SUBJECT: Stinson Beach constructed foredune vegetation design: native vegetation pattern, composition, and dynamics; preliminary revegetation methods and materials

1. Physical design alternatives (framework for vegetation management)
For simplification of design and ecological assessment, physical design alternatives are condensed to two profile types, which merge all artificial foredune (embankments and foredunes alike) with respect to vegetation design.

> **ALT-1: no cobble berm constructed seaward of artificial foredunes** (engineered dune embankment or artificially initiated foredunes). Major variations within this spectrum include high-crested, steep sand embankments, and low-crested broad foredune mounds or ridges.
>
> **ALT-2: flat-top cobble berm constructed seaward of artificial foredunes**; 80 ft wide overall, 50 ft wide flat top 2 ft below sand beach berm elevation (exposed during winter storm profile). Variations within this spectrum include cobble berms that overlap with (underlie) seaward slopes of constructed foredunes.

Both alternatives vary in width and profile design along the five Stinson Beach shoreline reaches. “Dune (sand) embankment” (artificial trapezoidal graded sand embankment) and “foredunes” (variable initial constructed landform shapes)”, with respect to vegetation, are both treated as artificially constructed foredunes, subject to modification by erosion, deposition, and environmental gradients. With respect to vegetation design, they are not significantly different, though their subsequent geomorphic and ecological dynamics are likely to differ, depending on initial dimensions and morphology.

The sand embankment and constructed foredunes would both be subject to significant and probably rapid (1-2 yrs) modification by coastal wind and wave processes, and would not persist as stable as-built landforms. Both are presumed to be composed of the same well-sorted predominantly medium beach sand, with no significant coarse or fine sediment. The presence or absence of a cobble berm (buried or exposed at the surface) at the seaward toe of the foredune zone distinguishes the two basic alternatives, because cobble or cobble-boulder substrates affect below-ground vegetation colonization, establishment, growth, and spread differently from homogeneous beach or dune sand.

2. Objectives for backshore and foredune vegetation: dynamics and management

Geomorphic process objectives:

- Maintain perennial regeneration of surface roughness to trap onshore wind transport of sand from the beach in the foredune zone
- Maximize accretion of onshore wind-blown sand in the foredune zone; intercept most onshore-transported sand (wind, overwash)
- Store and release dune sand to the backshore over cycles of (fair weather) beach accretion and storm erosion events
- Facilitate recovery of foredune topography following storm erosion events

Ecological process objectives:

- Support diversity of backshore and foredune vegetation native to the Bolinas-Point Reyes dune complex
- Establish zonal native foredune and backdune species distribution across a disturbance gradient of sand accretion and erosion rates (relatively more stable, sheltered landward backdune, relatively more dynamic shoreward foredune and backshore)
- Maintain a species pool of vegetative and seed propagules to recolonize backshore and foredune habitats following storm erosion events
- Establish a local self-regenerating borrow source of vegetative and seed propagules available for supplemental revegetation following erosion events.

3.0 Vegetation zones, dynamics, and conceptual design

3.1. Backshore (high tide beach) and Foredune Vegetation Zonation

The revegetation design assigns native species distributed across a disturbance gradient based on relative frequency and magnitude of cross-shore sand erosion and deposition rates. The gradient is inferred from qualitative long-term observations of Stinson Beach and analogous south-facing sand spits at Doran Beach (Bodega Bay) and eastern Limantour Spit (Point Reyes). The main physical gradients influencing vegetation (and thus vegetation design) in the backshore and foredune zones are:

- Annually variable wind-blown sand accretion rates (low-energy eolian sand burial),
- Intermittent washover and wave overtopping (high-energy wave bore sand deposition),
- Episodic storm wave erosion
- Annual wave runup/seawater flooding (pulses of sand salinization), salt spray
- Annual organic marine litter deposition (including propagule deposition)

The backshore zone is intermittently overtopped or overwashed by extreme high tides or high swell waves, but is typically dry during the active spring-summer-fall vegetation growth period season. Winter tides deposit seed and organic matter (drift-lines) in the backshore, which drives beach vegetation colonization by seedlings and regenerated vegetative fragments in late winter-spring. The alternate state of the backshore is an eroded beach scarp following extreme storm erosion events. This zone is inherently unstable ecologically, and would fluctuate between denuded, erosional phases and calm-weather (low storm intensity) periods of progradation and vegetation establishment. Incipient (embryo) foredunes establish in the backshore until they are eroded or coalesce with foredunes.

The seaward foredunes are the primary zone in which relatively continuous or large patches of vegetation intercept onshore-blown sand. The alternate state of the seaward foredune zone is a foredune scarp (wave-cut cliff in moist, coherent sand) or an overwashed, flat, widened backshore zone formed by storm wave bores.

