resting in footprint depressions along the upper beach face, near the berm crest) in a zone where backshore widths were greatest along the beach. While Snowy Plovers are unlikely to breed at highly populated Stinson Beach, but their presence as wintering groups indicates a need to incorporate project measures to monitor their distribution and movements, and avoid disturbance or adverse habitat modification during any project implementation phases. Potential habitat enhancement could occur through activities that widen the sand berm or beach face, provide heterogeneous beach surfaces (shell, pebble) and maintain very sparse vegetation cover (significantly less than 5%) on most of the backshore where species may occur. Encroachment of backshore by any continuous or dense beach/foredune vegetation would be interpreted as an adverse habitat modification to this species. Specific short-term construction impacts and longer term impacts to shorebirds will be evaluated and described in the alternatives evaluation task of the study.

Western snowy plovers forage in the saturated sand on the lower beach face, and rest cryptically in footprint depressions in the upper beach face above the active swash zone, Patios Reach, late afternoon Dec. 20, 2019. (P. Baye)

Western snowy plovers resting among pebbles and cobbles near the swash uprush limit, and in recent footprint depressions on the upper beach face, Patios Reach late afternoon Dec. 20, 2019. (P. Baye)

4.2.4. Onshore Conclusions

Nearly all of the Stinson Beach shoreline segments exhibit indicators of significant long-term and short-term erosion with minimal post-storm recovery of backshore and foredune vegetation or dune morphology. Backshore annual and perennial vegetation regeneration at the end of the 2019 growing season is extremely limited (mostly absent), compared with extensive establishment at Doran Beach (Bodega Bay), which has comparable levels of intensive public recreational use, but no shoreline armoring to cause "coastal squeeze" of the backshore and foredune zones. The recent trends at Stinson Beach show an eroded foredune scarp-dominated morphology contrast with early 20th century trends of slow recovery of a mounded, low-relief dune field following major wave overtopping after the 1906 earthquake. The existing foredunes in the central Seadrift and Patios reaches appear to be relict features from former shoreline positions and backshore configurations; and do not appear to be maintained by ongoing processes that can be enhanced in current prevailing annual shoreline conditions.

Vegetation conditions at Stinson Beach reflect the constraints of "coastal squeeze" caused by recent shoreline erosion events combined with fixed positions of armoring or residential development from the mid/late 20th century. Where backshores are absent in the winter (storm season) beach, only scarped foredunes occur, with no significant post-storm recovery (sand accretion or vegetative regeneration). Marram is the most efficient sand-trapping and dune-building vegetation, so locations where it fails to initiate or support foredune recovery in current conditions (lack of over-winter backshore areas) strongly indicates a major constraint for any purely nature-based (native vegetation management) approaches, too. The inherent lack of consistent annual onshore sand transport by wind – a function of both backshore width and shoreline orientation to dominant sand-transporting winds – is the apparent relevant physical constraint for natural foredune vegetation recovery and dune building. The wide beach surveyed in October 2019 indicate space is available to construct natural infrastructure but any features built along Stinson Beach would require robust monitoring and management plans to maximize their effectiveness and longevity.

Western snowy plovers (*Charadrius alexandrinus nivosus*), Pacific coast population, are present as a wintering population at Stinson Beach, and they occur in the foreshore and backshore within some reaches of the Stinson Beach study area. They are expected to occur in the shoreline segments with the widest profiles. They are less likely to occur within the study area during the breeding season (spring-summer). This federally listed species is highly inconspicuous, and frequently forages and rests in upper intertidal zones with footprints, and adjacent wider backshore beach zones with surface litter or other sparse cover. Snowy Plovers have been seen nesting at the western tip of the sand spit as well as along the Seadrift Reach but are not likely to nest along the more traversed eastern reaches but have been observed foraging along the shoreline as recently as December 2019.

Onshore Ecological Conclusions by Study Reach

Seadrift Reach: The backshore zone is essentially absent along the western boulder revetment in the Seadrift Reach, and a steep beach profile (with an apparent inshore intertidal or subtidal trough) leaves no space for seasonal or inter-annual foredune evolution. The central Seadrift foredunes appear to have almost no over-winter backshore space needed for foredune initiation nor the sufficient wind-driven sand accretion to regenerate and recover wave-eroded foredune scarps. The exposed eastern revetment indicates low potential for natural foredune development along this segment of Seadrift.

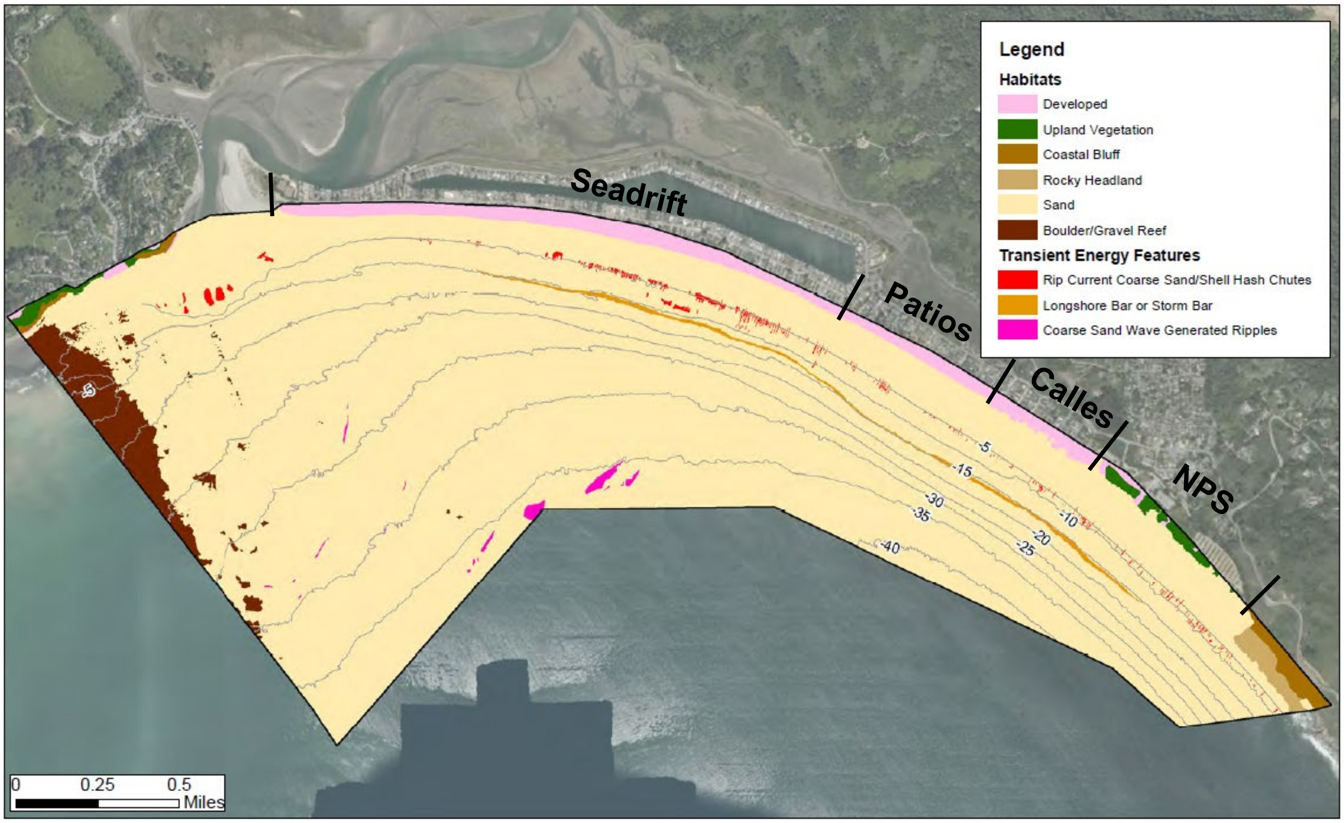
Patios Reach: The Patios Reach is characterized by set-back homes that appear to have allowed the entire beach profile to migrate landward, leaving geomorphic space for foredunes as well as post-storm ecological and geomorphic recovery. It has some potential feasibility for "living shoreline" management actions, though is constrained by apparently low natural onshore wind-driven sand transport and foredune accretion rates even with a wide backshore.

Calles Reach: The Calles Reach has alternating residential lots that project directly onto the beach with no foredune morphology and set-back lots with some limited foredunes seaward of them. The reach also appears to have no geomorphic space available for embryo foredune persistence or growth in a backshore that remains temporarily stable long enough to support them.

NPS Reach: The foredune wetland scrub and marsh vegetation associated with high groundwater seeps and springs in the beach along the west NPS Reach are hydrologically and geomorphically unique features along the Central Coast of California. The high groundwater saturating the backshore and foreshore would strongly influence vegetation management here. The GGNRA overflow parking foredunes have almost unrestricted potential undeveloped space for landward transgression, but are apparently restricted by intermittent or past parking lot road maintenance grading and spoil disposal of onshore-blown dune sand. The wide, gently sloped backshore, prevalence of finer medium sand, and greater exposure of the NPS reach to dominant westerly winds makes it the most conducive to potential natural foredune accretion and transgression with shoreline retreat given limited development in the reach.

4.2 Offshore

Offshore habitats are an important consideration for adaptation activities on Stinson Beach. The offshore portion of the study area is within the Greater Farrallones National Marine Sanctuary. As part of the topographic survey and sediment sampling for the study, Merkel and Associates conducted subtidal habitat mapping offshore of Stinson Beach in October 2019. Figure 11 shows the habitat types and transient features observed during the survey. Offshore habitat photos are provided in **Appendix D**.



SOURCE: Merkel and Associates, ESRI

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Figure 11
Benthic Habitat Features Along Stinson Beach

The offshore survey covered a total of 1,197 acres of acoustically mapped subtidal habitat. Areas not mapped by acoustic means were generally restricted by being too shallow for vessel operation, interference by air entrained in waters of the surf zone, or as a result of being out of the water at the time of the survey. In order to provide seamless habitat coverage across the marine/terrestrial interface, mapping was expanded with ESA topographic survey data to include the shoreline margin along the marine habitat mapping area. This expanded the study area to a total of 1,303 acres.

The offshore survey noted five habitat types within the survey area. There were six habitat types mapped by aerial interpretation and acoustic survey. These included upland features and two subtidal marine features including sand bottom and boulder gravel reef. Sand extended from subtidal environments to supratidal environments so this habitat occurred in both terrestrial and marine environments, while the boulder/gravel reef was restricted to subtidal and intertidal environments.

In addition to mapped habitats there were also three transient sand features that were discernable in the acoustic data set. These included longshore or storm bars, rip-current coarse sand/shell hash chutes, and coarse sand wave generated ripples. In most habitat mapping programs, extracting these features is not done as they are not indicative of persistent conditions. However, for the present investigation, it was deemed useful to map energy driven conditions as they provide insights into the physical processes affecting this segment of the coastline. Upland habitats mapped are generic features that provide context to the interface area. The marine habitats are described below and example acoustic images are provided in **Appendix D**.

Boulder/Gravel Reef – This habitat consists of a gradient of features from large unconsolidated boulders to fine gravels that have been derived from the erosion of the bluff shoreline of Bolinas. The study area does not appear to include much, if any of the bedrock of the larger Duxbury Reef off Duxbury Point that defines the sheltering hooked headland to the west of the study area. However, the material size class of the reef material generally diminishes from south to north along the western margin of the survey area such that gravel and cobble dominates the areas of reef nearest the Bolinas Lagoon mouth and large boulder dominates the area towards Duxbury Reef.

Sand – This habitat feature dominates the subtidal and intertidal landscape of Stinson Beach, occupying more than 90 percent of the total mapped habitat. In general, the sand bottom is a relatively featureless bottom with minor sand rippling in deep water and more pronounced rippling with sharper ridges occurring in shallow water. Sharp ridges in the sand ripples denote more recent development of the features, while smoother ridges occur as the features weather with age. Within the sand habitat there were noted several energy features that could be mapped as discrete elements. While they have been mapped, they are transitory features more indicative of coastal processes influences on the geomorphology of the seafloor than being unique habitat features that are biologically separable from sand bottom over prolonged periods. These features are:

> **Rip Current Coarse Sand/Shell Hash Chutes** – These features form within and immediately below the surf zone as a function of wave drain-out from the shoreline at localized points. The highest concentration of rip current features occurs near Seadrift East about midway down the beach. A second feature that has been classified together with rip current chutes is a scour feature in the ebb bar outside of Bolinas Lagoon. These features are generally developed differently from the archetypical rip current chute in that these are thalwegs of drainage courses on the surface of the ebb bar that tend to concentrate ebb tide energy due to slight depression of the bed form along the channels. These features shift around and will disappear and reform based on many factors influencing the ebb bar.
>
> **Longshore Bar or Storm Bar** – Along the shore margin at about -10 feet near the more protected western end of Stinson Beach and at about -15 feet towards the more exposed eastern end of the study area there is a narrow and relatively small longshore bar located offshore of the beach. These bars form seasonally and as a result of storm events. They are an unconsolidated temporary feature where beach sand is deposited following erosion from the upper beach face and typically occur immediately outside of the surf zone. The bar at Stinson Beach was notably small and non-descript in October 2019, which is typical of a seasonal minimum bar geometry post constructive summer wave conditions.
>
> **Coarse Sand, Wave Generated Ripples** – These features are not to be confused with widespread minor sand rippling that occurs in shallow waters near shore where the bottom exhibits small and highly transitory rippling due to high frequency wave influence. Rather the ripples that are mapped under this energy feature are long-period deeper water features that depict evidence of large storm influence and directionality of storm waves. The largest of these features occur below -35 feet and are likely the result of concentrating swell energy by the Duxbury Reef headland. Smaller features also occur in waters between -20 and -30 feet towards the western end of the study area. These are similarly likely the result of swell energy being focused by Duxbury Reef as it enters Bolinas Bay and are likely sand transport pathway (see Section 6).

5. Reference Sites

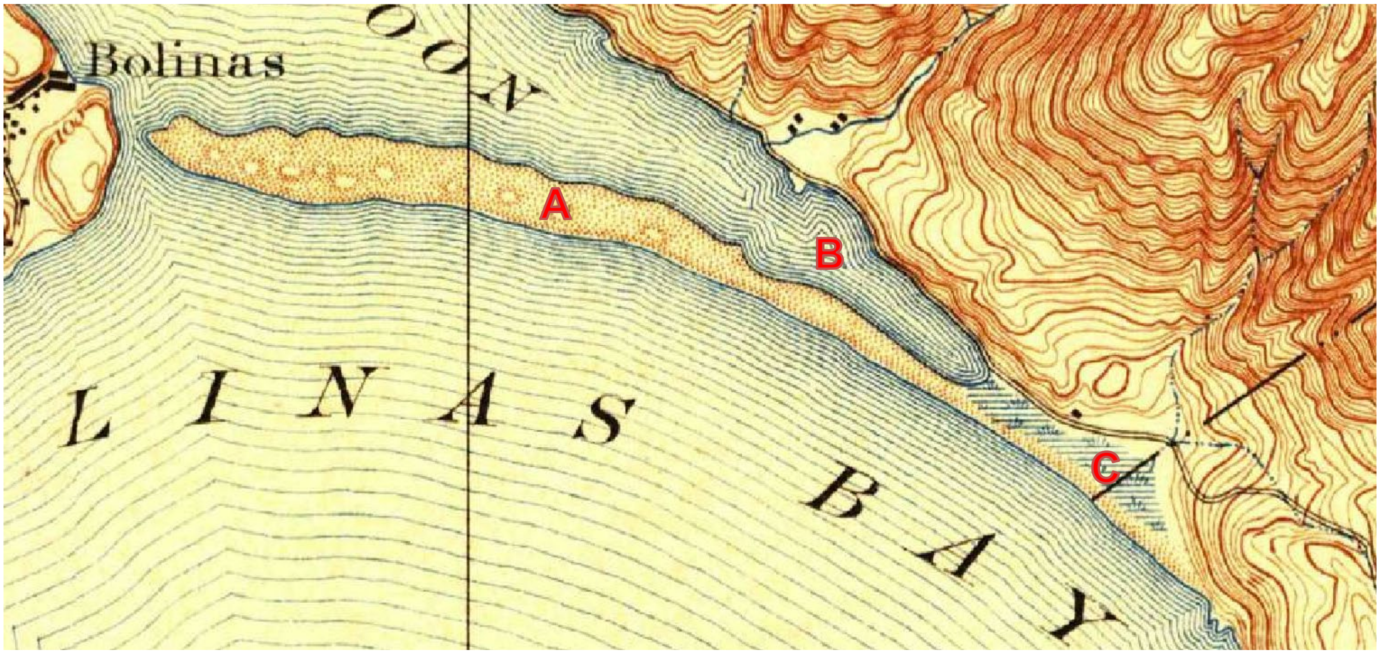
Reference sites were selected to develop a baseline understanding of (1) geomorphology and (2) to native foredune vegetation in similar coastal systems to Stinson Beach. Reference sites provide a natural context for the existing conditions at Stinson Beach and will inform the designs of nature-based adaptation alternatives that are selected for evaluation. Specific attributes that were examined for reference sites include the following:

