January 12, 2024

**Memo: Analysis of PI-SWERL Measurements in Plover Exclosure Area**

**From**: Scientific Advisory Group (SAG)

**To:** Karl Tupper, San Luis Obispo Air Pollution Control District (APCD)
Jon O'Brien, California Department of Parks and Recreation (CDPR)
Ronnie Glick, California Department of Parks and Recreation (CDPR)

**Cc**: Sarah Miggins, California Department of Parks and Recreation (CDPR)
Gary Willey, San Luis Obispo Air Pollution Control District (APCD)

In an extensive memorandum entitled "**Updated SAG Recommendations for Establishing Emissivity Grids to be used in Modeling of Pre-Disturbance Conditions and Future Excess Emissions Reduction**" (December 19, 2023) the Scientific Advisory Group (SAG) presented a detailed analysis of PI-SWERL measurements collected in the Oceano Dunes State Vehicular Recreation Area (ODSVRA) between 2013 and 2022. Not included in that analysis were a series of measurements (N=198) made in the footprint of the current Plover Exclosure (PE) area between 2013 and 2019. The reason for not considering these data is that the PE was not permanently closed to Off-Highway Vehicle (OHV) traffic and camping until October 1, 2021. Prior to that date, the area was 'seasonally exclosed' meaning that OHV traffic was not allowed between March 1 and September 30 of every year, but the area was open to recreational riding in the winter season between October 1 and February 28. Thus, this area cannot be classified as exclusively 'riding' or 'non-riding' for purposes of analysis, unlike most other areas in the ODSVRA (with some exceptions). Therefore, the PI-SWERL measurements in the PE prior to closure cannot be pooled with other measurements taken before 2021. Note that there were 23 measurements made in the PE in late September of 2022, after the area had been effectively closed for 19 months (i.e., since March 1, 2021) and arguably longer given COVID-related access restriction in the park during winter 2020-21. These 23 measurements were classified as 'non-riding' and were included in the overall analysis summarized in the December 19, 2023 memorandum (i.e., they are not included in the 198 measurements made when seasonal access was allowed).

In this memo, a summary analysis of the 198 PI-SWERL measurements (2013-2019) in the footprint of the PE area is presented and compared to the 23 measurements in 2022. It is not anticipated that these data will be used for purposes of assessing excess mass emissions as per the Stipulated Order of Abatement (SOA), but the information from the analysis may be relevant to understanding how OHV riding may (or may not) have influenced the potential for dust emissions from the PE area, and perhaps elsewhere in the ODSVRA.

The locations of sampling points within the PE are presented in Figure 1. There were five measurement campaigns with unequal spatial coverage, but all following the general north-south trend of the area. The earliest campaigns (2013 and 2014) had slightly broader coverage than the later campaigns (2015, 2016, 2019), which followed a single north-south transect situated generally in the middle of the PE with respect to west-east span (as did the 2022 campaign). There are insufficient data to assess whether there are west-east trends in emissivity, and such an analysis would be confounded by the large north-south extent of the PE area. As a consequence, no attempt was made to sub-divide the PE into separate zones—all data were pooled into one management zone for purposes of statistical analysis of the temporal differences.

