Memorandum

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Subject: Broad Beach Dune Creation and Enhancement – Discussion Points on Salinity and Grain Size Issues

The following information is intended to provide a starting point for discussions on salinity and grain size issues related to the proposed dune creation and enhancement at Broad Beach. The information presented below applies to dune creation and enhancement only; it does not apply to beach nourishment. Finally, the information presented below is intended for discussion purposes only.

Background

A range of potential sand sources have been investigated for use in dune creation and enhancement at Broad Beach, including both offshore and inland sources of sand. Initial investigations into offshore sources of sand suggested that these sources would have extremely high salinity levels (approximately 10,000 ppm) and would have a high percentage of very fine sand (approximately 44% of the sample fell between 0.15 and 0.05 mm). These issues, as well as difficultly locating a suitable donor site for offshore sand, have precluded the use of offshore-sourced sand for dune creation and enhancement. A search of potential sources of inland sand revealed three potentially suitable sources with the ability to supply the quantity of sand required for the proposed dune creation and enhancement, all of which are established sand quarries located in southern California. Initial analyses of the sand from the three inland sources indicate that grain size is, on average, larger than that of existing foredune habitat at Broad Beach. An extensive literature review failed to reveal quantitative studies on the effects of grain size on dune geomorphology or the establishment of dune vegetation. The literature reviewed by WRA, including a range of books, review articles, and restoration reports all indicate that grain size "compatibility" is important for dune creation and restoration projects; however, an explicit definition of compatibility, such as a specific size range, is not provided in the literature. The sources we have reviewed indicate, however, that larger particle sizes are preferred as smaller particle sizes (i.e., silts and clays) can lead to problems with erosion, cementation, and other physical aspects of dune geomorphology and the establishment of dune vegetation. There is no indication of the size ranges associated with “larger” or “smaller” grain sizes. Here we highlight some of the relevant research related to dune salinity and grain size and provide discussion points on the pros and cons of using the potential sources of sand investigated for use in dune creation and enhancement at Broad Beach.

Salinity

Dune-adapted plant species are generally tolerant of high salinity levels; however, they do not necessarily require high salinity levels. At the opposite end of the spectrum, many non-coastally adapted native and non-native plants are not adapted to high salinity levels and cannot persist in environments subject to salt spray or high soil salinity. The ideal sand for use in dune creation and enhancement at Broad Beach will demonstrate salinities in the range of what occurs in existing foredune habitat at Broad Beach; however, most sand sampled to date is either extremely saline (i.e., offshore-sourced sand) or contains negligible salinity levels (i.e., some of the inland-sourced sand). Finding a “perfect match” for Broad Beach is unlikely to occur unless the sand is sourced from Broad Beach itself or from one of the nearby beaches. Salinity levels for existing foredune habitat at Broad Beach as well as for potential offshore and inland sources of sand are provided in Table 1. Of these potential sources of sand, inland sample 1 (Grimes Quarry), most closely matches the existing foredunes at Broad Beach in terms of salinity.

Table 1. Salinity values for existing foredune habitat at Broad Beach and for potential offshore and inland sources of sand.

Source	Salinity (ppm)	Salinity (dS/m)
Broad Beach Foredunes	1,920	3.0
Offshore	9,088	14.2
Inland 1 (Grimes)	1,472	2.3
Inland 2 (PBG)	128	0.2
Inland 3 (Cemex)	192	0.3

Discussion Points:

- High salinity sand may inhibit establishment of target species but may aid in preventing the establishment of weeds. Increased salinity may be required by some halophytic species.

- Low salinity levels in inland-sourced sand is likely to be more amenable to plant establishment, including for invasive weeds. Some halophytic species may require salt for germination and optimal growth. That said, most dune-adapted species are not obligate halophytes (Pickart and Barbour 2007), and as such, should be able to grow in non-saline soils.

- Salt spray is a significant source of salinity in northern California beach/dune habitats and has been shown to be an important factor in plant zonation there (Holton and Johnson 1979 *in* Pickart and Barbour 2007).

- Deposition of salt from salt spray at Point Reyes in northern California was estimated between 10 and 50 mg/dm^2 (Barbour 1978 *in* Pickart and Barbour 2007). It is unclear how such high deposition rates may affect the salinity of sand; however, it is assumed that salt deposition will result in some increase in the salinity of dune sand.