- Backshore beach grain size – wind erosion potential, proportion medium sand
- Backshore (high tide) beach width – summer, winter profile (sand erosion fetch)
- Beach orientation to dominant W winds and dry high-velocity NW winds
- Backshore beach (berm top) width variability: calm (post-storm recovery phase) and post-storm profiles
- Foredune annual wind-driven sand accretion rate (volume/shore length, and vertical accretion rate)
- Foredune plant species composition
- Foredune vegetation structure related to sand trapping and regrowth (serial dune accretion): continuity/patchiness, shoot canopy height, shoot density
- Trampling intensity (impacts on perennial foredune vegetation and regeneration, post-storm recovery).
- Presence/absence of underlying cobble berms or terraces (washovers)

5.1 Geomorphic Reference Sites

5.1.1. Historical Stinson Beach ("Baulenes" or Bolinas Spit)

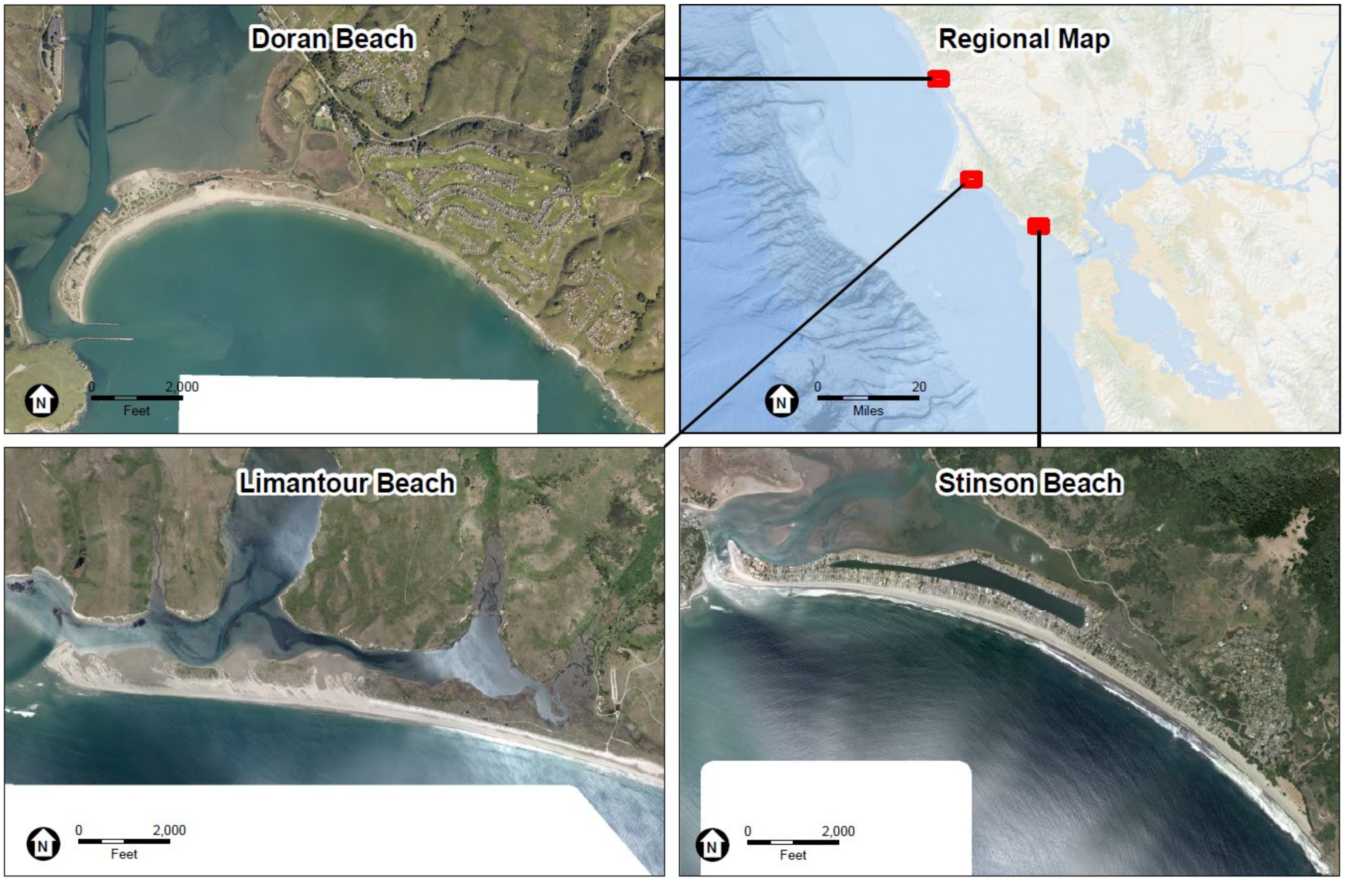
The original Stinson Beach foredune conditions are a dynamic (non-equilibrium) historical reference condition that needs further evaluation. The 1854 "snapshot" of the eastern Stinson barrier beach topography and crude vegetation types are illustrated in the U.S. Coast Survey sheet T-452 south (excerpt shown below). The remainder of the barrier beach is not represented in the corresponding north sheet of T-452. This provides a partial representation of at least one state of the spit before intensive modification. Aboriginal (Coast Miwok) modification of the sand spit was likely low in impact, since dunes have low food resource values and burning of salt-spray influenced (hygroscopic) native foredune vegetation is extremely difficult to fuel.



Detail excerpt of 1897 Tamalpais U.S. Coast Survey T-sheet, showing Stinson-Seadrift sand spit, showing narrow dunes with no significant topographic relief (Label A), narrow fringing backbarrier tidal marsh (Label B), and fringing non-tidal backbarrier freshwater wet meadow/scrub wetland with pond at the east end bordering all fed by canyon drainages (Label C). The distribution of freshwater wetlands roughly corresponds with modern willow scrub swamp behind the GGNRA parking lots today.

5.1.2. South-facing Embayed Sand Barrier Spits (refracted swell)

Bolinas Lagoon and Stinson Beach are embayments formed by co-seismic subsidence of the San Andreas Fault that underlies them. The closest comparable analogs of this barrier beach and lagoon setting are Bodega Harbor/Doran Beach and Limantour to the north (Figure 12).



SOURCE: Marin County, Sonoma County, ESRI

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Figure 12
Geomorphic Reference Sites for Stinson Beach

Doran Beach is another south-facing barrier beach sheltered from direct exposure to Pacific swell. It is smaller in length (approximately 8,850 ft) than Stinson Beach, but similar in width of unfilled or excavated barrier beach (approximately 430-450 ft). Doran Beach exhibits a more concave seaward plan form than Stinson Beach (leading to more swell dispersion into the bay and lower wave action). The jetty at Doran beach's tidal inlet is dissimilar to Stinson Beach, but it exhibits little evidence of net beach accretion at the jetty, consistent with near-equilibrium with incoming wave energy. The high tide dry beach is dissipative, gently sloping, and medium-grained. The backshore of Doran Beach is also medium sand, with a typically wide, flat berm profile in non-storm conditions. The Doran Beach berm profile appears to be distinctly wider than Stinson, possibly because storm-driven erosional retreat of the foredunes has been able to accommodate recovery space for the full berm profile, while the developed, filled Stinson shoreline restricts retreat of the equilibrium berm/foredune profile. The Doran Beach dune field exhibits minimal topographic relief, gently sloping landward (north) with undulating topography, indicating little wave-driven dune blowout activity during its formation. This is consistent with the offshore orientation of the beach and dune field to dominant, dry, high-velocity NW winds. The dune field is now dominated by marram and iceplant, but there is little evidence of strong morphological influence of the modern vegetation on the original dune topography. Marram typically builds steep, hummocky dune fields where onshore wind sand transport rates are high, or where blowout activity is high. The eastern end of the spit has a narrow berm and lacks embryo foredunes, and maintains a retreating scarp in older dune deposits (indicated by brownish organic-stained, weathered old dune soil horizons and some charcoal fragments). The central beach has a wider backshore with disorganized, trampled low-relief embryo foredunes, and low foredunes with small blowouts associated with disturbed, trampled, de-vegetated pedestrian paths. The maximum height of foredunes, despite marram dominance, is 2-3 m above adjacent slightly deflated backshore beach elevations.

Limantour Spit is the other geomorphically similar south-facing barrier beach north of Bolinas Bay and is nearly the same length (close to 16,000 ft) as Stinson Beach. The width of Limantour Beach varies with older spit reformations and washovers which increase towards the west, but proximal (east) end barrier widths of the apparent dune field range between about 120-600 ft. The foredune topography at the landward end of the spit is a nearly continuous, steep, periodically scarped foredune ridge (marram-dominated) with moderate to low-relief backdune topography. The wide backshore beach includes a dynamic embryo foredune zone that forms from storm-deposited tidal litter, and develops moderate height (mostly less than 1 m) between storms. The low embryo foredunes develop under the influence of mixed native and non-native (marram, iceplant, sea-rocket) beach and dune vegetation.

A common feature of these two reference barrier beaches and Stinson Beach is exposure to southwesterly winds, but sheltering from stronger, drier NW winds. This offshore orientation contrasts with the onshore orientation of NW winds for typical Central Coast foredunes. An important difference between the two reference barrier beaches and Stinson is the backshore beach width gradient. Doran and Limantour beaches have wide, dry backshore berms at least intermittently, which provide wide dry sand fetch to SW winds that can transport sand to the foredune zone. The narrow backshore beach and general wind climate at Stinson may constrain onshore wind sand transport, especially during high tides, to the embryo foredune zone. Wind climate at Stinson is discussed in Section 6. This aspect of reference and study site beach conditions may be valuable to monitor during brief, episodic onshore wind events during dry weather and wet weather, to estimate variability in onshore wind sand transport rates.

Wide backshore beach (Berm top) at Doran Beach, view to E, provides a long sand deflation fetch for SW winds. Marram dominates the Doran Beach foredune ridge, which ranges between about 1-2 m high (locally lower or higher). The steep seaward slope is a reformed foredune scarp (post-storm profile recovery by vegetation regrowth and sand trapping). (P. Baye July 2009)

Drift-line and embryo foredune development occurs episodically, and to limited extent, between major storm events at central Doran Beach. The slow vertical accretion of embryo foredunes despite the wide backshore deflation sand source, and exposure to SW winds, is instructive for estimating rates of natural foredune building at Stinson Beach. (P. Baye July 2015 left, July 2009 right)

Limantour Beach foredunes include small areas of native beach wildrye foredune vegetation (A) which form gentle slopes and spread widely. Most of the foredunes at the proximal end of the spit (most similar to Stinson Beach) are narrow, continuous foredune ridges 2-4 m high dominated by marram, with wide, irregular zones of embryo foredunes in varying stages of development in post-storm recovery of the beach/foredune profile, during gradual net shoreline retreat. (P. Baye)

5.2 Native foredune vegetation reference sites

These reference sites are recommended based on (a) geographic range compatibility with native plant species composition of Stinson Beach; (b) utility of models for dune-building next to residential areas with high foot traffic. These exclude sites with dominant marram, a European beachgrass, or iceplant. Local (near Bolinas Lagoon) and Regional (Marin-Sonoma coast) foredune reference sites are described below along with two other Central California reference sites.

5.2.1. Local – Landward (eastern) End Stinson Beach GGNRA

The eastern end of Stinson Beach (GGNRA overflow parking lot, normally closed) is the closest (on site) reference site for Stinson foredune design. It formed by a mix of artificial and natural sand deposition, and plant colonization. GGNRA maintenance crews years ago scraped wind-blown sand from the parking lot and pushed it in windrows along the seaward edge. These piles of mixed dirt and sand formed nuclei of embryo foredunes. The foredunes include mostly native vegetation. Foredune height has grown in the range of 2-3 m (above adjacent backshore beach) over about 15 years.

GGNRA Stinson Beach foredunes vegetation extends from the edge of the willow swamp foredunes (Vancouver wildrye) east to the cliffs, where assemblages also include pink sand-verbena, yellow sand-verbena, beach-bur. (P. Baye)

5.2.2. Local – West Kent Island foredune terrace

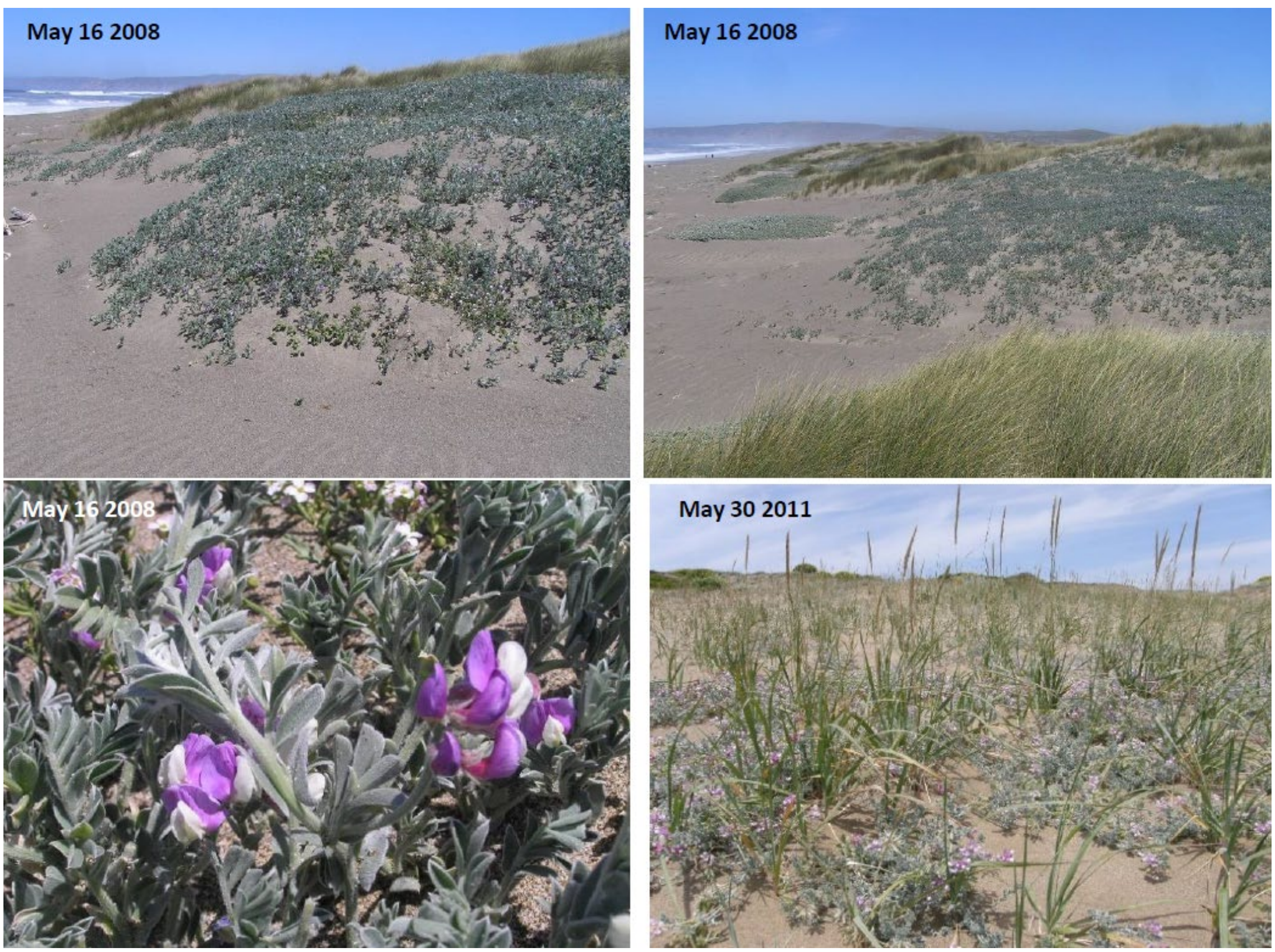
The west end of Kent Island is a dynamic sheltered beach in the tidal inlet (aggraded supratidal flood tidal delta). It cycles through erosion and accretion phases driven by the adjacent shallow tidal channel and sandy flood tidal shoals. During growth phases, it develops a wide, low foredune terrace dominated by Vancouver wildrye, which also occurs at both Limantour and east Stinson (GGNRA) beaches. This is a natural hybrid of native dune and seasonal wetland wildrye species. It is associated with other species shared at Doran, Stinson, and Limantour, including north coast sand verbena, and saltgrass. This site is in effect a low-energy extension of the sand spit foredune vegetation of Stinson Beach.

West Kent Island (Bolinas Lagoon) foredune terrace rapidly developed Vancouver wildrye foredunes, during a beach growth phase between 2012-2017. (P. Baye).

5.2.3. Regional – Restored Abbott's Lagoon Foredunes

GGNRA has removed marram and released native dune vegetation from its inhibitory influence for over 10 years. Though the west-facing beach is exposed to strong, dominant onshore NW winds, the relatively coarse beach sand has a higher threshold for onshore wind transport and thus limits dune accretion potential. Excellent examples of local native foredune vegetation stands, including single-species dominants and mixed assemblages, occur here. Major stands of silvery beach-pea occur here as single-species and mixed stands with beach wildrye, providing both a model and potential propagule source for these valuable dune-building species with complementary growth-forms.