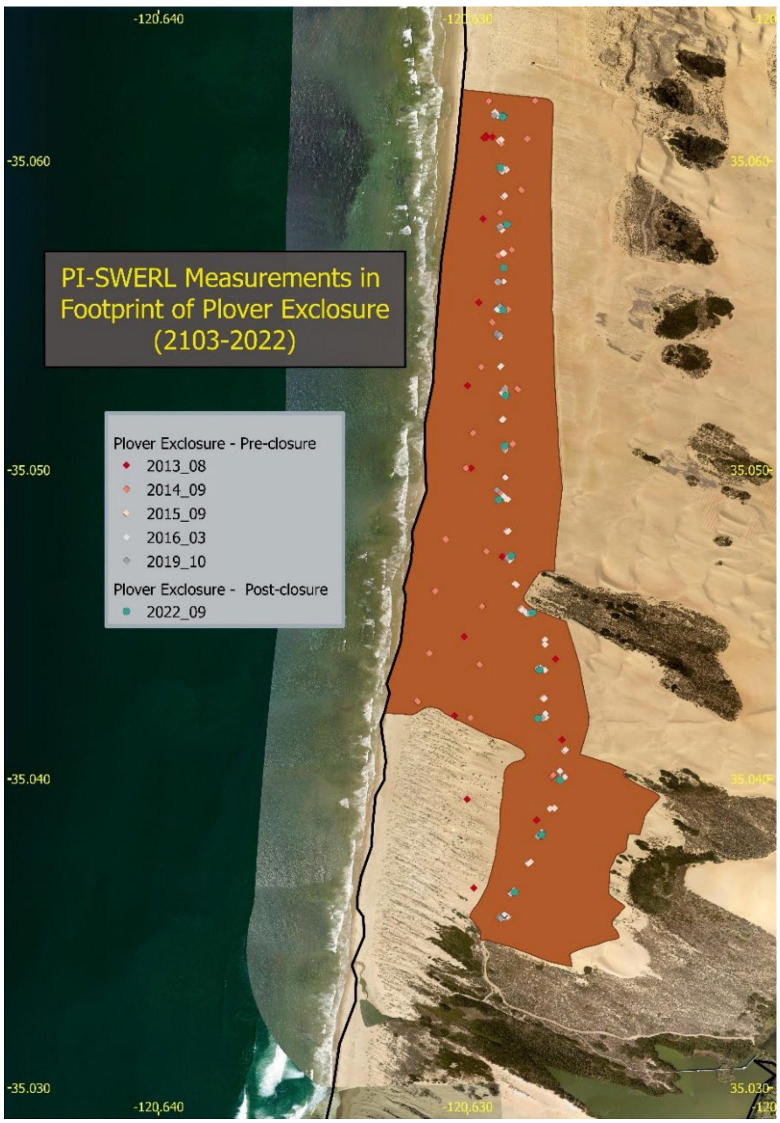


**Figure 1: Sampling locations for PI-SWERL measurements within the Plover Exclosure area (brown color) from 2013 through 2022.**

Summary statistics for each of the PI-SWERL measurement campaigns are portrayed graphically in Figure 2. The three panels correspond to the discrete RPM settings of the PI-SWERL instrument during the testing process (i.e., Low, Medium, and High), with values of the corresponding shear velocity presented in the upper right of each panel. It is noteworthy that four of the campaigns (2013, 2014, 2015, 2019) were conducted in late September or early October, at the end of the seven-month period of non-riding (March through September, inclusive), but during a management era that allowed for seasonal OHV access (October through February, inclusive) in every year. In contrast, the campaign in 2016 was conducted at the beginning of March, right after the area had been exposed to OHV traffic for five months. As mentioned previously, the September 2022 data were measured during a different management regime after 19+ months of permanent closure. It is important to recognize that most measurement campaigns in the PE were conducted during relatively dry periods (as measured by the SLO County Public Works Department, Ocean Station #795), with the exception of the September 26-30, 2022 campaign, which may have been influenced by rainfall events on Sept. 18 (0.44”), Sept. 19 (1.40”), and Sept. 20 (0.04”). In general, then, the sand surface should have been reasonably dry during all PI-SWERL measurement campaigns with no restrictions on dust emission potential based on surface moisture controls.

The box-and-whisker plots demonstrate consistency across the three PI-SWERL rotation speeds, so the focus of discussion will be on the Medium RPM panel, for expediency. It is evident that the March, 2016, campaign had the largest emissivity values, with median and mean values more than twice as large as other campaigns. Note also that unlike any other year, the 2016 data are not heavily skewed toward large emissivity values, as indicated by the fact that the median value is only slightly larger than the mean whereas in other years the median is consistently smaller than the mean. It is possible that these 2016 data distribution 'abnormalities' (relative to other campaigns) is due to the fact that the measurements were taken immediately after a five-month period of sand surface disturbance by OHV traffic, leading to homogenization of the surface sand admixture and a general increase in emissivity potential. A correlation between OHV riding and increased emissivity was documented by Gillies et al. (2022), and the trends shown in Figure 2 seem to corroborate this association.

