A Difference-in-Differences Approach for Assessing the Effectiveness of Dust Mitigations at the Oceano Dunes

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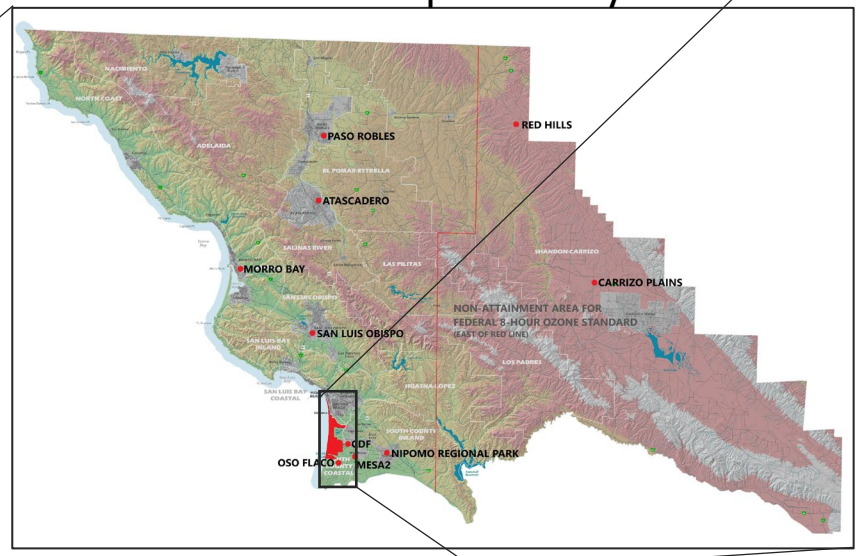
Pittsburgh, PA

Karl Tupper, Senior Air Quality Scientist

SLO COUNTY apcd | Air Pollution Control District
San Luis Obispo County

Oceano Dunes State Vehicular Recreation Area (ODSVRA)

San Luis Obispo County

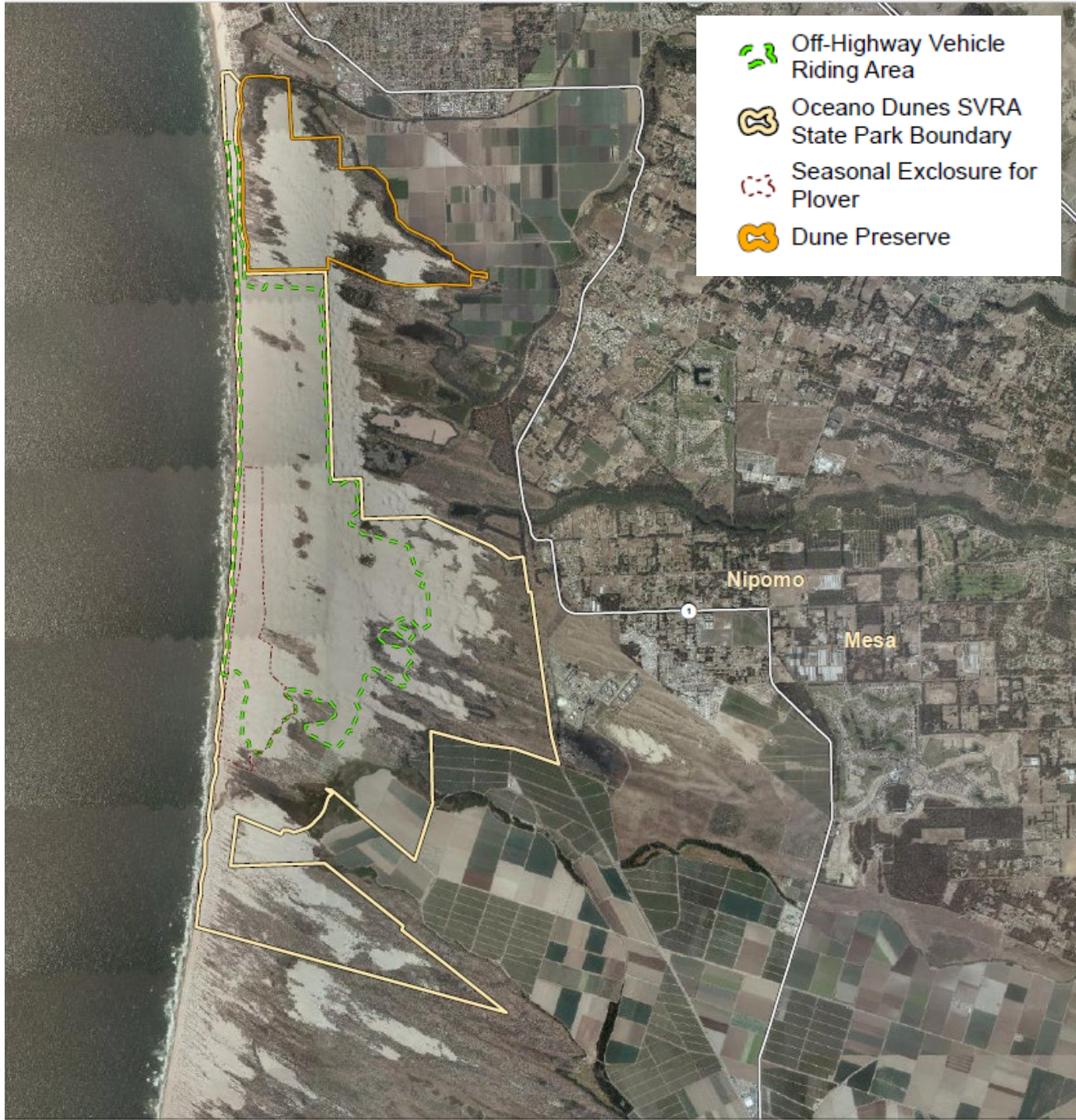


ODSVRA

6 mi

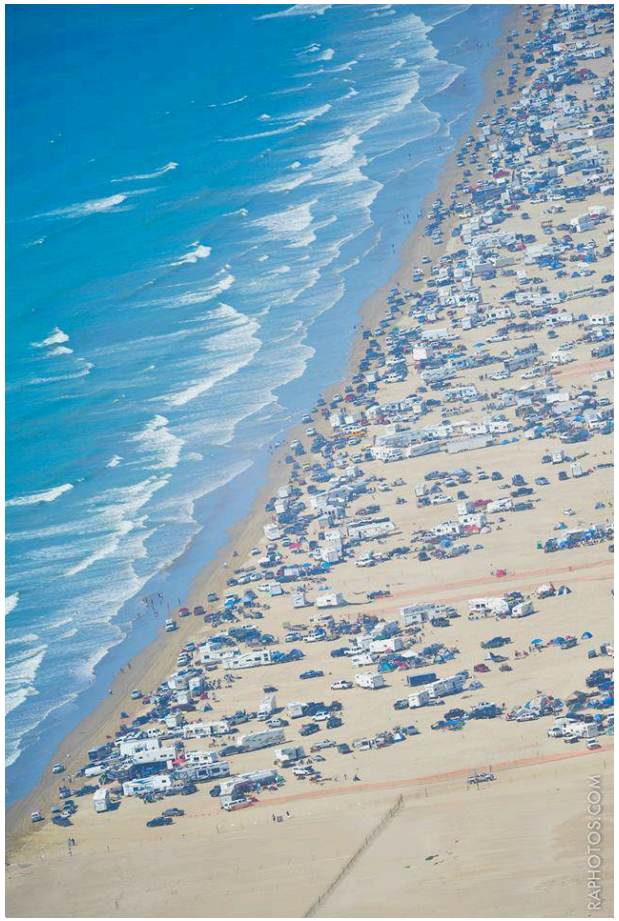
ODSVRA

- Calif. State Park, est. 1982
- 5.5 square miles / 3,600 acres
- Day use: $5; Camping $10/night
- 1.6 millions visitors/year
- Up to 2,580 **vehicles**/day
  - Street legal + ATVs, dune buggies, etc.
- Up to 1,000 “camping units” per night (pre-COVID)



Map adapted from State Parks

“Huckfest” 2013



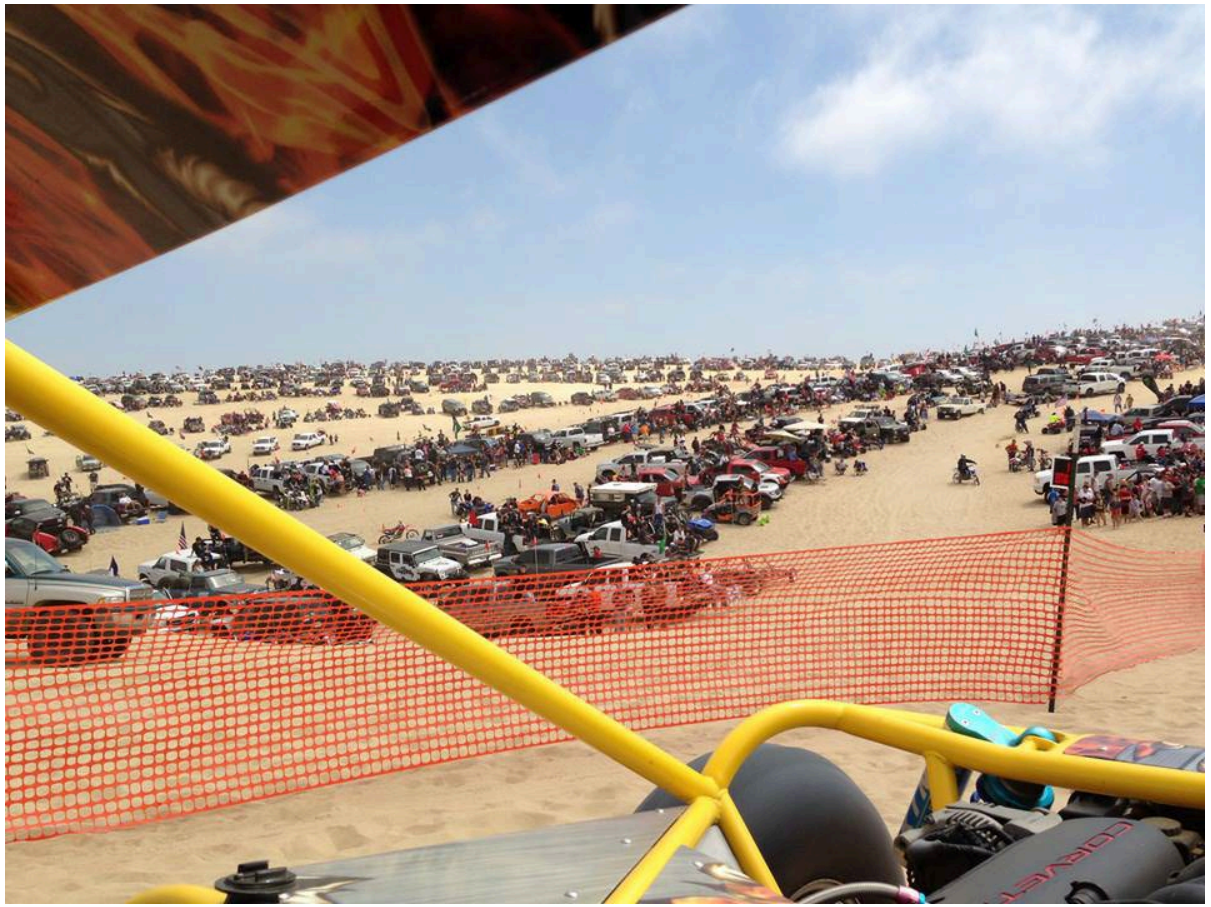


Photo credits: RAPHOTOS.com

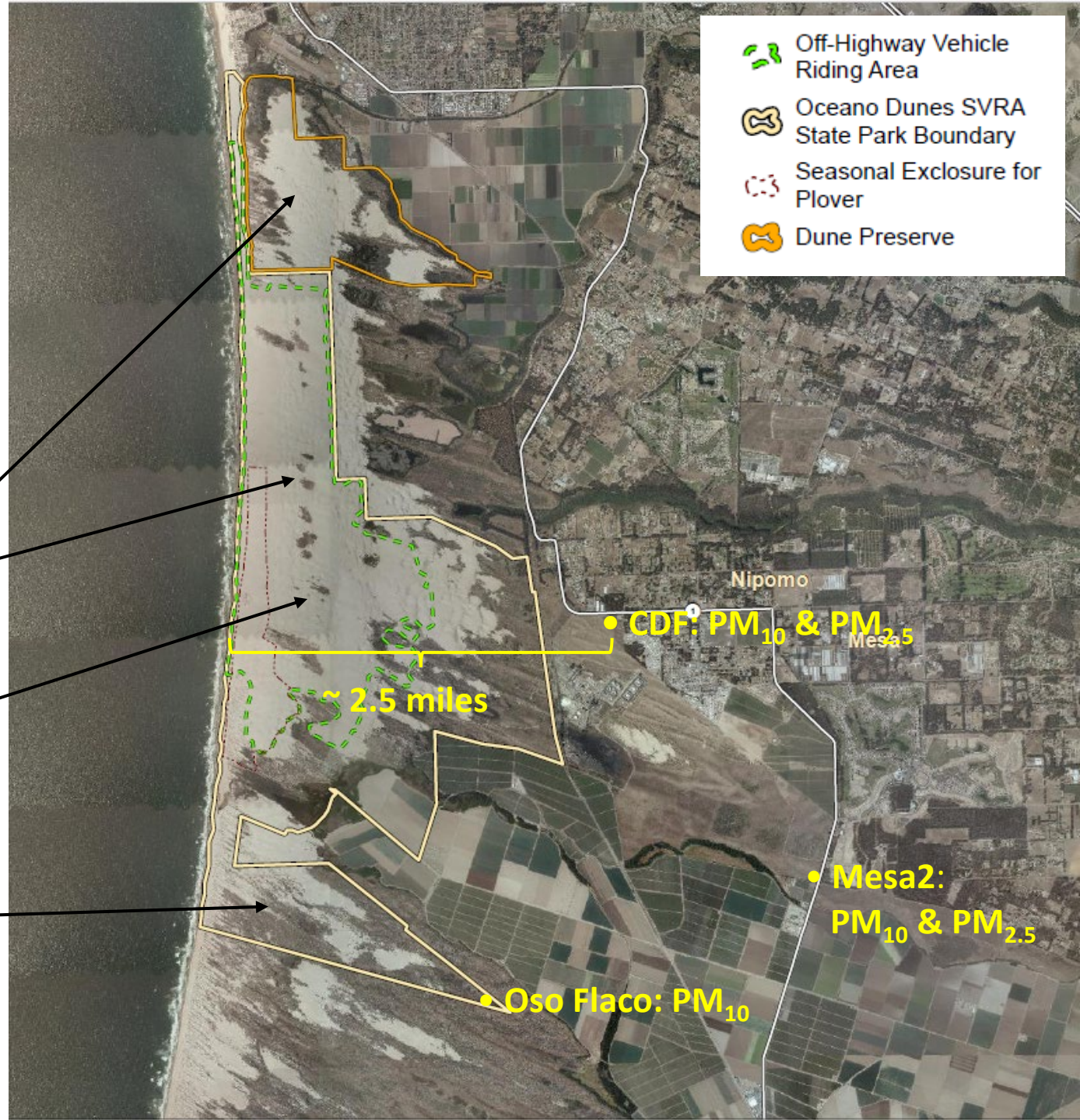
ODSVRA Tour

Dune Preserve – 700 acres, riding prohibited (orange)