Beach wildrye foredunes at north Abbott's Lagoon, Point Reyes, develop gentle seaward slopes. Driftwood is incorporated in the fabric of these foredunes. (P. Baye, April 2017).



The ornamental native silvery beach-pea occurs in single-species creeping (clonal) stands and forms gently sloping foredunes at Abbott's Lagoon. It also forms mixed stands with beach wildrye here, providing a potential model for Stinson Beach. (P. Baye)

5.2.4. Regional – Doran Beach.

Doran Beach embryo foredunes near the central segment of the beach (near parking lots and restrooms) have maintained a diverse assemblage of native foredune and beach plants, including the uncommon North Coast (intermediate) pink sand-verbena that also occurs at Stinson Beach. Associated native species include beach-bur, yellow sand-verbena, whiteleaf beach saltbush, saltgrass and beach wildrye.

North Coast (intermediate) pink sand-verbena at Doran Beach. (P. Baye)

Embryo foredune vegetation at central Doran Beach, dominated by native beach wildrye and non-native sea-rocket. Sand accretion rates are very slow here between storm erosion intervals; little vertical dune building occurs during beach growth phases. Note low foredune ridge dominated by the efficient sand-trapping marram vegetation landward of the embryo foredunes. (P. Baye)

5.2.5. Regional – Muir Beach

Muir Beach (GGNRA) is a pocket (headland-bound) barrier beach in a river valley south of Bolinas Lagoon. The north end of the beach has a cobble-gravel terrace formed from washovers that rework stream gravel and cobble deposits over which the beach retreats. A thin, low foredune terrace dominated by beach wildrye, Vancouver wildrye, and beach-bur forms over the coarse washover fan and stream delta.

The north end of Muir Beach is a reference site for low foredunes over a cobble beach terrace (washover) dominated by beach wildrye, Vancouver wildrye, and beach-bur vegetation. (P. Baye)

Muir Beach (north end) foredune terrace vegetation is similar to that of Kent Island's west end, but on a cobble washover terrace. (P. Baye)

5.2.6. San Mateo County – Pacifica State Beach (foredune and cobble terrace)

Pacifica State Beach at Linda Mar, Pacifica is a west-facing, coarser barrier beach with a drained and filled developed backbarrier lagoon wetland in its valley. The central foredunes were planted with beach wildrye, which formed a continuous, self-maintaining gently sloping foredune ridge up to about 3 meters above backshore berm top elevations, over a 10-year period, despite relatively high recreational use. Foot traffic is managed by symbolic fencing and brush placement over closed foot trails. Other segments of the foredunes are dominated by prostrate native dune vegetation, such as beach morning-glory, which scarcely builds foredunes above beach level. The seawall-lined parking lot is fronted by a restored beach (imported sandy fill) that spontaneously developed native foredune mounds of beach-bur despite location in a heavily trampled recreational beach area. These are all elements with potential application to Stinson Beach.

Linda Mar, Pacifica State Beach, has a wide, coarse berm and a low foredune zone. (P. Baye 2009)

Foredune vegetation in areas of high recreational use includes beach-bur (mounds) and beach wildrye (low, gently sloping ridge). (P. Baye)

Wide backshore sand deflation fetch at Pacifica State Beach provides wind-driven sand accretion source for low, hummocky foredune zones north of the beach wildrye foredune ridge. (P. Baye)

Brush mats close foot trails that may initiate dune blowouts on the lee (landward) slope of the foredunes at Pacifica State Beach. Seaward slopes of foredunes are "self-healing" under low rates of trampling, where creeping beach wildrye recolonizes gaps before blowouts develop. Symbolic fencing deters excessive trampling. (P. Baye)

Beach morning-glory has a prostrate growth habit that provides diversity but little dune accretion. (P. Baye)

The restored cobble-boulder beach (washover) terrace at the south end of Pacifica State Beach has a thin dune veneer supporting beach-bur and whiteleaf beach saltbush. (P. Baye)

5.2.7. Santa Cruz County – Wadell Creek (embryo foredune and cobble beach terrace)

Waddell Creek Beach, Santa Cruz, is a state park sandy barrier beach at the mouth of a river valley, formed over a cobble-gravel stream delta foundation, like Muir Beach. Part of the cobble beach terrace is exposed south of the creek mouth, where Marram removal has released native embryo foredune vegetation formed around nuclei of driftwood. The foredune vegetation assemblage includes most of the elements found at Doran, Stinson, and Limantour Beach, including beach wildrye, pink and yellow sand-verbena, whiteleaf beach saltbush, and beach-bur. The vegetation undergoes little trampling pressure. The beach has medium sand and a wide low tide terrace exposed to deflation from strong, dry northwest winds. Foredune accretion rates at the south end of the beach are likely to be higher than Stinson Beach, for a given vegetation stand type.

Waddell Creek sandy barrier beach and cobble-gravel, foredunes. (P. Baye)

6. Shore Dynamics Characterization

The geomorphic setting at Stinson Beach provides important context for both traditional and nature-based hazard mitigation projects. Shore dynamics at Stinson Beach are a function of tides and storm surge, waves and wind climate. The characterization summarized in this section will directly inform design criteria for backshore protection, project life and maintenance requirements (e.g., reconstruction of dunes after erosion) and limiting potential adverse effects (e.g., sand deposition in the inlet). This section summarizes the wind and wave climate, quantifies potential longshore sediment transport and calculates recent and long term shoreline evolution.

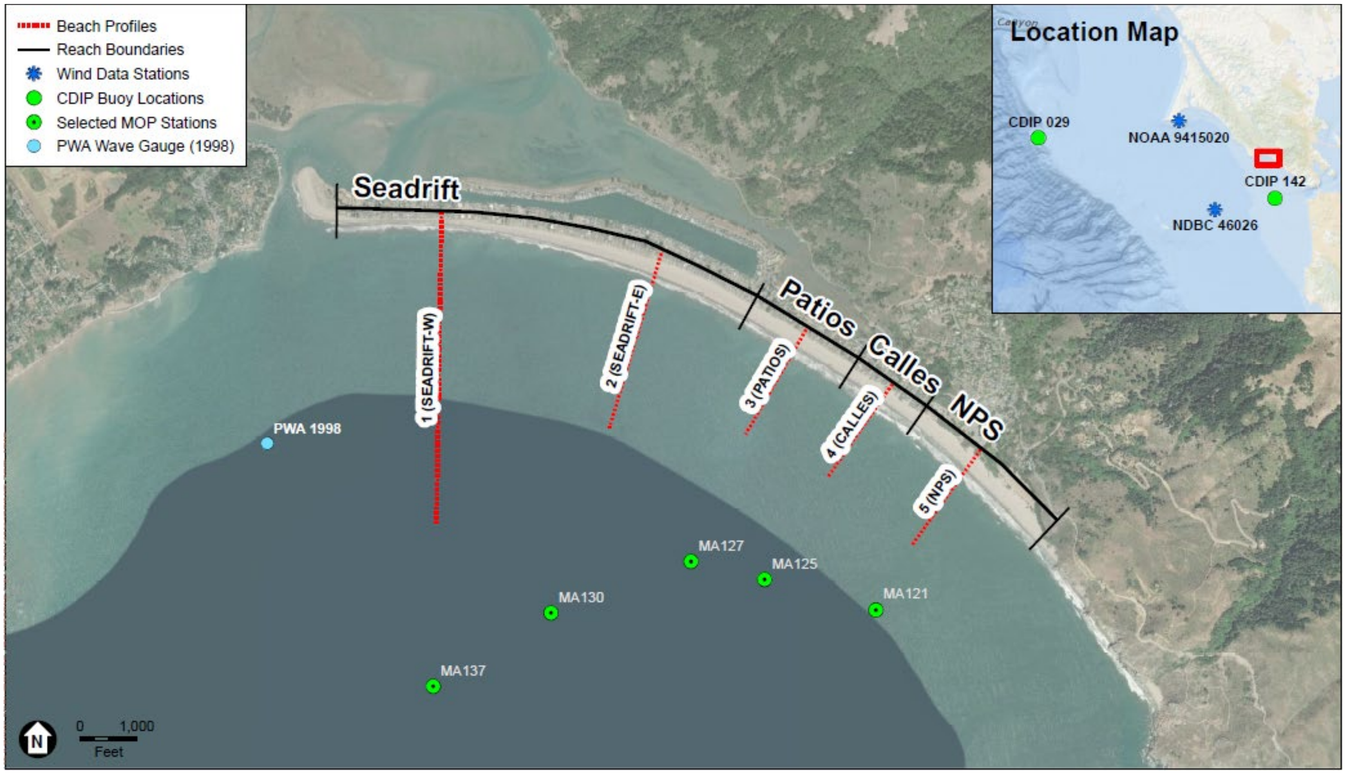
The environmental data gathered for the characterization includes observed offshore and modeled nearshore wave conditions from the Coastal Data Information Program (CDIP), wind and tide data from National Oceanic and Atmospheric Association (NOAA) and wind data from National Data Buoy Center (NDBC). Historic shorelines were derived from available digital elevation models produced by the U.S. Geological Survey (USGS), U.S. Army Corps of Engineers (USACE), NOAA as well as the ESA survey conducted in October, 2019. Figure 13 below shows the various environmental data stations that were accessed in order to characterize shore dynamics at Stinson Beach. Several Appendices were developed to illustrate shoreline dynamics at Stinson Beach:

Appendix E includes shoreline data collected for the study showing Mean High Water lines from specific dates between 1929 through 2019 to illustrate the seasonality of beach width at Stinson Beach.

Appendix F contain maps of existing FEMA flood hazard zones along the study area that indicate the existing exposure to a 100-year coastal storm event.

Appendix G contain maps of coastal flooding and wave run-up extents for existing sea-level for comparison to FEMA results. The hazard maps were obtained from Our Coast Our Future (OCOF), an online mapping tool hosted by Point Blue Conservation Science and produced by USGS CoSMoS (2.0). Note that the OCOF flood zone represents areas that are flooded for at least 2 minutes, while wave run-up points show the maximum landward extent of wave run-up. In contrast, FEMA distinguishes wave run-up areas with high velocity potential (VE zones) from lower velocity propagating waves (AO).

Appendix H describes the longshore sediment transport analysis performed for this study, which provides estimates of annual net sediment transport potential based on current shore conditions and SWAN modeling of wave data spanning 2007-2017.



SOURCE: NOAA, NDBC, CDIP, ESA

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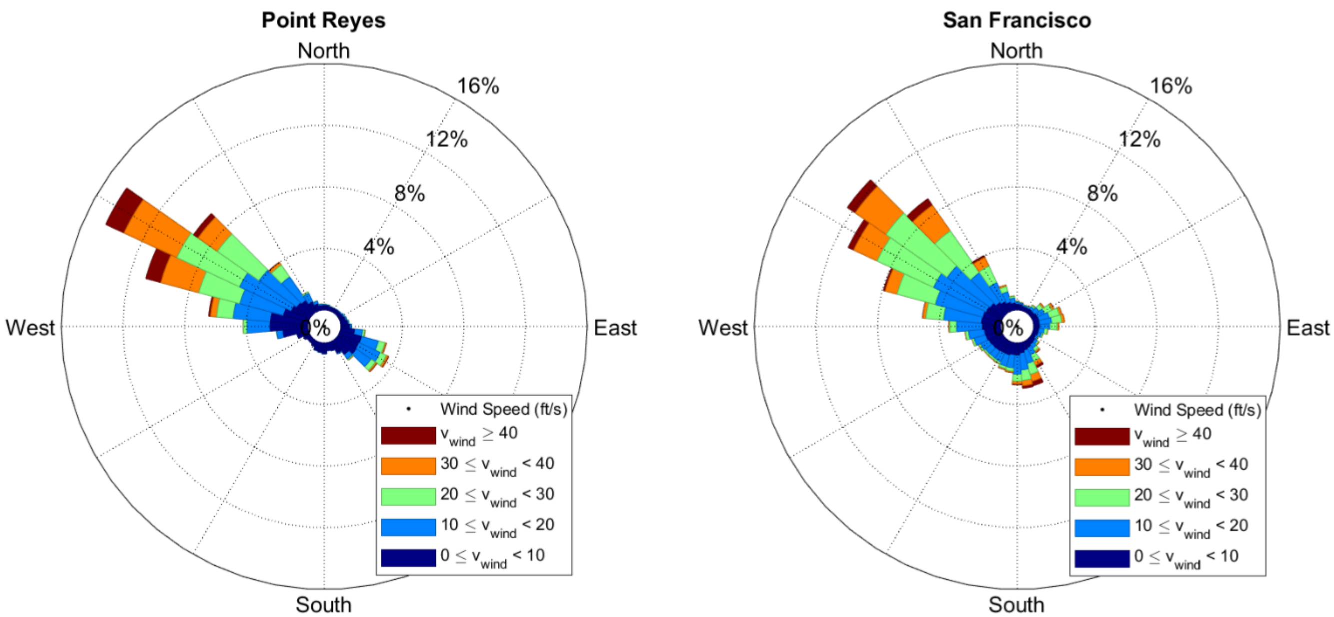
Figure 13
Environmental Data Stations

6.1 Wind

The feasibility of naturally maintaining and growing vegetated foredunes at Stinson Beach depends in part on wind-driven sand transport of the dry beach sediment. Figure 14 summarizes wind patterns at the two closest wind gauges to the study area: Point Reyes (NOAA tide gauge 9415020) and San Francisco (NDBC wave buoy 46026). The locations of these stations are shown on the location inset map in Figure 13 above. Both stations record hourly wind data; Point Reyes's data record spans from 1982-2018 while San Francisco's record spans from 2009-2018. Wind Roses based on these two datasets show that the predominant wind direction at both Point Reyes and San Francisco is from Northwest (Figure 14). At Point Reyes the secondary direction is from Southeast, while at San Francisco secondary directions include the South and Northeast. The data from each station confirm the observations made in the ecological characterization: there are limited onshore wind events (southwest) at Stinson Beach that would transport sand from the dry beach up into foredunes constructed for natural infrastructure.



SOURCE: NOAA, NDBC, ESA

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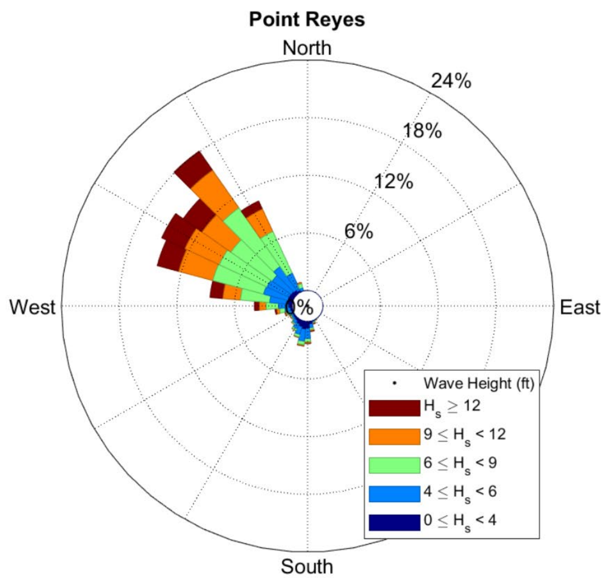
Figure 14
Wind Roses for Two Nearby Recording Stations

6.2 Waves

Ocean waves are primarily responsible for the formation of the Stinson-Seadrift sand spit and thus play an important role in the development and feasibility of nature-based adaptation alternatives along the shore. Wave action and tidal currents influence the movement of sand, which in turn leads to changes in beach morphology. Changes to the width, elevation, slope and orientation of the beach occur over the long- and short-term in response to the seasonality and year-to-year variations in wave climate. In general, energetic winter waves (short period waves generated by local storm winds and the Northern Pacific) erode sand from the beach face to subtidal bars immediately offshore. During summer and fall, more organized waves (long period waves coming from southern hemisphere storms) gradually transport sand onshore and build up the beach. In response to these seasonal wave patterns, beaches at Seadrift and Stinson usually vary in width and elevation in response to the seasonality of wave conditions. Extreme winter storms associated with El Nino conditions have even greater impacts to beach widths and upland assets, as discussed below. This section discusses the wave climate at Stinson Beach, based on observed data, regional wave modeling and new modeling conducted by ESA for this study.

6.2.1 Offshore Wave Buoy Data

Offshore (unsheltered, open ocean) wave conditions were characterized based on nearby buoy records and nearshore wave modeling results from the Coastal Data Information Program (CDIP). Offshore wave records were obtained from two CDIP deep water buoys: Point Reyes (CDIP 029) and San Francisco (CDIP 142). Buoy locations are shown in Figure 13. Wave roses depicted in Figure 15 show that the predominant wave directions are from the Northwest at Point Reyes and from the West at San Francisco. The significant wave heights can reach over 12 ft. The San Francisco wave gauge is located landward of the Cordell Bank and Farallone Islands and is affected by wave refraction effects in the vicinity (Battalio & Trivedi 1996; Battalio 2014), and hence is not representative of offshore waves incident to Stinson.