The campaign years (2013, 2014, 2015) during the era of 'seasonal exclosure' show fairly consistent results with similar median emissivity values and approximately similar data ranges. Under the presumption that the OHV riding periods that punctuated these campaigns yielded similar emissivity profiles as for March, 2016, it is reasonable to conclude that an initial short-term adjustment to non-riding status occurs relatively quickly and rather consistently. Although the 2019 data distribution is considerably broader than those in 2013, 2014, and 2015, with several instances of large emissivity values, the median value is only slightly smaller than for the earlier campaigns. Again, this suggests a relatively rapid short-term adjustment period, consistent with the findings of Gillies et al. (2022), even though long-term adjustment toward ‘natural’ conditions without OHV disturbance may take years to decades as vegetation re-colonizes open sand surfaces.

Of particular interest are the small emissivity values measured in September, 2022. At this time, the reasons for such small values is unknown, but there are two potential factors that may account for this. First, there was a significant amount of rainfall received 6-8 days prior to the measurement campaign so the sand surface may not have been thoroughly dry. Second, there had been no OHV disturbance for at least 19+ months, allowing for extensive surface re-organization and textural adjustment.

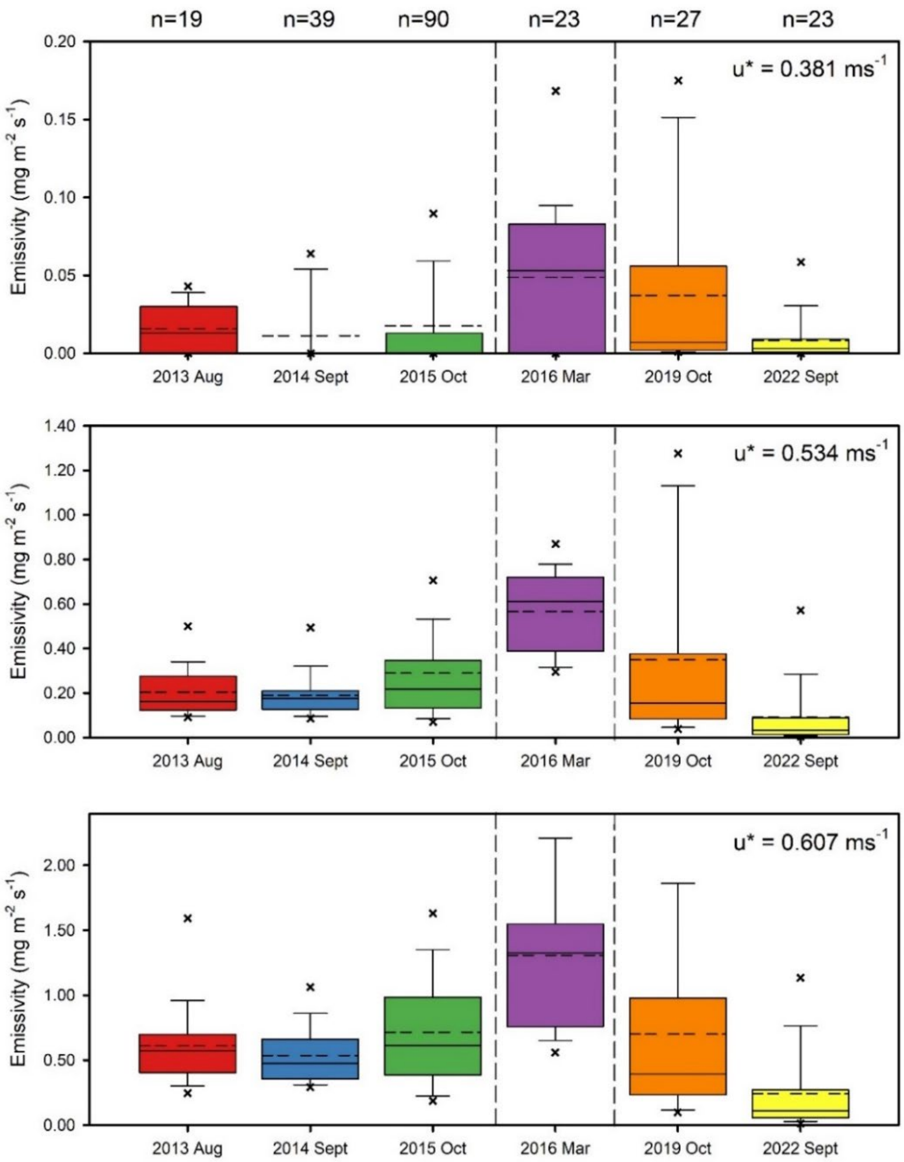


**Figure 2: Box-and-whisker plots of the PI-SWERL measurements for each of the six field campaigns. The colored boxes define the range of the 25$^{th}$ and 75$^{th}$ percentiles; the whiskers correspond to the 10$^{th}$ and 90$^{th}$ percentiles; and the outer symbols (x) indicate the 5$^{th}$ and 95$^{th}$ percentiles. The median value is given by the horizontal solid line within the box, whereas the arithmetic mean (average value) is shown by the horizontal dashed line. The three panels correspond to the three RPM speeds used in the PI-SWERL device to characterize dust emissions at any single measurement location. Vertical dashed lines are inserted to differentiate the 2016 measurements as representative of the post-riding period whereas all other campaigns were conducted at the end of the non-riding period.**

As noted earlier, the last four measurement campaigns (2015, 2016, 2019, 2022) followed a north-south transect. By isolating common sampling locations (and eliminating intervening points that could not be paired with other campaign years) a set of four comparable transects was assembled (Figure 3) showing emissivity values plotted according to latitude. With focus again on the Mid RPM panel, the trends support the conclusions reached with respect to Figure 2. Specifically, the 2016 measurements, taken