Pilot Study Proposal:
Investigate the Use of Shrubland Communities to Control Dust Emissions

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Outline

• **Introduction** to Shrubs as Dust Control
• **Background** on Dust Emission from Drylands
  • Fundamentals
  • Effects of Vegetation on Dust Emissions
• **Modeling Approaches**
• **Model Implementation and Parameterization**
• **Proposal** for Testing Dust Control Efficiency of Shrubland
Pilot Study Objectives

• Establish a robust methodology to quantitatively characterize shrublands and estimate dust control efficiency for any specific area

• Using this methodology, establish the thresholds needed to attain the levels of dust control required by regulators
Vegetation Already Controls Dust on Owens Lake

- Natural shrubland communities dominate most off-lake areas in the Owens Valley (Elmore et al. 2003)

- Shrubs stabilize many shoreline dune systems around Owens Lake (Dahlgren et al. 1997)

- Parry's saltbush and Greasewood are common off-lake and resilient to conditions on the Owens Playa (Dahlgren et al. 1997)

- Engineered salt grass communities have been an effective BACM on Owens Lake
Mature Greasewood Community
Northeast of Owens Lake Lake Looking Southeast
Sparse Greasewood and Saltgrass
South of Owens Lake Looking South
Saltgrass “Farm” on Owens Lake
Shrubland as Dust Control

• Compared to salt grass, shrubs are taller, more porous, less pliable, and have narrower aspect ratios

• The control efficiency of shrubland will thus be different than salt grass communities

• A shrubland dust control measure must take into account these differences
Dust Emission Mechanisms

(a) Aerodynamic entrainment

(b) Soil aggregate disintegration

(c) Saltating aggregate disintegration

PM$_{10}$ sized particles

From Kok et al. 2012, adapted from Shao (2008)
The Effect of Roughness on Airflow

- Particles and static roughness features absorb momentum from the wind.

- The downward flux of momentum reflects the energy absorbed by the surface and is expressed as the friction velocity, $u_*$.

- Rougher surfaces (higher $z_o$) absorb more momentum and reduce wind speeds at the ground.
Friction Velocity vs. Saltation Flux and PM$_{10}$ Emissions

- Saltation starts once the threshold velocity, $u_{*t}$ is reached

- Horizontal saltation flux and PM$_{10}$ emissions increase to the $3^{rd} - 4^{th}$ power of the friction velocity ($u_*$)

- PM$_{10}$ emissions are often assumed to scale with horizontal sand flux
Dust Control Mechanisms

- Armoring
  - Soil Stabilizers
  - Gravel Blanket
  - Brine
  - Soil Moisture

- Airflow Modification
  - Sand Fence
  - Shrub MV
  - Tillage

- Trapping
Effect of Vegetation on Saltation Flux

1. Covers the soil surface
2. Extracts momentum from the air
3. Traps soil particles

Wolfe and Nickling (1993)
Airflow Around an Isolated Shrub

From Mayaud and Webb (2017), adapted from Wolfe and Nickling (1993)

A) Approach flow
B) Displaced profile
C) Bleed flow
D) Quiet zone
E) Mixing zone
F) Re-equilibration zone
Effect of Plant Spacing on Flow Regime

Adapted from Mayaud et al. (2017), adapted from Wolfe and Nickling (1993)
Mechanism of Dust Emission

Suter-Burri et al. (2013)
Modeling Dust Emission in Shrublands

Two Approaches:

- **Drag Partitioning**  
  (Raupach, 1992; Marticorena and Bergametti, 1995)

- **Okin (2008) Model**

Figures from Okin (2008)
Okin Model Framework

- Given wind speed, we can estimate friction velocity ($u_*$) in lieu of vegetation elements *(if we assume a $z_o$)*
- We can derive saltation flux ($q$) from $u_*$:
  \[
  q = A \frac{\rho}{g} u_* (u_*^2 - u_{*t}^2) \quad (where \, u_* > u_{*t})
  \]
  (Shao and Raupach, 1993)

- We then assume:
  - No emissions occur where plants exist
  - Vegetation reduces $u_*$ in plant lees thus reduces the saltation flux in plant lees

