Oceano Dunes Pilot Projects

Executive Summary

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Executive Summary

Introduction: This report provides information in support of the development of a Particulate Matter Reduction Plan (PMRP) for the Oceano Dunes State Vehicular Recreation Area (ODSVRA) by documenting the results of three Stage I-Pilot Projects: (1) the addition of artificial roughness to a sand surface (straw bale roughness demonstration plot); (2) establishment of a vegetation cover (vegetation effectiveness demonstration site): and (3) reduction or elimination of surface disturbance from driving of off-road vehicles (the vehicle exclosure transect).

Approach: The approach adopted in this study is based on the theoretical relationships (confirmed by numerous field studies) that sand transport rates and dust emissions scale as a power function of wind speed or wind friction speed. Reduction of sand flux therefore has a non-linear effect on dust emissions. The concept behind pilot projects 1 and 2 is based on field and laboratory wind tunnel studies, which have shown that significant reductions in sand transport rates occur as a result of the presence of non-erodible surface roughness elements, including vegetation and solid objects (cylinders, cubes, etc.). This is the result of two complimentary processes: 1) the partitioning of the wind shear stress between the surface and the roughness elements so that sand transport rates through areas of surface roughness are determined to a large extent by the number and size of roughness elements per unit area, or the roughness density λ (λ=n b h/ S, where n =number of roughness elements, b=element breadth, m, h=element height, m, and S is the area of the surface that contains all the elements), and 2) a roughness element height effect, where the taller the element the greater the enhancement provided by the roughness to reduce sand transport and the associated dust emissions.

Demonstration sites: The sand transport reduction effectiveness was measured and documented in projects 1 and 2 to assess their viability as long-term strategies for dust emissions reduction. Sand transport was measured at the straw bale and vegetation sites using a combination of sand traps and electronic sand flux sensors (Sensit).

The straw bale roughness demonstration plot consisted of a 100 m by 50 m area of gently undulating sand on which 210 straw bales were placed in a staggered array designed to achieve a roughness density (λ) of 0.022 and a target reduction in sand flux of 50% at the trailing edge of the roughness array. The plot was aligned with the long axis parallel to the prevailing sand transporting wind and instrumented with 24 Cox Sand Catchers and 6 BSNE sand traps, together with an anemometer and sand flux sensors. During the 18-day study period (April 15 – May 3, 2011) sand transport occurred on all days except April 20 and 23. A total of 14 sand transport events lasting several hours or more each provided sufficient mass in the traps to allow for estimation of the sand flux reduction due to the added straw bale roughness. This was accomplished by comparing the sand flux measured at the upwind and downwind edges of the array, normalized to the upwind sand flux to enable comparison of reduction factors between events. A modal sand flux reduction of 40 – 50% was measured by the Cox Sand Catchers and 60-70% was measured by the BSNE traps. These values are consistent with theory and prior experimental results (Fig. 1). Significant sand deposition occurred within the straw bale array over the course of the pilot project and resulted in the development of shadow dunes in the lee of the bales. However, the overall effectiveness of the array for sand flux reduction did not appear to be impaired over the duration of the project.

The vegetation effectiveness demonstration site was designed to show that existing dune vegetation does indeed restrict sand transport, by comparison of sand flux between un-vegetated and vegetated areas in an area of variably vegetated dunes and sand sheets northwest of Oso Flaco Lake. Vegetation cover (mainly lupine), determined using line intersect transects, averaged 37%, with a range from 66% to 25%. As a result, sand flux was reduced by as much as 90-95% within the first 50 m from the upwind boundary of the vegetated area, and 90 – 99% further downwind, as measured by the Cox Sand Catchers and BSNE traps, resulting in minimal sand flux in the open sand areas between the vegetation.

Restriction or elimination of surface disturbance by vehicle traffic represents a third potential control measure, based on the hypothesis that disturbance may increase sand transport and dust emissions relative to undisturbed areas under similar wind regimes. This hypothesis was tested by measuring dust emissions (for a given wind shear velocity) using the DRI Portable In Situ Wind ERosion Laboratory (PI-SWERL) device for an undisturbed and immediately adjacent disturbed (riding) area along a transect across part of the dunefield. The data on dust emissions potential for this transect indicate that the effect of restricted driving on dust emissions is not certain. There are indications that the undisturbed area emits dust at lower rates that the driving area, but the range of emission rates obtained overlaps to a considerable degree between undisturbed and disturbed areas.