at the conclusion of the riding period, had generally greater emissivity values than any other year at virtually all sampling locations (two exceptions at around 35.052° and 35.042°). In contrast, the 2022 measurements, taken after a lengthy non-riding period, had the smallest emissivity values (with two exceptions at around 35.057° and 35.042°). The sampling location at 35.042° appears to be somewhat unusual in having consistently large emissivity values relative to other locations. Google Earth imagery reveals that there is little to no foredune development upwind of this sampling location—it consists of an extensive corridor of open sand. This is also the approximate location where pipeline maintenance by bulldozer is undertaken on a semi-regular basis (T. Carmona and R. Glick, personal communication). The emissivity values for 2015 were generally greater than those for 2019, and both were situated between the extremes of 2016 on the high end and 2022 on the low end. Thus, there is spatial consistency in the temporal differences identified in the pooled data (Figure 2). There does not appear to be any discernable north-south trend in the data for the non-riding measurement campaigns (2015, 2019, 2022). Visually, however, it does appear that there is a progressive increase in emissivity toward the north (decrease to the south) in the 2016 data, which may be related to intensity of OHV use.

The question arises as to whether the emissivity values measured in the PE are unusual in some manner with respect to those measured in other areas of the ODSVRA. In other words, can the PE measurements reveal anything about the temporal-spatial biases in the overall data set (as identified in prior documents)? Figure 4 (top panel) shows the Mid RPM data for the PE (identical to the middle panel in Figure 2) relative to the PI-SWERL measurements made in the same years for the Non-Riding Area (NRA) Central represented in the lower panel (refer to https://storage.googleapis.com/slocleanair-org/images/cms/upload/files/SAG%20Memo_Emissivity%20Grids%20for%20Future%20Modeling%20of%20Excess%20Emissions%20-%2020231219.pdf for details regarding the NRA Central). There are a few differences that need to be highlighted at the outset. First, the 2019 and 2022 measurements in the NRA Central were conducted at different times of the year than for the PE, so they are not strictly comparable given slightly different moisture regimes (discussed below). Second, the 2016 measurements in the PE were conducted immediately after a five-month period of OHV disturbance, whereas the NRA Central region precludes OHV access at all times. Third, the measurements in the PE prior to 2020 were characterized by 'seasonal exclosure' (i.e., periodic disruption by OHV traffic) whereas the NRA Central measurements had no such disruptions.