SOURCE: NOAA, NDBC, ESA

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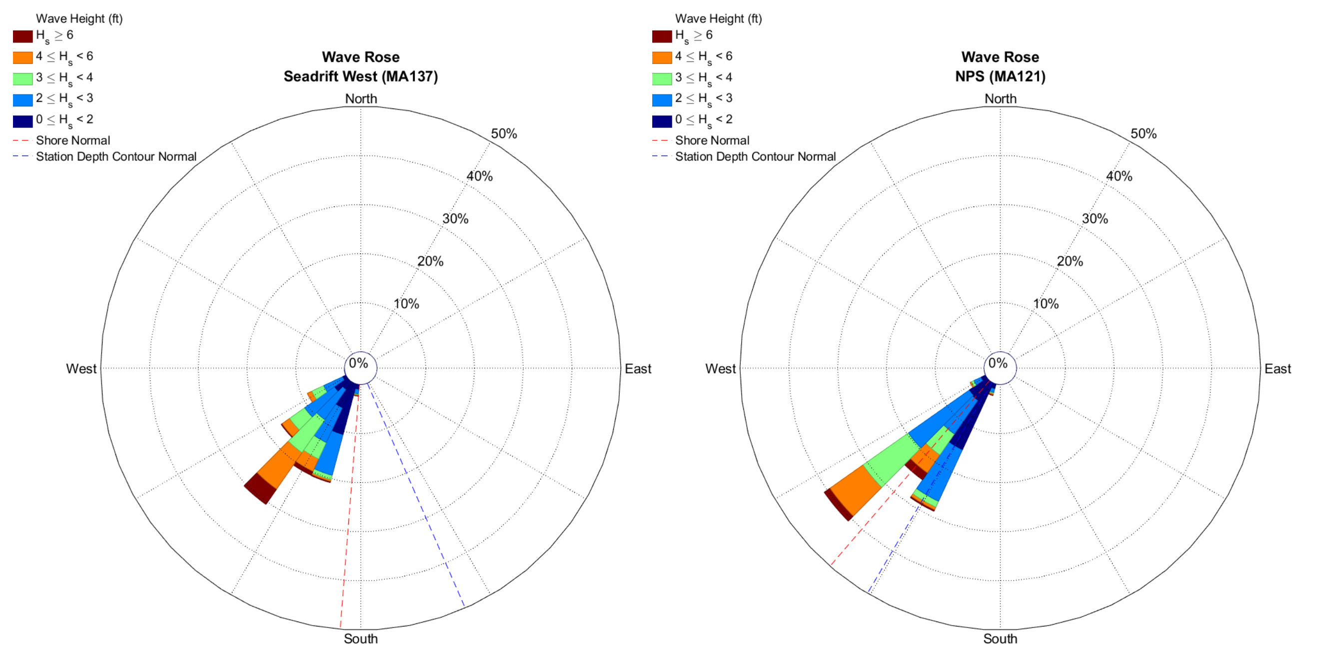
Figure 15
Offshore Wave Roses for Two Nearby Buoy Locations

6.2.2 CDIP Nearshore Wave Data

Nearshore wave conditions along Stinson Beach were first characterized from available nearshore wave data produced by the Coastal Data Information Program (CDIP). Five CDIP modeling output point (MOP) stations were selected near each of the five study shore profiles (Figure 13). Upon review, the MOP data were found to misrepresent the nearshore wave direction and height for the western profiles. Due to their location (located offshore at about -30 feet NAVD), the CDIP MOP results do not accurately represent the wave shadowing effects of the Duxbury reef, which results in wave diffraction for the western study reaches in particular, nor the wave spreading (wave refraction) that occurs as wave propagate farther into Bolinas Bay. Wave distribution roses depicted in Figure 16 show the unrealistically large relative wave angle for Seadrift West compared to NPS. ESA developed a wave transformation model in order to improve our understanding of the wave climate at Stinson Beach, discussed in the following section.



SOURCE: NOAA, CDIP, ESA

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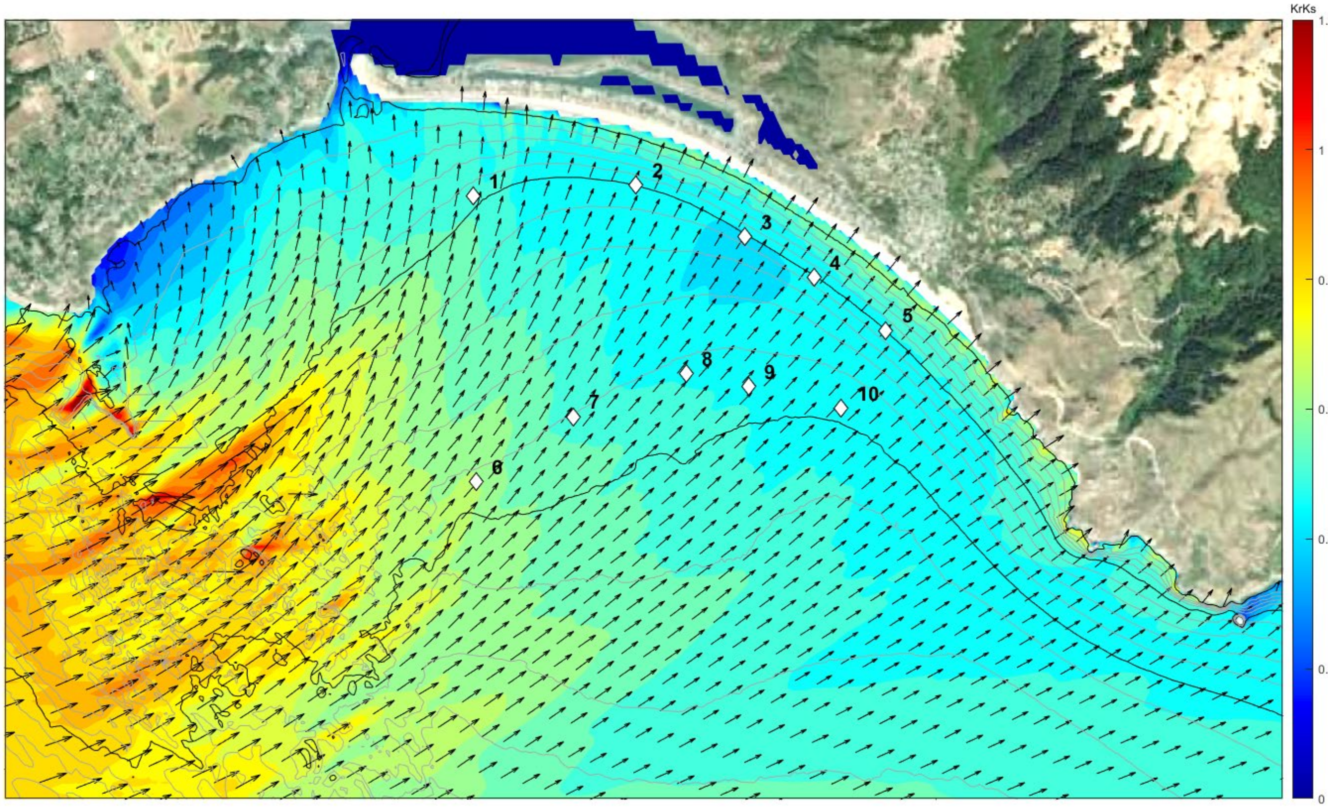
Figure 16
Nearshore Wave Roses for CDIP MOP Locations at West Seadrift and NPS Profile Locations with Normal Angle at Shoreline and Wave Model Point

6.2.3 Modeled Nearshore Wave Conditions at Stinson Beach

The primary purpose of evaluating the nearshore waves is to assess nearshore wave behavior to support sediment transport analysis and evaluate the coastal flooding and erosion along the study area. The CDIP modeled nearshore wave results were found to over-represent the swell height and relative angle of approach to the shoreline for the Seadrift reach in particular, as illustrated in Figure 16. ESA developed a wave transformation model in order to improve our understanding of the nearshore wave climate at Stinson Beach. The Storm Waves Affecting Nearshore (SWAN) model was developed, which used tide data from Point Reyes NOAA Station and wave data from available observation buoys and model output points near the site. The transformed nearshore wave conditions along the study area were used to compute a historic record of total water levels and detailed wave run-up for extreme events (described below) as well as refine estimates of longshore sediment transport (Section 6.3).

The following two figures summarize the importance of the SWAN modeling and results. Figure 17 below shows an example case from the SWAN model, which illustrates the shadowing effect of Duxbury Reef. Points 1 to 5 are SWAN nearshore output locations used to characterize wave climate for the study profiles, points 6 to 10 are the CDIP MOP locations investigated initially. Note the difference in wave size resulting from additional refraction between point 8 (CDIP MOP for Seadrift West profile) and point 1 (SWAN output for Seadrift West). The CDIP wave roses in Figure 16 for Seadrift West (CDIP point 6) and NPS (CDIP point 10) are quite different from those computed with SWAN which are respectively, points 1 and 5 (Figure 18). The newly modeled nearshore waves from SWAN were used to calculate a historic record and extreme event total water levels at the study area (described in Section 6.2.4) and estimate longshore sediment transport potential.

The SWAN wave transformations are considered adequate for this project. However, it is noted a more detailed modeling effort could improve results. Areas where improvement could be employed are wave diffraction, wave approach angles, wave breaking over Duxbury Reef and direct modeling of directional wave spectra for particular events.



SOURCE: NOAA, CDIP, ESA

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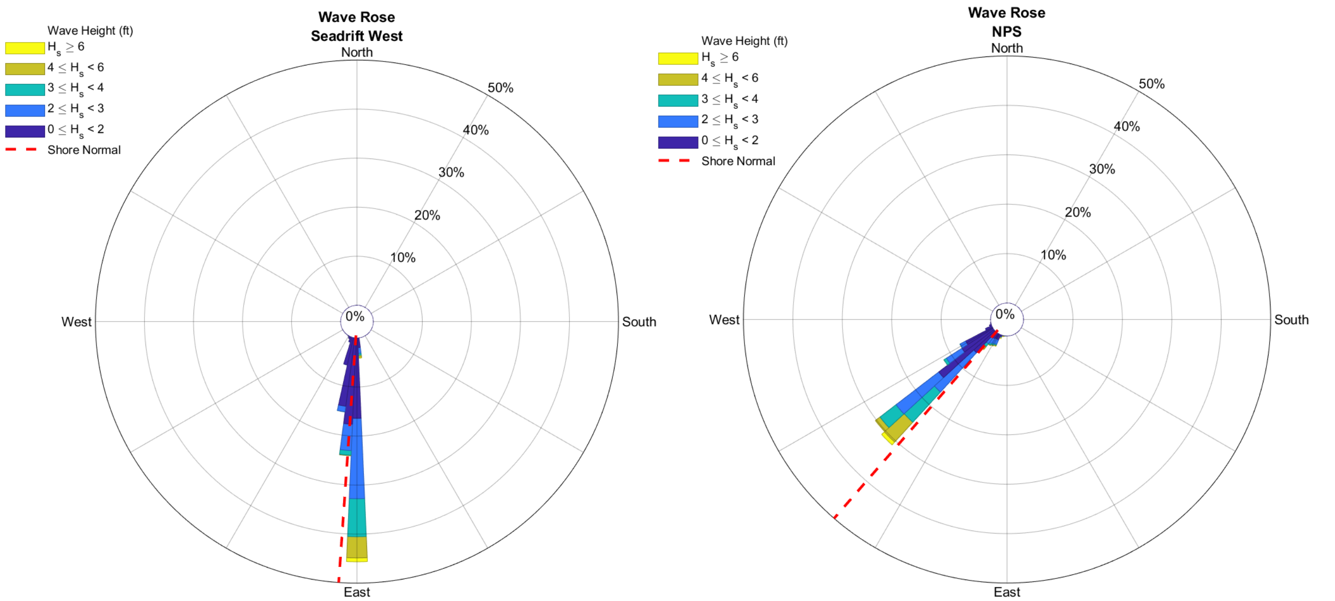
Figure 17
SWAN Model Extraction Locations and Example Wave Case
270 Degrees Direction, Tp = 20 sec, MHHW



SOURCE: NOAA, CDIP, ESA

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Figure 18
Nearshore Wave Roses for SWAN output points at West Seadrift and NPS Profile Locations with Normal Angle at Shoreline

6.2.4 Extreme Coastal Storm Wave Events at Stinson Beach

Extreme coastal storm waves were characterized based on existing reports, FEMA data and results of ESA wave transformation (described above) and run-up modeling developed for this study. A number of notable coastal storms have impacted Stinson Beach over the last few decades. Ecker and Wheelan (1984) estimated the highest breaking wave from 1951 to 1984 to be 18.6 feet at Stinson Beach Park and 12.3 feet at Seadrift (December 28, 1965) with corresponding wave run-up at high tide estimated to be 16 feet and 15 feet NAVD respectively. The following sections summarize extreme wave run-up computed for FEMA flood mapping along the study area and ESA-modeled wave run-up computed for each study profile using transformed nearshore wave data spanning 1983-2019.

FEMA Base Flood Elevations for Wave Run-up along Study Area

The Federal Emergency Management Agency (FEMA) published Flood Insurance Study for Stinson Beach (2017) estimates wave run-up elevations from 16 feet at NPS reach to 22 feet NAVD at the Seadrift Reach (details for each FEMA analysis transect are presented in Table 3). The most severe storms to hit the Stinson shoreline occurred in 1978, 1983 and 1997 (FEMA 2017). FEMA Digital Flood Insurance Rate (DFIRM) maps for the study area are provided in **Appendix F**.

Note that the wave run-up elevations in Table 3 are higher for the Seadrift reach than for the NPS reach, even though the wave exposure is the opposite (lower at Seadrift, higher at NPS): this is because the shore is steeper and the beach narrower due to armoring at the Seadrift while the NPS beach is flatter and wider, providing space for dissipation of wave run-up. Table 3 also shows that the run-up values computed for this study compare well with the FEMA values (compare the FEMA values to the values in the 1% column): This is partly because FEMA used similar methods and likely the same run-up equation, called the Stockdon equation (Stockdon 2006; FEMA

2005). This equation is often used for natural beaches without steep backshores, and is also favored for its ease of use.

TABLE 3
FEMA PACIFIC COAST STUDY TRANSECTS AND TOTAL WATER LEVELS AT STINSON BEACH

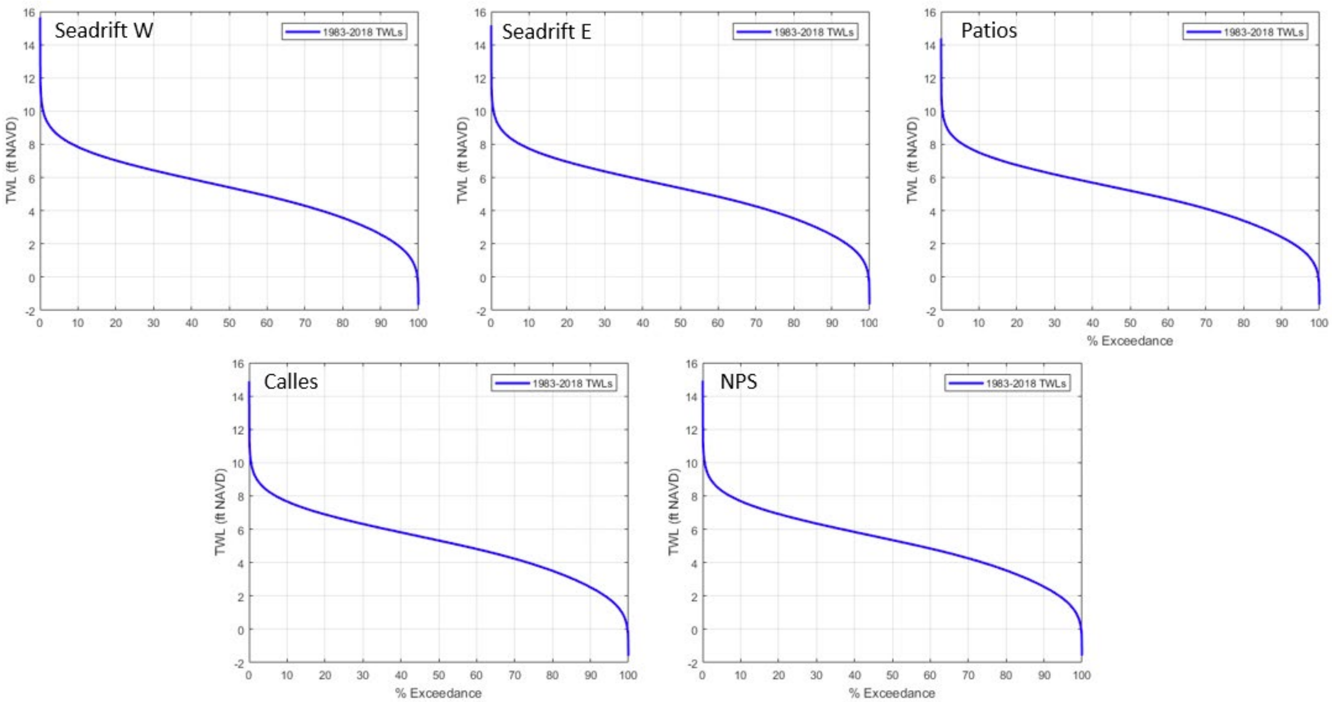
Profile	Stinson Study Reach	Description	Total Water Level (feet NAVD88)				BFE
			10% 10-yr	2% 50-yr	1% 100-yr	0.2% 500-yr	100-yr
P54	Seadrift	From the shoreline north to 322 Seadrift Road, Stinson Beach	18.2	20.9	21.9	24.4	22
P55	Seadrift	From the shoreline north to 234 Seadrift Road, Stinson Beach	16.7	18.6	19.4	20.8	19
P56	Seadrift	From the shoreline north-northeast to 142 Seadrift Road, Stinson Beach	18.8	21.3	22.2	24.2	22
P57	Patios	From the shoreline northeast to 9 Rafael Patio, Stinson Beach	15.1	18.9	21.0	27.5	21
P58	Calles	From the shoreline northeast along Calle Del Onda, Stinson Beach	13.8	15.1	15.6	16.7	16
P59	NPS	From the shoreline northeast to the Stinson Beach Parking Lot, Stinson Beach	13.9	15.4	16.0	17.4	16

Notes: Total water levels (combined tide, storm surge and wave run-up) are provided for various % annual chance of occurrence. A 1% chance annual occurrence corresponds to a 100-year storm, etc. Base flood elevations (BFE) are the FEMA designated flooding elevation for flood insurance purposes.

