2013 Intensive Wind Erodibility measurements at and Near the Oceano Dunes State Vehicular Recreation Area: Preliminary Report of Findings

Vicken Etyemezian, John Gillies, Dongzi Zhu, Ashok Pokharel, and George Nikolich
Division of Atmospheric Sciences
Desert Research Institute
755 E. Flamingo Rd, Las Vegas, NV

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Prepared for:

California Department of Parks and Recreation
Oceano Dunes District
340 James Way, Suite 270
Pismo Beach, CA 93449

Introduction

An important factor in the overall understanding of dust emissions from the Oceano Dunes is the characterization of the variability in the wind erodibility. This variability, along with the distribution of wind conditions over the Oceano Dunes constitute the principal factors that determine how much PM10 is emitted from a given region at a given point in time. In an earlier pilot study, a portable wind tunnel-like device was used to determine its suitability for measuring variability and for pilot measurement of wind erodibility from several different surface types at the Oceano Dunes. The Portable In-Situ Wind Erosion Lab (PI-SWERL) was adopted as a tool for providing larger scale assessments of variations in wind erodibility in support of the PMRP.

In order to ensure that this larger scale series of tests resulted in a high quality data set, a site visit for the purpose of planning was conducted the week of July 8, 2013. One PI-SWERL unit was available for in-field testing during the site visit. There were three goals: 1) testing of a vehicle-mounted system for transporting the PI-SWERL; 2) in-field training of two DRI personnel that were unfamiliar with the operation of the PI-SWERL; 3) identification of field procedures that would result in high quality data and the ability to compare measurements procured with two or more different PI-SWERL units.

Based on information gained during the July 2013 scouting trip, the vehicle-mounted system for transporting the PI-SWERL was redesigned, field data sheets were developed for use with every measurement, a protocol was established for frequent collocation testing of all PI-SWERLs to be used at any one time, and a plan was developed for covering as much of the SVRA as well as non-riding areas as possible during a longer, more intensive field effort.

Methods

Intensive field measurements using two PI-SWERL units began on August 26, 2013 and ended on September 5, 2013. In total, 360 individual PI-SWERL tests were completed among the two units used, with each responsible for one-half of the total. Each testing day was started at the beginning of a chosen transect by collocating the two PI-SWERL units within about 5 meters of each other and running the same test (Hybrid 3500). The PI-SWERL units were then moved a nominal distance of a meter or so and another collocation test was completed. This procedure was completed one more time so that each PI-SWERL had completed three replicate measurements and the two PI-SWERLs were collocated for the span of these replicate measurements. Next, for nominally East-West transects, one PI-SWERL was moved approximately 100 m in the direction of the transect, while the other unit was moved 200 m from the original point of collocation. One test was completed before the units were subsequently moved 200 m each so that one PI-SWERL was at 300 m from the original point of collocation and the other was 400 m from that same point. This “leap-frog” pattern was continued until whichever came first: the end of the transect, the end of the day, or each PI-SWERL had completed six tests since the last point of collocation. At that time another series of replicate (three per PI-SWERL) and collocated (among the two PI-SWERLs) measurements was completed. Since the two PI-SWERL units were using the same testing cycle, any differences in PM_{10} concentrations that occur in response to the cycle between the two PI-SWERLs could be tracked over the entirety of the measurement campaign by comparing the PI-

SWERL results obtained during corresponding collocation tests. Moreover, the “leap-frog” approach was intended to further reduce any potential bias resulting from using two different PI-SWERL units.

At each location where a PI-SWERL test was completed, bulk soil material was obtained in the immediate vicinity (within a few centimeters) of where the PI-SWERL was placed. Approximately 500 grams of material from the top 1 centimeter of sand were scooped into a plastic bag and saved for subsequent analyses. Results of those analyses will be included in a future report.

Figure 1 displays all of the locations where valid PI-SWERL measurements were completed. In all, eight East-West transects were completed with four corresponding to the instrumented arrays numbered “1”-“4”. Additional transects were conducted between “1” and “2”, between “2” and “3” (two transects), and between “3” and “4”. Several North-South transects were also completed. For this direction of travel, the PI-SWERLs were spaced 300 m apart rather than 100 m apart owing to the much longer transect extents. In general, it was more difficult to maintain a straight line of travel along the North-South direction because of topographic relief. This was especially true in the Dunes Preserve area. Four (4) long North-South transects were used to improve spatial coverage between the East-West transects within the riding area. At the western edge, the North-South transect started in the Plover exclosure in the south and finished at the northern boundary of the riding area. Two transects ran from the riding area into the Dune Preserve in the north. Three additional short North-South transects were completed between towers “3b” and “3c”, and in the Oso Flaco area.

Each PI-SWERL test was examined to ensure compliance with quality criteria. The criteria included adequate RPM (blade revolutions per minute) convergence to program values, DustTrak concentration upper limits, and clean air blower maintaining set-point values. There were very few cases where data had to be invalidated for any reason. Of the 360 tests, there were seven tests (five for unit #2 and two for unit #3) where the last step in the Hybrid program (3500 RPM) resulted in the DustTrak upper limit being exceeded (locations are shown in Figure 2 after data analysis techniques are discussed). The data from the 3500 RPM interval were considered invalid for those tests. The effect of those invalid data points is considered to be negligible in terms of impacting overall data quality.

Each PI-SWERL test was analyzed for DustTrak PM_{10} emissions at the three “step” portions of the hybrid test corresponding to 2000, 3000, and 3500 RPM as shown in Figure 3. The threshold RPM was also obtained using an automated algorithm that identifies systematic movements in the two optical gate sensors (OGS 1 and OGS 2). Ultimately, the data analyst reviews the findings of the algorithm in every case to ensure that it has adequately identified the threshold. The criteria are that both OGS sensors indicate sustained, systematic signals indicating sand movement and the PM_{10} concentration increases abruptly immediately after the RPM identified as the threshold is exceeded. An example of how the algorithm to detect the threshold for OGS 1 and 2 works is shown in Figure 3.