The outer, seaward zones (backshore, seaward foredune slope) are expected to be subject to annual low-intensity eolian sand accretion rates (up to about 20 cm/yr, often about 2-5 cm/yr), and occasional major wave erosion rates. Native beach and foredune plant species vary in their ability to tolerate sand accretion (burial) and erosion rates.

3.2. Backshore and Foredune Vegetation: Basis for Conceptual Design and Evaluation of Ecological Performance

The two alternatives differ in the effect of buried or surface-exposed cobble on beach and foredune vegetation types, and the regeneration and spread of vegetation following erosion events. The vegetation designs of alternatives differ primarily in the distribution of creeping (rhizomatous, spreading-rooted) and tap-rooted prostrate perennial plants that build foredunes.

Creeping perennial dune and beach grasses are generally most efficient at trapping wind-blown sand and building low foredunes, especially species with erect leafy shoots like beach wildrye (*Leymus mollis*, syn. *Elymus mollis*) and its natural hybrid Vancouver wildrye (*Leymus ×vancouveriensis*, syn. *E. ×vancouveriensis*). At relatively low rates of onshore eolian sand transport (as at Stinson Beach), these grasses may exhibit similar sand-trapping efficiency as non-native invasive marram grass, *Ammophila arenaria*). Their laterally spreading root and rhizome structure enables them to rapidly colonize beach and dune sand, but it also restricts their ability to establish directly in near-surface cobble deposits that impede penetration of rhizomes and fibrous, spreading root systems. Stinson Beach also has foredunes with native saltgrass (*Distichlis spicata*), a low-growing salt marsh plant that forms turfs, especially where beach groundwater is often high (near seeps). It has relatively low capacity for sand-trapping and dune building. Some creeping broadleaf forbs also occur (less frequently) in patches within foredunes, such as the nitrogen-fixing silvery beach pea (*Lathyrus littoralis*), which provides limiting nutrients to dune grasses, but has relatively low influence as a geomorphic agent of foredune accretion. The prostrate perennial creeping beach morning-glory (*Calystegia soldanella*) also has low geomorphic influence.

Tap-rooted native perennial broadleaf beach and dune plants, in contrast, are better able to colonize both sand and cobble deposits, but their shoot architecture and prostrate (ground-hugging) shoot growth habits make them less efficient at dune-building than foredune grasses. Dominant tap-rooted prostrate foredune forbs (beach-bur, *Ambrosia chamissonis*; yellow sand-verbena, *Abronia latifolia*) tend to slowly build broadly mounded or hummocky foredunes. In contrast, creeping perennial grasses with erect shoots tend to trap sand more uniformly, and build more continuous gently undulating low foredune ridges.

Tap-rooted foredune perennial forbs and creeping foredune grasses differ substantially also in their patterns and processes of spread and regeneration after erosion events. Rhizomatous grasses tend to recolonize foredune and beach zones extensively and rapidly by vegetative regeneration of fragmented viable shoots and rhizomes, or persistent embedded rhizomes left in place after erosion. Tap-rooted foredune forb crowns, in contrast, usually re-establish as seedlings distributed in uneven patches, though they may occasionally persist and regenerate vegetatively from erosion-exposed crowns. The seedling regeneration process is sensitive to constraints of trampling (high recreational use of the backshore), and seedling restrictions of cobble or small boulders occupying the root zone with only interstitial sand. Their prostrate shoots and leaves provide relatively limited low-height surface roughness to trap wind-blown sand, compared with rhizomatous grasses with erect shoots. These differences distinguish the potential differences in vegetation dynamics of sand-only alternatives, and alternatives with cobble berms below or seaward of artificial foredune landforms.

3.3. Cobble berm beach and foredune vegetation

There are few cobble beaches on the north-central or north California coast connected to foredunes, and their flora is a subset of coastal foredune plant species. Cobble and interstitial sand substrates select for a sparse vegetation composed of tap-rooted perennial forbs, primarily beach-bur (*Ambrosia chamissonis*), and occasionally California saltbush (*Atriplex leucophylla*). With increasing thickness of a foredune cap, vegetation cover, density and diversity may increase. Cobble berms constrain the growth and spread of foredune vegetation in part by impeding plant root zone access to deeper layers of moist freshwater-influenced sand near terrestrial groundwater capillary fringes during the dry, rainless growing season. Plant species with large, deep tap-roots can establish in interstitial sand within cobble or cobble-boulder berms, but at relatively low frequency and vigor compared with sand beaches and foredunes. Foredune grasses and forbs with shallower spreading root and rhizome systems are strongly restricted or excluded by near-surface cobble substrates.

Significant restriction of foredune vegetation growth and spread may be expected when the cobble berm is either exposed at the surface, or only shallowly buried by sand (about 10-30 cm sand depth). In this condition, the stability and growth of dune grasses is likely to be restricted, and only tap-rooted perennial forbs would likely establish with significant frequency or abundance where cobble berms dominate the root zone. Cobble berms with shallow foredune caps are likely to support mostly sparse, mounded, discrete low foredunes.