ODSVRA – 3,600 acres total (yellow)

Riding Area – 1,500 acres (green dashes)

Oso Flaco area – riding prohibited



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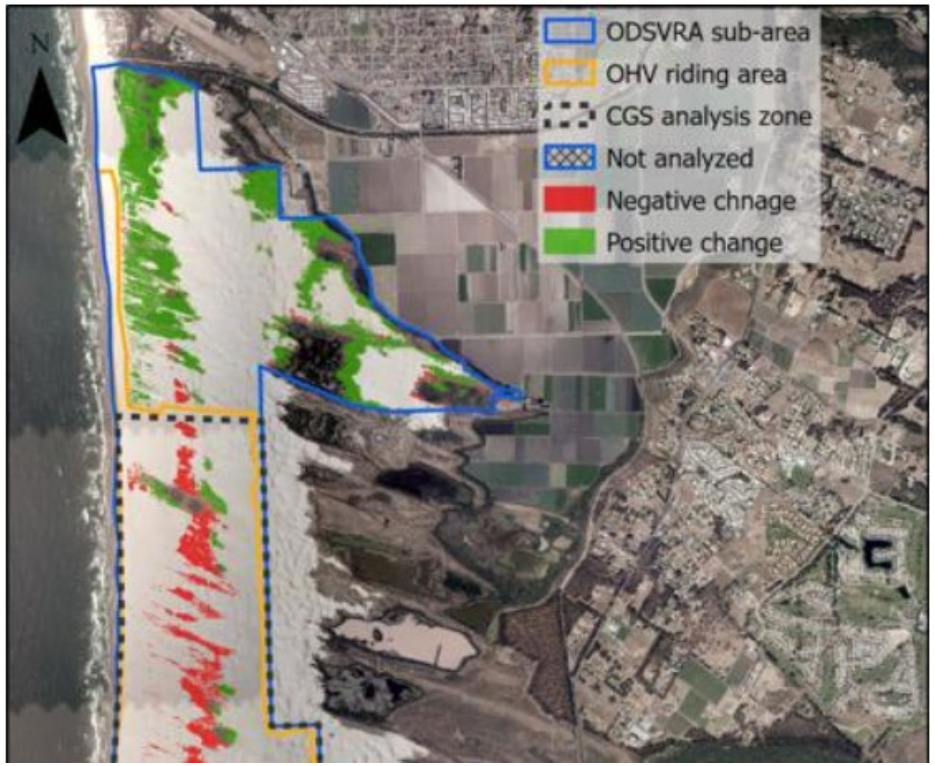
Map adapted from California State Parks

Effects of Off-Roading on the Dunes

Vegetation change 2010 vs 1939



Ian Walker et al. (2022). "UCSB Historical Vegetation Cover Change Analysis (1939-2020) within the Oceano Dunes SVRA"
https://slocounty.granicus.com/MetaViewer.php?meta_id=414120

Dune PM_{10} Emissions vs Wind Speed

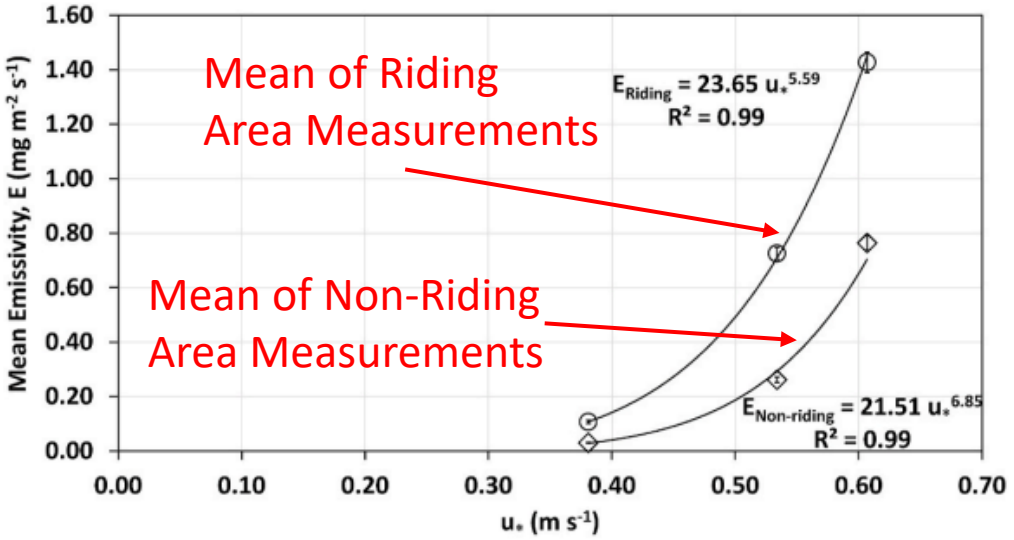


Fig. 9. The relation between mean E (mg m^{-2} s^{-1}) and u_* (m s^{-1}) for the amalgamated data from 2013 to 2019 for the riding (circles) and non-riding areas (diamonds). Error bars represent the standard error of the estimate (standard deviation/(#observations-1)$^{0.5}$).

Gillies, J. A., Furtak-Cole, E., Nikolich, G., Etyemezian, V. (2022). "The role of off-highway vehicle 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

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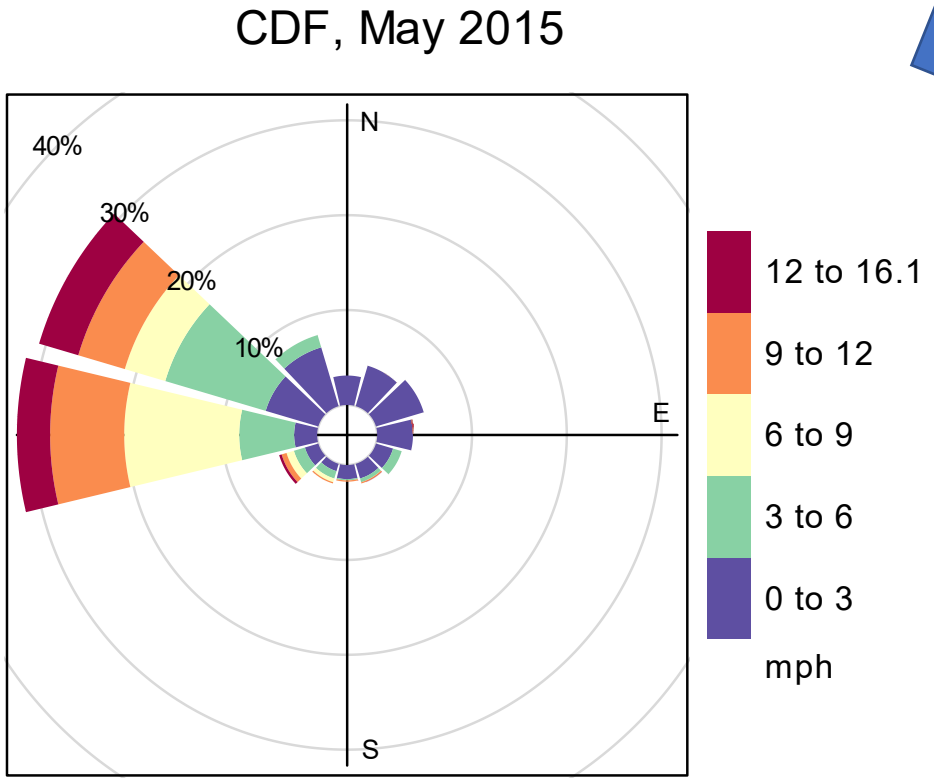
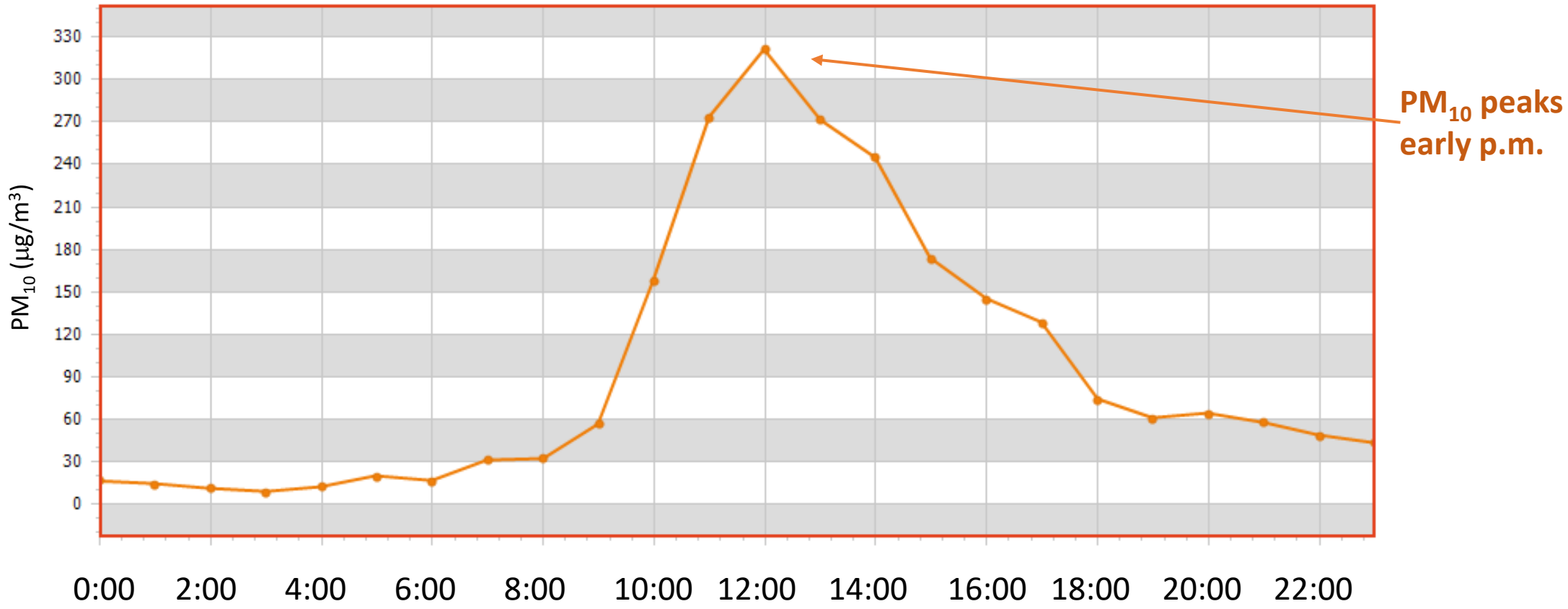
Meteorology



