# Synthesizing NERR Sentinel Site data to improve coastal wetland management across New England

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August 22, 2019

Wells National Estuarine Research Reserve



*Supported by the National Estuarine Research Reserve System Science Collaborative, funded by the National Oceanic and Atmospheric Administration and managed by the University of Michigan Water Center (NA14NOS4190145)*

Waquoit Bay National Estuarine Research Reserve

wellsreserve Wells National Estuarine Research Reserve

Great Bay National Estuarine Research Reserve

University of New Hampshire

Narragansett Bay Research Reserve

National Estuarine Research Reserve System Science Collaborative

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August 22, 2019 Wells National Estuarine Research Reserve

## AGENDA

***8:30-10*** **Optional morning field trip to Little River Marsh**
***Methodological Challenges of Point Intercept and Ocular Comparison to determine plant composition***

***9:45*** **Morning snack & Networking**

***10:30*** **Greeting and Review Workshop Objectives**
*10:45* *NERRS and Sentinel Sites; Methodology and Protocols*
*11:10* *Presentation of results [in context of questions previously posed by stakeholders]*
*11:15* *Integrating Vegetation methods*
*11:30* *Vegetation differences across 4 New England NERRs*
*12:00* *Documenting change over time*

***12:30*** **Networking LUNCH (provided)**
*1:15* *Inundation Model results from four Reserves*
*2:00* *Discussion of Management Implications*
*3:00* *Next steps*

***3:40*** **Workshop Evaluation and Close**

DRAFT

**Detailed meeting notes found at the end of the slidedeck, starting on page 117**

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Waquoit Bay National Estuarine Research Reserve
wellsreserve Wells National Estuarine Research Reserve
Great Bay National Estuarine Research Reserve
University of New Hampshire
Narragansett Bay Research Reserve
National Estuarine Research Reserve System Science Collaborative







# National Estuarine Research Reserves

-Sentinel Sites Program-

# OUTLINE

- Introduction to the NERRS
- Introduction to SWMP
- Introduction to Sentinel Sites/SSAM-1
    - Purpose, components, methods
- Products/syntheses
- NERR Science Collaborative
    - Catalyst grants
        - Current Burdick et al. project to synthesize New England data

# We are the NERRS

(not the NEERS!)

- Est. in 1972
- Currently 29 sites
- Federal/state partnerships
- Multi-sector

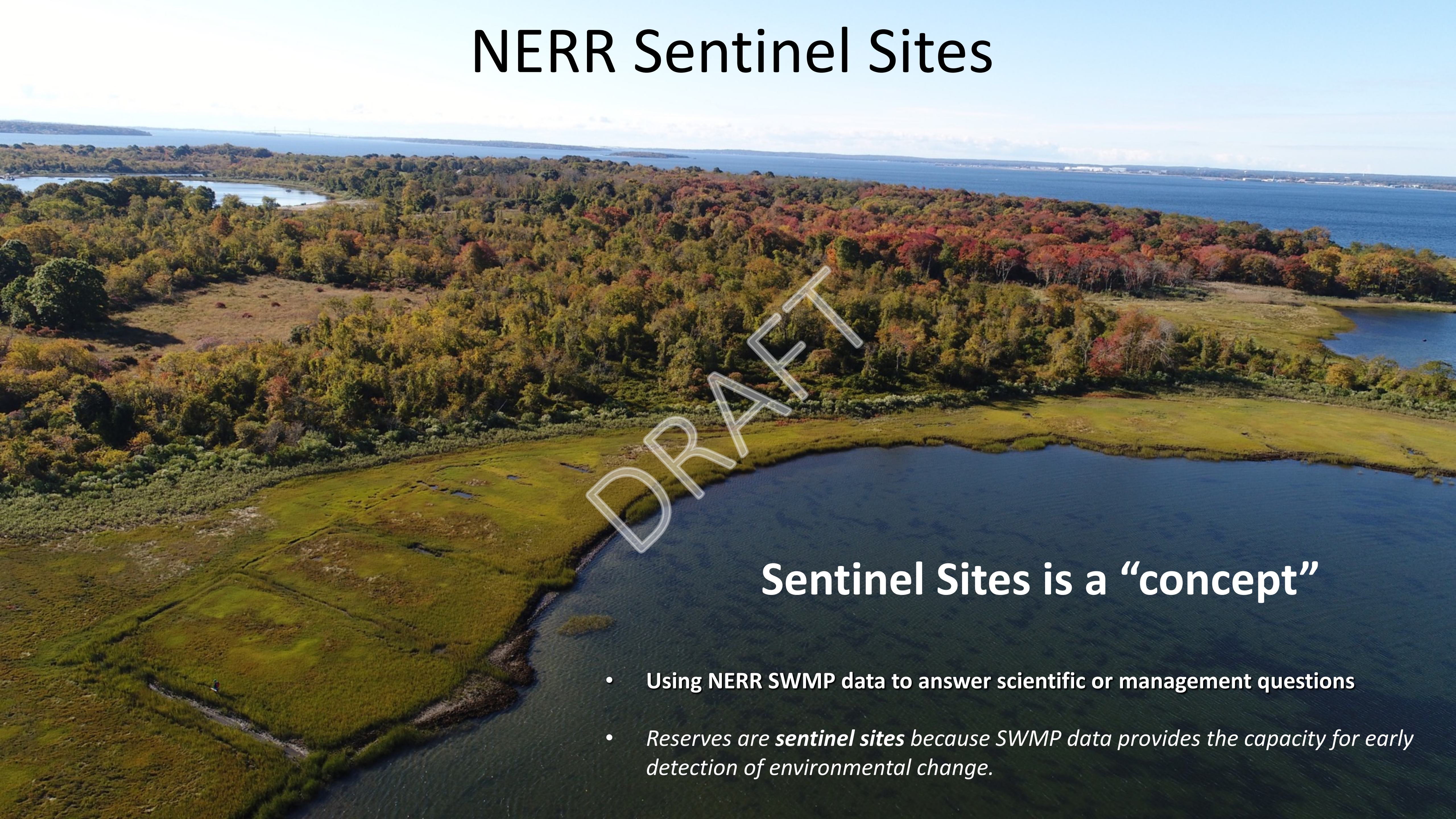
# NERR SWMP
# System-wide Monitoring Program

- Most national NERR monitoring falls under umbrella of SWMP
- Established in 1995; periodic enhancements since
- Designed to detect short term variability and long-term change
- Three major program elements:
  - Abiotic indicators of water quality and weather
  - Biological monitoring
  - Watershed, habitat, and land use mapping





# NERR Sentinel Sites





## Sentinel Sites is a "concept"

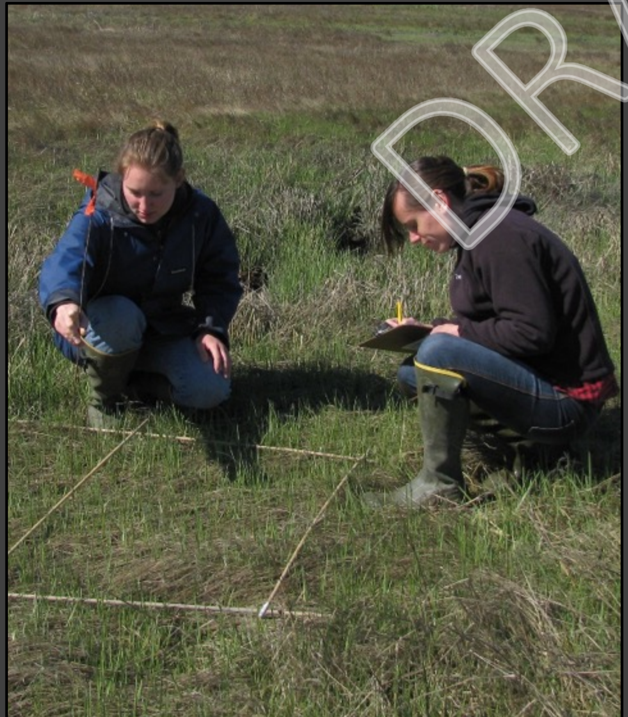
- **Using NERR SWMP data to answer scientific or management questions**
- *Reserves are **sentinel sites** because SWMP data provides the capacity for early detection of environmental change.*

# Sentinel Sites Application Modules (SSAMs)

Putting the concept into application

**SSAM-1: "Understanding responses of coastal wetlands to changes in sea level and inundation"**





# SSAM-1 Monitoring Components

*and examples of questions that we can answer*



**VEGETATION**

*How is marsh cover and composition changing?*

**WATER LEVELS**

*How are water levels changing?*


**MARKER HORIZONS**

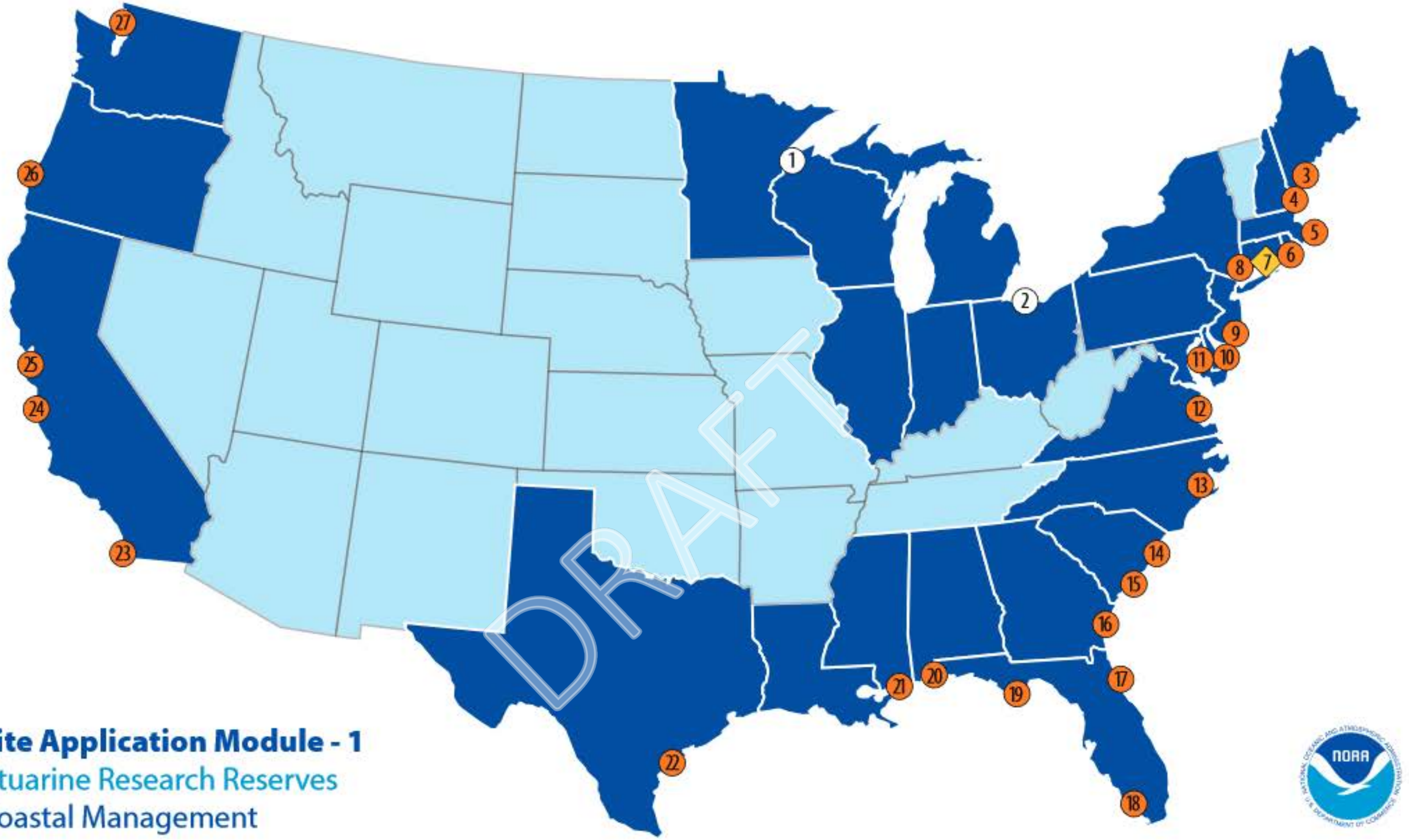
*How fast are marshes accreting sediment?*

**SURFACE ELEVATION TABLES**

*Is marsh elevation tracking changing water levels?*

**MARSH ELEVATIONS**

*Is our marsh high or low in the tidal frame?*





**Sentinel Site Application Module - 1**
National Estuarine Research Reserves
Office for Coastal Management

# SSAM-1 Outputs To Date

- OVERALL
  - 6 publications
  - 3 national products
  - 4 Science Collaborative proposals
  - 6 reserves integrating SSAM-1 into TOTE workshops;

- NATIONAL-SCALE SYNTHESES
  - Multi-metric indices of marsh vulnerability (Raposa et al. 2016, *Biological Conservation*)
  - Relative impacts of crabs and SLR on US marshes (Wasson et al. 2019, *Ecology*)
  - NERRS as reference sites for restoration projects (Raposa et al. 2016, *Estuaries and Coasts*)

# NERRS Science Collaborative

http://nerrssciencecollaborative.org/

"Supports user-driven, collaborative research that addresses coastal management issues important to the National Estuarine Research Reserve System"

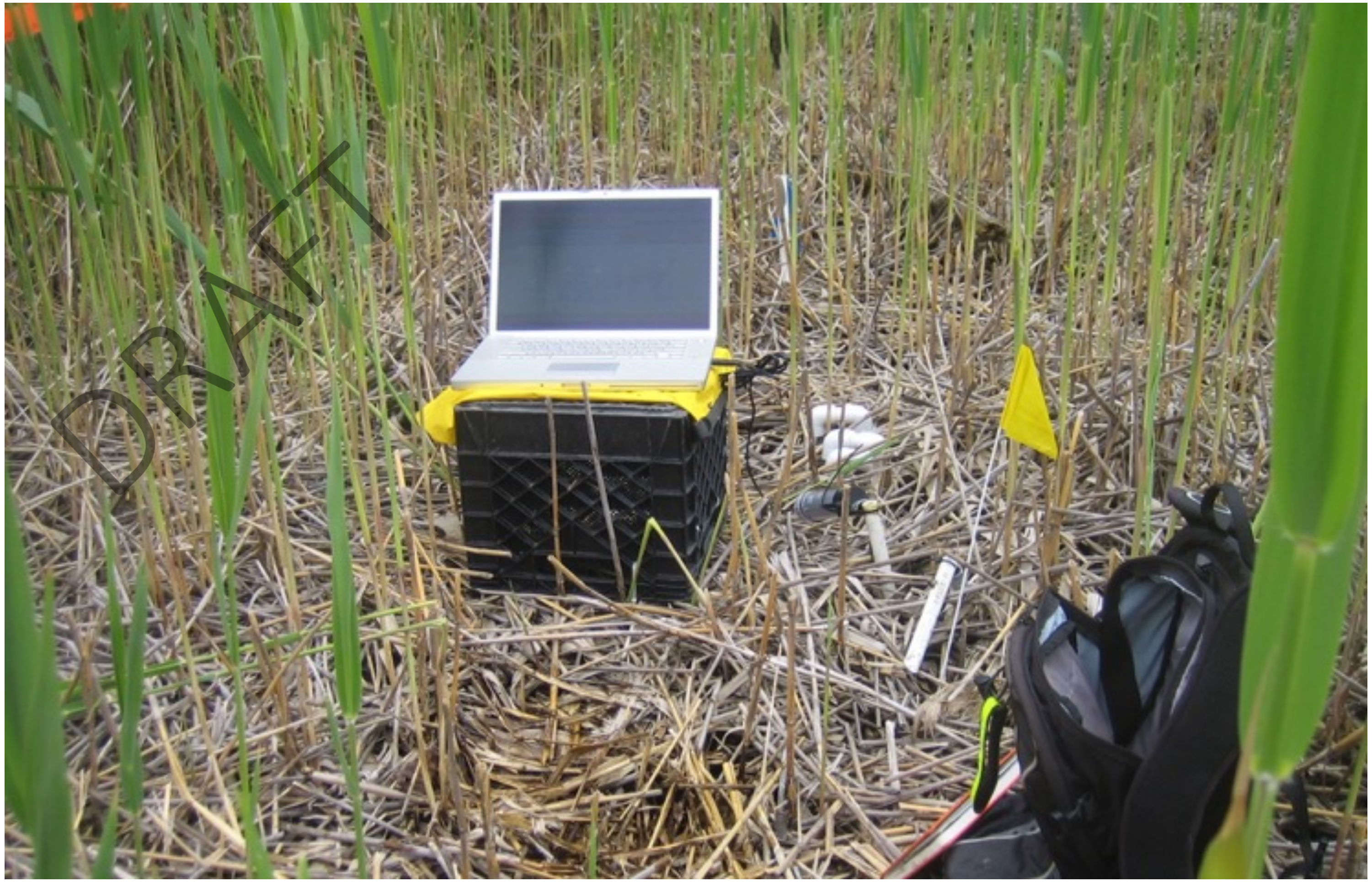


- Fostering:
  - Collaborative science
  - Multi-NERR collaborations and syntheses
- Project types:
  - Collaborative research
  - Integrated assessments
  - Transfer grants
  - Catalyst grants (scoping new ideas; synthesizing data)
    - Burdick et al: "Synthesizing NERR Sentinel Site data to improve coastal wetland management across New England"

National Estuarine Research Reserve System Science Collaborative

# Vegetation Community Analyses

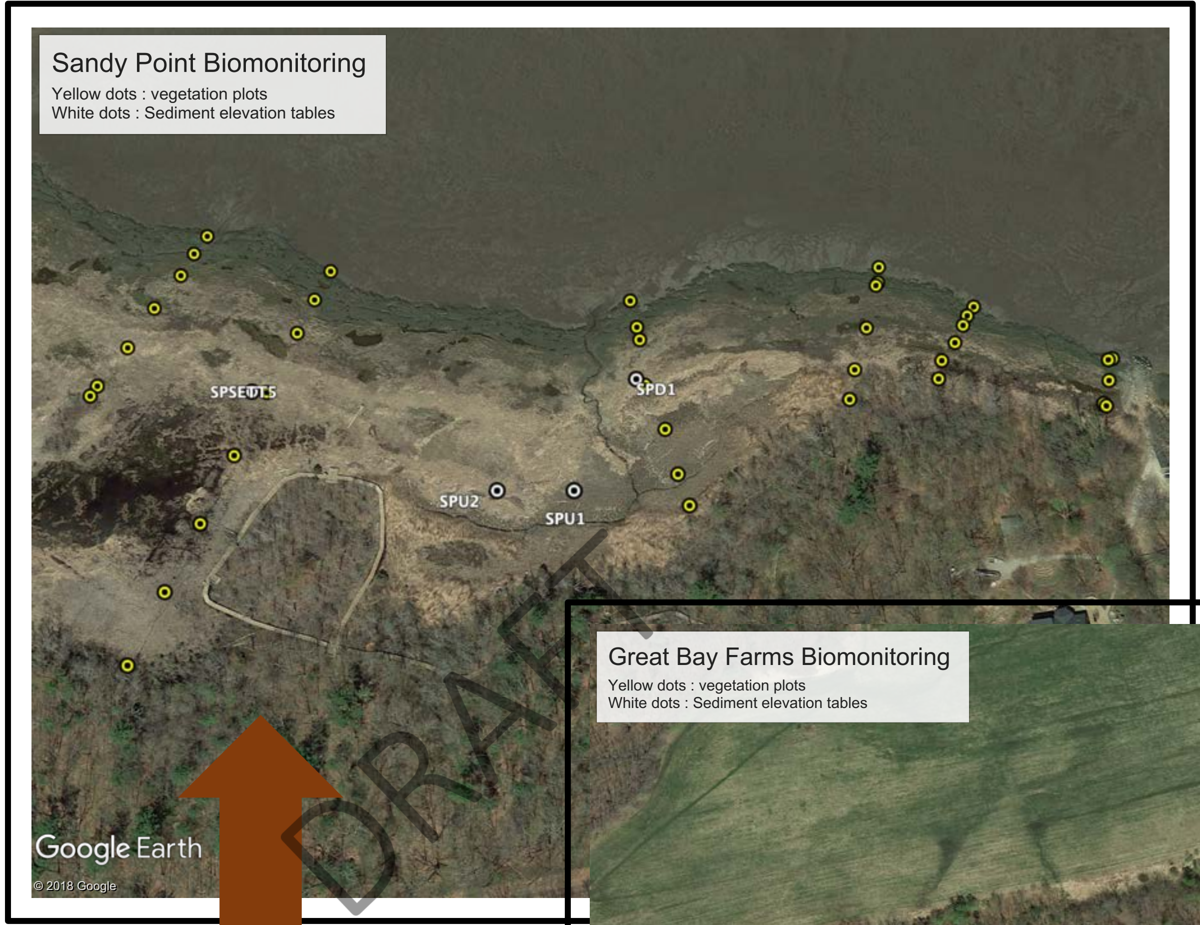
- Database Development
  - Crunching
- Summary
  - Pie charts
- Univariate
  - Regression models
- Multivariate
  - Primer

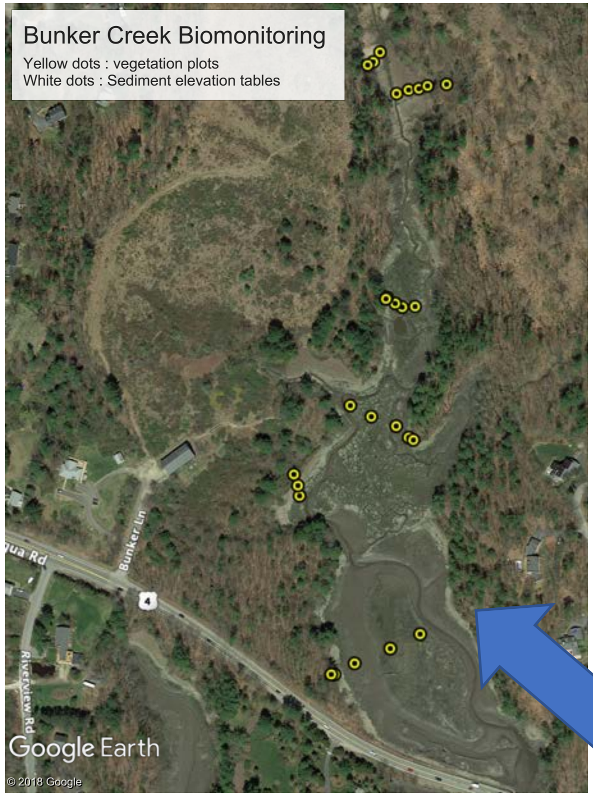


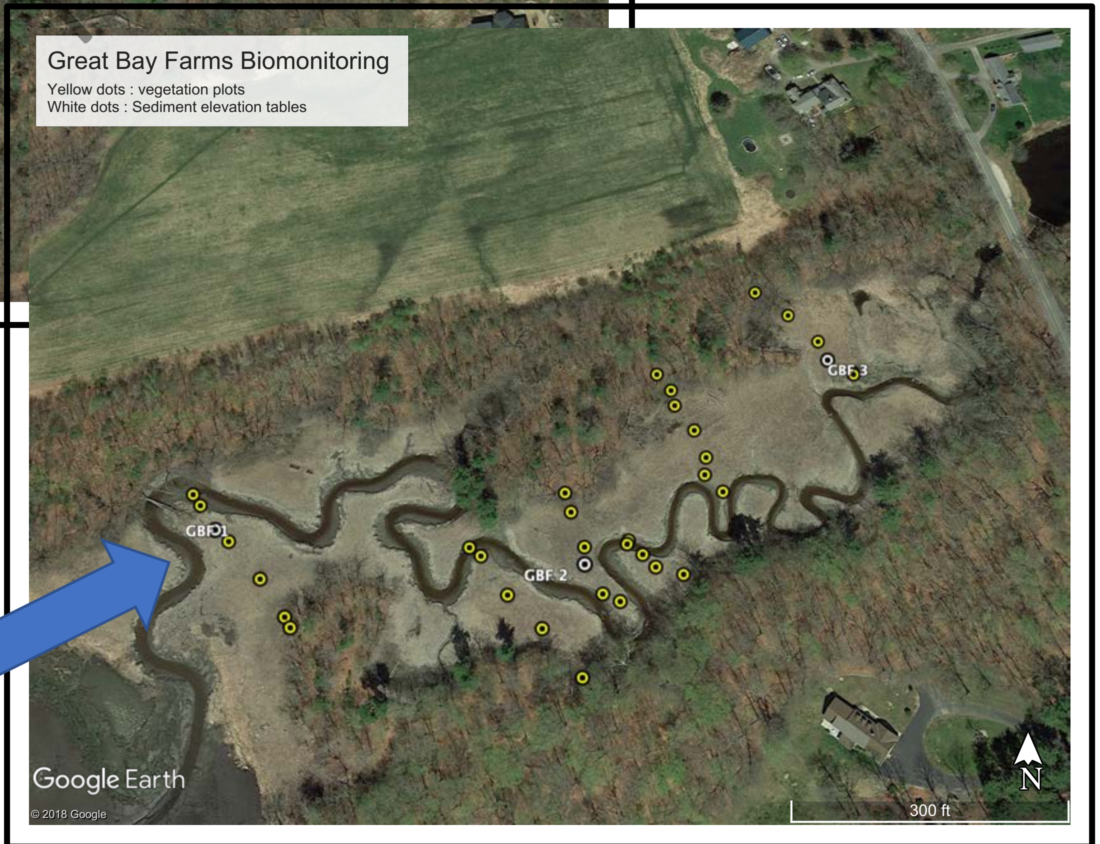
# Wells, ME


1R
1I
2I
2R
3I
3R
4I
4R
Vegatation Monitoring 2011
Webhannet River, Wells ME
0
0.25
0.5
1 Kilometer

# Great Bay, NH



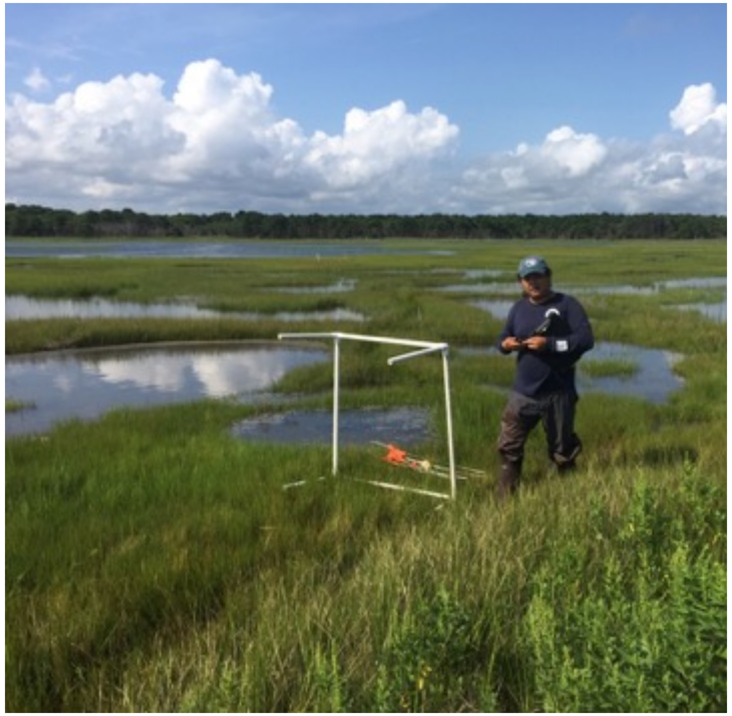



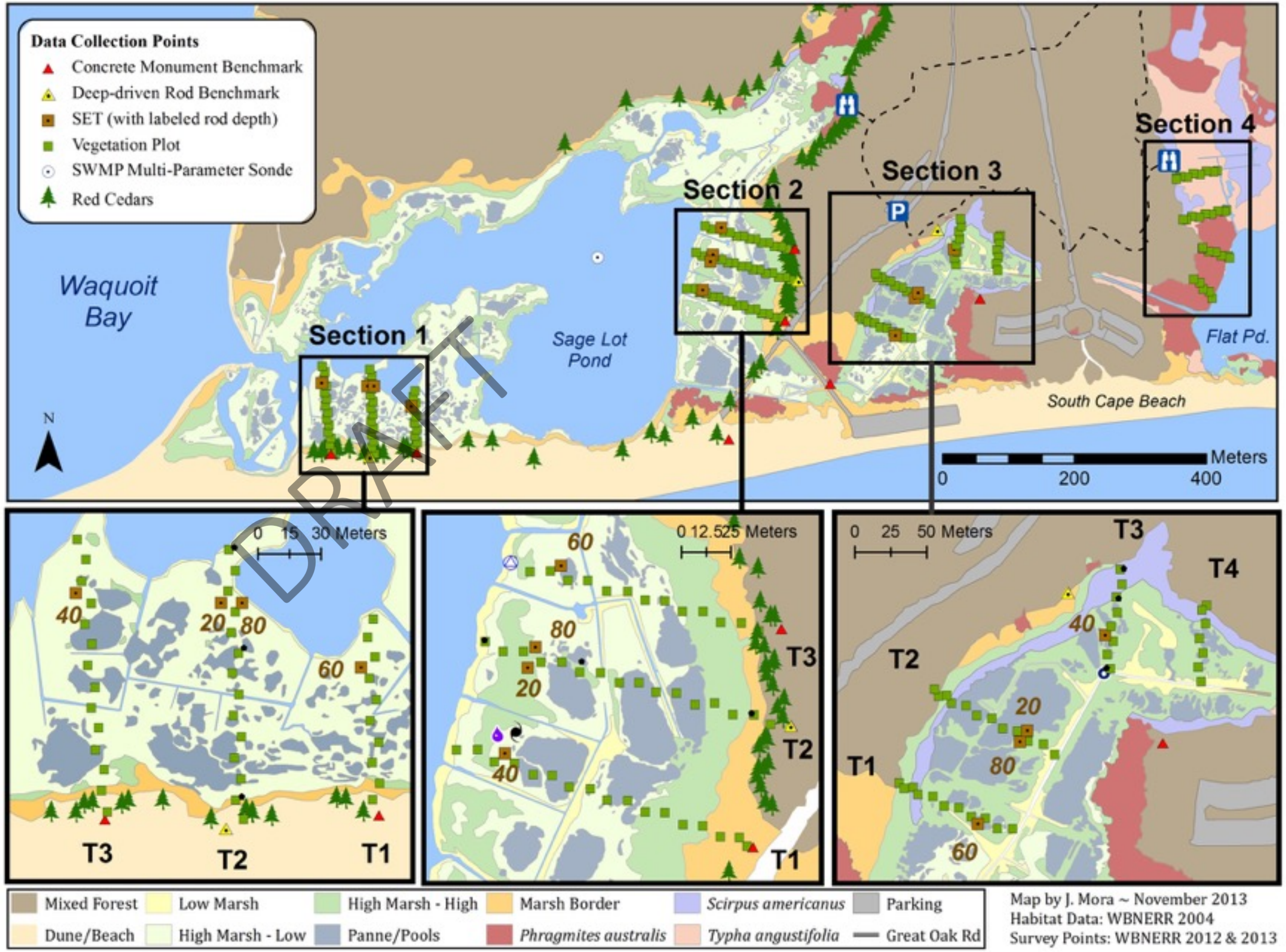

Bay front marsh

Riverine marshes

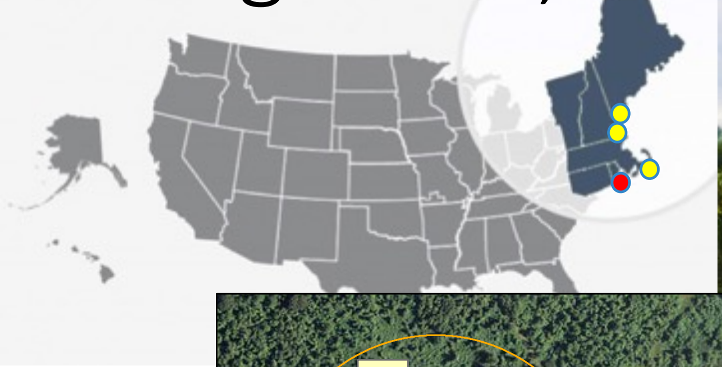
# Waquoit Bay, MA

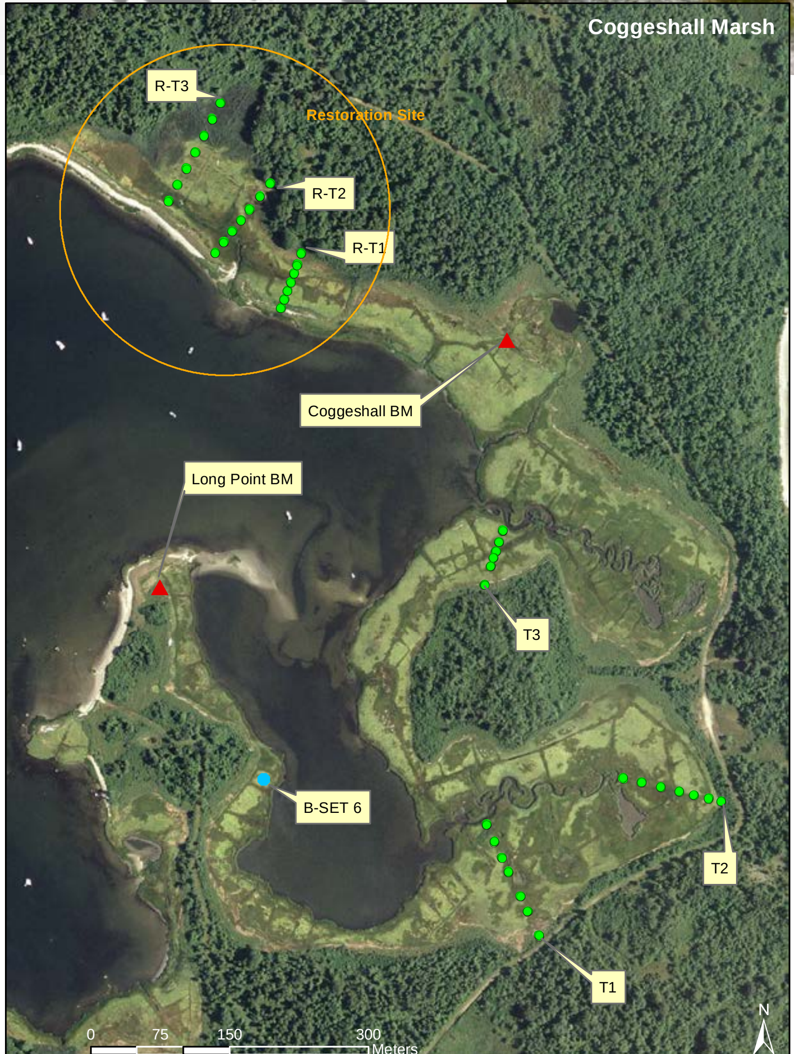


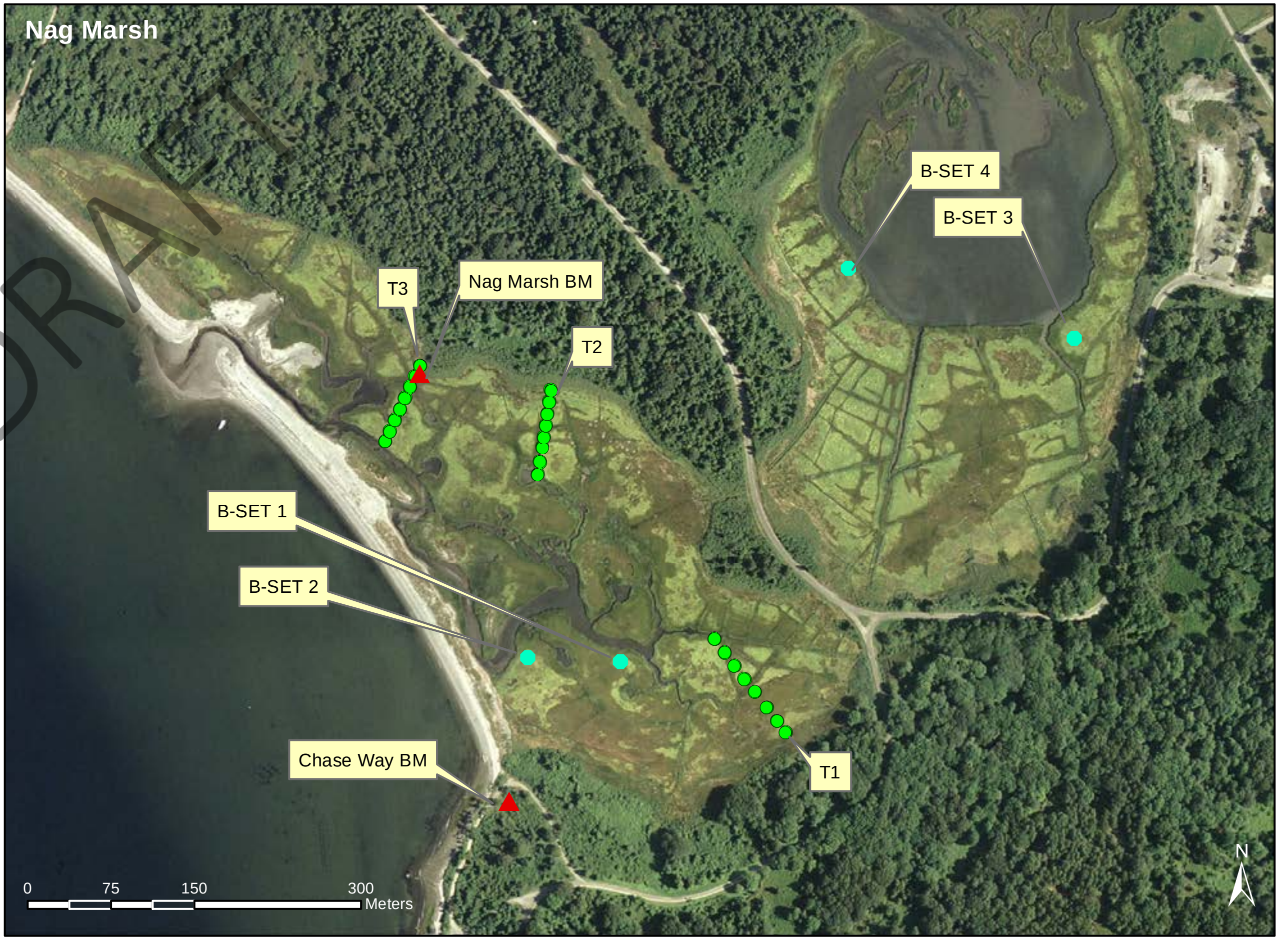
## WBNERR Salt Marsh Observatory (SMO): Long-Term Salt Marsh Biomonitoring Project



# Narragansett, RI

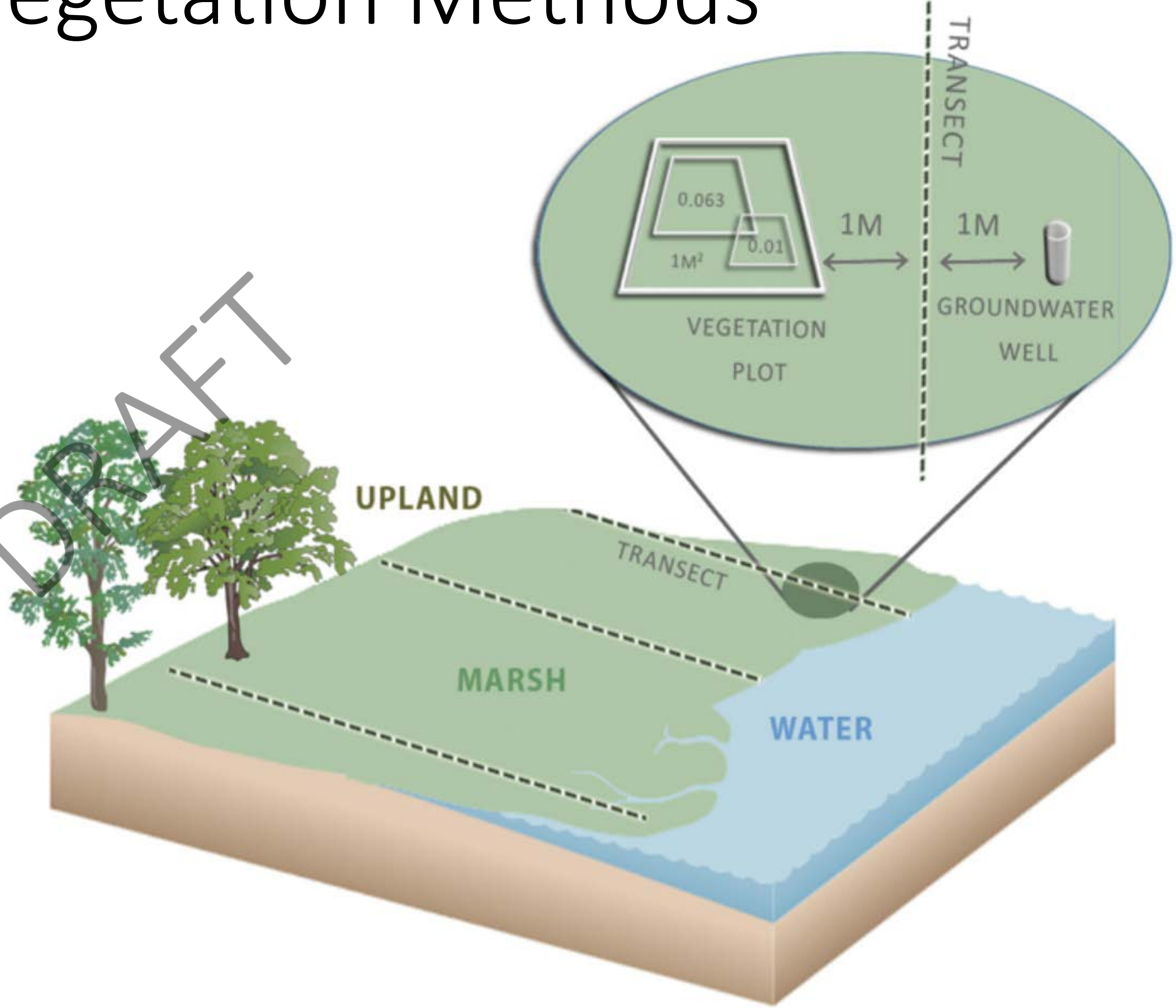




# Database development: Integrating Vegetation Methods

- ➢ Point-intercept vs Ocular Cover
- ➢ Other community differences
- ➢ Database



# Database development:
## Integrating Vegetation Methods

| | Vegetation | | | Ecotone | | | Porewater Salinity | Hydrology ** | Elevation | SET | Local Tide Data |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cover | Density | Height | Boundary* | Plots* | Other | | | | | |
| 2008 | 2 | | | | | | 1 | | 1 | | 1 |
| 2009 | 1 | | | | | | 1 | 1 | | | 1 |
| 2010 | 2 | 2 | 1 | | 1 | | 2 | 1 | 2 | | 1 |
| 2011 | 4 | 4 | 4 | | 1 | 1 | 3 | 3 | 1 | 2 | 2 |
| 2012 | 2 | 2 | 2 | | | 1 | 1 | 1 | 2 | 3 | 2 |
| 2013 | 3 | 2 | 3 | | 1 | 2 | 1 | 1 | 1 | 4 | 2 |
| 2014 | 4 | 3 | 4 | 1 | 1 | 1 | 1 | 1 | 2 | 4 | 2 |
| 2015 | 2 | 1 | 2 | 1 | | 1 | | | 1 | 2 | 2 |
| 2016 | 4 | 3 | 4 | 1 | 1 | 1 | 2 | 1 | 2 | 4 | 2 |
| 2017 | 4 | 3 | 4 | 1 | 1 | 1 | 1 | | 1 | 3 | 3 |

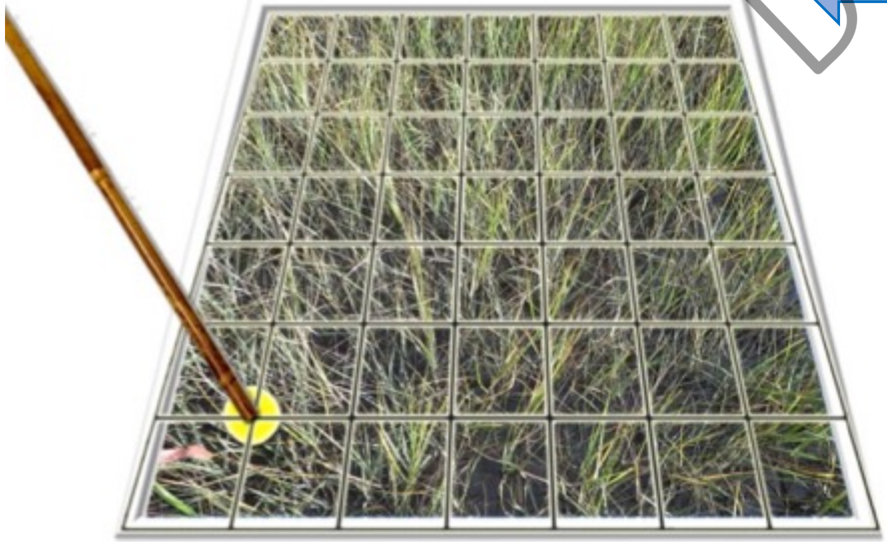
# Integrating Vegetation Methods

**Point-intercept** VS. **Ocular Cover**

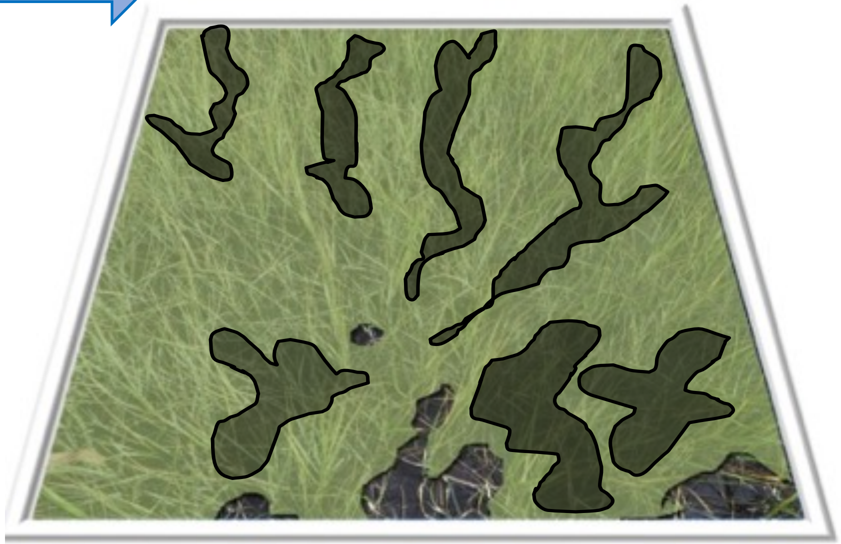


# PI vs OC

*S. alterniflora* 84%
Bare 16%



*S. alterniflora* 60%
Bare 40%

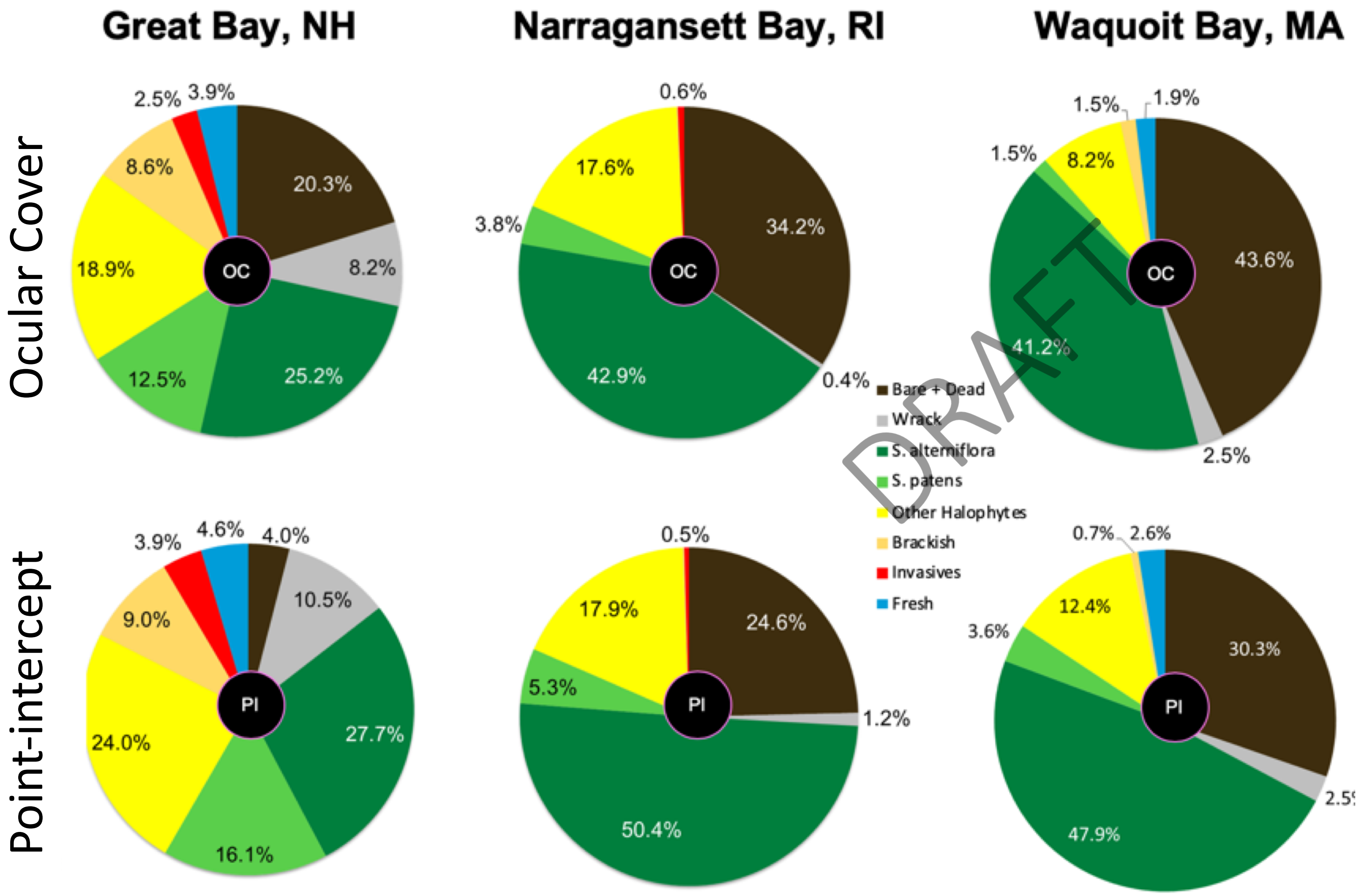


# PI vs OC

| | Point-intercept | Ocular Cover |
|---|---|---|
| TIME | 5 to 30 minutes | 1 to 15 minutes |
| STAFF | Variable | Consistent / Group |
| EQUIPMENT | Strings, legs, 5 dowels | Quadrat only |
| ACCURACY | Objective | Subjective |
| AREA MEASURED | < 0.0001 $m^2$ | 1 $m^2$ |
| EXCEPTIONS | Bare and dead: "2nd class" cover | All covers weighted equally |
| REPRESENTATION | Presence / absence | 2D representation of plot |
| BIASES | Spreading, thin-leaved | Taller canopy, broad-leaved |
| CANOPY | All layers weighted equally | Taller covers weighted more |
| BIOMASS | Better? | |
| PHOTO | No | Yes |
| ANALYSIS | More difficult | Simple |



