Spatial and temporal differences in parameters affecting eelgrass restoration success (*Zostera marina* L.)

Erin Aiello

**Cal Poly**

_San Luis Obispo_
Study site: Morro Bay Estuary

- Bay mouth
- Fore bay
- Mid bay
- Salt marsh
- Back bay
- Eelgrass habitat
Why the Morro Bay Estuary

- Short (~ 6 km)
- Heterogeneous environment
- Historically, eelgrass habitat throughout
- Recently limited to fore bay environment only
The sad news:

Eelgrass recently declined in the Morro Bay Estuary
Patterns of decline

- 95% acreage lost
- 300 acres ➞ 14 acres
- Beds remain in fore bay only
- Failed restoration
Restoration: When, where and why?

- Transplanted eelgrass
  - 2 Different locations
  - 2 Different seasons

- Measured environmental parameters
  - At transplant sites
  - Bay mouth
  - Bay wide
Transplanting and Monitoring

- Planted in fore bay and mid bay
- 288+ plants per site
- Spring and summer
- Monitored density

Modified from Morro Bay National Estuary Program

Photo by Kyle Nessen
Transplant season
• Spring

*Error bars represent the standard error of the mean of four plots per site.
Fore-bay transplants: both seasons

Mid-bay transplants: both seasons

*Error bars represent the standard error of the mean of four plots per site.
What parameters are most important to eelgrass restoration?

- Temperature
- Light
- Salinity
- Sediment grain-size distribution
- Sediment chemistry
- Presence of epiphytic algae
- Grazing pressure
- Presence of disease
- Planting depth
- Anchorage of plants
Temperature and Salinity

- Measured at three mooring stations
- Bay mouth, Fore bay, and Mid bay mooring stations spread evenly

Photo by Dr. Ryan Walter, Cal Poly

Modified from Walter et al, 2017
Temperature is higher at the mid bay site where eelgrass died.

Modified from Walter et al, 2017.
Salinity is lower and more variable in the mid bay.

Modified from Walter et al, 2017
Light measurements

Summer, 2017
• Logged PAR at fore-bay and mid-bay transplant sites
• Sensors at mid-blade-length

Spring, 2018
• Hung sensor from boat between fore and back bay on rising and falling tides
• Recorded light and GPS data every 10 s

Water clarity affects light

https://www.licor.com/env/products/light
Light may be limited in the mid bay, where eelgrass died.

Fore-bay mooring station had consistently higher light levels than the mid-bay mooring station.

Irradiance (µmol PAR photons/m²s)

https://www.licor.com/env/products/light
Light variation across the bay

- Fore bay receives more light
- Mid bay receives less light
Two distinct water bodies in the estuary

**From Dr. Ryan Walter**

**Transition region**

- Decreased turbidity
- Short flushing times
- Large exchange
- Oceanic (cooler)
- Normal DO

**Increased turbidity**

- Long flushing times
- Minimal exchange
- Hyperthermal (warmer)
- Hypersaline (saltier)
- Low DO
Sediment Analyses

- Looked at grain size distribution and sediment chemistry
- Each sample is comprised of 10 cores per site, taken across a distance of roughly 100m.
Sediment grain-size distribution

- Clay percent is higher in the mid and back bay than the fore bay
Spatial patterns in sediment chemistry
Spatial patterns in sediment chemistry

- Magnesium
- Carbon
- Carbon:Nitrogen ratio
- Potassium
- Boron
- Clay percent
- Nitrogen
- Organic matter
- Sodium
- Zinc
- Manganese
- Iron
- Calcium
- Copper

Contribution to Gradient

eelgrass present  eelgrass gone
Evidence that a gradient of habitat suitability exists

Fore bay (green) (yellow and red)
Ocean mixes Ocean does not mix
Cooler summer Warmer summer
Less variable salinity Variable salinity
High light Low light
Low carbon % High carbon %
Low clay % High clay %

And differing sediment chemistry

*conceptual drawing – not from data
What could be affecting eelgrass habitat suitability?