Map adapted from California State Parks

Typical Wind Event

CDF, May 29, 2022. 24-hr PM_{10}: 92 µg/m³



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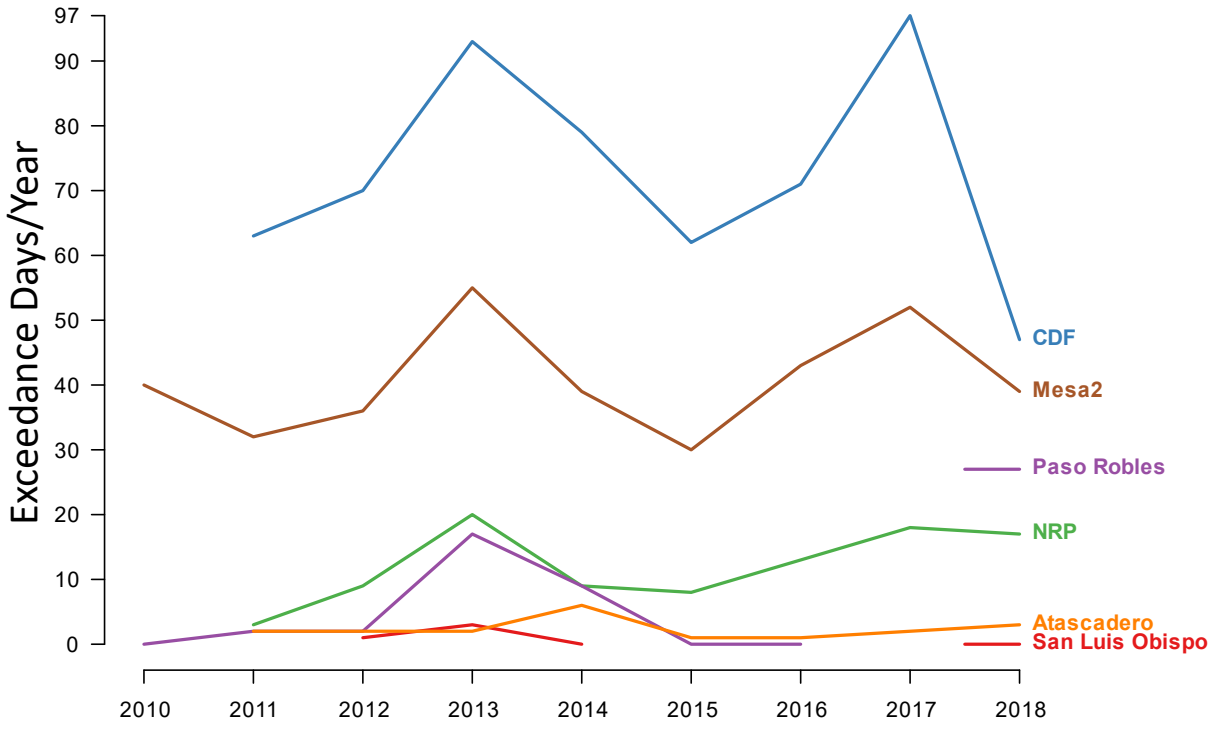
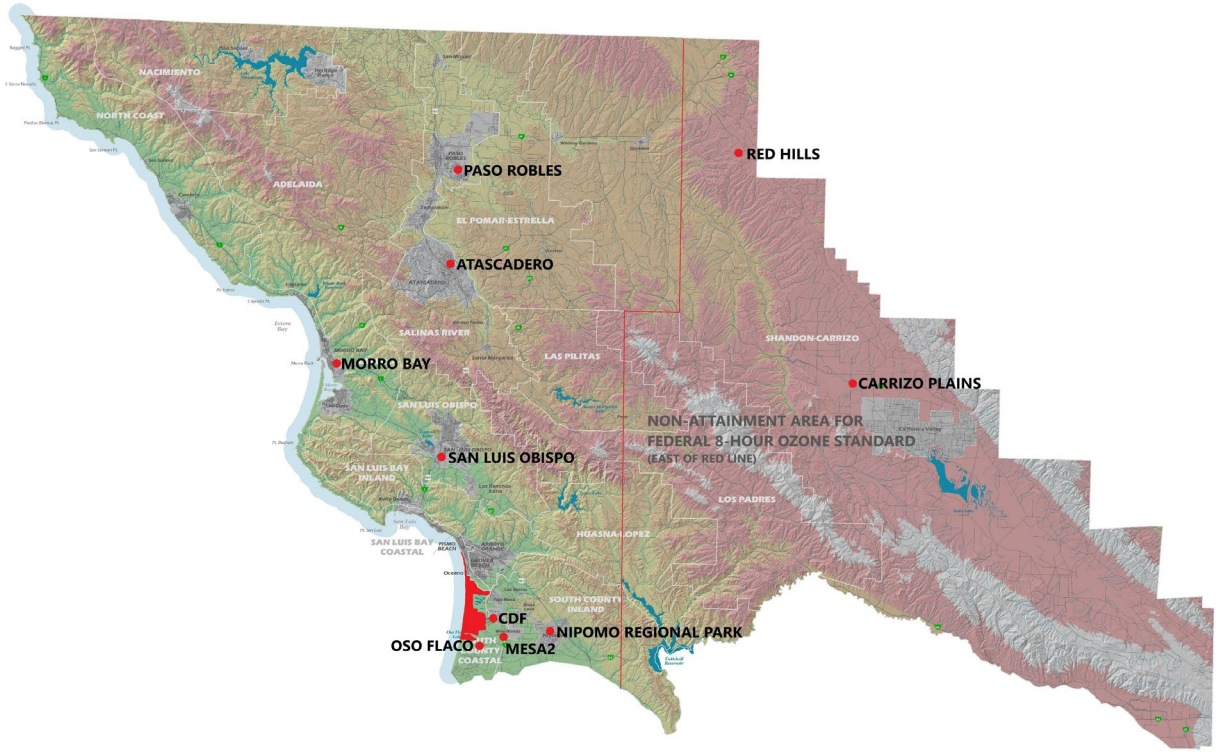
Plume from 4/28/2011

CDF 24-hr PM_{10}: 135 µg/m^3
CDF peak hour: 442 µg/m^3

Annual Exceedances of Calif. PM_{10} Standard

California PM_{10} Std: 50 μg/m^3 over 24 hours





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Brief History of APCD Involvement

- 2007 “Phase 1 Study”
- 2010 “Phase 2 Study”
- 2011 Local Rule 1001, *Coastal Dunes Dust Control Requirements*
- 2013 South County Community Monitoring Study
- 2017 Hearing Board Petitioned, Case 17-01
- 2018 Stipulated Order of Abatement in Case 17-01 (SOA)
- 2019 SOA Amended
- 12+ Lawsuits from off-road advocates

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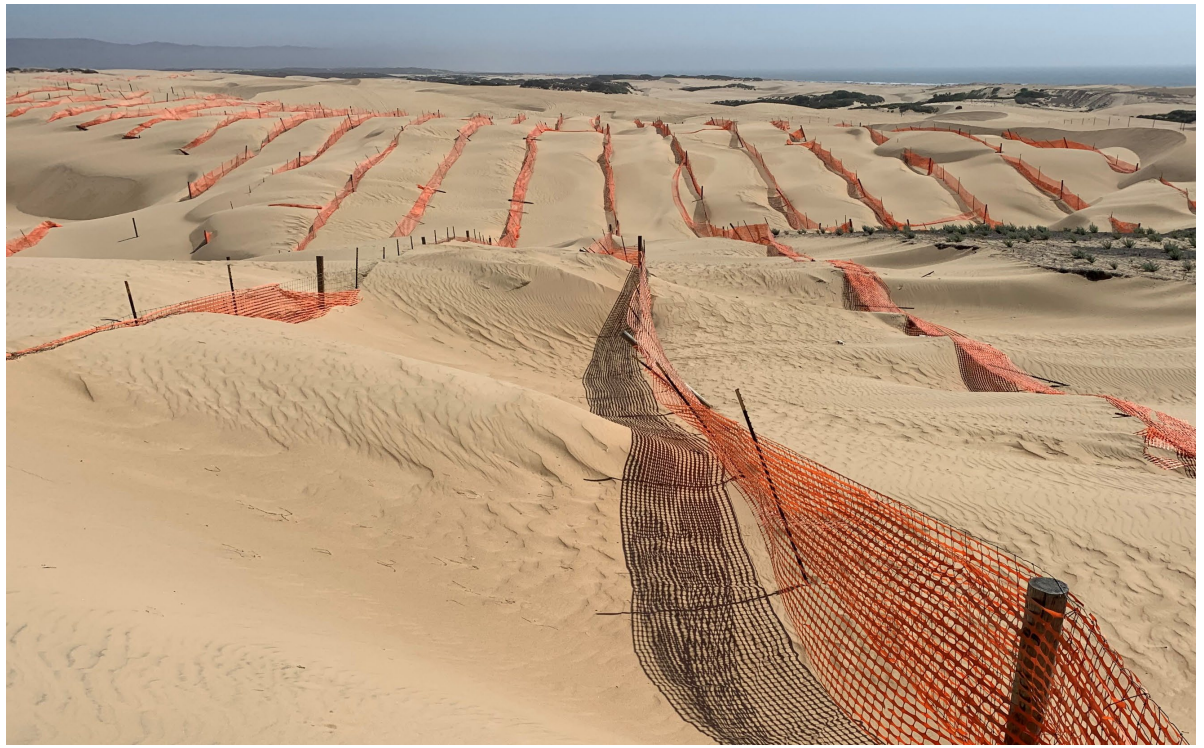
Dust Mitigations

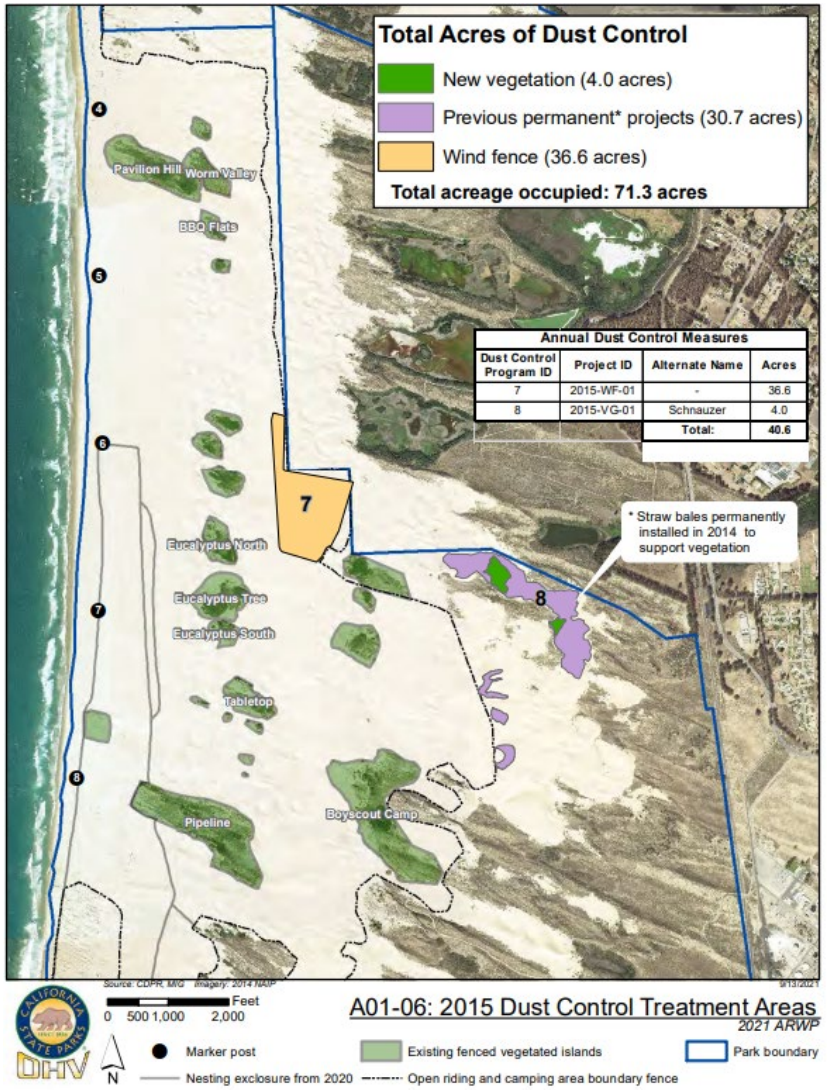
Revegetation

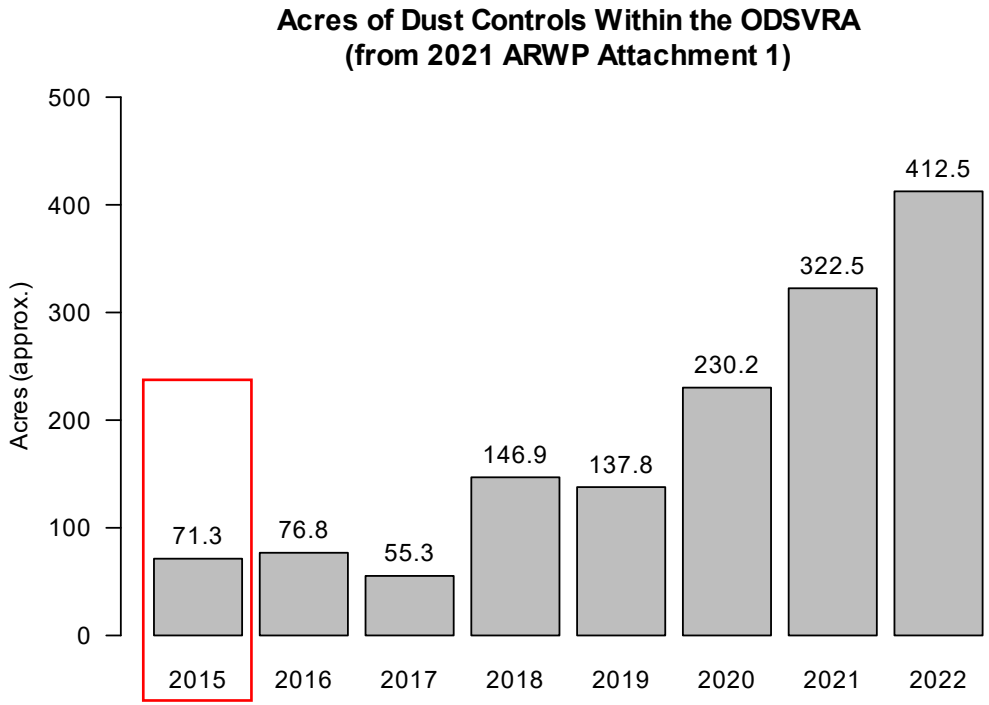
Wind Fence Arrays



Photos: Ian Walker UCSB/ASU

Evolution of Dust Controls





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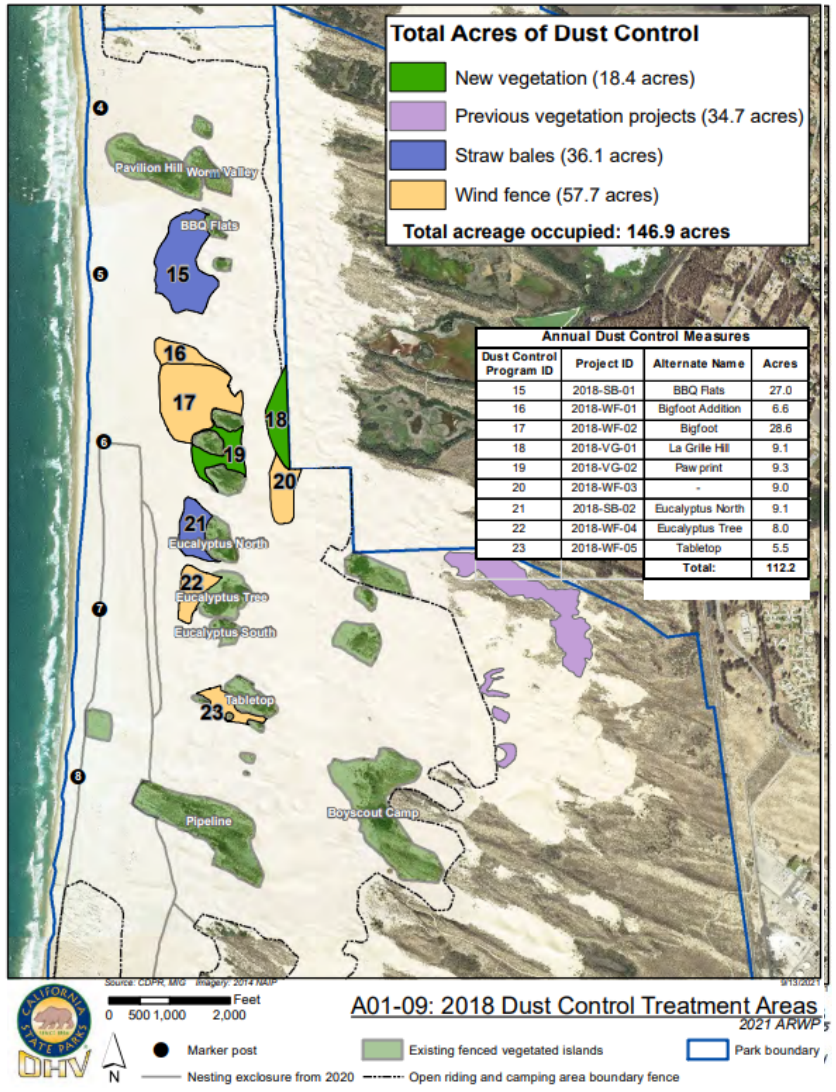