Okin (2008)
Okin Model Framework

- $u_{*x/h}$ can be derived by down-scaling $u_*$ given observational data of plant wakes

- We can thus derive the saltation mass flux at any point to the upwind distance to the nearest plant

$$q_{x/h} = A \frac{\rho}{g} u_{*x/h} \left(u_{*x/h}^2 - u_{*t}^2\right)$$  \hspace{1cm} (where $u_{*x/h} > u_{*t}$)  

Okin (2008)

Data from: Bradley and Mulhearn (1983)
Okin Model Framework

- \( P_d(x/h) = \) Probability that any one point \( n \times/h \) distance from the nearest upwind plant.

\[
Q_{Tot} = \int_{0}^{\infty} P_d(x/h) q_{x/h} d(x/h)
\]

- \( P_d(x/h) \) can be either a prescribed gamma function or derived from remote sensing data of a specific area.

Okin (2008)
Plant Wake Characterization

From Mayaud et al. (2017)

Kalahari Desert

From Mayaud et al. (2017)
Models of Wind Speed Decline in Plant Wakes

From Mayaud et al. (2017)
Plant Porosity Affects Wake Characteristics

From Mayaud et al. (2017)
Porosity Affects Wake Characteristics

Cheng et al. (2018)
Porosity and Aspect Ratio Affects Wake Characteristics

Cheng et al. (2018)
Okin Model Performance

- Li et al. (2013) validated Okin (2008) against 65 BSNE Sand Catchers
- 13 of these sites were in Owens Valley
  - Observed May – Sept 2009
  - Mixed community of Parrys Saltbrush, Greesewood and Saltgrass
- They estimate a “relative error” of 2.1 or 1.0 if model is linearly corrected afterwards
- Much of the uncertainty came from uncertainties in $u_*$ and wind speed
- They identified a need to use an oddly high $z_o$ parameterization
Proposal: Pilot Study Objectives

• Establish a robust methodology to quantitatively characterize shrublands and estimate dust control efficiency for any specific area

• Using this methodology, establish the thresholds needed to attain the levels of dust control required by regulators
Pilot Study: Field Sites

- Instrumented with meteorology, and sand flux (BSNE, and/or CSC, Sensit) for 6 months (winter)

- In-situ and remote sensing observations of:
  - Plant gap spacing / arrangements
  - Plant height and width distributions
  - Plant porosity distributions
  - Threshold velocity

9 acres

Isolated Roughness? Wake Interface? Skimming?
Pilot Study: Site Instrumentation

- Meteorology
  - Wind at 6m, 4m, 2m, and top of vegetation
  - 2m temperature
  - Aerodynamic roughness length ($z_o$)

- Sand flux
  - BSNE or Cox Sand Catchers
  - Sensits – real-time detection of particle impaction

- In-situ Observations
  - Threshold Velocity – PI-SWERL (Etyemezian et al. 2007)
  - Plant dimensions and porosity distributions
    (Kenney et al. 1987)
Pilot Study: Remote Sensing

Plant gap spacing / arrangement:

• UAV or aerial imagery, 3-D structure using SfM

• Many studies have used these data to build datasets of plant height and gap spacing (Sankey et al., 2013, Van Puijenbroek et al., 2017, Cunliffe et al., 2016; Karl, et al. 2012)
Pilot Study: Methodology Development

- Implement the Okin (2018) using met station data, in-situ and remote sensing observations at the 3 field sites
- Test parameterization approaches (especially $z_o$) suggested by Li et al. (2013)
- Implement wake curves suggested by Mayaud et al. (2017) and/or Cheng et al. (2018)
- Test porosity and aspect ratio parameterizations suggested by Cheng et al. (2018)
- Evaluate windspeed effect on plant wakes
- Validate sand fluxes against sand catches and Sensit data following the approach of Li et al. (2013)
Pilot Study: Threshold Determination

- Test the full parameter space for varying plant gap distributions, and plant height distributions
  - Okin (2008) provides a method to synthesize hypothetical plant gap distributions
  - Plant height distributions can be built from growth rates of species of interest
- Run model with no plants \((x/h = \infty)\) to provide denominator for control efficiency (CE) estimates
- Find plant spacing and height characteristics that satisfy 99% CE
Conclusions

• Once the characteristics necessary to attain the required CE are determined, DWP can look into the feasibility establishing shrubland communities for specific areas.