When the cobble berm is buried by more than two feet of sand providing a non-resistant root/rhizome zone, the inhibitory effect of cobble our boulder substrates on below-ground growth of foredune vegetation is likely to be reduced to root zone disconnection from deeper, moister sand influenced by the capillary fringe of the fresh/fresh-brackish water table of the backshore. The majority of the physiologically active root and rhizome system of creeping foredune grasses occurs in the upper two to three feet of sand. This zone may be more prone to desiccation over summer if cobble layers restrict subsurface capillary or water vapor/condensation gradients connected to terrestrial beach groundwater.

3.4. Storm erosion and recovery: dynamic processes of foredune vegetation

Unlike landscape architecture designs, artificial foredunes are inherently dynamic, and their vegetation cannot be designed to remain at planted locations, or occupy static zones and positions along shoreline gradients. Variable beach and foredune zones respond dynamically to stages of beach erosion (beach and foredune scarp formation, overwash) and post-storm recovery (swash deposition, eolian deposition). The idealized full profile (maximum post-storm recovery to prograding) in conceptual designs (Figures 13, 20, ESA 2021) is shown as “time zero” for post-construction planting stage. It provides an idealized initial stage of vegetation during the growing season after construction, not a stable, persistent vegetation gradient or set-point for maintenance or management.

The seaward zones of constructed foredunes without underlying cobble berms are likely to alternate between a scarped (wave-cut sand cliff) condition, and a foredune regeneration phase of sand accretion and plant recolonization. The more seaward the position of the constructed foredunes relative to the unimpeded storm high tide line position, the more time the backshore-foredune vegetation profile is likely to persist in a scarped (steep sand cliff, sharp vegetated edge) state. The landward zones of the foredune are more difficult to predict or design, because the frequency of dune disturbance by sand burial, wave overtopping, or wave erosion (scarp retreat) reaching the landward end of the gradient are likely to be irregular and intermittent, associated with less frequent extreme erosion and accretion conditions. A diverse assemblage of backdune plants adapted to stable dune surfaces or slow sand accretion rates are proposed for the most landward slope of the foredune zone. This zone may become unstable and invaded by accreting sand and mobile foredune grasses and forbs, however.

The seaward zones of constructed foredunes with underlying or fronting cobble berms would also be subject to alternating scarp erosion and retreat due to storm wave bore erosion impacts, but with reduced foredune scarp slumping from beach erosion below the foredune. Cobble berms are expected to significantly inhibit beach scarp retreat below the foredune. Cobble berms are also likely to cause some inhibition or delay of onshore wind transport of sand from the beach face to the foredune scarp, until sand beach accretion forms a continuous ramp profile from the upper foreshore to the scarp. Seedling and vegetation establishment on exposed cobble berms will also likely be inhibited by near-surface erosional exposure of cobble substrates. Therefore, erosion of constructed foredunes may be reduced by cobble berms, but ecological and geomorphic post-storm recovery processes of foredunes may also be inhibited by them.

The qualitative basis for this assessment of dynamic beach and foredune vegetation zones is derived from long-term observation of three south-facing Marin-Sonoma Coast embayed barrier beaches: Doran Beach, east Limantour Beach, and the west and east ends of Stinson Beach. These foredune systems are dominated by marram grass (*Ammophila arenaria*), but include local patches of native foredune and beach vegetation. Additional foredune and stable backdune species roles are inferred from larger, neighboring beach-dune systems at Abbott's Lagoon and Sand Point (Dillon Beach-Lawson's Landing) dunes.

4.0 Beach and Foredune Vegetation Zone Design

The initial species zonation of planting (and some limited, minor direct seeding) of constructed foredunes (both sand embankments and artificially graded low-relief "nuclei" of foredunes) is summarized in the table below, based on the disturbance gradient assessed in Section 3.0. The "backdune" zone refers to the landward sloping portions of the gradient, landward of the topographic highs (crests) of the constructed sand mounds or ridges. The distribution and relative abundance for plantings of each species is identified by abbreviations in the table, and quantified in subsequent discussions of each zone. The design increases the relative importance and dominance of local native foredune grasses beach wildrye and Vancouver wildrye above their natural frequency and dominance. This adaptation is recommended to optimize the rate and distribution of natural post-storm foredune recovery processes, but it is expected to support a significant net increase in plant species diversity over existing conditions if the constructed foredunes persist, or are maintained artificially.

The majority of revegetation propagules on seaward foredune slopes and backshore areas would be vegetative (clonal) divisions or transplants of field-grown populations (see Section 5), harvested and pruned (tops trimmed) in early winter, and transplanted during cool, humid or wet weather. Transplanting in other weather conditions or seasons will result in predictable high mortality and poor growth of survivors. The smaller landward-sloping backdune area would be revegetated with a combination of transplants and vegetative divisions (perennials, shrubs) and seeding (annual forbs). Transplanting would occur in unevenly distributed patches, with overlap between some species. An overall transplant density (backshore, seaward and mid-upper foredune zones) would probably approximate 2-3 ft spacing. No temporary stabilization by brush fencing or wood slat sand fencing is expected to be needed, given the low risk of significant wind-blown sand transport and high risk of storm erosion.