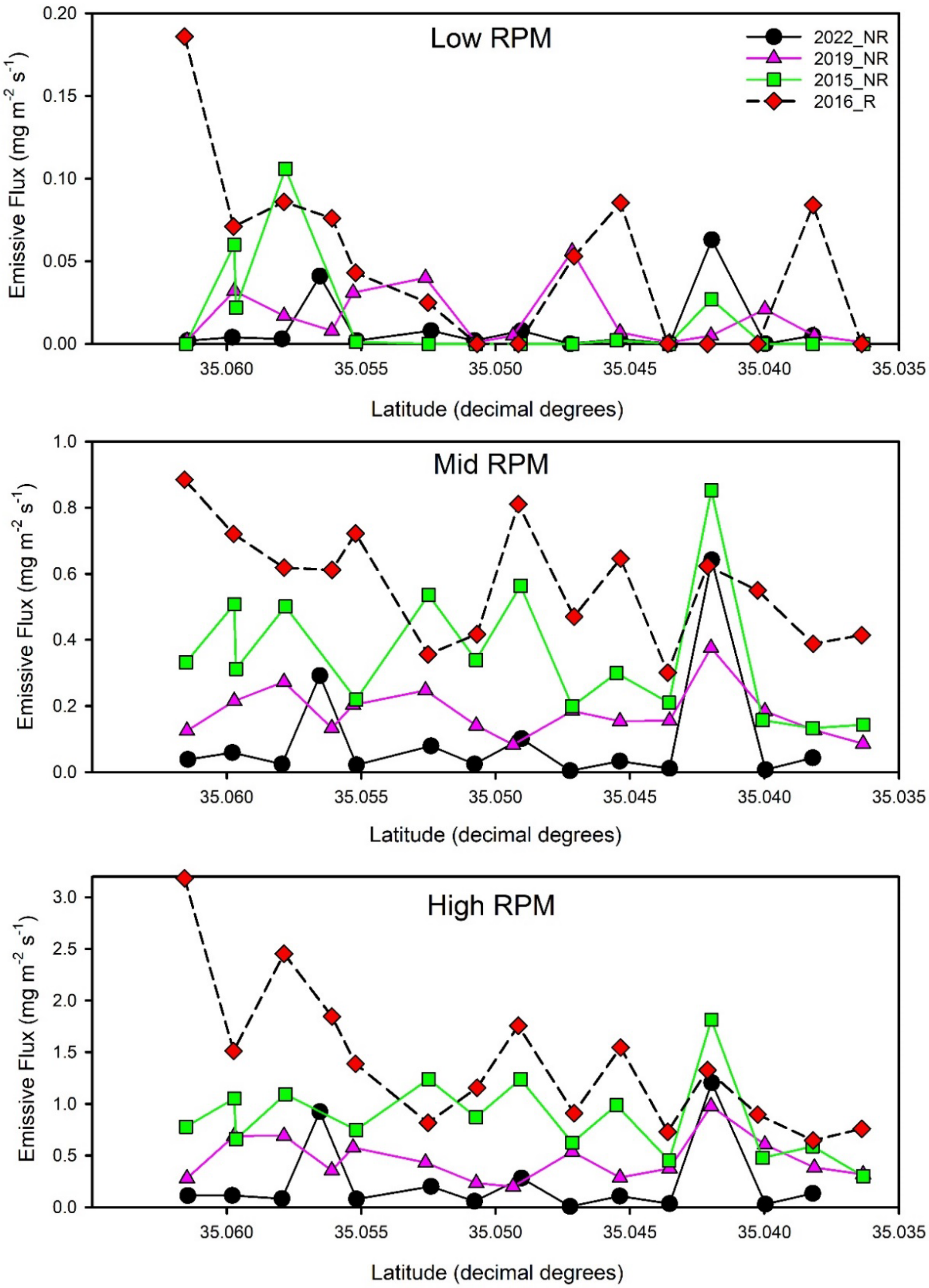


**Figure 3: Emissivity trends in the North-South direction along the sampling transect shown in Figure 1. Only common sampling locations were extracted and plotted. North is on left and South is on right of each panel. NR refers to measurements taken at the end of the non-riding period; R refers to measurements taken at the end of the riding period.**