Dust emission potential: The potential for emission of dust of PM_{10} (10 micron aerodynamic diameter) size ($\mu g\ m^{-2}\ s^{-1}$) and saltation activity (particle counts s^{-1}) as a function of wind (friction) speed was assessed at all locations using the PI-SWERL device. At all sites, dust emissions are highly correlated (r^2 >0.99) with increasing wind shear velocity and therefore with wind speed (Fig. 2). Although the sand transport activity measurements should only be considered as a semi-quantitative measure of sand movement, there is a strong correlation (r >0.9) between sand movement and dust emissions at all sites. The variation in dust emission potential between sites for a given applied wind friction speed is small and not statistically meaningful. This is likely controlled in large part by the texture of the Oceano Dunes sediments (i.e., percent sand, silt, and clay) as texture of the top centimeter of sands at all test locations is similar and dominated by the sand fraction (99%). The silt- and clay-sized particles comprise 1% or less of the sediment in all test locations.

Conclusions: This study established that addition of roughness in the form of vegetation and/or artificial elements (e.g., straw bales) is an effective way to reduce sand movement, and the accompanying dust emissions at Oceano Dunes. The reduction in sediment transport is caused by the need for higher regional wind speeds to initiate dust emissions thus reducing the range of wind speeds that result in emission, and by partitioning of the available shear stress between the roughness elements and the surface. At the straw bale site, sand movement was reduced by approximately 57% compared to upwind values. Using the relationship between wind friction speed and dust emissions derived from the PI-SWERL testing in combination with theoretical and empirically-verified relationships between the density of roughness elements and the amount of regional wind shear stress that reaches the ground surface between the elements, we estimate that 48% of the regional shear stress reaches the intervening surface among the straw bales, which would result in a lowering of the PM_{10} emissions as a function of wind friction velocity by ≈98% (for all friction speeds above the sand transport threshold), as compared with the surface in the absence of straw bale roughness. In addition, we estimate that the minimum wind velocity (at 10 m height) required to initiate sand transport in the spaces between the straw bales at the straw bale site (≈7.9 m/sec) is higher than it is for bare sand (≈5.3 m/sec). Thus the overall PM_{10} emissions will decrease because higher wind speeds will be required to activate the sand and dust transport system.

The vegetation pilot site has even greater potential to reduce PM_{10} emission compared to bare sand through the almost complete elimination of sand transport within this area. The roughness control method as tested in two configurations is a highly effective method for PM_{10} control and could form the basis for viable control strategies at Oceano Dunes. The effectiveness of restricted driving to reduce PM_{10} emissions is less certain than the clear results from the roughness demonstration projects. There was some indication that emissions of dust for the same wind speed were lower in the exclosure area than in the driving area. This difference was modest and less than factor of two.

Recommendations: Based on the pilot study results and reviewing some of the uncertainties that remain we have some recommendations for additional actions that could be pursued to provide better understanding of the Oceano Dunes dust emission system, which would allow better plans to be developed to control those emissions.

Currently the available data suggest that variability in PM_{10} emissions is limited at least across the pilot test areas, suggesting that controls applied in either of the three test locations would be equally valuable in reducing the overall PM_{10} emissions originating within these dune areas. To better determine if the observed lack of variability is restricted or if the available data reflect a bias due to the small sample size, we recommend additional PI-SWERL measurements be made along transects from the high water line inland towards the eastern edge of the park. This will allow for the determination of the existence of high emitting areas, or whether variability in emissions lies within a restricted range, which will have an impact on the nature of any control strategies adopted.

Related to this is the continued uncertainty as to the relative sand transport and emission activity among different areas on the dunes. Although we can now be confident that the vegetated areas have low sand flux rates and low emission potential due to the roughness effect, there are only limited data available to judge the relative activity levels of sand movement in the driving area versus the exclosure area. We recommend that active monitoring of wind speed and direction and sand movement be considered for each area.