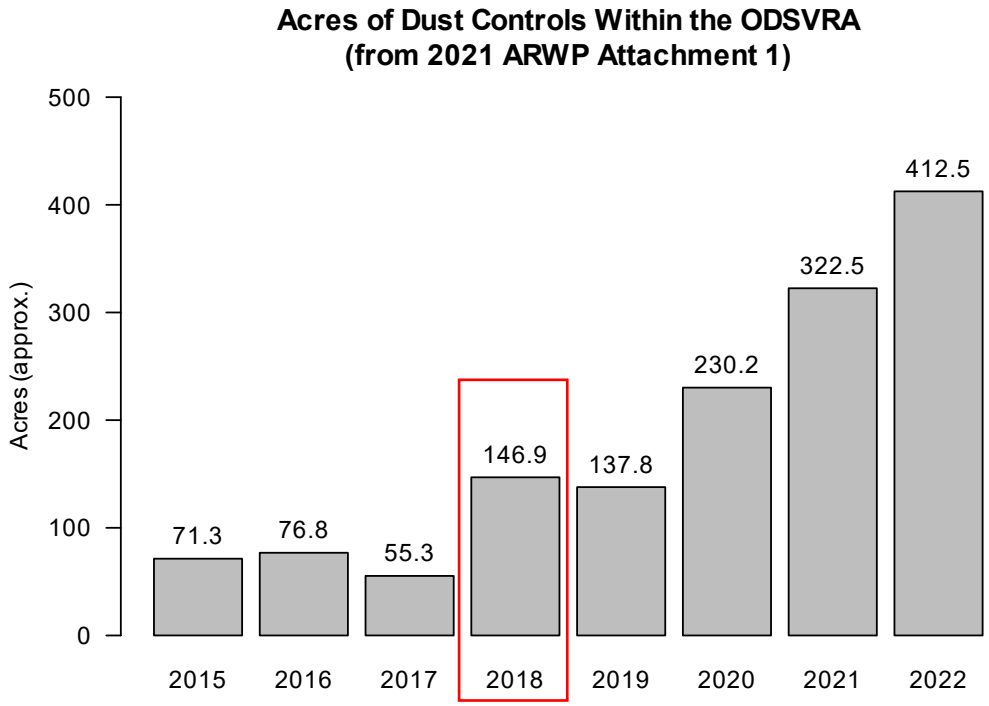

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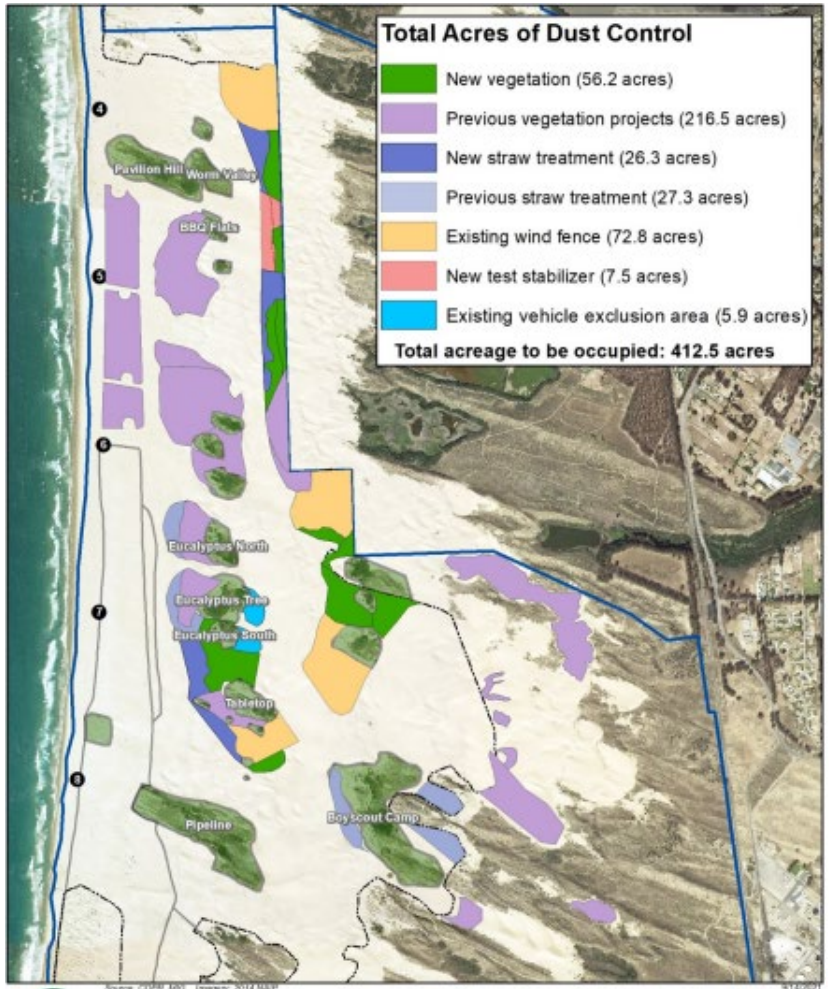
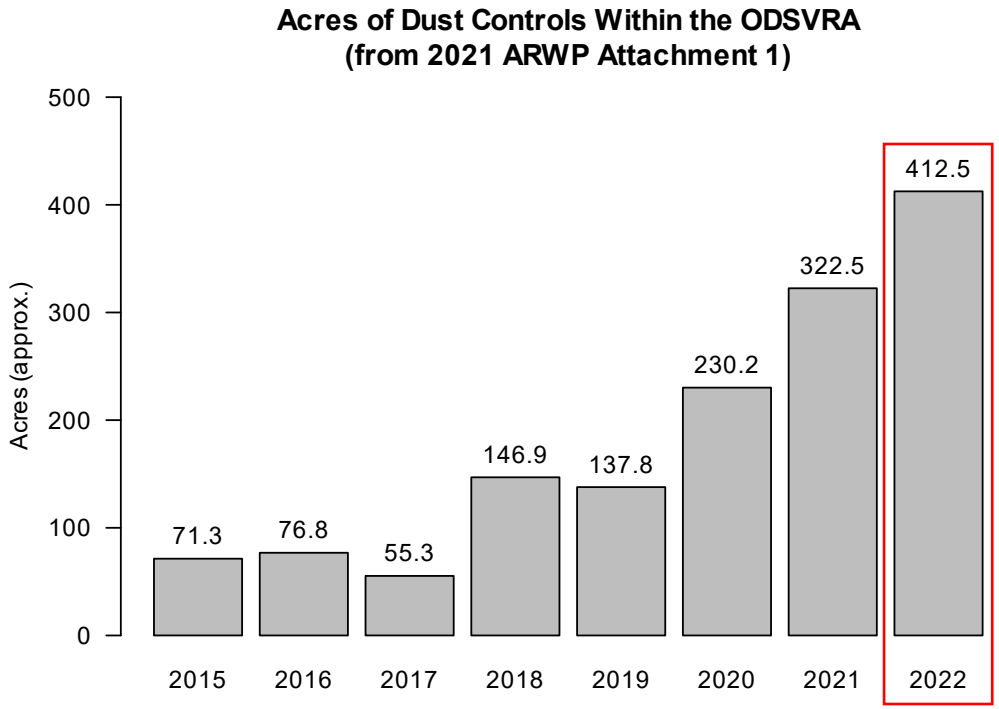
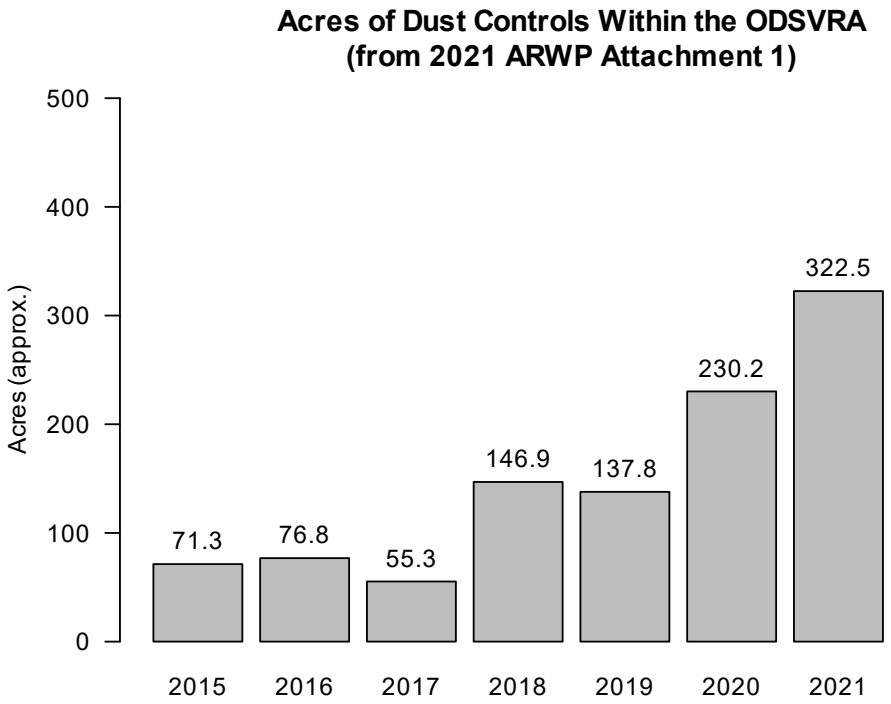
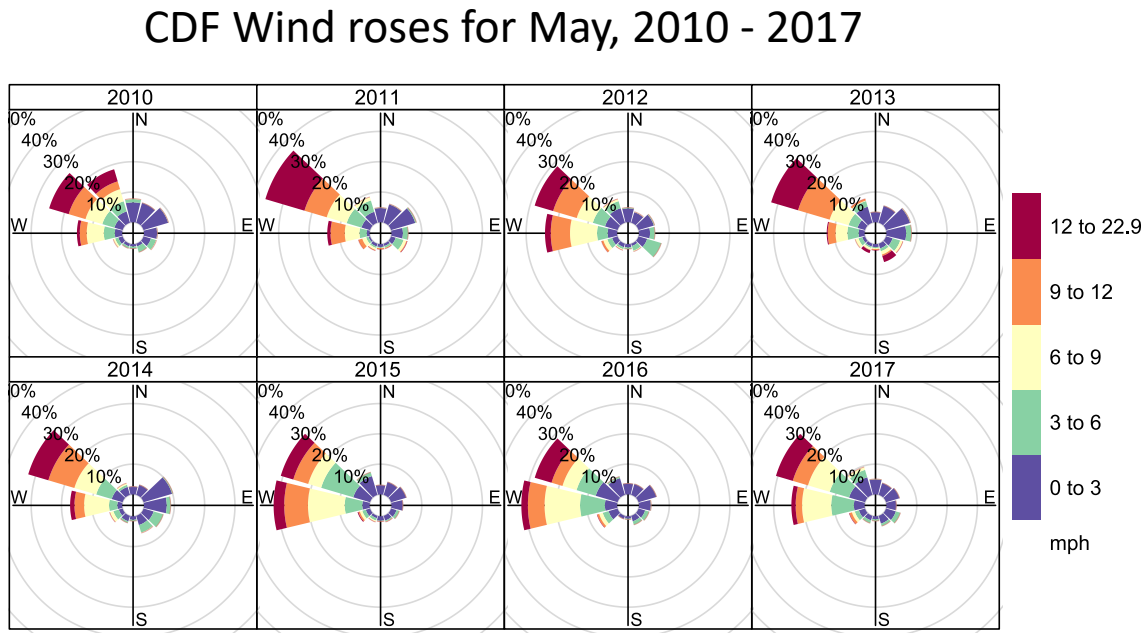


Figure 3-1: Proposed 2022 Dust Control Treatment Areas
2021 ARWP



How Have Dust Controls Affected PM_{10} Downwind?