- Temperature
- Transplant season
- Gradient in sediment chemistry:
  - Boron
  - Sodium
  - Potassium
  - Copper
  - Clay percent
  - Nitrogen
  - Organic matter
  - Carbon
- High variance in salinity
- Low light.
- High sed. clay percent
- Magnesium
- Carbon
- Manganese
- Zinc
- Iron
- Calcium
- Magnesium
Importance of results

- Confirms previous studies: Season is important (Park and Lee, 2007; Li et al., 2014)
- Current habitat suitability models lack salinity, water temperature and sediment chemistry
- High environmental heterogeneity in ~6 km

*conceptual drawing – not from data
Acknowledgements

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Supporters and my reason to succeed
Contact:
Erin Aiello
UC Santa Cruz Parker Lab
eaiello@ucsc.edu
Health parameters

- Percent of blade covered with algae
  minimized photosynthesis
- Broken tips
- Side erosion
  both: grazing indicators
- Percent of blade necrotic
  indicates disease
More necrosis in the mid bay

Repeated Measures ANOVA

<table>
<thead>
<tr>
<th>Effect</th>
<th>DF</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>1</td>
<td>39.27</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Time</td>
<td>1</td>
<td>1.43</td>
<td>0.23</td>
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<tr>
<td>Site * Time</td>
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<td>5.16</td>
<td>0.024</td>
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<tr>
<td>Plot [Site]</td>
<td>6</td>
<td>1.53</td>
<td>0.16</td>
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</tbody>
</table>

Least Square Means Contrasts

<table>
<thead>
<tr>
<th>Test</th>
<th>Week</th>
<th>T-Ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Tissue Necrotic</td>
<td>0</td>
<td>T = 0.924</td>
<td>1</td>
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<tr>
<td></td>
<td>7</td>
<td>T = 6.19</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>T = 2.55</td>
<td>0.02</td>
</tr>
</tbody>
</table>

- Site: forebay
- Site: midbay

[Graph showing comparison of percent of leaf blade necrotic over weeks since transplant]
More broken tips in the mid bay

Repeated Measures ANOVA

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<thead>
<tr>
<th>Effect</th>
<th>DF</th>
<th>F</th>
<th>P</th>
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</thead>
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<tr>
<td>Time</td>
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<td>1.56</td>
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Least Square Means Contrasts

<table>
<thead>
<tr>
<th>Test</th>
<th>Week</th>
<th>T-Ratio</th>
<th>p-value</th>
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</thead>
<tbody>
<tr>
<td>Proportion tips broken</td>
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<td>T = 0.45</td>
<td>1</td>
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<td></td>
<td>7</td>
<td>T = 4.43</td>
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<tr>
<td></td>
<td>15</td>
<td>T = 2.48</td>
<td>&lt;0.0001</td>
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</table>
No difference in epiphytes or erosion
Spatial patterns in sediment chemistry

![Graph showing principal components analysis (PCA) for sediment chemistry variables.](image)

<table>
<thead>
<tr>
<th>Component 1 (56.6%)</th>
<th>Component 2 (17%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>Phosphorous_weak</td>
</tr>
<tr>
<td>sulfur_ppm</td>
<td>calcium_ppm</td>
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<tr>
<td>Carbon_to_Nitrogen_Ratio</td>
<td>manganese_ppm</td>
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<tr>
<td>Percent Organic Matter</td>
<td>phosphorous_ppm</td>
</tr>
<tr>
<td>potassium_ppm</td>
<td>magnesium_ppm</td>
</tr>
<tr>
<td>calcium_ppm</td>
<td>phosphorous_weak</td>
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<tr>
<td>Sodium_ppm</td>
<td>Percent Organic Matter</td>
</tr>
<tr>
<td>sulfur_ppm</td>
<td>Zinc_ppm</td>
</tr>
<tr>
<td>Clay_percent</td>
<td>Copper_ppm</td>
</tr>
<tr>
<td>iron_ppm</td>
<td>boron_ppm</td>
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<tr>
<td>pH</td>
<td>Carbon_percent</td>
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<tr>
<td>Clay_percent</td>
<td>Carbon_to_Nitrogen_Ratio</td>
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<td>Carbon Percent</td>
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<td>Carbon_percent</td>
<td>Carbon_to_Nitrogen_Ratio</td>
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</table>

**Loading Matrix**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Prin1</th>
<th>Prin2</th>
<th>Prin3</th>
<th>Prin4</th>
<th>Prin5</th>
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</thead>
<tbody>
<tr>
<td>Percent Organic Matter</td>
<td>0.87736</td>
<td>0.05883</td>
<td>-0.08923</td>
<td>0.20827</td>
<td>0.41885</td>
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<tr>
<td>Phosphorous_weak</td>
<td>0.19624</td>
<td>0.74601</td>
<td>-0.62073</td>
<td>-0.00610</td>
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<tr>
<td>phosphorous_ppm</td>
<td>-0.34673</td>
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<td>0.20442</td>
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<td>potassium_ppm</td>
<td>0.91928</td>
<td>-0.22924</td>
<td>-0.31241</td>
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<td>magnesium_ppm</td>
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<td>calcium_ppm</td>
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<td>Sodium_ppm</td>
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<td>manganese_ppm</td>
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<td>0.12056</td>
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<td>iron_ppm</td>
<td>0.74895</td>
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<td>Copper_ppm</td>
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<td>boron_ppm</td>
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<td>0.11298</td>
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<td>pH</td>
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<td>0.10932</td>
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<tr>
<td>Clay_percent</td>
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<td>0.00056</td>
<td>0.07136</td>
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<tr>
<td>Nitrogen_percent</td>
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<tr>
<td>Carbon_Percent</td>
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<td>Carbon_to_Nitrogen_Ratio</td>
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<td>0.22524</td>
<td>-0.05243</td>
<td>0.16329</td>
<td>0.11450</td>
</tr>
</tbody>
</table>
Dissolved Oxygen is more variable in the mid bay than at the mouth.
Anchoring the plant is crucial to transplant success.
Spring transplants: both sites