ESA Wave Run-up Calculations for Stinson Shore Profiles

To further understand wave run-up at Stinson Beach for this study, ESA conducted new modeling to characterize wave run-up at each study profile location. The modeling provides a reach-specific baseline understanding of wave run-up and establishes the tools to evaluate adaptation alternatives with respect to long term and storm event erosion from waves with sea-level rise.

ESA used the SWAN wave transformation modeling described above to convert offshore wave data to the nearshore along Stinson Beach. Offshore wave data from multiple sources were combined to produce a continuous record of offshore waves that were then transformed to nearshore to estimate long shore sediment transport potential (Section 6.3.2) as well as refine wave run-up estimates for each reach. Total water level (TWL) was first computed for each profile using the time series of waves and water levels and the Stockdon (2006) method, which is specific to wide beaches such as the eastern Study area. Figure 19 shows the total water level exceedance along the study area based on the transformed waves and foreshore slopes at each study profile. The highest predicted total water levels spanning 1983 to 2017 range from 14 to 16 feet.



SOURCE: ESA

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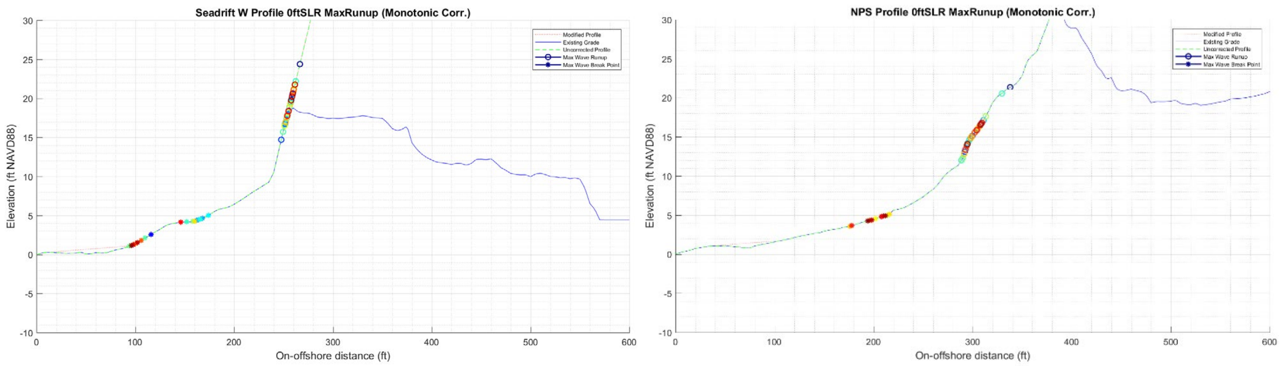
Figure 19
Computed total water level exceedance at study profiles using Stockdon wave run-up

Annual maximum events from 1983 to 2017 were identified from the computed time series of total water levels. The annual maxima were used to perform additional wave run-up calculations and extreme value analysis to estimate the 20-year and 100-year storm conditions at each study profile. The additional wave run-up calculations were performed using a composite slope method considered appropriate for steep backshores (FEMA 2005). This method requires more detailed calculations than the Stockdon method, but provides additional information about wave run-up specific to the shore profile.

Figure 20 shows detailed wave run-up computed for the annual maximum events using the composite slope method at the Seadrift West and NPS profiles for comparison. Compared to the Stockdon method, which uses a single shoreface slope (MLLW to MHHW) to estimate wave run-up elevation, the composite slope method (FEMA 2005) accounts for the overall shape of the beach profile and produces more accurate assessments especially for steep shores. The top 3 TWL events on each profile occurred in January 1983, February 1999 and January 2010. Because the largest TWL events generally occur in the winter, composite slope wave run-up was computed using typical winter profile conditions. Winter shore profiles were extracted from January 2018 County LiDAR for the composite slope wave run-up modeling. Of the historic annual maximum events modeled, a majority overtop the Seadrift West revetment. Maximum potential run-up for the 1983 event was modeled to be nearly 25 feet at Seadrift West, compared to 22 feet at NPS.



SOURCE: ESA

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Figure 20
Wave run-up of annual maximum events using composite slope method

Extreme value analysis was performed on the annual maximum events computed for the two wave run-up methods to estimate storm conditions at each study profile. Resulting extreme values for the 20-year and 100-year storm event based on Stockdon and composite slope run-up are shown in Table 4. The more detailed composite-slope extreme total water levels will be used to estimate the potential storm erosion along the study area and will inform the design and performance of nature-based adaptation alternatives in subsequent tasks of the project.

TABLE 4
EXTREME TOTAL WATER LEVELS AT STINSON PROFILE LOCATIONS BASED ON STOCKDON AND COMPOSITE SLOPE WAVE RUN-UP CALCULATIONS

		Stockdon		Composite Slope	
Profile	Reach	5% 20-year	1% 100-year	5% 20-year	1% 100-year
1.1	Seadrift West	14.8	16.4	23.4	26.4
1.2	Seadrift East	14.3	15.9	23.6	27.7
2	Patios	13.6	15.0	24.7	28.6
3	Calles	14.1	15.6	19.9	22.8
4	NPS	14.1	15.6	19.8	22.7

Notes: Values based on Gumbell Least Squares fitted distribution.

6.3 Sediment Transport and Shoreline Evolution

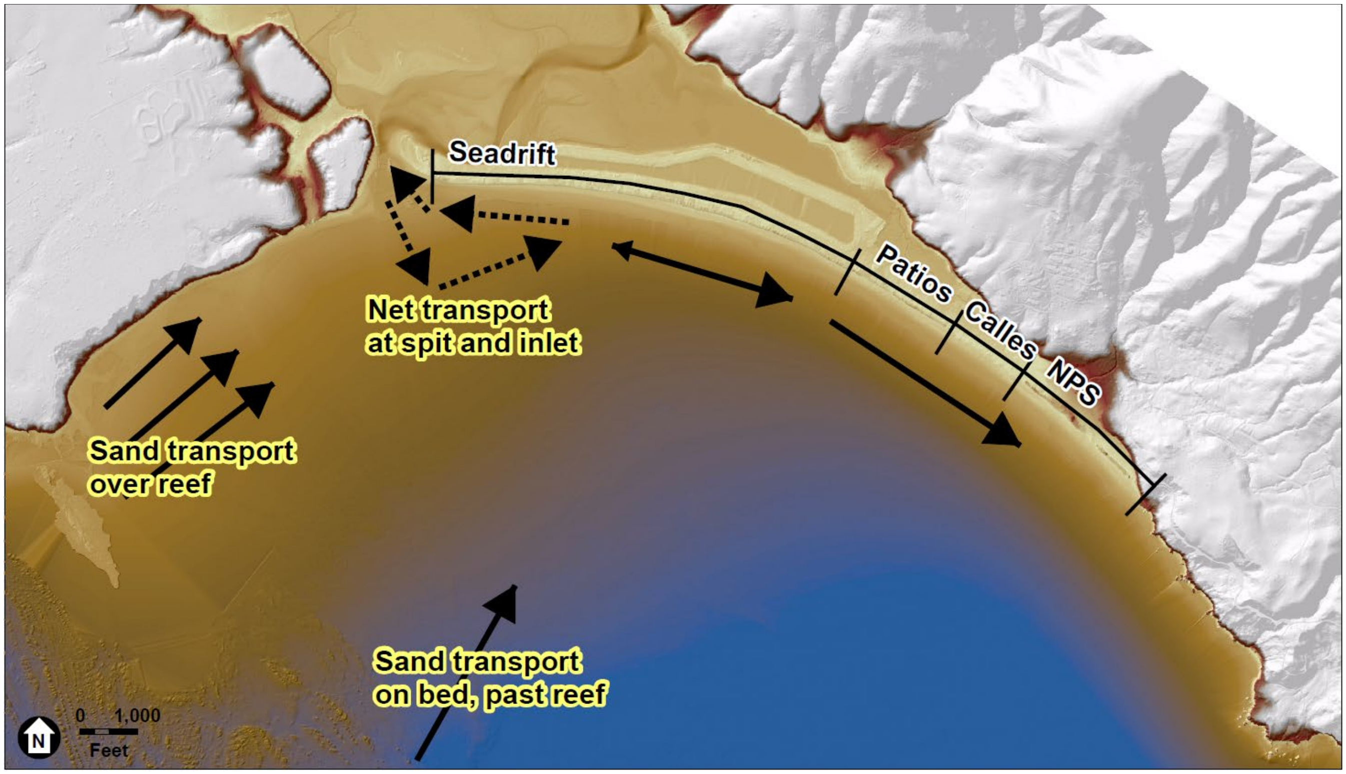
Shoreline (and beach, dune) evolution depends on long term and seasonal patterns in wave climate and shore geometry. To understand the ongoing dynamics along Stinson Beach, longshore sediment transport potential and shoreline evolution (long term and seasonal changes) were analyzed using existing data and new modeling. The longshore sediment transport potential and shoreline change characteristics presented here will be used to evaluate the feasibility of preferred nature-based adaptation approaches such as dune nourishment.

Conceptually, a given shore location undergoes seasonal changes in the beach profile such that the beach is eroded during stormier winter conditions and subsequently recovers during calmer summer seasons. This process is known as cross-shore (perpendicular to shore) sediment transport that can be regular and stable for a given location over time. If a winter is exceptionally stormy, the beach and upland can experience increased erosion that impacts dunes and or development, as occurred during the 1983-84 El Nino and others along the study shore. Longshore sediment transport occurs laterally along the shore and may fluctuate in magnitude and direction with the wave climate throughout the year. The combination of cross-shore and longshore sediment transport processes at Stinson Beach influence the overall shoreline evolution and have direct implications to the design and performance of nature-based adaptation alternatives. The following sections present the analyses of longshore sediment transport and shoreline evolution along Stinson Beach as well as geomorphic interpretation of Stinson study profiles for the purpose of estimating sea-level rise impacts to the shoreline in subsequent tasks.

6.3.1 Conceptual Description of Sediment Transport along the Stinson Shoreline

A simplified conceptual explanation of sand transport in Bolinas Bay focused on sand transport "throughput" is described below and shown in Figure 21.

- Bolinas Bay is a hook-shaped (logarithmic spiral) bay that is generally in equilibrium with waves and sand throughput. The shore fluctuates under storm / swell, seasonal, and possibly climatic (ENSO, PDO) cycles but is generally "dynamically stable" except for the effect of sea-level rise and the effect of development. Predominate wave driven sediment transport is from west-to-east and north-to-south. Duxbury Reef dissipates waves and is the upstream headland of the Bay; sand bypasses over it and in deeper water around it. Locally, near the lagoon inlet, along shore transport is toward the inlet.
- The Bolinas lagoon has a tidal inlet with sand exchange with the beach littoral sediments as well as sediment discharge of inland sources. Overall, the sand moves "through" and "past" the mouth after a somewhat circuitous "subcell" affected by tidal currents and inlet morphology. Hence, locally the net sand transport is at times westward from Stinson into the inlet, returning back out to the ocean with the ebb tide and then eastward under approaching waves. These flow paths are likely partly affected by the bathymetry and currents, which also affect the incident waves, at different tides with transport into the mouth at flood tides (especially after lower tides) and transport out at ebb tides and eastward mostly after higher tides.
- The net transport is more strongly eastward as you get to the Calles and the NPS reaches.
- There are various local sand sources and local spatial and temporal pathways
- Recent changes to sediment transport processes along Stinson Beach:
    - The armoring of the Seadrift spit has changed the mouth and spit dynamics, reducing sand supply to Seadrift via mouth migration, reduced sand overwash and spit building.
    - The reduction of tidal prism within Bolinas Lagoon may have resulted in a net deposition of sand from the ocean and or reduced discharge of sand from terrestrial sources. Higher sea-levels could increase the tidal prism of the lagoon along with the tide-driven sediment transport potential in and out of the lagoon mouth.
    - The armoring of the Seadrift shore has increased wave reflection and reduced beach elevations and could lead to nearshore trough growth and increased longshore transport rates.



SOURCE: ESA, USGS, ESRI

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Figure 21
Conceptual Diagram of Sediment Transport In Bolinas Bay

6.3.2 Longshore Sediment Transport Calculations

Longshore sediment transport (LST) potential at Stinson Beach was further studied to inform the overall feasibility of nature-based adaptation measures. LST influences shoreline erosion rates and can be used as an indicator of the potential longevity of natural infrastructure on the Pacific shore at Stinson and the potential impacts that natural features may have on adjacent coastal areas. For example, one concern may be that sand placed to widen the beach at Seadrift could lead to increased sedimentation at the lagoon mouth, potentially affecting navigation and other services.

ESA performed a preliminary assessment of Longshore Sediment Transport (LST) rates for Stinson Beach (see **Appendix H** for details). The analysis includes the use of the nearshore waves estimated for this study described in Section 6.2 and accepted methodologies and formulas to estimate the LST potential. Shore characteristics used to calculate LST potential are summarized in Table 5 below. The shore normal angle for each reach was estimated using the shoreline change analysis tool from USGS (USGS, 2020). The beach slope was measured from the MLLW water elevation to the MHHW water elevation for each beach profile for winter conditions when most LST occurs. The sediment size D50 used is the average D50 for all the samples for each profile location (sediment samples are discussed in Section 7). D50 refers to the sand grain diameter for which 50% of the sediment sample is smaller. D50, also known as median grain size, is one simplified measure of grain size.

TABLE 5
SEDIMENT AND SHORE CHARACTERISTICS USED IN LST ANALYSIS

Profile Location	D50[1] (mm)	Shore Normal[2] (degrees)	Slope[2]
Seadrift West	0.5	184	2.4%
Seadrift East	0.4	198	2.5%
Patios	0.3	211	2.4%
Calles	0.3	214	2.5%
NPS	0.4	221	2.4%

[1] averaged for each profile location, average grain sizes per sample are reported in Table 8
[2] angle and winter profile slope between MLLW (-0.02 ft NAVD) and MHHW (5.74 ft NAVD)

The LST potential along the Stinson shoreline was estimated as the average annual rate (cubic yards per year) determined from 11 years of spectral wave data (2007 to 2017). Potential LST rates along the study shoreline calculated from multiple equations are listed in Table 6. The reported accuracy of the industry-standard CERC equation is +/ 50% (USACE 1984; 2002), although there are indications that the calculated transport is biased high (over-prediction) of at least 25 % (Battalio 1985) and by a factor of 2 to 5 (van Rijn 2002). Consequently, several newer equations were applied, named after their lead developers (Kamphius 1991; van Rijn 2002). Results (Table 6) indicate that the potential net LST rate under current conditions is 230k cy/year northwest at Seadrift West and 120k to 350k cy/year southeast for all the other reaches.

The calculated rates represent the potential transport capacity of the waves (i.e., the actual transport rate will be lower if sediment supply is a limiting factor). While the sediment grain size and beach slope are comparable among reaches, the difference between the estimated potential LST is primarily due to the variation of shoreline orientation, which is consistent with findings in the literatures of LST studies. Our interpretation is that more accurate wave transformation modeling would result in smaller wave approach angles and lower net transport rates. Longshore transport calculations are very sensitive to the computed angle of incidence, especially near the zero angle (wave crests parallel to the shore) which is typical at hooked bay shores, especially given the high wave power along the California coast (Battalio 1985). The Van Rijn values are likely closer to the actual net magnitudes. The directions generally correspond to the conceptual diagram in Figure 21. Missing from these localized potential longshore transport calculations is transport during ebb flows from Bolinas lagoon, and wave driven transport across the Bolinas Bay floor beyond the surfzone. Combining the Van Rijn potential rates and the conceptual diagram, we posit that about 50,000 to 200,000 cubic yards per year enter Bolinas Lagoon from the west, passing over and around Duxbury Reef, and eventually mostly leaves Bolinas Bay to the east except for the sand that deposits in Bolinas Lagoon (about 30,000 cubic yards per year, PWA 2006). Some of the sand entering Bolinas Bay moves along the Bolinas shore to the lagoon mouth, and some moves across the bay floor to the surfzone in the vicinity of Seadrift East – Patios-Calles Reaches: We do not know the relative magnitudes of the transport along these alternative paths. Most sand then continues southeast and out of the Bay, but some sand moves north into Bolinas Lagoon and recirculates out during ebb tides, and then likely back toward the project area and east out of the Bay.