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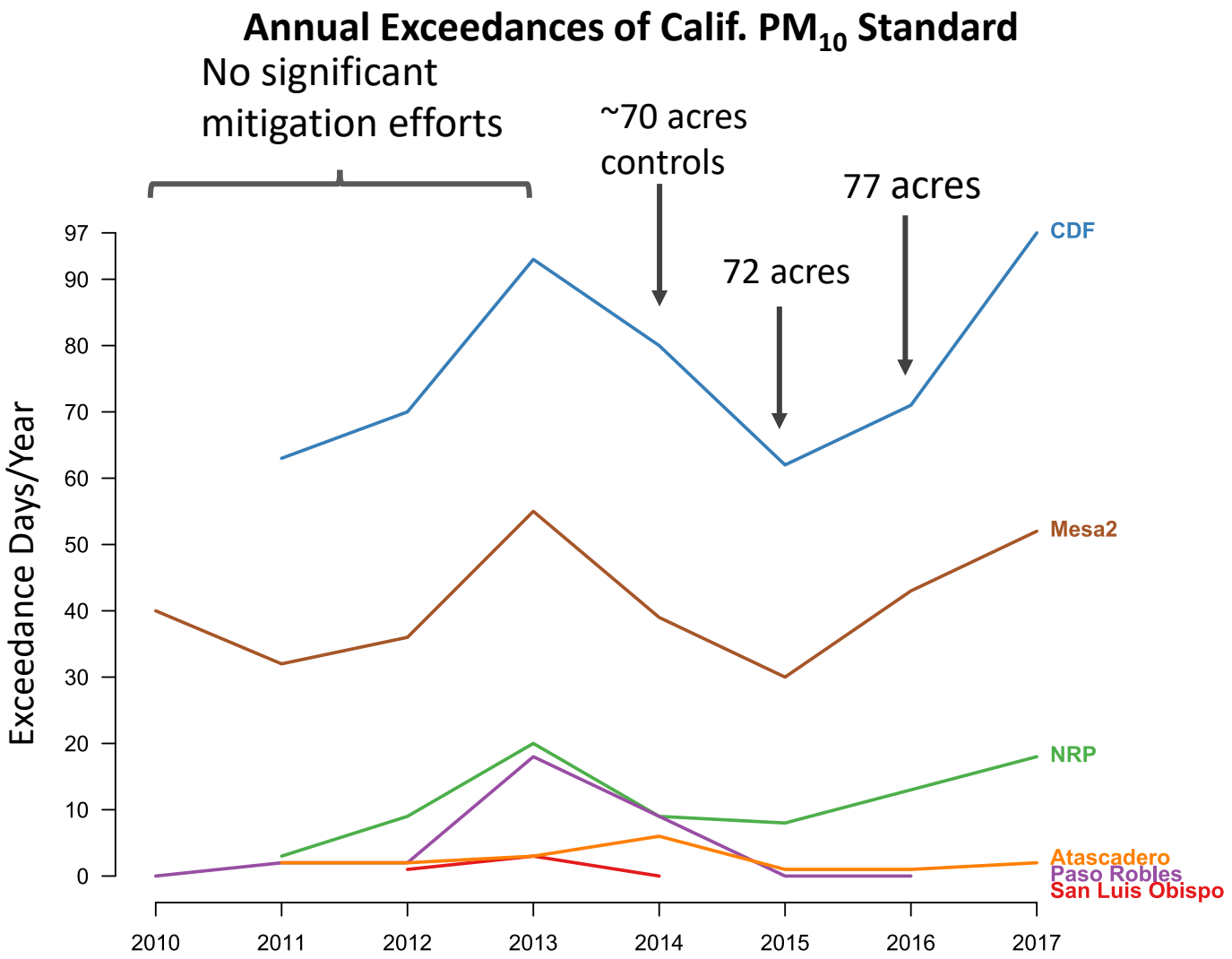
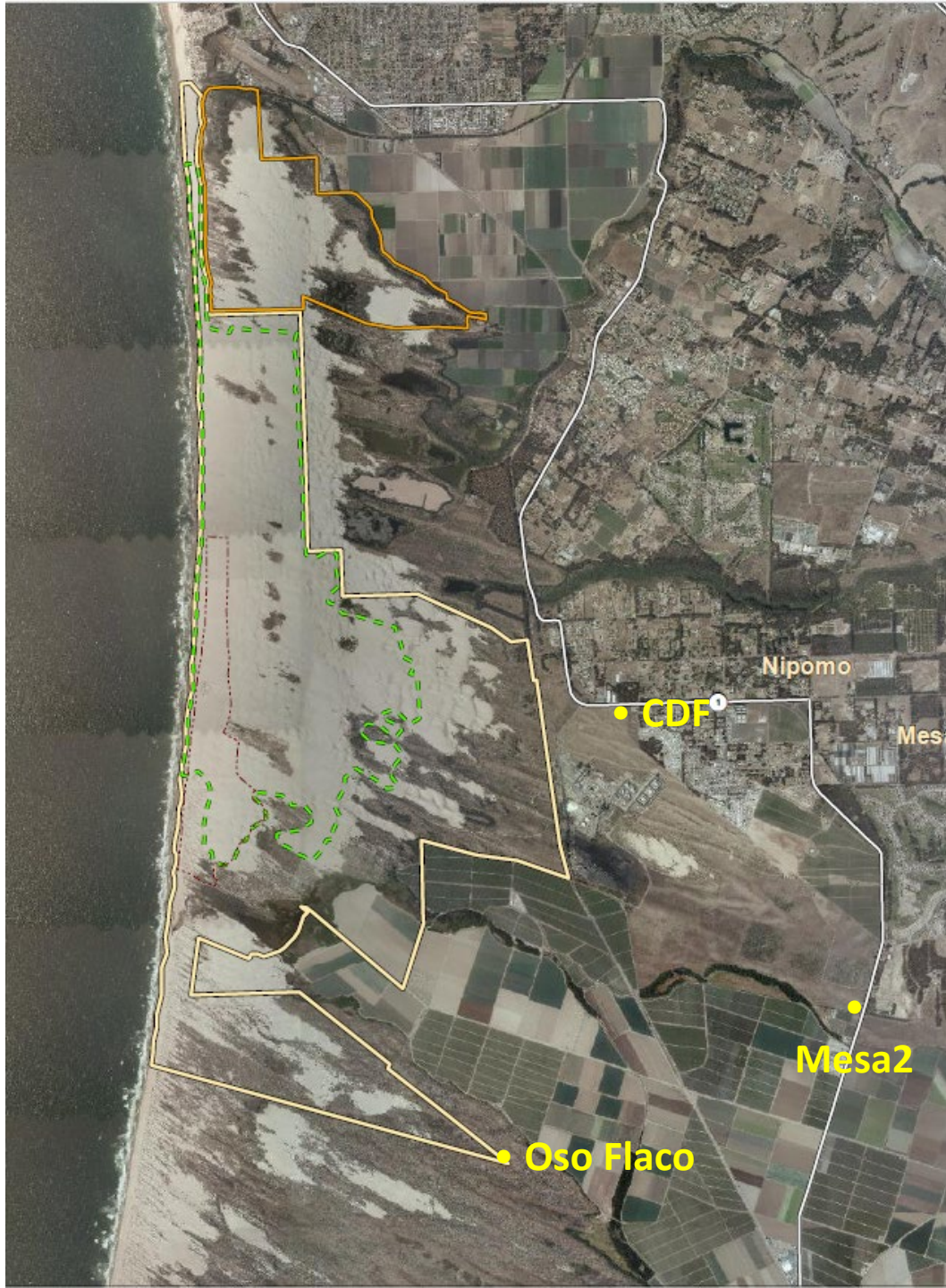


PM_{10} Downwind of the Oceano Dunes

- Usual sources
  - Background (aerosols, traffic, sea salt)
  - Wildfire smoke (Aug – Oct 2020, 2017)
  - Regional Dust (e.g., Oct 2019)
- Wind-blown dust (saltation derived)
  - Influenced by:
    - ODSVRA Dust Control Projects
    - Winds



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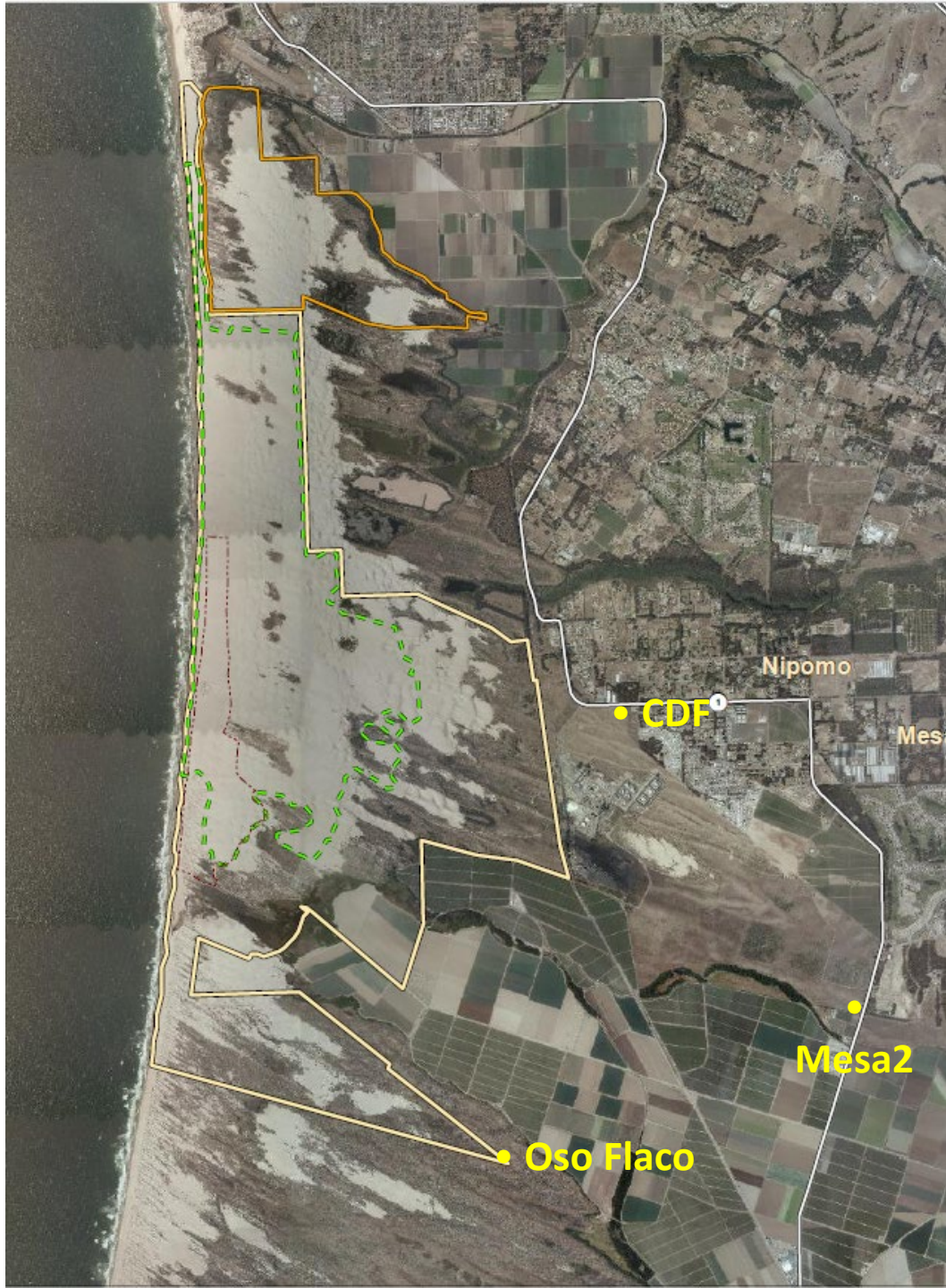
How Can We Disentangle Effects Of Mitigation And Meteorology?

- Difference-in-differences approach (DiD)
  - Inspired “parallel-ness” of CDF and Mesa2 trends
  - Idea from observational economics – 2021 Nobel Prize Economics (David Card)
  - Uses analogous experimental unit to implicitly control for other variables

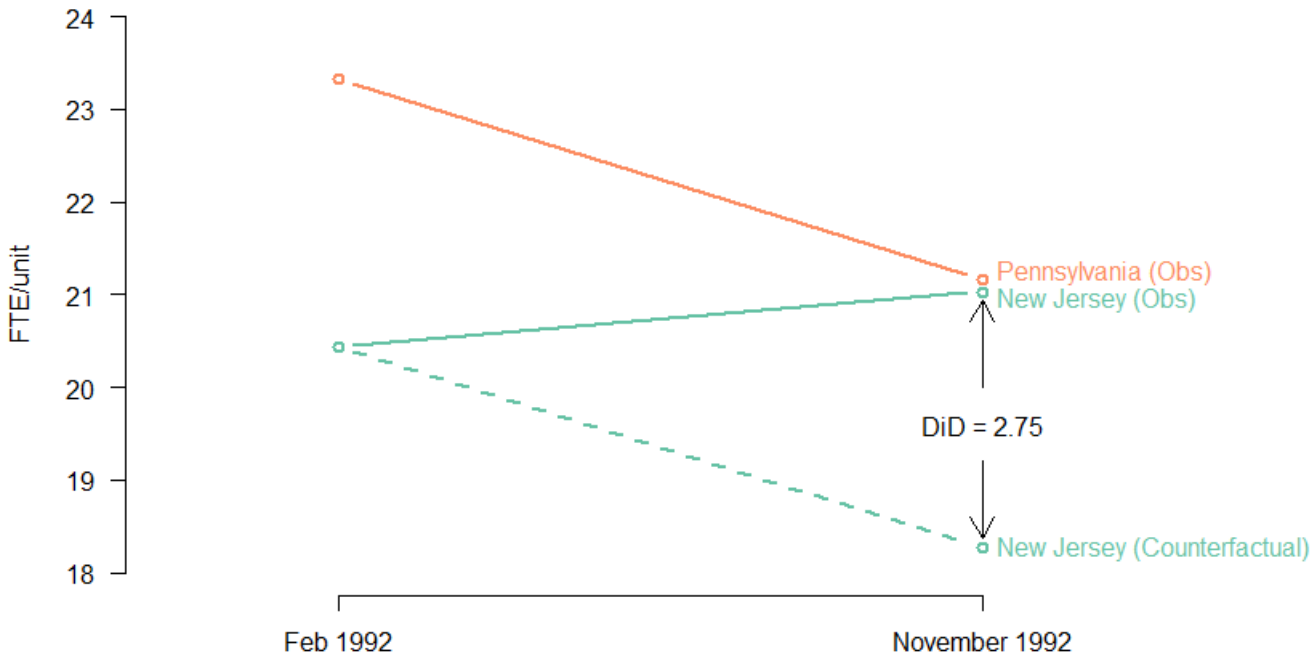


DiD Example: Card & Krueger (1994) (From Wikipedia)

Effect of minimum wage increase on fast food employment

- April 1992 – NJ minimum wage increased from $4.25 to $5.05
- NJ FTE/restaurant
  - Feb (before change): 20.44
  - Nov (after change): 21.03
  - Δ_{NJ} = 21.03-20.44 = +0.59
  - **Was change due to wage increase or weather, seasonality, macroeconomic variables?**
- PA FTE/restaurant
  - Feb (before change): 23.33;
  - Nov (after change): 21.17
  - Δ_{PA} = 21.17-23.33 = -2.16
  - **No wage increase in PA, but other factors should affect PA about the same as NJ**
- Assume change in NJ would have been same as PA were it not for intervention (i.e. wage increase)
  - **DiD estimate = Δ_{NJ} - Δ_{PA} = 2.75**

Δ FTE/restaurant



Applied to ODSVRA

Assumptions:

- Inter-annual variations in meteorology have same effect on PM_{10} trends at CDF and Oso Flaco
- Trends in non-ODSVRA sources impact CDF and Oso Flaco similarly
- Changes in mitigations affects CDF but not Oso Flaco.