- Studies in southern California indicate that soil salinity caused by storm washover events may be more limiting than the effects of salt spray (Cuniff 1984, Fink 1987, Fink and Zedler 1990, *all in* Pickart and Barbour 2007).

- Typical root zone salinity in beach/dune habitats of temperate regions is 1,000 ppm; however, this can increase to 10,000 ppm following inundation (Barbour et al. 1985 *in* Pickart and Barbour 2007).

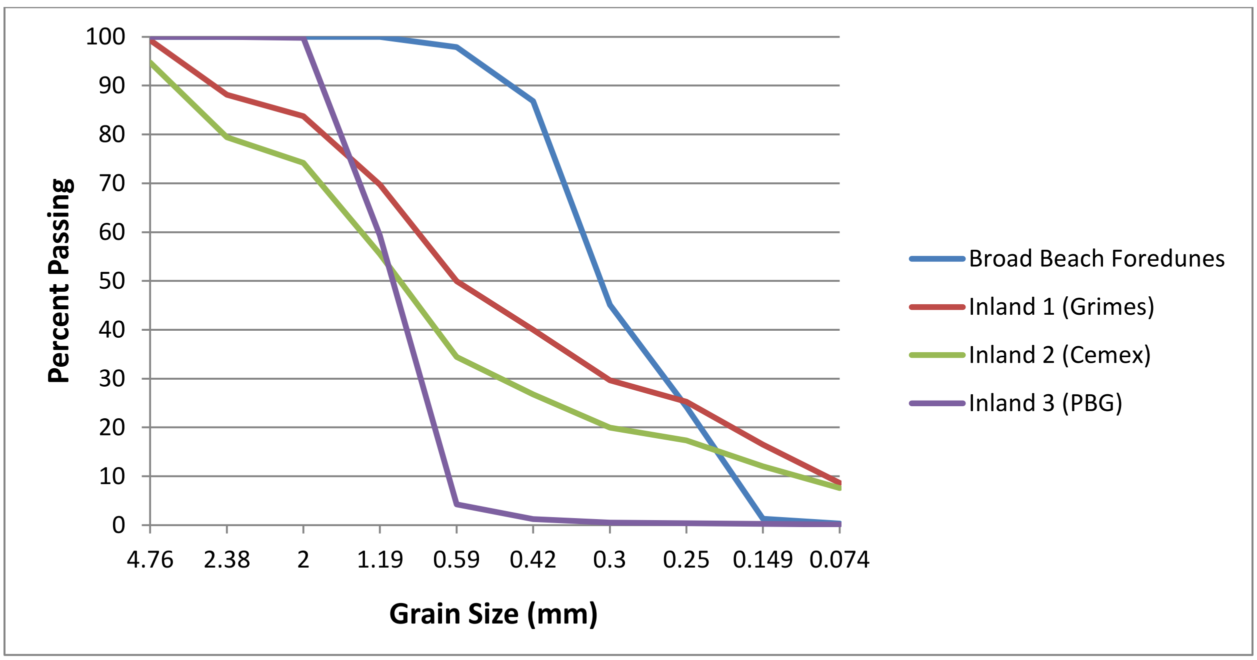
- Effects of salinity on plant species are more pronounced during germination and seedling growth relative to established plants (Pickart and Barbour 2007). *Abronia maritima* and *Ambrosia chamissonis* become established only in years of late spring/early summer rainfall (De Jong 1979 *in* Pickart and Barbour 2007), suggesting that these species require reduced salinity for germination and establishment. Germination in *A. maritima* was dramatically reduced at salinity levels of 5,000 ppm (Johnson 1978 *in* Pickart and Barbour 2007). Germination in the non-native *Cakile maritima* is inhibited at NaCl concentrations above 1,000 ppm; germination in its cogener, *C. edentula*, is uninhibited at NaCl concentrations up to 10,000 ppm (Barbour 1970; Boyd and Barbour 1986, 1993 *all in* Pickart and Barbour 2007). Some species, such as *Carpobrotus chilensis*, exhibit salt stimulation in which seeds exposed to salt have higher germination rates (Weber and D'Antonio 1999).

- Several dune restoration efforts in northern California and Oregon have attempted to use saltwater irrigation to control established *Ammophila* (Pickart and Sawyer 1998). Results are inconclusive, but suggest that this may not be an effective method, particularly for clonal species. It is not clear how irrigation with salt water may affect seed germination for native and non-native species; however, it is well known that plants are more vulnerable to high salinity during seed germination and subsequent seedling establishment (Pickart and Barbour 2007). As such, there is potential for irrigation with salt water to negatively affect the germination of seeded dune species.