# PI vs OC




| | PI | OC |
|---|---|---|
| Bare | ↓ | ↑ |
| Dead | ↓ | ↑ |
| Live Cover | ↑ | ↓ |
| Taller | ↓ | ↑ |
| Lower | ↑ | ↓ |
| Broad | ↓ | ↑ |
| Thin | ↑ | ↓ |

# PI vs OC

## PI Transformations

1. PI: 2x to 100 points/plot

2. PI-N: Normalized to 100%

$$X = \frac{100 - (Bare + Dead)}{Total\ Live\ Cover} * \text{PI}$$

3. PI-RN: Regressions using PI, normalized after

4. PI-NRN: Regression using normalized PI, re-normalized after

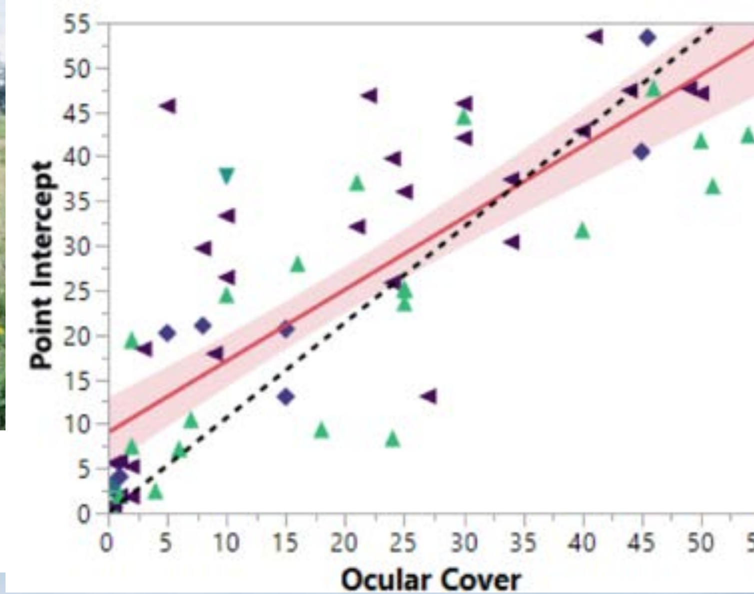
Morphological Archetypes



| | PI | OC |
|---|---|---|
| Bare | ↓ | ↑ |
| Dead | ↓ | ↑ |
| Live Cover | ↓ | ↑ |
| Taller | ↓ | ↑ |
| Lower | ↑ | ↓ |
| Broad | ↓ | ↑ |
| Thin | ↑ | ↓ |

# Morphological Archetypes



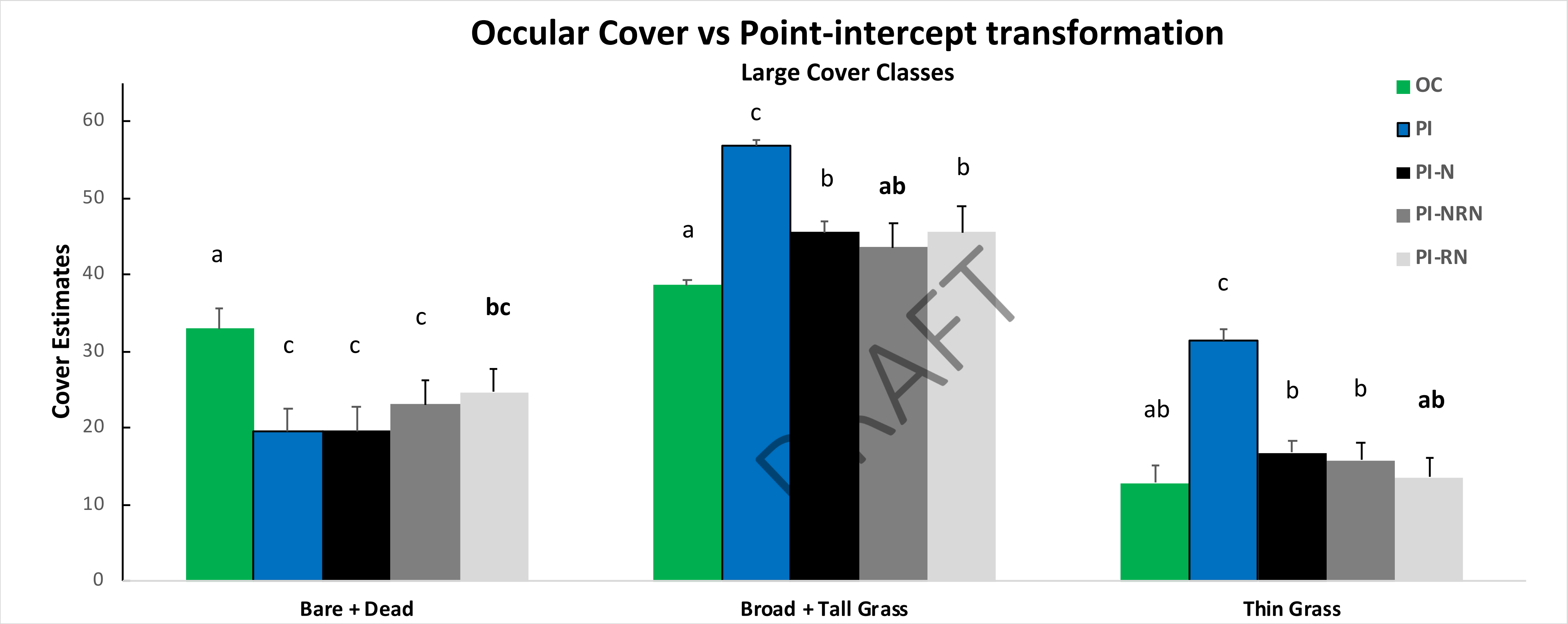




**Transforming Point-intercept to Ocular Cover**

Synthesizing NERR Sentinel Site Data to Improve Coastal Wetland Management Across New England
Wells Reserve, Maine August 22, 2019

| Morphological Archetypes | Cover | Morphological Archetypes | Cover |
|---|---|---|---|
| Bare/Dead | Bare Ground | Broad 'Grasses' | *Agropyron pungens* |
| Bare/Dead | Dead | Broad 'Grasses' | *Ammophilia breviligulata* |
| Ground / Algae | *Algae* | Broad 'Grasses' | *Carex spp.* |
| Ground / Algae | *Ascophyllum nodosum* | Broad 'Grasses' | *Phragmites australis* |
| Ground / Algae | *Fucus spp* | Broad 'Grasses' | *Phragmites australis var. americanus* |
| Ground / Algae | *Fucus vesiculosus* | Broad 'Grasses' | *Schoenoplectus maritimus* |
| Ground / Algae | *Gracilaria sp.* | Broad 'Grasses' | *Schoenoplectus robustus* |
| Ground / Algae | *Moss* | Broad 'Grasses' | *Spartina alterniflora* |
| Ground / Algae | *Ruppia maritima* | Broad 'Grasses' | *Spartina pectinata* |
| Ground / Algae | *Ulva Lactuca* | Broad 'Grasses' | *Typha angustifolia* |
| Ground / Algae | *Wrack* | Thin' Grasses' | *Agrostis stolonifera* |
| Forbs | *Atriplex patula* | Thin' Grasses' | *Distichlis spicata* |
| Forbs | *Galium palustre* | Thin' Grasses' | *Festuca rubra* |
| Forbs | *Impatiens capensis* | Thin' Grasses' | *Juncus balticus* |
| Forbs | *Iris versicolor* | Thin' Grasses' | *Juncus gerardii* |
| Forbs | *Lepedium virginicum* | Thin' Grasses' | *Spartina patens* |
| Forbs | *Limonium nashii* | Climbers | *Calystegia sepium* |
| Forbs | *Mentha arvensis* | Climbers | *Cuscuta gronovii* |
| Forbs | *Oenothera biennis* | Climbers | *Cuscuta spp.* |
| Forbs | *Onoclea sensibilis* | Climbers | *Parthenocissus quinquefolia* |
| Forbs | *Osmunda cinnamomea* | Climbers | *Smilax spp.* |
| Forbs | *Plantago spp* | Climbers | *Solanum dulcamara* |
| Forbs | *Polygonum ramosissimum* | Climbers | *Toxicodendron radicans* |
| Forbs | *Salicornia depressa* | Shrubs & Trees | *Acer rubrum* |
| Forbs | *Salicornia maritima* | Shrubs & Trees | *Alnus spp* |
| Forbs | *Salicornia spp* | Shrubs & Trees | *Baccharis halimifolia* |
| Forbs | *Solidago sempervirens* | Shrubs & Trees | *Iva frutescens* |
| Forbs | *Spergularia marina* | Shrubs & Trees | *Juniperus virginiana* |
| Forbs | *Suaeda linearis* | Shrubs & Trees | *Myrica pensylvanica* |
| Forbs | *Sueda maritima* | Shrubs & Trees | *Myrica spp* |
| Forbs | *Symphyotrichum novi-belgii* | Shrubs & Trees | *Picea spp* |
| Forbs | *Symphyotrichum spp.* | Shrubs & Trees | *Prunus maritima* |
| Forbs | *Symphyotrichum subulatus* | Shrubs & Trees | *Quercus rubra* |
| Forbs | *Teucrium canadense* | Shrubs & Trees | *Rosa multiflora* |
| Forbs | *Thalictrum dioicum* | Shrubs & Trees | *Rosa rugosa* |
| Forbs | *Thalictrum polygamum* | Shrubs & Trees | *Spiraea tomentosa* |
| Forbs | *Trientalis borealis* | | |

# Morphological Archetypes






**Legend**

**OC**: Ocular cover

**PI**: Point-intercept to 100 point plot (i.e., 2x)

**PI-N**: Point-intercept normalized to 100% using the Burdick method: Keep bare and dead values, but normalize rest

**PI-RN**: Regression using Point-intercept data, then normalized all to 100%

**PI-NRN**: Regression using Point-intercept normalized data the Burdick way, then normalized all to 100%

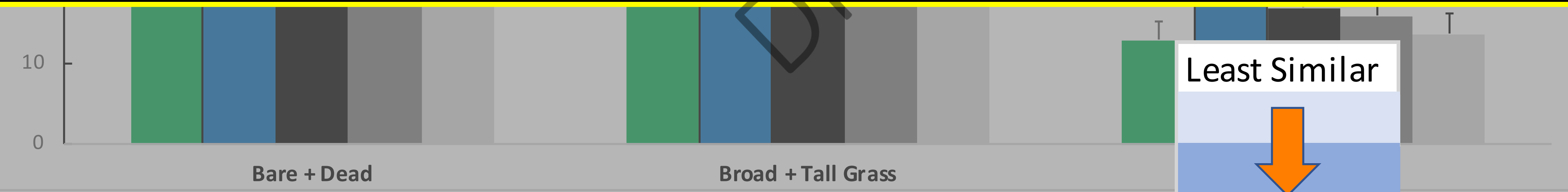
# Morphological Archetypes

## Occular Cover vs Point-intercept transformation

Large Cover Classes

| | Bare + Dead | Broad + Tall Grass | Thin Grass | Climbers | Forbs | Ground + Algae | Shrubs + Trees |
|---|---|---|---|---|---|---|---|
| **OC** | 32.99 | 38.61 | 12.86 | 1.56 | 4.47 | 6.94 | 3.10 |
| **PI** | 19.64 | 56.96 | 31.41 | 2.67 | 11.80 | 11.78 | 4.93 |
| **PI-N** | 19.64 | 45.50 | 16.72 | 1.07 | 5.76 | 8.57 | 2.74 |
| **PI-NRN** | 23.06 | 43.51 | 15.71 | 1.31 | 5.23 | 8.18 | 3.02 |
| **PI-RN** | 24.66 | 45.56 | 13.51 | 1.07 | 4.12 | 7.89 | 3.13 |






Least Similar

Most similar

**Legend**

**OC**: Ocular cover

**PI**: Point-intercept to 100 point plot (i.e., 2x)

**PI-N**: Point-intercept normalized to 100% using the Burdick method: Keep bare and dead values, but normalize rest

**PI-RN**: Regression using Point-intercept data, then normalized all to 100%

**PI-NRN**: Regression using Point-intercept normalized data the Burdick way, then normalized all to 100%

# Other Dissimilarities

## Vegetation

- Density
- Height
- Cover: Dead, wrack, algae
- Transect
  - Length, location, plot spacing
- Ecotone



## Auxiliary

- SET: accretion
- Porewater

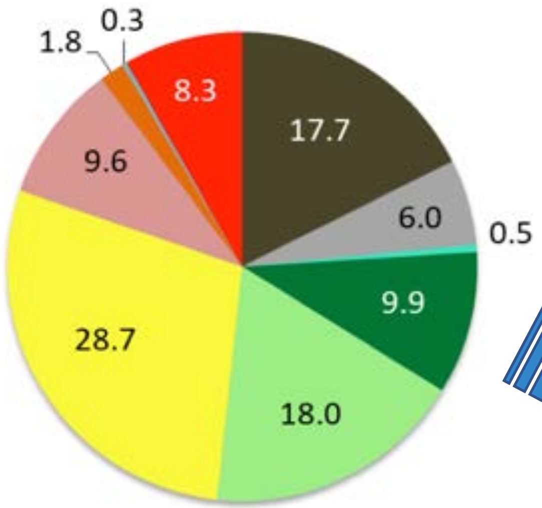
## Database

- Time 90/10
- New England Species list
  - 189 spp.
- 50,000 veg data points
- Marsh zones

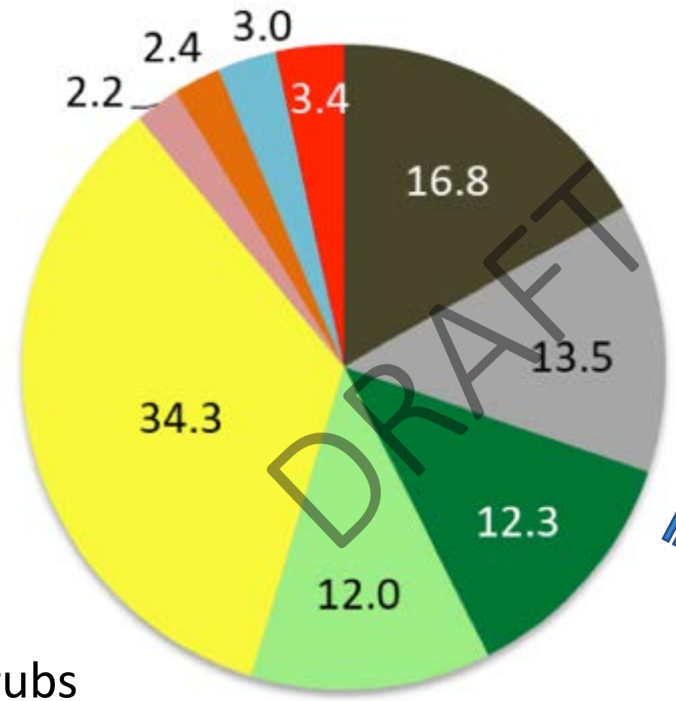
# ‘Tracking’ Marshes Over Time

# Great Bay, NH

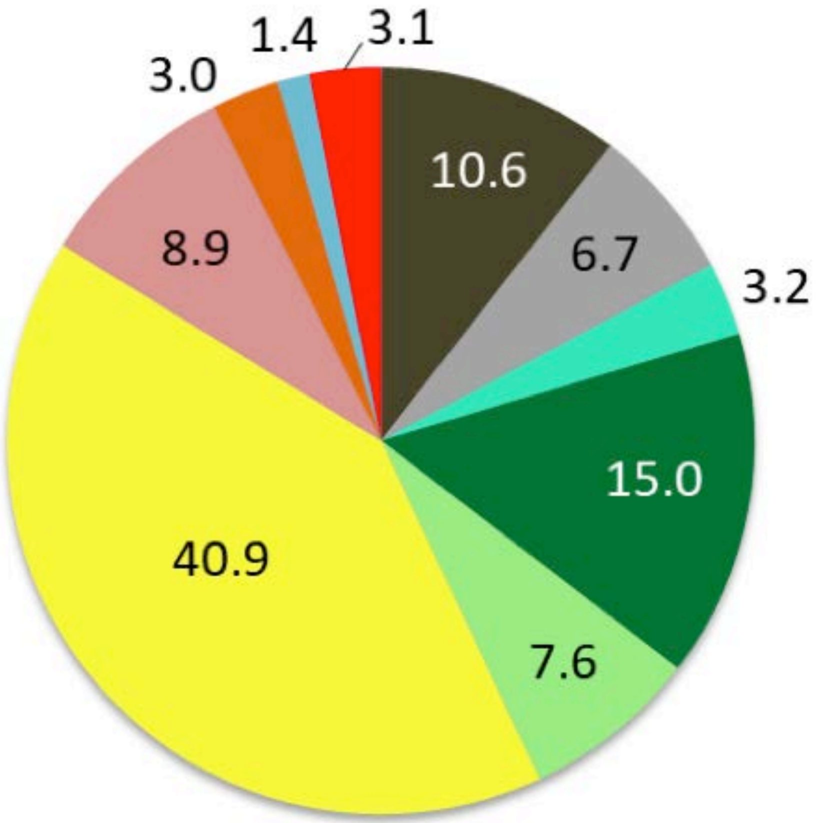
Sandy Point: High Marsh


2010



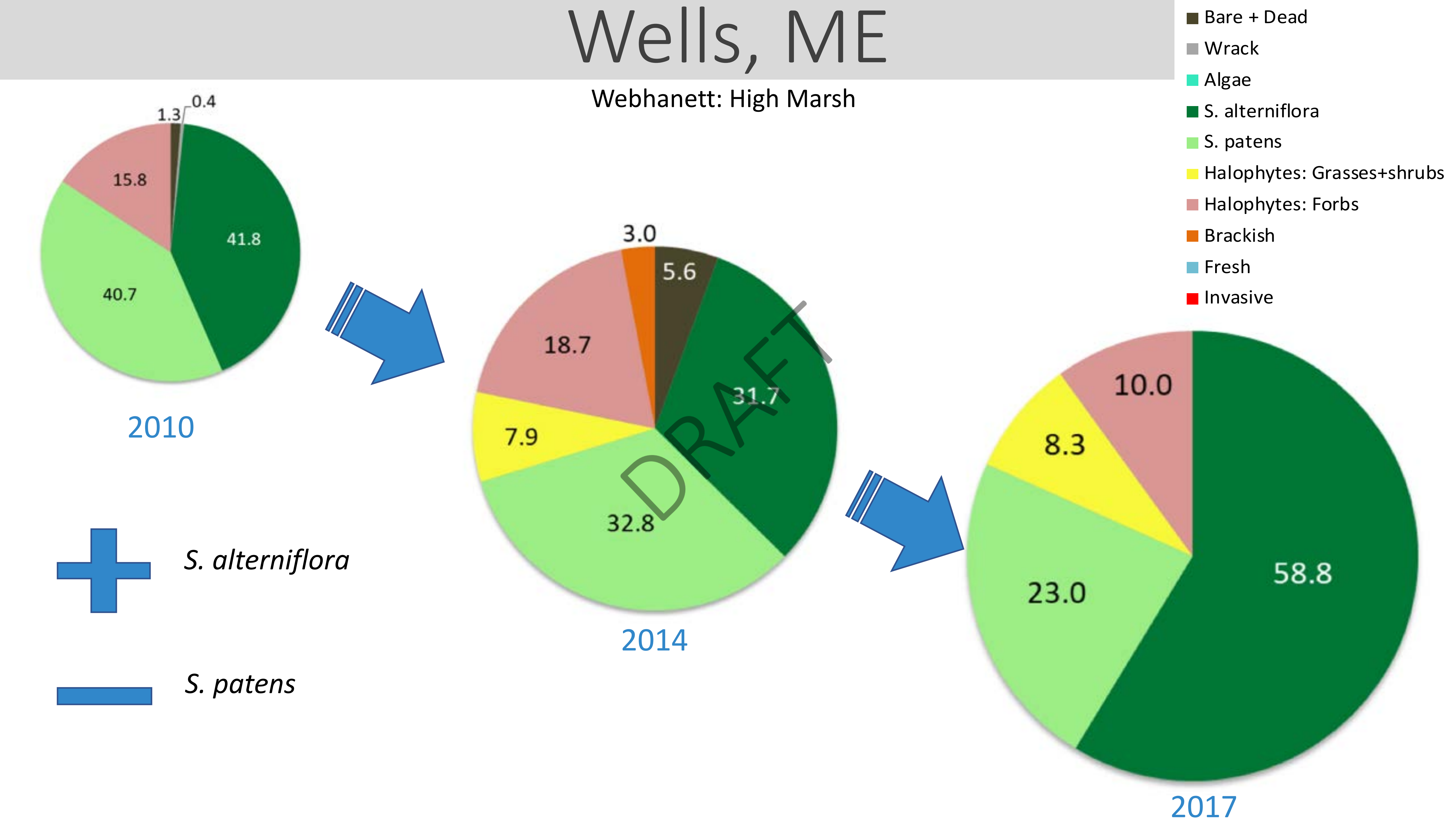

2014




2017

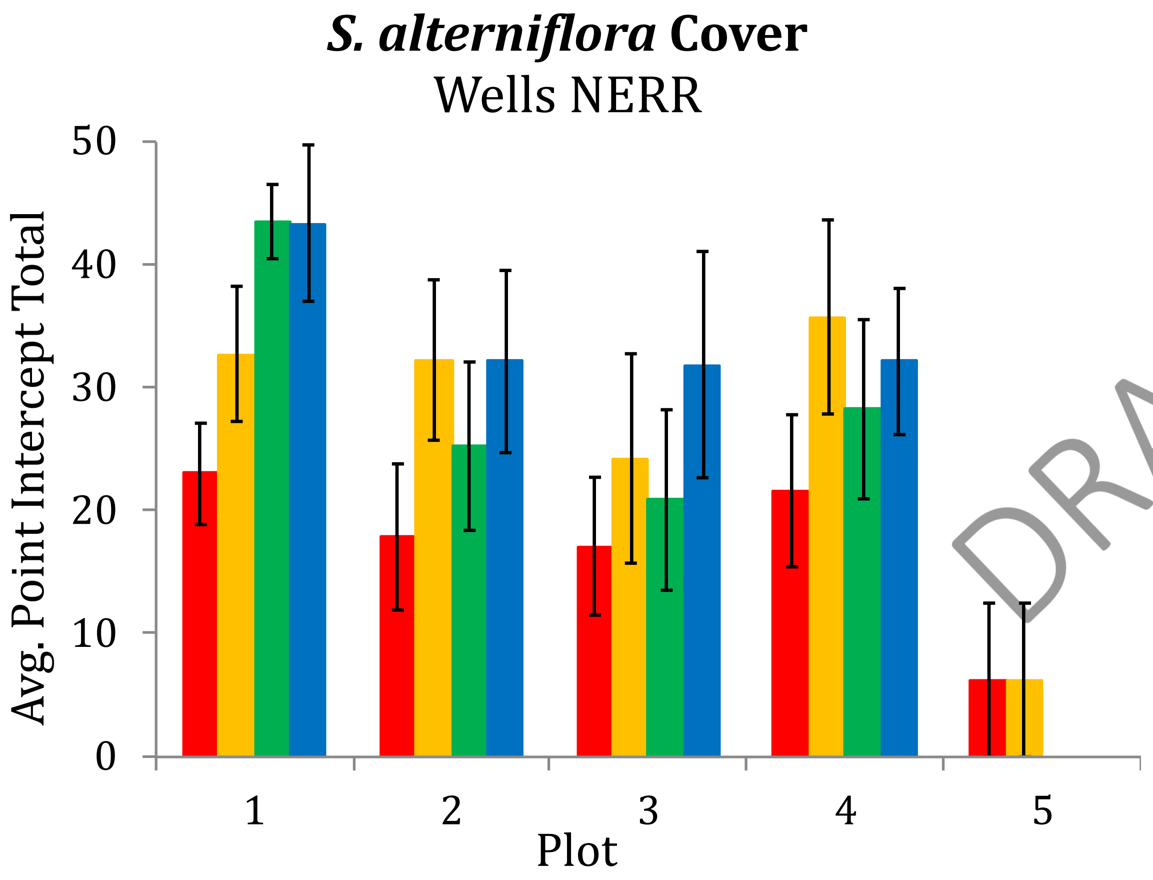
+ S. alterniflora
Halophytes: grasses + shrubs

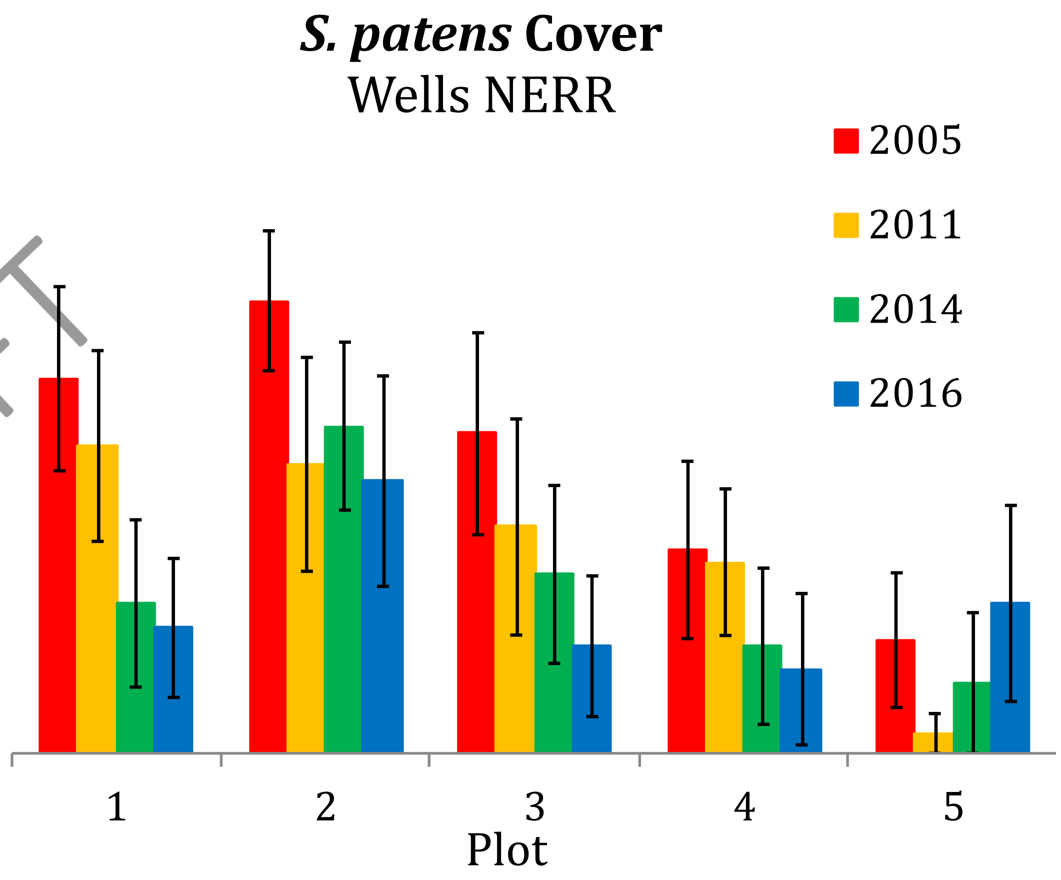
− *S. patens*
Bare


Wells, ME
Webhanett: High Marsh
Bare + Dead
Wrack
Algae
S. alterniflora
S. patens
Halophytes: Grasses+shrubs
Halophytes: Forbs
Brackish
Fresh
Invasive
1.3
0.4
15.8
41.8
40.7
2010
3.0
5.6
18.7
31.7
7.9
32.8
2014
DRAFT
10.0
8.3
23.0
58.8
2017
S. alterniflora
S. patens

# Wells, ME

Webhanett, ME



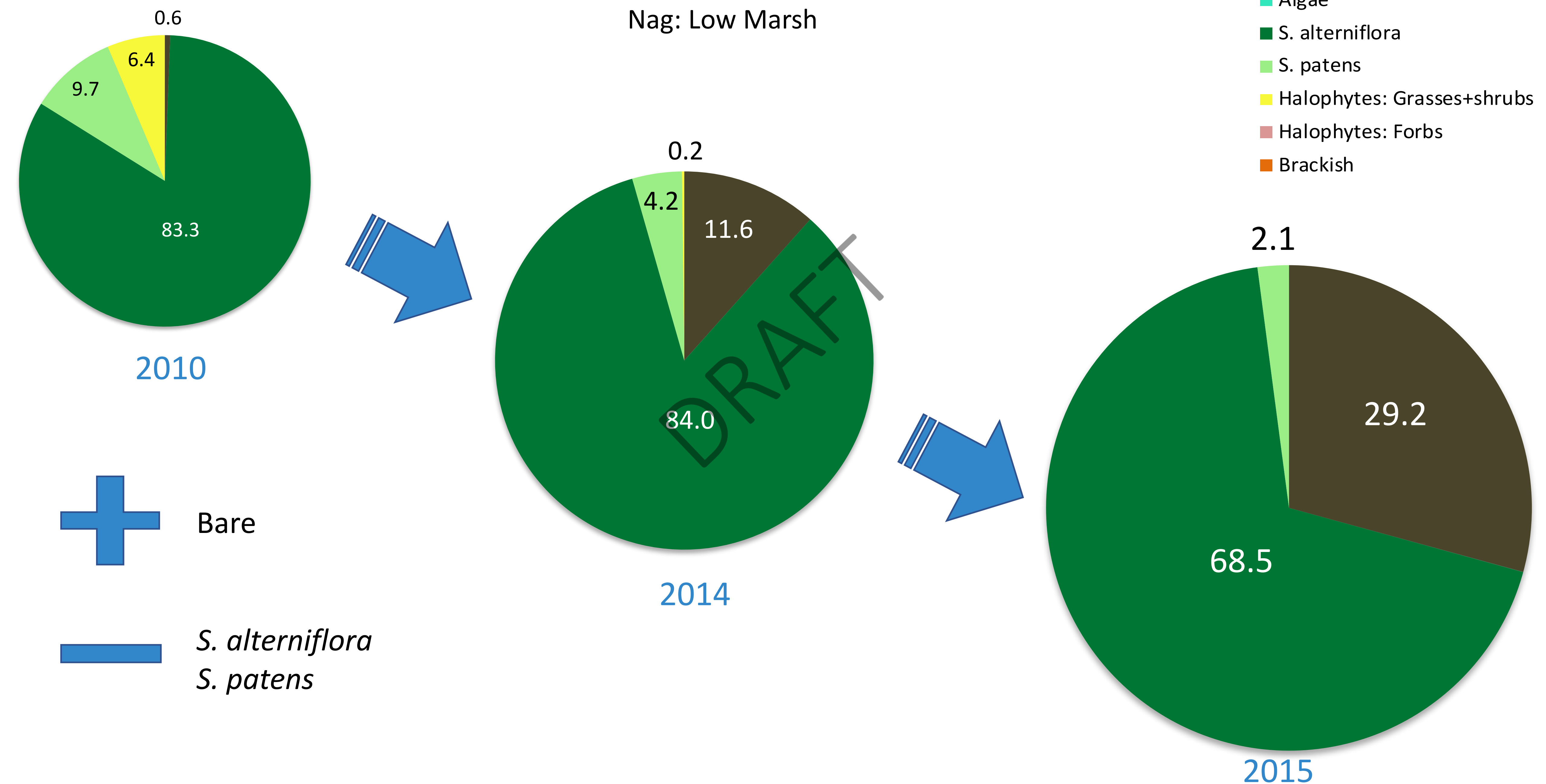






*S. alterniflora*

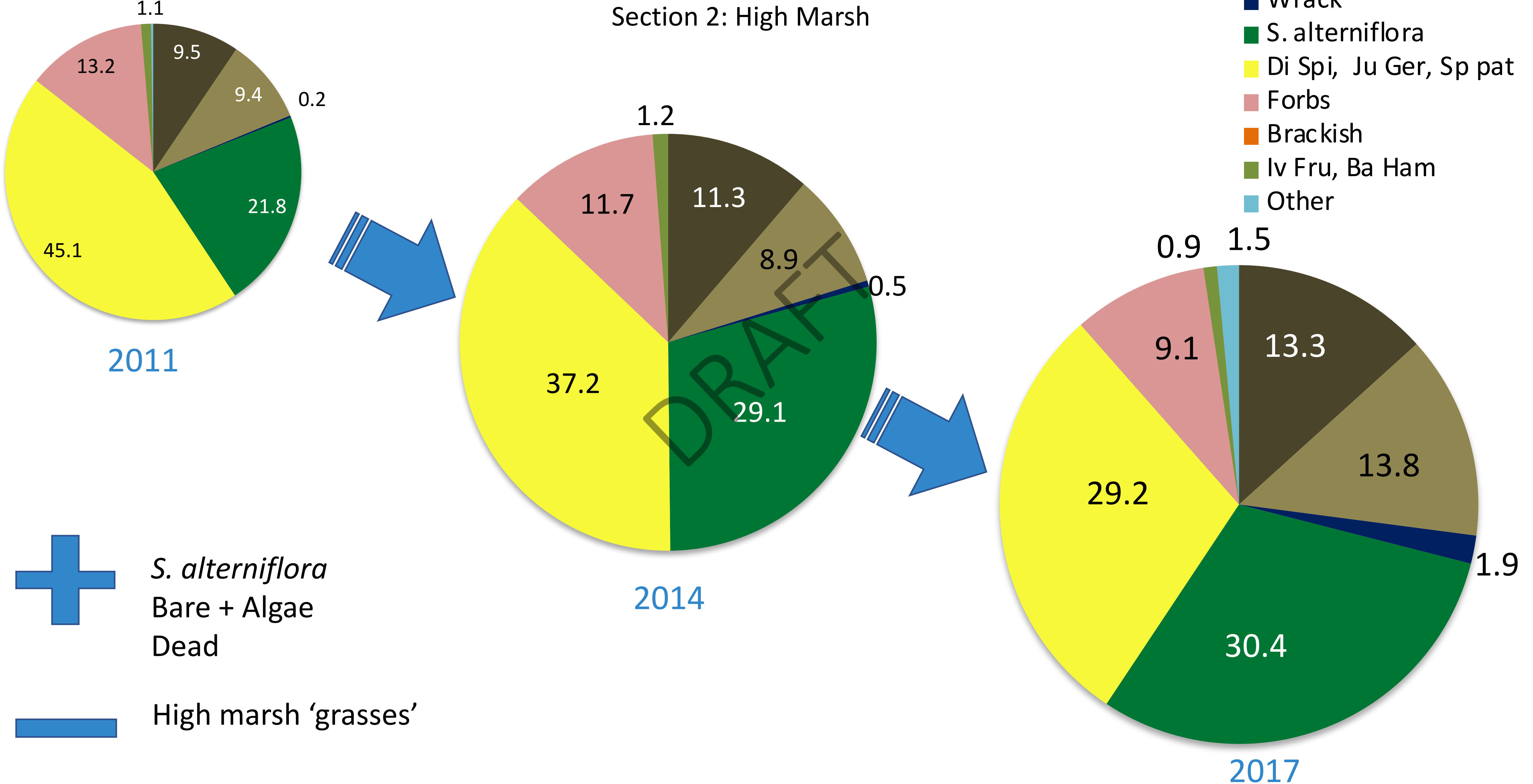
*S. patens*

# Narragansett, RI



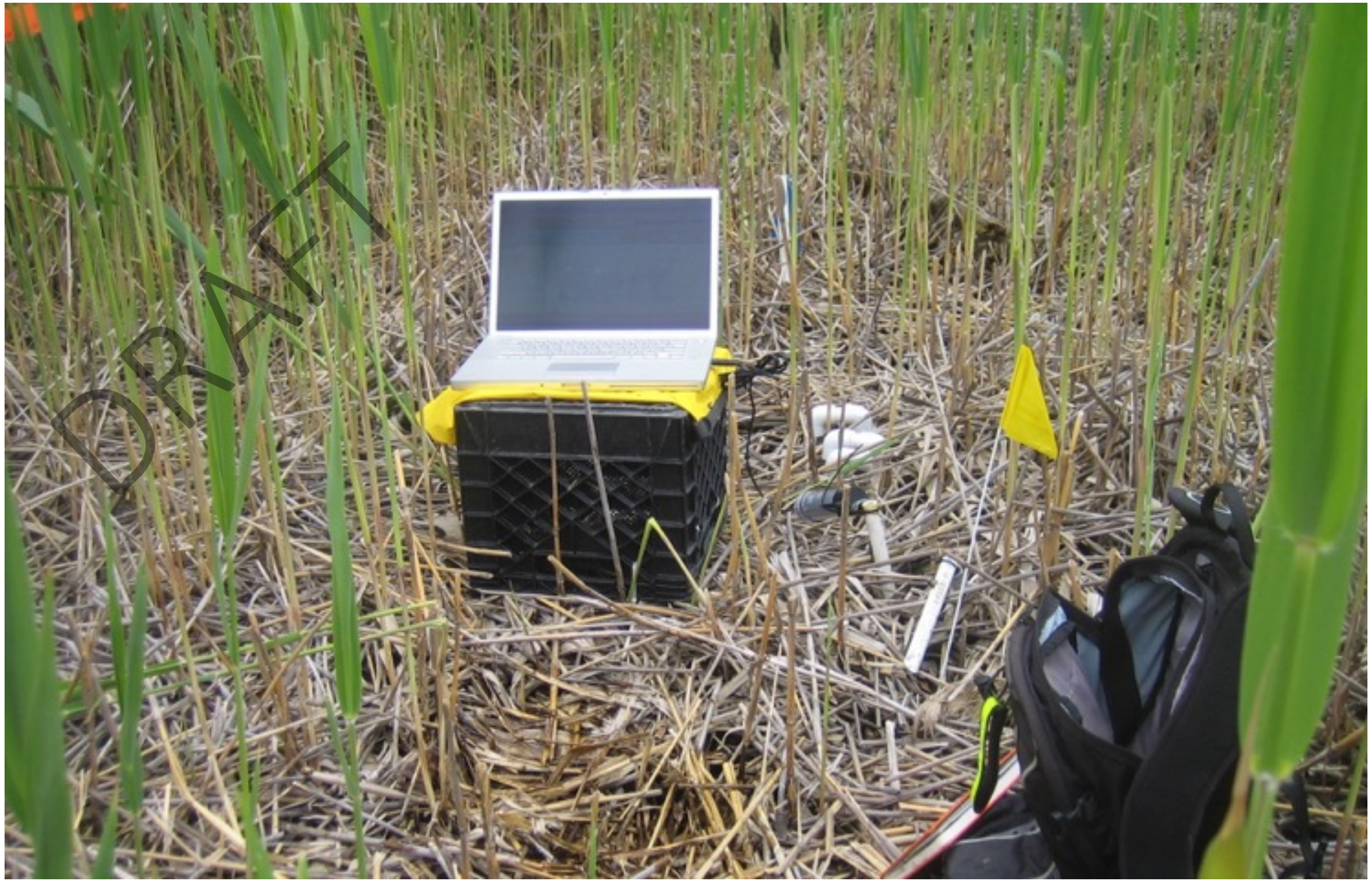
# Waquoit Bay, MA

Section 2: High Marsh



# Next: Univariate Analyses

- ➢ Database Development
  - ➢ Crunching
- ➢ Summary
  - ➢ Pie charts
- ➢ Univariate
  - ➢ Regression models
- ➢ Multivariate
  - ➢ Primer



# Univariate Analyses of Vegetation Data

1) Must Identify habitat for any reasonable analysis (too much variability unexplained w/o habitat)

2) Broad trends can be identified across NE, within North/South regions, and within reserves

3) BUT drilling down within reserves can provide details on how habitats are changing at different marshes.

Next sets of slides will begin at 20,000 ft and zoom in from:

1) NE (all 4 Reserves)

2) Regions:

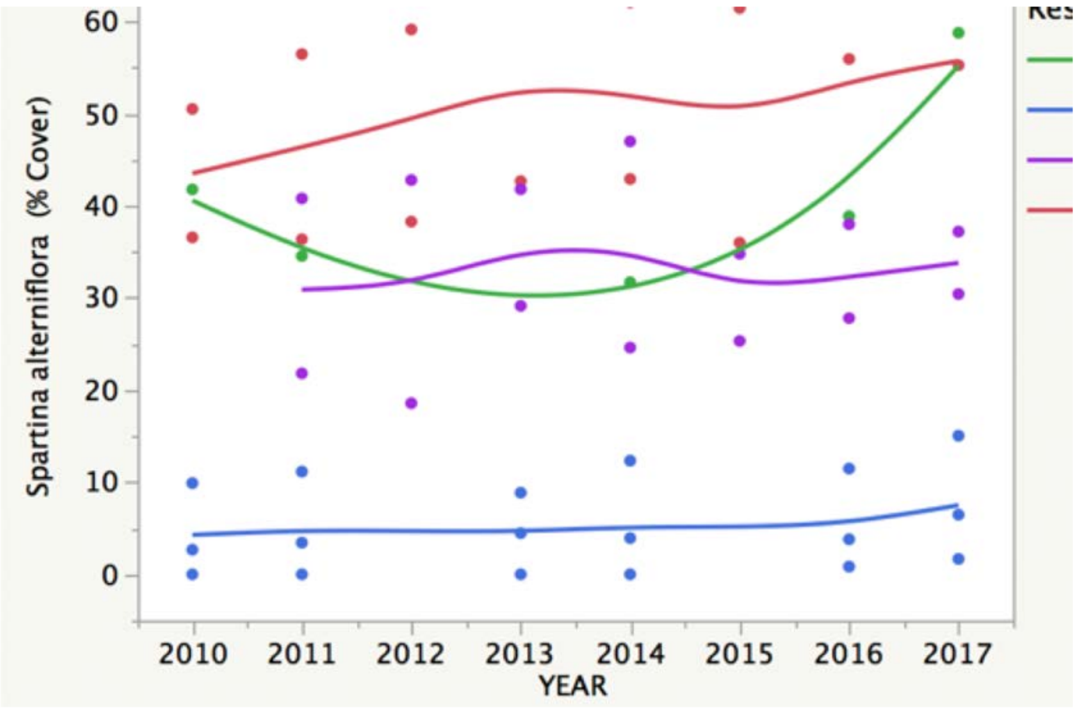
2 Reserves in the north with 2-3 m tides

2 Reserves in the South with 1 m tides

3) Great Bay Reserve focus



**Spartina alterniflora in High Marsh**



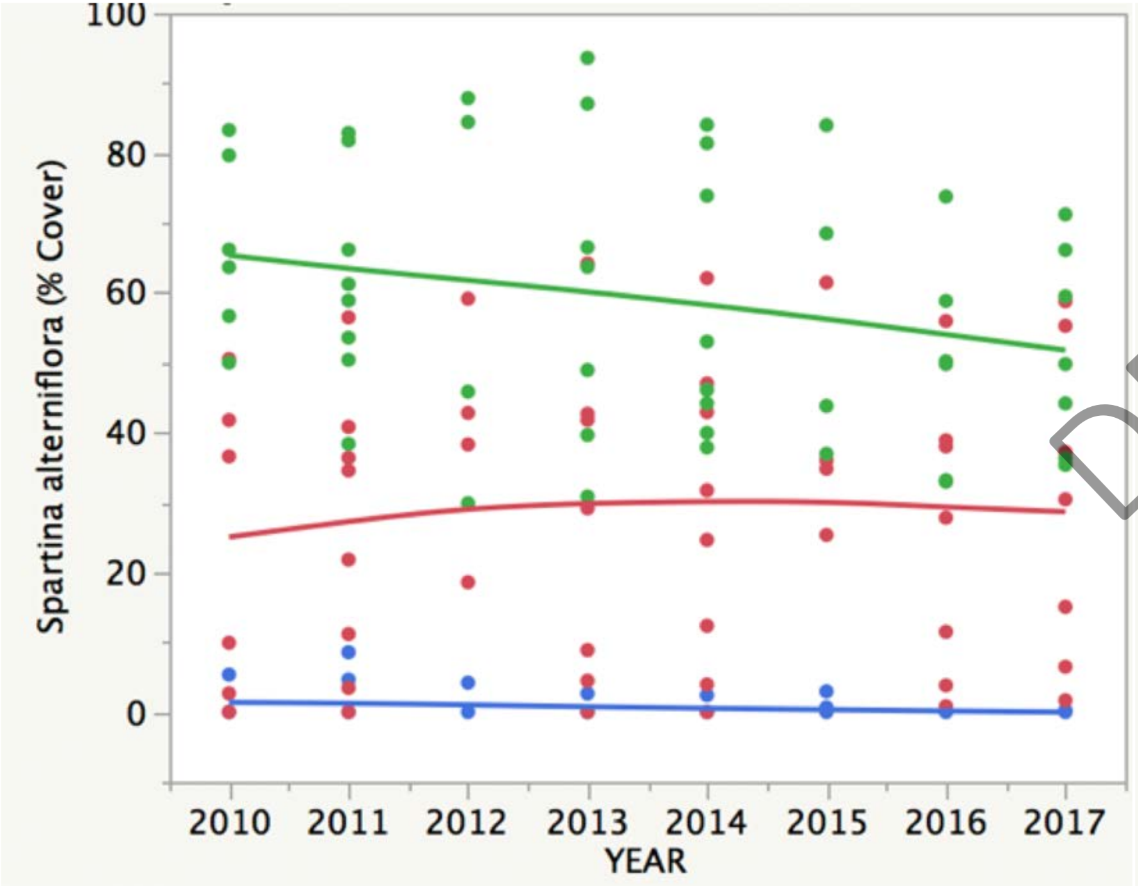
# Univariate Analysis: All Four Reserves Combined

## Statistical ANCOVA Model

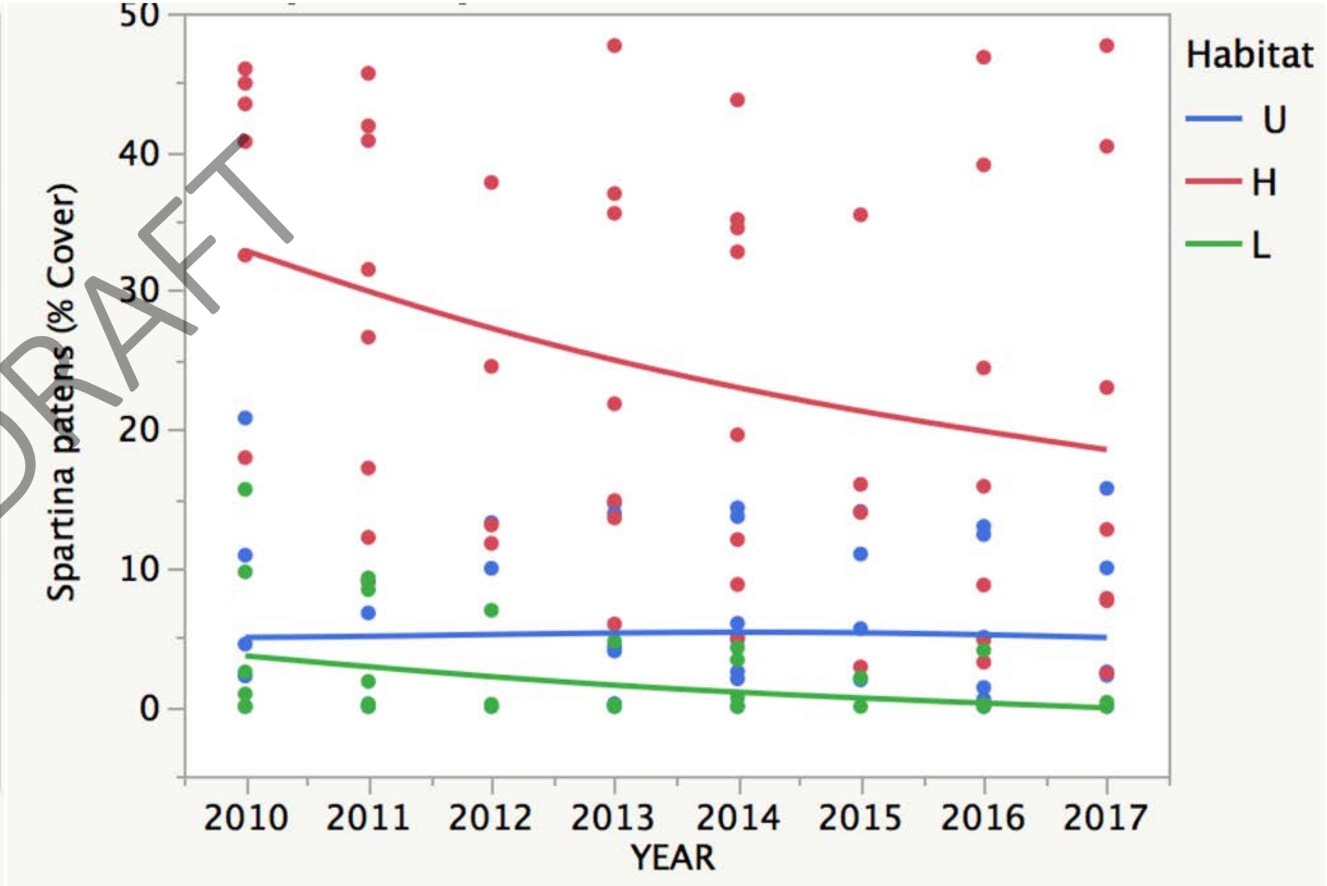
| Dependent Variable | SITE | HABITAT | YEAR | Site X Habitat | Year X Habitat | Year X Site | Overall F | R2 |
|---|---|---|---|---|---|---|---|---|
| Non-Living | 0.0001 | 0.0001 | 0.0003 | 0.0001 | 0.8612 | 0.0319 | 26 | 0.89 |
| Spartina alterniflora | 0.0001 | 0.0001 | 0.3354 | 0.0001 | 0.0025 | 0.0964 | 72 | 0.96 |
| Spartina patens | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 257 | 0.99 |
| SA : SP Ratio | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0056 | 277 | 0.99 |
| Halophytes | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.5210 | 0.0214 | 29 | 0.90 |
| Dispi + Juger + Sppat | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0308 | 0.0001 | 194 | 0.98 |
| Forbs LN | 0.0001 | 0.0001 | 0.1973 | 0.0001 | 0.2356 | 0.2608 | 1.54 | 0.14 |
| Species richness | 0.0001 | 0.0001 | 0.4295 | 0.0001 | 0.2200 | 0.1758 | 40 | 0.93 |