Low-dose slow-release fertilizer would be applied only directly below roots of transplants; no broadcast fertilizer would be compatible with dune vegetation because of potential indirect effects on weed competition. No irrigation is recommended for winter wet-season transplants in moist sand. Dry sand surfaces are highly water-repellant and inhibit penetration of wetting fronts of overhead irrigation, and localized drip irrigation (wetting cones) is disadvantageous to proper development of resilient spreading root systems needed by dune plants. Irrigation cannot substitute for off-season (late winter or spring) transplanting, which must be synchronized with with low temperatures (both below- and above-ground) and moist sand conditions during the winter rainy winter season.

Backshore beach zone	Seaward foredune zone	Mid-upper foredune zone (to crest)	Backdune zone (landward of crest)
Abronia umbellata (O, LC)	*Abronia latifolia (O)*	*Abronia latifolia (O, LD)*	*Artemisia pycnocephala (D)*
Atriplex leucophylla (LD)	*Ambrosia chamissonis (C, LD)*	*Ambrosia chamissonis (C, LD)*	*Camissoniopsis cheiranthifolia ssp. cheiranthifolia (C)*
Ambrosia chamissonis (LC)	*Lathyrus littoralis (LD)*	*Leymus mollis (D)*	*Ericameria ericoides (LD)*
Calystegia soldanella (O, LC)	*Leymus mollis (D)*	*Leymus Xvancouverensis (LD)*	*Eriogonum latifolium (D)*
	Leymus xvancouverensis (D)		*Poa douglasii (LD)*
			Phacelia distans (LC)

Constructed foredune species assemblage zones and relative abundance
D = dominant or co-dominant (widespread, prevalent and most abundant)
LD = locally dominant (large patch)
C = common (widespread and frequent but not dominant or abundant)
LC = locally common (not widespread but frequent where it occurs locally)
O = occasional, intermittent
I = infrequent

4.1. Backshore beach to seaward edge of constructed foredune

The proposed backshore beach profile would occupy a portion of the existing backshore beach during a progradation (seaward accretion) phase. The backshore zone alternates between a completely unvegetated state (erosion phase; undermined substrate during beach scarp retreat or wave scour removes all perennial vegetation), and early colonization stage pioneer vegetation (seedlings and early-stage vegetative recovery of viable perennial plant fragments deposited in drift-lines), potentially through phases of incipient foredune vegetation (established perennial vegetation modified by dune sand deposition). The duration of these stages depends on the return interval of significant backshore wave erosion and overwash events.

Backshore beach zone plant species	**Common name**	**Growth form**	**Target average patches /100 ft**	**Relative target abundance**	**Approximate planting density within patches /100 ft^2**
Abronia umbellata var. *breviflora* (intermediate)	NORTH COAST PINK SAND-VERBENA	Prostrate short-lived perennial forb	< 1	Locally common to patchy and occasional	10
Atriplex leucophylla	BEACH SALTBUSH	Prostrate to mounded tap-rooted perennial forb	1-5	Locally abundant	5
Ambrosia chamissonis	BEACH-BUR	Prostrate to mounded tap-rooted perennial forb	20	Locally dominant	5-10
Calystegia soldanella	BEACH MORNING-GLORY	Prostrate rhizomatous perennial forb	< 1	Locally abundant	5-10

4.2. Seaward foredune zone

The seaward foredune zone refers to the transition between pioneer perennial drift-line vegetation of the backshore beach, and the lower slope of the wind-deposited foredune or constructed foredune slope. The seaward foredune slopes are most likely to intercept most onshore-transported dune sand blown from the backshore and upper foreshore beach eolian "sweep zone". Sand would be trapped by roughness of the vegetation, depending on the height and density of its shoot canopy, so high relative abundance of erect dune grass canopies is prescribed. Relatively low average rates of onshore dune sand transport are expected (0.1-0.5 ft/yr) in this zone most years. Return intervals of erosional (scarp profile) states would likely correlate with the position of the constructed foredune toe relative to the high tide line (drift-line) during erosional beach phases. Each species would be planted in unevenly distributed colonies or patches within the zone, not uniformly or in rows. Gaps between colonies would be filled by lateral vegetative spread over 2-3 years.