Average PM_{10} DustTrak concentrations at each of the three RPM steps were used to estimate equivalent PM_{10} emissions at those RPM values. Since there are unit-to-unit variations in DustTrak response to dust, all DustTraks that were used in the study, including spare units, were collocated in the lab and exposed to a common level of dust concentration in a resuspension chamber. This procedure was completed once before the field experiments and once after. A specific unit (SN: 85200415) was arbitrarily chosen as a reference unit for normalizing all other units. Table 1 shows the slope calculated between the reference unit and the three other units used in the field measurements for the in-lab tests as well as the slopes obtained from the collocation measurements of the two PI-SWERL units in the field. On the whole, it appears that the maximum uncorrected difference between DustTrak pairs is less than 15%. In any event, the slope calculated from the in-field collocations was used to correct three of the DustTraks used to equivalent reference unit PM_{10} concentrations. We note for clarity that only one DustTrak is used per PI-SWERL during any specific test and that a total of four were collocated so that there would be spares available for rotation as needed.

Table 1. Slope relationship between DustTraks used throughout study. Collocation measurements in the field were used to obtain actual correction factors. Collocation of DustTraks in the lab before and after field deployment are also shown for comparison.

Instrument SN	SN85200415*	SN21970	SN22639	SN85200431
Before field Use				
Slope	1	0.935	0.982	0.864
R squared	1	0.994	0.999	0.991
After field Use				
Slope	1	0.906	0.952	1.022
R squared	1	0.999	0.997	0.999
Collocation during field Use*				
Slope	1	0.99	1.03	1.00
Number of Tests	61	103	76	120

*Used as arbitrary reference unit.

**Used as correction factors

Dust emissions at specific values of RPM were calculated by averaging the one-second dust concentrations over the RPM step as indicated in Figure 3 and using the equation:

$$E_i = \frac{\left(C_{DT,i} \times \frac{F_i}{60\times1000}\right)}{A_{eff}}$$

where E_i is the PM_{10} dust emissions in units of mg/(m^2 • second) at the ith step, $C_{DT,i}$ is the average DustTrak PM_{10} in mg/m^3 (corrected to reference unit), F_i is the the clean air flow rate in (and out of) the PI-SWERL chamber in liters per minute, and A_{eff} is the PI-SWERL effective area in m^2 (0.035 m^2).

Note that threshold RPM values that are obtained by the technique demonstrated in Figure 3 have been translated into an approximate 10-meter threshold wind speed for more intuitive interpretation of data in Figure 4. This is accomplished by invoking the relationship between friction velocity, u_*, and PI-SWERL RPM that was proposed by Etyemezian et al. (2014):

$$u_{*,eff}(RPM) = C_1 \cdot \alpha^4 \cdot RPM^{C_2/\alpha}$$

where C_1 and C_2 are constants (with values of 0.000683 and 0.832, respectively), and α is a parameter that depends on the surface roughness, having a value of unity for smooth surfaces and a value of 0.84 for the roughest surfaces tested by Etyemezian et al. (2014) – corresponding approximately to a 40% gravel cover. For all the surfaces tested as part of this project, it was assumed that α was equal to unity. The threshold friction velocity (given in meters per second by the above empirical equation) was translated into an approximate 10-meter wind speed using the well-known law of the wall equation:

$$u_z = \frac{u_*}{\kappa} ln \frac{z}{z_0}$$

where u_z is the wind speed (m/s) at height z (10 m) and z_0 is the aerodynamic roughness height (assumed to be 0.26 mm for all surfaces tested based on regression data from S1 tower).

Deviations from proposed methods as documented in March 5, 2013 document ("Proposal" hereafter) entitled, "Using the Portable In-situ Wind ERosion Lab (PI-SWERL) to Characterize the Dust Emission Potential of the ODSVRA and Associated Dunes Natural Preserves."

Methods employed in the field and summarized in the present report generally followed those that were outlined in the Proposal. There are a few notable differences that were instituted either as improvements over the original Proposal method or in response to information gained between the time the Proposal was approved and actual data collection began in earnest.

First, as stated in the Proposal, subsequent to a few preliminary tests, it was determined that the highest RPM that the PI-SWERL should be programmed to reach should be 3500. Early testing in the field indicated that at the higher value of 4000 RPM, the DustTrak instruments would likely be frequently "out of range" due to high dust concentrations. Since data corresponding to these "out of range" periods are difficult to make use of, it made sense to lower the highest RPM level so that there would be valid data for as many tests as possible, thereby allowing for direct comparison of emission potential at all RPM steps among sites and regions.

Second, the number of East-West transects completed with the PI-SWERL units was less than was preliminarily suggested in the Proposal (8 versus 10 within Park Boundaries). East-West transects in the Guadalupe Dunes were not sampled at all due to logistical difficulties of obtaining permissions and transportation to and from the site. Additional North-South transects were completed beyond those shown in Figure 2 of the Proposal, especially in the Dunes Preserve Area. All in all, the number of samples collected (360) was slightly higher than the number estimated in the Proposal (300).

Third, in the Proposal, a technique that involved using a reference DustTrak unit was described as a potential means to reduce bias from using two different PI-SWERLs during the study. On further, subsequent consideration a better technique was adopted as described in detail above in the Methods section. Briefly, the two PI-SWERL units were: a) collocated frequently for the duration of three complete measurement cycles, and b) alternating measurement locations along a transect were completed with alternating PI-SWERL units. This was in addition to the collocation of the DustTrak units prior to the beginning of the field measurement campaign. In this way, when spatial data of emission potential from a transect or a region of interest are averaged, the average includes the same number of data points from each of the two PI-SWERL units.

Results

Figure 4 shows the distribution of threshold values of estimated 10-meter wind speed whereas Figure 5-Figure 7 show the emissions estimates for PM_{10} at 2000, 3000, and 3500. Data in these figures have been divided into quantiles of 20% so that each category shown in the legend contains 20% of the data for the displayed field. The same data are given in tabular summary form in Table 2. Data in Table 2 are grouped by region as shown in Figure 8. Given the differences in emissions between large regions of the study area, this grouping is likely more useful for planning than trying to identify "hot spots" of emissions.