Grain Size

The grain size composition of beach and dune sand is dependent on a number of factors including parent material, transport dynamics, wave energy, etc. Dune sand is generally well sorted due to a combination of sorting that occurs on the beach from wave action and sorting that occurs during subsequent aeolian transport from the beach to the dunes and further inland. The grain size distribution for the existing foredunes at Broad Beach and for the three potential inland sources of sand is shown in Figure 1, below. The majority of sand in the existing foredune habitat at Broad Beach ranges from approximately 0.5 to 0.14 mm in size. In general, sand from the inland quarries has a broader particle size distribution, with the Grimes and Cemex sources containing a larger fraction of both large and fine particle sizes and the PBG source having a more narrow size distribution, but a larger average grain size than what occurs at Broad Beach. Little information is available in the literature defining suitable grain sizes for dune creation and enhancement or on how grain size might affect plant establishment. However, most literature indicates that larger grain sizes are preferred for increased stability and that smaller grain sizes can cause issues with erosion, cementation, and other aspects of soil physics and chemistry. In general, "smaller" refers to silt and clay particles which fall below 0.05 mm in size. However, because the literature we reviewed does not provide an explicit size range associated with these the terms "larger" and "smaller", it is not clear whether the term "smaller" may also include fine (0.1 > 0.05 mm) or very fine (0.05 > 0.02 mm) sand particles. Although a number of references indicate that smaller particle sizes can be problematic, it is unclear how smaller particles sizes may affect plant establishment.

Figure 1. Grain size envelope for Broad Beach and comparison to three inland sources of sand (data from Moffat and Nichol).



Discussion Points:

- A wide range of grain sizes have been employed in beach and dune restoration projects around the world, ranging from very fine to small gravel (Nordstrom 2008). Grain size affects a range of dune properties and processes including aeolian transport, compaction, and drainage, among others. Most discussions of grain size in the literature indicates that sand should be of compatible grain size; however, we have been unable to locate a quantified definition of what “compatible” means.

- Most discussion in the literature is qualitative in nature. Qualitative discussion of the effects of grain size in dune restoration indicates that larger grain sizes can result in greater stability of beaches but can also result in a decrease in species richness and abundance (in reference to larger grain sizes such as gravel; Nordstrom 2008). Smaller grain sizes (e.g., silts and clays) can result in decreased hydrologic conductivity and drainage and increased compaction (Nordstrom 2008). This can affect plant establishment by increasing water retention in the soil (making it easier for non-dune-adapted plants to become established) and can affect burrowing organisms (making it harder for them to burrow to appropriate depths). That said, increased water retention could reduce the need for irrigation during the initial establishment phase.

- We have been unable to find information on specific grain sizes used in dune restoration projects on the west coast. Most projects have used either natural dune building methods (e.g., allowing windblown sand to accumulate behind sand fencing or vegetation) or opportunistic sources of beach or dune sand. For example, the Surfer’s Point Managed Retreat project in Ventura used sand that had been removed from residential lots at Pierpont Beach. Such sources of sand, by their very nature, are “compatible” with dune creation. Dune restoration efforts at Duxbury Beach Reservation in Massachusetts have had good results with dune construction using quarried sand (O’Connell 2008). At this site, quarried sand was used to create dune mounds which were then covered by 6 inches of native dune sand. It is not clear what ranges of grain size were used in this restoration effort, or how such results might apply to dune restoration in southern California.

- Most quantitative information available on grain size focuses on beach nourishment and the physical aspects of beach geomorphology such as aeolian transport, energy dissipation, etc. Although beach nourishment and dune restoration are interrelated, it is not clear how studies on the dynamics of beach geomorphology apply to dunes. That said, most literature related to grain size and beach nourishment indicates that fine particles such as silts and clays are more problematic for restoration project than are larger grain sizes. At Surfer’s Point, they originally used imported upland sand with a high amount of fine materials for dune creation and had problems with cementation (Paul Jenkins, Surf Rider Foundation, pers. com.). Other work indicates that finer grain sizes are less stable and more prone to erosion or aeolian transport (Department of Boating and Waterways 2002).