Seaward foredune zone plant species	Common name	Growth form	Target average frequency patches /100 ft shoreline	Relative target abundance	Approximate planting density within patches /100 ft^2
Abronia latifolia	YELLOW SAND-VERBENA	Prostrate long-lived perennial forb, large taproot	1-2	Moderate to low	5-10
Ambrosia chamissonis	BEACH-BUR	Prostrate long-lived perennial forb, large taproot	1-2	Moderate to low	5-10

Lathyrus littoralis	SILVERY BEACH PEA	Spreading to mounded long-lived perennial forb, short rhizomes	5-10	Moderate to low	5-10
Leymus Xvancouverensis	VANCOUVER WILDRYE	Coarse extensively creeping perennial grass	2-5	High, dominant	20-30
Leymus mollis	BEACH WILDRYE, AMERICAN DUNEGRASS	Coarse widely creeping perennial grass	5-10	High, dominant	20-30

4.3. Mid-upper foredune zone

This zone would extend from the middle of the profile to the crest of the foredune. This zone is designed to be dominated by creeping sand-trapping native dune grass canopies, with patches of dune forbs such as beach-bur. Yellow sand-verbena may be expected to colonize this zone from seaward zones following erosion events.

The mid to upper foredune slope would be likely to develop a relatively stable surface dominated by accumulation of vegetation litter, except in years of unusually strong onshore transport of dune sand, where it either saturates the vegetation canopy of the seaward foredune vegetation, and allows transport further landward, or where bare sand gaps occur. This zone would likely alternate between vegetated and accretionary states, erosional scarps or washovers, and stages of post-erosion recovery or persistence of unvegetated sand (or cobble-gravel berm) exposure. Exposure of buried cobble-gravel berm surfaces would likely restrict the rate of recovery of creeping, sand-trapping vegetation, and select for tap-rooted annual and perennial broadleaf plants with lower capacity for dune-building.

Mid-Upper foredune zone plant species	**Common name**	**Growth form**	**Target average patches /100 ft**	**Relative target abundance**	**Approximate planting density within patches /100 ft^2**
Ambrosia chamissonis	BEACH-BUR	Prostrate to mounded tap-rooted perennial forb	20	Locally dominant	5-10
Leymus Xvancouverensis	VANCOUVER WILDRYE	Coarse extensively creeping perennial grass	2-5	High, dominant	20-25
Leymus mollis	BEACH WILDRYE, AMERICAN DUNEGRASS	Coarse widely creeping perennial grass	5-10	High, dominant	20-25

4.4. Backdune zone

The backdune zone would consist of the slopes landward of the foredune crest, potentially incorporating remnants of existing scarped foredunes in the new constructed foredune profile, following removal of invasive marram grass. Remnant foredunes may also be incorporated by regrading and contouring them in the new constructed foredune or embankment profile, providing that marram grass rhizomes and shoots are segregated and removed.

The backdune species would include a mix of burial-tolerant native dune plants, and high-roughness (shrubbier) native species structurally suited to stabilize existing sand surfaces, and trap sand efficiently in the short-term. The burial-tolerant sand-stabilizing species are needed to provide resilience during vegetative "self-repair" in post-erosion phases, when destabilized dunes resume eolian or overwash sand transport. Backdune zones would be initially surface-stabilized by inert straw mulch, preferably by locally salvaged, recycled desiccated (inviable) marram grass, which has extremely low rates of seedling establishment in dry backdunes. Annual forb patches may and should overlap with those of perennial forbs and shrubs. Annual forbs would be established by seeding. Perennial forbs and shrubs would be established initially by transplanting, and subsequently would be expected to spread by seed in stabilized sand.

Mid-Upper foredune zone plant species	**Common name**	**Growth form**	**Target average patches /100 ft**	**Relative target abundance**	**Approximate planting or seeding density within patches /100 ft^2**
Artemisia pycnocephala	DUNE SAGE	Erect perennial basally branched forb	5	Abundant to co-dominant	Transplants 20-50 (seed parents)
Camissoniopsis cheiranthifolia ssp. *cheiranthifolia*	BEACH EVENING-PRIMROSE	Prostrate annual to biennial perennial forb	10	Common but low abundance	Seed 5,000+
Calystegia soldanella	BEACH MORNING-GLORY	Prostrate wide-spreading perennial forb	1-2	Low	Transplants 5-10
Ericameria ericoides	MOCK-HEATHER	Erect low shrub	1-2	Locally abundant to dominant	Transplants 20-30
Eriogonum latifolium	COAST BUCKWHEAT	Procumbent low shrub	3-5	Abundant to co-dominant	20-30
Poa douglasii	DUNE BLUEGRASS	Slender turf-forming perennial grass	10	Abundant to co-dominant	Transplants (sod) 20-30
Phacelia distans	DUNE PHACELIA	Annual erect forb	10		Seed 5,000+