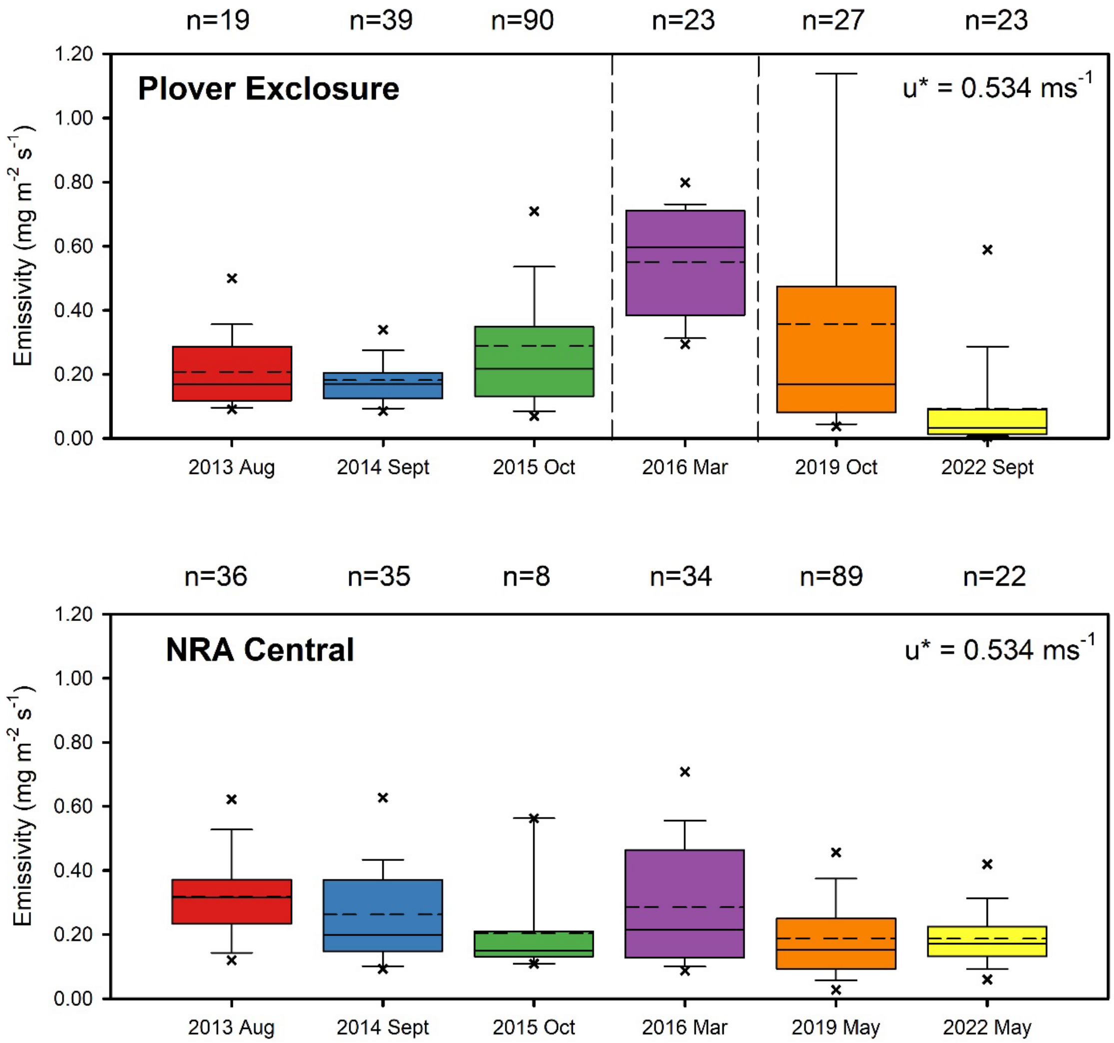


**Figure 4: Box-and-whisker plots of the Mid RPM PI-SWERL measurements for each of the six field campaigns in the Plover Exclosure (upper panel) and in the Non-Riding Area Central (lower panel). The colored boxes define the range of the 25$^{th}$ and 75$^{th}$ percentiles; the whiskers correspond to the 10$^{th}$ and 90$^{th}$ percentiles; and the outer symbols (x) indicate the 5$^{th}$ and 95$^{th}$ percentiles. The median value is given by the horizontal solid line within the box, whereas the arithmetic mean (average value) is shown by the horizontal dashed line.**

The box-and-whisker plots in Figure 4 provide visual clues as to similarities and differences between the PE and NRA Central, but a series of statistical tests was also conducted to assess such differences quantitatively. Table 1 shows the results of the pair-wise Mann-Whitney Rank Sum tests comparing the data distributions in a single year from the PE and NRA Central. The campaigns in 2014 and 2015 were not statistically different whereas there was a difference between the PE and NRA Central measurements in 2013. All three of these years were during the management era of seasonal exclosure within the PE, which might lead one to conclude that the PE should have had, on average, greater emissivity potential than within the NRA Central where there was no OHV disruption. This was the case for 2015 but not the other years. It is also noteworthy that the 2015 campaign only had eight (8) measurements in the NRA Central, and these were closely spaced, whereas the PE had ninety (90) measurements. Small sample sizes lead to greater statistical uncertainty and questionable representativeness.