Note that the transport rates used here are called “average annual net”. Average annual means that the values vary by year and during the year. Net means the difference between transport in one direction and the other direction, meaning sand actually moves in either direction depending on the particular wave conditions, such that the total sand movement (called the “gross”) is greater than the net. Often the gross transport rate is a useful concept, for example providing a better indicator of the “loss rate” of sand placed to widen a beach, which perturbs the shore such that waves spread the sand away from the placement location over time, typically in both longshore directions.

The implications of this analysis are:

- The results are logical within practice-standard method and data uncertainty, and the analysis results are adequate for use in this study, for wave run-up, erosion and sand transport.
- Wave exposure is powerful enough to quickly move large amounts of sand, especially if the sand forms a perturbation from the shoreline planform which is in dynamic equilibrium.
- Beach nourishment may quickly be dispersed and some may move toward the Bolinas Lagoon mouth. Hence, widening the beach is riskier than adding sand to the back shore where it would only be mobilized after the shore has eroded, and the sand would help restore the equilibrium shore more than move away from the placement reach.
- With sea-level rise, the risks associated with beach nourishment will abate, and therefore beach nourishment is a future adaptation measure that should be considered. This finding may seem abstract at this point in the study but can be elaborated upon later.

TABLE 6
POTENTIAL LONGSHORE SEDIMENT TRANSPORT RATES ALONG STINSON BEACH

	Potential LST (CY/year) by Method (- is northwest, + is southeast)				
Profile Location	**CERC**	**Kamp**	**Kamp2**	**Van Rijn**	**AVERAGE**
Seadrift West	-227,300	-325,300	-237,100	-128,000	-229,400
Seadrift East	115,100	178,100	131,100	47,300	117,900
Patios	133,400	248,600	209,600	42,800	158,600
Calles	360,200	457,800	376,600	193,500	347,000
NPS	259,500	352,600	282,900	110,000	251,300

6.3.3 Shoreline Evolution Analysis

The long-term (100 years) shoreline position along the study area has been stable and has recently accreted 1-2 feet per year with the exception of Seadrift, which has eroded over the long term and has recently stabilized in its current location. The shoreline trends in the eastern reaches bodes well for natural infrastructure feasibility in terms of the available beach space and stability for average conditions. However, the exposure of Stinson Beach to storm wave impacts may pose a challenge to natural infrastructure. This section presents an analysis of long term shoreline change as well as potential impacts from extreme coastal storms at Stinson Beach.

Historic shoreline positions (mean high water, MHW=5.1 feet NAVD) were compiled from available sources and processed with the USGS Digital Shoreline Analysis Software (DSAS) to calculate long-term and seasonal shoreline changes along Stinson Beach. Historic shorelines collected for this study are shown in **Appendix E**. The oldest shoreline was derived from 1920s T-Sheets by the USGS, while the most recent shoreline was taken from Marin County LiDAR flown in January 2018. LiDAR flights conducted before and after El Nino winters provide great insight to extreme winter impacts. Table 7 below summarizes long term and seasonal shoreline evolution for each study reach. Shoreline change values correspond to the Linear Regression Rate (LRR) computed with DSAS in feet per year while seasonal fluctuations (winter/spring to summer/fall) are provided in feet.

TABLE 7
HISTORIC SHORELINE EVOLUTION SUMMARY BY STUDY REACH

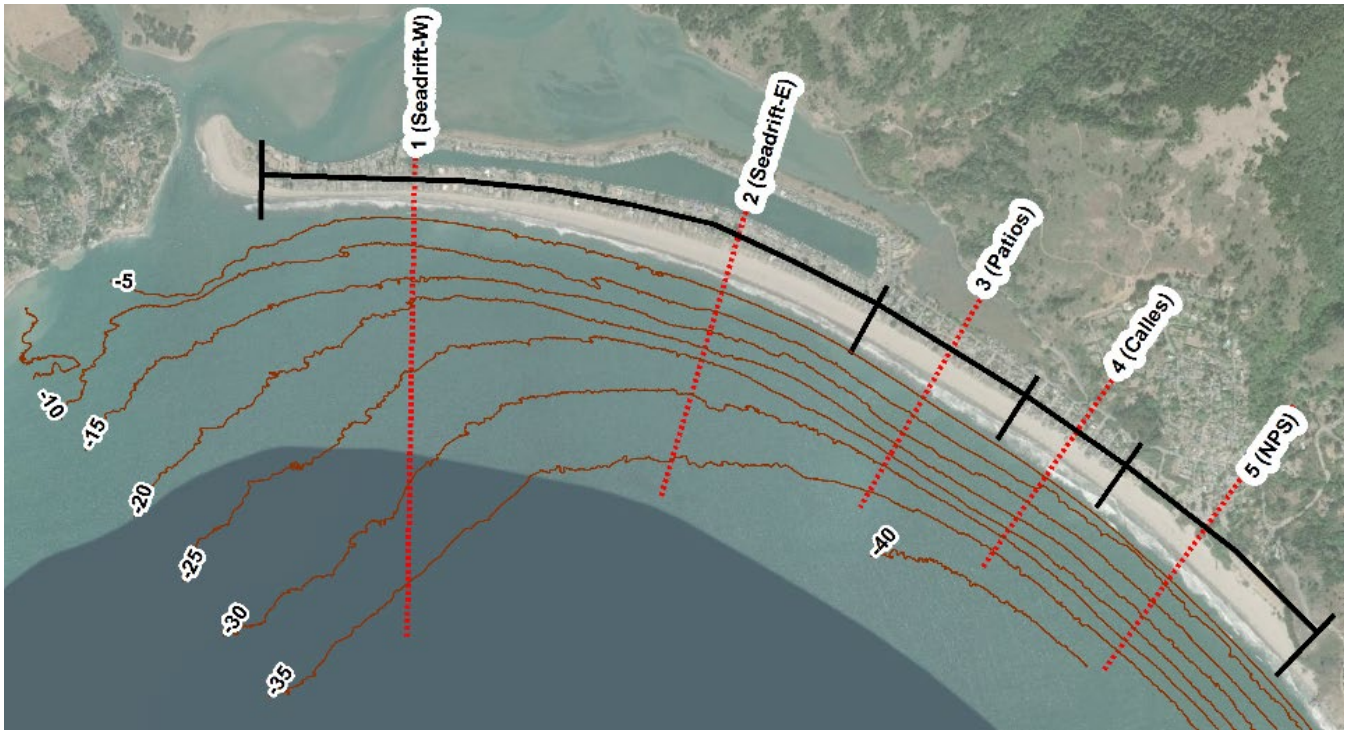
Reach	October 2019 Average Beach Width (feet)	Recent (post 1990s) shoreline change (feet/year)	Long-term (post 1920s) average shoreline change (feet/year)	Extreme winter shoreline change (feet)	
				1998 El Nino	2016 El Nino
Seadrift	156	0.2	-0.9	89	104
Patios	250	1.0	-0.1	94	151
Calles	235	1.8	0.2	47	158
NPS	264	1.4	0.1	31	136

Note: Values are averages for each reach based on transects spaced ~160 feet alongshore

Over the past century, the overall shoreline position has been relatively stable along the eastern study reaches (erosion or accretion of just inches per year) general while the Seadrift Reach has eroded steadily (0.9 feet/year on average). Positive short-term accretion rates suggest the shoreline and beach have undergone steady recovery since the 1990s. Over a similar timeframe, significant erosion events along the Stinson backshore have impacted development, wasted dunes and led to the construction of the Seadrift rock revetment (after the 1983 El Nino). These storm-driven erosion events are distinct from the average shoreline accretion taking place at Stinson and present a challenge for nature-based infrastructure solutions. To quantify the potential impacts of extreme winters at Stinson beach, MHW shorelines were extracted from available LiDAR DEMs for two recent extreme winters. Airborne LiDAR was collected before and after both El Nino winters of 1998 and 2016 by the USGS for the west coast. The recent 2016 El Nino resulted in 100 to 160 feet of shoreline erosion along the Stinson shoreline while the 1998 El Nino resulted in 30 to 100 feet of shoreline erosion. While the shoreline mostly recovered after these events, these extreme winters provide an indication of the potential impacts to natural infrastructure that is constructed on the current available beach footprint along Stinson.

6.3.4 Shore Profiles and Geomorphic Interpretation

The ESA-Merkel surveyed profile elevations were plotted with other recent elevation data for comparison and geomorphic interpretation each shore profile. Shore profile locations are shown in Figure 22 along with 5-foot depth contours developed from ESA ground survey and Merkel Sidescan Sonar.

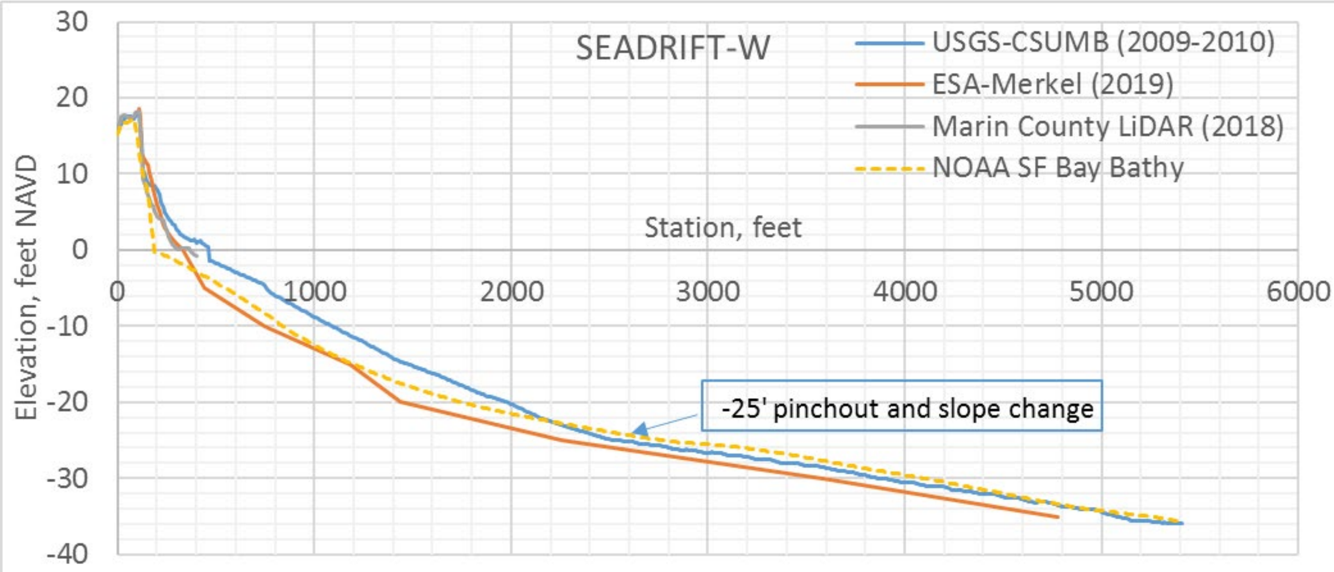


SOURCE: ESA, Merkel and Associates, Marin County

Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 22
Study Profiles and Nearshore Depth Contours

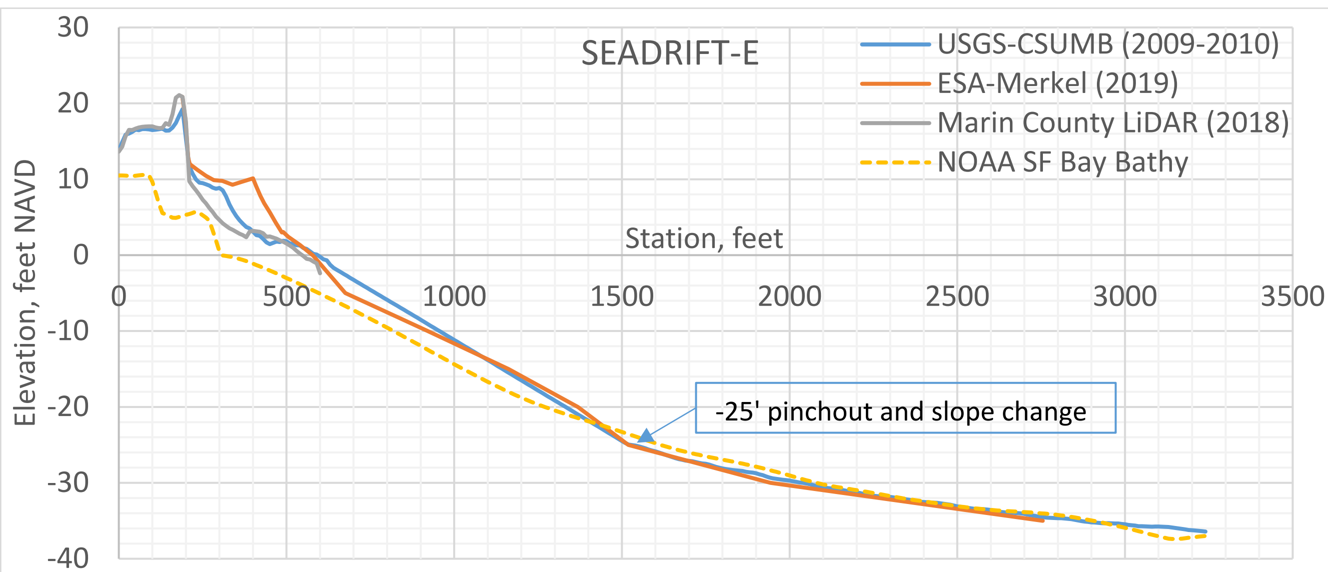
Figure 23 to Figure 27 below show the surveyed shore profiles at each of the study reaches compared with other available data sources. The profiles are annotated with the approximate limit of the shore face, the location on the shore profile above which wave-driven transport is most active (labelled as pinchout). Note that negative elevations shown on the ESA-Merkel profiles are not official survey bathymetry but are derived from the offshore ecology sonar survey by Merkel and are included for reference. As shown on the profiles in Figure 23, the lower elevations along Seadrift West profile intercept the ebb shoal at the Bolinas Lagoon mouth, making the active shore face ambiguous. The active shore face for sea-level rise response could be shallower in this location, perhaps around –20 feet NAVD, indicating a steeper shore face slope and less recession with sea-level rise. Profiles to the east shown in Figure 24 to Figure 27 exhibit a more defined shore face indicated by smaller variation between profile data sources at each location.