The availability of measured PM_{10} emission rates as a function of wind friction speed from the PI-SWERL measurements offers the opportunity to use dispersion modeling to evaluate how control measures could affect the downwind concentrations of PM_{10} outside the park. We recommend that to better inform the development of an overall control strategy a dispersion modeling exercise be undertaken to estimate how much area would need to be controlled at the dunes, given its known emission potential and wind climatology, to reach PM_{10} levels downwind of the dunes to meet air quality standards.

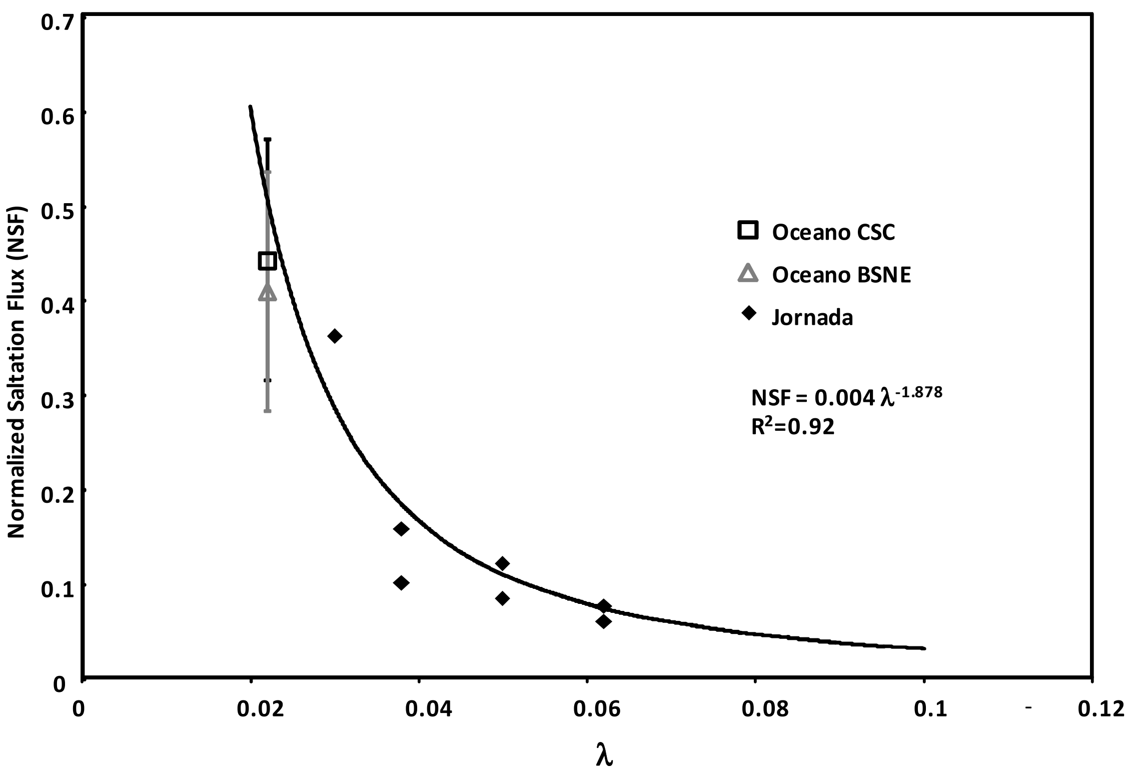