Applied to ODSVRA

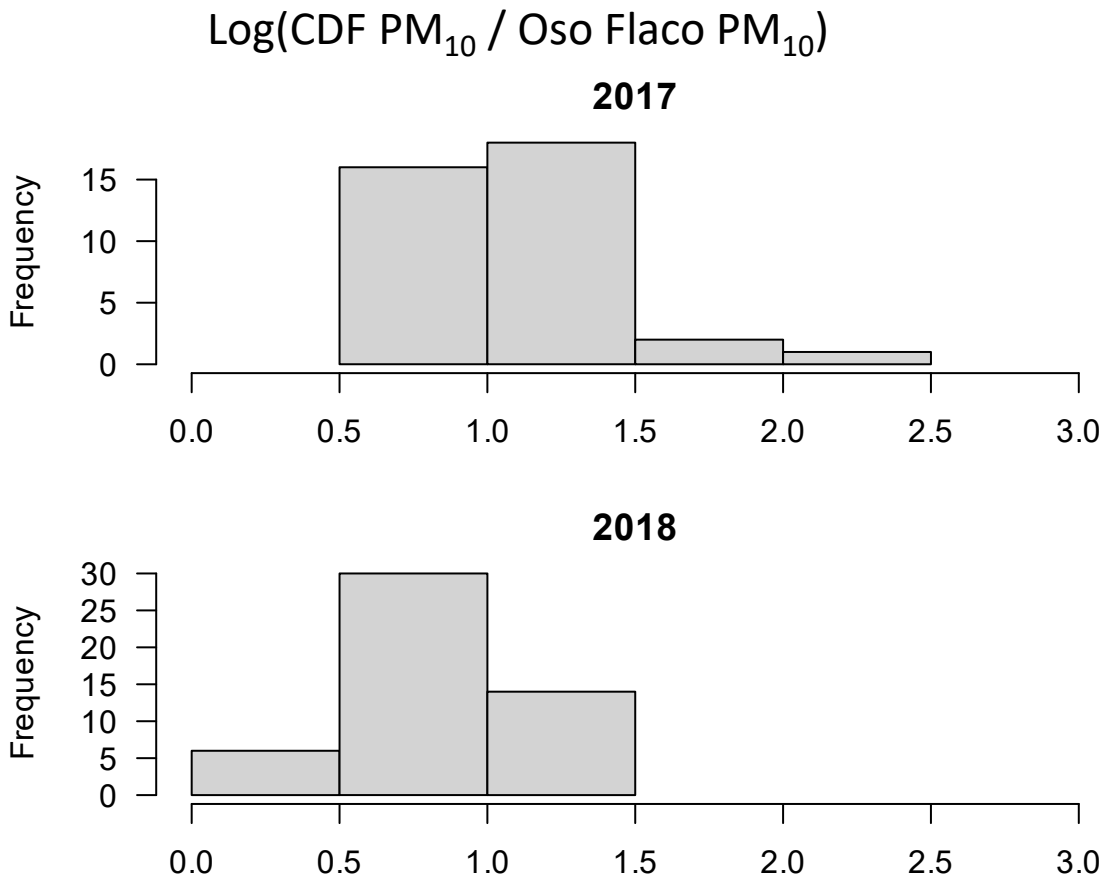
- Look at 24-hr PM_{10} from only “wind event days”, to filter out “noise”.
  - Wind Speed within ODSVRA at 3 pm > 21 mph
  - Wind Direction at CDF at 1 pm from 289 - 360 deg
  - Remove any days impacted by wildfire smoke or dust transported from San Joaquin Valley (n = 1)
- Log transform PM_{10} data to Gaussian distribution
- Use 2017 as “baseline year” for all comparisons

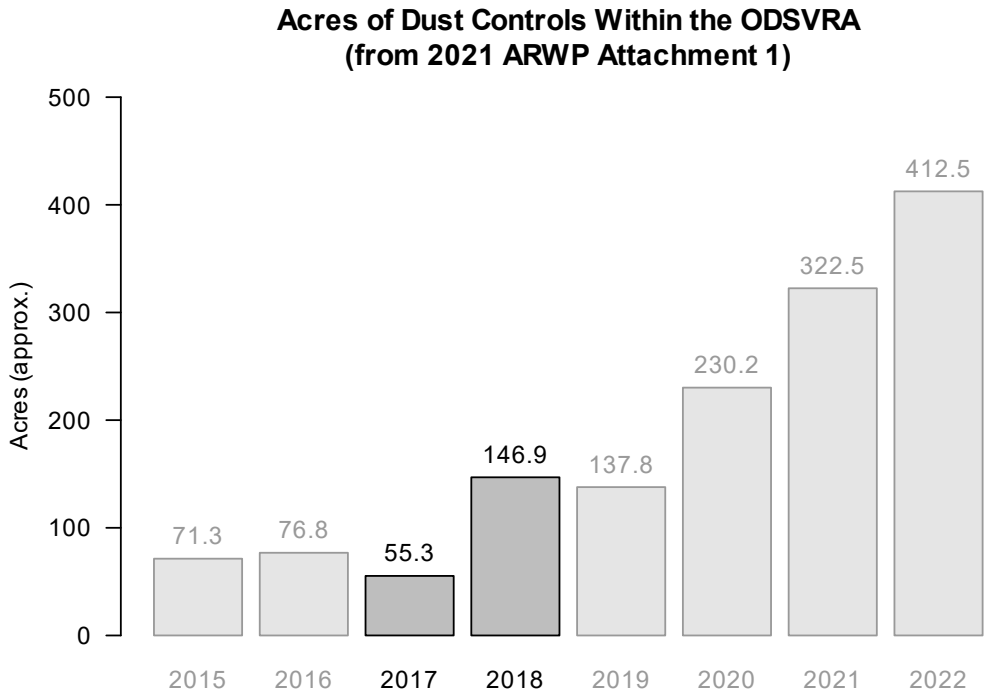
Applied to ODSVRA

- Essentially…
  - Calculate log(CDF PM_{10}) – log(Oso Flaco PM_{10}) for every wind event day
    - Equivalent to log(CDF PM_{10} / Oso Flaco PM_{10})
    - *First difference*
  - Perform *t*-test comparing logged PM_{10} ratios of year of interest to baseline year (2017)
    - *Second difference—the difference in differences*
- In practice…
  - Analyze data using R software package
  - Use generalized least squares (nlme::gls) to explicitly account for:
    - temporal autocorrelation
    - non-constant variance from year to year
  - Get p-values and confidence intervals

```
Generalized least squares fit by REML
  Model: log(cdf/oso) ~ contrasts
  Data: dd.events
  Subset: year == 2021 | year == 2017
       AIC      BIC    logLik
  89.15323 99.19666 -40.57661

Correlation Structure: Continuous AR(1)
 Formula: ~index
 Parameter estimate(s):
      Phi
0.6166614

Coefficients:
                    Value  Std.Error   t-value p-value
(Intercept)     1.0401173 0.09367776 11.103140   0e+00
contrastsx2021 -0.4078346 0.11853322 -3.440678   9e-04

 Correlation:
               (Intr)
contrastsx2021 -0.79

Standardized residuals:
       Min         Q1        Med         Q3        Max
-2.9014580 -0.6431351  0.1581515  0.6042657  2.3440624

Residual standard error: 0.4107929
Degrees of freedom: 93 total; 91 residual
```

Quantifying Mitigation Effectiveness at CDF





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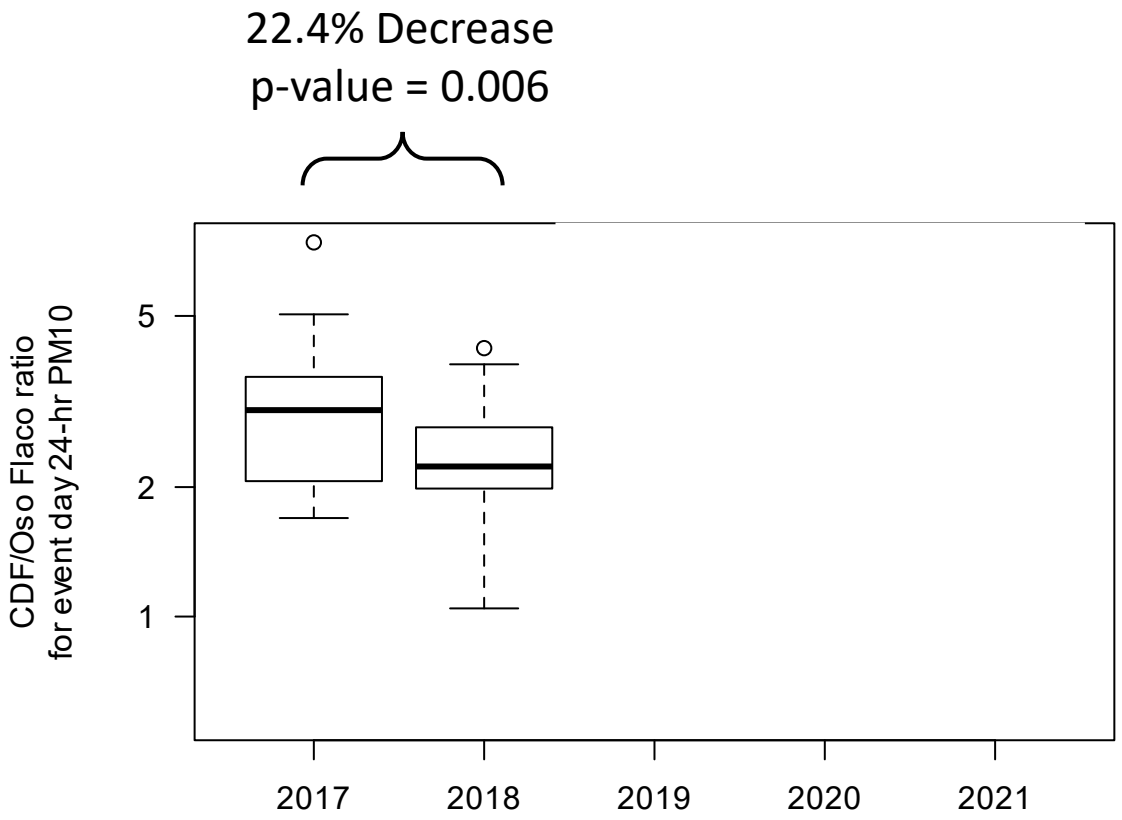

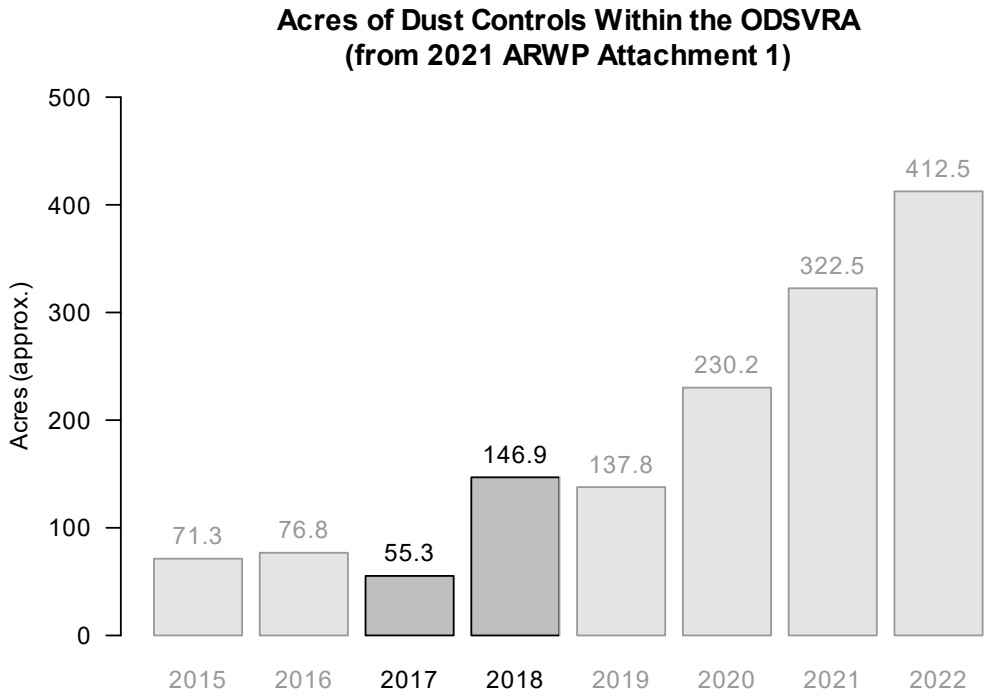

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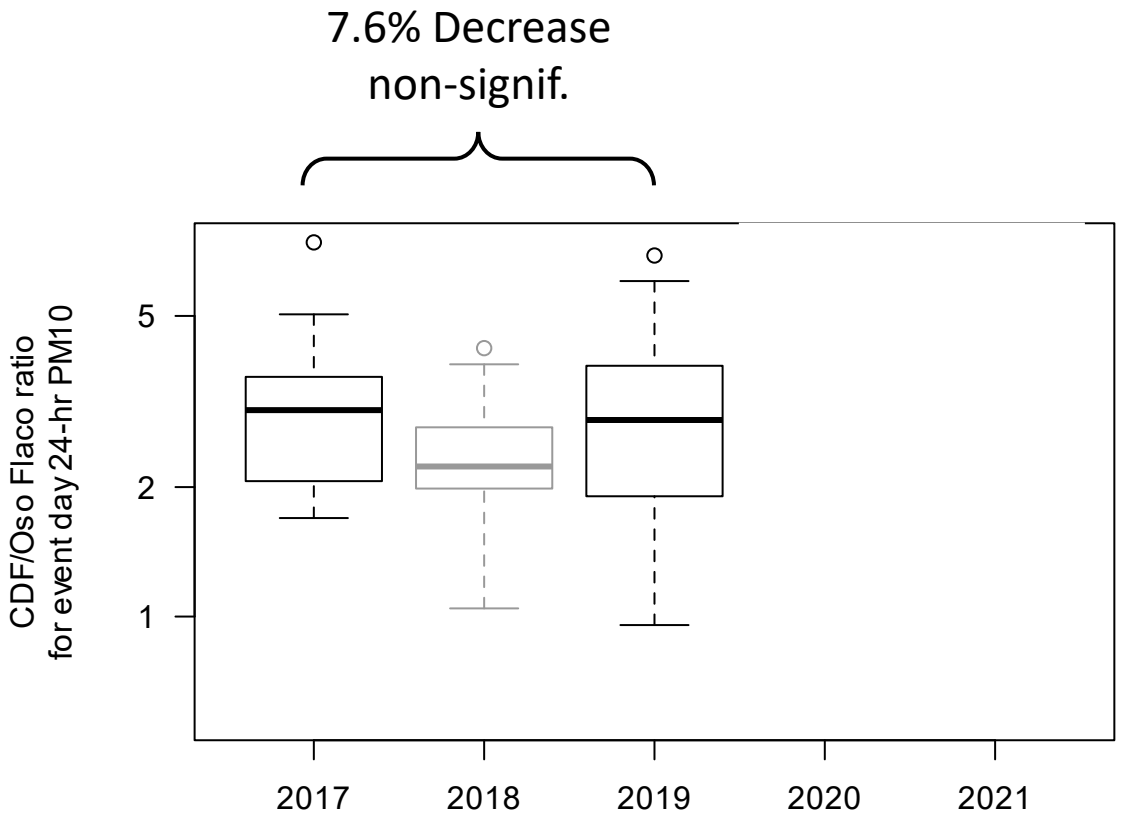