SOURCE: ESA

Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

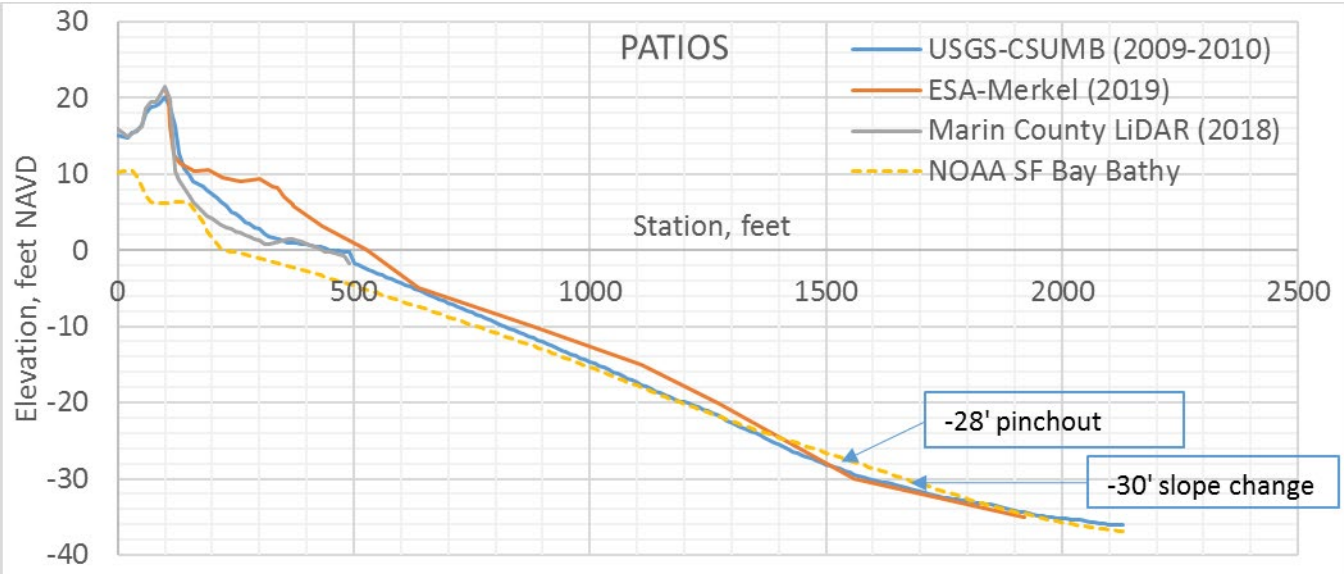
Figure 23
Seadrift West shore profile interpretation



SOURCE: ESA

Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

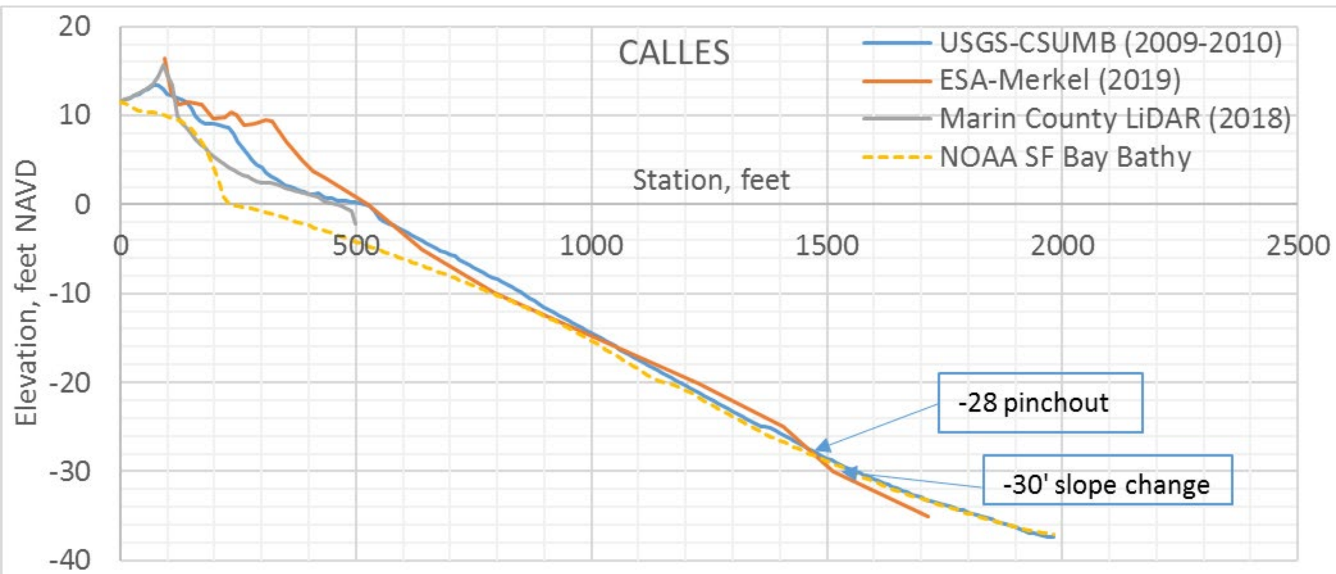
Figure 24
Seadrift East shore profile interpretation



SOURCE: ESA

Stinson Beach Nature-Based Adaptation Feasibility Study. 171009.00

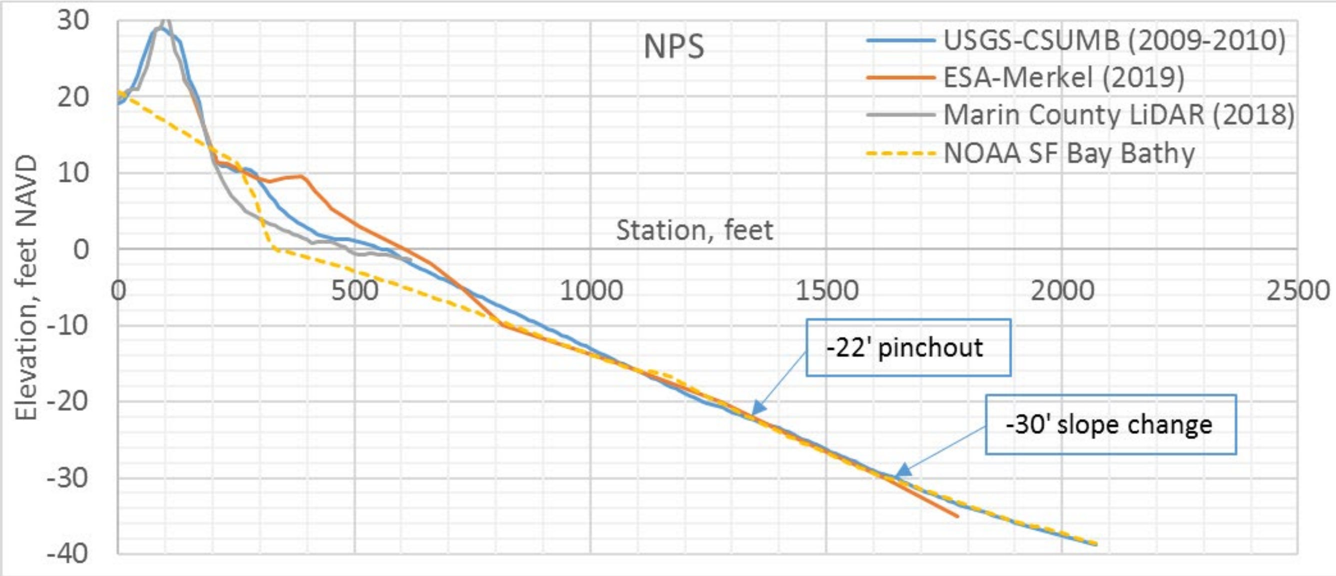
Figure 25
Patios shore profile interpretation



SOURCE: ESA

Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 26
Calles shore profile interpretation



SOURCE: ESA

Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 27
NPS shore profile interpretation

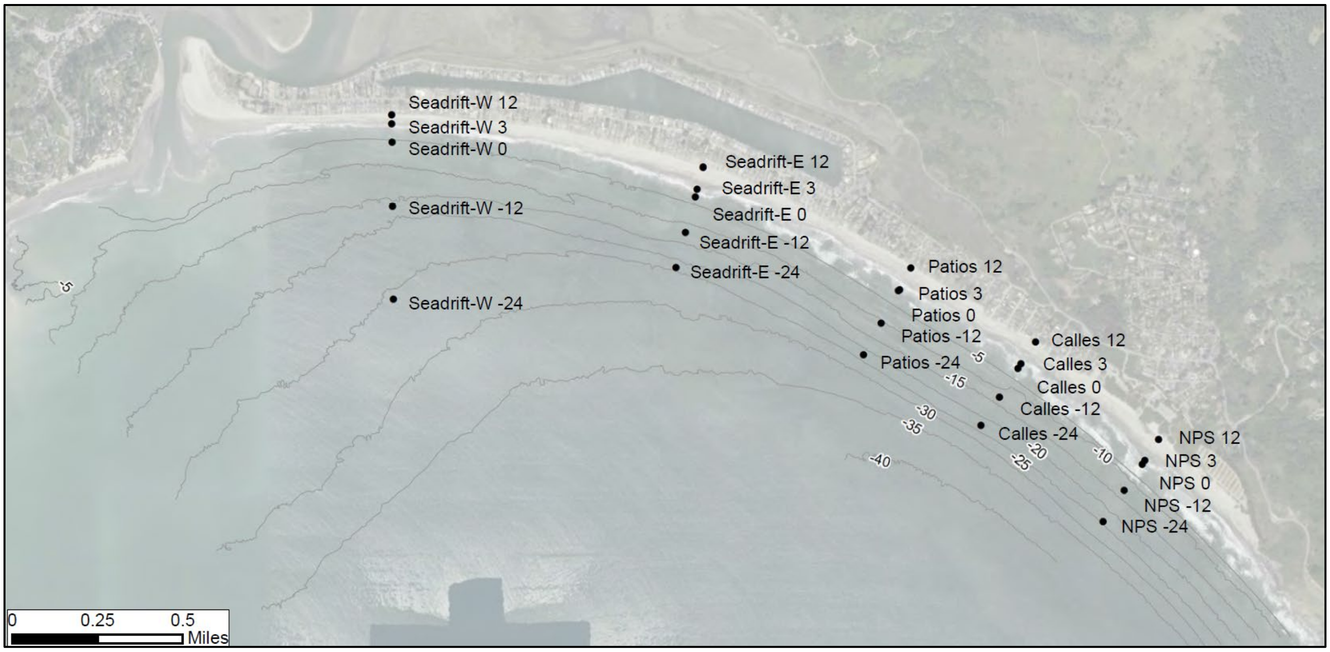
7. Sediment Characterization

7.1 Stinson Beach Sediment Sampling and Analysis

In the spirit of nature-based adaptation at Stinson Beach, any given project would ideally have limited adverse impacts on the local ecology both during construction and over time. Therefore, it is important to source sediments that adequately match the characteristics (e.g. grain size, fines content) present along Stinson Beach. Sediment at Stinson Beach was characterized to provide baseline conditions for which sources can be compared for compatibility. In general, compatible sources of sediment similar to the sand at Stinson Beach in terms of size, mineralogy, roughness and appearance. From a regulatory perspective, imported beach sediment should have at least 80% sand (less than 20% fines) and be free of contaminates and organics. Dune sediment is frequently finer than beach sediment and accumulates fines including organics, and hence requirements for the sand dunes may differ.

Sediment grab samples were collected from the upper beach through the surf zone to the depth of closure (offshore limit of the active shore profile, approximately -30 feet NAVD for Stinson Beach) at the five study shore profiles shown in Figure 13. From these collections, samples were field characterized as to the nature of the sediment. The field characterization indicated that material offshore in the study area is predominantly clean sands. Only in deeper waters of the study area was silt a major component of the material. For interest purposes, a sample was collected well outside of the study area at approximately -60 feet. This sample was similarly classified as predominantly sand, albeit silty sand.

From the collected samples, 25 samples were selected to be further analyzed for sediment grain size to characterize the surface sediments of the beach and nearshore subtidal environment. These samples were well distributed across the beach and elevation range from approximately +12 to -24 feet NAVD (Figure 28). Samples were analyzed by Eurofins Calscience (see **Appendix D** for details). Post collection analyses of sampling location and bathymetry from survey data resulted in correction of some sampling elevations that did not fully match intended sample elevations and sampling IDs at the time of collection. For this reason, elevation has been reported in Table 8 along with sample results. Table 8 presents simplified information from the laboratory analysis as the mean grain size and total percent sand for each analyzed location while grain size envelopes were created for each profile (Figure 29) by combining the grain size distributions for each sample taken along the profile. Surface Sediments ranged from coarse to medium sand with a generally remarkably high sand fraction and low silt content across all analyzed samples.



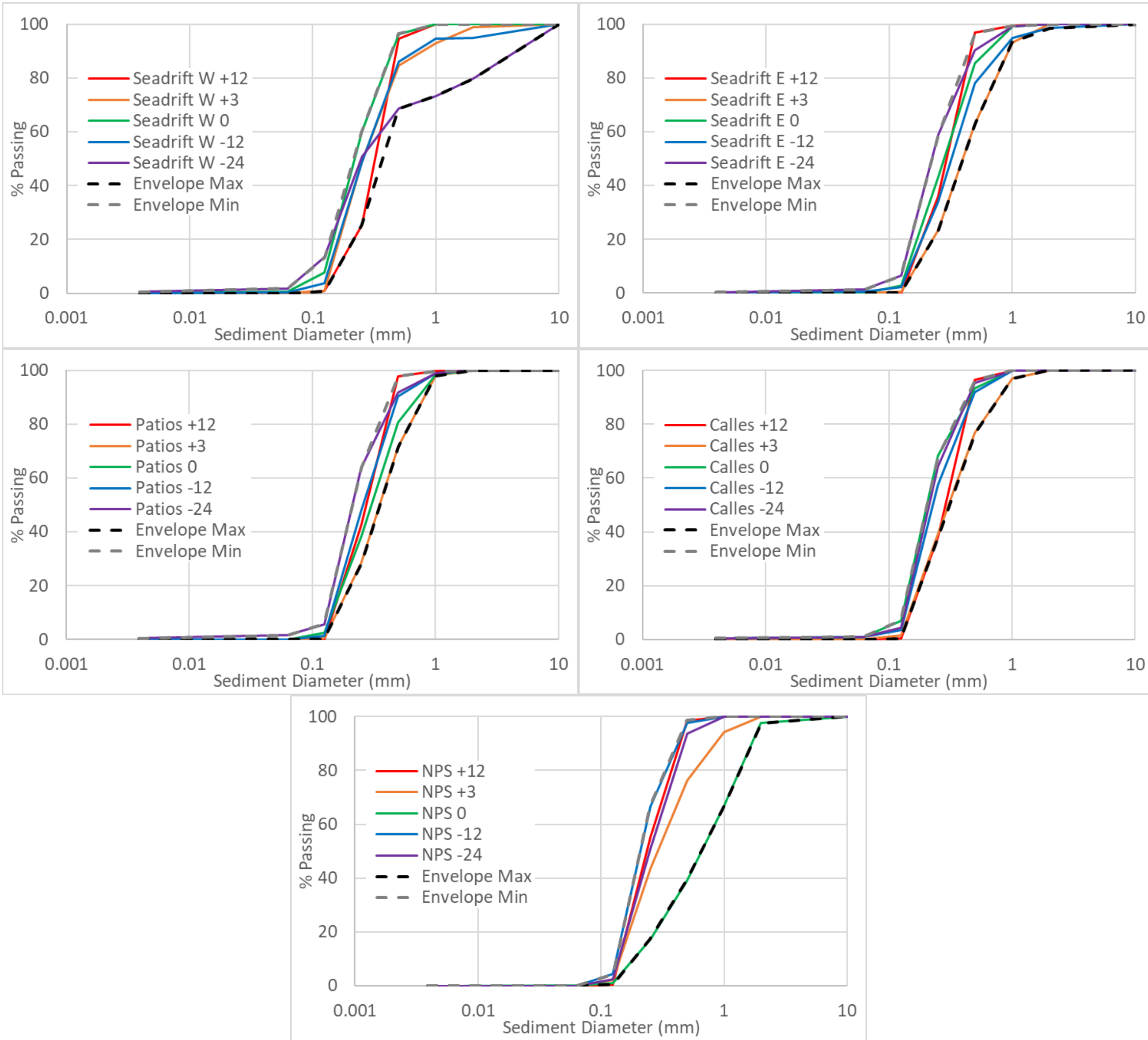
SOURCE: ESA, Merkel & Associates, ESRI

Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 28
Locations of Sediment Grab Samples Analyzed for Grain Size

TABLE 8
STINSON BEACH SEDIMENT GRAB SAMPLE SUMMARY

Sample	Elevation (ft NAVD)	Mean Grain Size (mm)	% Sand
Seadrift W 12	12	0.317	100
Seadrift W 3	3	0.398	98.9
Seadrift W 0	-5	0.248	99.4
Seadrift W -12	-16	0.445	94.6
Seadrift W -24	-25	0.965	78.0
Seadrift E 12	12	0.299	100
Seadrift E 3	3	0.481	100
Seadrift E 0	0	0.327	100
Seadrift E -12	-12	0.428	97.9
Seadrift E -24	-24	0.278	98.7
Patios 12	12	0.283	100
Patios 3	3	0.41	100
Patios 0	0	0.356	100
Patios -12	-12	0.304	100
Patios -24	-22	0.268	99.4
Calles 12	12	0.292	100
Calles 3	3	0.382	100
Calles 0	0	0.248	99.0
Calles -12	-13	0.274	99.1
Calles -24	-24	0.249	98.9
NPS 12	12	0.25	100
NPS 3	3	0.395	100
NPS 0	0	0.849	97.5
NPS -12	-12	0.236	100
NPS -24	-24	0.278	100



SOURCE: ESA, Eurofins Calscience

Stinson Beach Nature-Based Adaptation Feasibility Study . 171009.00

Figure 29
Sediment Grain Size Distributions and Envelopes at Study Profiles

7.2 Potential Sediment Sources

Building natural infrastructure at Stinson Beach will require clean, appropriately sized sediments. Dune features would likely also be constructed with clean beach quality sand although a wider range of characteristics may be acceptable. Beach sediment samples collected along the Stinson study area in October 2019 were mostly sand (95-100 %) at all locations from the back of beach to outside of the surf zone, with median grain sizes ranging from 0.25 mm to 1 mm (Section 7.1). Coarser, more erosion resistant sediments are needed for cobble-gravel berm features. The sediments that could be beneficially reused for constructing natural infrastructure at Stinson Beach fall into three sediment classes (per ISO classification[1]):

- Sand: medium to coarse sands for dune features and mixing into cobble-gravel berm when needed, sediment grain size ranges from 0.2 mm to 2 mm
- Gravel: fine to coarse gravels to mix into cobble-gravel berms (to fill voids between cobbles), size ranging from 2 mm to 63 mm
- Cobble: coarser, erosion resistant material to be used in buried cobble-gravel berms and lags, sediment grain size ranges from 63 mm to 200 mm.