# Univariate Analysis: All Four Reserves Combined

## *Spartina alterniflora*

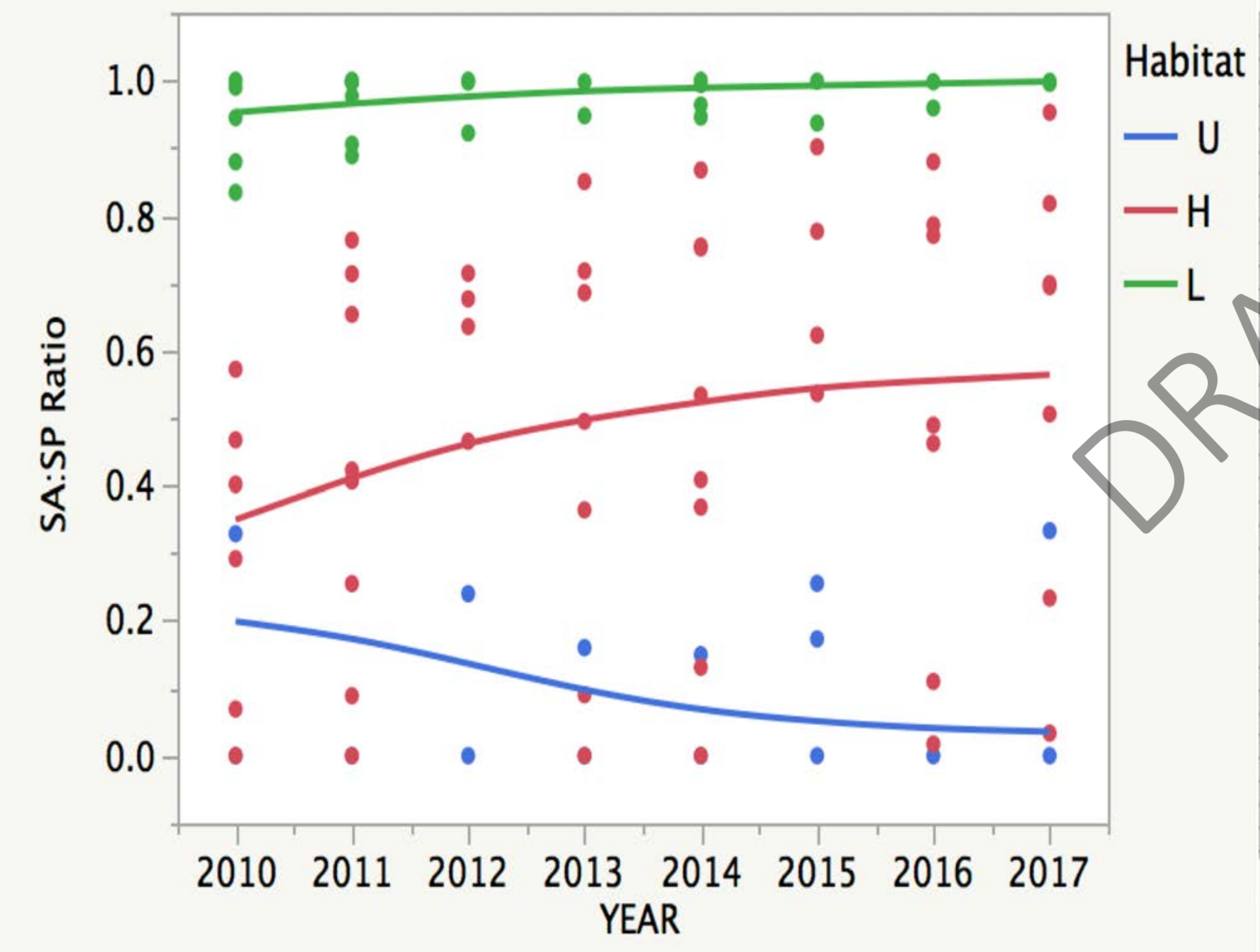


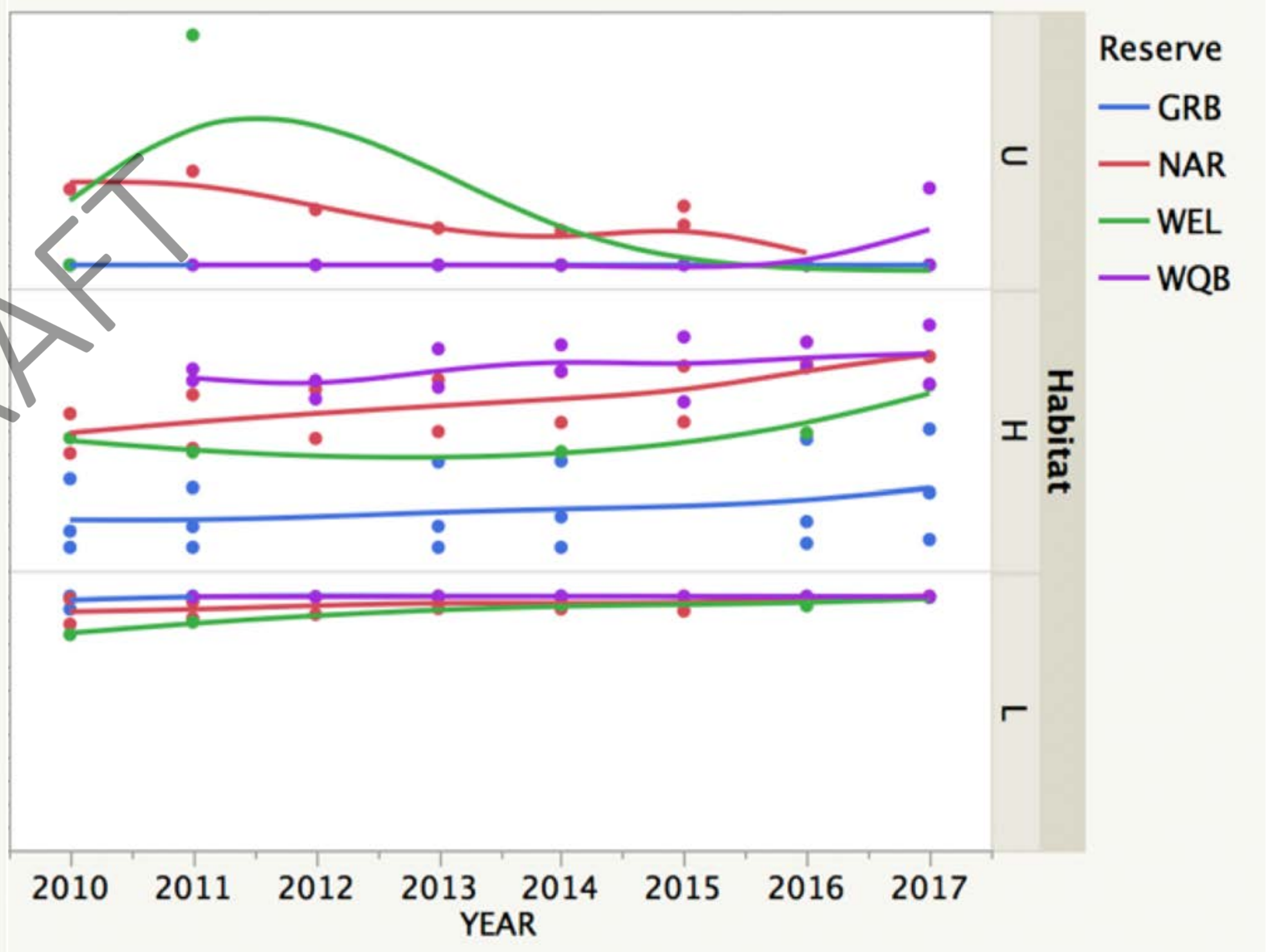

## *Spartina patens*



# Univariate Analysis: All Four Reserves Combined

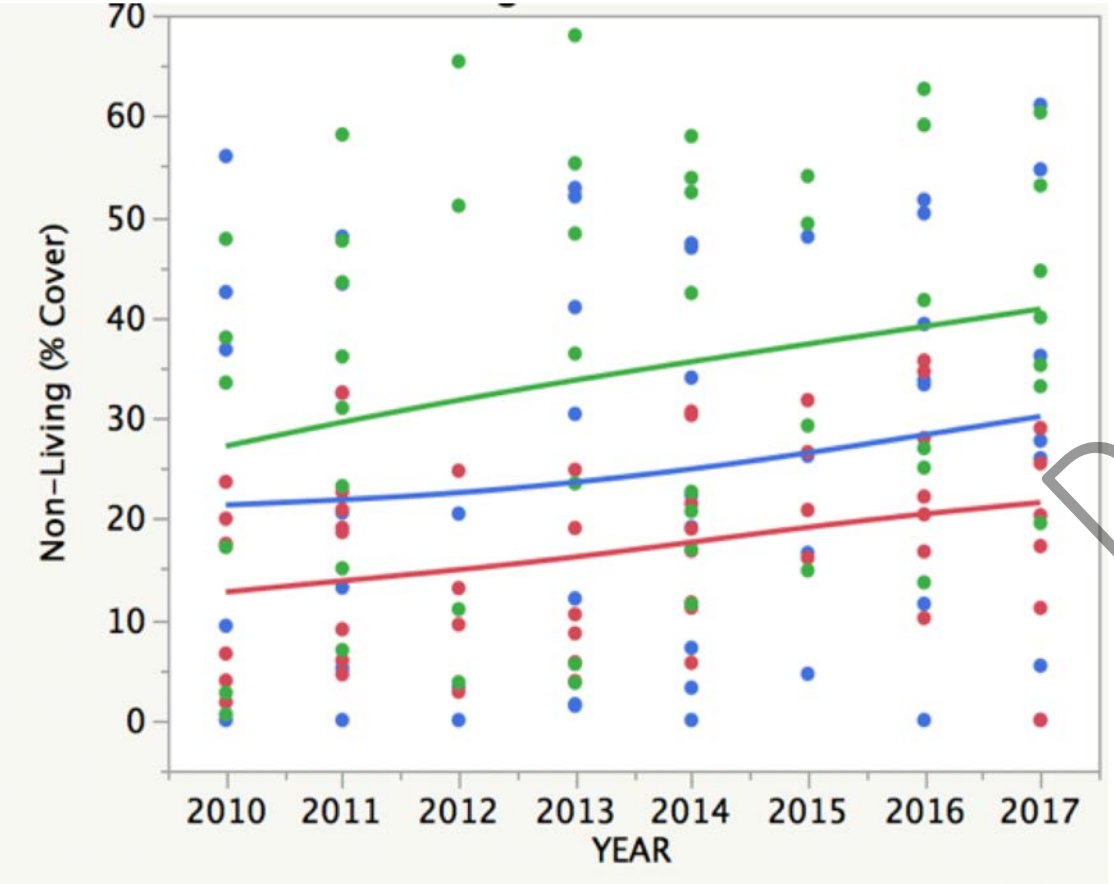
## SA:SP Ratio



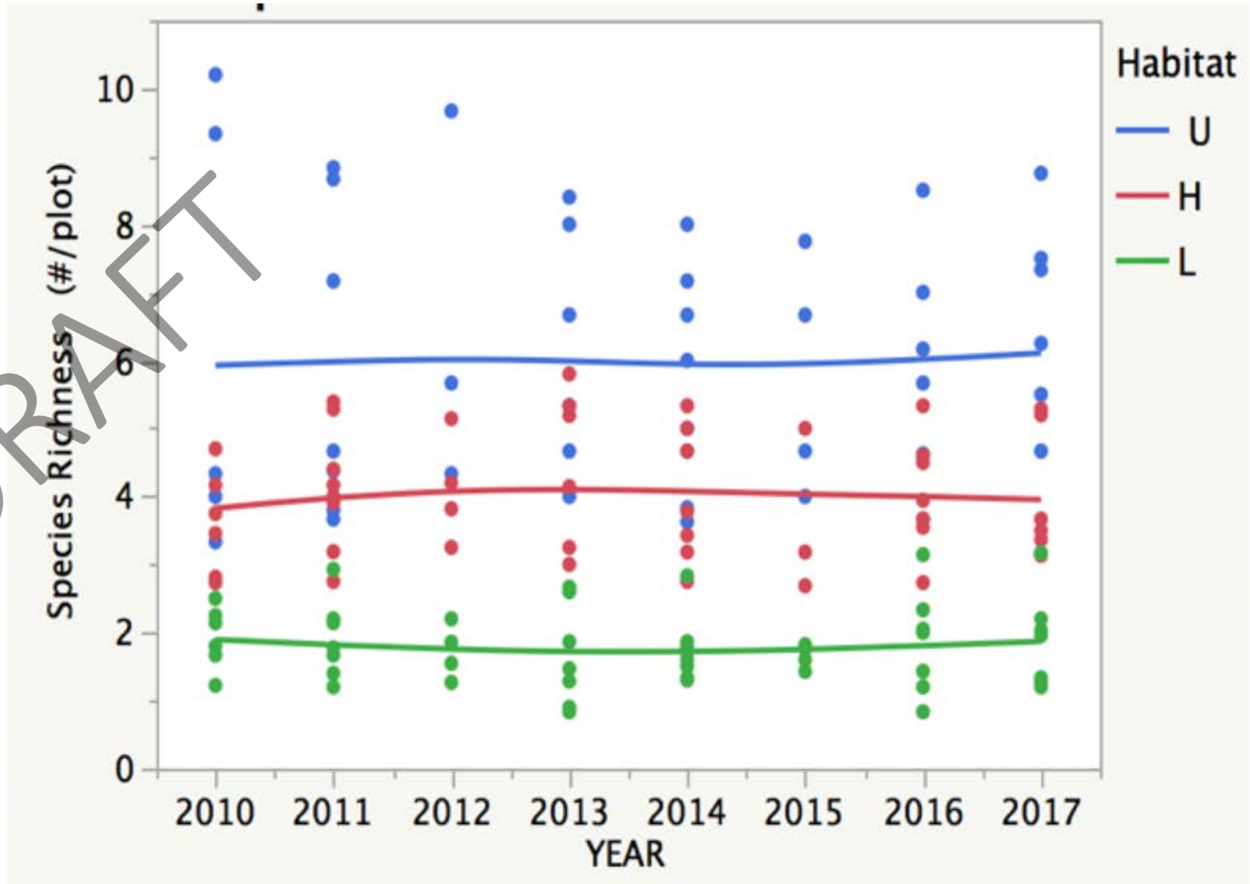



# Univariate Analysis: All Four Reserves Combined

## Non-Living Cover




## Species Richness



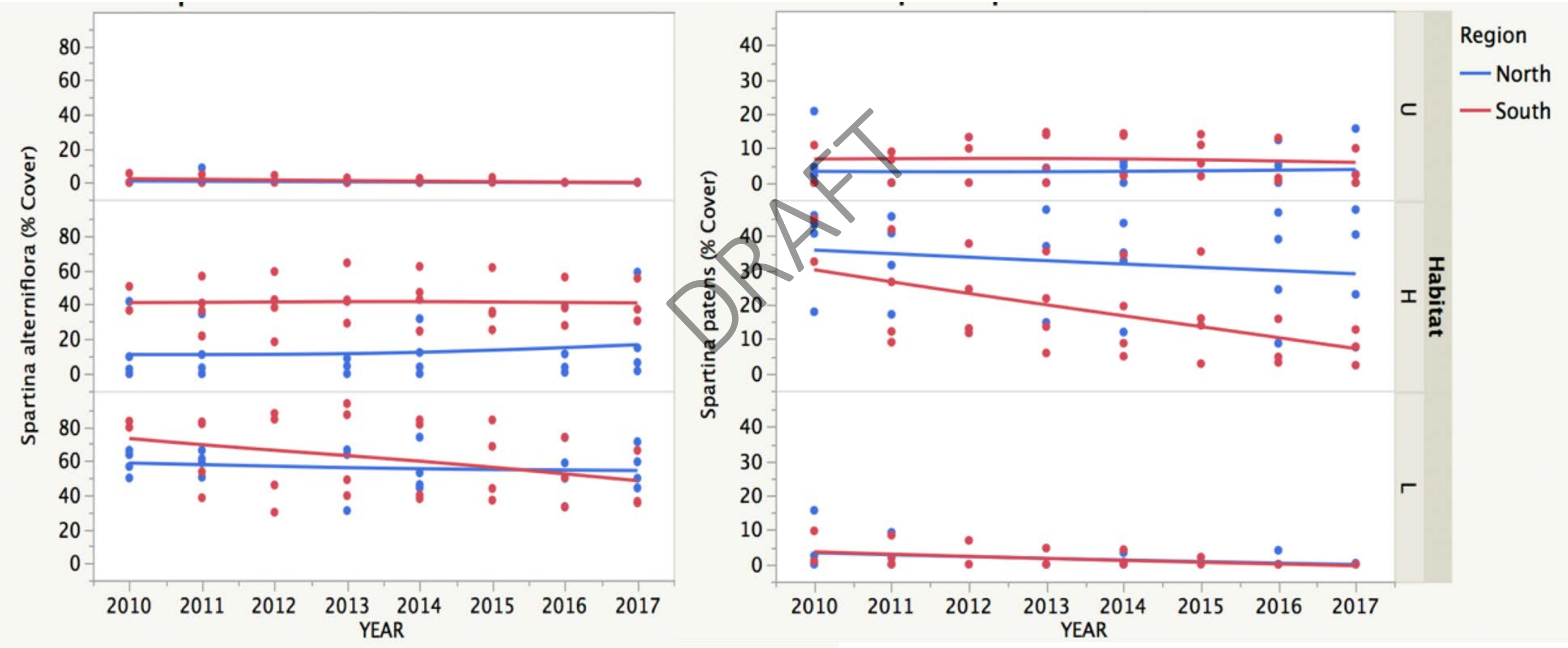
# Univariate Analysis By Region (North-South)

## Statistical ANCOVA Model

| VARIABLE | REGION | HABITAT | YEAR | Year x Habitat | Year x Region | Region x Habitat | Overall F | R2 |
|---|---|---|---|---|---|---|---|---|
| Non-Living LN | 0.0171 | 0.0005 | 0.0013 | 0.8885 | 0.0009 | 0.0295 | 26 | 0.89 |
| Spartina alterniflora LN | 0.0001 | 0.0001 | 0.3285 | 0.1234 | 0.1825 | 0.0001 | 72 | 0.96 |
| Spartina patens. LN | 0.6962 | 0.0001 | 0.0077 | 0.0968 | 0.1367 | 0.0002 | 257 | 0.99 |
| SA : SP Ratio | 0.0001 | 0.0001 | 0.5158 | 0.0008 | 0.4069 | 0.0001 | 277 | 0.99 |
| Dispi + Juger + Sppat | 0.0001 | 0.0001 | 0.0007 | 0.9454 | 0.0084 | 0.0001 | 194 | 0.98 |
| Species richness | 0.3510 | 0.0001 | 0.6484 | 0.8699 | 0.0918 | 0.8949 | 40 | 0.93 |

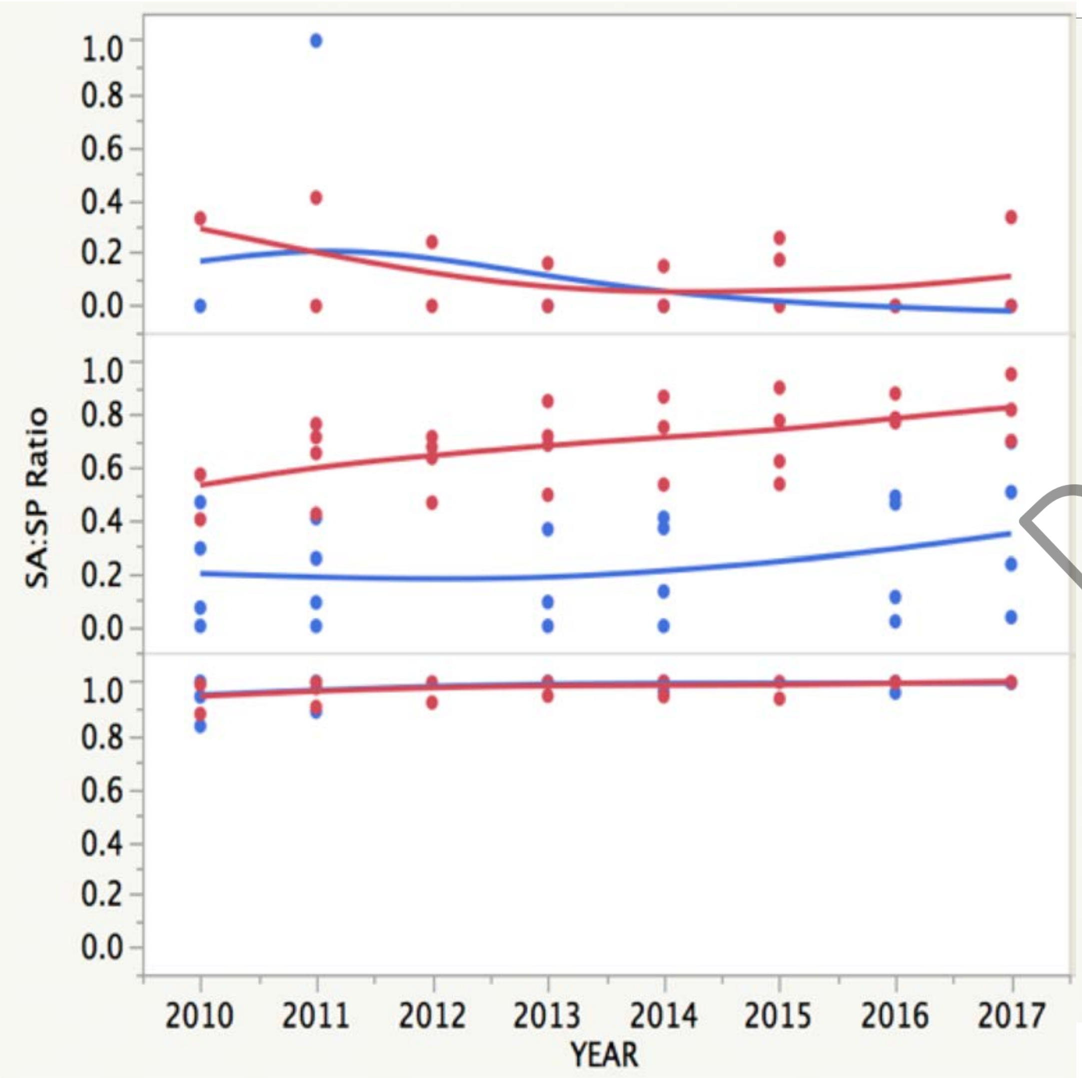
# Analysis By Region (North-South)

## *Spartina alterniflora* *Spartina patens*

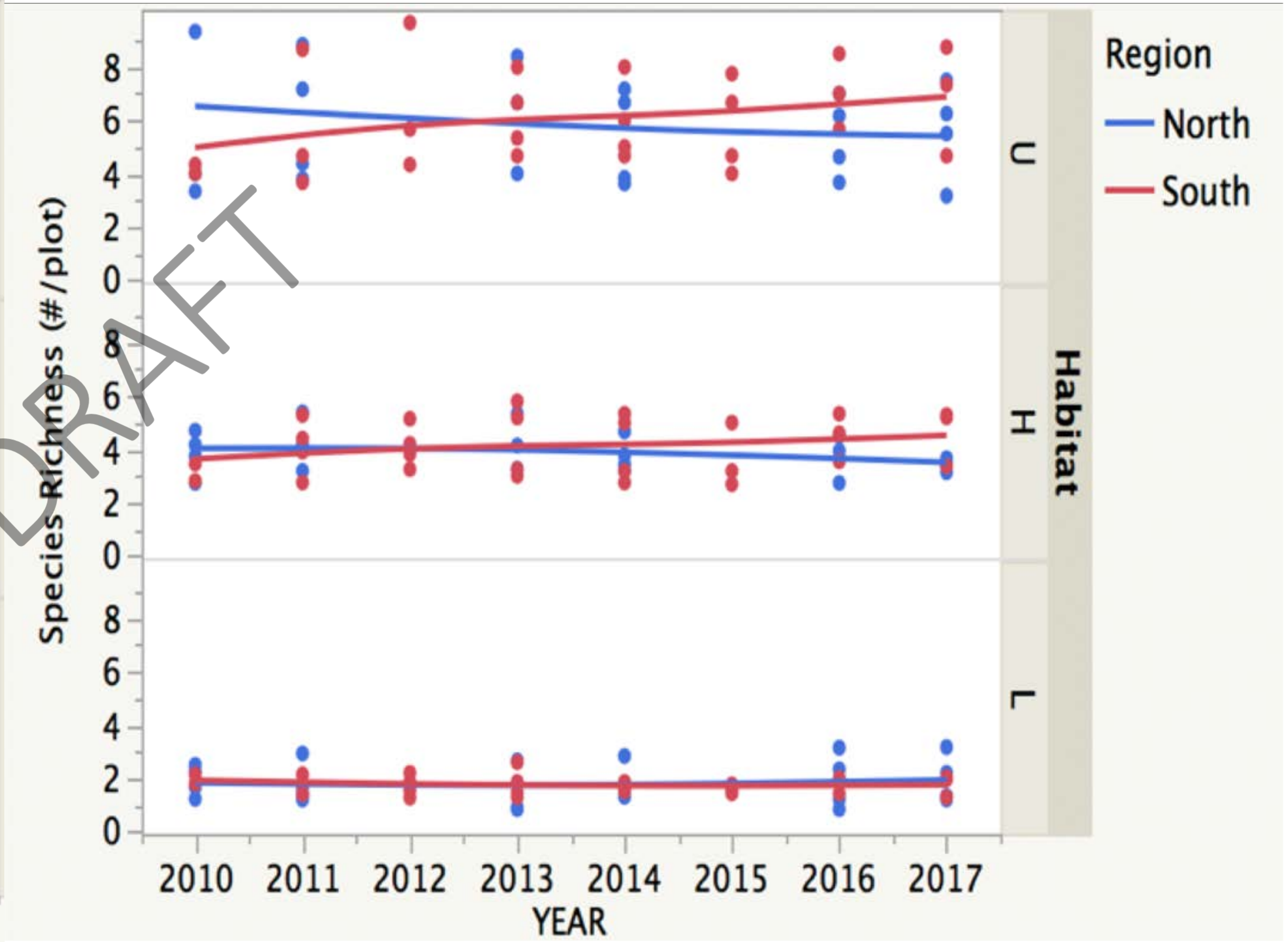


# Analysis By Region (North-South)

## SA:SP Ratio

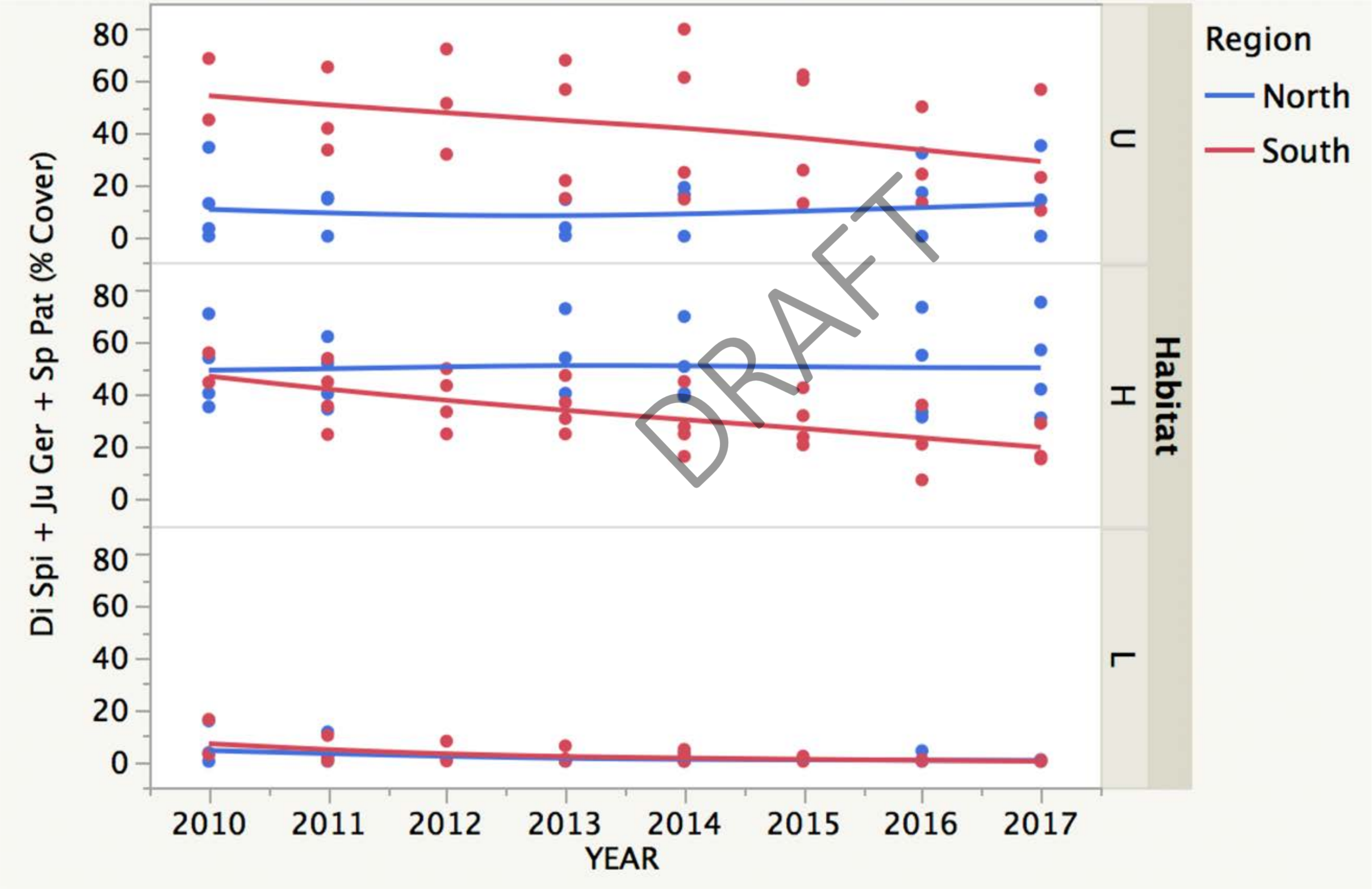



## Species Richness



# Analysis By Region (North-South)

## Distichlis + Juncus + S. patens

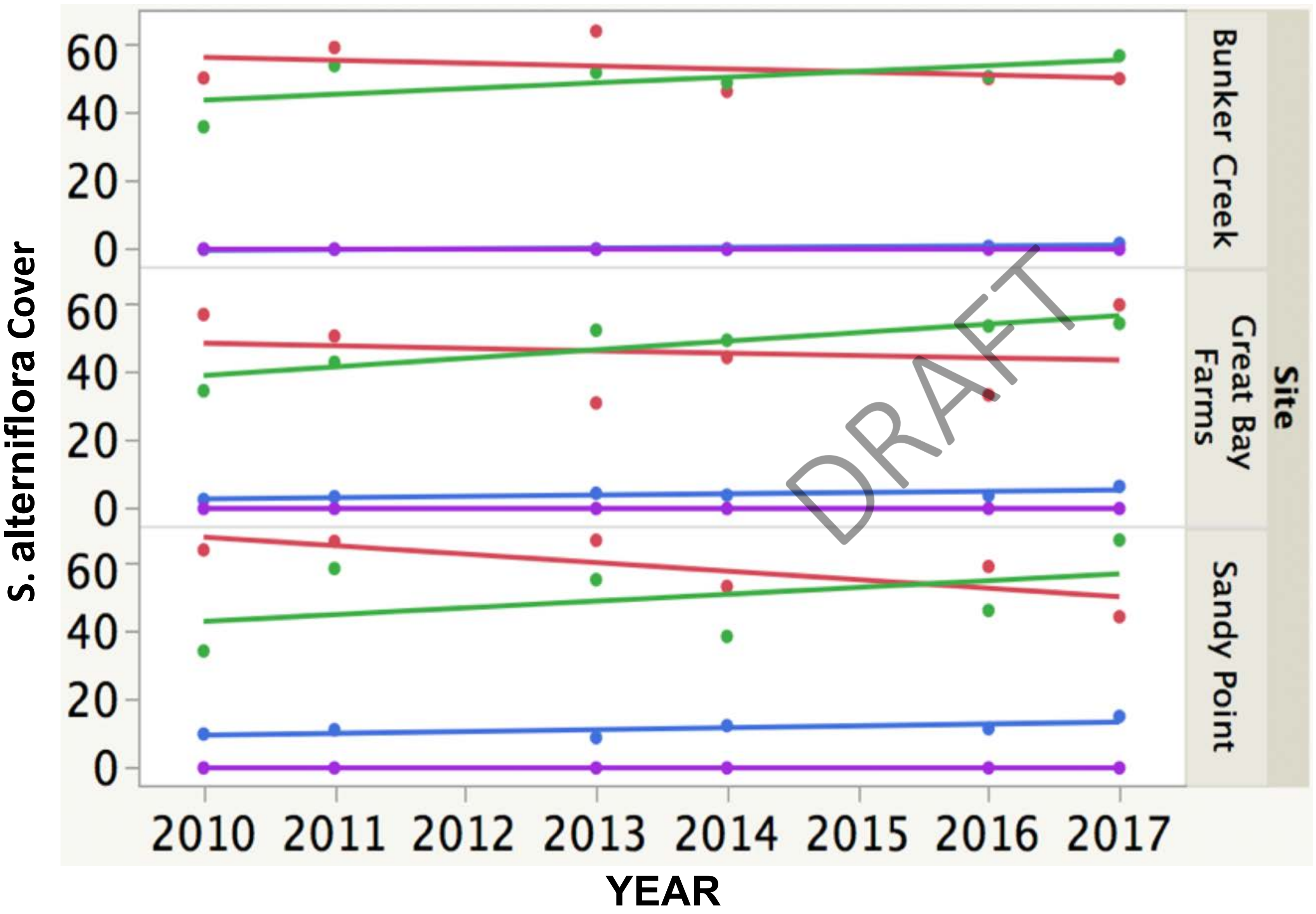


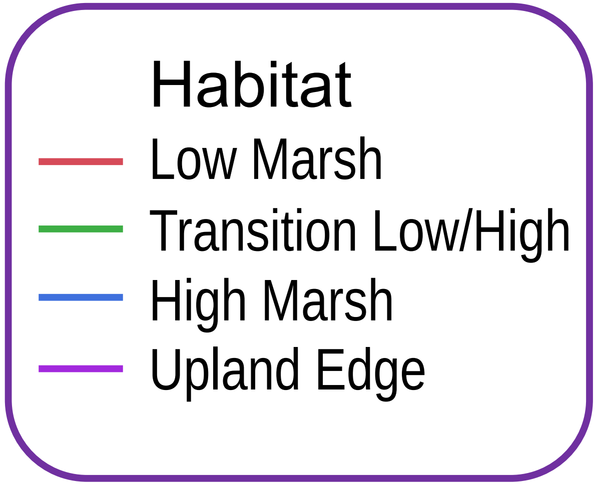
# Univariate Analysis By Reserve: Great Bay

## Statistical ANCOVA Model

| Dependent Variable | SITE | HABITAT | YEAR | Site X Habitat | Year X Habitat | Year X Site | Overall F | R2 |
|---|---|---|---|---|---|---|---|---|
| Water LN no Upland | 0.0362 | 0.0019 | 0.2574 | -------------- | -------------- | -------------- | 4.5 | 0.32 |
| Bare | 0.0001 | 0.0001 | 0.1666 | 0.001 | -------------- | -------------- | 23 | 0.83 |
| Dead LN | 0.5726 | 0.0001 | 0.0184 | -------------- | 0.0268 | -------------- | 36 | 0.84 |
| Wrack. LN | 0.0003 | 0.7756 | 0.1141 | -------------- | -------------- | -------------- | 3.7 | 0.26 |
| Non-Living | 0.002 | 0.0001 | 0.7513 | 0.0001 | -------------- | -------------- | 13.5 | 0.73 |
| Spartina alterniflora LN | 0.0053 | 0.0001 | 0.3393 | 0.0469 | 0.001 | -------------- | 81 | 0.95 |
| Spartina patens | 0.0001 | 0.0001 | 0.057 | 0.0001 | -------------- | -------------- | 94 | 0.95 |
| SA : SP Ratio | 0.0005 | 0.0001 | 0.0014 | 0.0001 | -------------- | -------------- | 176 | 0.97 |
| Halophytes | 0.0861 | 0.0001 | 0.7346 | 0.0001 | -------------- | -------------- | 67 | 0.93 |
| Forbs LN | 0.0004 | 0.0001 | 0.1032 | 0.0001 | -------------- | -------------- | 14 | 0.74 |
| Brackish no Low/T | 0.002 | 0.0001 | 0.3082 | 0.0001 | -------------- | -------------- | 20 | 0.81 |
| Algae no Upland | 0.0001 | 0.0001 | 0.036 | 0.0001 | 0.0462 | 0.0236 | 7.4 | 0.71 |
| Fresh&Upland ln no Low/T | 0.014 | 0.0001 | 0.9246 | -------------- | -------------- | -------------- | 106 | 0.93 |
| Invasive Spp. LN NO Low/T | 0.0001 | 0.0001 | 0.0005 | 0.0001 | -------------- | 0.0171 | 41 | 92 |
| Species richness | 0.0001 | 0.0001 | 0.0002 | 0.0001 | 0.0031 | -------------- | 58 | 0.94 |

# *Spartina alternifora* Cover, Great Bay NERR, 3 sites



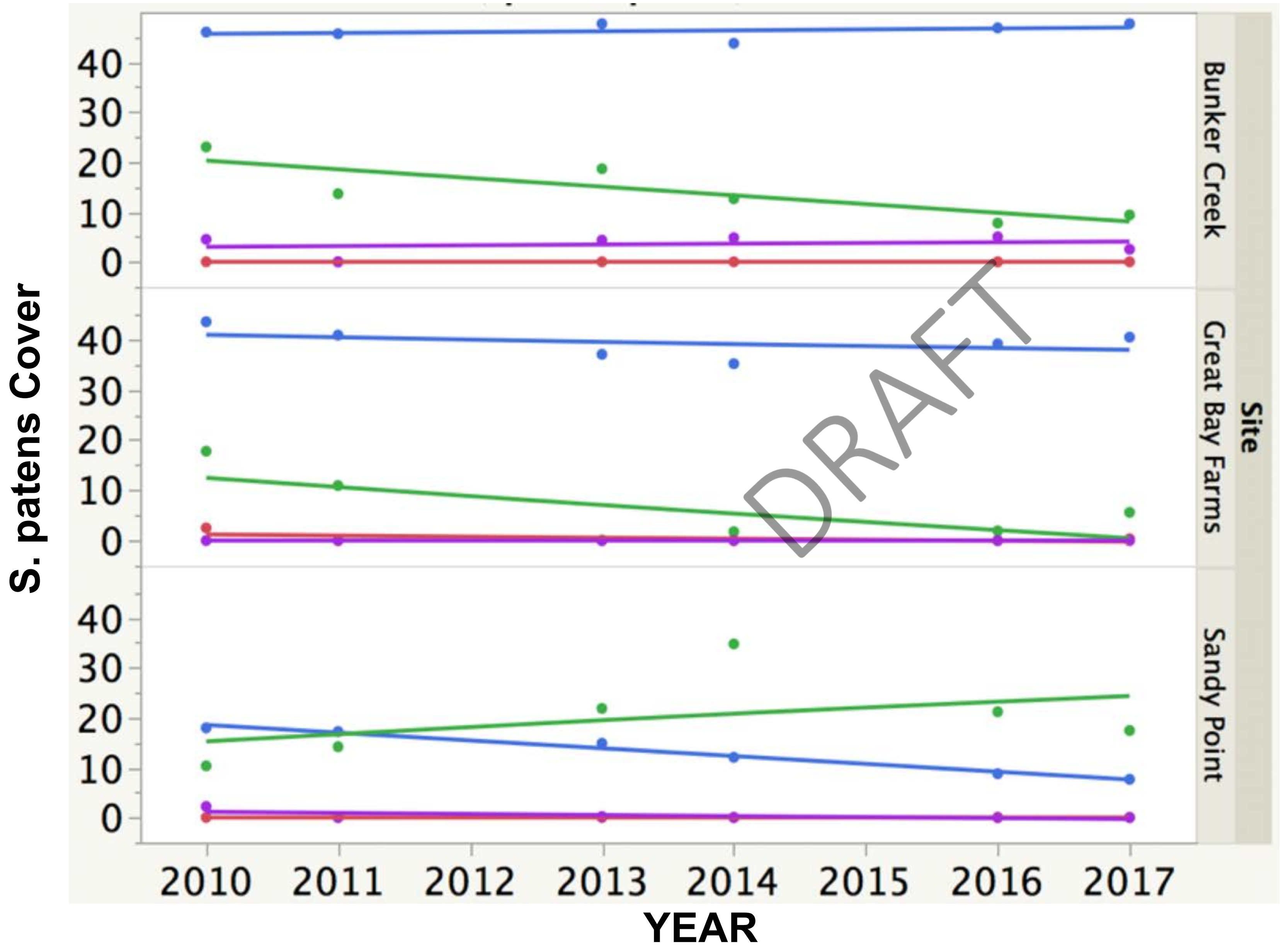

***All sites showed declines in Sp.alt. in Low Marsh and increases in the Transition zone. More Sp.alt. in High Marsh at Sandy Point***

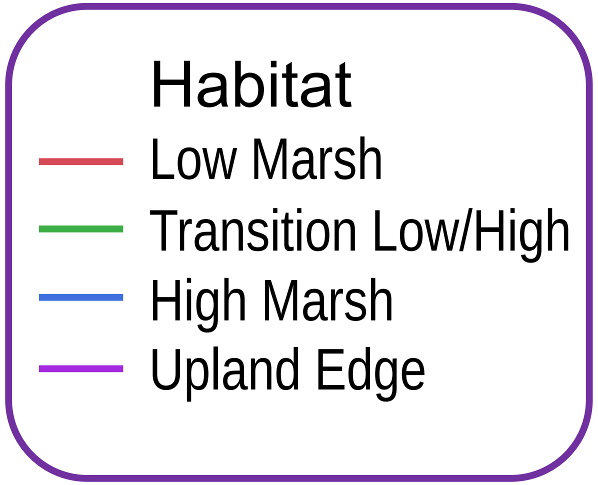
Model: F = 570; P<0.0001; $R^2$=0.99

**Effect Tests**

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Site | 2 | 2 | 4.08150 | 79.4928 | <.0001* |
| Habitat | 3 | 3 | 203.18277 | 2638.177 | <.0001* |
| Site*Habitat | 6 | 6 | 11.47083 | 74.4701 | <.0001* |
| Year | 1 | 1 | 0.27921 | 10.8759 | 0.0017* |
| Year*Habitat | 3 | 3 | 0.76130 | 9.8850 | <.0001* |

# *Spartina patens* Cover, Great Bay NERR, 3 sites



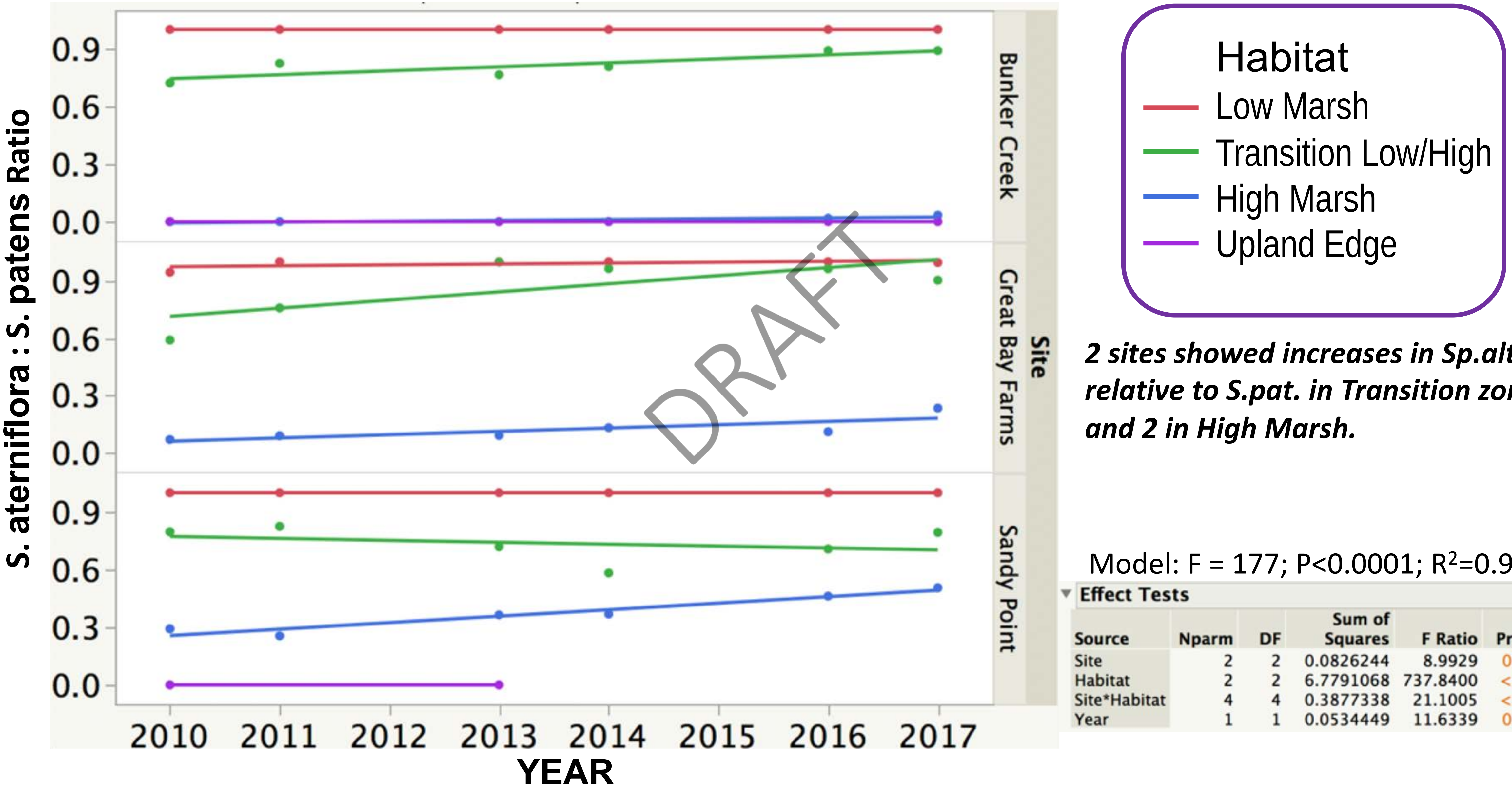

***2 sites showed declines in Sp.pat. in Transition zone.***
***1 Site on Bay showed increase in Transition Zone and decrease in high marsh (landward Wrack)***

Model: F = 94.7; P<0.0001; $R^2$=0.95

**Effect Tests**

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Site | 2 | 2 | 706.073 | 23.8706 | <.0001* |
| Habitat | 3 | 3 | 12471.647 | 281.0901 | <.0001* |
| Site*Habitat | 6 | 6 | 3576.122 | 40.2999 | <.0001* |
| Year | 1 | 1 | 55.726 | 3.7679 | 0.0570 |