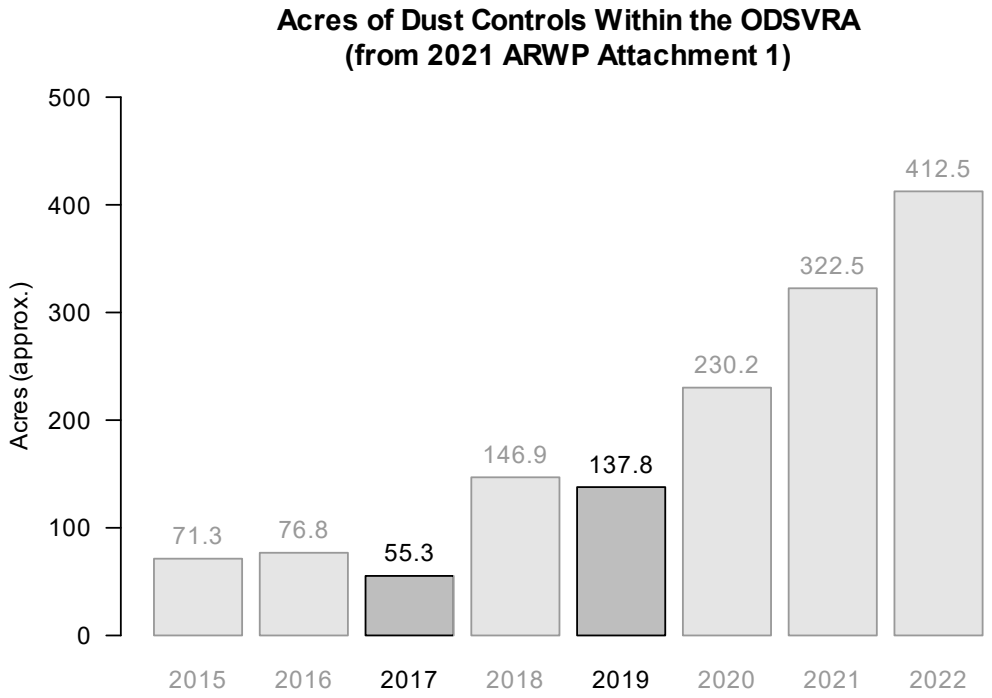

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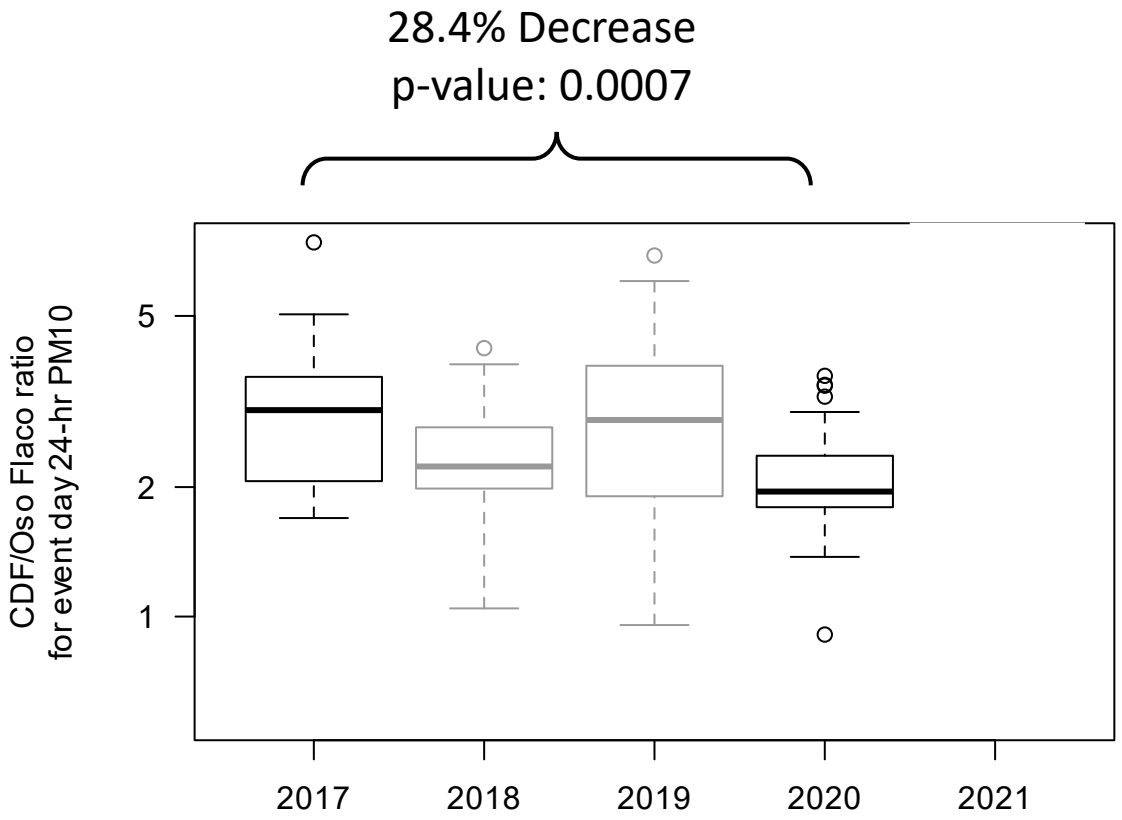

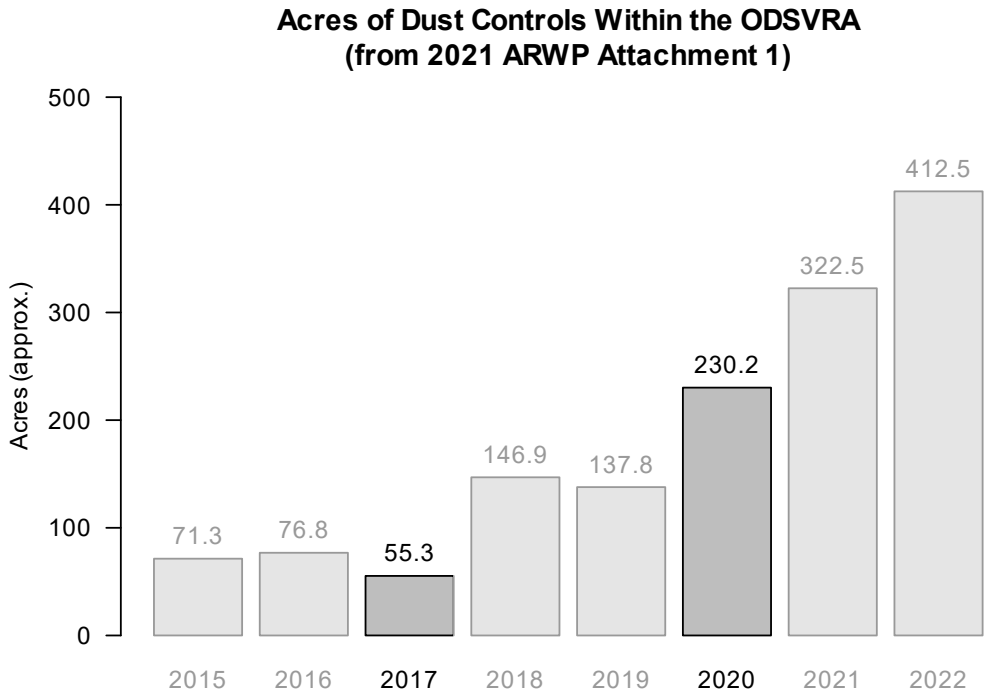

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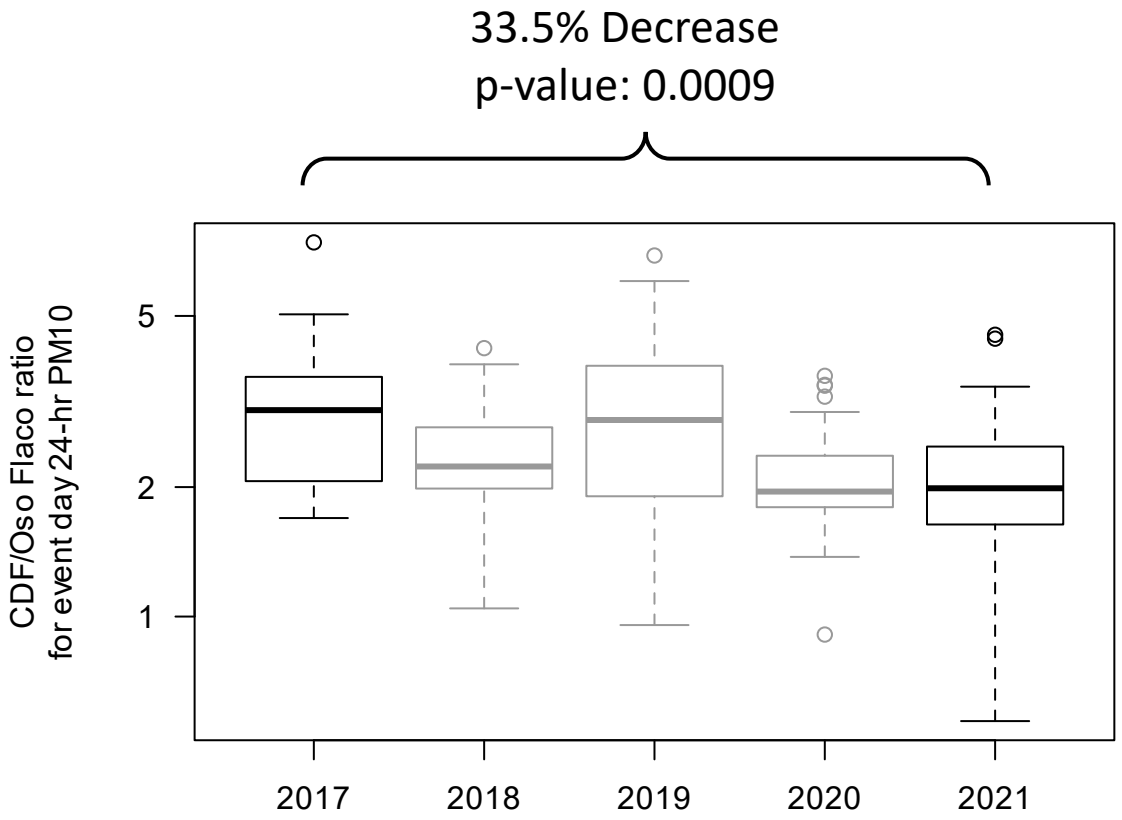

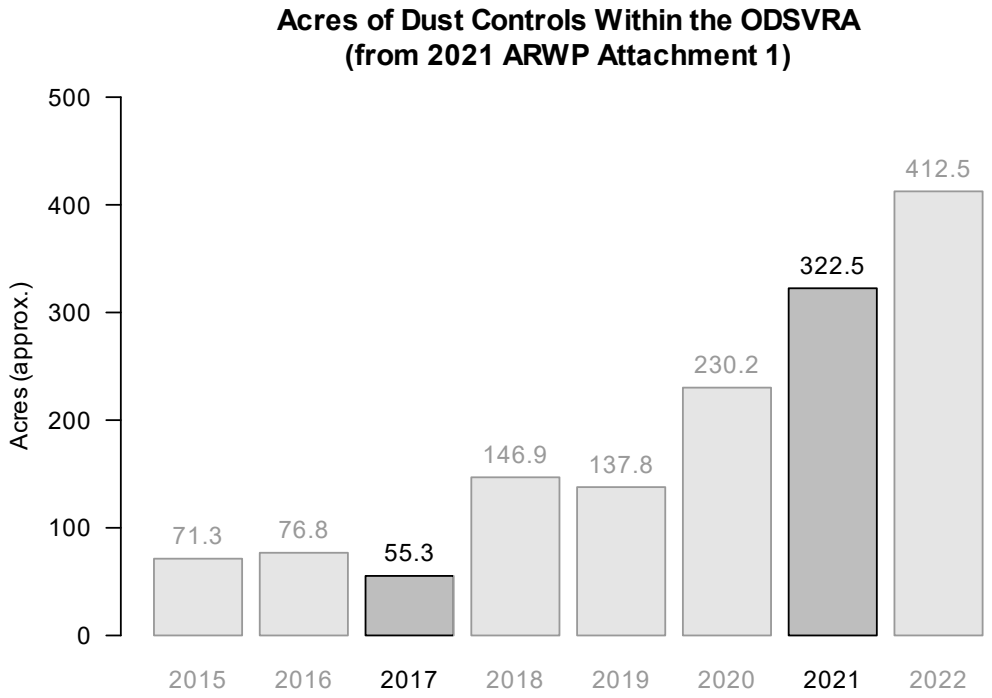

Change, vs 2017 baseline, in Ratio of Wind-Event-Day PM_{10} (CDF vs Oso Flaco)

Year	Total Dust Mitigation Extent (approx. acres)	Percent Change	95% Confidence Interval	P-value
2021	322.5	- 33.5%	-16.1% to -47.3%	0.0009
2020	230.2	- 28.4%	-13.9% to -40.4%	0.0007
2019	137.8	- 7.6%	+23.2% to -30.7%	0.593
2018	146.9	- 22.4%	-7.4% to -34.9%	0.006
2017	55.3	- 0 %	n. a.	n. a.