5.0. Methods, materials and costs of revegetation and maintenance or repair

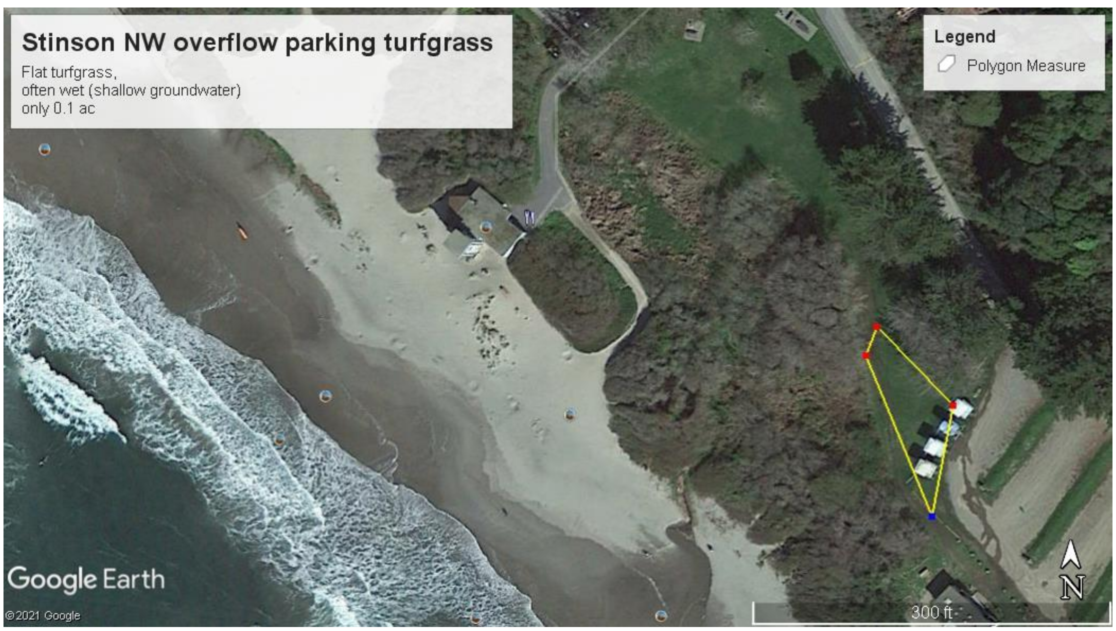
5.1. Sand quality. Dune and beach vegetation depends on well-sorted medium sand with no physiologically significant component of fines (clay, silt), closely matching well-sorted beach and dune sand. Even low content of fines (1%) in sand is highly significant physiologically and ecologically, and consequential for restoration. This is due to the enhancement of moisture and nutrient-holding capacity of sand by addition very small amounts of fine sediment, which enables generalist terrestrial weeds to establish and compete with dune and beach plants. Terrestrial weed invasions of "dirty" sand in artificial foredunes may cause significant adverse impacts, negating target ecological benefits. If sand contaminated by even minor amounts of silt or clay from dredged sand sources are used in construction of artificial foredune landforms, it should be capped by at least 1 ft of washed or wind-sorted medium beach or dune sand.

5.2. Managed donor populations of stock plants and seed. Even with phased construction, the length of the Stinson Beach foredune system would be infeasible and inefficient to revegetate by transplanting of greenhouse-grown or nursery-grown container stock, like small-scale terrestrial revegetation projects. Native plant nurseries in the region have limited capacity to grow high-quality stock of maritime species that physiologically require cool maritime climates and sandy substrates. Large-scale dune revegetation projects in the U.S. are supplied by vegetative divisions of dormant (winter, wet-season in CA) vegetative stock, or transplants of local field-grown stock, or field collection of seed. Relatively small areas of high-density donor stands can be managed or cultivated to supply very large quantities of transplant stock or seed on site. Clonal perennial plant donor beds (like dune grasses) are self-replenishing: they spontaneously regenerate under sustainable rates of harvest, which can increase growth rates. Seed-grown transplants of non-clonal forbs and shrubs grow larger, deeper, more viable root systems for dune transplanting than container-grown plants, but they do require active propagation and replacement after harvest. Donor beds can be sustained as native vegetation stands (compatible with ecological goals) while they are kept in service to re-supply revegetation over construction phases, or long-term maintenance or repair-related revegetation during sea level rise and shoreline retreat.

This approach of developing on-site donor beds of field-grown transplants (especially creeping, clonal perennial grasses, grass-like plants and forbs) was applied successfully to the GGNRA Muir Beach/Redwood Creek restoration project. GGNRA is currently evaluating development of semi-cultivated donor beds of wetland and floodplain plants for the Easkoot Creek overflow channel revegetation, and development of donor beds of foredune plants. In cooperation with San Francisco Department of Parks and Recreation, GGNRA is also evaluating dune plant donor beds for large-scale dune revegetation and ongoing maintenance of South Ocean Beach. Donor beds would be located in suitable substrate of low-quality invasive vegetation, which native plant populations would replace. This method would reduce revegetation costs from full nursery/greenhouse production and transport from off-site, to on-site low-intensity field cultivation (transplanting and seeding of donor beds with little or no irrigation) and harvest prior to transplanting, with all local transport. Development of on-site donor beds at the Oro Loma Ecotone Levee demonstration project in San Leandro by Save the Bay significantly reduced unit costs and increased propagule availability for revegetation of constructed wet meadow. Dune plant donor beds initiated in early winter would require at least two full growing seasons to become sufficiently productive for division.