Table 3 shows results of statistical tests of significance for the threshold RPM as well as the emissions calculated at the three step RPM levels (2000, 3000, and 3500). A value <0.05 indicates that the difference between the two groups for that parameter is statistically significant at the alpha equals 0.05 level.

Emissions are highest in the La Grande riding area at the 2000 RPM step. They are also higher at the 3000 and 3500 RPM steps than at all the other locating groups. However, the difference between the La Grande and South West riding areas at these higher RPM levels is not statistically significant (at α = 0.05). It is interesting that despite quite different values in emission potential, the threshold for emissions is quite similar between the Dune Preserve and La Grande Riding Areas. This suggests that the distribution of sand grain sizes in the two regions is comparable. Indeed, there appears to be an overall increase in threshold across the entire area where measurements were conducted from the Dune Preserve in the North to Oso Flaco in the South, this was also observed for the measurements of PM_{10} and saltation activity along the four instrumented transects (Gillies and Etyemezian, 2014). This may be an indication in the overall coarsening of surface sand as one travels from North to South. Similarly, based on the fact that the difference in threshold between the East and South West riding areas is significant, it may be that the sand size distribution in the East riding area is comparatively finer. At the time of writing of this report, detailed size distribution results have not been finalized. Relationships between emissivity and threshold as measured by the PI-SWERL and size distribution of dune particles will be discussed in greater detail once size distribution data have been finalized.

After the La Grande riding area, the region with the next highest, but rather comparable emissions (especially at 3000 and 3500 RPM) is the South West riding area. Next highest are the Dune Preserve and the East riding area followed by Oso Flaco and the Plover Exclosure.

Discussion

These PI-SWERL measurements have made it clear that the La Grande and South West riding areas, and to a lesser extent the East riding area, are exhibiting the potential for windblown PM_{10} emissions that is higher than the non-riding areas that were tested. What these measurements do not elucidate is the cause for this elevated potential for emissions in the riding areas. If OHV riding is causing the elevated potential for emissions, then it would be very useful to determine by what physical means this is occurring. If OHV riding and elevated potential for emissions are simply coincidental, this too would be important as it has direct implications for possible control measures.

There is the possibility of critical insight in reconciling two observations arising from the PI-SWERL data analysis. The first observation is that the threshold for emissions is similar between the Dune Preserve and the La Grande riding area and second is that the potential for emissions is substantially greater in the La Grande riding area. This situation could arise if the distribution of sand in the saltation size range (approximately 0.07 – 0.25 mm) is comparable between the two regions but the La Grande riding area has much higher content of small, suspendable dust particles (approximately 0.2 – 10 microns). Bulk samples collected during the PI-SWERL study are being re-examined with an eye towards determining if such a difference in the suspendable dust fraction exists. If successful, results from that effort could provide insight into the physical differences that give rise to differences in emission potential.

The present work provides an estimate of the potential for emissions of PM_{10} dust from a surface when that surface is subjected to specific, recreated (i.e., by the PI-SWERL) wind conditions. In the larger context of windblown dust emissions from the Oceano Dunes and implications of these emissions for air quality, the characteristics of the actual ambient wind and the topography must also be considered. For example, there appears to be a gradient in wind strength (e.g., gusts or short-term averages during high wind events) from the North to the South (Gillies and Etyemezian, 2014). This may be one of the reasons that although the potential for PM_{10} emissions in the riding areas is several fold (see Table 2) the potential from non-riding areas, concentrations of PM_{10} at Oso Flaco during high wind events are comparable to or even higher than concentrations along the La Grande riding area for the same wind storms (Gillies and Etyemezian, 2014). As with (and likely related to) the distribution of wind, the distribution of topography may also have a role in the ultimate emissions from a region.