# *S. alternifora : S. patens* Ratio, Great Bay NERR, 3 sites



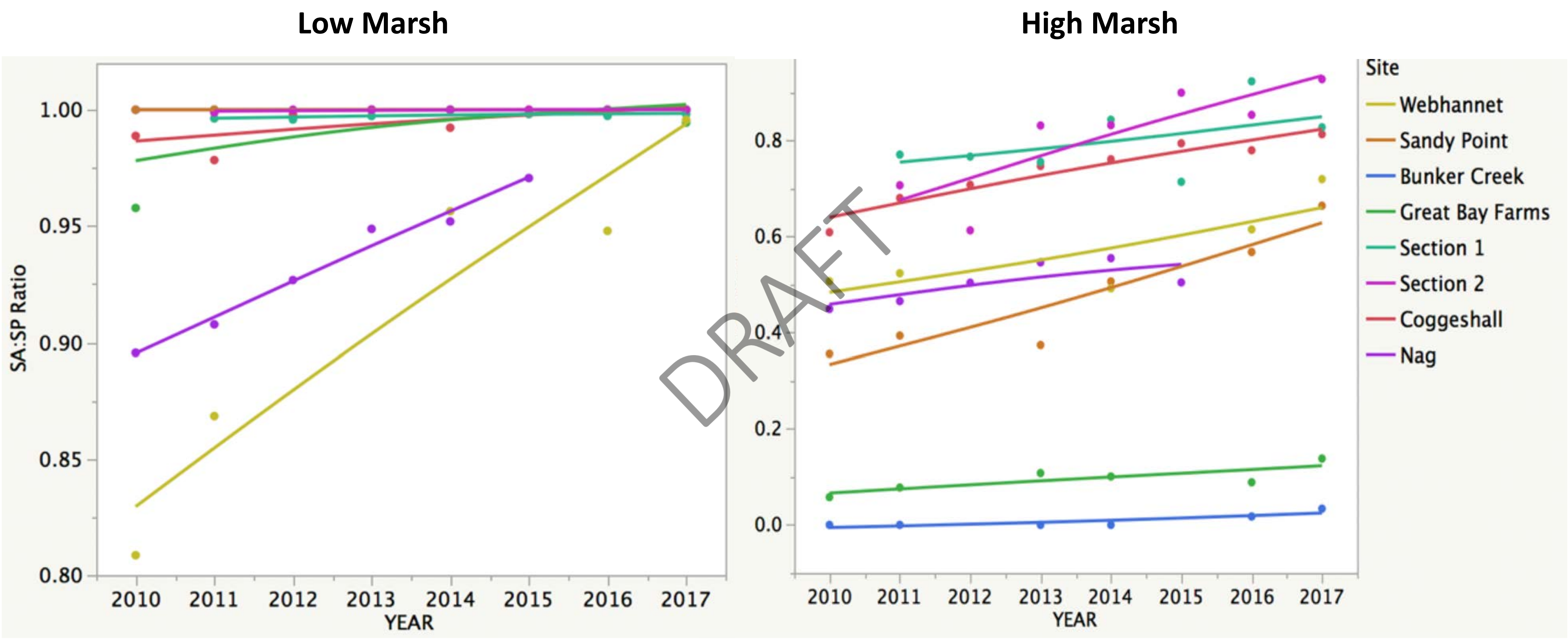

***2 sites showed increases in Sp.alt. relative to S.pat. in Transition zone and 2 in High Marsh.***

Model: F = 177; P<0.0001; $R^2$=0.97

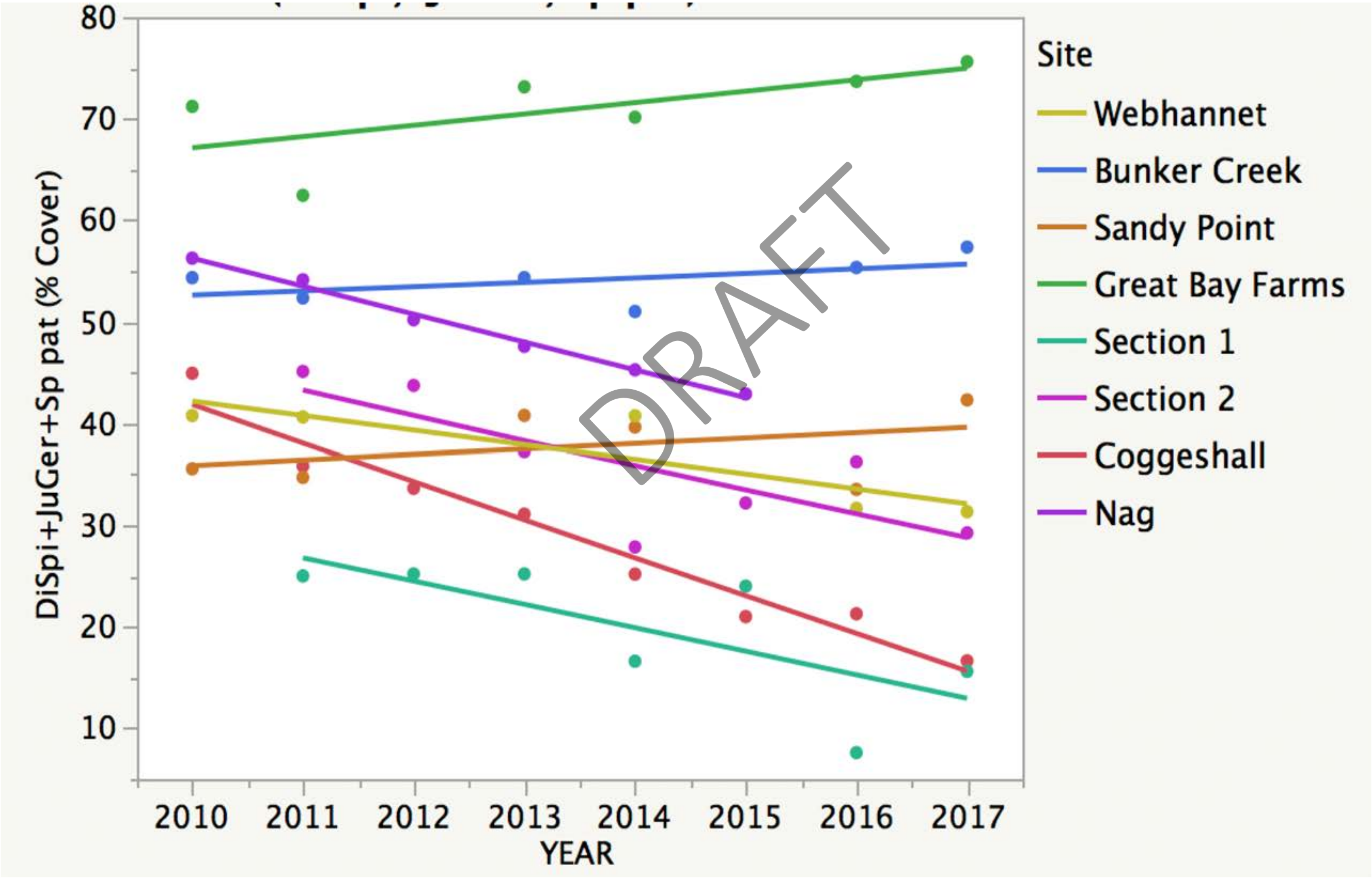
**Effect Tests**

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Site | 2 | 2 | 0.0826244 | 8.9929 | 0.0005* |
| Habitat | 2 | 2 | 6.7791068 | 737.8400 | <.0001* |
| Site*Habitat | 4 | 4 | 0.3877338 | 21.1005 | <.0001* |
| Year | 1 | 1 | 0.0534449 | 11.6339 | 0.0014* |

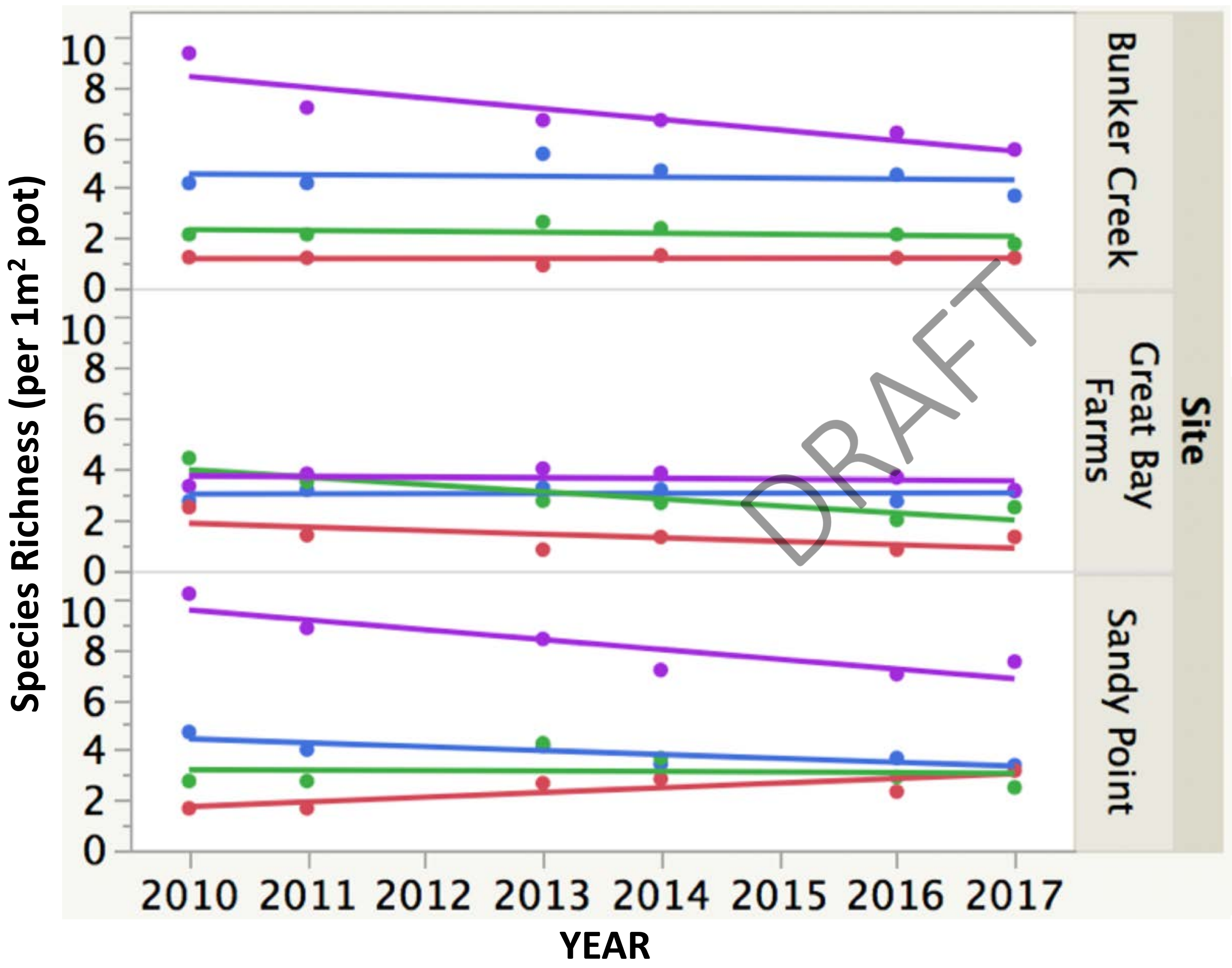
# SA:SP Ratio by Marsh Habitat: 8 New England Marshes



# High marsh grasses (Dispi+Juger+Sppat) declining everywhere . . . but Great Bay NERR



# Species Richness, Great Bay NERR, 3 sites




Habitat
- Low Marsh
- Transition Low/High
- High Marsh
- Upland Edge

**Summary of Fit**

| | |
|---|---|
| RSquare | 0.922734 |
| RSquare Adj | 0.907018 |
| Root Mean Square Error | 0.645293 |
| Mean of Response | 3.60908 |
| Observations (or Sum Wgts) | 72 |

**Analysis of Variance**

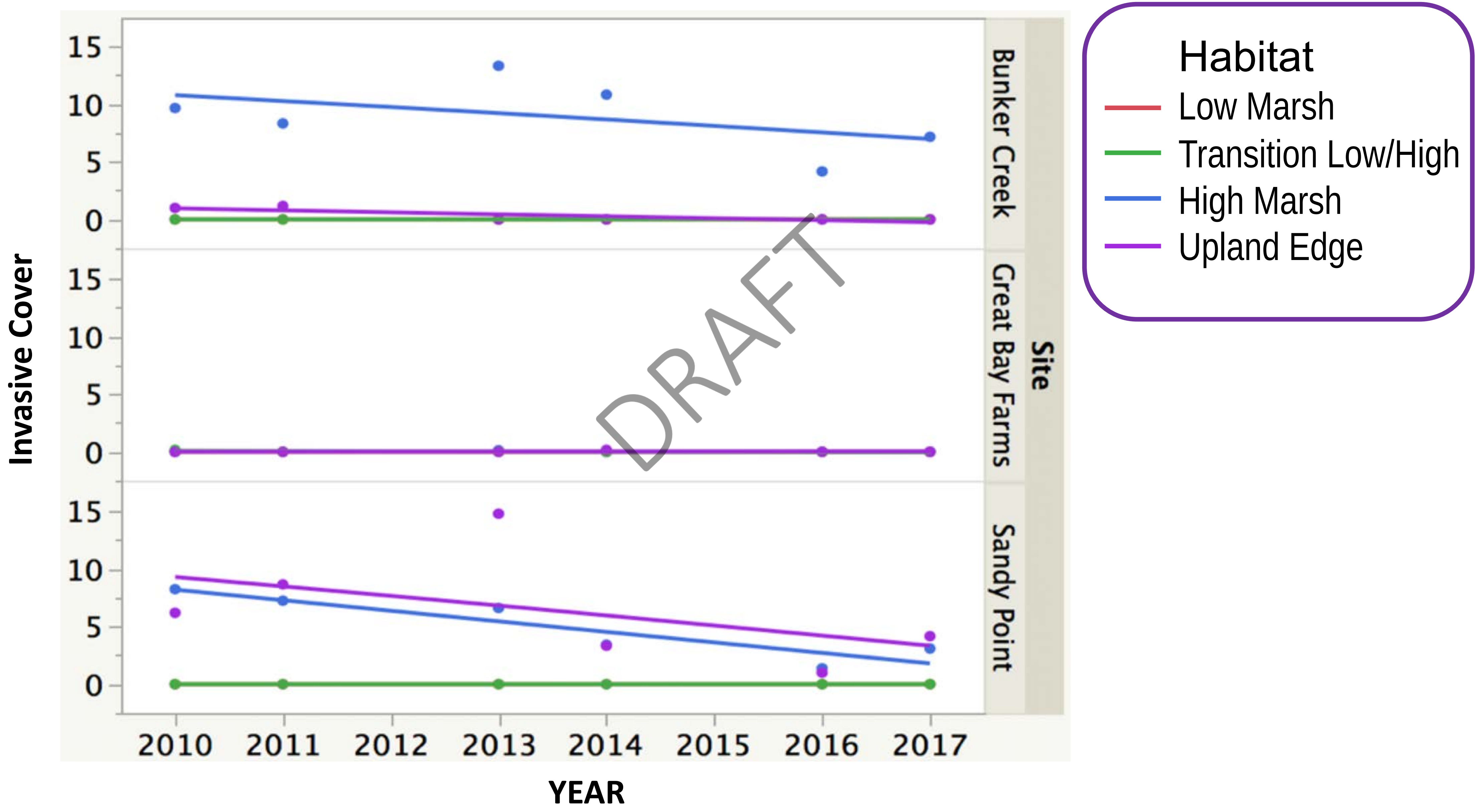
| Source | DF | Sum of Squares | Mean Square | F Ratio |
|---|---|---|---|---|
| Model | 12 | 293.39354 | 24.4495 | 58.7159 |
| Error | 59 | 24.56775 | 0.4164 | Prob > F |
| C. Total | 71 | 317.96129 | | <.0001* |

**Parameter Estimates**

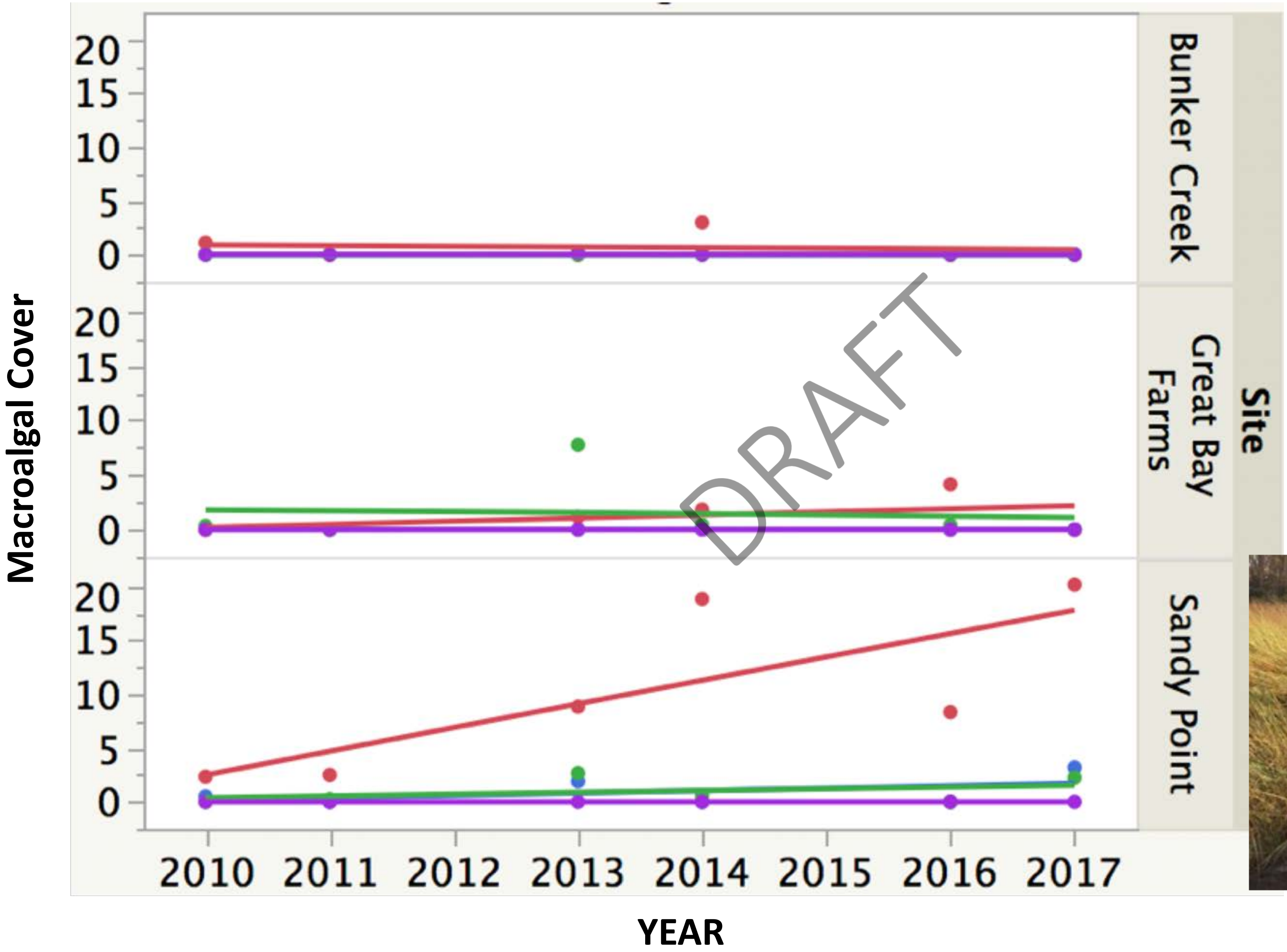
**Effect Tests**

| Source | Nparm | DF | Sum of Squares | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Site | 2 | 2 | 32.59361 | 39.1371 | <.0001* |
| Habitat | 3 | 3 | 207.85775 | 166.3917 | <.0001* |
| Site*Habitat | 6 | 6 | 47.56127 | 19.0366 | <.0001* |
| Year | 1 | 1 | 5.38091 | 12.9224 | 0.0007* |

# Invasive Species Cover, Great Bay NERR, 3 sites



# Macroalgal Cover, Great Bay NERR, 3 sites




**Seaweed increases in Great Bay**

# Analytical Summary

With a carefully designed and executed monitoring plan, analysis can include:

a) Graphical interpretation (pie charts/bar charts)

b) Univariate statistical analysis using ANOVA and ANCOVA

c) Multivariate analysis using PRIMER and SIMPER

d) Grouped variables and ratios (SA:SP) can reduce single species variability

Across the Reserves of New England:

a) Low marsh has more open water, non-living cover, and less *Spartina alterniflora* (drowning)

b) *Spartina alterniflora* is moving into the high marsh, displacing *S. patens* and others

c) Over the whole marsh:

i) Thin perennial grasses of the high marsh are in decline (except for Great Bay)

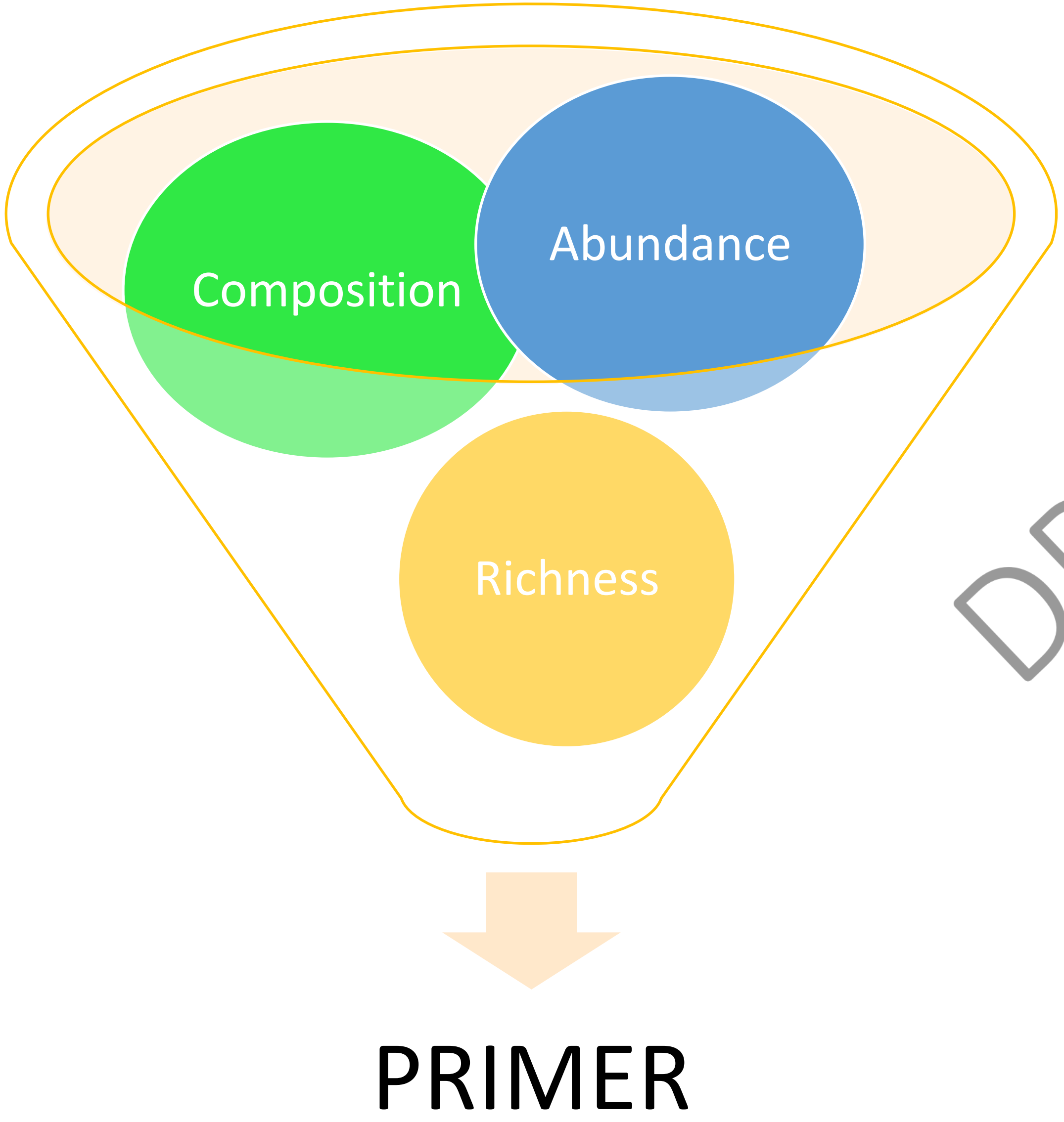
ii) Species richness is decreasing

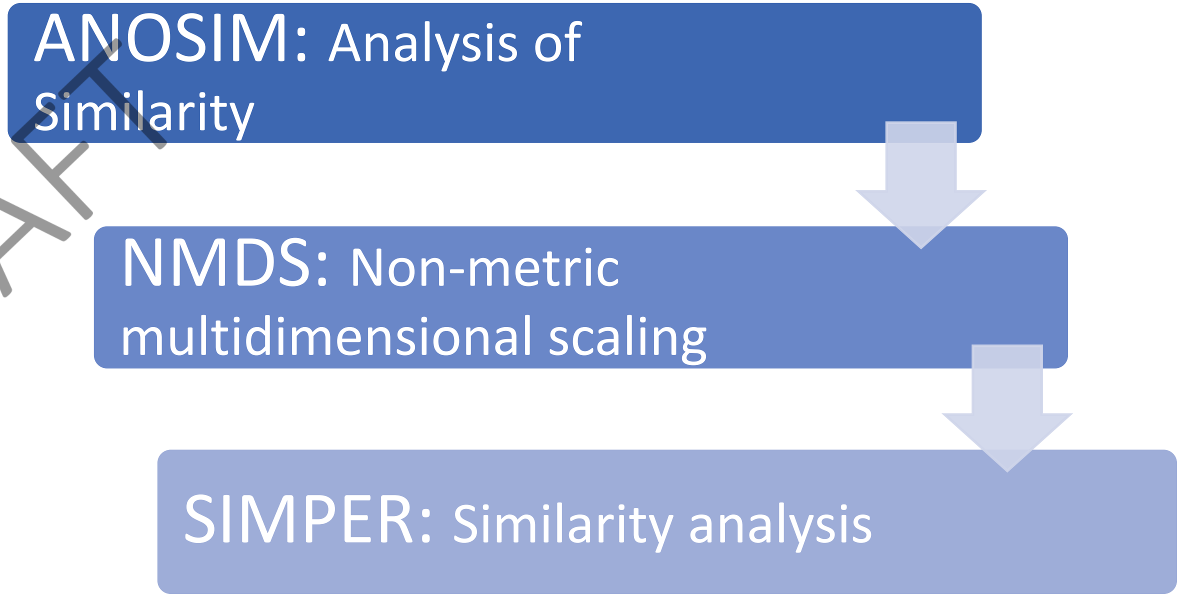
iii) Invasive species cover is declining

Reserves with lower tide ranges (south) when compared with higher tide ranges (north):

Have more *S. alterniflora* and exhibit greater declines in *S. patens* in the high marsh

# Multivariate Analyses



# Great Bay, NH

| | Bunker Creek | | | |
|---|---|---|---|---|
| 2010 vs 2017 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.280 | | | |
| Low Marsh | 0.110 | X | **Water**, Bare | Sp alt, Dead |
| Transition | 0.618 | | | |
| High Marsh | 0.606 | | | |
| Upland Edge | 0.113 | X | **Bare**, Ju ger | Dead, Sy ten |

| | Great Bay Farms | | | |
|---|---|---|---|---|
| 2010 vs 2017 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.351 | | | |
| Low Marsh | 0.658 | | | |
| Transition | 0.003 | X | Sp alt, Di spi | **Sp pat**, Bare |
| High Marsh | 0.764 | | | |
| Upland Edge | 0.803 | | | |

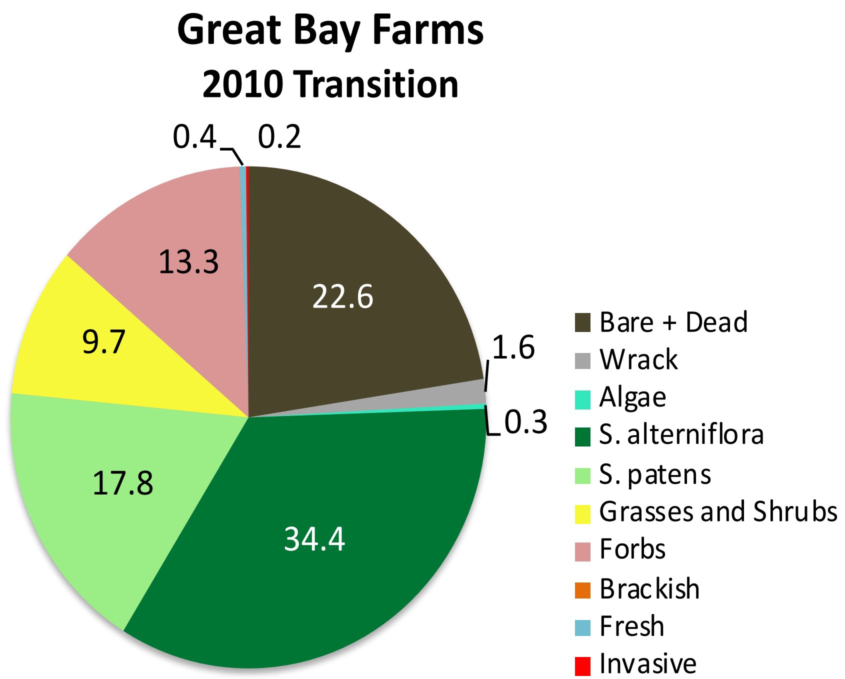
| | Sandy Point | | | |
|---|---|---|---|---|
| 2010 vs 2017 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.427 | | | |
| Low Marsh | 0.437 | | | |
| Transition | 0.001 | X | **Sp alt**, Sp pat | Dead, Wrack |
| High Marsh | 0.839 | | | |
| Upland Edge | 0.156 | X | **Dead**, To rad | Wrack, Ph aus |

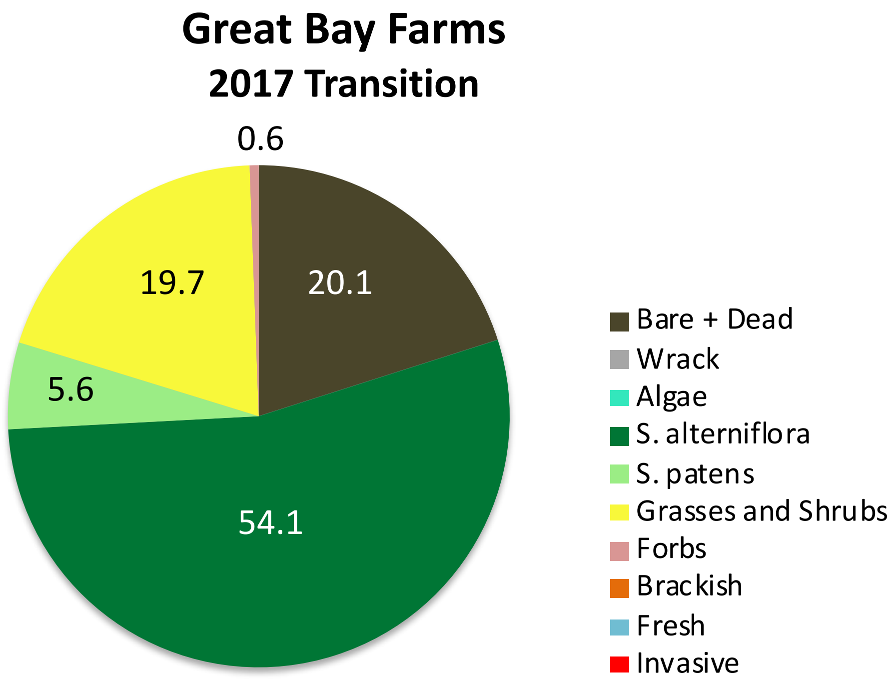


# Great Bay, NH

| | Bunker Creek | | | |
|---|---|---|---|---|
| 2010 vs 2017 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.280 | | | |
| Low Marsh | 0.110 | X | **Water**, Bare | Sp alt, Dead |
| Transition | 0.618 | | | |
| High Marsh | 0.606 | | | |
| Upland Edge | 0.113 | X | **Bare**, Ju ger | Dead, Sy ten |
| | **Great Bay Farms** | | | |
| 2010 vs 2017 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.351 | | | |
| Low Marsh | 0.658 | | | |
| Transition | 0.003 | X | Sp alt, Di spi | **Sp pat**, Bare |
| High Marsh | 0.764 | | | |
| Upland Edge | 0.803 | | | |
| | **Sandy Point** | | | |
| 2010 vs 2017 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.427 | | | |
| Low Marsh | 0.437 | | | |
| Transition | 0.001 | X | **Sp alt**, Sp pat | Dead, Wrack |
| High Marsh | 0.839 | | | |
| Upland Edge | 0.156 | X | **Dead**, To rad | Wrack, Ph aus |





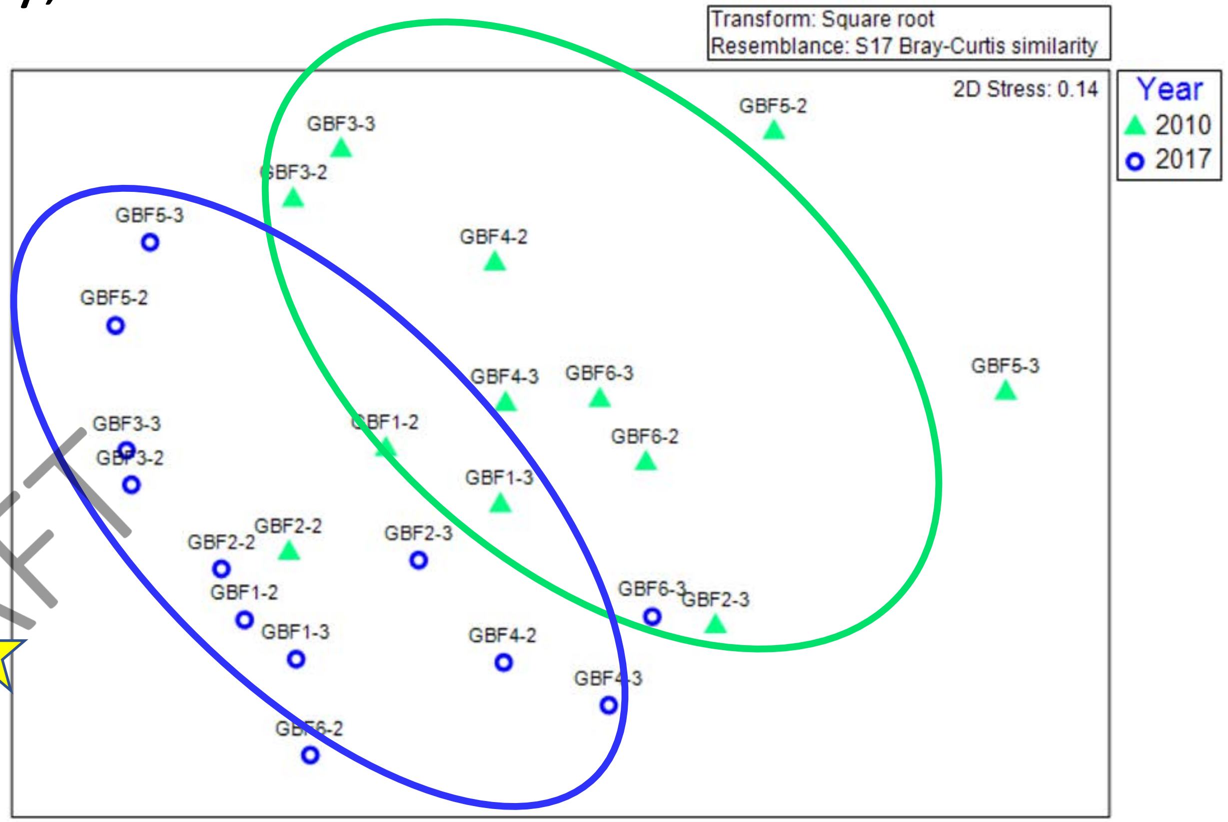
# Great Bay, NH

| | Bunker Creek | | | |
|---|---|---|---|---|
| 2010 vs 2017 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.280 | | | |
| Low Marsh | 0.110 | X | **Water**, Bare | Sp alt, Dead |
| Transition | 0.618 | | | |
| High Marsh | 0.606 | | | |
| Upland Edge | 0.113 | X | **Bare**, Ju ger | Dead, Sy ten |

| | Great Bay Farms | | | |
|---|---|---|---|---|
| 2010 vs 2017 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.351 | | | |
| Low Marsh | 0.658 | | | |
| Transition | 0.003 | X | Sp alt, Di spi | **Sp pat**, Bare |
| High Marsh | 0.764 | | | |
| Upland Edge | 0.803 | | | |

| | Sandy Point | | | |
|---|---|---|---|---|
| 2010 vs 2017 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.427 | | | |
| Low Marsh | 0.437 | | | |
| Transition | 0.001 | X | **Sp alt**, Sp pat | Dead, Wrack |
| High Marsh | 0.839 | | | |
| Upland Edge | 0.156 | X | **Dead**, To rad | Wrack, Ph aus |

*GRB-GBF*
*2010 vs 2017 Transition*



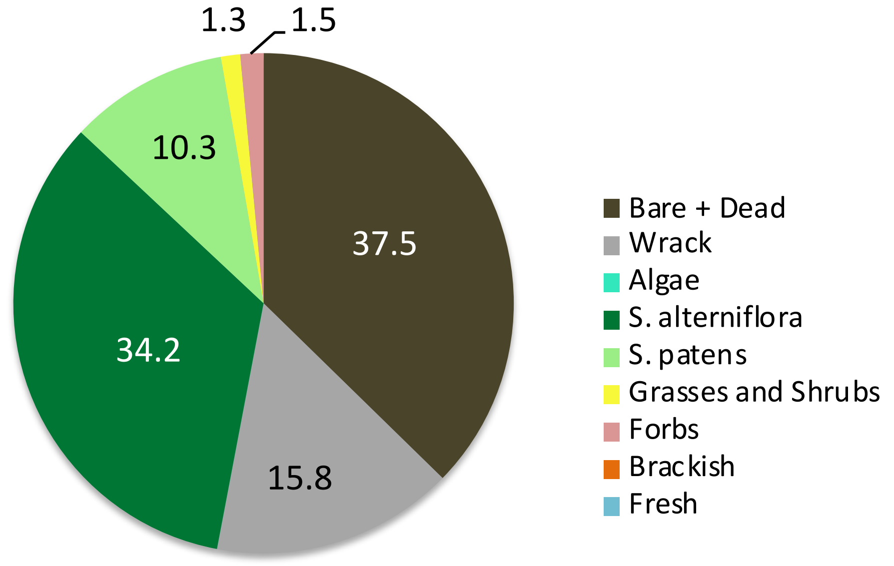

| Species | Group 2010 Av.Abund | Group 2017 Av.Abund | Av.Diss | Contrib% | Cum.% |
|---|---|---|---|---|---|
| **Spartina patens** | **17.75** | **5.58** | **8.13** | **16.94** | **16.94** |
| **Spartina alterniflora** | **34.42** | **54.08** | **7.18** | **14.95** | **31.9** |
| **Distichlis spicata** | **9.58** | **17.17** | **6.33** | **13.19** | **45.09** |
| **Bare Ground** | **20** | **18.92** | **5.91** | **12.3** | **57.39** |
| Water | 18.75 | 2.92 | 5.65 | 11.78 | 69.17 |
| Atriplex patula | 11.58 | 0.17 | 5.49 | 11.44 | 80.61 |
| Dead | 2.54 | 1.17 | 2.56 | 5.33 | 85.94 |
| Wrack | 1.58 | 0 | 1.6 | 3.34 | 89.28 |
| Solidago sempervire | 0.67 | 0.33 | 1.08 | 2.25 | 91.54 |

# Great Bay, NH

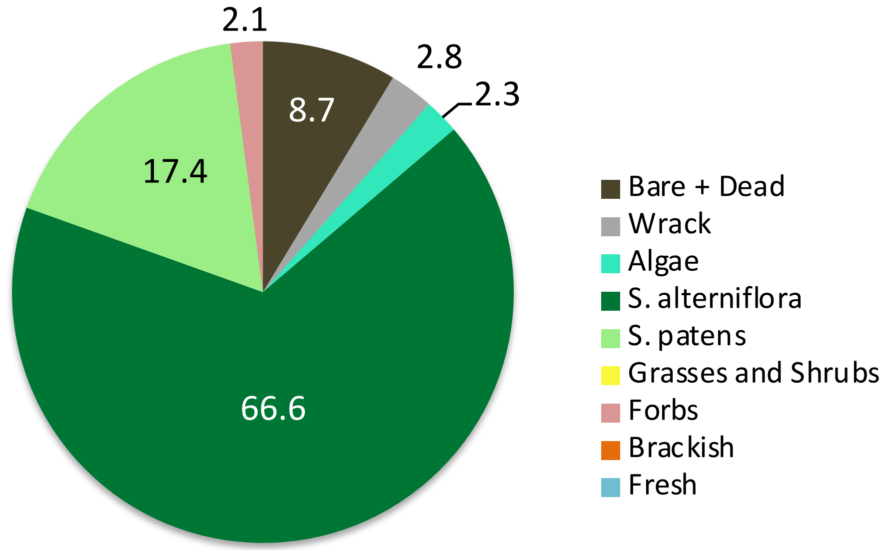
| | Bunker Creek | | | |
|---|---|---|---|---|
| 2010 vs 2017 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.280 | | | |
| Low Marsh | 0.110 | X | **Water**, Bare | Sp alt, Dead |
| Transition | 0.618 | | | |
| High Marsh | 0.606 | | | |
| Upland Edge | 0.113 | X | **Bare**, Ju ger | Dead, Sy ten |
| | **Great Bay Farms** | | | |
| 2010 vs 2017 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.351 | | | |
| Low Marsh | 0.658 | | | |
| Transition | 0.003 | X | Sp alt, Di spi | **Sp pat**, Bare |
| High Marsh | 0.764 | | | |
| Upland Edge | 0.803 | | | |
| | **Sandy Point** | | | |
| 2010 vs 2017 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.427 | | | |
| Low Marsh | 0.437 | | | |
| Transition | 0.001 | X | **Sp alt**, Sp pat | Dead, Wrack |
| High Marsh | 0.839 | | | |
| Upland Edge | 0.156 | X | **Dead**, To rad | Wrack, Ph aus |



**Sandy Point**
**2010 Transition**

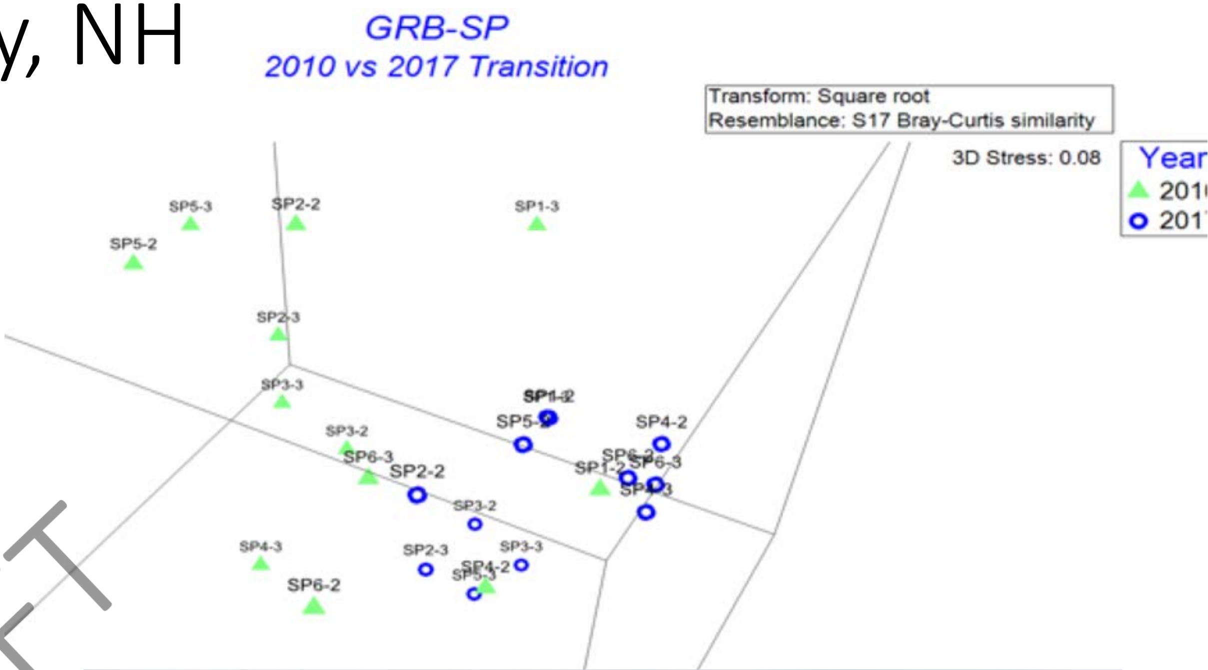



**Sandy Point**
**2017 Transition**



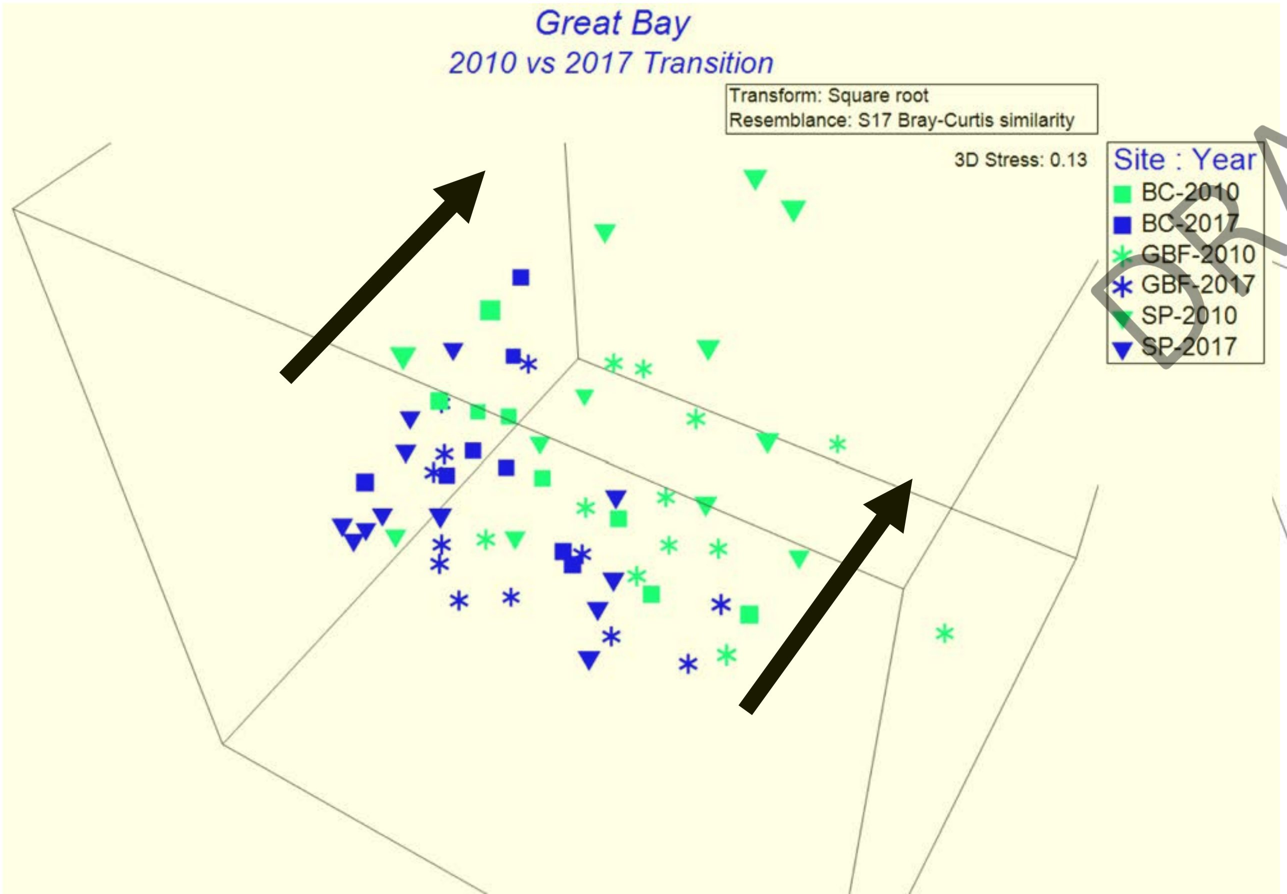
# Great Bay, NH

| | Bunker Creek | | | |
|---|---|---|---|---|
| 2010 vs 2017 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.280 | | | |
| Low Marsh | 0.110 | X | **Water**, Bare | Sp alt, Dead |
| Transition | 0.618 | | | |
| High Marsh | 0.606 | | | |
| Upland Edge | 0.113 | X | **Bare**, Ju ger | Dead, Sy ten |
| | **Great Bay Farms** | | | |
| 2010 vs 2017 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.351 | | | |
| Low Marsh | 0.658 | | | |
| Transition | 0.003 | X | Sp alt, Di spi | **Sp pat**, Bare |
| High Marsh | 0.764 | | | |
| Upland Edge | 0.803 | | | |
| | **Sandy Point** | | | |
| 2010 vs 2017 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.427 | | | |
| Low Marsh | 0.437 | | | |
| Transition | 0.001 | X | **Sp alt**, Sp pat | Dead, Wrack |
| High Marsh | 0.839 | | | |
| Upland Edge | 0.156 | X | **Dead**, To rad | Wrack, Ph aus |

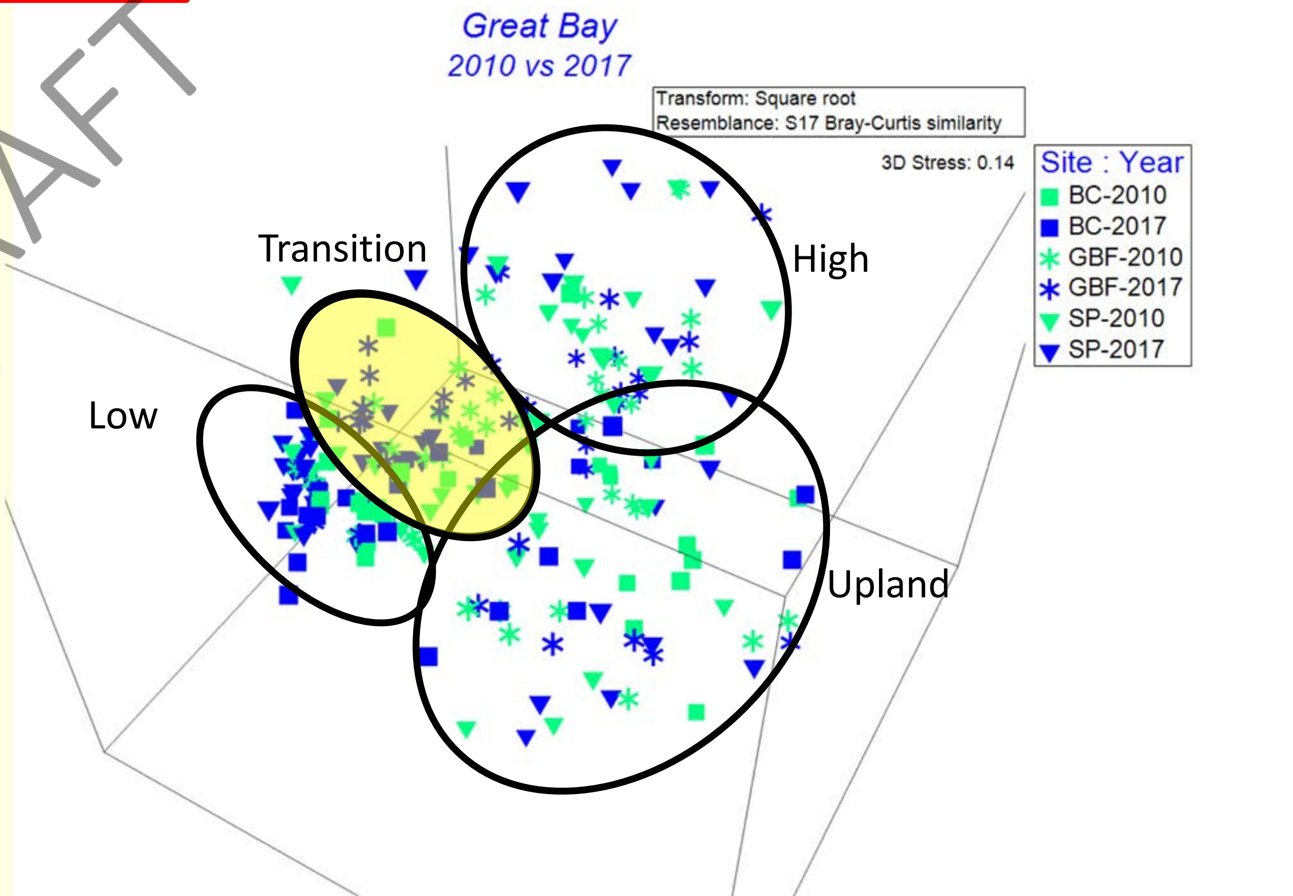



# Great Bay, NH

| | Great Bay | | | |
|---|---|---|---|---|
| | ANOSIM | NMDS | + SIMPER | - |
| 2010 vs 2017 | 0.026 | X | **Sp alt**, Bare | Sp pat, Dead |
| 2010 vs 2017 L | 0.228 | | | |
| 2010 vs 2017 T | 0.001 | X | Sp alt, Bare | **Sp pat**, Dead |
| 2010 vs 2017 H | 0.324 | | | |
| 2010 vs 2017 U | 0.160 | X | **Bare**, Dead, To rad | Wrack |