**Table 1: Results from Mann-Whitney Rank Sum tests on the PE and NRA Central data for individual PI-SWERL measurement campaign years. Mid RPM data were used for this analysis.**

| | Plover Exclosure | | NRA Central | | Statistically Different? | |
|---|---|---|---|---|---|---|
| **YEAR** | **Median** | **N** | **Median** | **N** | | **P value** |
| | (mg $m^{-2}$ $s^{-1}$) | # | (mg $m^{-2}$ $s^{-1}$) | # | | |
| | | | | | | |
| **2013** | 0.162 | 19 | 0.316 | 36 | Yes | <0.001 |
| **2014** | 0.175 | 39 | 0.198 | 35 | No | .079 |
| **2015** | 0.218 | 90 | 0.151 | 8 | No | .259 |
| **2016** | 0.612 | 23 | 0.214 | 34 | Yes | <0.001 |
| **2019** | 0.155 | 27 | 0.152 | 89 | No | .493 |
| **2022** | 0.032 | 23 | 0.171 | 17 | Yes | <0.001 |

The March 2016 data show that the PE had much greater emissivity values than the NRA Central—almost three times as emissive—and that the difference is statistically significant ($P < 0.001$). A likely explanation is that these measurements in early March were conducted directly after a five-month period of OHV disturbance within the PE, leading to greater emissivity potential, whereas the NRA Central was not similarly disrupted. Indeed, the median emissivity values in the NRA Central are quite consistent from year-to-year (with the exception of 2013, which is characterized by greater emissivity values throughout all zones of the ODSVRA).