Summer transplants: both sites

*Error bars represent the standard error of the mean of four plots per site.*
Sediment C% and N%  

All from June 2016

Coleman June ‘16 N content results not reliable - excluded
Sediment Chemistry

1.0 N ammonium acetate @ pH 7.0
Sediment Chemistry

Back bay

<table>
<thead>
<tr>
<th>Location</th>
<th>Weak Bray Phosphorous (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pecho Rd.</td>
<td>23</td>
</tr>
<tr>
<td>Mitchell Dr.</td>
<td>18</td>
</tr>
<tr>
<td>Pasadena Pt.</td>
<td>21</td>
</tr>
<tr>
<td>Midbay Site Site</td>
<td>28</td>
</tr>
<tr>
<td>Windy Cove</td>
<td>24</td>
</tr>
<tr>
<td>Forebay Site</td>
<td>16</td>
</tr>
<tr>
<td>Coleman Beach</td>
<td>20</td>
</tr>
</tbody>
</table>

Fore bay

Ammonium Fluoride/HCL
Sediment Chemistry

Phosphorus (ppm NaHCO3-P)

Back bay ——— Fore bay

Sodium Bicarbonate @pH 7.0
Sediment Chemistry

Bar graph showing calcium content in ppm at different sites:
- Pecho Rd.
- Mitchell Dr.
- Pasadena Pt.
- Midbay Site
- Windy Cove
- Forebay Site
- Coleman Beach

Sites are classified as Back bay and Fore bay.
Sediment Chemistry

[Sodium concentration graph showing data from various sites ranging from Back bay to Fore bay]
Sediment Chemistry

DTPA – Sorbitol
Inductively
Coupled Plasma
Spectrometry
Sediment Chemistry

![Bar chart showing manganese concentrations in different locations. The chart compares concentrations between back bay and fore bay locations: Pecho Rd., Mitchell Dr., Pasadena Pt., Midbay Site, Windy Cove, Forebay Site, and Coleman Beach. The chart highlights significantly higher manganese concentrations in the back bay compared to the fore bay.]

DTPA – Sorbitol Inductively Coupled Plasma Spectrometry
Sediment Chemistry

![Bar graph showing iron concentrations in sediment from various sites (Pecho Rd, Mitchell Dr, Pasadena Pt, Midbay Site, Windy Cove, Forebay Site, Coleman Beach) with values in ppm Fe, comparing Back bay and Fore bay.

DTPA – Sorbitol Inductively Coupled Plasma Spectrometry]
Sediment Chemistry

Back bay → Fore bay

DTPA – Sorbitol Inductively Coupled Plasma Spectrometry
Sediment Chemistry

[Bar graph showing the distribution of Boron (ppm B) among sites such as Pecho Rd., Mitchell Dr., Pasadena Pt., Midbay Site, Windy Cove, Forebay Site, and Coleman Beach. The x-axis represents various sites, and the y-axis represents Boron concentration (ppm B).]

Back bay → Fore bay

DTPA – Sorbitol
Sediment Percent Organic Matter

loss on ignition at 360°C
Sediment Chemistry

![Graph showing pH levels at different sites with Back bay and Fore bay labeled.]
Sediment Chemistry

Back bay → Fore bay

1.0 N ammonium acetate @ pH 7.0
Sediment Chemistry

<table>
<thead>
<tr>
<th>Location</th>
<th>Nitrogen (ppm NO3-N)</th>
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</thead>
<tbody>
<tr>
<td>Pecho Rd.</td>
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<td>Pasadena Pt.</td>
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<tr>
<td>Midbay Site</td>
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<tr>
<td>Windy Cove</td>
<td>1.0</td>
</tr>
<tr>
<td>Forebay Site</td>
<td>1.0</td>
</tr>
<tr>
<td>Coleman Beach</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Total Kjeldahl + NO3-N

Back bay ————> Fore bay