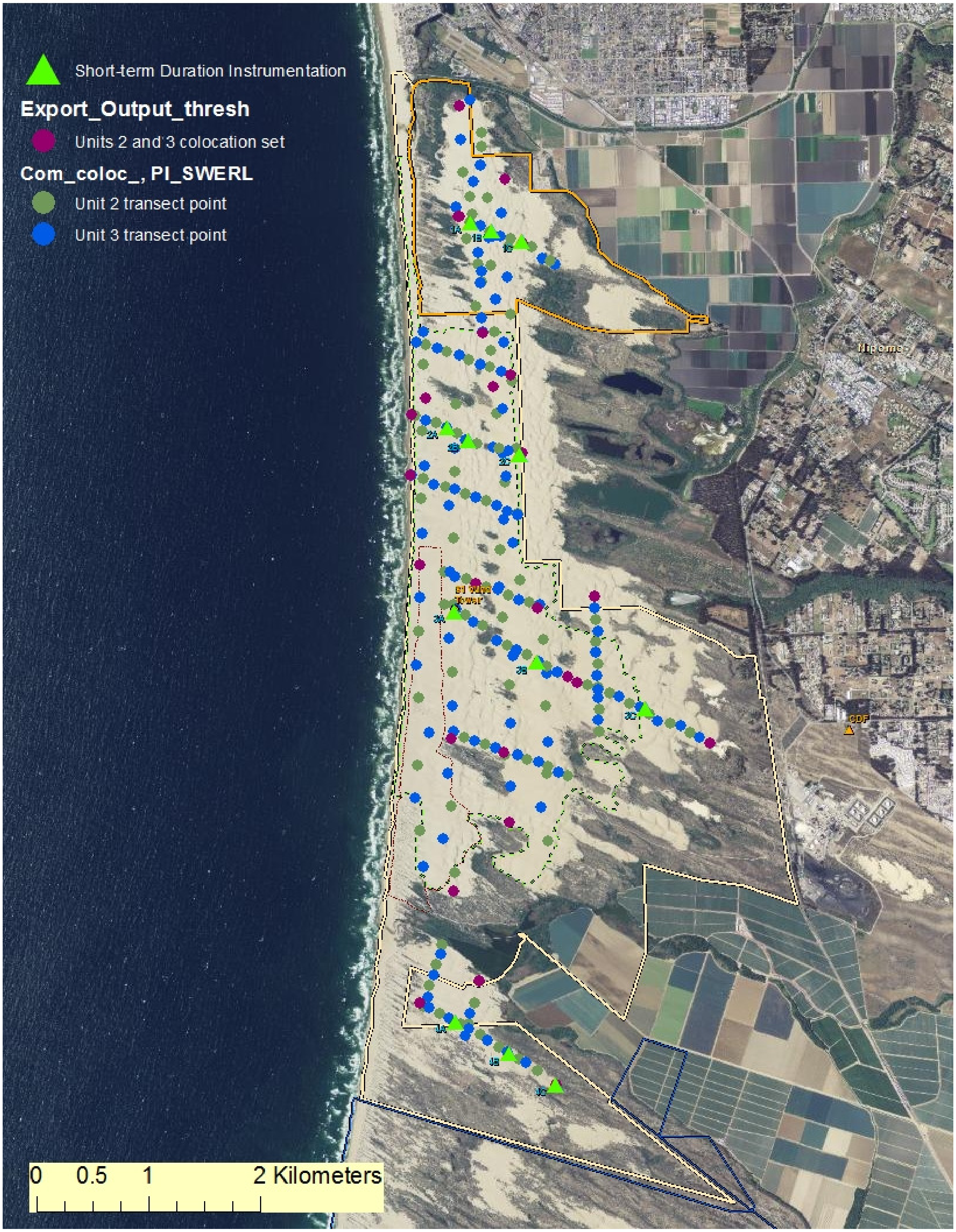

Figure 1. Locations of PI-SWERL transect measurements for units #2 (khaki) and #3 (blue) and collocation sets (fuchsia).

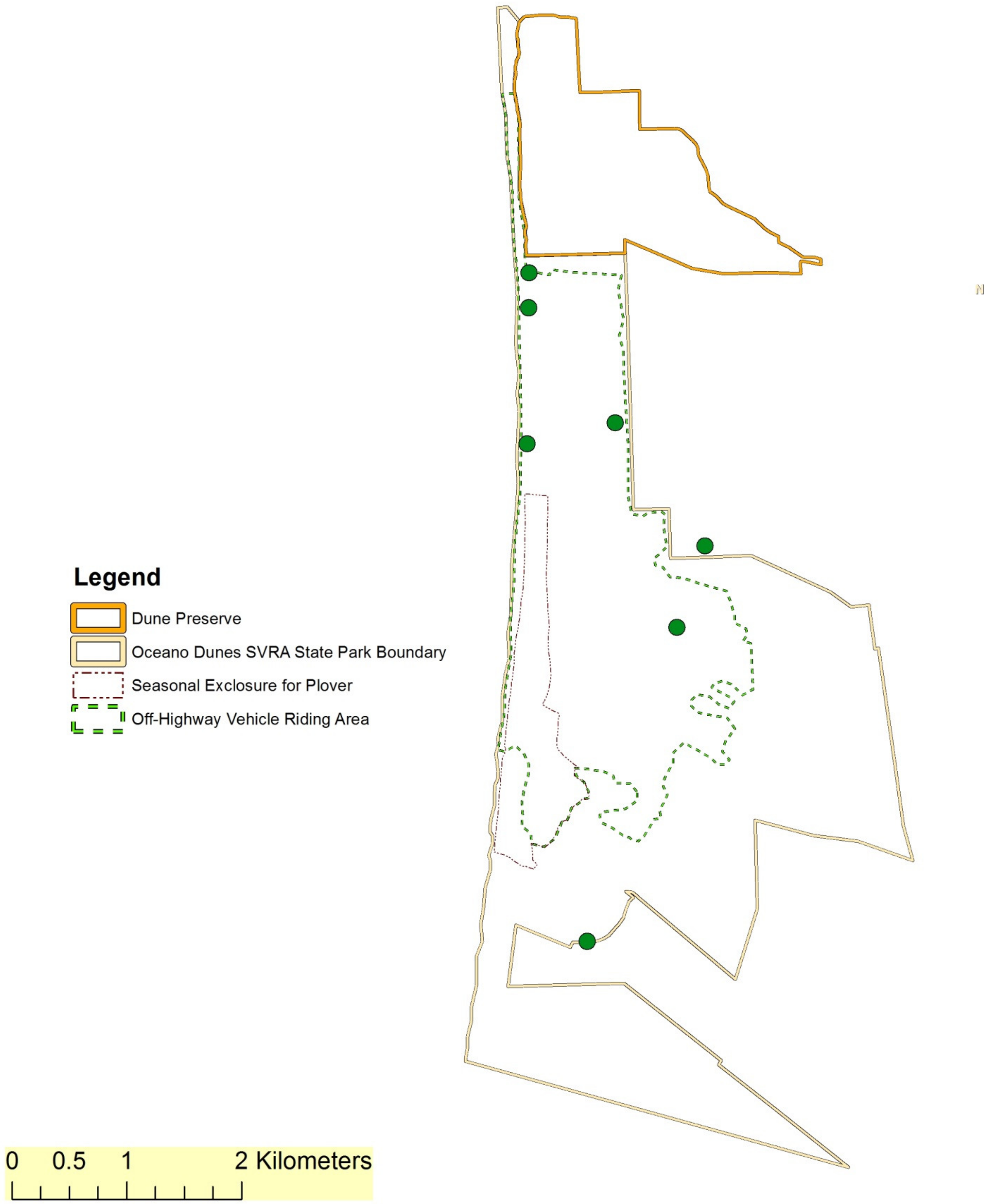

Figure 2. Locations of 7 measurements where emissions at the 3500 RPM step where invalid due to exceedance of the DustTrak measurement range.