Potential locations of two small (0.1 acre each) dune plant cultivation sites on GGNRA Stinson Beach turfgrass areas with relatively low public use are shown in the figures below. They include turfgrass areas in former backdune wetlands, which remain waterlogged near the surface for much of the winter, spring, and early summer in non-drought years, and have relatively low public use compared with the beach. The turfgrass areas can be disked, mulched (wood chips), and planted with Vancouver wildrye and beach wildrye, which tolerate (and often thrive in) moist soil conditions. Plowing ridges and troughs for improved drainage (like strawberry farming) would enhance productivity. A third sandy strip cultivation site to grow other dune broadleaf forbs may be located at the landward foot of the foredunes seaward of the overflow parking lot, which are a narrow linear zone of mixed dune sand and parking lot fill.


Stinson wet backdune flat
Flat turfgrass,
often wet (shallow groundwater)
only 0.1 ac
Legend
Polygon Measure
Google Earth
©2021 Google
200 ft
N


Stinson NW overflow parking turfgrass
Flat turfgrass,
often wet (shallow groundwater)
only 0.1 ac
Legend
Polygon Measure
Google Earth
©2021 Google
300 ft
N

5.3. Costs of initial revegetation and maintenance.
If donor beds are established on degraded foredunes within GGNRA overflow parking edges, a long-term sustainable harvest supply of vegetative stock may be available for phased implementation of the project. This would substantially reduce costs of revegetation compared with off-site native plant nursery production of containerized stock, and it would supply superior quality (vigor, size) well-acclimated stock for transplanting. A rough estimate of 0.25 acre elongated (narrow, nearly linear) donor bed area would be a one-time cost, consisting mostly of of mechanical tillage (discing) and planting, with first-season manual weed control. Most subsequent costs would consist of labor for field crew costs to harvest, trim, bag, and transport vegetative stock and transplant to project areas. Production rates of 50-60 propagule units/hour/person (harvest, trim, bag), and field transplant rates of 10-15 propagule units/hour/person are probably feasible or conservative, and may be increased by training and efficient organization of teams.

6.0. Assessment of potential foredune ecological benefits, impacts, and management needs
[corresponding with 6.4. Geomorphic and Ecologic Benefits, 6.6. Environmental Impacts and Regulatory Considerations]

6.1. Ecological consequences of artificial foredune size and shape. Dimensions and slopes of sand embankments fitted to the various Stinson Beach reaches are not yet established. The frequency of foredune erosional scarp development is primarily influenced by storm wave energy and storm tide height, position of the foredune toe in relation to the winter high tide line, and foredune (or sand embankment) slope steepness and crest heights relative to backshore elevations. Higher foredune crests and steeper slopes (more wave-reflective foredune ridge morphology) are likely to result in more frequent development and persistence of foredune scarp profiles, compared with gently sloping, low-height foredunes. Scarped profiles establish abrupt or sand accretion and disturbance gradients in the backshore, which are less favorable for maintenance of high native plant diversity than low-angle, relatively continuous dissipative foredune slopes.

6.2. Ecological consequences of artificial foredune encroachment of the backshore (winter backshore swash zone). Constructed sand embankments or artificial foredunes that encroach on the existing backshore zone (dry high tide summer beach, winter swash zone), may result in conversion of flat, sparsely vegetated beach habitat to more continuously vegetated foredune habitat, and narrowing of the backshore. The backshore beach seaward of the winter storm high tide line (foredune dune erosion line) is habitat for seedling establishment ("nursery" habitat) for some rare strand plant species, like North Coast pink sand-verbena. Habitat trade-off between unvegetated or sparsely vegetated flat sand beach (invertebrate and shorebird habitat), to more terrestrial vegetated foredune (vascular plant and terrestrial insect habitat) is a direct consequence of constructing vegetated foredune features in the backshore.

Foredunes or sand embankments constructed seaward of the current storm high tide line (foredune scarp position in the beach profile) may frequently exist in a transitional erosional state with a persistent steep, erosional scarp profile, or exposure of cobble berms. Seaward displacement of the foredune into the backshore zone influenced by surface or near-surface cobble substrates may depress post-storm recovery of foredune vegetation following major erosion episodes.

The cobble berm alternatives would likely impose some trade-offs for ecological and geomorphic benefits (see Section 3 above). Seasonal or chronic exposure of cobble berm substrates at or near the sand surface (shallow sand veneers over cobble) would likely restrict the colonization and establishment (regeneration niche) of native foredune and backshore vegetation, and select for species with plant functional traits that are less efficient at trapping sand and naturally rebuilding foredunes, even if wind-transported sand supply is sufficient. Cobble berms that underlie foredune vegetation may restrict root penetration to deeper, moister beach sand layers that supply permanent moisture to large tap-rooted perennial native plants. Chronic deep long-term burial of cobble berms by thick sand deposits (beach or dune) would reduce the potential inhibitory impact of cobble berms on regeneration of foredune vegetation.