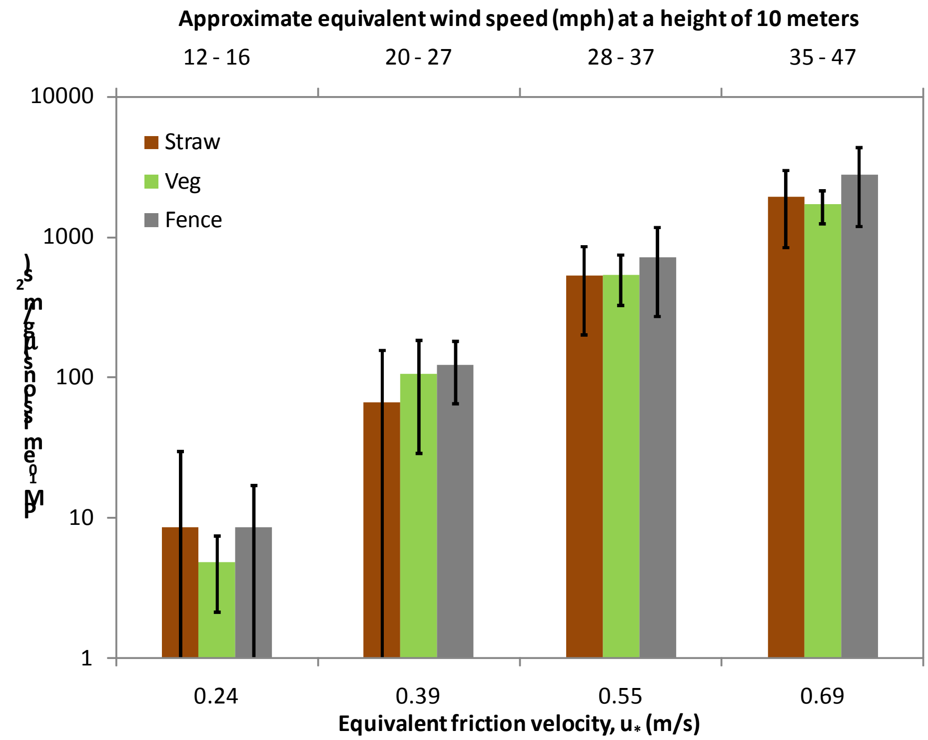
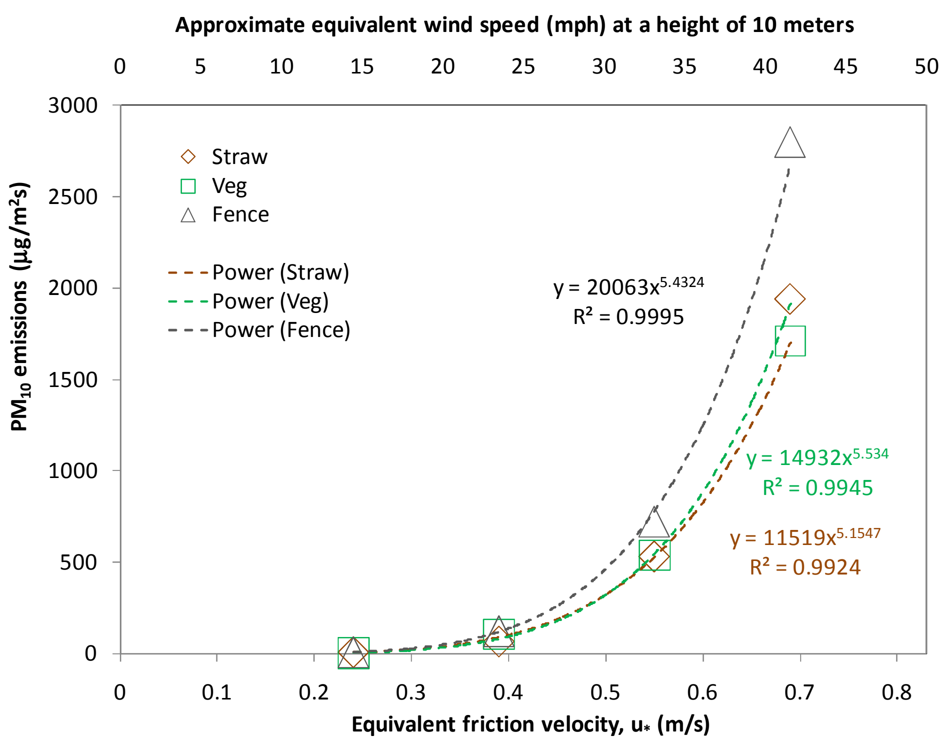


Figure 1. Comparison of the normalized sand flux at the trailing edge of the straw bale roughness with data from a similar experiment carried out by Gillies et al. (2006) using 5 gallon-buckets as roughness elements at the USDA Jornada Experimental Range, New Mexico.



a. Comparison of PM_{10} dust emissions magnitudes across three locations



b. Power fits to PM_{10} dust emissions for measurements at three test locations

Figure 2. Relative magnitudes of emissions from straw bale, vegetated, and along-fence measurements using combined data from both PI-SWERLs.