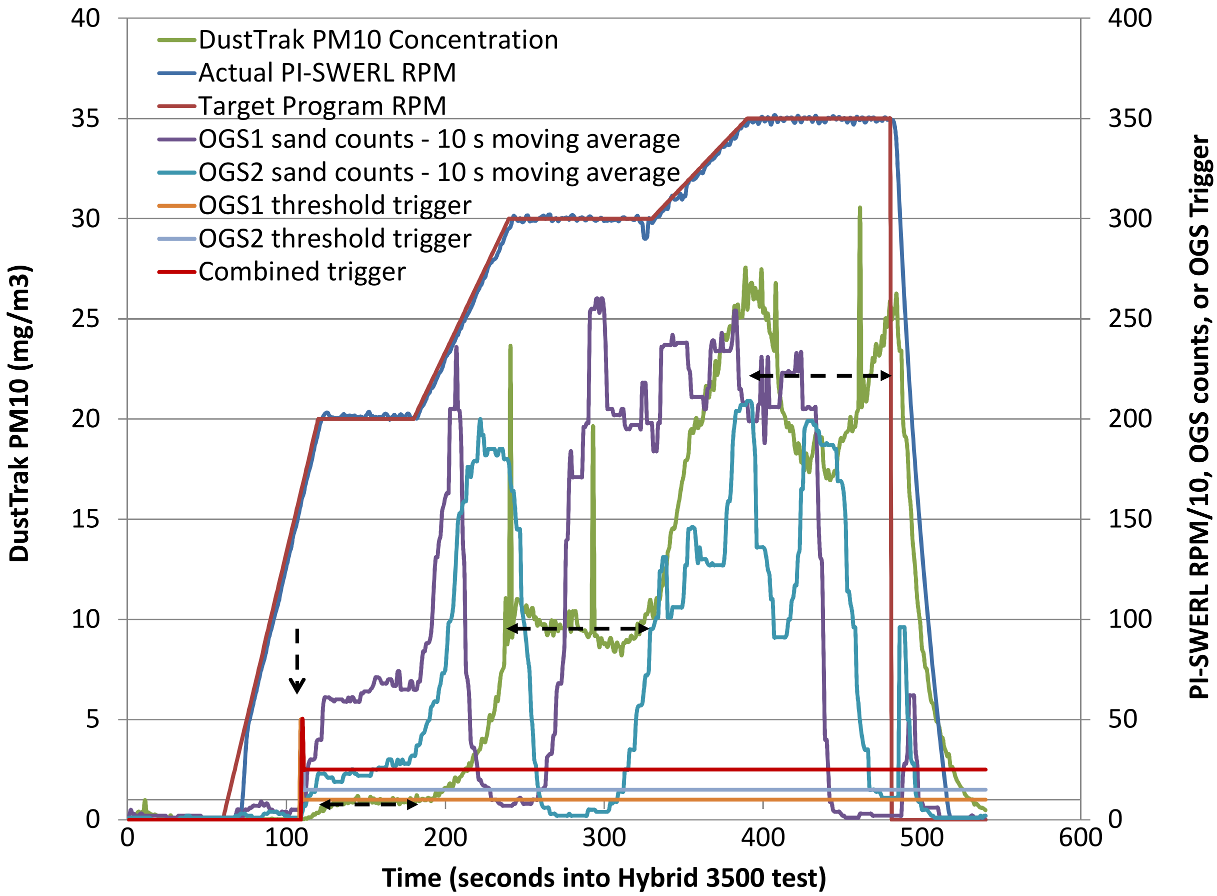

Figure 3. Example of data extraction from an individual PI-SWERL test. The dashed black, horizontal lines correspond to the periods of time the DustTrak PM_{10} average was extracted to represent the 2000, 3000, and 3500 RPM steps. The vertical dashed, black line shows the point at which threshold detection algorithms for both OGS 1 and 2 indicate that threshold has been achieved – 1609 RPM in the example above. Note that once OGS counts exceed about 200 – 250 counts per second, the sensors become overloaded and cannot accurately count sand grains. OGS data after this level of counts is reached are likely nonsensical. This is the reason for the apparent (but not actual) dip in sand movement around t = 250 seconds into the test.