- Dune restoration at Duxbury Beach Reservation and other beaches in Massachusetts have had good results using a clean cap of dune sand (approximately 6 inches) over imported quarry sand (O'Connol 2008). This may be a feasible approach for Broad Beach.

Synthesis

Given the large volume of sand needed for the proposed dune creation and enhancement and the limited availability of sand sources, it is unlikely that an "ideal" source of sand can be found. The goal for sourcing sand at Broad Beach should be to minimize the potential for negative outcomes given the available sources of sand, each of which will have advantages and disadvantages associated with their use for dune creation and enhancement. Ultimately, the source of sand used for dune creation and enhancement must be suitable for building dunes and establishing dune vegetation, but must also be financially and logistically feasible.

Offshore-sourced sand has been removed from consideration due to the potential for such sand to be prohibitively saline and to contain a large fraction of very fine particles and because of the difficulty in locating potential donor sites. A number of potential inland sources of sand are available; however, inland sources of sand also have grain size compatibility issues. In addition, inland sources of sand generally have low levels of salinity which could affect plant establishment.

Sand from the Grimes quarry most closely matches the sand in the existing foredunes at broad beach in terms of salinity. Use of this sand would provide suitable salinity levels for promoting the establishment of native, dune-adapted species which are tolerant of elevated salinity levels while at the same time discouraging the establishment of non-native species which are not tolerant of elevated salinity levels. That said, the elevated salinity levels of the Grimes sand may not be elevated enough to discourage the establishment of iceplant, which is arguably the most detrimental weed species that occurs on dunes. The other two potential inland sources of sand have negligible salinity levels. Although dune-adapted species are tolerant of high salinity levels, they do not necessarily require high salinity, and as such, should be able to grow in low-saline sand. Similarly, however, many non-native species which might otherwise be inhibited by high salinity levels would also be able to grow in the low-saline sand. Despite the ultimate source of sand used for dune creation and enhancement at Broad Beach, an aggressive weed control program will be necessary. If saline sand is used, the weed control program would be primarily focused on preventing the establishment of iceplant. If non-saline sand is used, the weed control program would be expanded to include additional species.

In terms of grain size, the Grimes and Cemex sources have a similar distribution. Both of these sources have a relatively even distribution of grain sizes ranging from small gravel to fine silts and clays. A larger fraction of the sand from these two sources falls within the range of grain sizes found in the foredunes at Broad Beach; however, these two sources of sand also have a higher proportion of very large and very fine particle sizes. Whereas larger particles sizes can be sieved out relatively easy, removing the fine particle sizes (finer than 100 mesh or 0.149 mm) is likely to be prohibitively costly. Most literature reviewed by WRA indicates that smaller particle sizes are more problematic than larger sizes, and the relatively large fraction of fine particle sizes in the Grimes and Cemex sources could negatively affect foredune creation and enhancement by creating cementation, reducing water percolation, or other effects. Although sand from the PBG quarry is, on average, larger than that of the existing foredunes at Broad Beach, it shows has a narrow grain size distribution, with the majority of the material falling between 2.0 and 0.59 mm in size. The amount of fine particles in the PBG sand is substantially lower than that of the Grimes and Cemex sources, and is comparable to that of the existing foredune habitat at Broad Beach. Use of the larger sand from the PBG quarry is unlikely to result in cementation or decreased drainage. To the opposite effect, the larger grain size is likely to result in increased drainage. It is not clear how this increased drainage may affect plant establishment on the created and enhanced foredunes.

References

Department of Boating and Waterways and State Coastal Conservancy. 2002. California Beach Restoration Study. Sacramento, California.

Nordstrom, K.F. Beach and Dune Restoration. Cambridge University Press, New York.

O'Connol, J. 2008. Coastal Dune Protection and Restoration Using 'Cape' American Beachgrass and Fencing. Marine Extension Bulletin. Woods Hole Sea Grant and Cape Cod Cooperative Extension.

Pickart, A.J. and M.G. Barbour. 2007. Chapter Six. Beach and Dune. *In* M.G. Barbour, T. Keeler-Wolf, and A. A. Schoenherr (eds.). Terrestrial Vegetation of California, Third Edition. University of California Press, Berkeley, California.

Weber, E. and C.M. D'Antonio. (1999). Germination and growth responses of hybridizing *Carpobrotus* species (Aizoaceae) from coastal California to soil salinity. American Journal of Botany 86: 1257-1263.