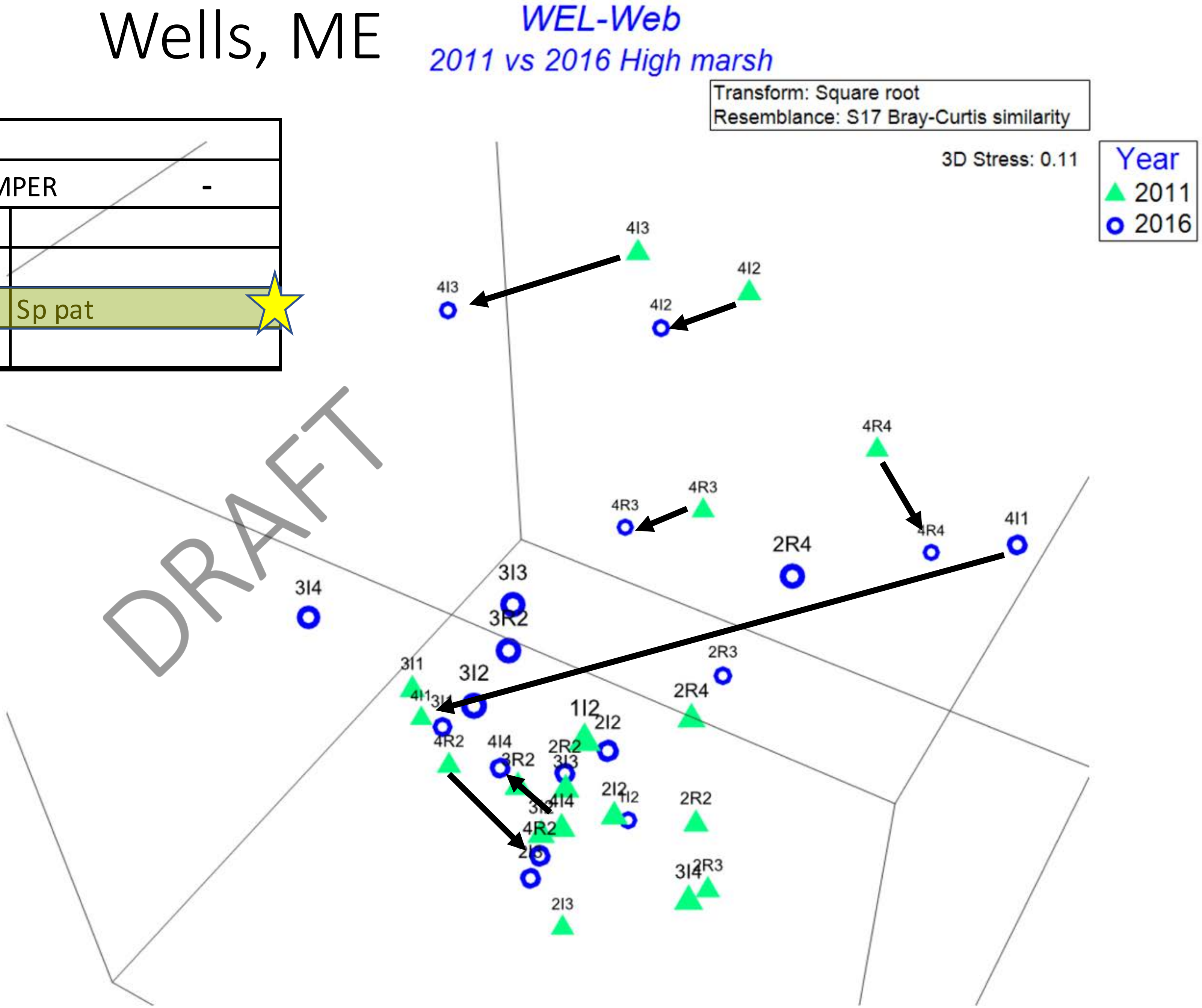




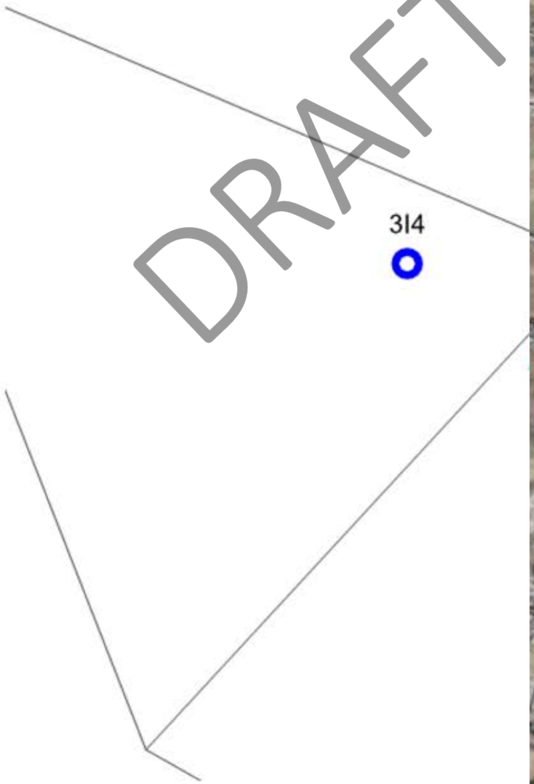
# Wells, ME

| | Webhannet | | | |
|---|---|---|---|---|
| 2011 vs 2016 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.646 | | | |
| Low Marsh | 0.371 | | | |
| High Marsh | 0.131 | X | **Sp alt**, Tr mar, Di spi | Sp pat |
| Upland Edge | 0.263 | | | |



# Wells, ME

| | Webhannet | | | |
|---|---|---|---|---|
| 2011 vs 2016 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.646 | | | |
| Low Marsh | 0.371 | | | |
| High Marsh | 0.131 | X | **Sp alt**, Tr mar, Di spi | Sp pat |
| Upland Edge | 0.263 | | | |



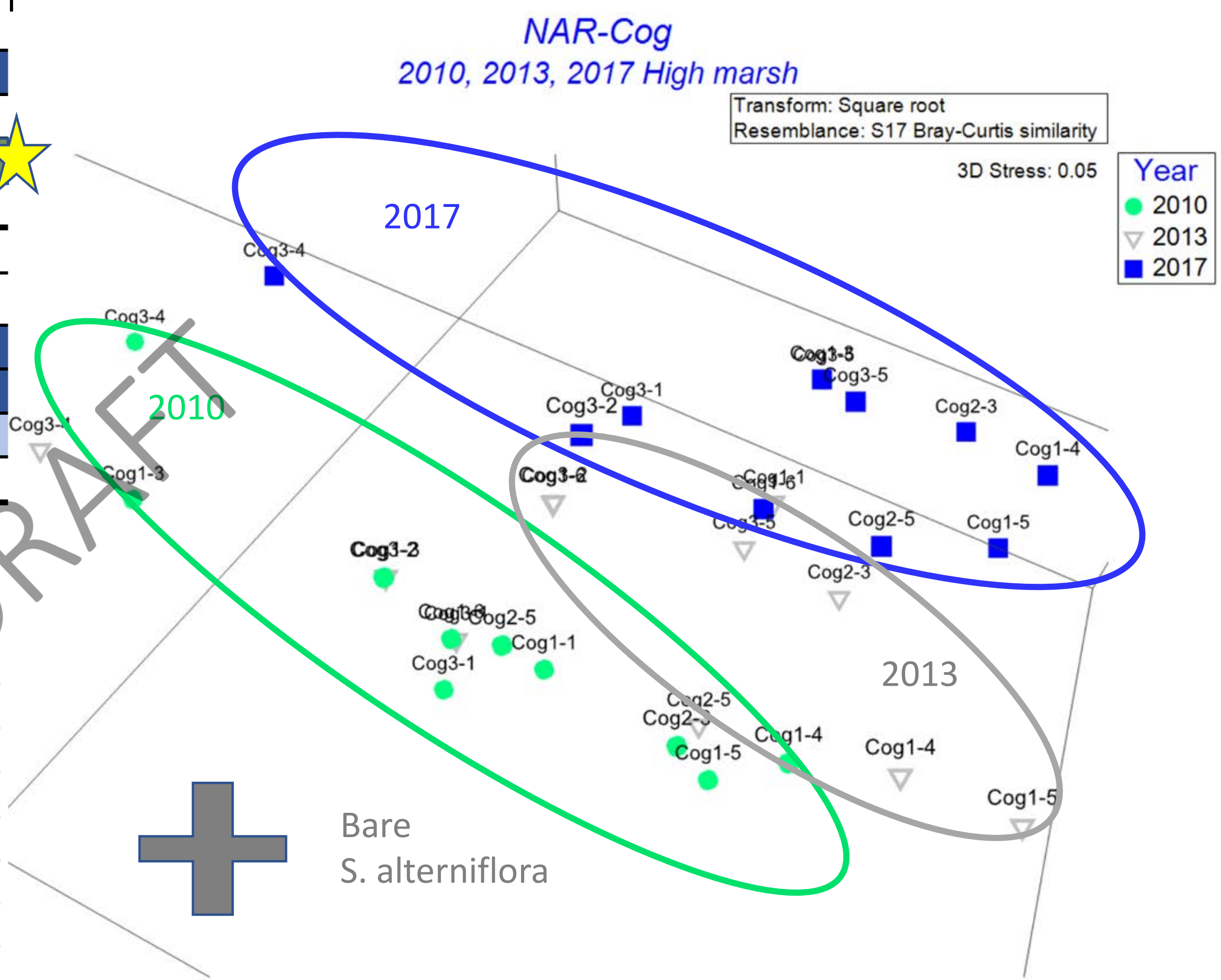



# Narragansett Bay, RI

| | Coggeshall | | | |
|---|---|---|---|---|
| 2010 vs 2017 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.020 | X | **Bare** | Sp alt, Sp pat, Di spi |
| Low Marsh | 0.839 | | | |
| High Marsh | 0.001 | X | **Bare**, Sp alt | Sp pat, Di spi |
| Upland Edge | 0.600 | | | |

| | Nag | | | |
|---|---|---|---|---|
| 2010 vs 2015 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.018 | X | Bare | **Sp alt**, Sp pat, Di spi |
| Low Marsh | 0.016 | X | **Bare** | Sp pat, Sp alt, Di spi |
| High Marsh | 0.084 | X | Bare | **Sp alt**, Sp pat, Di spi |
| Upland Edge | 0.800 | | | |






Pairwise Tests

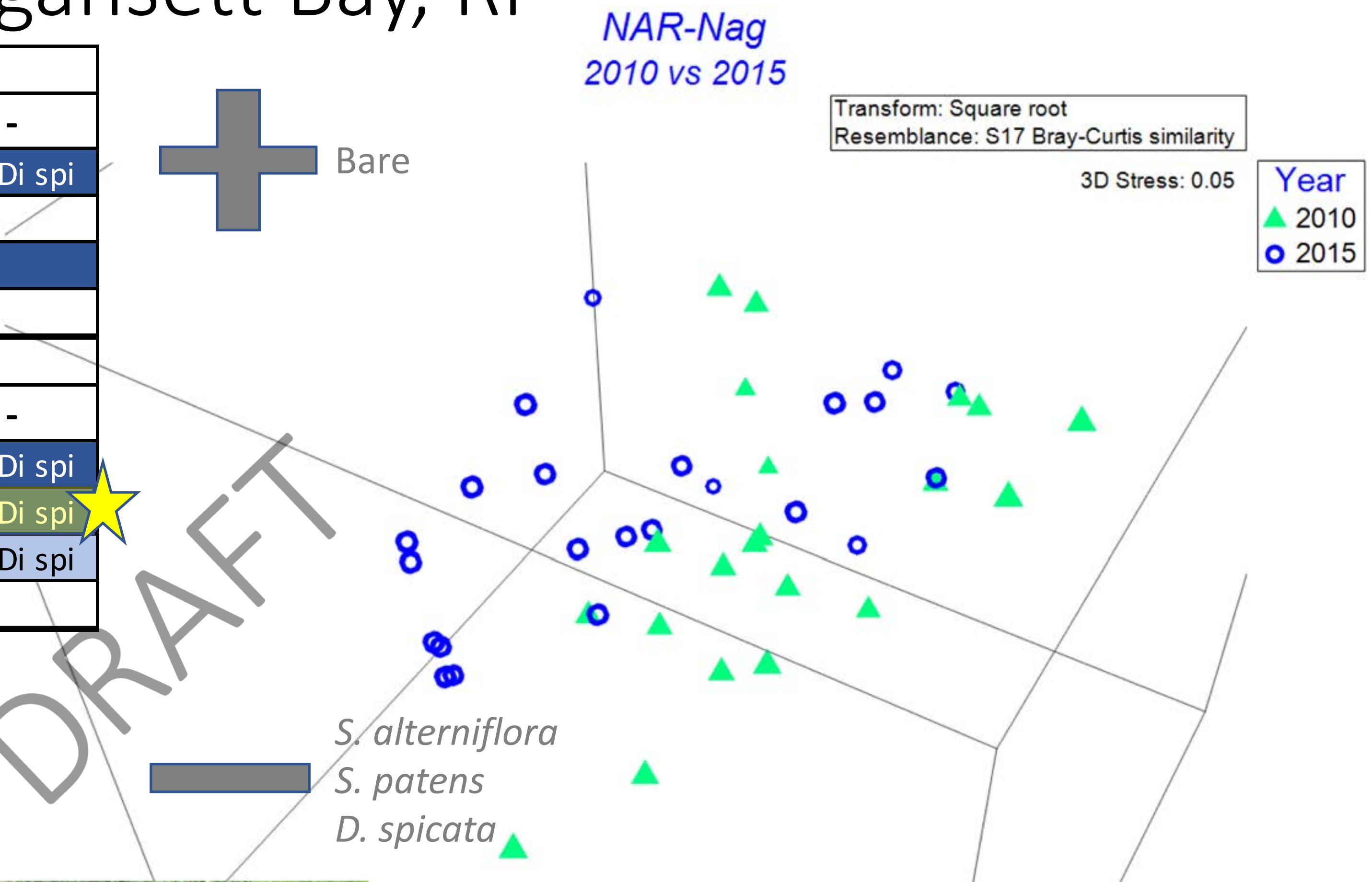
| Groups | Significance Level | Possible Permutations | Actual Permutations | Number >= Observed |
|---|---|---|---|---|
| 2010, 2011 | 0.600 | 352716 | 999 | 599 |
| 2010, 2012 | 0.506 | 352716 | 999 | 505 |
| 2010, 2013 | 0.428 | 352716 | 999 | 427 |
| 2010, 2014 | 0.032 | 352716 | 999 | 31 |
| 2010, 2015 | 0.006 | 352716 | 999 | 5 |
| 2010, 2016 | 0.019 | 352716 | 999 | 18 |
| 2010, 2017 | 0.003 | 352716 | 999 | 2 |

+ Bare
S. alterniflora

− *S. patens*
*D. spicata*

# Narragansett Bay, RI

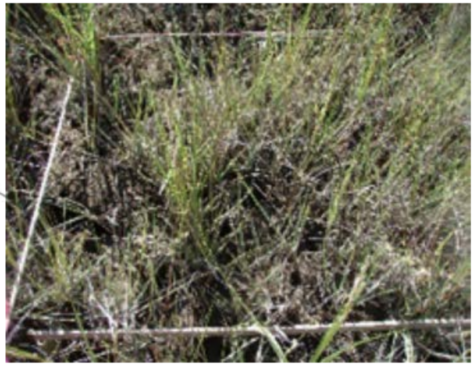
| | Coggeshall | | | |
|---|---|---|---|---|
| 2010 vs 2017 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.020 | X | **Bare** | Sp alt, Sp pat, Di spi |
| Low Marsh | 0.839 | | | |
| High Marsh | 0.001 | X | **Bare**, Sp alt | Sp pat, Di spi |
| Upland Edge | 0.600 | | | |
| | **Nag** | | | |
| 2010 vs 2015 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.018 | X | Bare | **Sp alt**, Sp pat, Di spi |
| Low Marsh | 0.016 | X | **Bare** | Sp pat, Sp alt, Di spi |
| High Marsh | 0.084 | X | Bare | **Sp alt**, Sp pat, Di spi |
| Upland Edge | 0.800 | | | |







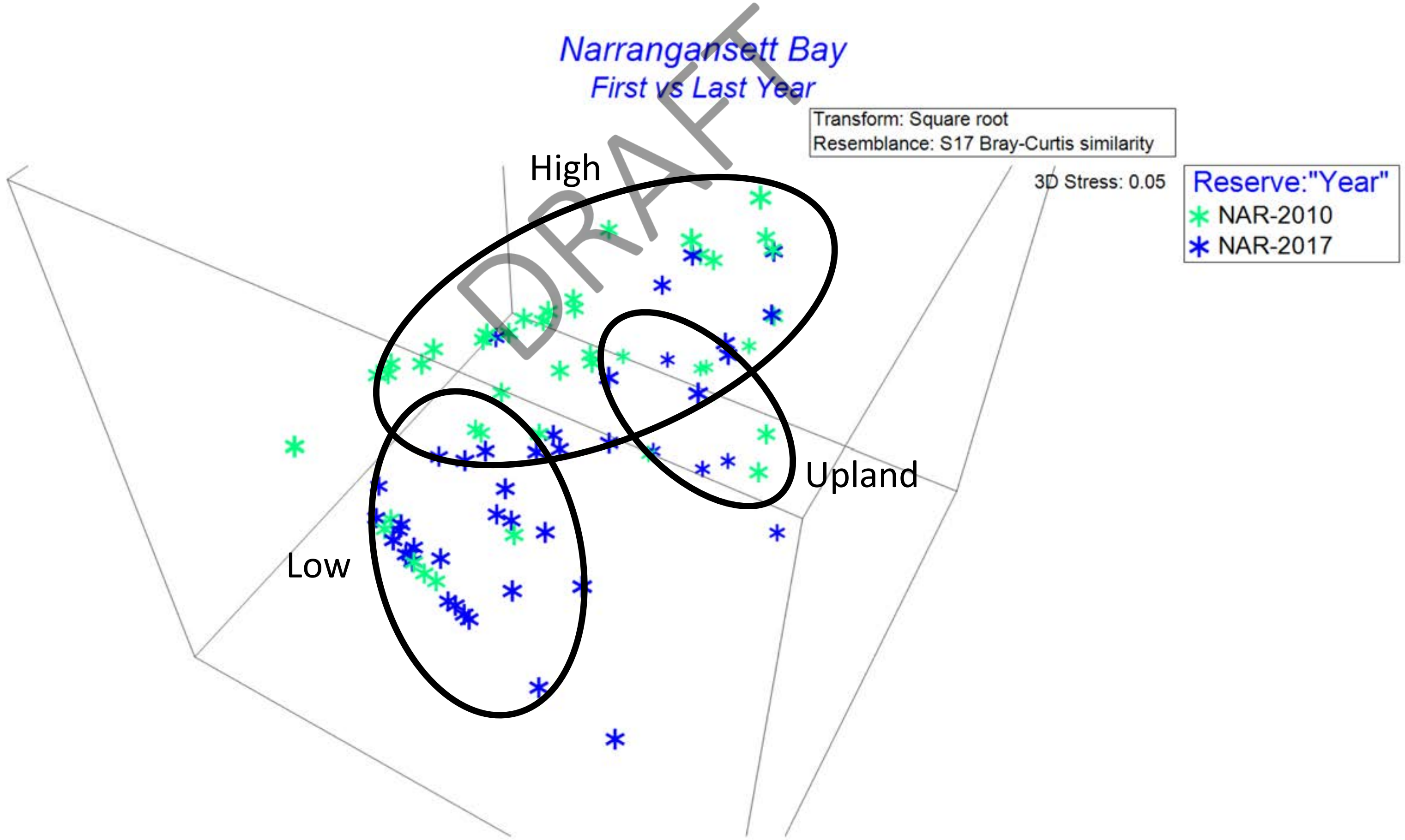





2011 → 2016

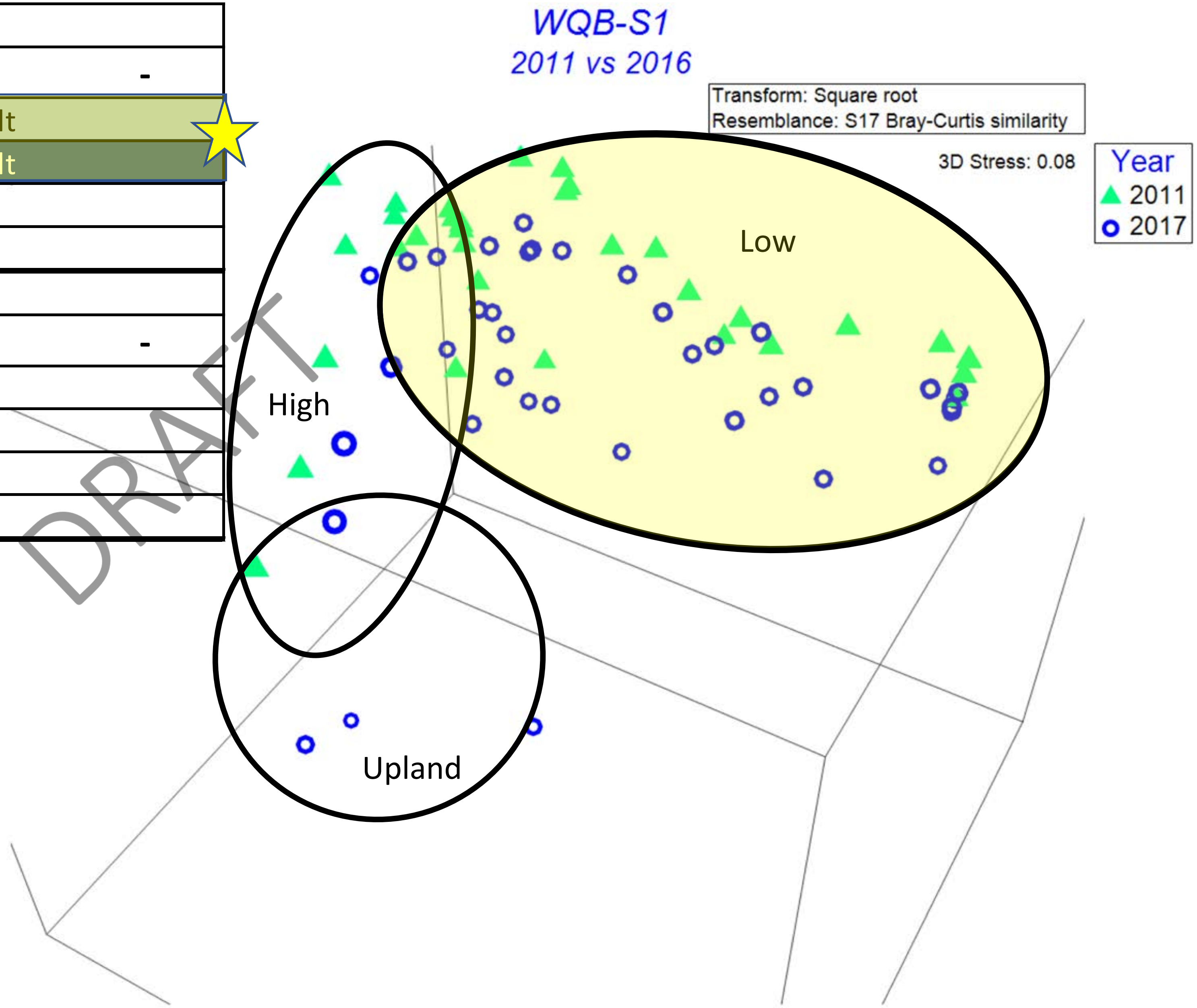
# Narragansett Bay, RI

| | Narragansett Bay | | | |
|---|---|---|---|---|
| | ANOSIM | NMDS | + SIMPER | - |
| 2010 vs 2015 | 0.001 | X | Bare | **Sp alt**, Sp pat, Di spi |
| 2010 vs 2015 L | 0.016 | X | Bare | **Sp alt**, Sp pat, Di spi |
| 2010 vs 2015 H | 0.002 | X | **Bare**, Sp alt | Sp pat, Di spi |
| 2010 vs 2015 U | 0.597 | | | |



# Waquoit Bay, MA

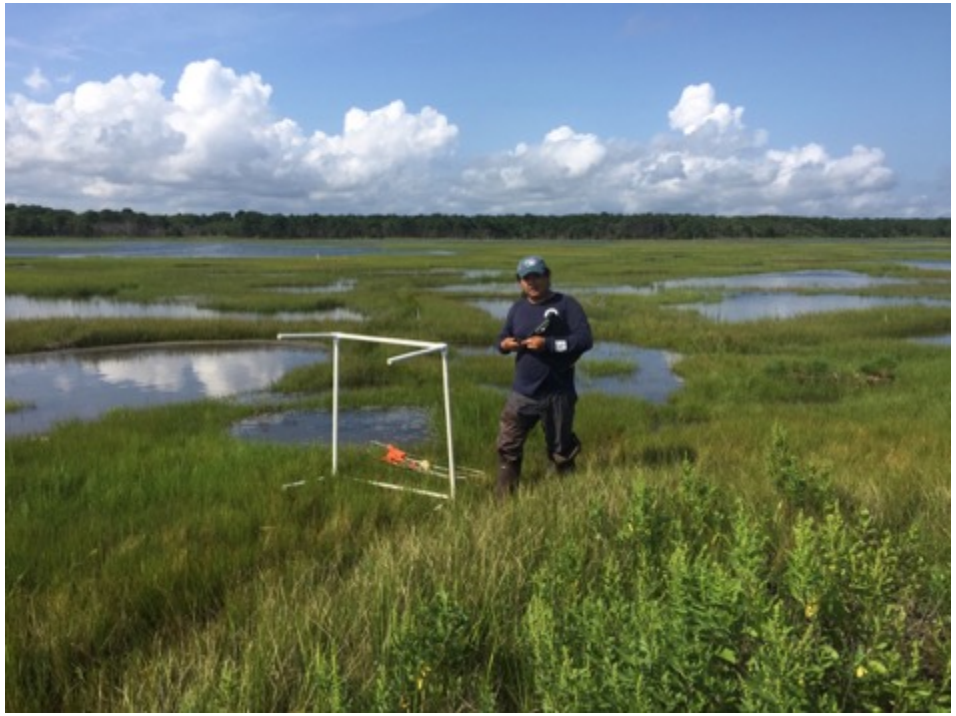
| | Section 1 | | | |
|---|---|---|---|---|
| 2011 vs 2017 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.054 | X | **Water**, Bare, Dead | Sp alt |
| Low Marsh | 0.029 | X | **Water**, Bare, Dead | Sp alt |
| High Marsh | 0.770 | | | |
| Upland Edge | 0.900 | | | |
| | **Section 2** | | | |
| 2011 vs 2017 | ANOSIM | NMDS | + SIMPER | - |
| All Plots | 0.530 | | | |
| Low Marsh | 0.681 | | | |
| High Marsh | 0.413 | | | |
| Upland Edge | 0.500 | | | |



# Waquoit Bay, MA

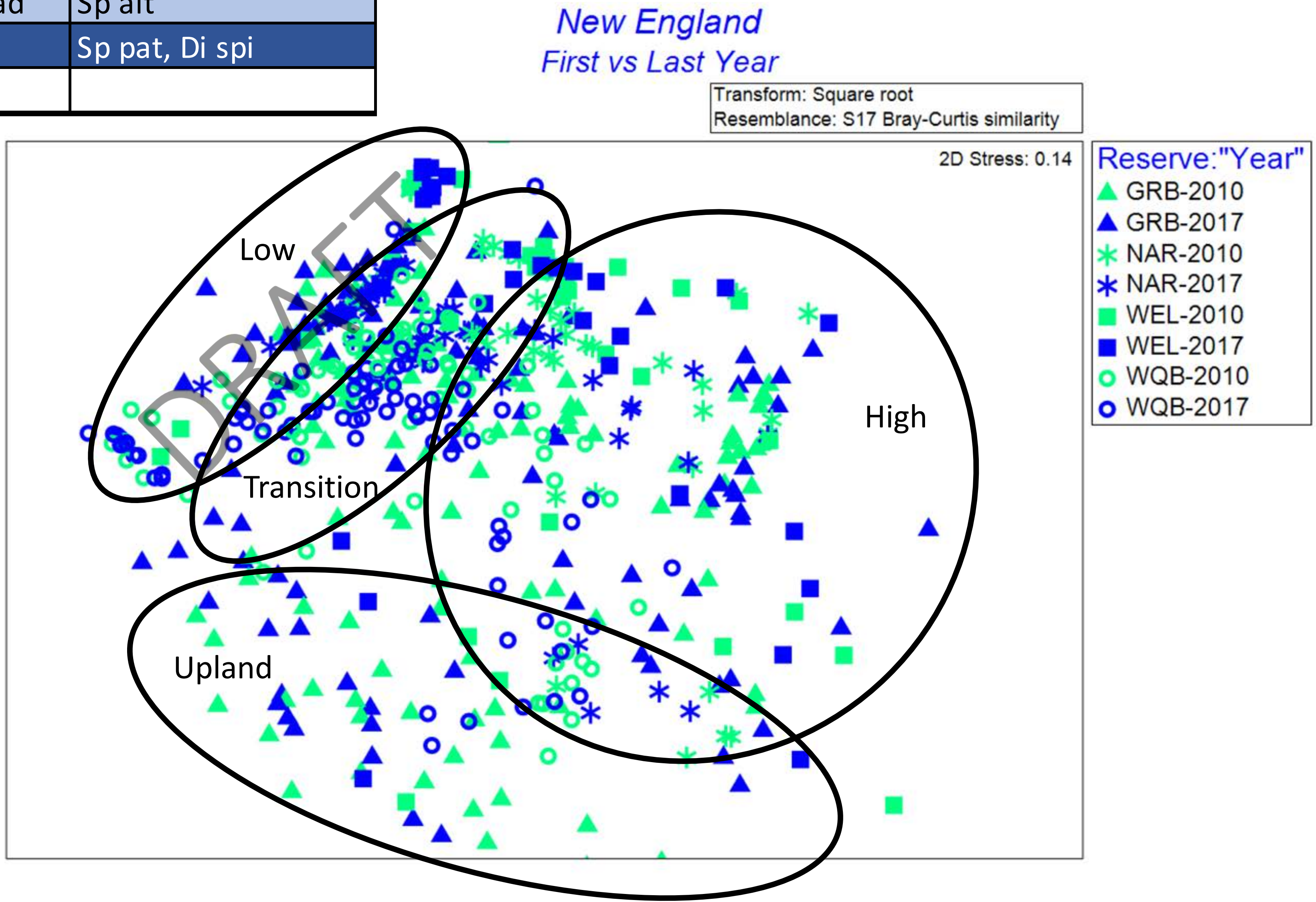
| | Waquoit Bay | | | |
|---|---|---|---|---|
| | ANOSIM | NMDS | + SIMPER | - |
| 2011 vs 2017 | 0.139 | X | **Water**, Bare | Sp alt, Dead |
| 2011 vs 2017 L | 0.064 | X | **Water**, Bare, Dead | Sp alt |
| 2011 vs 2017 H | 0.425 | | | |
| 2011 vs 2017 U | 0.792 | | | |





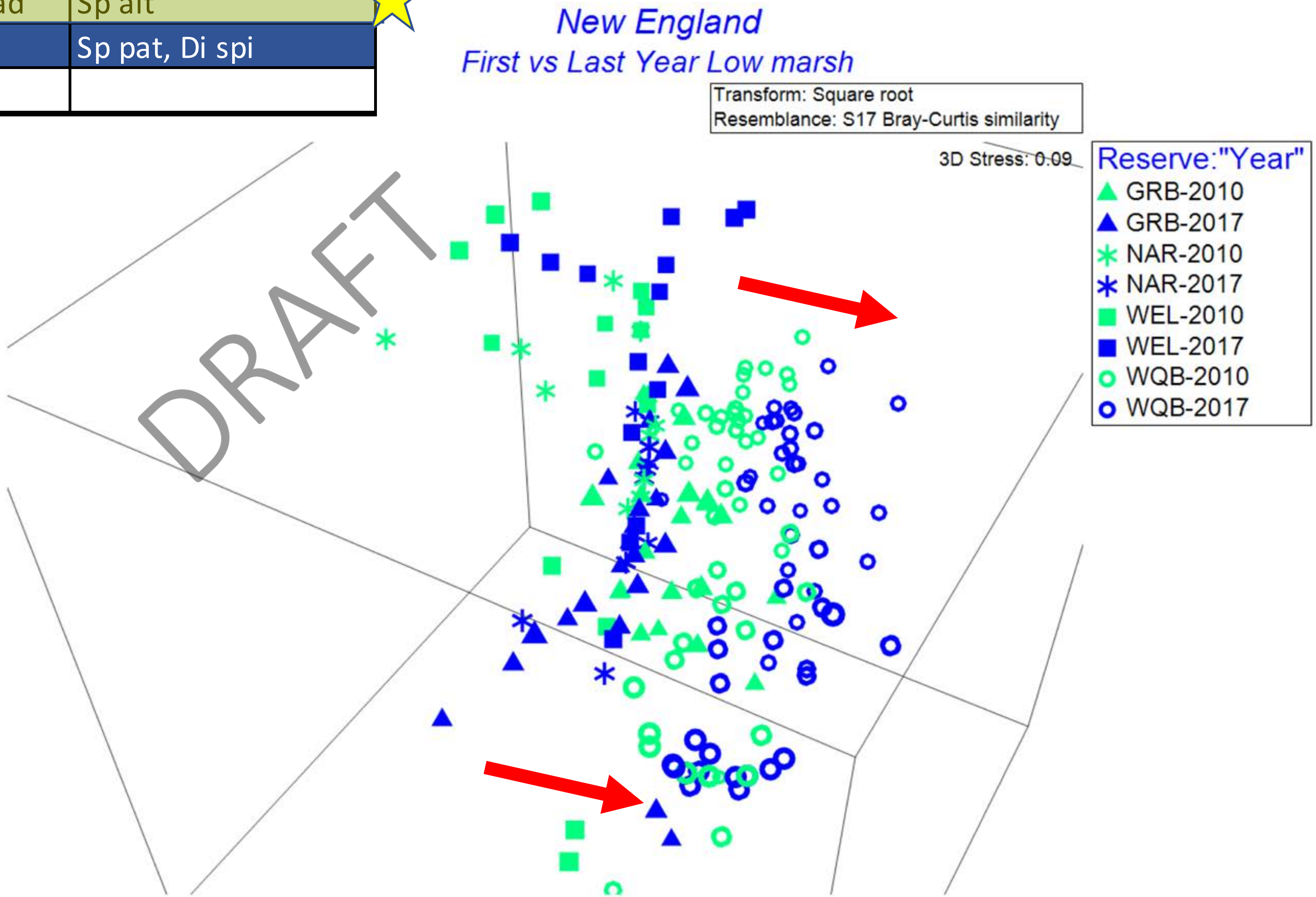
# New England

| | New England | | | |
|---|---|---|---|---|
| | ANOSIM | NMDS | + SIMPER | - |
| Overall | 0.007 | X | **Sp alt**, Bare | Sp pat, Di spi |
| Low marsh | 0.103 | X | **Water**, Bare, Dead | Sp alt |
| High marsh | 0.023 | X | **Sp alt**, Bare | Sp pat, Di spi |
| Upland edge | 0.542 | | | |



# New England

| | New England | | | |
|---|---|---|---|---|
| | ANOSIM | NMDS | + SIMPER | - |
| Overall | 0.007 | X | **Sp alt**, Bare | Sp pat, Di spi |
| Low marsh | 0.103 | X | **Water**, Bare, Dead | Sp alt |
| High marsh | 0.023 | X | **Sp alt**, Bare | Sp pat, Di spi |
| Upland edge | 0.542 | | | |




Bare
Dead
Water

+

S. alterniflora

−

| | Northern New England | | | |
|---|---|---|---|---|
| | ANOSIM | NMDS | + SIMPER | - |
| Overall | 0.029 | X | **Sp alt**, Bare | Sp pat, Dead |
| Low marsh | 0.492 | | | |
| High marsh | 0.282 | | | |
| Upland edge | 0.802 | | | |

| | Southern New England | | | |
|---|---|---|---|---|
| | ANOSIM | NMDS | + SIMPER | - |
| Overall | 0.004 | X | Bare, Water | **Sp alt**, Sp pat |
| Low marsh | 0.047 | X | **Water**, Bare, Dead | Sp alt |
| High marsh | 0.003 | X | **Sp alt**, Bare | Sp pat, Di spi |
| Upland edge | 0.674 | | | |

# Multivariate Summary

| | |
|---|---|
| ↑↓ S. alterniflora | 卌 卌 \| |
| ↑ Bare | 卌 卌 |
| ↓ S. patens | 卌 卌 |
| ↓ D. spicata | 卌 \|\|\| |
| ↑↓ Dead | 卌 \| |
| ↑ Water | \|\|\| |
| Wrack | \|\| |
| J. gerardii | \| |
| S. tenuifolium | \| |
| P. australis | \| |
| T. radicans | \| |
| T. maritima | \| |

- Transition plots = higher sensitivity

- Drastic changes in Southern New England




- What will the future hold?
  - Marsh transformations coming northward?
  - South become more wet & barren?

# Surface Elevation Tables and Marker Horizons

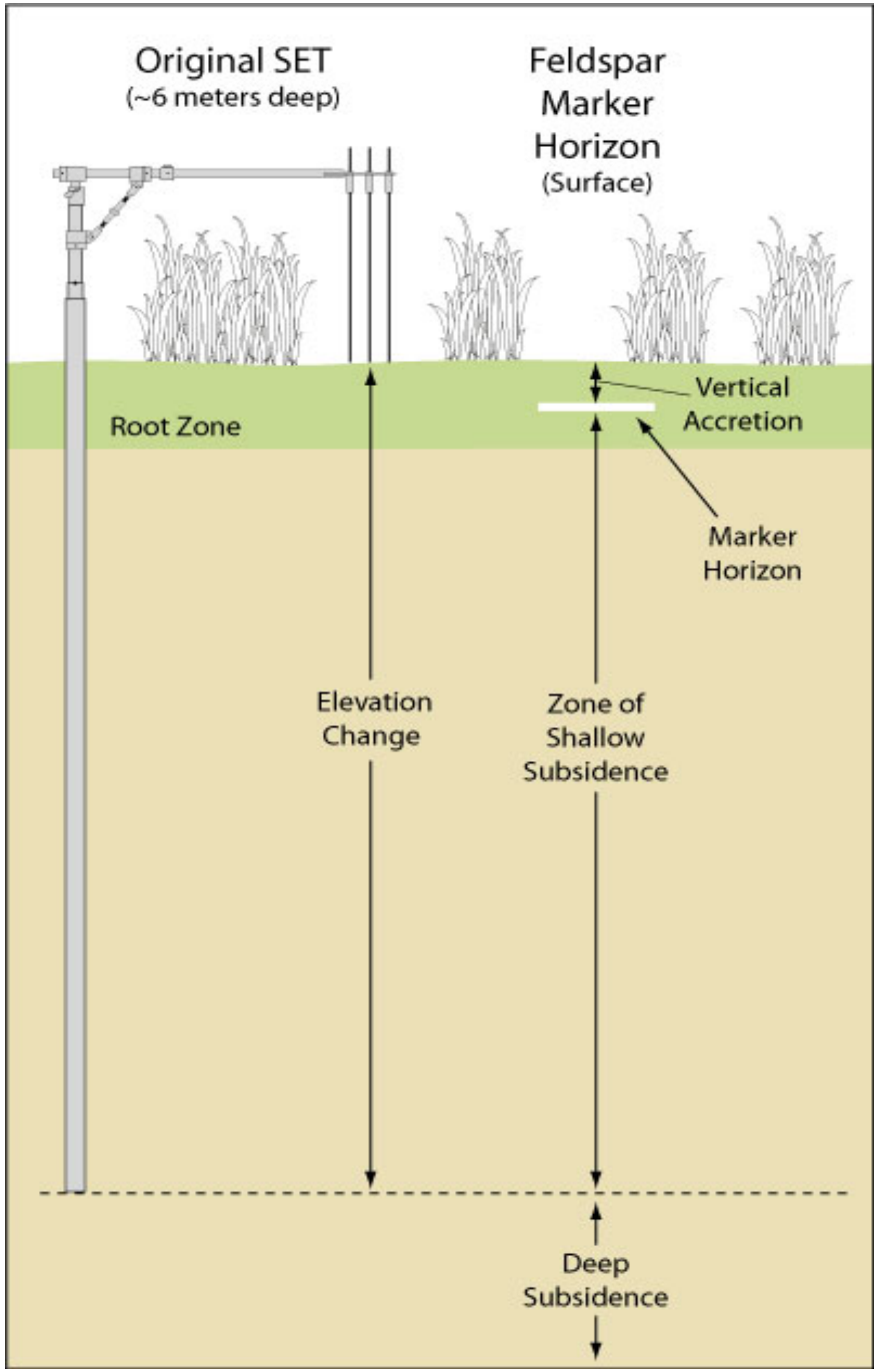
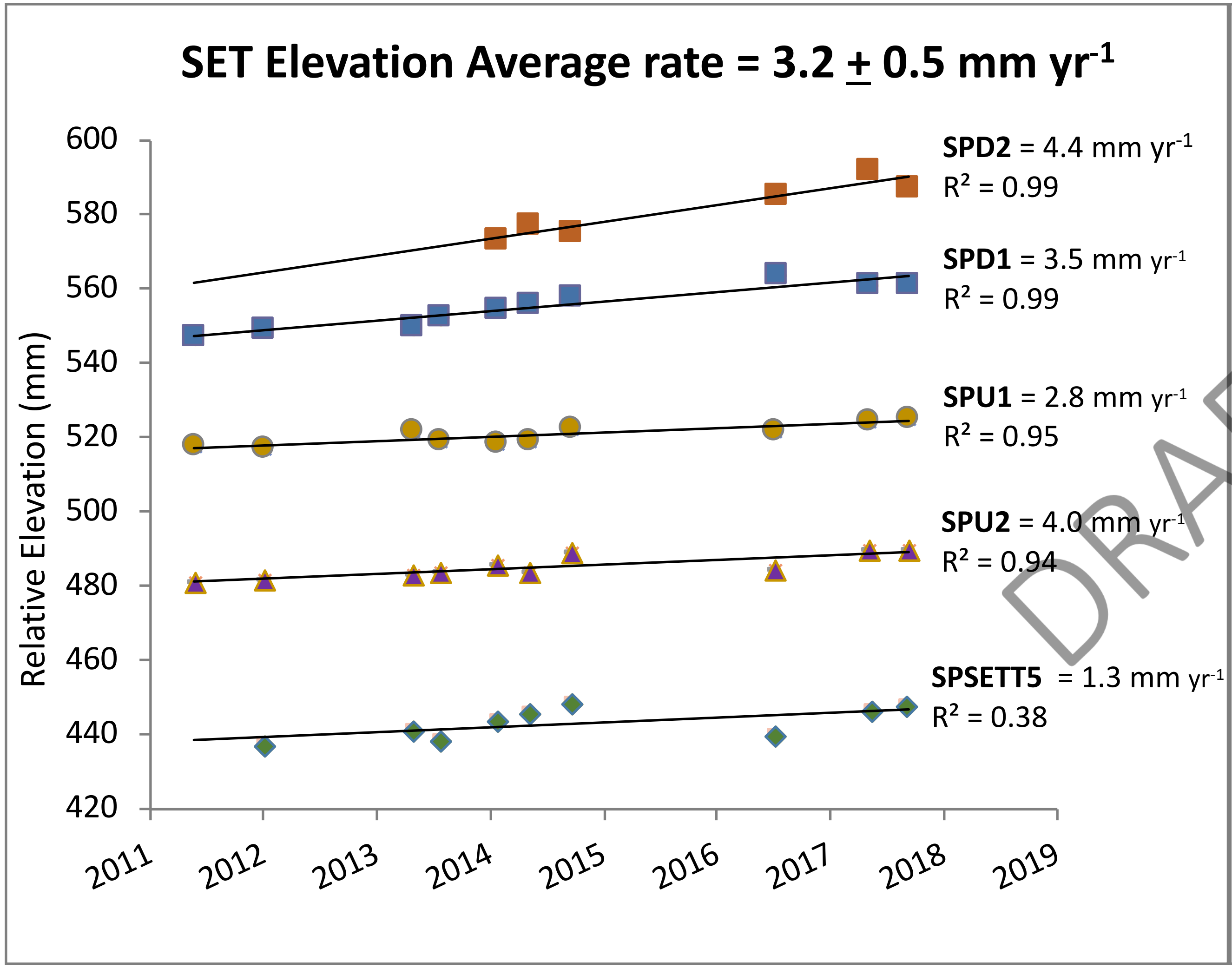
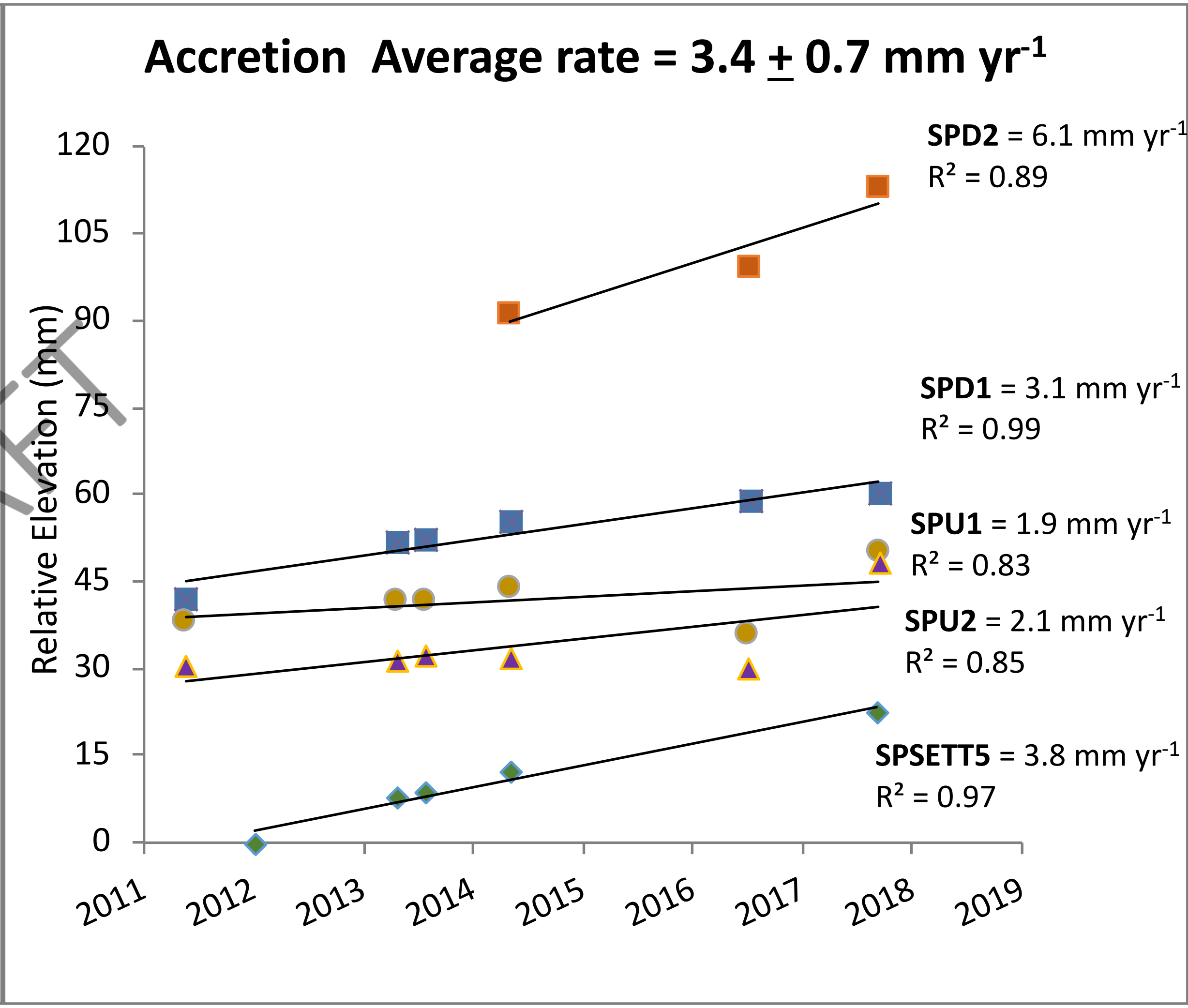