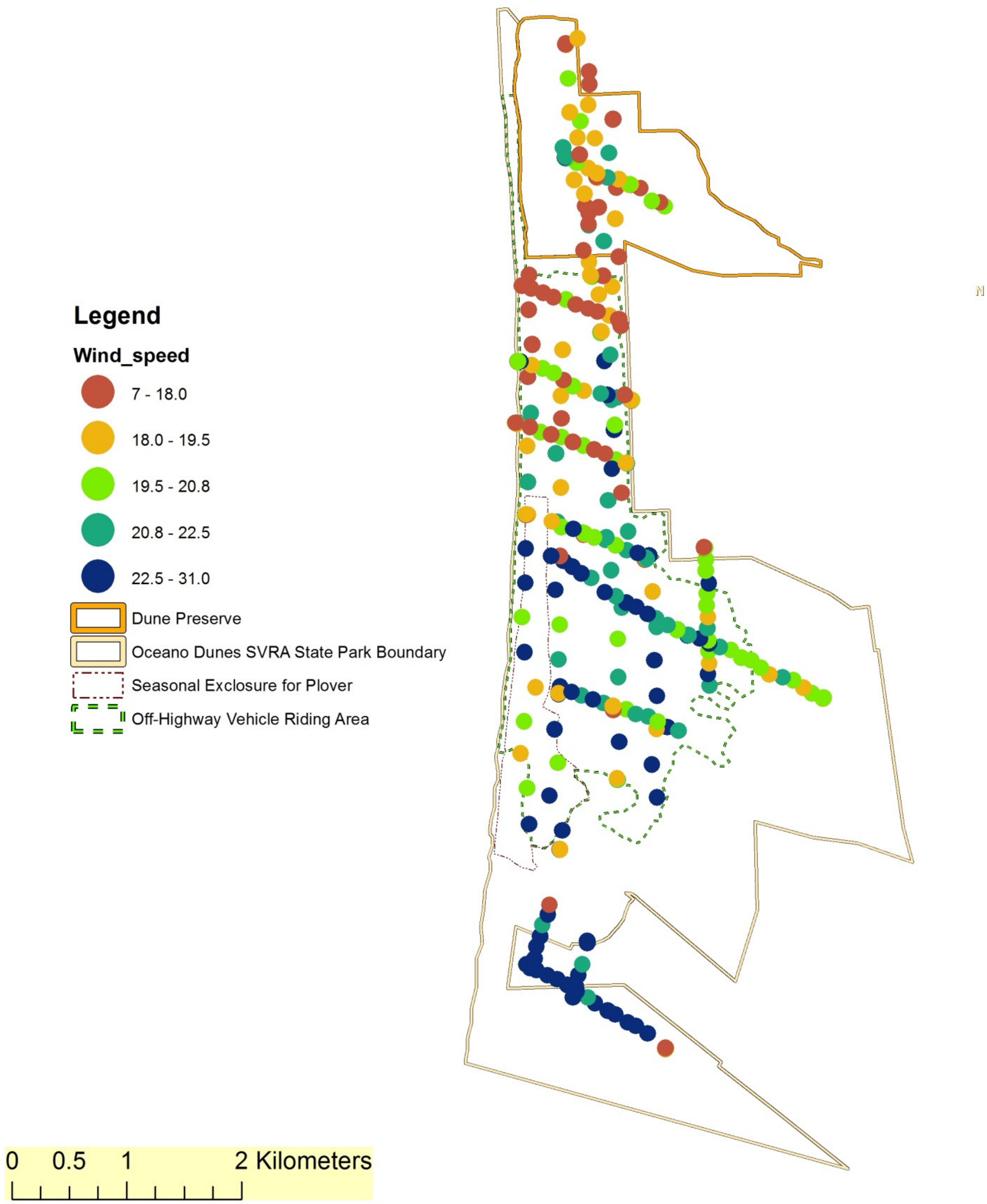

Figure 4. Threshold 10-meter Wind speed. Categories are chosen so that each category contains 20% of all data.

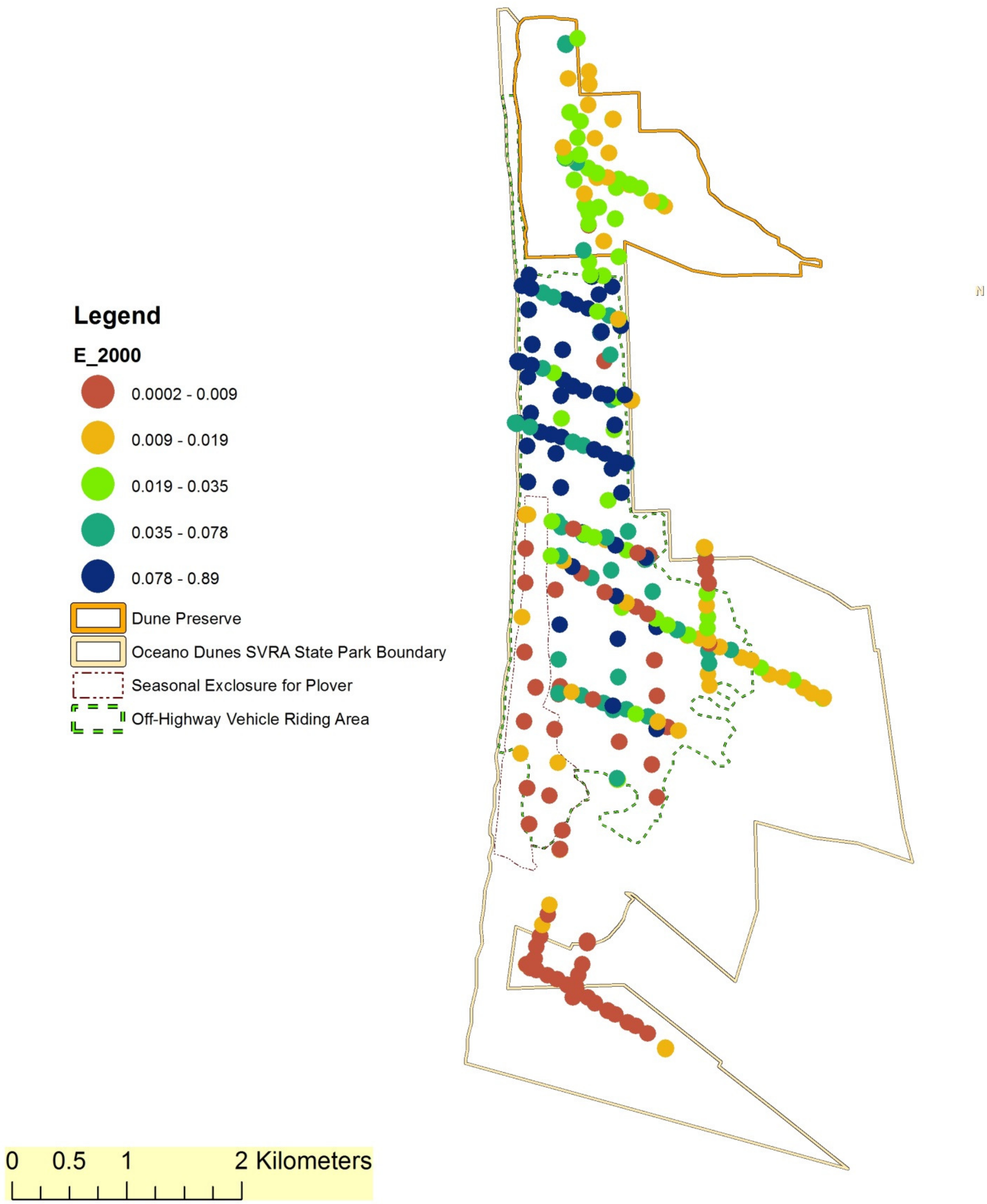

Figure 5. PI-SWERL-measured emissions at 2000 RPM (23 mph) in units of mg of PM_{10} /m^2 sec. Categories are chosen so that each category contains 20% of all data.