• Our hope for this forum is to evaluate these ideas and provide constructive feedback and suggestions on the proposed approach, models and assumptions.

• If successful, the study findings could support a future Shrub BACM application to the District.

• More specifics on the literature and pilot study plan will be provided in a separate report to OLSAP.
References


Friction Velocity vs. Mass Flux

Table 2.1. List of the most commonly used saltation mass flux relations.

<table>
<thead>
<tr>
<th>Mass flux equation</th>
<th>Comments</th>
<th>Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Q_{\text{Bagnold}} = C_B \sqrt[3]{\frac{D_p}{D_{250}}} \frac{\rho_a}{g} u_*^3 )</td>
<td>( C_B = 1.5, 1.8, ) or ( 2.8 ) for uniform, naturally graded, and poorly sorted sand, respectively.</td>
<td>Bagnold (1941)</td>
</tr>
<tr>
<td>( Q_{\text{Kawamura}} = C_K \frac{\rho_a}{g} u_<em>^3 \left( 1 - \frac{u_{</em>\text{it}}^2}{u_<em>^2} \right) \left( 1 + \frac{u_{</em>\text{it}}}{u_*} \right) )</td>
<td>( C_K = 2.78 ) (Kawamura 1951) or ( 2.61 ) (White 1979). The origin of this relation is often confused to be White (1979); see Namikas and Sherman (1997).</td>
<td>Kawamura (1951)</td>
</tr>
<tr>
<td>( Q_{\text{Owen}} = \frac{\rho_a}{g} u_<em>^3 \left( 0.25 + \frac{v_t}{3u_</em>} \right) \left( 1 - \frac{u_{<em>\text{it}}^2}{u_</em>^2} \right) )</td>
<td>( v_t ) is a particle’s terminal fall speed.</td>
<td>Owen (1964)</td>
</tr>
<tr>
<td>( Q_{\text{Lettau}} = C_L \sqrt[3]{\frac{D_p}{D_{250}}} \frac{\rho_a}{g} u_<em>^3 \left( 1 - \frac{u_{</em>\text{it}}}{u_*} \right) )</td>
<td>( C_L = 6.7 ).</td>
<td>Lettau and Lettau (1978)</td>
</tr>
<tr>
<td>( Q_{\text{UH}} = C_{\text{UH}} \rho_a u_<em>^2 \left( 1 - \frac{u_{</em>\text{sfc}}^2}{u_*^2} \right) )</td>
<td>Ungar and Haff (1987) did not estimate a value of ( C_{\text{UH}} ).</td>
<td>Ungar and Haff (1987)</td>
</tr>
<tr>
<td>( Q_{\text{Sorensen}} = \frac{\rho_a}{g} u_<em>^3 \left( 1 - \frac{u_{</em>\text{it}}^2}{u_<em>^2} \right) \left( \alpha + \gamma u_{</em>\text{it}} / u_* + \beta u_{<em>\text{it}}^2 / u_</em>^2 \right) )</td>
<td>( \alpha, \beta, ) and ( \gamma ) are parameters that characterize the dimensions of a typical saltation hop.</td>
<td>Sorensen (2004)</td>
</tr>
<tr>
<td>( Q_{\text{DK}} = C_{\text{DK}} \rho_a u_{<em>\text{it}} u_</em>^2 \left( 1 - \frac{u_{<em>\text{it}}^2}{u_</em>^2} \right) )</td>
<td>( C_{\text{DK}} \approx 5 ).</td>
<td>Proposed here and in Durán et al. (2011a)</td>
</tr>
</tbody>
</table>

\( D_{250} \) is a reference diameter of 250 \( \mu m \).
Threshold for Onset of Particle Motion

- Sand-sized particles will start saltating at lower friction velocities than PM$_{10}$ sized particles.
Porosity and Aspect Ratio Affects Wake Characteristics

From Cheng et al. (2018)