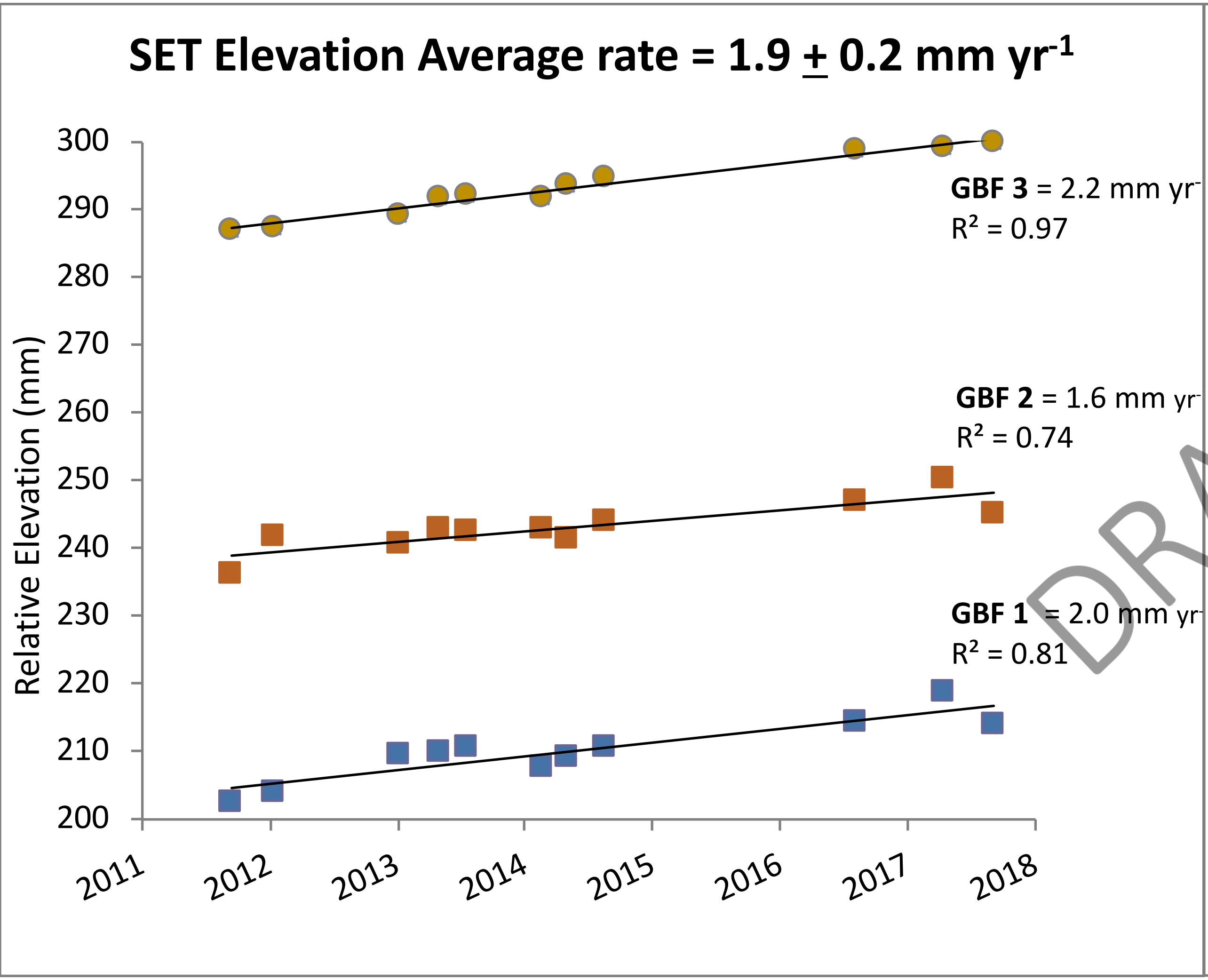

Image from Don Cahoon and Jim Lynch:
http://www.pwrc.usgs.gov/set/

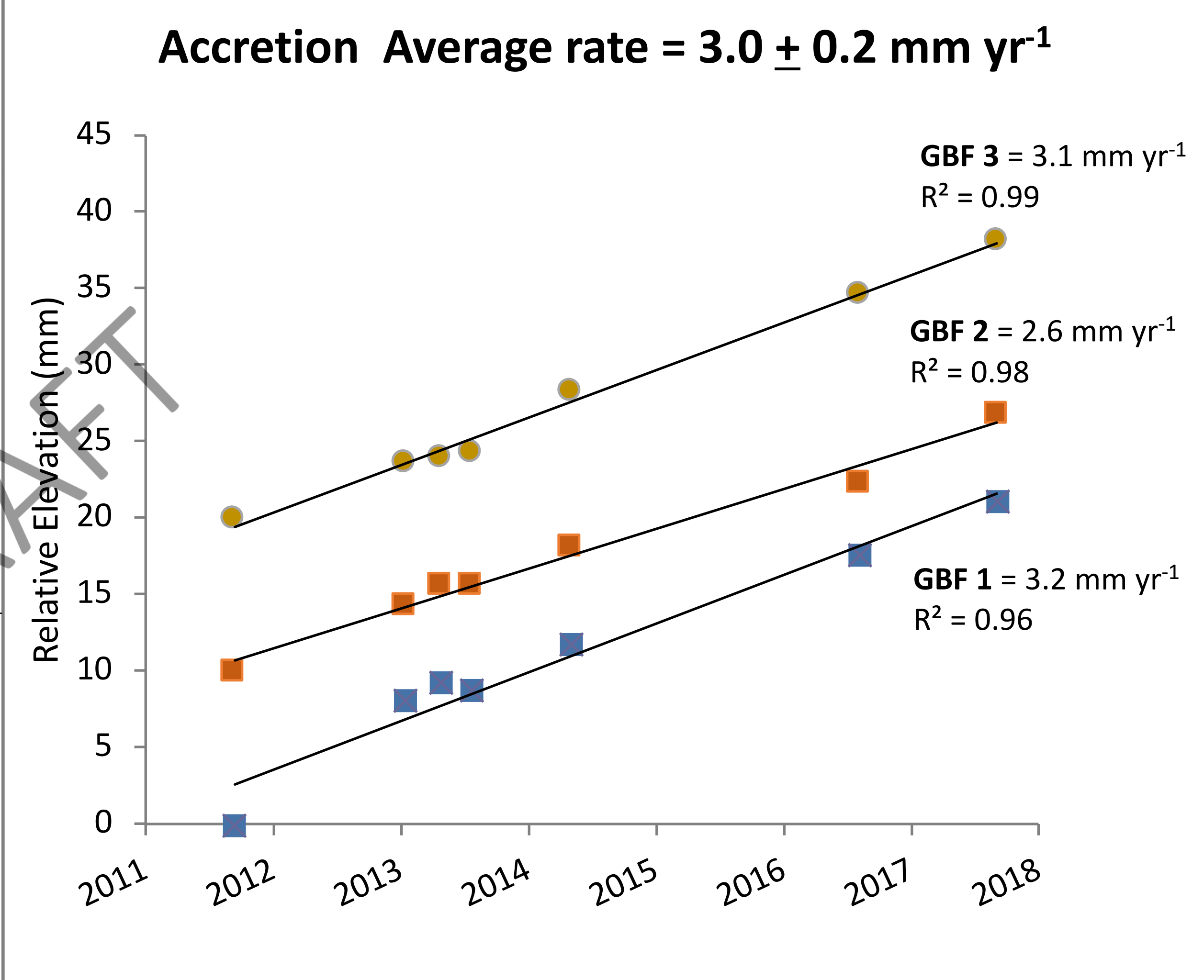
# Sandy Point, Great Bay



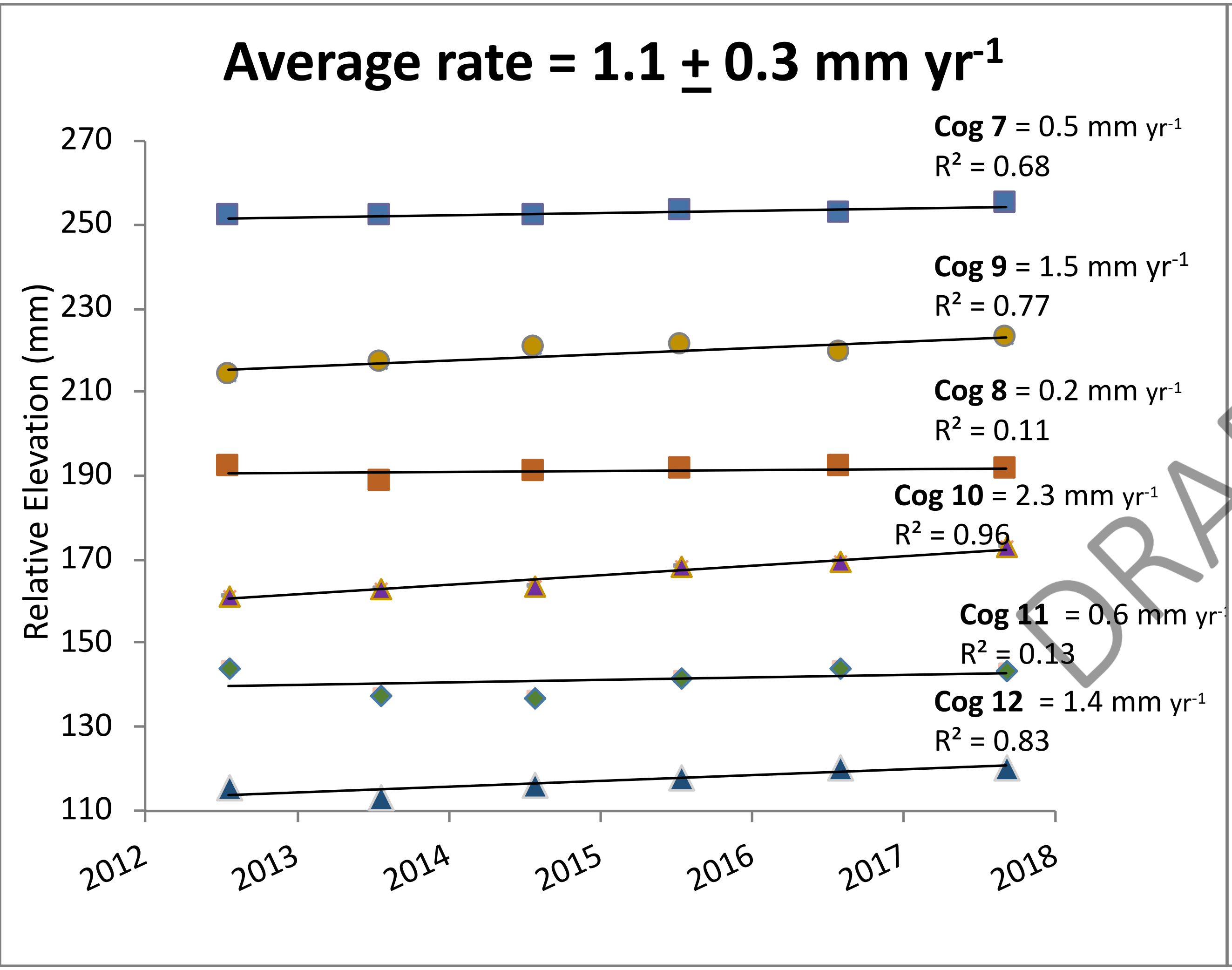



# Great By Farms, Great Bay

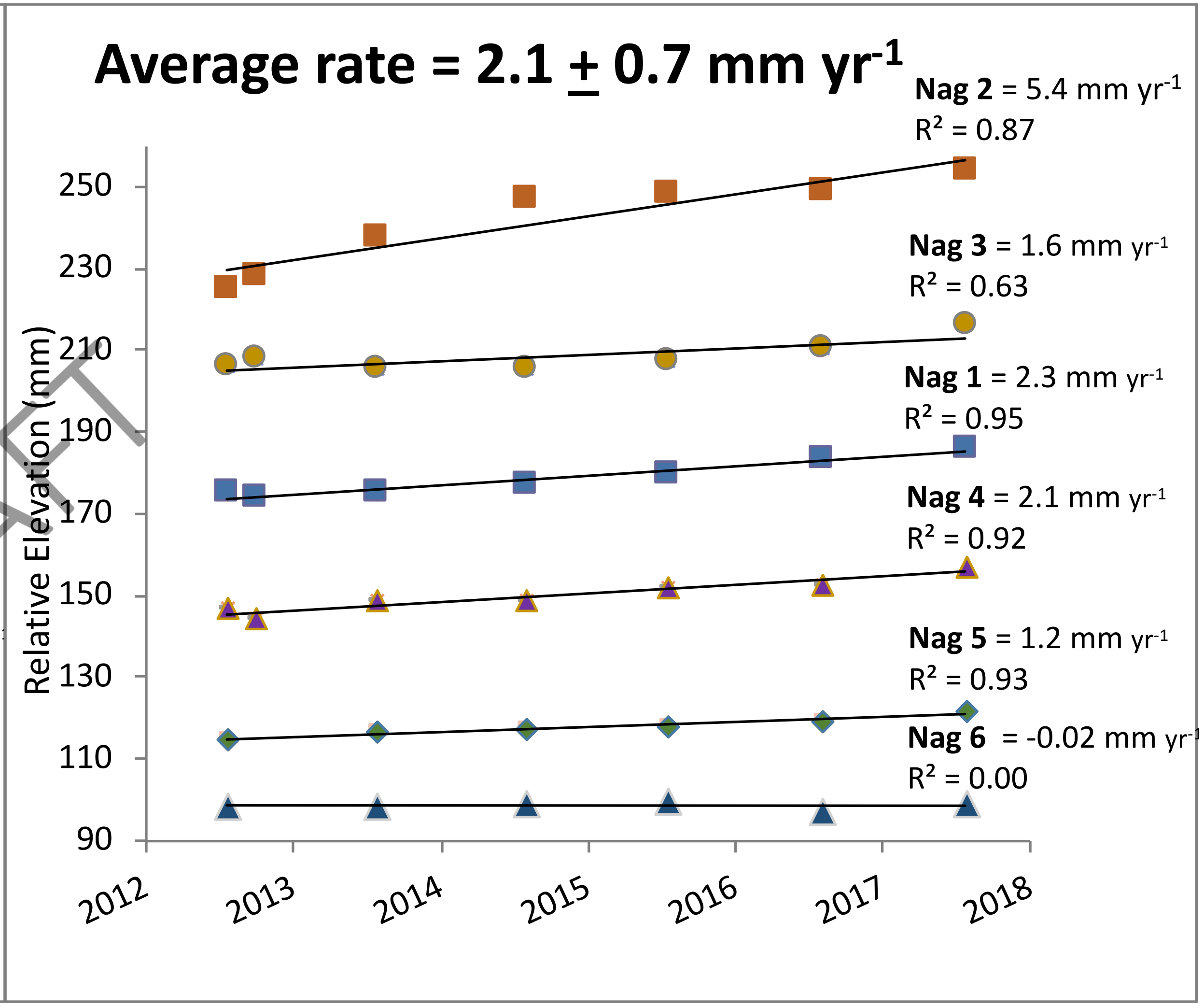


# Coggeshall and Nag SET Data, Narragansett Bay

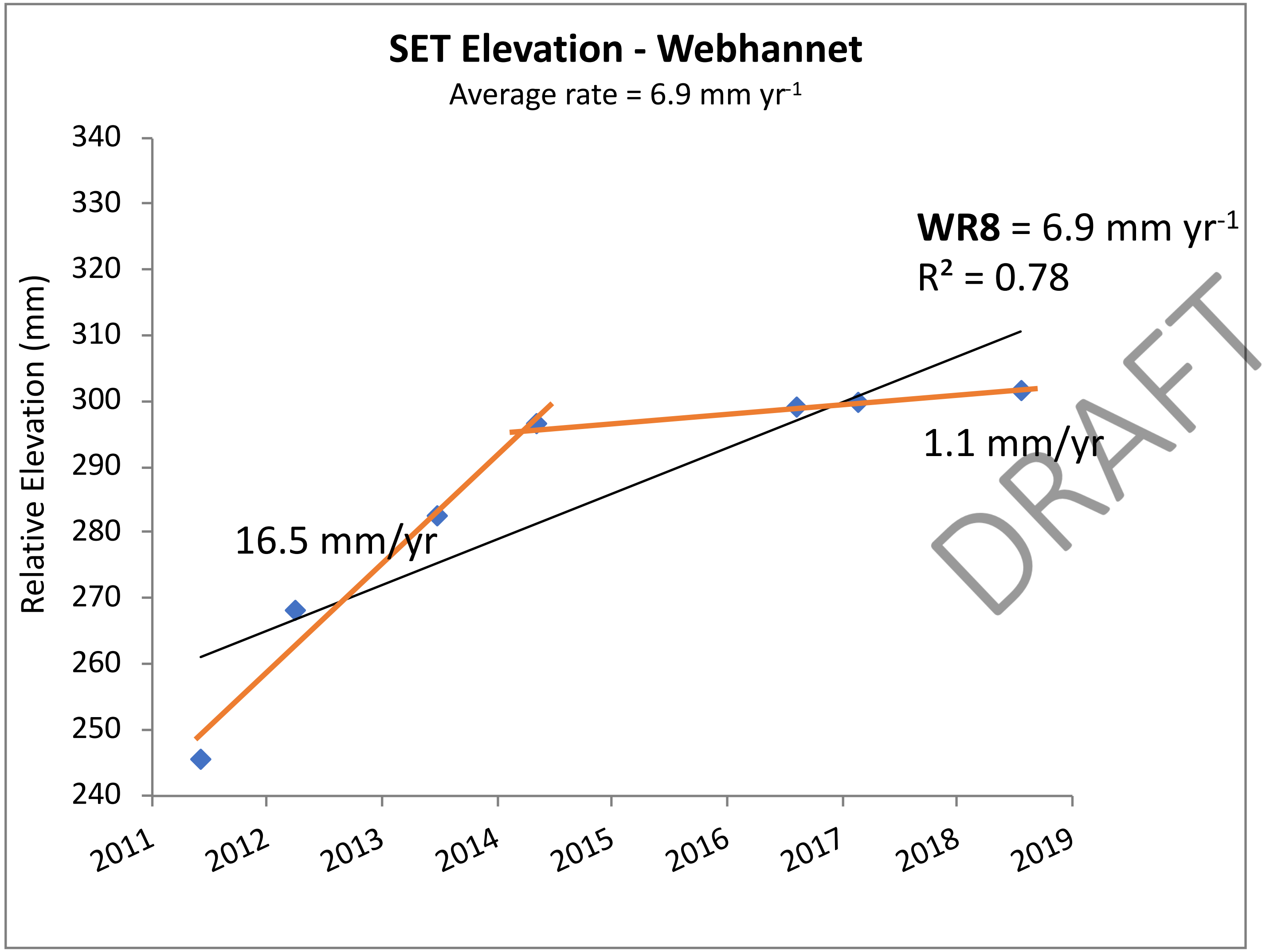



*No MH graph, only one year of data




*No MH graph, only one year of data

# Webhannet, Wells



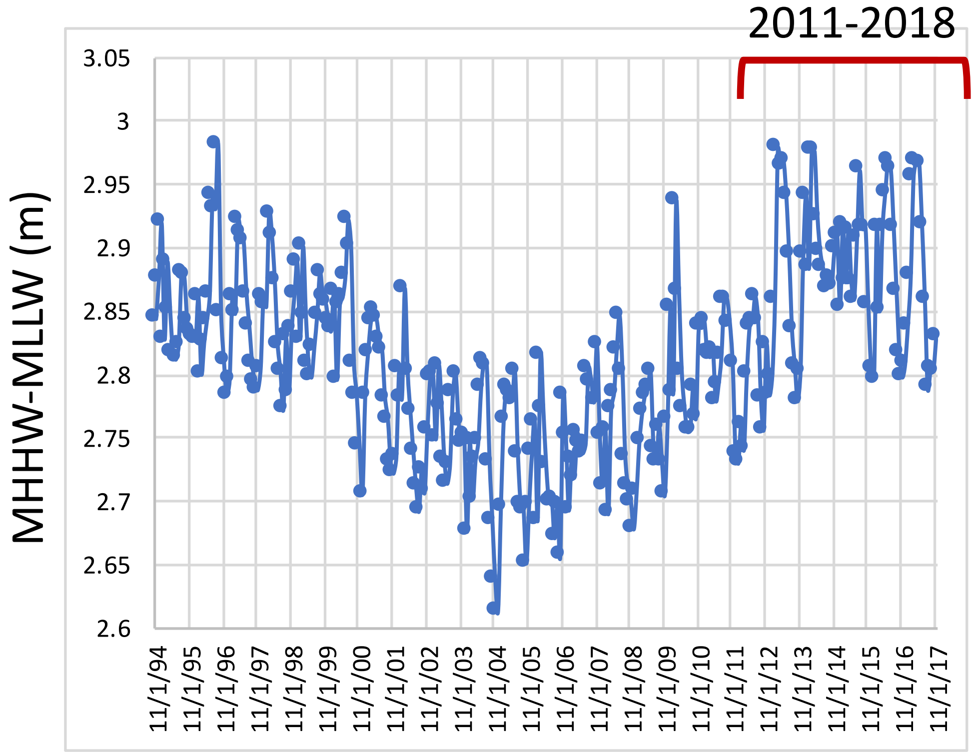

*No MH data

Possible Explanations:

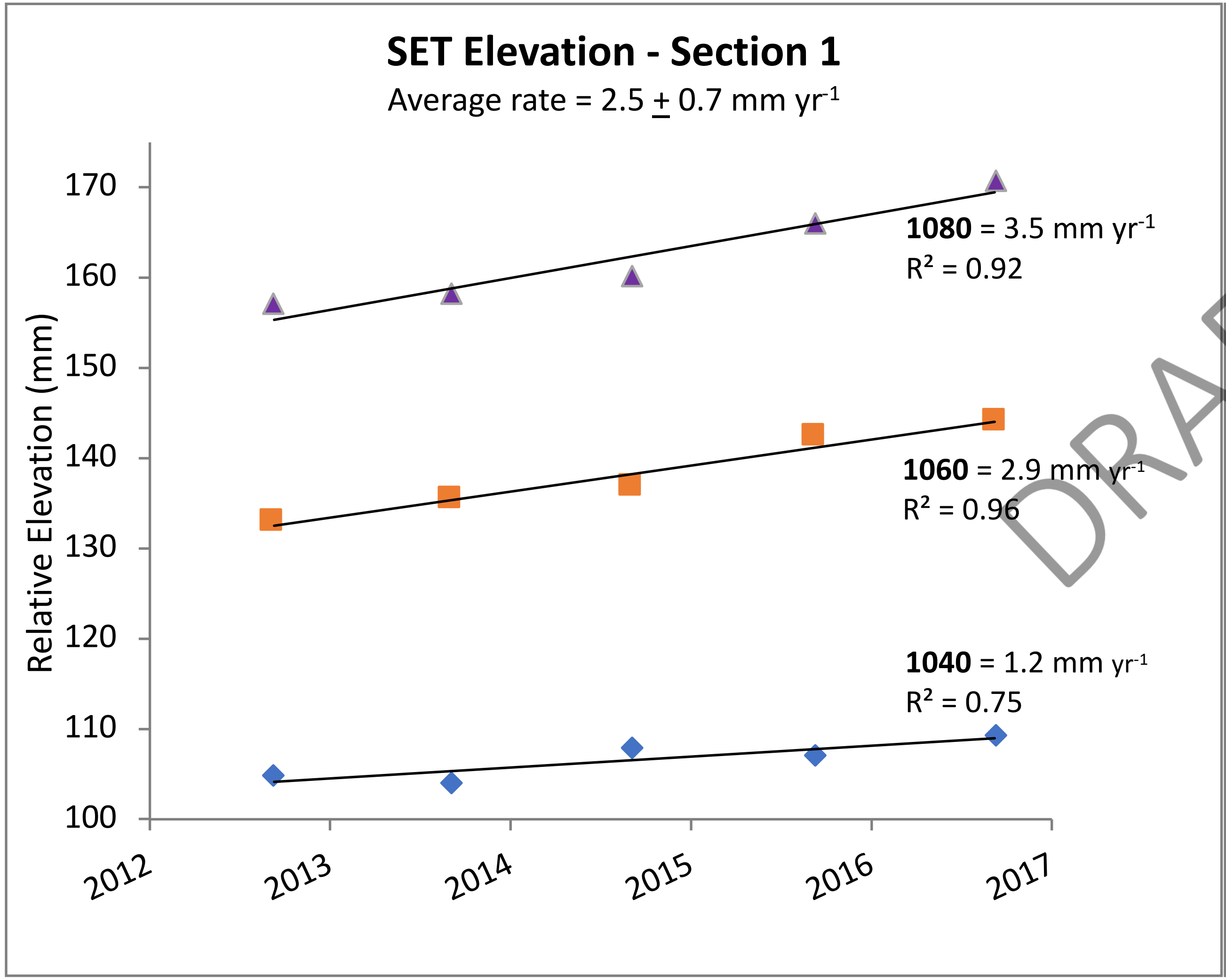
Metonic Cycle

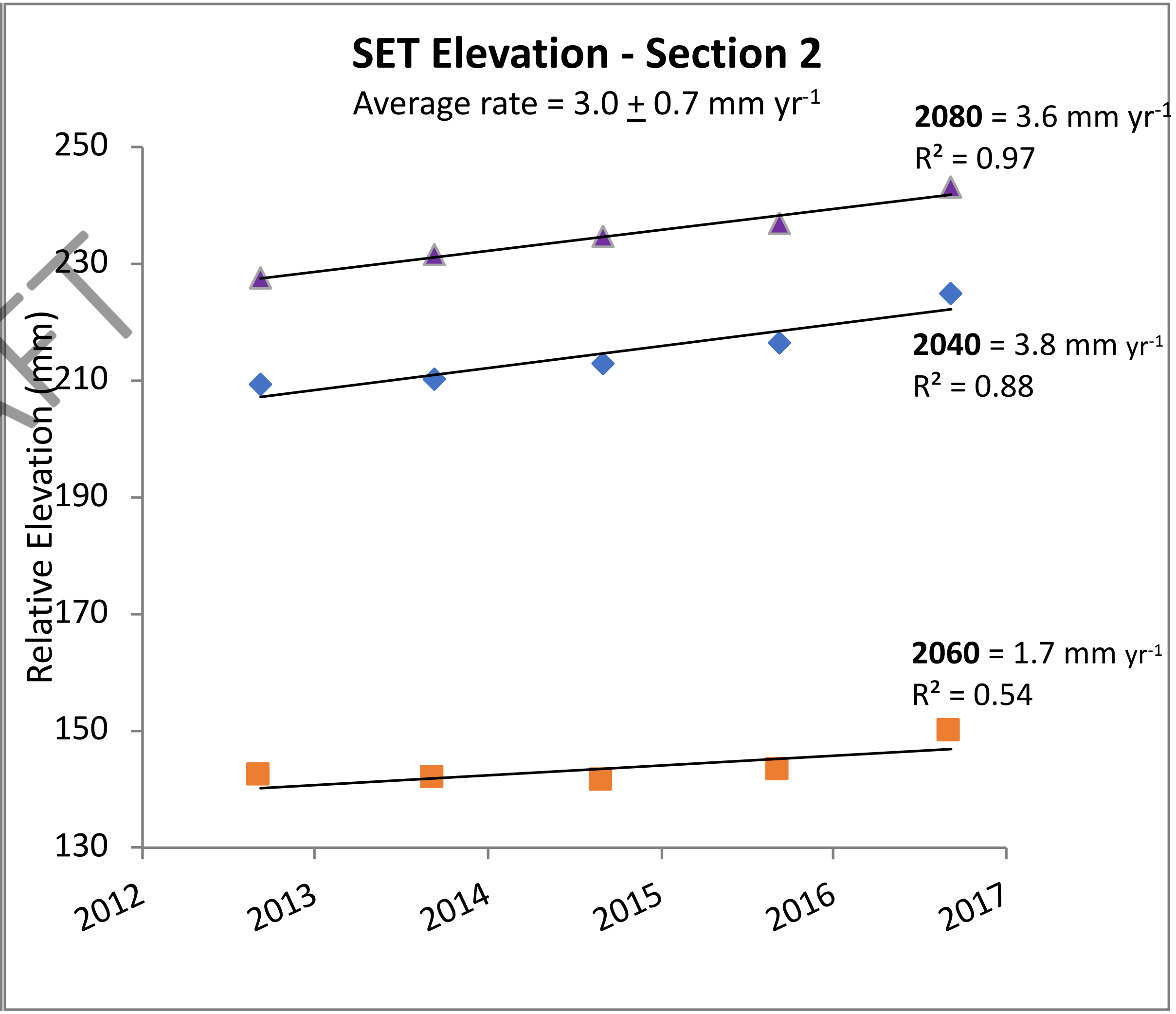
tide range maxima 2015

Inlet Dredging



# Marsh Sections 1 and 2, Waquoit Bay




*No MH data

# SET Results from 2011 to 2017 (roughly)

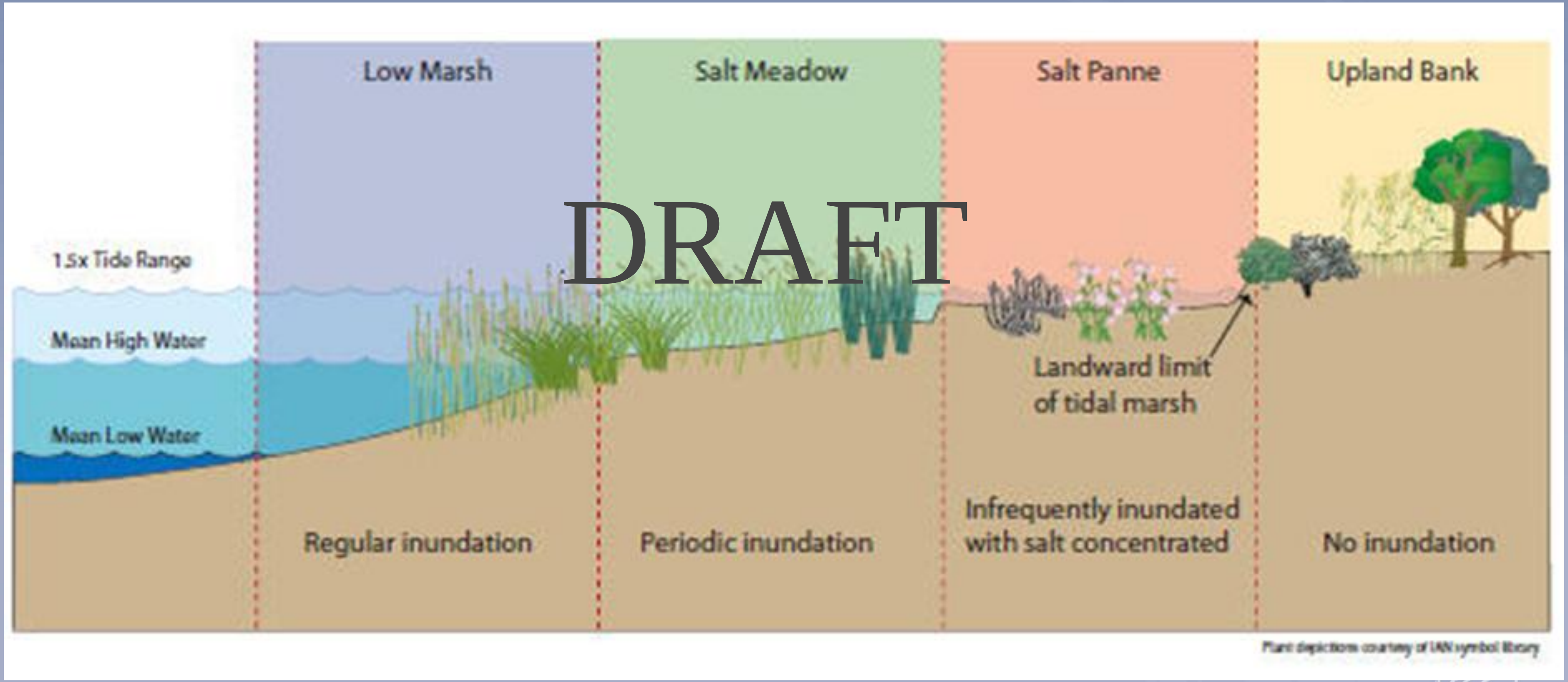
| Reserve | Marsh | Rate of Change in mm/year: Surface Elevation | Error | Accretion | Subsidence | SLR = 3.23 mm/yr* Difference | Result |
|---|---|---|---|---|---|---|---|
| **Wells** | **Webhannet** | **6.9** | na | | | **+3.7** | **GAINING** |
| **Great Bay** | **Sandy Point** | **3.2** | 0.5 | 3.4 | 0.2 | **0.0** | **EQUAL** |
| | **Great Bay Farms** | **1.9** | 0.2 | 3 | 1.1 | **-1.3** | **LOSING** |
| **Waquoit** | **Section 1** | **2.5** | 0.7 | | | **-0.8** | **LOSING** |
| | **Section 2** | **3.0** | 0.7 | | | **-0.2** | **EQUAL** |
| **Narragansett** | **Coggeshall** | **1.1** | 0.3 | | | **-2.1** | **LOSING** |
| | **Nag** | **2.1** | 0.7 | | | **-1.1** | **LOSING** |

DRAFT

* Sea Level Rise at Wells, ME Calculated from monthly Mean High Water data 2010 through 2018 from NOAA; Global Sea Level Rise for 1993 to 2010 calculated 3.26 mm/yr (Nicholls and Cazenave 2010)

# Inundation analyses

Jenny Allen, Jordan Mora, Vitalii Sheremet, Megan Tyrrell






Center for Coastal Resources

# Inundation Analyses

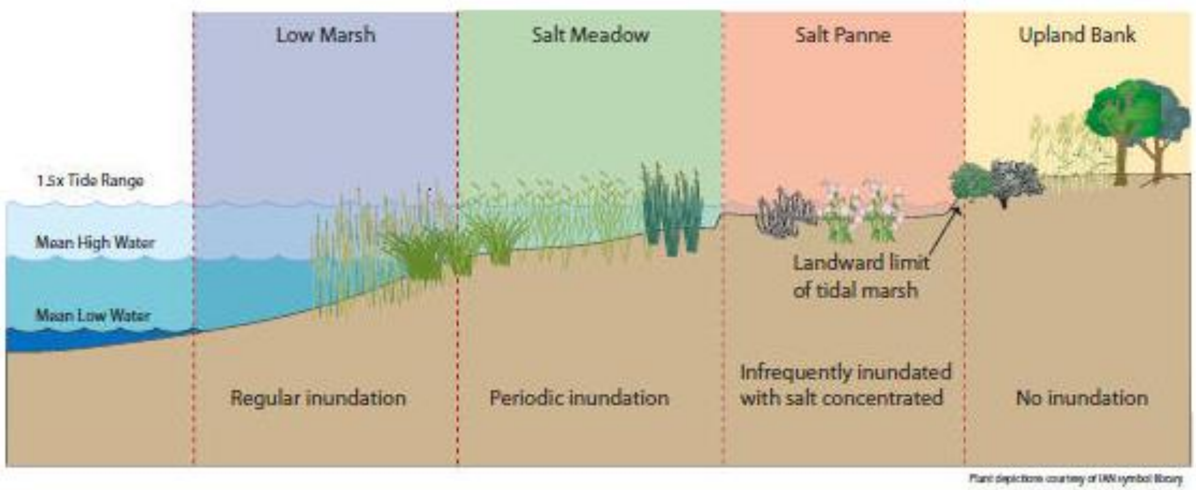
- MS Excel Macro developed by Jim Lynch, National Park Service
- R Tides package also available
- Useful for calculating frequency, depth and duration of tidal inundation for discrete elevation observations (e.g. a monitoring plot) These metrics can be related to changes in vegetation distribution and abundance

# TIDAL INUNDATION REGIME

***KEY QUESTIONS OFTEN ASKED WHEN STUDYING TIDAL INUNDATION REGIMES***

- ❑ *How often did the tide reach the marsh plain?*
- ❑ *What was the duration for each period of inundation?*
- ❑ *What was the duration between inundation events?*






*Center for Coastal Resources*

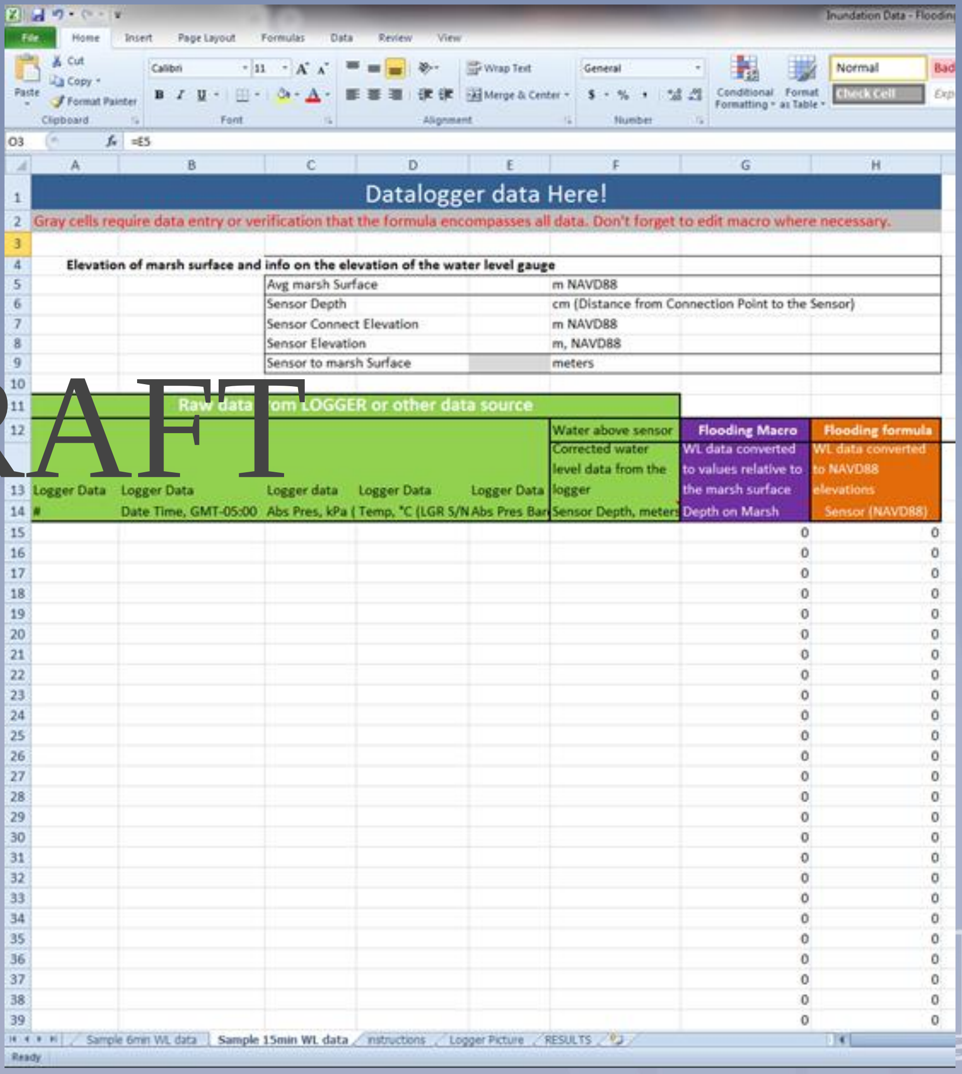


Slide credit: NERRS annual meeting training, Pt. Aransas, TX 2017

# Inundation Analysis Tool

- Requires:
  - Water level data (green) from logger or sonde

  If no local water level data avail, can use from nearby station (tidesandcurrents.noaa.gov)



# Inundation Analysis Tool

For a given input (e.g. elevation point), outputs calculated are:

| Flooding (Macro) | |
|---|---|
| This macro gives info on each flood event | |
| Summary | |
| Start Date | 1/1/2016 0:00 |
| Stop Date | 12/30/2016 23:45 |
| Days | 365.0 |
| Total Hours Data | 8782.75 |
| Flood Hours | 280 |
| # Flood events | 91 |
| % flooded | 3.19 |
| Longest Flood | 24hours |
| Flood Depth | 6.60cm |

| Flooding (formula) | | |
|---|---|---|
| This formula will only summarize the flooding | | |
| Marsh Elevation | | 0.761m, NAVD88 |
| | Flooding = | 280.00hours |
| | Total time = | 8784hours |
| % time flooded | 3.19 | |

DRAFT

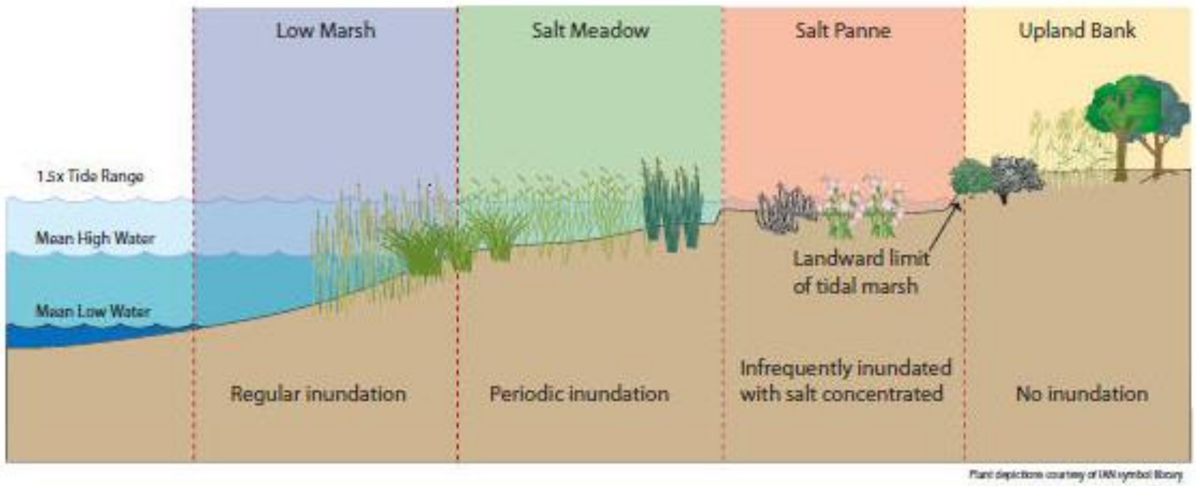
For every vegetation plot, we can quickly calculate inundation time & change analysis for each time elevation and water level data is updated

## TIDAL INUNDATION REGIME

***KEY QUESTIONS OFTEN ASKED WHEN STUDYING TIDAL INUNDATION REGIMES***

- *How often did the tide reach the marsh plain?*
- *What was the duration for each period of inundation?* ***% FLOODING***
- *What was the duration between inundation events?*






*Center for Coastal Resources*



Slide credit: NERRS annual meeting training, Pt. Aransas, TX 2017

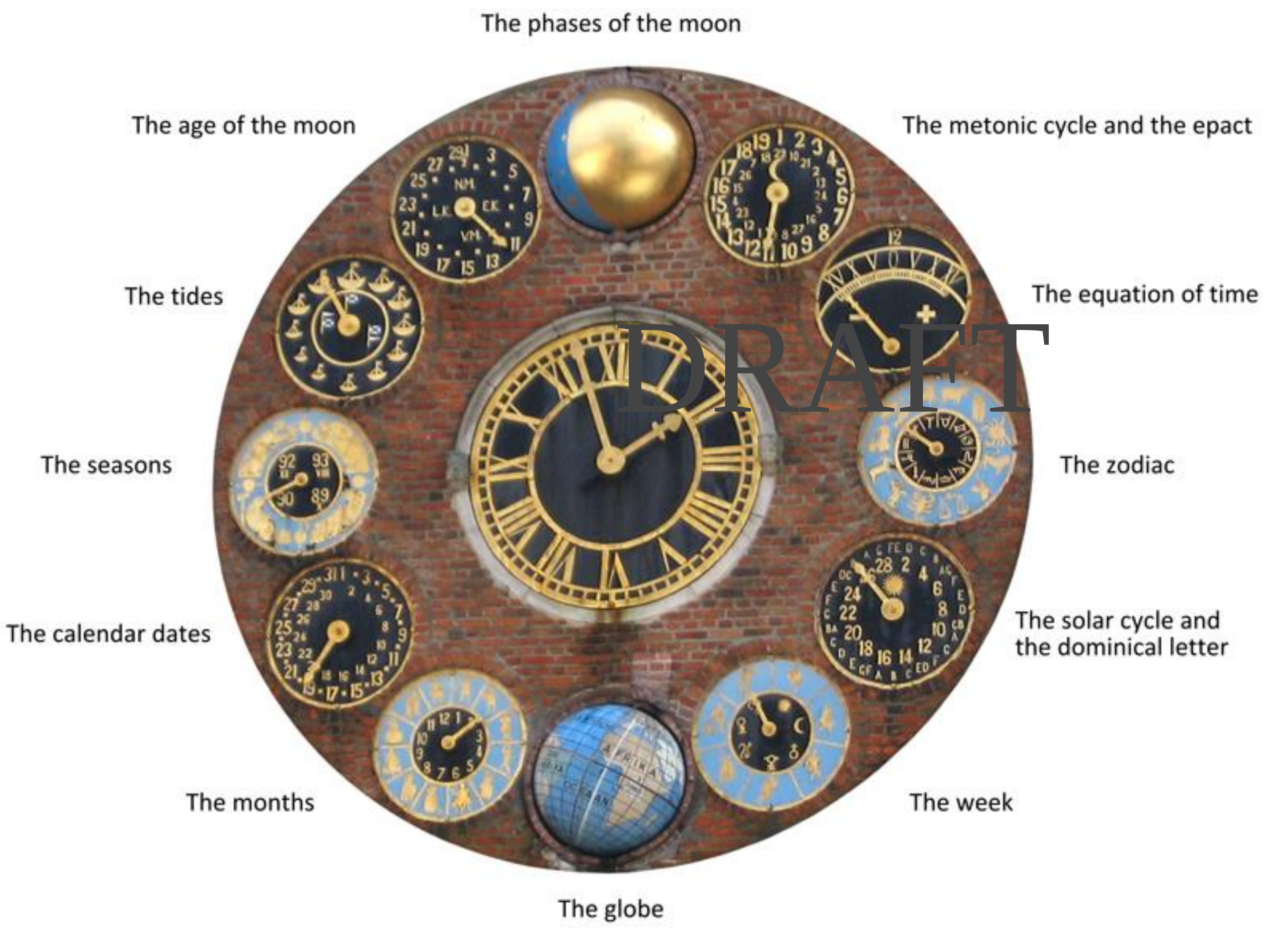
# Water levels vary:

- Daily (high and low tides)
- Bi-monthly (neap/spring tides)
- Monthly (perigee/apogee)
- Annually- King tides (perihelon [winter]/aphelion [summer])
- ~19 years- metonic/tidal lunar cycle



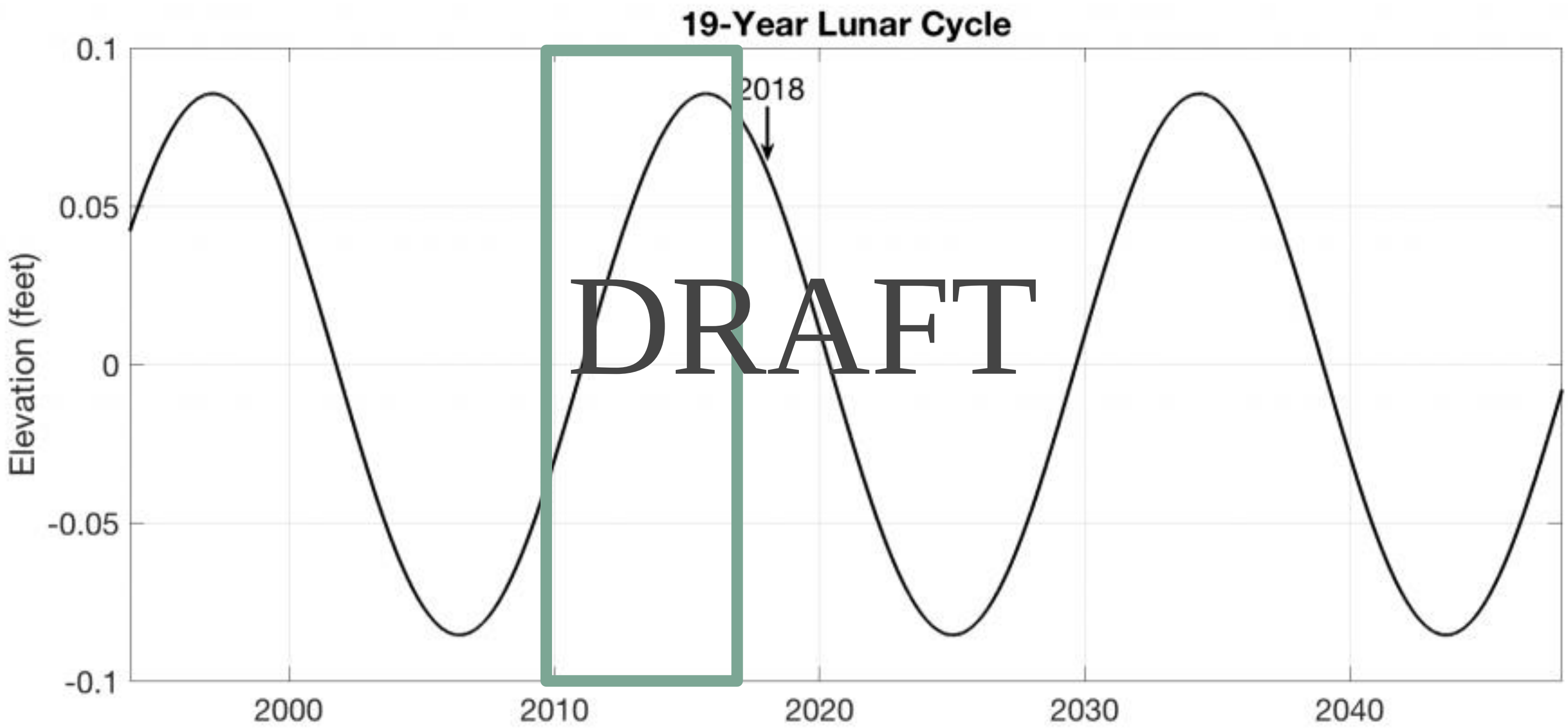
https://jacket2.org/commentary/motions-and-relations-metonic-cycles-myung-mi-kim

# Zimmer tower




One revolution/19 years.
Then the different phases of the moon will fall on the same calendar date

# We analyzed a (mostly) increasing phase

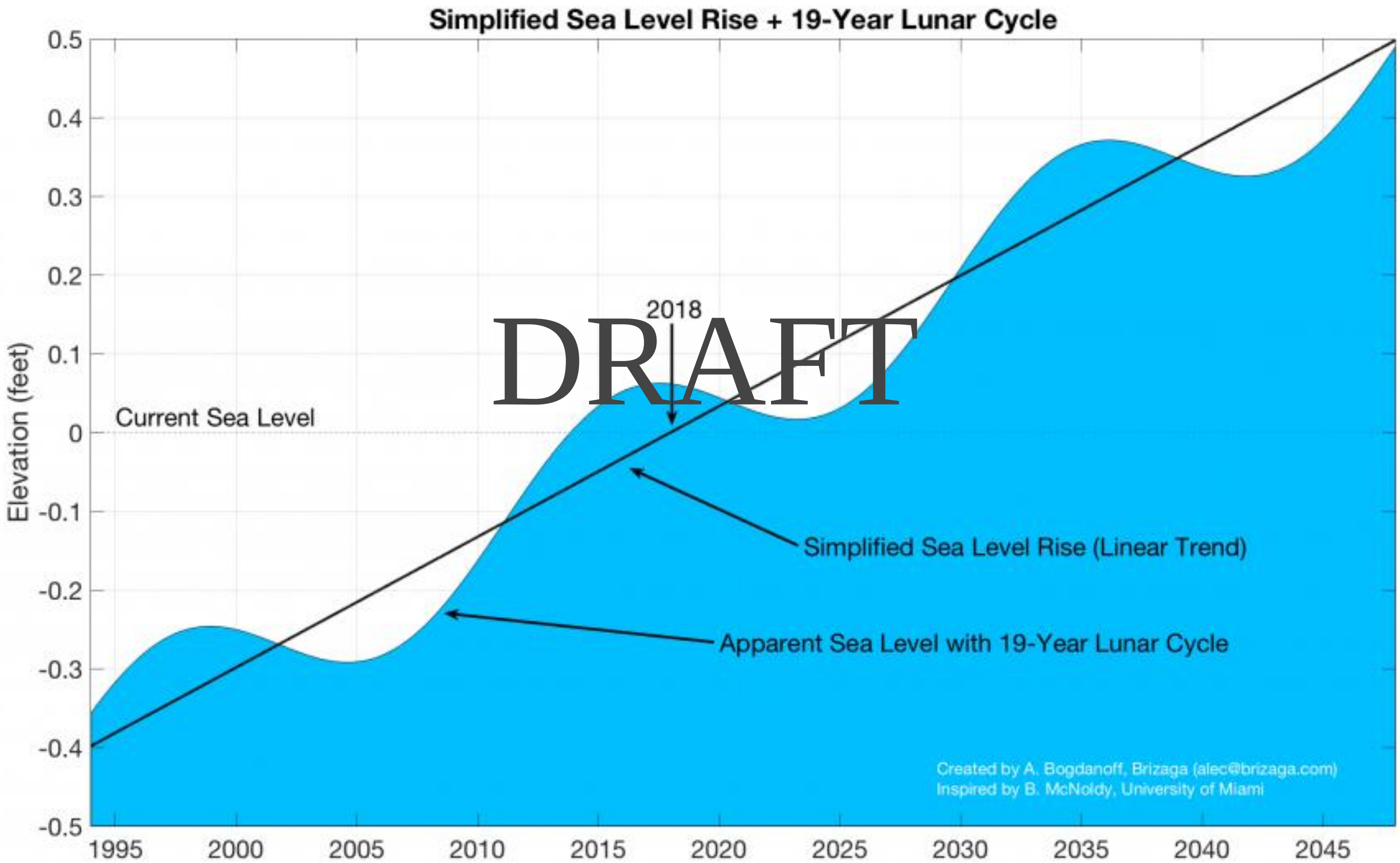





2015 was peak of the lunar nodal cycle

https://www.johnenglander.net/wp-content/uploads/2018/02/Lunar-Nodal-Cycle-line-only-1.png