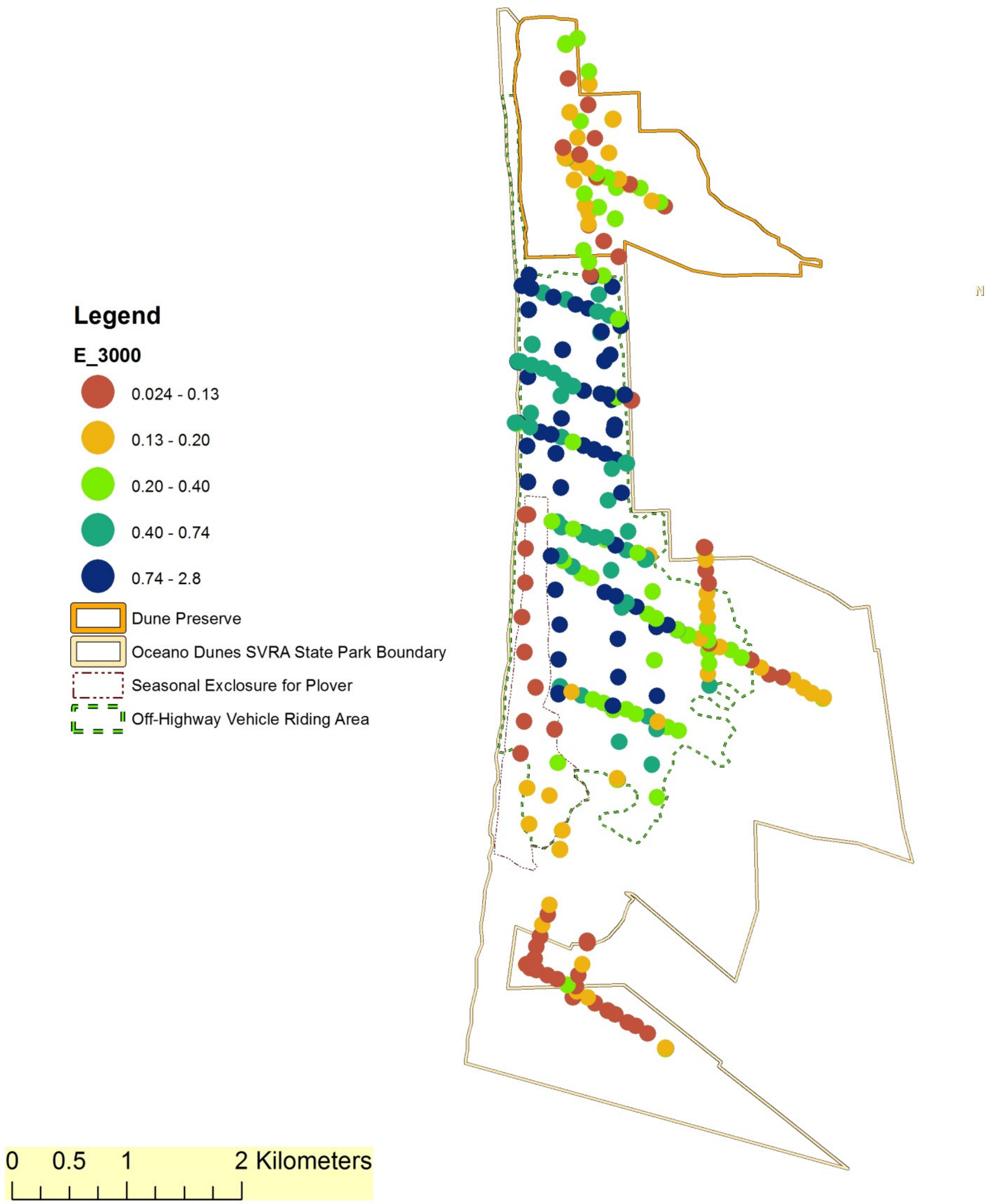

Figure 6. PI-SWERL-measured emissions at 3000 RPM (32 mph) in units of mg of PM_{10} /m^2 sec. Categories are chosen so that each category contains 20% of all data.