Potential sediment sources for nature-based adaptation features at Stinson Beach include regional maintenance dredging sites, offshore deposits and local watershed sources. This section summarizes sediment characteristics for each source as determined from existing reports and personal communications with agency staff. Based on this initial assessment, it appears that there is a fairly significant volume of sediment that could be made available for a resilience/restoration project at Stinson Beach. However, additional research is needed to determine timing of availability and potential regulatory issues that need to be resolved. Table 9 below summarizes the sediment sources identified as potentially suitable and available for use at Stinson Beach. Additional information is provided for each source below. Note Table 9 focuses on opportunistic sources and does not include commercially mined sources (e.g. Angel Island/Presidio Shoal), as these would require purchase and may be cost prohibitive, and the future of this source is subject to future permitting by resource agencies.

[1] International Organization for Standardization (ISO) 14688-1:2002, establishes the basic principles for the identification and classification of soils on the basis of those material and mass characteristics most commonly used for soils for engineering purposes.

TABLE 9
SUMMARY OF POTENTIAL SEDIMENT SOURCES FOR NATURE-BASED ADAPTATION AT STINSON BEACH

Source Type	Location	Potential Volumes*	Sediment Type	Notes	Suitability
Maintenance Dredging	Bodega Harbor Entrance Channel	25k to 50k cy	>80% sand	Dredged every 10-12 years. Next episode expected in 2028.	High
	Pinole Shoal Channel	~180k cy per year	>80% sand and gravel	Dredged annually	High
	Phillips 66 Marine Terminal	4,238 — 16,720 cy	Predominantly sand in Dredging Areas 1 and 3	Dredged annually	Med
	Saint Francis Yacht Club	3,500 — 41,000 cy	> 94% sand in all but 1 of 10 dredging areas	Dredged annually	High
	San Francisco Main Ship Channel	200K to 488K cy per year	90% to 99% sand	Dredged annually	High
Offshore	Bolinas Graben				High
	Bolinas Lagoon Mouth	n/a	sand		
	Russian River	n/a	n/a		
Local Watershed	Easkoot Creek	600-700 cy/year	Cobble, gravel and fines.	No longer extensively dredged, but limited sediment removal at bridge crossings. Future projects to address creek flooding could provide additional sediment.	High
	Other nearby creeks	n/a	n/a		
	Upland stockpiles	n/a	n/a		

cy = cubic yards
** Includes material that is suitable for beneficial reuse and not material that is only suitable for Unconfined Aquatic Disposal*

7.2.1 Maintenance Dredging sites

Bodega Harbor Entrance Channel

Bodega Harbor is one of the three sediment sinks identified on the Marin/Sonoma County Coastline in the Greater Farallones National Marine Sanctuary's (GFNMS) 2017 Coastal Resilience Sediment Plan, accumulating at a rate of approximately 6,300 tons/year. This Plan recommends identifying potential sites to receive clean dredged material from Bodega Harbor, seeking opportunities for designing nearby restoration projects, and investigating ways to maximize beneficial reuse of clean dredged material within the system (Kordesch et al 2019).

Historically, Bodega Bay Harbor has been dredged every 10-12 years by private sector companies under contract to the US Army Corps of Engineers (USACE, 2019). The last dredging occurred in 2017 with a total volume of 70,216 cy dredged. Of the total volume, 47,915 was disposed of at SF-DODS and the remaining 22,301 (the sand) went to SF-8 for beneficial reuse (Ross 2020). In 2004 a total of 153,300 cy was dredged, with 48,300 cy of sand going to SF-8 (beneficial reuse) and the rest (fines) going to SF-DOS (Ross 2020).

Five dredging episodes occurred beginning in early 1960s. The amount of material dredged has ranged from 69,000 to 383,000 cubic yards per episode. Historically, when Bodega Harbor has been dredged, the material was placed on the beach at the local upland site near the base of the Doran Spit, however that hasn't occurred for many years. The next maintenance dredging would be tentatively planned for 2028, based on historical dredging (Kordesch et al 2019).

The most recent Sediment Sampling and Analysis Report available for Bodega Harbor is from 2016. The report documented that two of the five samples were composed of greater than 80% sand, and therefore not analyzed for chemistry. Sandy material was found in sampling areas BB1, BB2, BB3-1, and BB3-2 (where projected 2017 dredging volume was between 22,000 and 38,000 cy) and was determined to be suitable for beneficial reuse by placement in the easternmost area of SF-8. Results of physical and chemical analyses are listed on page 17 of the 2016 SAR (ECM 2017). Testing results should be reviewed further for suitability for use at Stinson Beach as part of a nature-based coastal resilience approach.

Reports are available at: https://www.spn.usace.army.mil/Missions/Projects-and-Programs/Projects-by-Category/Projects-for-Navigable-Waterways/Bodega-Bay/

Pinole Shoal Channel

Pinole Shoal Channel is located within the boundaries of Contra Costa County in the southern portion of San Pablo Bay. The federal channel, approximately 11 miles long, has an authorized width of 600 feet. The channel is dredged by USACE under its O&M program. Since 2008 it has been dredged annually, with the exception of 2018. The average annual volume during that period was about 180,000 cy (USACE 2019). According to the most recent Sediment Sampling and Analysis Report (SAR) (2017), sediment from Pinole Shoal Channel was primarily composed of fine to medium grain size sand. Total sand and gravel was above 80 percent in all three sampling location composite areas, and chemical and metal concentrations were low. The 2017 SAR concluded that based on test results, all sediment is suitable for upland placement (ADHE 2017).

The last dredging occurred in Summer 2019. The volume dredged was 199,232 cy and 100% of the material went to in-Bay disposal at the SF-10 disposal site (Ross 2020). Since this site is typically dredged annually, the next maintenance dredging is anticipated in Summer 2020 or no later than Summer 2021. Based on the results of the 2019 Tier 1 Analysis the Army Corps determined that all material (estimated at 300,000 cy) is suitable for upland/beneficial reuse as wetland cover material. The most recent sediment analysis results (2017) are summarized beginning on page 5 of the 2019 Tier 1 Evaluation, while **Appendix C** includes results for previous sediment analysis for Pinole Shoal conducted since 2009 (USACE 2019). Analysis results for three sample locations indicate sediment in some areas may be compatible with use at Stinson (>90% sand) while fines content in other areas is too high for use on the beach (though area-based volumes were not provided). Testing results should be reviewed further for suitability for use at Stinson Beach as part of a nature-based coastal resilience approach.

Reports available online: https://www.dmmosfbay.org/site/alias__8959/171100/default.aspx

Phillips 66 Marine Terminal

Phillips 66 San Francisco Refinery (SFR) Marine Terminal is located southwest of the Carquinez Strait in Contra Costa County, between the cities of Rodeo and Crockett, CA. Dredging, of various volumes, has occurred annually since 2006 at this location. The most recent dredging (Dredging Episode 5) was completed in late 2019, with a total sediment volume of 15,400 cy. Of this material, 6,000 cy went to SF-8 for beneficial reuse and the remaining went to the Montezuma Wetlands Restoration Project (MWRP) (Ross 2020). Dredging episode 4 resulted in 8,145 cy being dredged in 2018, with disposal at SF-9. Disposal for past dredging episodes has included placement at SF-9 as well as beneficial reuse (except for 2013 and 2018). The volume of beneficial reuse placement varied between 4,238 cy and 16,720 cy (Pacific EcoRisk 2019).

Testing performed in 2007, 2011, and 2016 (the most recent testing date) indicated that the maintenance material was Suitable for Unconfined Aquatic Disposal at SF-8 or SF-9 and for placement at upland beneficial reuse sites at the Cullinan Ranch Restoration Project (CRRP), or MWRP because some material had too much fines. The dredging footprint for Phillips 66 includes up to 5 areas, though all 5 are not dredged during each episode. For example, for Episode 5, dredging is being proposed in Areas 1, 2, and 3 but not in 4 and 5. Areas 1 and 3 have historically been comprised of primarily sand (Pacific EcoRisk 2019). Testing results should be reviewed further for suitability for use at Stinson Beach as part of a nature-based coastal resilience approach.

Reports available online: https://www.dmmosfbay.org/site/alias__9032/172567/default.aspx

Saint Francis Yacht Club

SFYC is dredged annually at least since 2009. Dredge volume varied between 3,509 (I-Dock 2017) and 41,000 (Entrance Channel-Outer Basin, 2010) cubic yards. The summary of dredging episodes and suitability determinations for 2009-2018 are in a table on page 3 of the 2020 Tier 1 request memo. City of San Francisco Recreation and Park Department (RPD) is currently (2020) proposing to dredge 20,000 cy from the Entrance Channel. In 2019 dredging occurred in a small area surrounding the dock as well as the Entrance Channel for a total volume of 11,186 cy, with disposal at SF-8. In the past, disposal of dredged material has been at SF-8 or beneficial reuse for wetland restoration or other purposes (e.g. transfer to San Rafael Rock Quarry) (Boudreau 2020).

Sediment varies depending on areas being sampled, but most dredging areas are predominantly sand. Tier 1 memo from Boudreau Associates (June 2019) states “Grain size analysis results have consistently exhibited high sand content, although some samples have shown less than 80 percent sand and proportionally higher fines. The most recent sand percentage from a composite sample collected in 2016 was 95.4. Generally, the Entrance Channel material is predominantly sand (with less fines content) toward its northeastern (or bayward) end, with higher concentrations of fine material toward the western, or Marina-ward, portion of the area” (Boudreau 2020). While the entrance channel is predominantly sand, the April 2019 Sediment Analysis Report concludes that composite sediment sample that was tested from the small area surrounding the boat slip dock to be dredged, was mostly silt (64%) and clay (29%) (AWHE 2017).

Reports available online: https://www.dmmosfbay.org/site/alias__8975/171420/default.aspx

San Francisco Main Ship Channel

The SF Main Ship Channel provides deep draft entry for commercial vessels en route to the San Francisco Bay; the eastern end of the channel is approximately 4.5 miles from the Golden Gate Bridge. SF Main Ship Channel (i.e. SF Bar Channel), as congressionally authorized, is 2,000 feet wide and 26,200 feet long. The channel is dredged annually by the Army Corps under its Operations and Maintenance (O&M) program. Volumes of material dredged from the SF Main Ship Channel over the past 11 years have ranged from 200,312 to 488,464 cy. The Tier 1 Evaluation (2019) states that dredging was proposed for June 2019 of 567,562 cy to be placed at Ocean Beach Demonstration Site (OBDS) for beneficial reuse. Prior to that, 466,583 cy was dredged in 2018 and placed at OBDS. The dredging and placement history is shown in table on page 4 of the 2019 document.

Historically dredging has been completed either by the Army Corps or contractor and material is placed at OBDS and at SF-8 (USACE 2019).

The last grain size sampling event was in 2018, and the next sampling event is scheduled for 2026. Grain size analysis of shoaled sediment in the SF Main Ship Channel has historically and predictably been shown to be comprised of greater than 90% sand. The 2010 sampling event indicated the percentage of sand at over 97%. The most recent sampling event from 2018 showed 96% (USACE 2019).

Reports available online: https://www.dmmosfbay.org/site/alias__8956/171040/default.aspx

Angel Island / Presidio Shoal

Angel Island and Presidio Shoal are part of commercial sand mining leases and are not dredged for navigational purposes. Thus the sand would need to be purchased and would probably be cost prohibitive. However, these sources are included in this report as possible alternatives to purchase sand if opportunistic sources are not available.

7.2.2. Offshore sources

The following offshore sand sources require further investigation. An important consideration for these sources is the fact that they are within national marine sanctuaries.

Bolinas Graben

Grabens are depressed blocks of the Earth’s crust that are bordered by parallel faults. Two grabens exist where the San Gregorio Fault intersects the San Andreas Fault, north of Bolinas Lagoon. These depressions between the two faults occur offshore (Bolinas Graben) and onshore (Bolinas Lagoon, discussed below). The GFNMS 2020 Coastal Resilience and Sediment Plan (CRSP) (Kordesch et al 2019) includes a strategy to further characterize the sediment at this source and assess feasibility for use in beach nourishment for restoration purposes. Bolinas Graben is located within the Greater Farallones National Marine Sanctuary (GFNMS), and any dredging or extraction of sediment would require a Sanctuary permit since it is prohibited pursuant to the following GFNMS Regulation: “Constructing any structure other than a navigation aid on or in the submerged lands of the Sanctuary; placing or abandoning any structure on or in the submerged lands of the Sanctuary; or drilling into, dredging, or otherwise altering the submerged lands of the Sanctuary in any way.” GFNMS can consider a proposal to dredge sand from Bolinas Graben or Lagoon only if it is used for habitat restoration or shoreline resilience projects that enhance ecosystem functions. Since GFNMS has strict permitting criteria it would be very important to work with sanctuary staff early on. The permit application review process would include a NEPA analysis of by staff of potential impacts to the submerged lands (DeLaney 2020)

Bolinas Lagoon Mouth

Bolinas Lagoon was characterized as a sediment sink in the 2018 Marin-Sonoma Coastal Regional Sediment Management Report (CRSMR) with 5,180 tons/year accumulating (USACE 2019). This sediment sink was also identified in the GFNMS’ CRSP (2019) as a potential source of sand for beneficial reuse projects that could provide ecosystem benefits. The accumulated sediment at the Bolinas Lagoon mouth may serve as a potential opportunistic sediment source resulting from any future dredging of the lagoon mouth, no though no such activities have been proposed or planned. This location is within the boundaries of GFNMS, and is therefore subject to the permitting considerations described above. Sources of sediment to Bolinas Lagoon include Easkoot Creek, Pine Gulch Creek and the Bolinas cliffs.

Offshore of Russian River

Russian River, which discharges into the Pacific 45 miles northwest of Stinson Beach, has an estimated sediment source of 900,000 tons/year (George et al. 2018; Milliman and Farnsworkth, 2011) that accumulates offshore and can be considered as a potential offshore dredging source of sediment for Stinson Beach adaptation.

7.2.3. Local Watershed Sources

Easkoot Creek

Easkoot Creek is a tributary to Bolinas Lagoon, draining 1.59 square miles of watershed through Stinson Beach and finally draining into Bolinas Lagoon. Due to a lack of channel capacity it frequently overflows its banks in the area between Arenal Ave. and Calle de Arroyo. The creek runs adjacent to the Stinson Beach Parking lot and causes flooding in the lot during heavy rainfall events. Flooding issues are exacerbated by sedimentation in the creek that reduces channel capacity. Historically Easkoot Creek was dredged regularly and extensively, with the last large dredging episode in 1987, however recently dredging has been significantly reduce and limited to sites where the creek crosses roads. The reason for severe reductions in dredging of the creek in recent years is the presence of federally listed steelhead and unsustainable cost. In the past, several studies have been completed, looking at measures that could be taken to address persistent flooding issues at Easkoot Creek. Engineering studies in 1971 and 1984 investigated diverting high flows directly to the ocean. More recently, in 2008, an interagency working group developed the Bolinas Lagoon Ecosystem Restoration Project, which includes the following recommendations related to Easkoot Creek: 1) investigate using a portion of the GGNRA parking lot as a seasonal floodplain, 2) assess sediment sources and identify approaches that address problem areas, and 3) improving floodplain access and removing deltas along the Eastern shore of Bolinas Lagoon (Love 2009). Current sediment removal is focused excavation of “glory holes” near bridge crossings. This includes sediment removal about every two years near Parkside Café where the creek makes a bend. The material excavated from this location is primarily cobble and gravel with some fines as well, however no grain size analysis has been completed for sediments in the creek. Sediment volumes from dredging in the past few years have been between 600-700 cy. Marin County performs all dredging of the creek under permit and easement from National Park Service. Historically it was done by Marin County Roads but is now performed by private contractors (Epke, pers. comm.).

Coarse sand and gravels from Easkoot Creek could be used as dune anchors or mixed with cobbles for a buried cobble berm in the nature-based adaptation concepts developed for this study. Mean annual sedimentation for the period of 1979-2011 was estimated to be about 122-160 CY/yr in lower Easkoot Creek (OEI 2014). The sampled sediment size showed a median sediment diameter (D50) ranging from about 20 to 50 mm for surface sediment. Five bulk samples of the bed, gravel bar, and other deposits were also collected and analyzed, showing a D50 from about 6 mm to 16 mm, representing higher bed load sediment supply. Based on analysis of the two bulk samples from deposition gravel bars near Calle del Pradero and Calle del Pinos, an upper limit on the diameter of sediment typically transported through Easkoot creek to Bolinas Lagoon is about 20 mm.

Other nearby creeks

Coarse sand and gravels excavated for nearby creek sediment management activities could be beneficially reused at Stinson Beach (e.g. Lewis, Williams, Garden Club Canyon).

Other Potential Sources

Other sources of sand/sediment could include sand already dredged and stockpiled in upland "ponds" at places like Noyo Harbor where the cost of disposing of it in order to reclaim capacity is otherwise prohibitive; or dredged sand that will be transported a fairly long distance anyway that could be diverted to Stinson for a relatively small incremental cost, such as Pinole Shoal or Phillips 66. Purchasing sand already harvested by sand miners might be a last resort possibility. (Brian Ross, Pers. Comm.)

8. References

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