# Up phase ~ 5 cm/decade

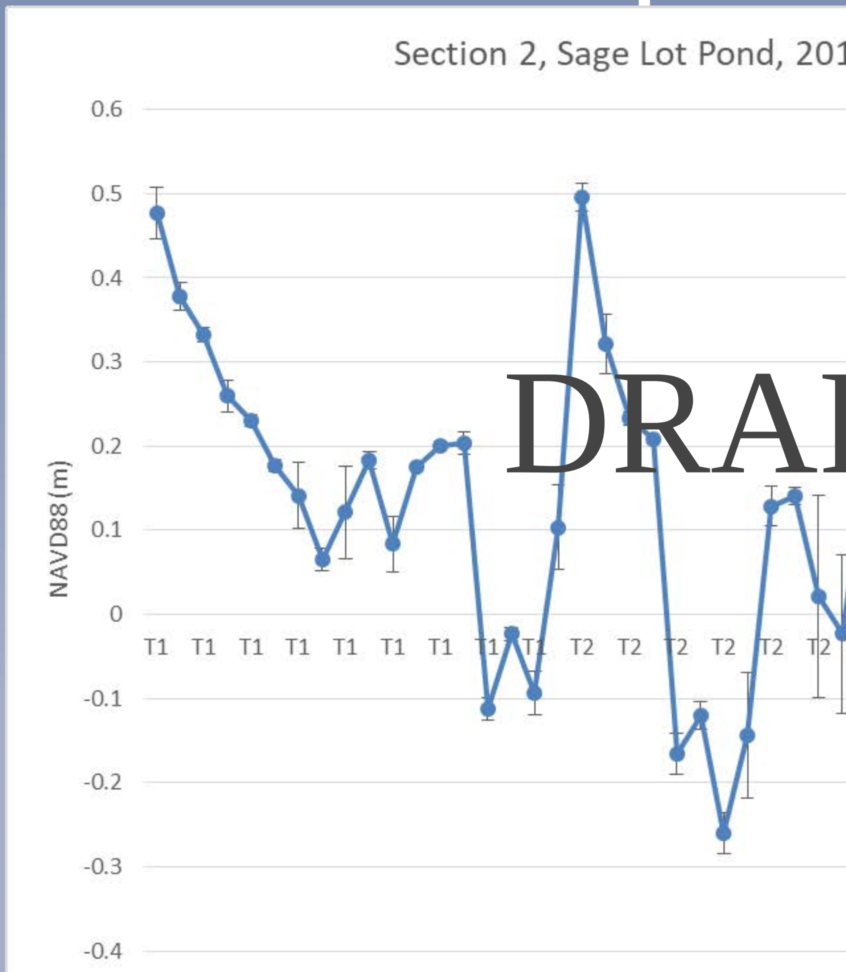



https://www.johnenglander.net/wp-content/uploads/2018/02/Lunar-Nodal-Cycle-line-only-1.png

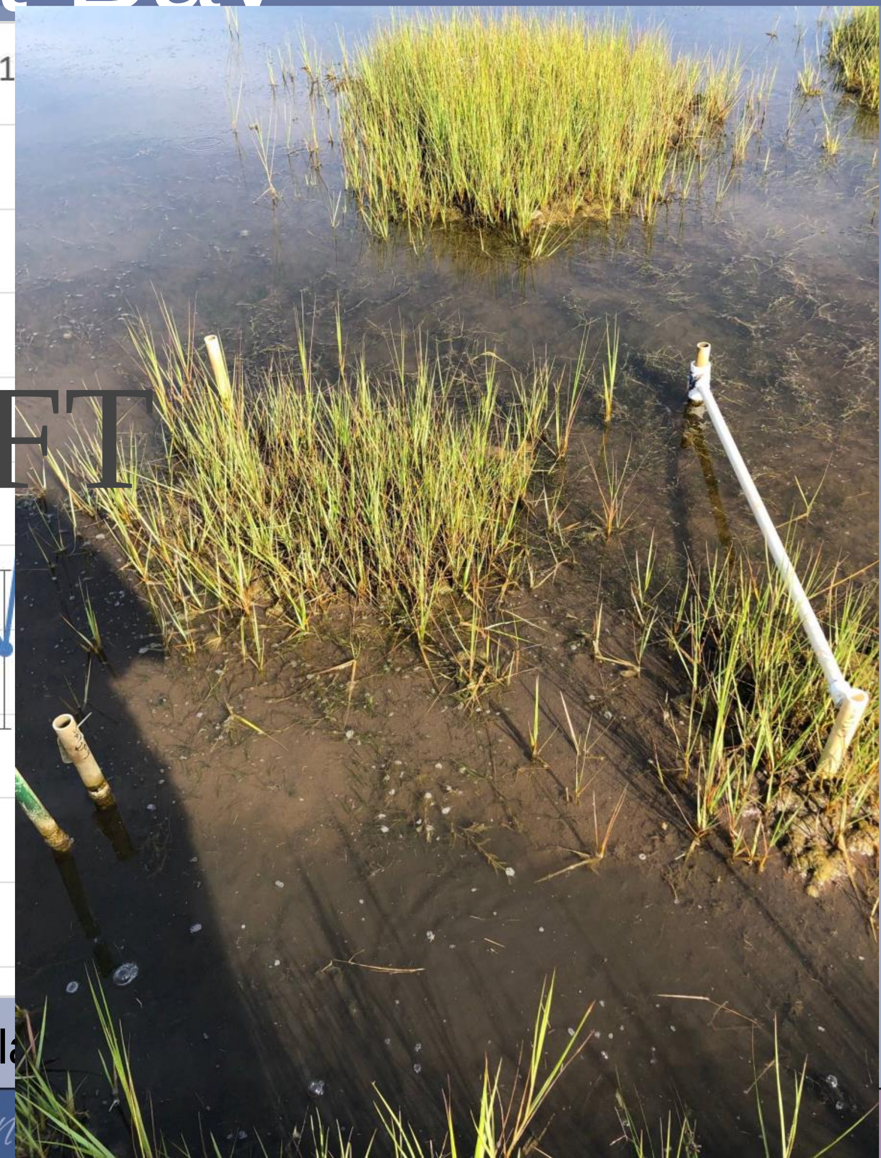
# Plot elevation data

- Not available for all Reserves
- NAR only Reserve that does it annually
- Equipment matters- RTK vs laser level
- QA/QC data, need stable benchmarks

# Distribution of plot elevations Waquoit Bay





Lower elevation plots have higher variability (la

# Highest/lowest plots early elevations (2010-2013)

| Reserve | Site | lowest (NAVD88 m) | highest (NAVD88 m) | Range |
|---|---|---|---|---|
| **Waquoit** | Section 1 | -0.375 | 0.862 | 1.237 |
| | Section 2 | -0.272 | 0.633 | 0.905 |
| | | | | |
| **Narragansett** | Coggeshall | -0.313 | 0.943 | 1.256 |
| | Nags | 0.379 | 0.754 | 0.375 |
| | | | | |
| **Wells** | Webhannett | 0.76 | 1.94 | 1.18 |



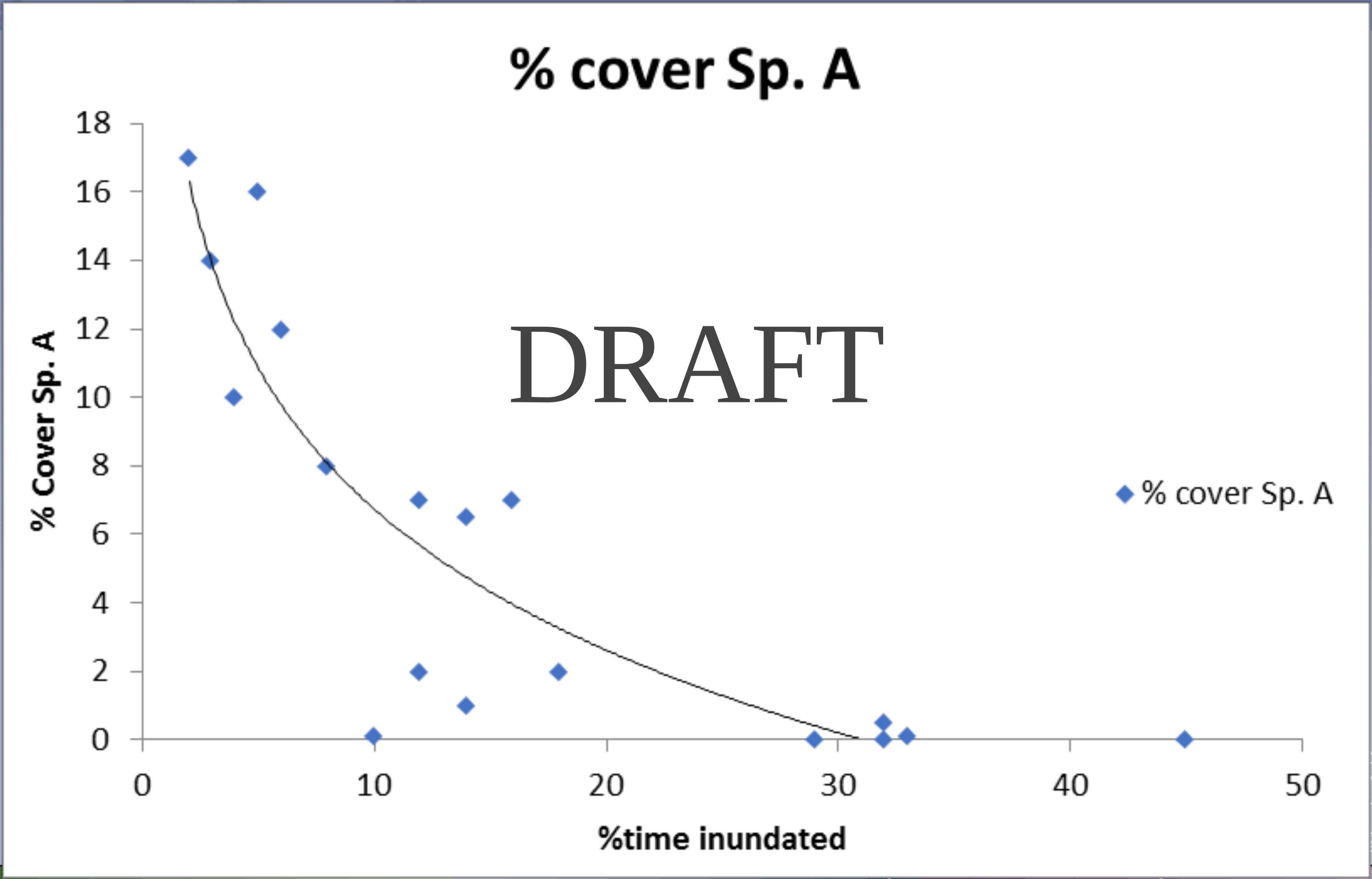
WQB has some *really* low plots but range is similar to NAR and larger than range at Wells

Lowest plot in Webhannet is same elevation as highest plot at Nags in the early elevation survey- but only NAR's Coggeshall marsh included in inundation analyses due to tide station applicability

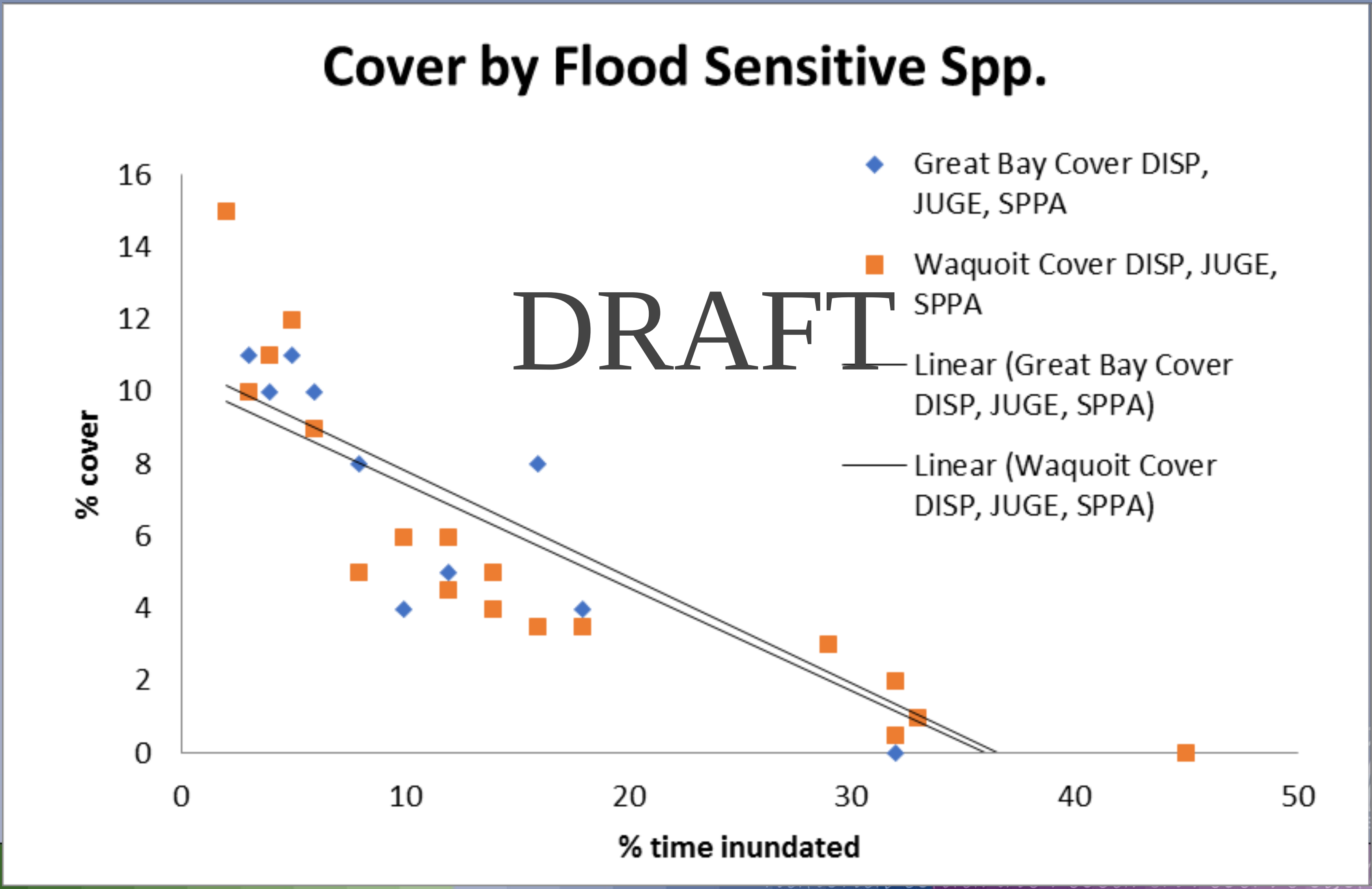
# Inundation Analysis Tool

- Results affected by: surface and groundwater hydrology, topography, soil characteristics, "neighborhood" characteristics – e.g. vegetation structure, density, ecads
- Quality of input data (GI/GO), any analysis should include *seasonal* variability in water levels as these vary substantially

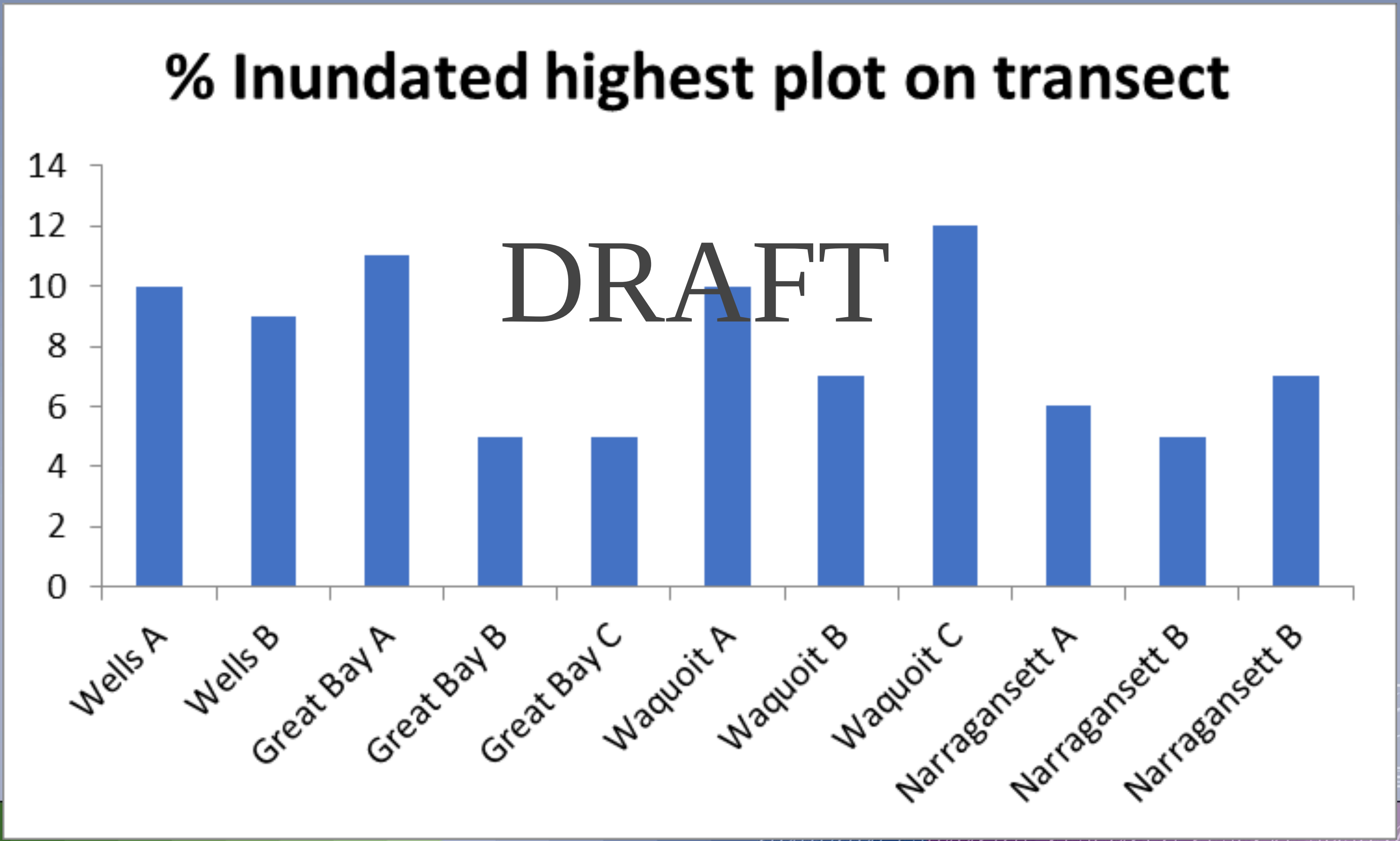
# Example outputs



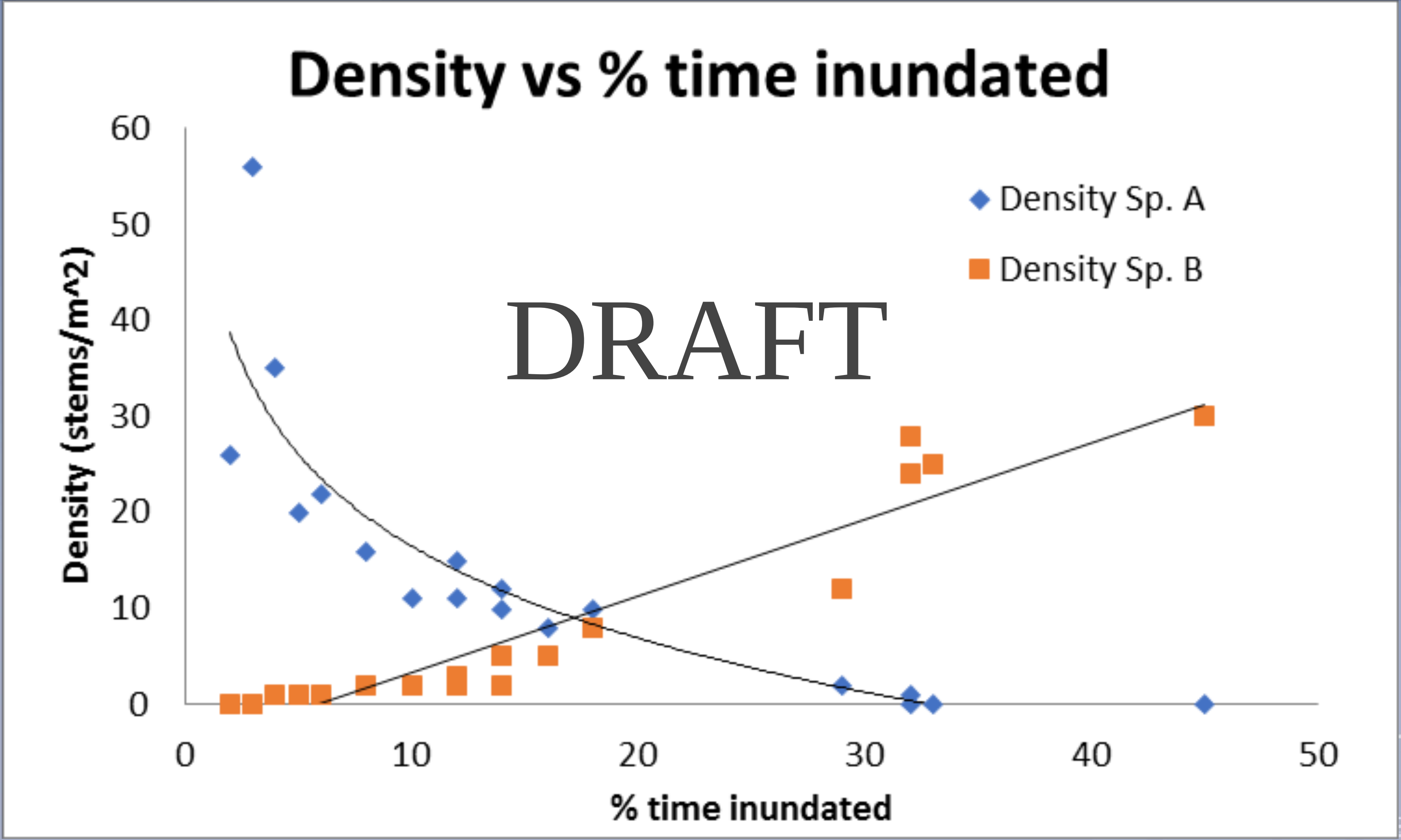
# Example Outputs



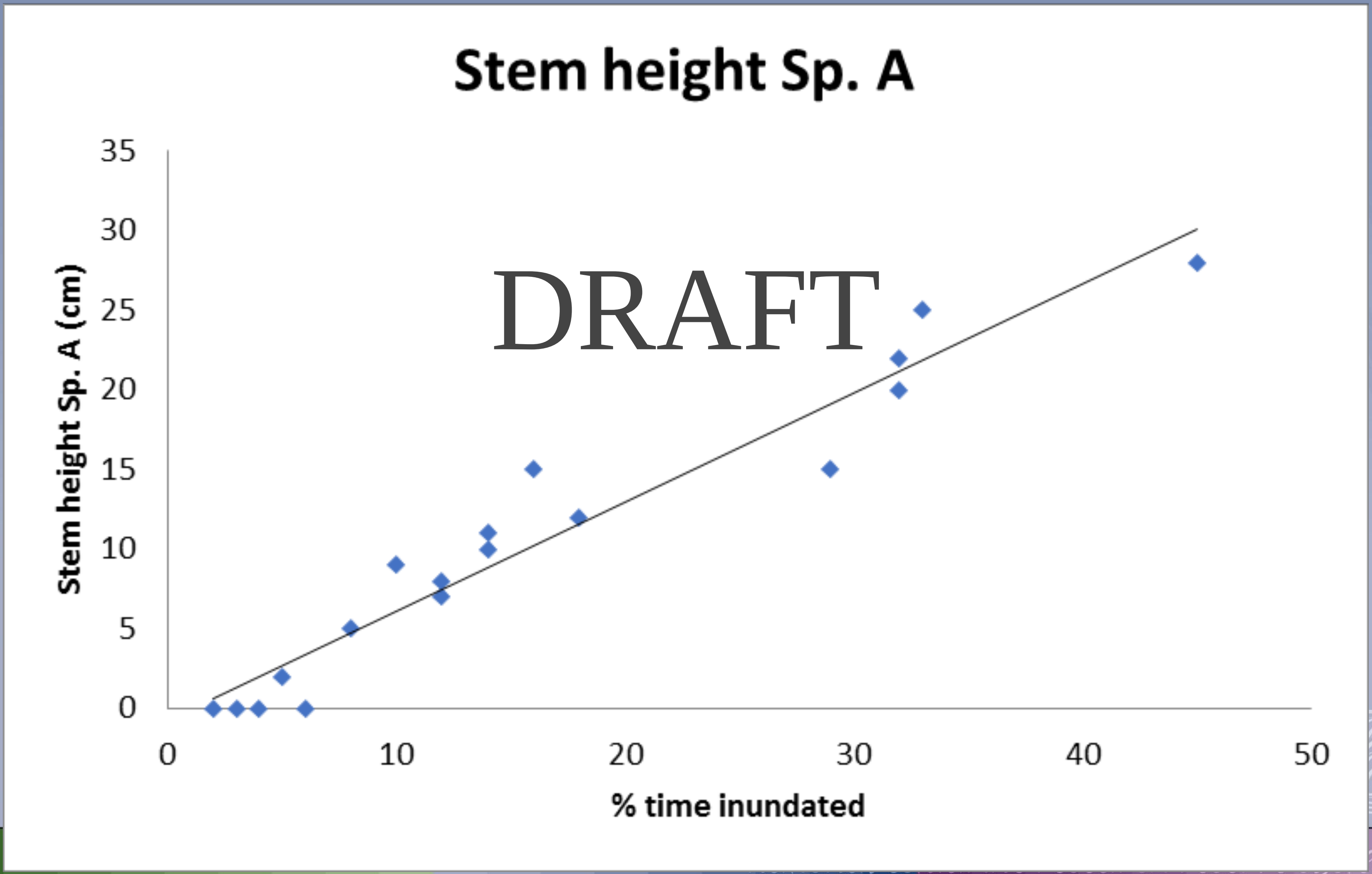
# Example outputs



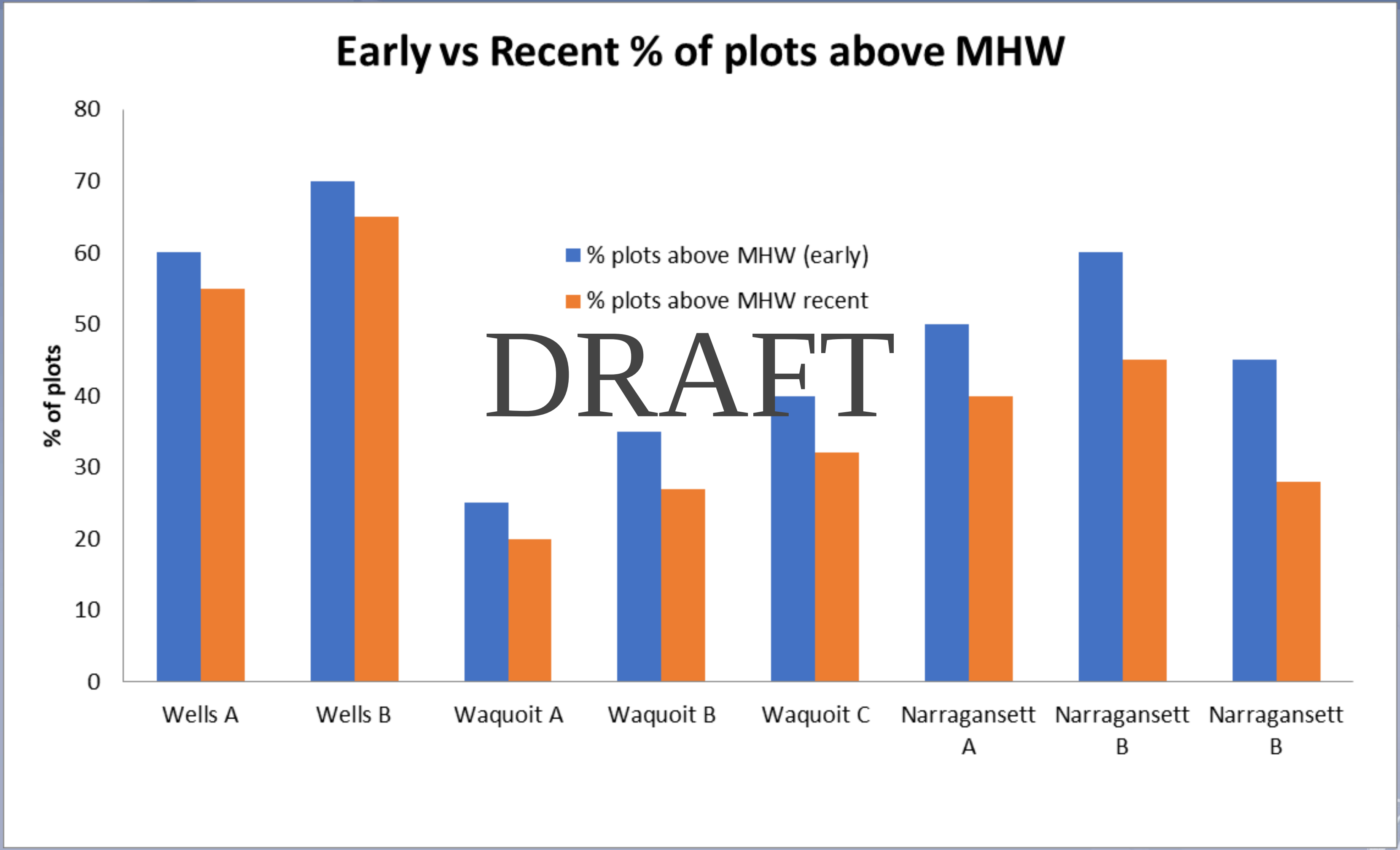
# Example outputs



# Example outputs



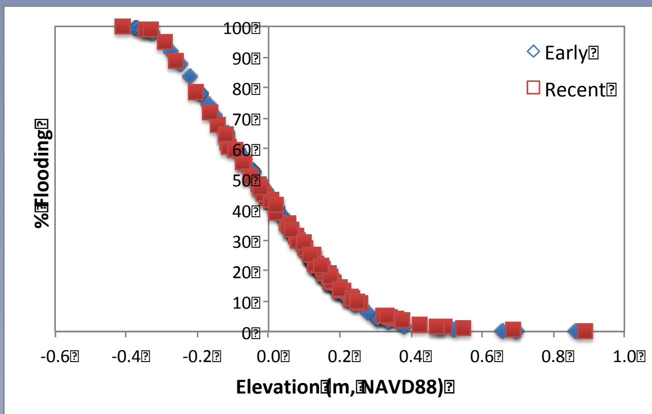
# Envisioned output



# Inundation Analysis Tool

- Outputs useful for:
  - Understanding veg change in sentinel site marshes
  - Marsh restoration planning
  - Quickly relating survey values (plot elevations) to inundation frequencies, and the changes in each over time

# Waquoit Bay




- % Flooding is lower in recent elevation survey

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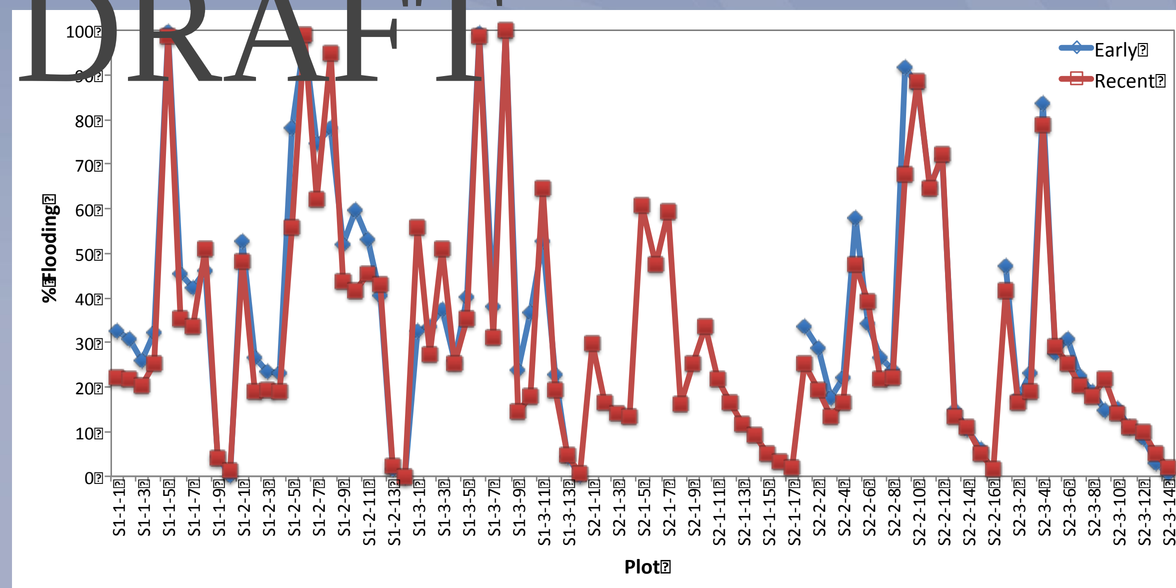
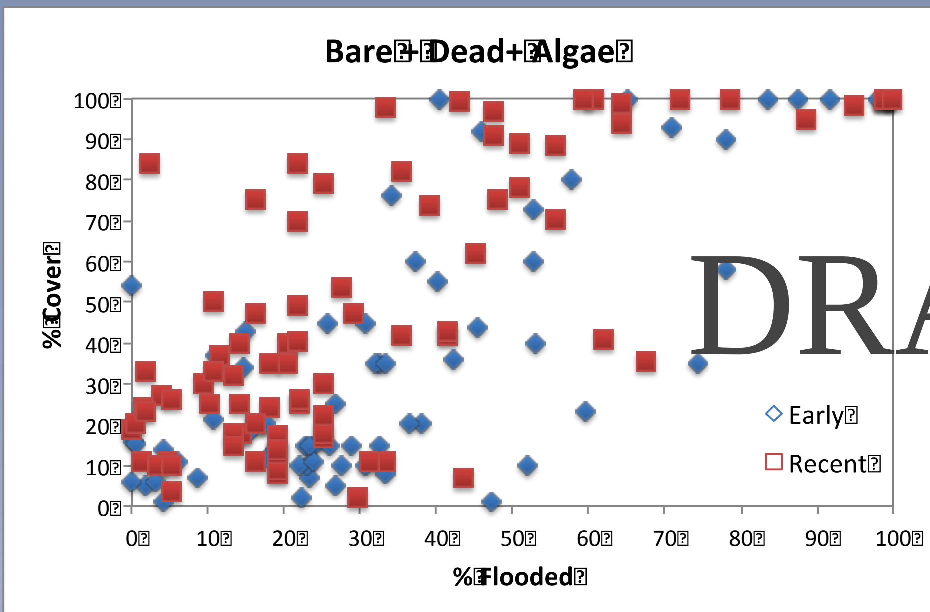
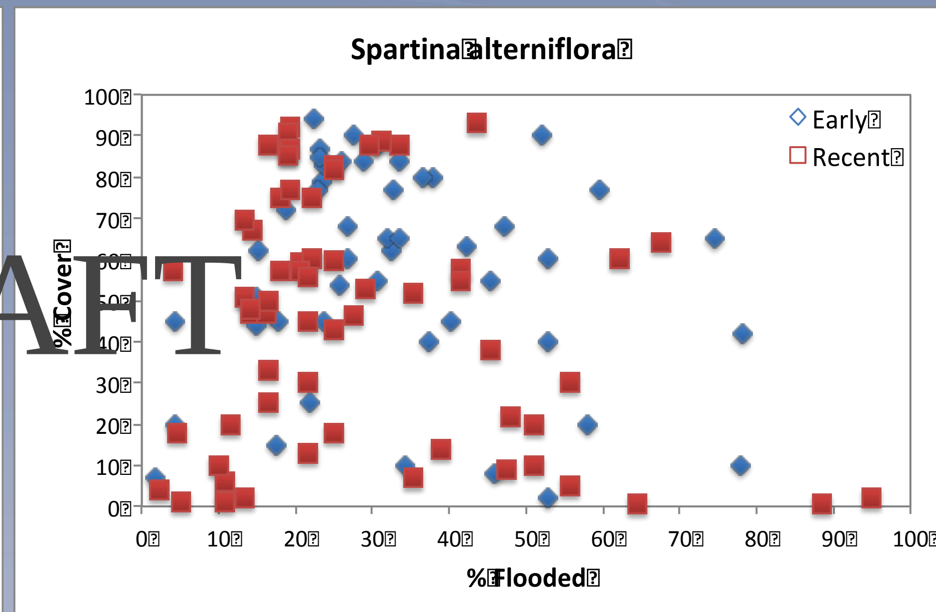


# Waquoit Bay



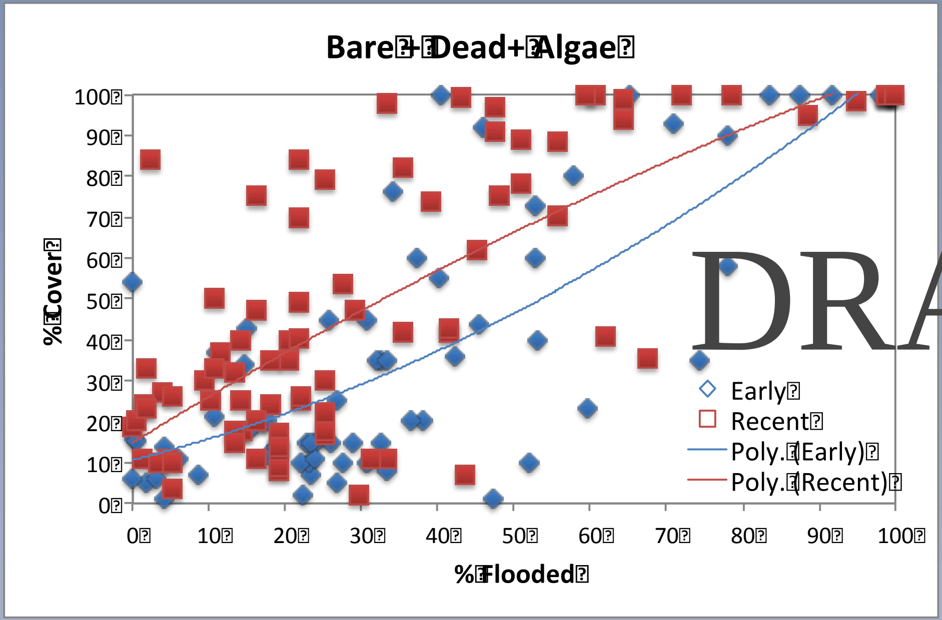


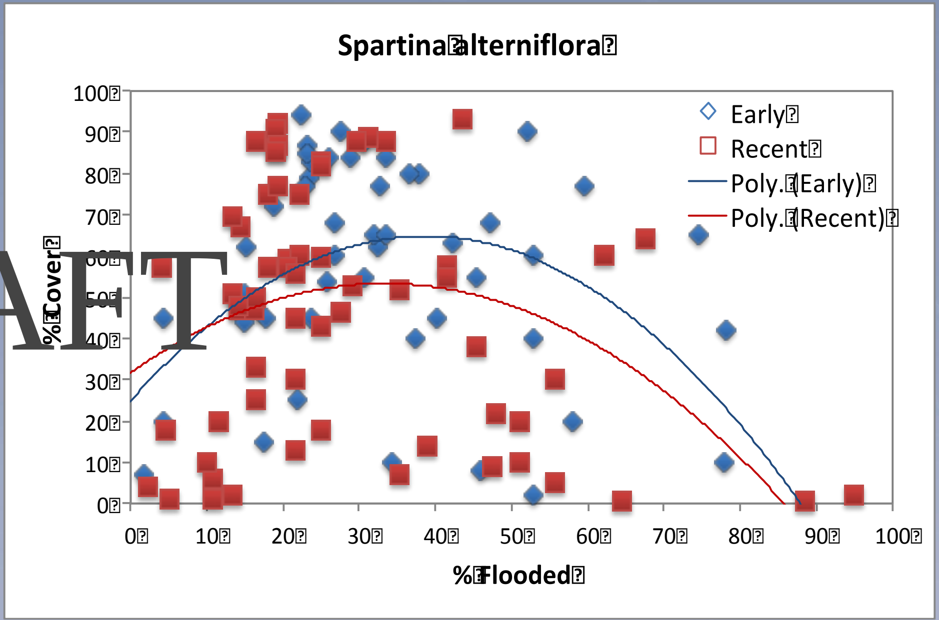

Plots flooded most of the time have more cover of "bare" category

Even infrequently flooded plots have some "bare"

Recently, *S. alterniflora* has higher cover in less frequently flooded plots

# Waquoit Bay

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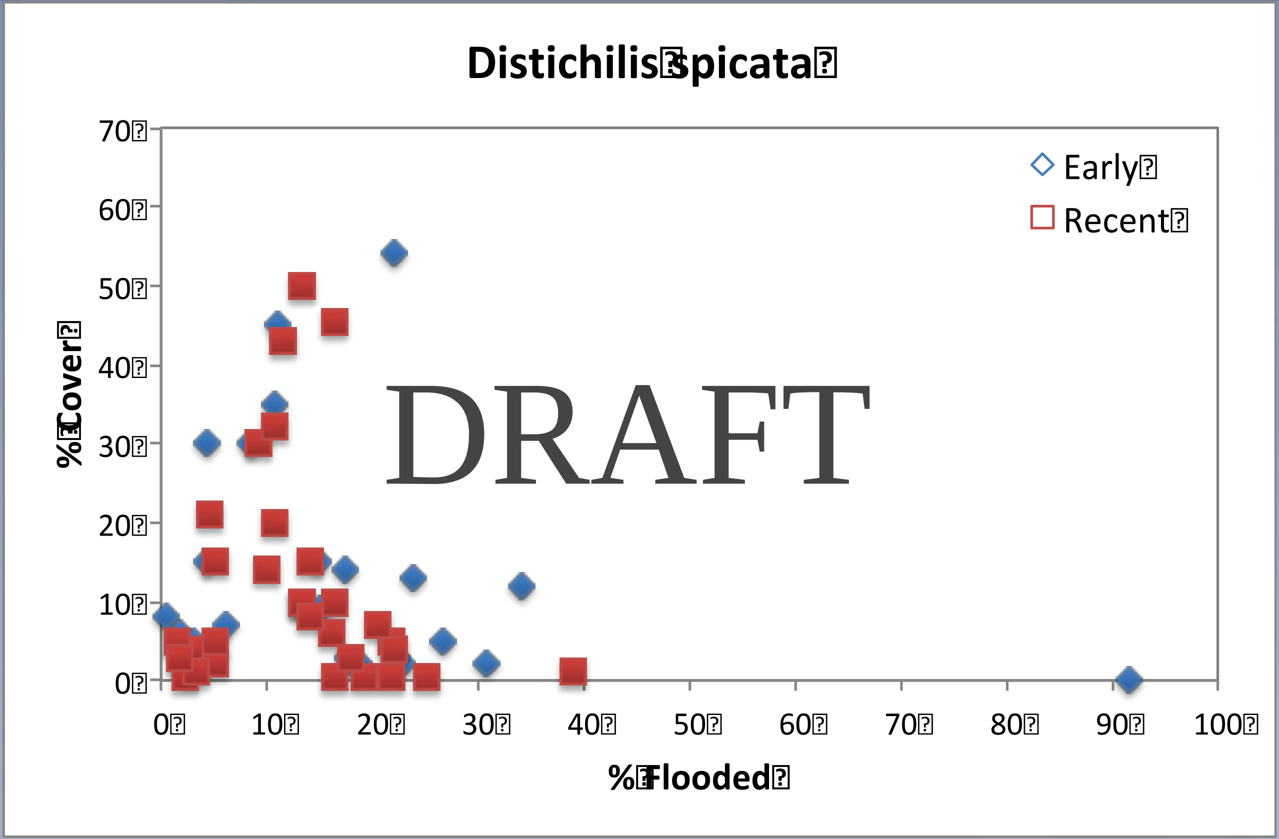
Amount of "Bare" is higher in recent survey than early survey

Consistent relationship between "bare" and % flooded

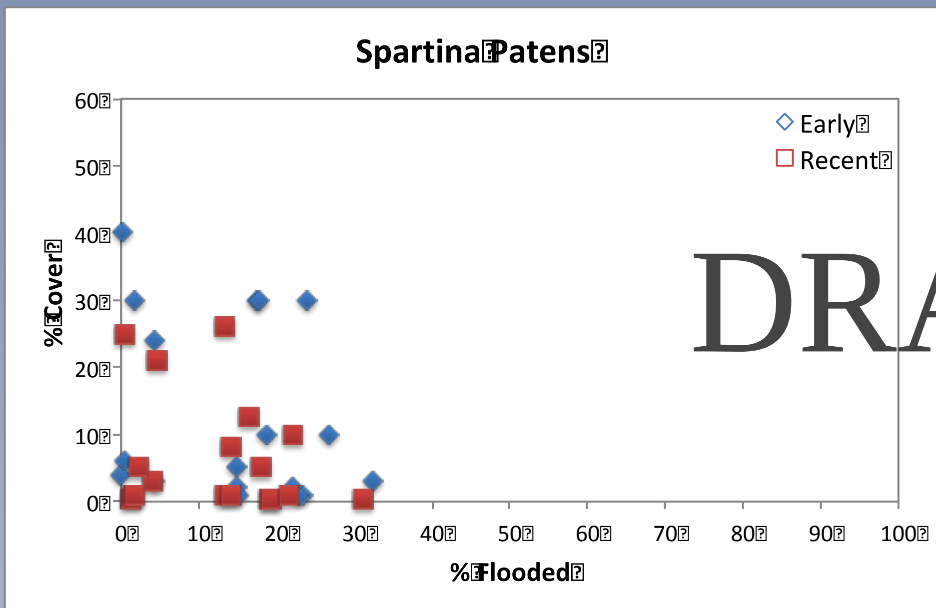
# Waquoit Bay

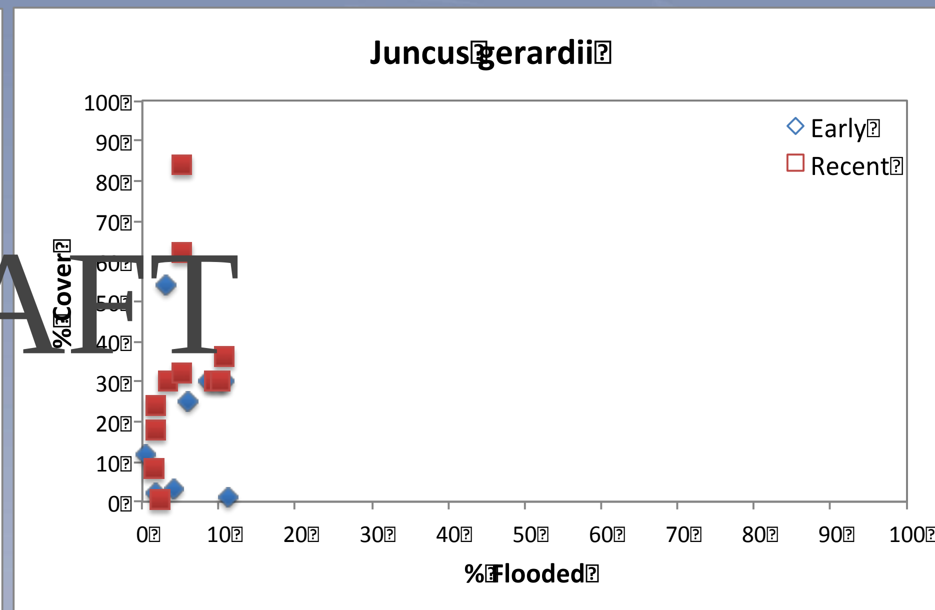



Rarely have this species when >25% flooding

Shift to less flooded, similar % cover

# Waquoit Bay



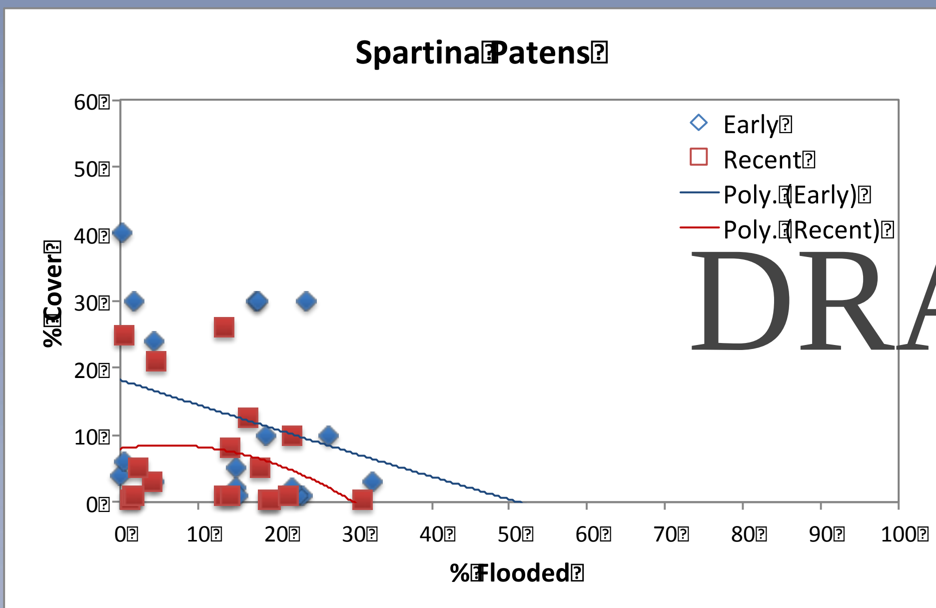



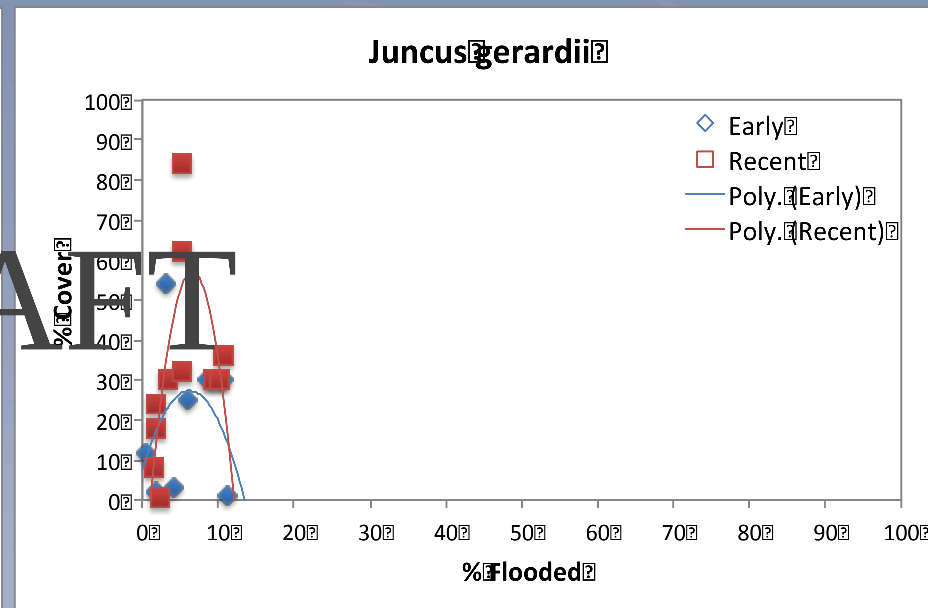



*S. patens* was never found in plots w. >30% flooding

Lots of variation in cover of *Juncus*, but never found in plots flooded >10% of time