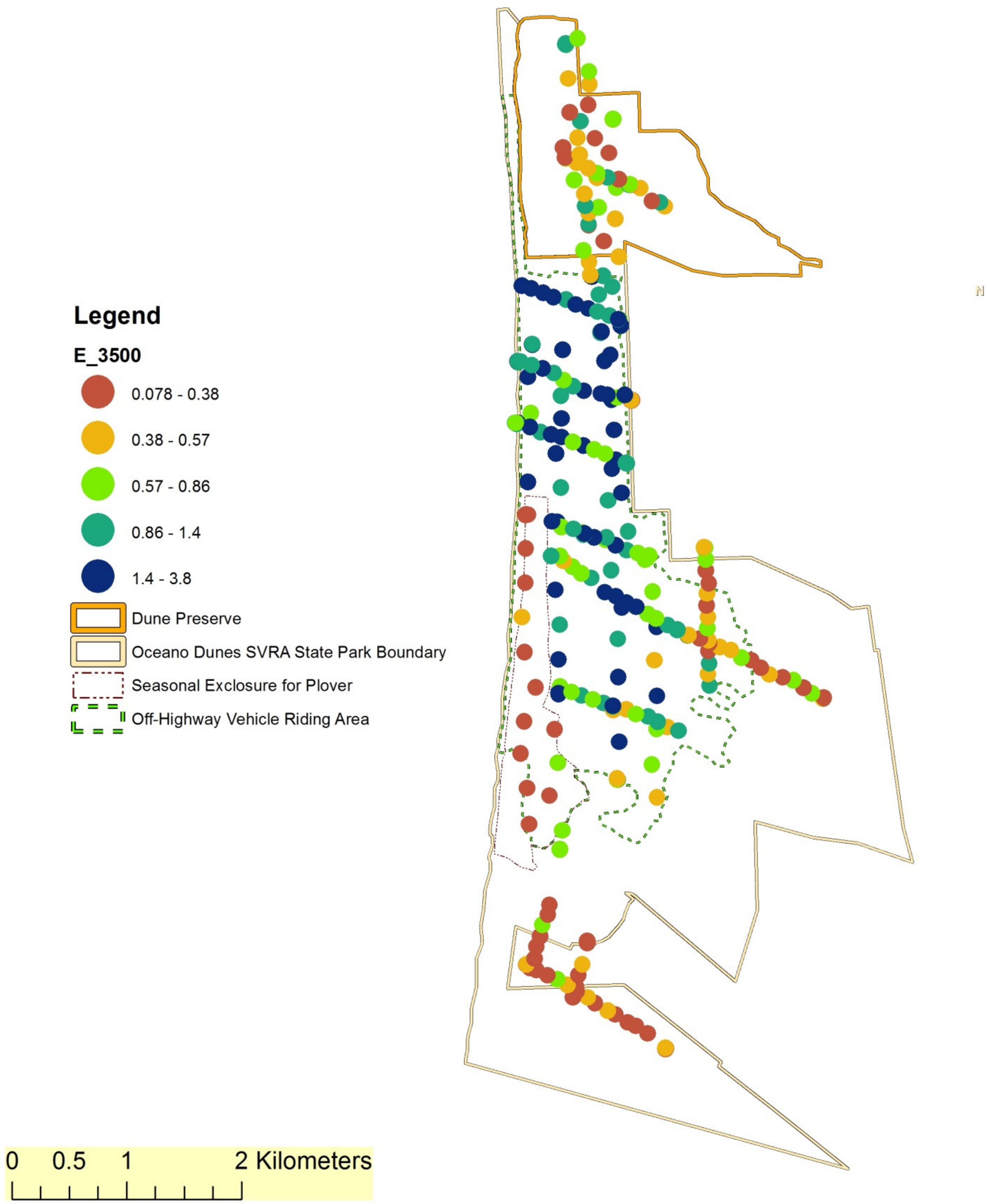

Figure 7. PI-SWERL-measured emissions at 3500 RPM (36 mph) in units of mg of PM_{10} /m^2 sec. Categories are chosen so that each category contains 20% of all data.

Table 2. Summary of threshold RPM and PM_{10} emissions by location grouping (number of independent tests in each group shown in parentheses).

	Threshold wind speed (mph)	PM_{10} Emissions at 2000 RPM (23 mph) (mg/m^2sec)	PM_{10} Emissions at 3000 RPM (32 mph) (mg/m^2sec)	PM_{10} Emissions at 3500 RPM (36 mph) (mg/m^2sec)
Oso Flaco (41)	23	0.0044	0.11	0.29
Plover Exclosure (25)	21	0.0080	0.11	0.38
Dune Preserve (66)	19	0.028	0.19	0.61
All Non-ride (132)	21	0.017	0.15	0.47
Riding Area – La Grande (122)	19	0.14	0.80	1.38
Riding Area South West (44)	22	0.046	0.67	1.27
Riding Area East (62)	21	0.026	0.29	0.60
All Ride (228)	20	0.088	0.64	1.15
Ratio: All Ride/All Non-ride		5.2	4.3	2.4
Ratio: La Grande/All Non-ride		8.1	5.4	2.9

Table 3. Results of test of significance between locating groups shown in Figure 8. The P-values shown are based on two sided t-tests of samples of unequal variances and unequal sizes (Welch's test). P-values greater than 0.05 (corresponding to differences between groups that are not significant at the alpha = 0.05 level) are bolded and in gray.

Threshold RPM	Riding Area - La Grande	Oso Flaco	Plover Exclosure	Dune Preserve	Riding Area - South West
Oso Flaco	(Y)/0.000				
Plover Exclosure	(Y)/0.002	(Y)/0.001			
Dune Preserve	**(N)/0.289**	(Y)/0.000	(Y)/0.000		
Riding Area - South West	(Y)/0.000	(Y)/0.005	**(N)/0.265**	(Y)/0.000	
Riding Area - East	(Y)/0.000	(Y)/0.000	**(N)/0.548**	(Y)/0.000	(Y)/0.013

Emissions at 2000 RPM (approximately 23 mph winds at 10 meters)	Riding Area - La Grande	Oso Flaco	Plover Exclosure	Dune Preserve	Riding Area - South West
Oso Flaco	(Y)/0.000				
Plover Exclosure	(Y)/0.000	(Y)/0.019			
Dune Preserve	(Y)/0.000	(Y)/0.000	(Y)/0.000		
Riding Area - South West	(Y)/0.000	(Y)/0.000	(Y)/0.000	(Y)/0.008	
Riding Area - East	(Y)/0.000	(Y)/0.000	(Y)/0.000	**(N)/0.658**	(Y)/0.008

Emissions at 3000 RPM (approximately 32 mph winds at 10 meters)	Riding Area - La Grande	Oso Flaco	Plover Exclosure	Dune Preserve	Riding Area - South West
Oso Flaco	(Y)/0.000				
Plover Exclosure	(Y)/0.000	**(N)/0.747**			
Dune Preserve	(Y)/0.000	(Y)/0.000	(Y)/0.000		
Riding Area - South West	**(N)/0.102**	(Y)/0.000	(Y)/0.000	(Y)/0.000	
Riding Area - East	(Y)/0.000	(Y)/0.000	(Y)/0.000	(Y)/0.000	(Y)/0.000

Emissions at 3500 RPM (approximately 36 mph winds at 10 meters)	Riding Area - La Grande	Oso Flaco	Plover Exclosure	Dune Preserve	Riding Area - South West
Oso Flaco	(Y)/0.000				
Plover Exclosure	(Y)/0.000	(Y)/0.048			
Dune Preserve	(Y)/0.000	(Y)/0.000	(Y)/0.000		
Riding Area - South West	**(N)/0.392**	(Y)/0.000	(Y)/0.000	(Y)/0.000	
Riding Area - East	(Y)/0.000	(Y)/0.000	(Y)/0.000	**(N)/0.852**	(Y)/0.000

Figure 8. Delineation of Regions summarized in Table 2.

References

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