The results for the 2019 campaigns are not statistically different, although the data range between maximum and minimum values for the PE is very large in comparison to that of the NRA Central (and all other years). This is a bit surprising given that there were 89 measurements in the NRA Central (small data range) and only 27 measurements in the PE (very large data range). Note that the PE measurements were conducted October 8-10, 2019, at the end of the OHV exclosure period, but one week into the open riding period. There may have been some OHV disturbance in some of the sampling locations (and not in others), and indeed, most of the large emissivity values were sampled in the northern sections of the PE where OHV access is more likely. The surface conditions were also very dry with no rain measured since May 26, 2019 (i.e., approximately 4.5 months prior). In contrast, the measurements in the NRA Central were conducted throughout the month of May, 2019, with multiple-day disruptions because of rainfall (April 29, May 6, May 15/16, May 18/19, May 21, May 26). Thus, the sand surface would have been uniformly moistened, potentially explaining the constrained data range and relatively small emissivity values.

As noted earlier, the emissivity values for the PE in September, 2022, were inordinately small, with a median value (0.032 mg $m^{-2}$ $s^{-1}$) that is about 20% of those in other years (e.g., 2013, 2014, 2015, and 2019). Surface moisture may have been a controlling factor, as noted above. The measurements in the NRA Central were conducted in May, 2022, also during a relatively wet period (also discussed above), and yet the surface emissivity values were five times greater (median = 0.171 mg $m^{-2}$ $s^{-1}$) than in the PE. The difference is statistically significant at $P < 0.001$ (Table 1). At this time, there is no definitive explanation for why the September, 2022 emissivity values in the PE were much smaller than in the NRA Central and also relative to prior measurement campaigns in the PE.

Based on the foregoing analysis of the PI-SWERL measurements in the PE between 2013 and 2022, one can make the following general observations:

(1) Surface disturbance by OHV traffic (or bulldozer) leads to an overall increase in emissivity potential of the sand surface and a wider data distribution (larger range between maximum and minimum values), as noted by Gillies et al. (2022). This is most evident when comparing the 2016 data (measured after the seasonal riding period) to data from other measurement campaigns (measured at the conclusion of the closure period), with the latter having consistently smaller emissivity values.

(2) A measurable decrease in emissivity values after OHV exclusion from the PE appears to occur relatively quickly (i.e., after 8 months). This is a somewhat speculative conclusion based on the fact that the emissivity values in 2013, 2014, and 2015 were similar despite intervening riding periods that would have disrupted the sand surface annually in a manner that is believed to have yielded data distributions similar to 2016.

(3) Emissivity values in the PE at the end of the non-riding period are not dissimilar to values measured in the NRA Central (i.e., similar means, medians, and ranges) with the noteworthy exceptions of the 2016 campaign when the PE measurements were influenced by OHV riding and the 2022 campaign for which the PE values are significantly smaller than the NRA Central (see Figure 4 and Table 1).

(4) The 2022 emissivity values in the PE during September 2022 were smaller than those measured in prior campaigns and also smaller than those measured in the NRA Central (measured in May 2022). The reason for such small emissivity values is unknown at this time, although moisture conditions may have played a role. The PE surface is currently in a stage of long-term adjustment toward a more undisturbed condition in the absence of OHV riding, but it is not known whether this involves a progressive asymptotic decrease to a stable low-emissivity state or whether the surface will revert to a higher-emissivity state that is similar to the NRA Central. Future PI-SWERL campaigns planned for 2024 (and beyond) will be critical in revealing whether the 2022 emissivity values were ‘outliers’ or, alternatively, the new norm for that management zone. In this regard, it is critical to appreciate that what was the ‘natural’ state in the pre-disturbance (1939) landscape (prior to significant human impacts) need not be the same as the ‘natural’ state that will evolve in the future (post human impacts) presuming OHV access continues to be restricted and no further management interventions are undertaken.

Gillies, J.A., Furtak,-Cole, E., Nikolich, G., Etyemezian, V., 2022, The role of off-highway activity in augmenting dust emissions at the Oceano Dunes State Vehicular Recreation Area, Oceano, CA. **Atmospheric Environment**, X 13. https://doi.org/10.1016/j.aeaoa.2021.100146