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Comparison To Modeling

Difference-in-Differences

- 2021 vs 2017
  - 33.5% reduction in PM_{10}
  - 95% CI: 16.1 to 47.3%
- 2020 vs 2017
  - 28.4% reduction in PM_{10}
  - 95% CI: 13.9% to 40.4%

Langrangian Dispersion Model

- 2021 vs 2017
  - 42.1% reduction in PM_{10}
- 2020 vs 2017
  - 41.9% reduction
- Desert Research Institute / Calif State Parks

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What Does This Mean?

- In 2021: 56 Wind Event Days
- Actual median wind-event-day PM_{10} at CDF: 52 $\mu g/m^3$
- Predicted median without change: 77 $\mu g/m^3$

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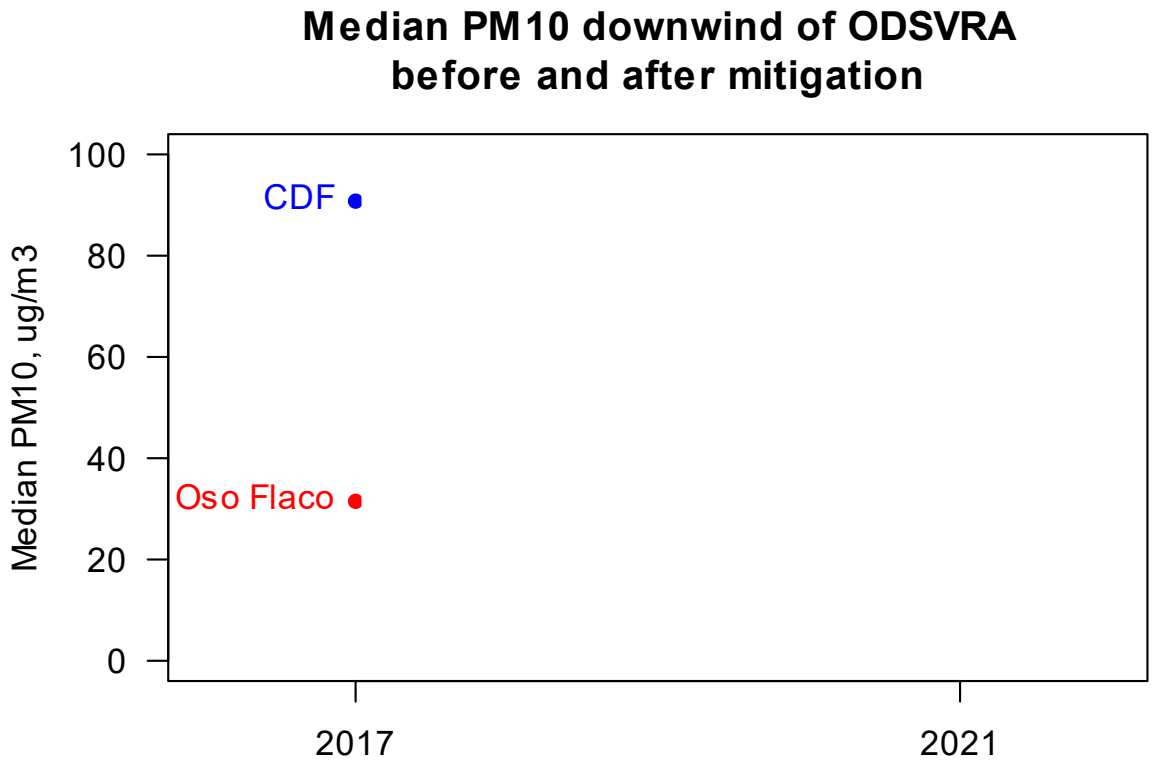

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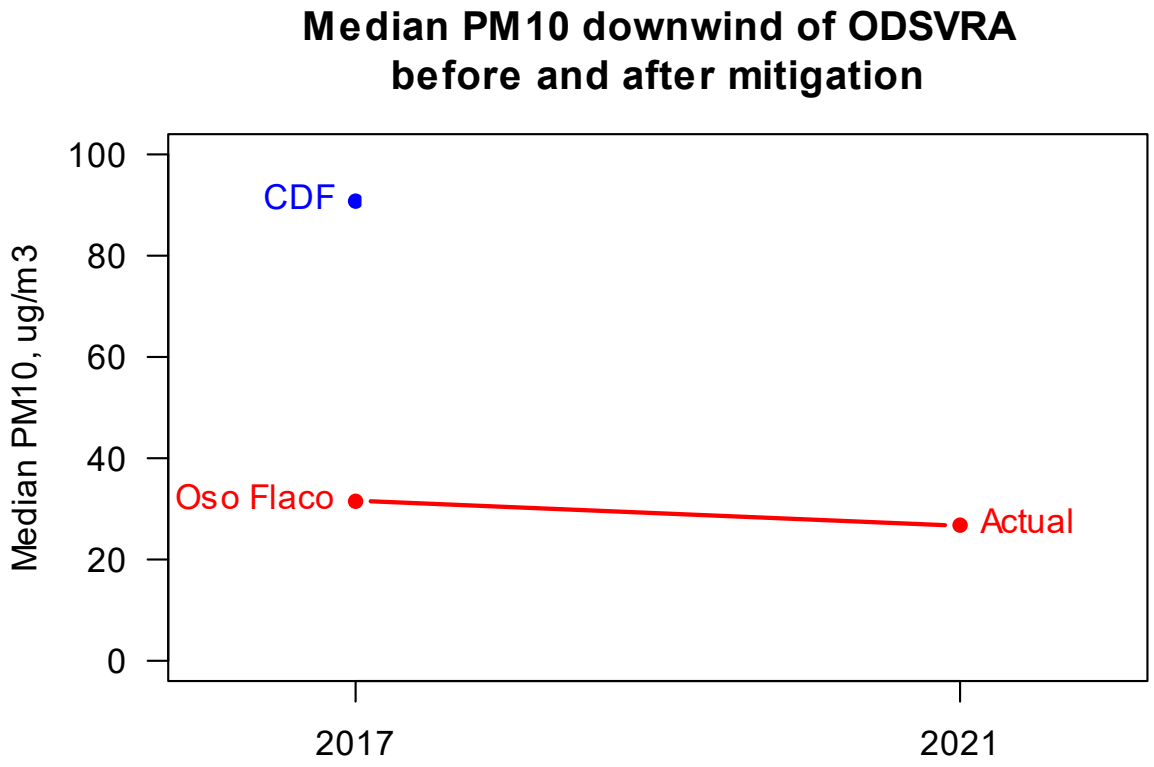

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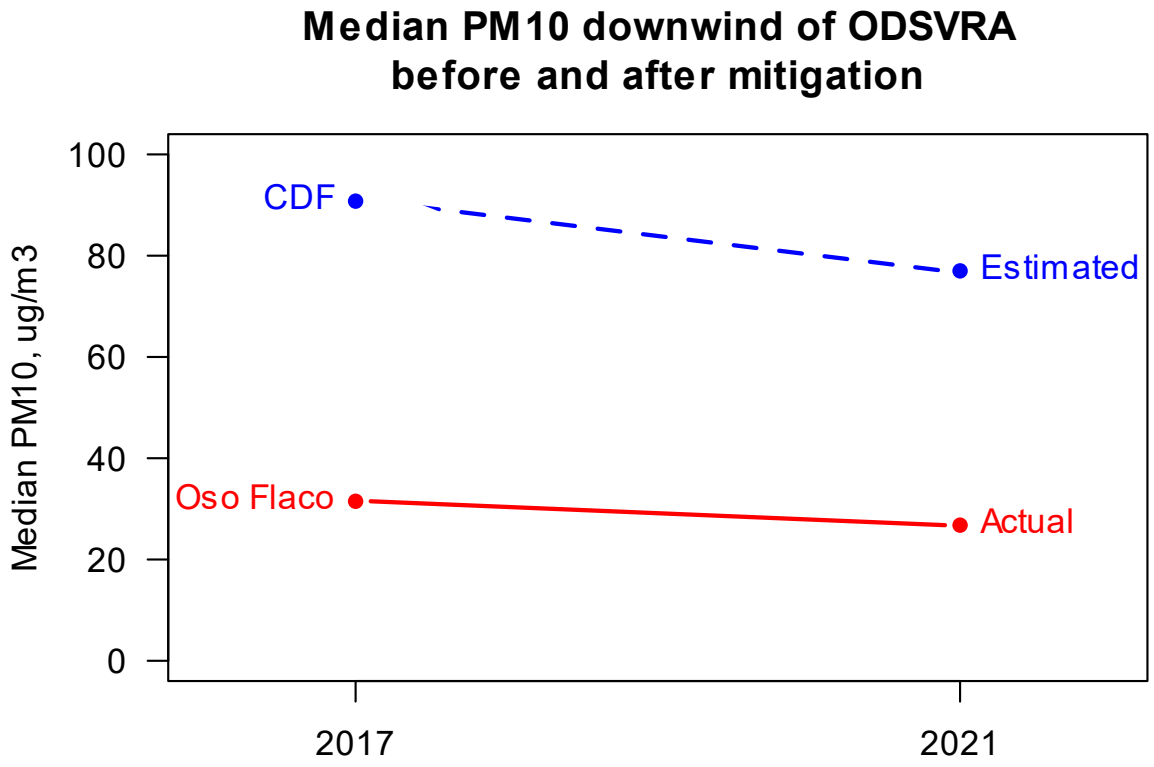

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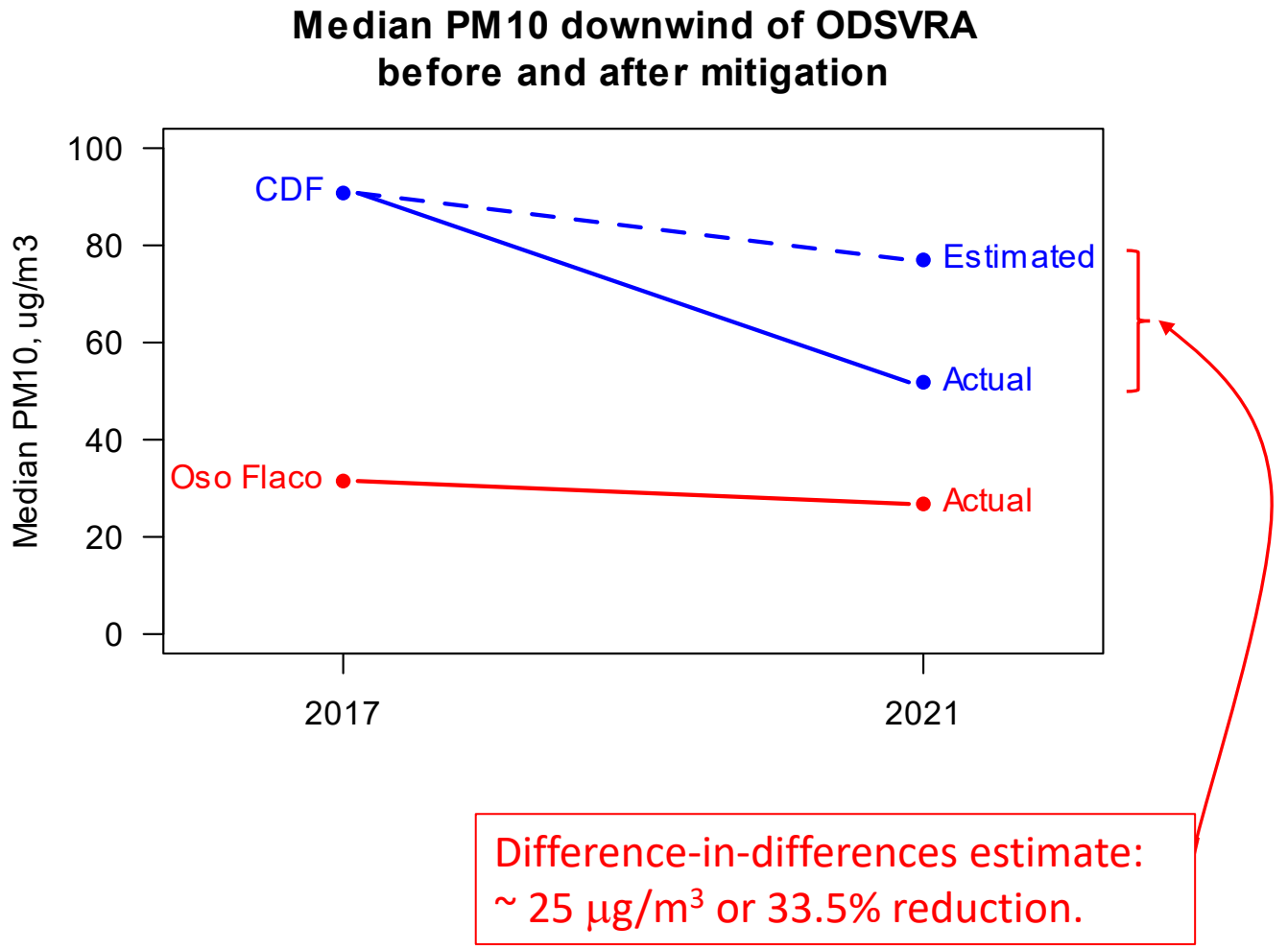

Summary

- Off-riding enhances PM_{10} emissions from the Oceano Dunes
- Extent of dust mitigations have steadily increased, currently >400 acres
- Variations in meteorology complicate interpretation of monitoring data
- Difference-in-differences approach implicitly controls for inter-annual variations in meteorology and impacts of non-dunes sources
- DiD analysis shows 33.5% improvement in wind-event-day PM_{10} levels downwind, 2017-2021
  - Corroborated by modeling

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Contact / Additional Info

Karl Tupper, Senior Air Quality Scientist
SLO County APCD
ktupper@co.slo.ca.us
www.slocleanair.org

ODSVRA-related materials:
https://www.slocleanair.org/air-quality/oceano-dunes-efforts.php
https://bit.ly/2ThvaFf

Hearing Board-related materials:
https://www.slocleanair.org/who/board/hearing-board.php
https://bit.ly/3dQRRtu