6.3. Climate-driven contingencies for ecological benefits or impacts of constructed foredunes.

Ecological benefits or impacts of these green infrastructure landforms to native foredune vegetation depends in part on the duration of their intermediate erosional states, and the disturbance intervals associated with maintenance or reconstruction. The artificial foredune construction and revegetation designs are more likely to provide net ecological benefits to native plant populations if relatively prolonged intervals of low-energy winter storm conditions (multiple consecutive years of low erosion and disturbance) follow construction and vegetation establishment, and ample winter rainfall. This sequence would enable vegetative bud banks and seed banks of native vegetation to accumulate before storm erosion occurs. However, low storm intensity may be associated with winter drought conditions that are unfavorable for initial foredune vegetation post-transplant survival and establishment. Wet, stormy winters following construction and revegetation of artificial foredunes are likely to cause erosion before bud banks and seed banks accumulate to sizes that effectively recolonize eroded beach and foredune zones. If erosion intervals recur frequently, with short post-storm recovery (beach accretion) intervals, foredune vegetation recovery periods may be insufficient to restore or enhance resilient biological diversity. Over a decade or more, if the constructed foredune system exists in prolonged post-erosion partial recovery states, it may likely require supplemental repair or maintenance (sediment replacement and replanting)

Since sea level rise rates and the frequency of major coastal storm erosion events are likely to increase within the next few decades, the likelihood of substantial net ecological benefits of constructed foredunes is likely to depend on external climate variables, or intensification of maintenance and repair actions. A “best-case” scenario for vegetation would entail weak storm conditions for 1-3 years after construction and revegetation, coinciding with average to wet well-distributed winter and spring rainfall. A “worst-case” scenario would entail either extreme heat or drought events (especially winter drought) coinciding with the first growing season after transplanting, or major storm erosion within the first 1-2 years. These circumstances are not readily predictable. Adaptive management based on contingencies for substantial supplemental revegetation or sediment replacement may be needed to offset ecological uncertainties.

If optimal or substantially successful vegetation outcomes are reached, the Stinson Beach foredune system may provide the longest foredune dominated by native vegetation on the North-Central Coast, and the largest population of (intermediate subspecies) North Coast pink sand-verbena, for a decade or more. Longer-term sustainability of the foredune under higher sea levels, however, would likely depend on landward transgression of the foredune zone, which is precluded by development except in the GGNRA reach. The GGNRA reach, therefore, is the most likely segment to sustain long-term ecological benefits for foredune vegetation.

7.0 Summary of backshore, foredune, and backdune plant traits and functions in vegetation

Species	Common name	Growth habit, life-form	Functional role and zone in design
Abronia latifolia	YELLOW SAND-VERBENA	Prostrate long-lived perennial forb, large taproot	Biological diversity, insect pollinator support; weak sand trapping
Abronia umbellata var. *breviflora (intermediate* var. *umbellata)*	NORTH COAST PINK SAND VERBENA (intermediate)	Prostrate short-lived perennial forb, small taproot	Beach colonization, biological diversity, insect pollinator support
Ambrosia chamissonis	BEACH-BUR	Prostrate long-lived perennial forb, large taproot	Beach colonization, weak sand trapping
Artemisia pycnocephala	DUNE SAGE	Erect perennial basally branched forb	Gap colonization in stable dunes
Calystegia soldanella	BEACH MORNING-GLORY	Prostrate wide-spreading perennial forb	Biological diversity, insect pollinator support; compatible with western snowy plover roost
Camissoniopsis cheiranthifolia ssp. *cheiranthifolia*	BEACH EVENING-PRIMROSE	Prostrate annual to biennial perennial forb	Gap colonization, Biological diversity, insect pollinator support
Ericameria ericoides	MOCK-HEATHER	Erect low shrub	Dune stabilization, Biological diversity, insect pollinator support - backdune
Eriogonum latifolium	COAST BUCKWHEAT	Procumbent low shrub	Dune stabilization, Biological diversity, insect pollinator support - backdune
Leymus mollis	BEACH WILDRYE, AMERICAN DUNEGRASS	Coarse widely creeping perennial grass	Primary gap colonization, eolian sand trapping & accretion, stabilization -foredune
Leymus Xvancouverensis	VANCOUVER WILDRYE	Coarse widely creeping perennial grass	Primary gap colonization, eolian sand trapping & accretion, stabilization - foredune
Poa douglasii	DUNE BLUEGRASS	Slender turf-forming perennial grass	Secondary gap (blowout) colonization, eolian sand trapping & accretion, stabilization – backdune
Phacelia distans	DUNE PHACELIA	Annual erect forb	Biological diversity, insect pollinator support - backdune