# Waquoit Bay

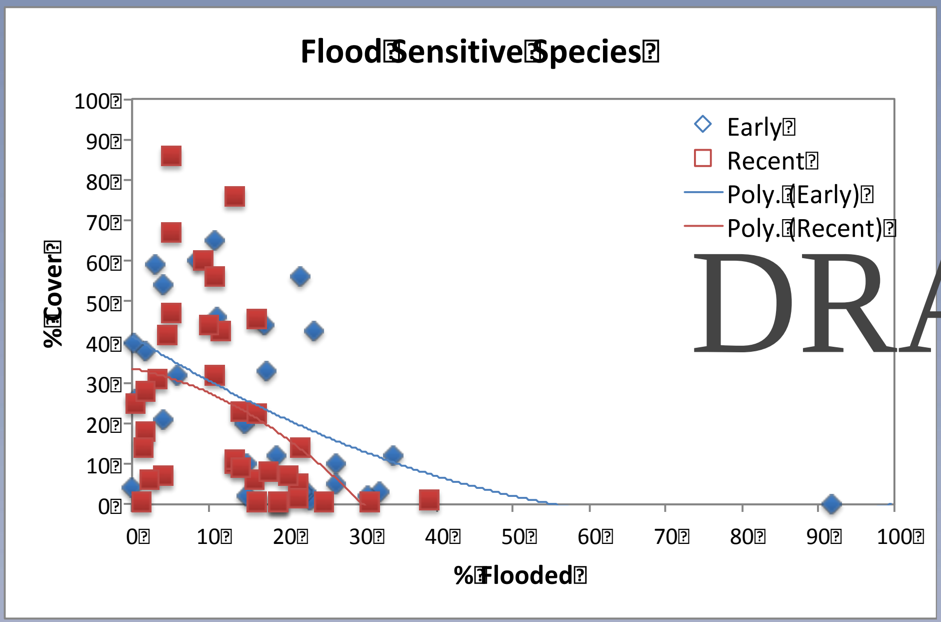


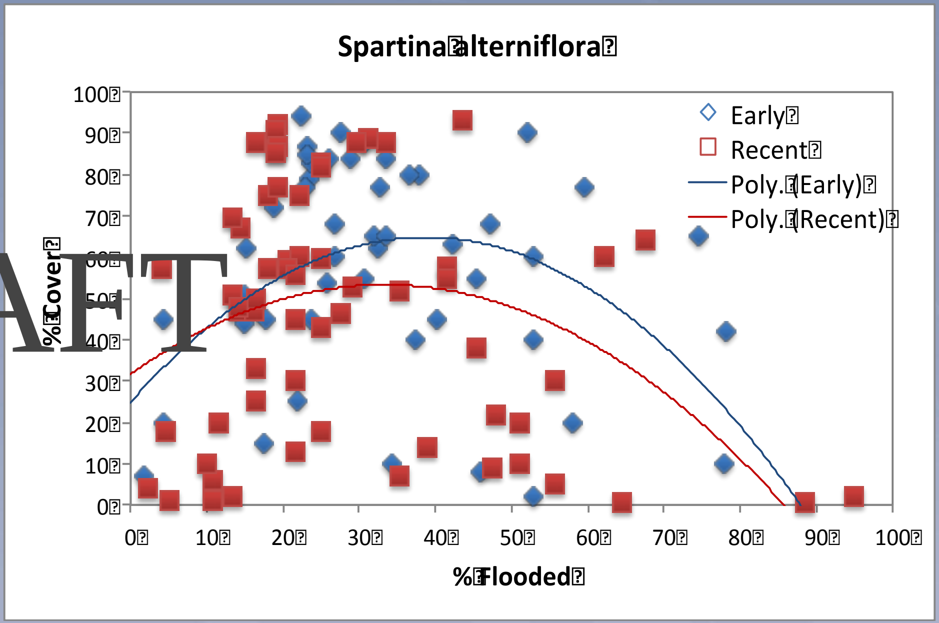






Recent survey has slightly less cover of *S. patens*

# Waquoit Bay- Summary



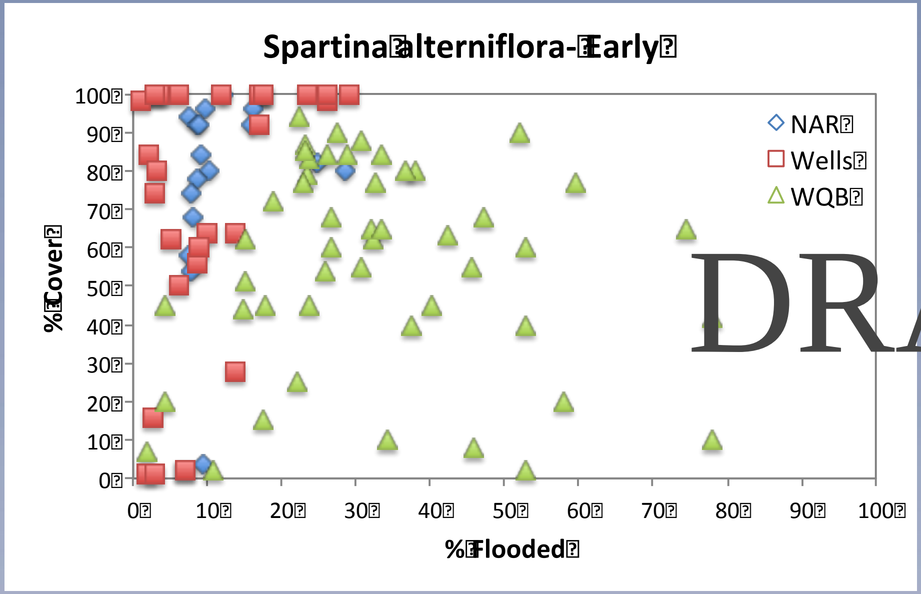


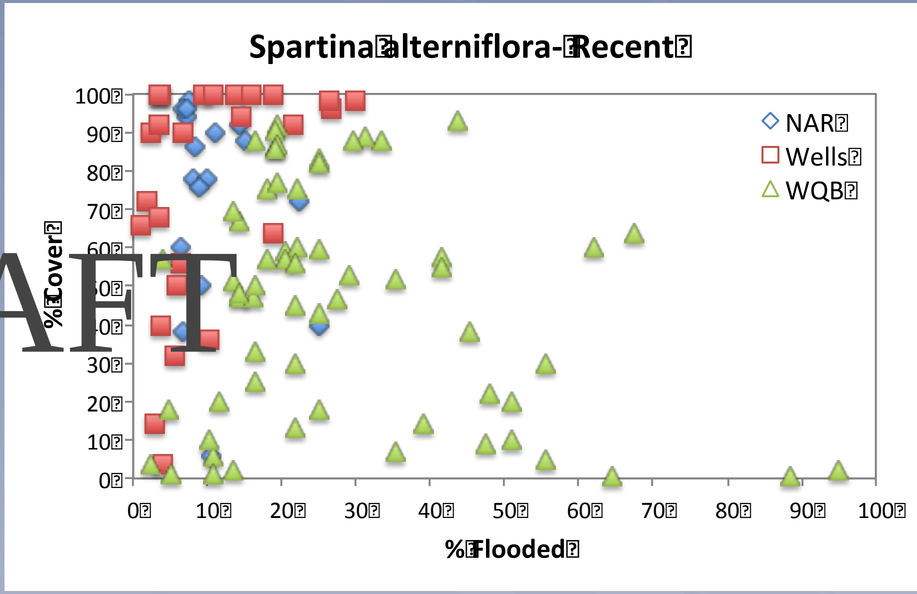

Flood sensitive species generally found in plots flooded <40% of time

Recent survey has slight shift to less frequently flooded

*S. alterniflora* shifting to less flooded zone potentially replacing flood sensitive species

# Reserve Comparisons

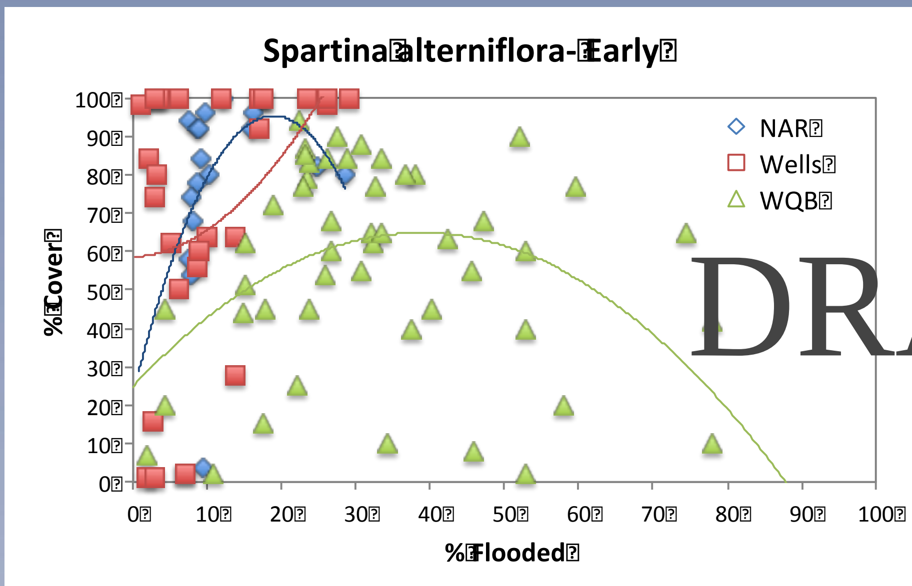


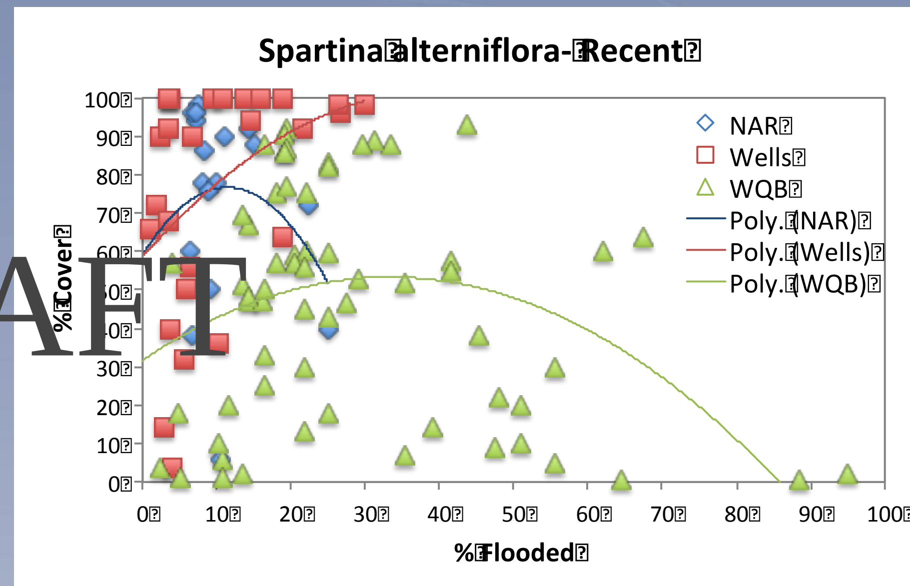






WQB has wide, bell shaped distribution

# Reserve Comparisons

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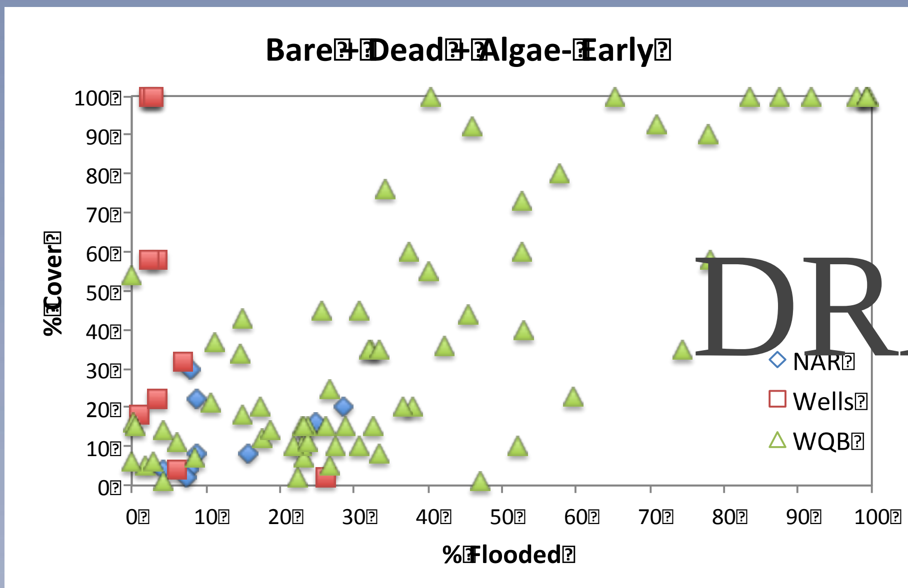
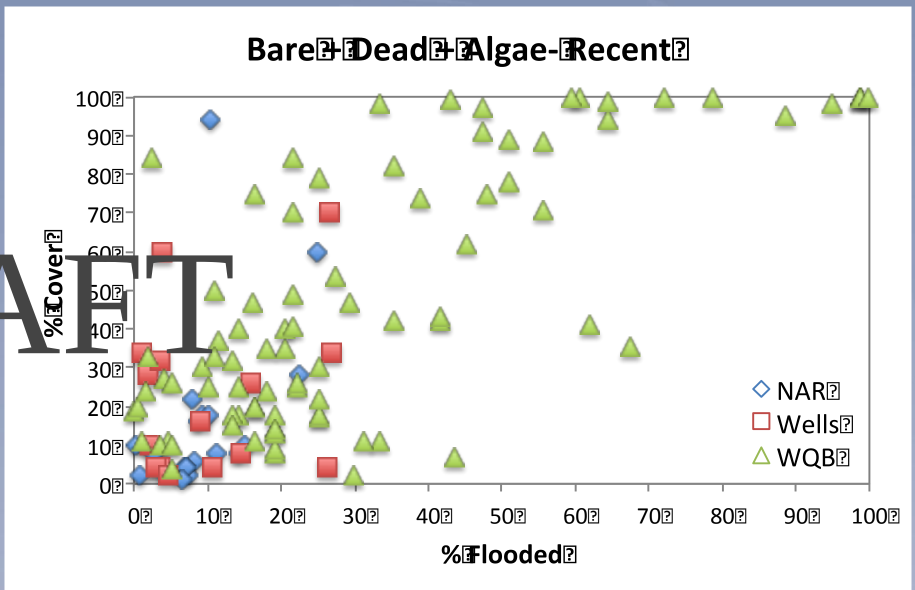
- Cover is decreasing at WQB and NAR
- More flooding recently at WQB
- Wells has some plots that are so high (esp early in the surveys) that they are very rarely flooded

# Reserve Comparisons



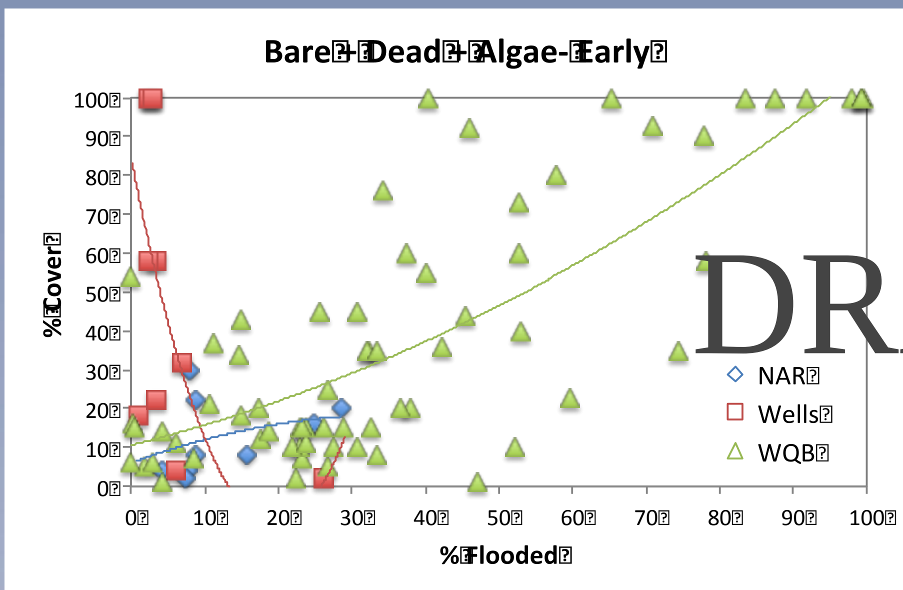



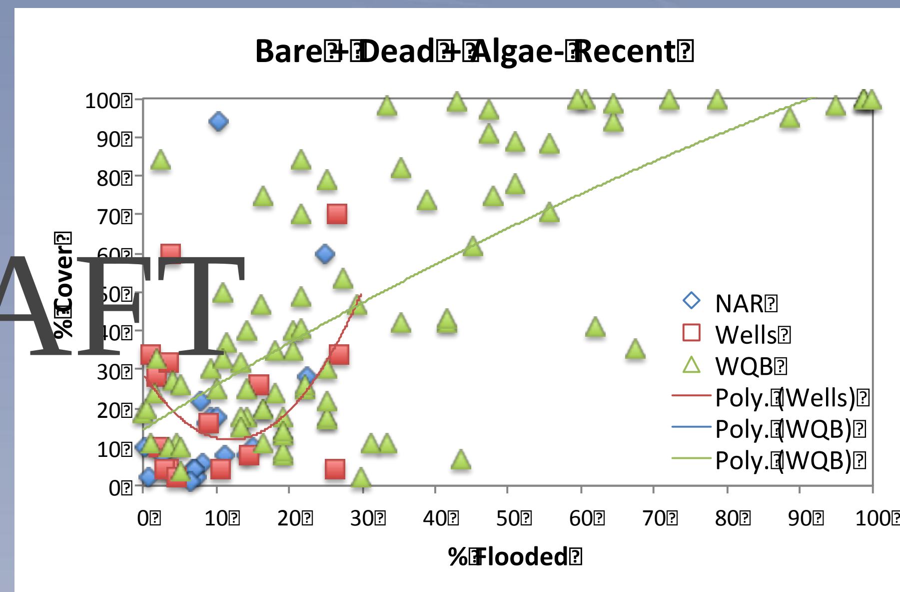



Only WQB has "dead" grouped in with "bare" category

Recently, more "bare" cover at all Reserves- at WQB these may be pools that are expanding over time

# Reserve Comparisons



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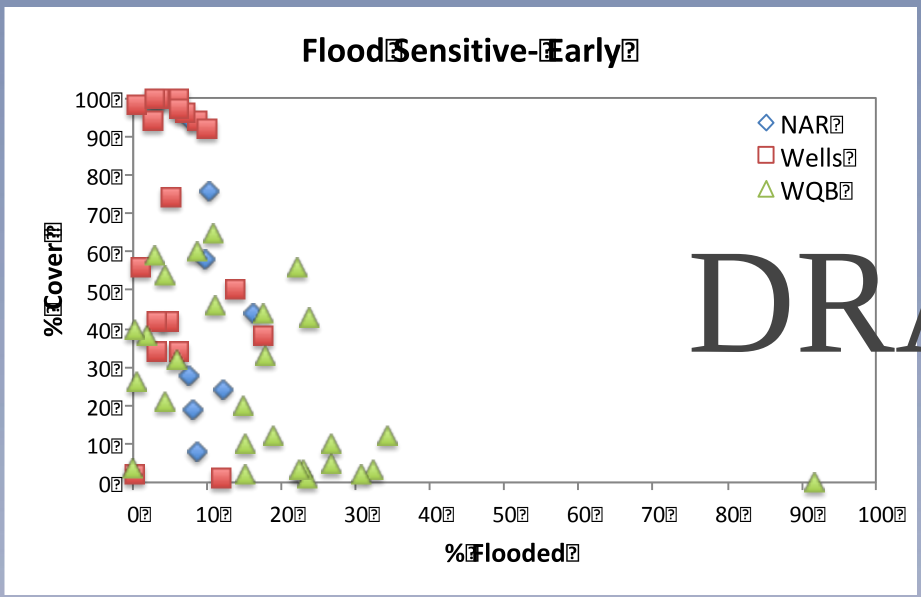
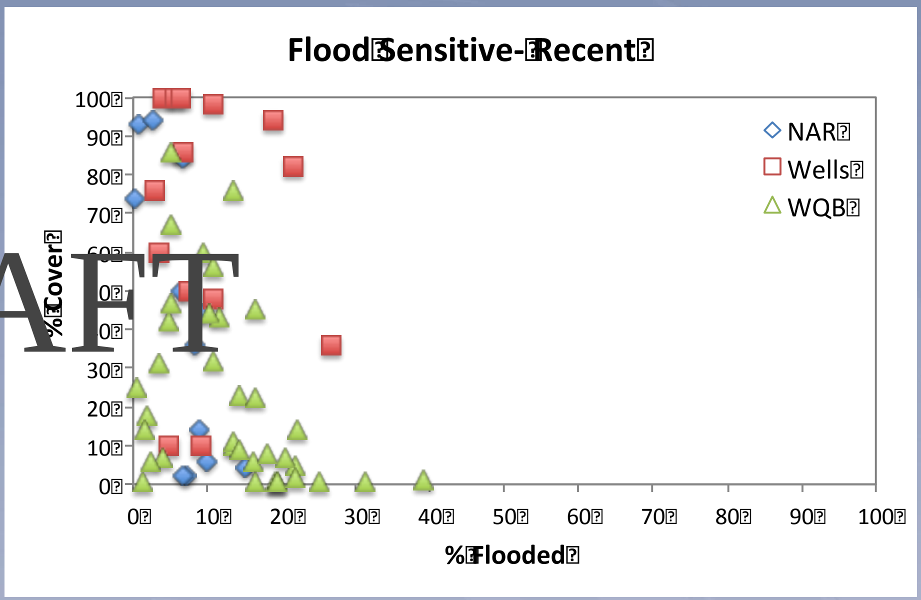


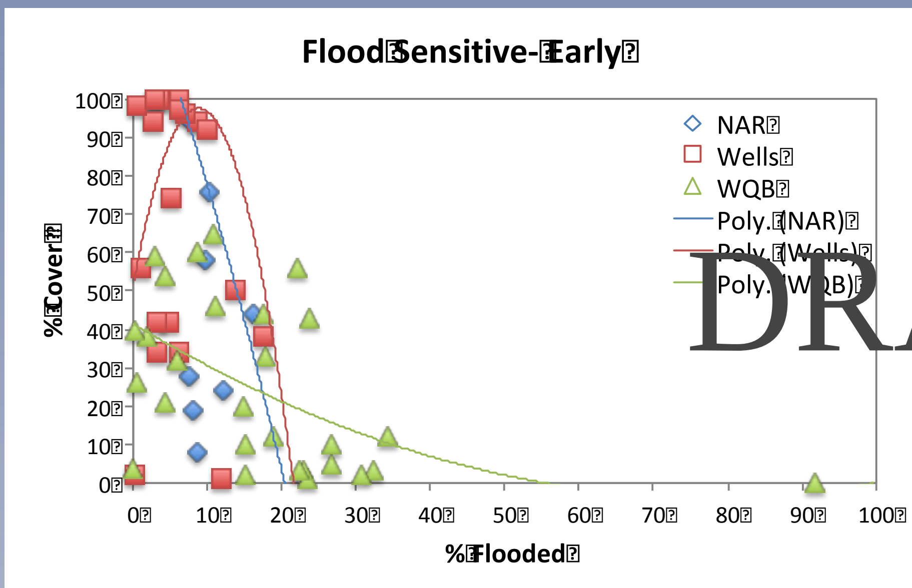



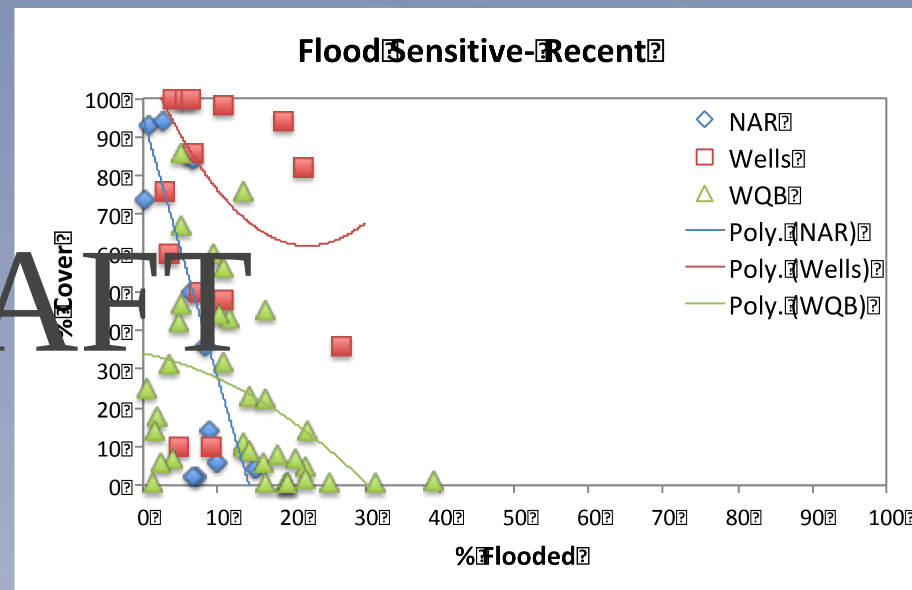



Elevation distribution for flood sensitive species is more constrained at NAR and Wells than WQB in early surveys

Wells' distribution wider in recent survey

# Reserve Comparisons



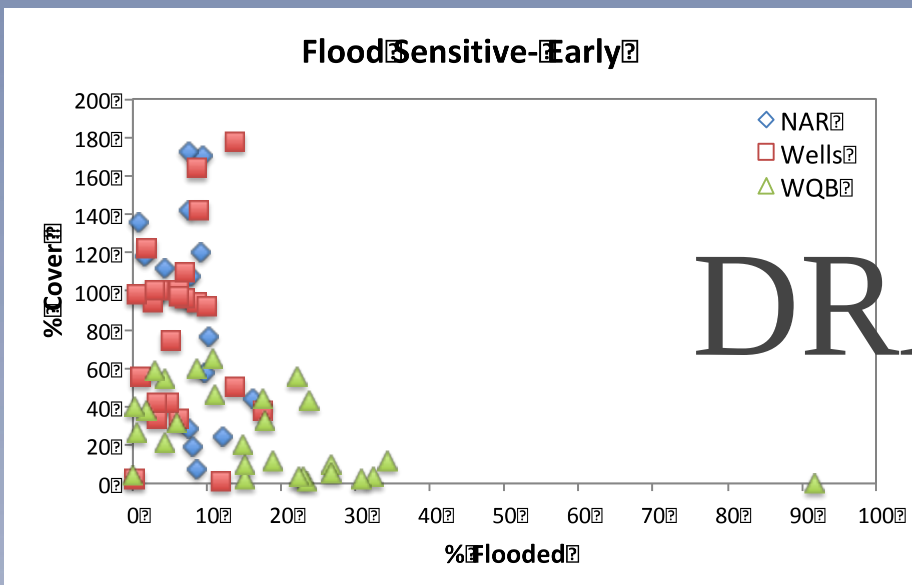



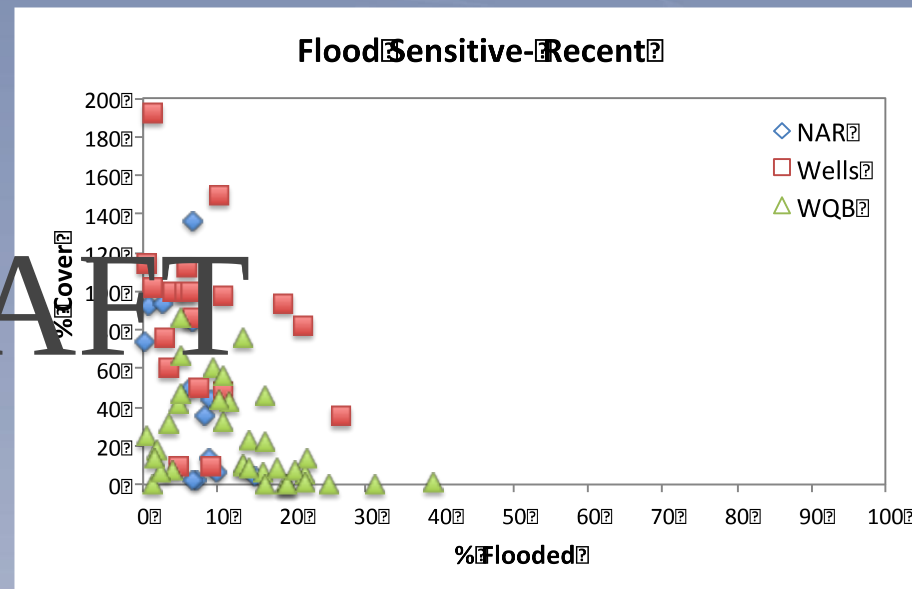



Elevation distribution for flood sensitive species is more constrained at NAR and Wells than WQB in early surveys

Wells' distribution wider in recent survey

# Reserve Comparisons



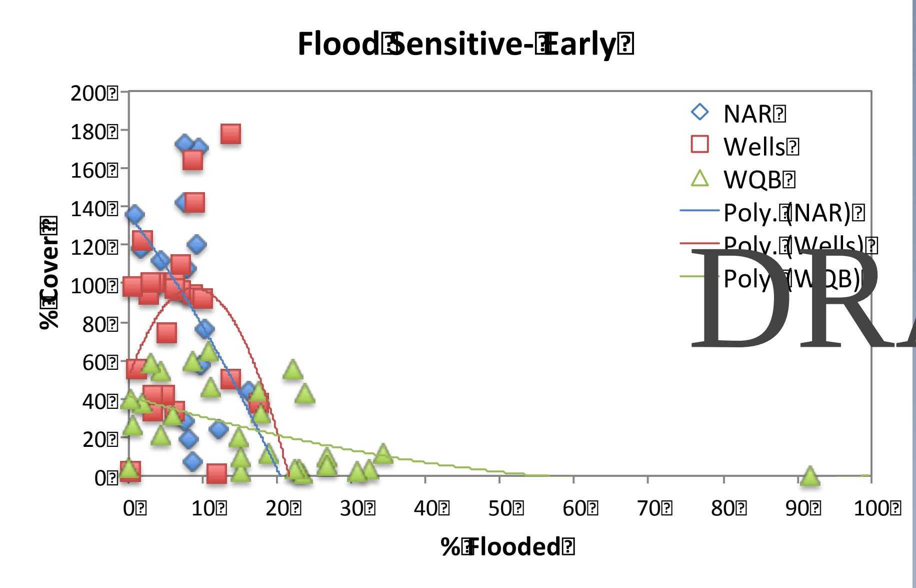



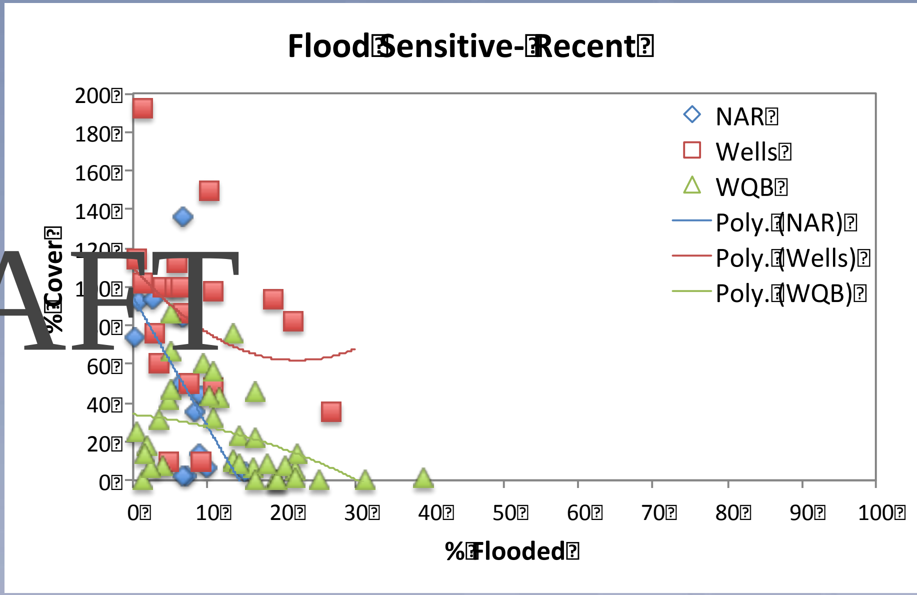



When not constrained to 100% to accommodate PI methods, NAR's decline in flood sensitive species in recent survey apparent

Wells' has similar decline in recent survey but to lesser extent

# Reserve Comparisons

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When not constrained to 100% to accommodate PI methods, NAR's decline in flood sensitive species in recent survey apparent

Wells' has similar decline in recent survey but to lesser extent

# Key Findings

- Flood sensitive species are showing diminished cover in recent surveys
- *S. alterniflora* (flood tolerant) appears to have increased cover over the elevation gradient
- Our findings generally support results shown by Burdick and Peter but are less sensitive

## Synthesizing NERR Sentinel Site Data to Improve Coastal Wetland Management Across New England
## WORKSHOP MINUTES
### August 22, 2019
### 10:30am – 4:00pm

**Purpose of Field Trip and Meeting:**

1. Discuss methodological challenges of point intercept and ocular cover comparison and ways to improve consistency in documentation of plant composition
2. Discuss challenges of combining varied data sets across multiple locations focusing on plant composition, SET and tidal inundation models
3. Share results of NERRS Sentinel Site data synthesis
4. Solicit input from managers about ways sentinel site data can be used and the best way to present data for management and conservation
5. Connect NERRS Sentinel Site monitoring program to regional efforts to improve coastal wetland management across New England
6. Solicit input on next steps to improve coastal wetland management across New England

David Burdick: I want to thank everyone in the National Estuarine Research Reserve system (NERRs) who worked to develop and implement the sentinel site concept. About 10 years ago, NERR really stepped up to fund establishment of the sentinel site program and I want to give a big thanks to those folks that provided all the data; many of them are here today. Plan for the day is for Kenny to talk about the Sentinel Site Program (SSP). Then Chris and I will do a presentation with some help with Jason on our results before lunch. After lunch, we will hear from Jenny and Megan from Waquoit on results from their inundation modeling of the data and discuss management implications.

**Presentation - NERRS and Sentinel Sites**
**Methodology and Protocols**
**Kenny Raposa**

KR: I'm the Research Coordinator at the Narragansett NERR. I've been in this position for 19 years. My goal is to give a brief overview of the NERR system and our newer sentinel site program (SSP). The SSP is the genesis of the project that Dave and Chris have been working on. I'll start with some basic stuff of the NERR system, then I'll flow into the System Wide Monitoring Program (SWMP). Then some of the methods and I'll explain what SAMs are as well. I'll finish with highlights of the program.

The NERRS was established in 1972 as a sanctuary program. Since then it has grown dramatically. We are up to 29 NERRs. The newest reserve is out in Hawaii. We have them all over. We are soon to be 30, one in Connecticut. This is a true state/federal funded program. It's amazing for all of us that work at reserves, it allows us to work on a local scale with national connections and impacts. Each reserve is multisector. We all have the same core programs and staff that support the programs. In addition to research, we have stewardship, the Coastal Training Program (CTP), and an education sector.

I consider the System Wide Monitoring Program (SWMP) one of our key programs. SWMP was established in 1995 and has grown since then. The aim was to detect short term variability and long-term change in our estuaries. In the beginning, it was developed mostly as an abiotic component. But it's grown since then. Now it includes three components: the water quality monitoring program, biological monitoring component and a mapping component. Then we have the Sentinel Site Program (SSP). It has grown organically for the last 10 plus years. Even so, sentinel sites are still confusing outside (and even within) the system. The way that I see it is SSP is an idea and concept of what reserves can be. It's an idea that each reserve can use SWMP data to answer management questions and detect environmental changes in estuaries.

How do you make the SWMP vision into a reality? Sentinel Site Application Models (SSAMs) are how we would do that. We have one SSAM and its goal is to allow reserves to understand responses of coastal wetlands to changes to sea level and inundation. How does a SSAM work? It works by allowing reserves to draw on monitoring protocols that are already present in the system under SWMP. To be a SSAM 1 site, a Reserve needs to monitor marsh vegetation in the field, water levels in or near the marsh, have conducted comprehensive measures of marsh elevation, and then monitor elevation change and accretion with SETs and marker horizons. A reserve can have more than one SSAM 1 site. This year there will be 26 of the 29 reserves that will have at least one SSAM 1 site. It's a strong national program. The best part is that we are doing all of this and we aren't just collecting data and sitting on it. We are doing things with these data, we are producing some great publications and products. We have at least six publications, three additional products that should be publications soon, four proposals using SSAM 1 data funded by the Science Collaborative, and six reserves are using this in their Teachers On The Estuary (TOTE) program. What I'm most proud of is our ability to synthesize these data across the country for large scale analyses of what is happening in US estuaries.

If you don't know of the NERRS Science Collaborative, it's a great program. It's being administered by University of Michigan. It's a federal grants program, where researchers need to work with one or more reserves, and need to do it in a collaborative way; working together during the entire course of each project. I wanted to mention that they have a few types of projects that they fund that you can read online. They are looking for innovative and untested ideas and have funded the regional analyses and workshop presented today.

**Presentation - Results of Sentinel Site data from Four Reserves**
**Vegetation Community**
**Chris Peter and Dave Burdick**

CP: Our work, funded by the Science Collaborative, is a huge undertaking by the whole regional NERR team. Our work took place in offices rather than a research lab. This is a very data heavy-based project. Most of our time was spent formatting and managing the data, which we will review quickly. Then we will jump into graphic and univariate analysis of the data, then multivariate parameters. First, let's look at the sites, north to south.

Webhannet Marsh, ME – there 8 short high-density transects. There are also road crossings dividing the transects. This is a back-barrier marsh system. With Great Bay in NH, we have a recessed estuary described as a drowned river valley following glacial retreat. We have two types of marshes, bay front in southern portion and riverine at the eastern and northern parts of Great Bay. Waquoit Bay is also a back-barrier system, where we will focus on section 1 and 2 near the mouth. We will look at the long transects including their ecotone plots. Lastly, Rhode Island marshes are both are on Prudence Island: Coggeshall Marsh and Nag Marsh. Here we are looking at transects running from the main tidal inlet to an upper edge. Across the four reserves, the eight marshes are all different systems with changing geography from north to south.

Database development was the heaviest lift by far which we will discuss 1st, then differences between PI vs OC, then database differences. For types of data, we will focus on the dark blue areas of data, for which we have comparisons across all four reserves. The talks we will give today focus on vegetation, ecotone, SETs and then punt on a few topics we hope to cover later. We don't have a complete New England dataset yet with respect to a variety of physical measures (water table, salinity, plot elevations, etc.). The Waquoit Bay folks will talk about hydrology, elevation and plant responses to their inundation model later on.

KR: We have protocols to monitor all these things, but there is flexibility built in. We learned that some other reserves are doing things a bit differently. The first time we tried to analyze this data, we were unable to pull the data together meaningfully. This is the first time that we are looking at this data on a large scale.

CP:  This slide is exactly what we did in our workshop fieldtrip this morning: point intercept and ocular cover.  There are differences, anyone out there care to share with the larger group?

- With point intercept, you can miss species, but add them as half a 'hit'.
- Differences in handling things like thatch and wrack.

Does point intercept work better?

- Ocular can be a bit more biased. Constraints on bias imposed by the PI method are absent for OC, which relies on standardized patterns to train the eye and multiple observers to curtail bias.
- OC measures the entire 1m2 plot in a very general and subjective way whereas PI measures <0.0001m2 of the plot in an objective way
- OC weights taller canopies more
- PI weights lower, spreading canopies more

Anything else?  I made a list.  Point intercept takes more time.

- If you're doing cover class-based data vs point intercept, it depends on what stats you would run potentially.
- With point intercept, we thought it was more unbiased with respect to abundance of plant species.

We did a lot of community analysis on the data.  But in theory OC should produce similar results as PI as long as you are not going across data sets of different reserves, which is one of our project objectives.  But, statistically it's really hard to analyze cover class.  Time for ocular assessment is usually shorter than point intercept. With staffing variable, you can still have consistent results with point intercept. I like to do ocular cover with a group to reduce bias.  Equipment is different with both methods.  Actual area measured is very small using the PI method.

Lesser points in methods comparisons include exceptions for different cover types - ocular cover rates plant dead and alive matter equally.  Biomass may be better represented by point intercept, though it hasn't been evaluated critically yet.  However, you could probably interpret OC better with a photo using.

Audience: Why do you consider point intercept more difficult?

CP:  Each method has its pros and cons, which we just listed. I have a more difficult time analyzing PI because its harder for me to grasp what exactly its measuring. With OC, its simply a 2D representation of the plot, like a photo taken directly above it. PI, in contrast, is not as straight-forward. It is the presence/absence of plants at 50 points, with exceptions made for non-live cover (bare, dead, wrack). Both methods try to estimate plant abundance is very different ways.

I'm only trying to lay out the differences between the two methods.  When you're talking about bare and dead or water, and point intercept is saying you're not including these cover types.  It makes sense to take a percentage of these things, especially when comparing different types of salt marshes, to get a sense for how veg cover or community is changing.

I think they both can show vegetation change, I just think they do it differently.  However, it's hard to reconcile those differences when you're analyzing the data.

DB:  We have two different models describing pant abundance. Our challenge is to put both of those methods together so we have valid comparisons between reserves.

Audience: When you're using ocular cover, are you taking it as a simple planar surface looking down, or …

CP: We are looking straight down. In the data that we collected this morning in the field, every group confirmed that bare and dead cover was better represented with the ocular cover method. Live plant cover was confirmed greater every time with point intercept. How do we make them similar?
1) Multiply it by 2 to get 100 points. Then normalize to 100%. We feel that the point intercept method results in lower bare and dead cover when this simple correction is used.
2 and 3) We also developed two methods with regressions based on morphological archetypes. Using Great Bay marshes, we found a lot of different morphologies within the plant community. This can be seen in the handout of Transforming Point-Intercept to Ocular Cover. The morphological archetypes is how we decided to group them. We made a statistical relationship for each archetype and corrected PI to OC, then grouped all cover data together and normalized to 100% cover.

There are a lot of calculations. We are only attempting to get these datasets to talk to each other. In addition to cover, we have other differences in vegetation and how it is measured. Stem density for example. Other cases of differences include estimating the importance of dead wrack and algae. It's hard to analyze when there are different ways to measure each of these components of the vegetation. Then we have ecotone sampling methods which are quite different as well. A lot of the difference is because some plots have forest community and our entire approach to vegetation assessment must be changed to capture changes in landscapes with trees. Lastly, we have differences in porewater collection schedules and methods.

For the next portion of the workshop, we'll look at the results from our data analysis. Though it's important to note that 90% of our team's time was spent on database development and collaboration and 10% on analysis; similar to an iceberg. For simple graphic analysis, we have these nice pie charts that are on display here in the room, we can look at this during the break or lunch. This is a great way to look at your data over time, which I'll briefly run through for each Reserve. In Great Bay, NH at Sandy Point marsh, we see *S. alterniflora* increasing by almost 2-fold in the high marsh from 2010-2017. This coincides with decreases in *S. patens* and bare. With greater sea-level-rise (SLR), we expect these changes, which are also seen in the Webhannet, ME and Waquoit, MA; greater *S. alterniflora* and less *S. patens* in the high marsh over time. Lastly, in RI and MA where high marsh is less ubiquitous and harder to delineate, we see other striking patterns; low marsh becoming less vegetated and more barren; losing about 20% of their live cover.

DB: One of the things that jumped out at me looking at the data, the Wells sites were set up in 2005 before the national protocol was established. They don't go all the way across the marsh to open water. So, to do any of this work, it's better if you have some basic hypothesis. Kenny set the stage with the SSAMs. Ours is, is the marsh changing over time? The protocols are really established to answer that question, but it's great that we are making it explicit. Here is a graph of *Spartina alterniflora*. When we look at the data together for all different reserves, the data is a mess-no trends are apparent. We need to know whether we are in the high or low marshes. If we don't identify habitat, the analysis falls apart. Once habitat is used as a covariable, we can identify broad trends, but we can also drill down to the within marsh variation. Now we can look at that data. We start with New England as a whole and then we will get into north vs. south reserves. Then we will focus on a single reserve, Great Bay, as an example of what we can learn from the data and pull in the other reserves a bit.

We used the same model that looked at different sites; we have 8 marsh sites. Habitats include high and low marsh and upland edge. All of these are highlighted by declines *in Spartina alterniflora* in low marsh and increases in high marsh; we also found declines in *Spartina patens* in the high marsh plots. These changes over time for the different habitats were not always statistically significant. However, we found that if you divide *Spartina alterniflora* cover by *alterniflora* plus *patens*, the ratio produced seems to be a pretty strong indicator. We also examined changes in species richness. You can see that the model fit the data well for many variables by the high $R^2$, but some variables were not fit well. Broad trends: *S. patens* is decreasing in all marshes; *S. alterniflora* is increasing in high marsh at the expense of *S. patens* and is declining slowly in the low marsh. Then you can see that if you divide the data into an analysis for each reserve, it doesn't vary much from year to year. The variation in the data is quite manageable compared to what I thought it might be. *S. patens* is getting squeezed out by all marshes. Dead and bare is increasing as well. Plants are drowning. At the regional level, we can't tell what is going on with species richness at all.

We dropped down from examining the entire region as a block to where we compare vegetation change in north vs south reserves. Great Bay and Wells with 3-meter tide ranges are compared with the southern, less than 1-meter tide ranges of Waquoit and Narragansett Bays. We looked at nonliving cover, *S. alterniflora* and *S. patens*, and species richness. Again, the $r^2$ variability lies within habitat, so that was defined for each plot and used as a covariable in the analyses.

Results: when looking at this set of graphs blue is north, red is south. Overall, *S. alterniflora* increased a bit in both areas. Southern marsh's low marsh shows *S. alterniflora* going down. Not so much for the northern marshes. For *S. patens*, changes in abundance are pretty flat in the uplands, which have low levels of *S. patens* and many other species. In the high marsh habitat, southern marsh *S. patens* is dying off dramatically. Also, it seems like in low marsh we capture some *S. patens* early on and then there was no *S. patens*. Note that for the *alterniflora:patens* ratio in this figure the more curve in the line, the lower the $R^2$. The ratio shows that in southern marshes there is a lot more *S. alterniflora* in the high marsh and less in northern marshes. Species richness seems to be increasing in southern marshes but declining in northern marshes. The sum of high marsh perennials (*S. patens* plus *Distichlis* and *Juncus*) is declining more rapidly in southern marshes.

Now, we'll look at Great Bay. The important ecotone between low and high marsh is sampled at the three Great Bay salt marshes with two plots on each transect. Graphically, you can see the abundance of *S. alterniflora* over time for these transitional plots crosses that of the low marsh plots in each marsh – showing less cover of *alterniflora* in the low marsh than the transitional area over time. *Spartina patens* shows declines in the transitional zone for two marshes and declines in the high marsh for two of the marshes. The ratio of *S. alterniflora* to *S. patens* shows increases in the transitional zones for two marshes and increases in the high marsh for two other marshes. The takeaway is that the low marsh is becoming less vegetated – going toward mudflat – and the high marsh is also becoming wetter, with *S. alterniflora* advancing over *S. patens*.

The SA:SP ratio for the other reserves shows similar trends. At Wells (northernmost site) and Nag Marsh (southernmost site) low marsh happened to begin with some *S. patens* cover in 2010 but by 2017 almost all of the S. patens was gone from these plots. In all the high marsh habitat except two marshes in Great Bay (Bunker Creek and Great Bay Farms) the ratio has increased dramatically in only seven years - from 2010 to 2017. Similarly, the combination of *S. patens*, *Distichlis* and *Juncus* also showed declines in all reserves and marshes except the three marshes in Great Bay. …

CP: There is a difference between habitat types at the different reserves. In low marsh habitat, there is more of a platform in Narragansett and Waquoit dominated by short form *alterniflora* vs. in the northern reserves where the low marsh is typically on a slope. One of the rules we had to come up with was: 'Does this plot have 90% low marsh species?' If the listed habitat had more then 10% of the plants that aren't typically found there, then we would look at that plot again more carefully to assign it a habitat type; examining what the other species are, distance from tidal source, aerial photos. It's not a perfect system, but that's our general application to determine habitat type in the southern marshes.

Audience: First, when you're doing the transformation of the data, do you feel confident in that and do you feel that in the field that should then be a practice?

CP: Yes, transforming the data using regressions has shown the best fit, although not perfect especially when looking at bare and dead estimate. I wouldn't recommended using both methods in the field or one vs another. Whatever you do, do it consistently. It's a tradeoff between many things, but the most obvious: time and objectivity.

Audience: What happens when you cannot see a plant species from overhead using OC method?

DB: We try to get 100% in the field for each plot with ocular cover. If they are not visible from the surface, we just give plants underneath a half percent cover, similar to the addition of rare plants for the PI method (given ½ a ''hit').

Audience: Did you include location of transition zone by recording distance from a fixed position on the transect?

We haven't done it in our database yet. In the field we don't track the transition point because sometimes it's hard to see the vegetation change as a point rather than a zone. As *S. alterniflora* advances over the high marsh, the transition becomes ever more difficult to define.

Audience: But it does seem important to capture the transition zone.

CP: The results speak for themselves. Great Bay transition zones highlighted some areas that we wouldn't have seen. The NERRS has used an ecotone protocol where marshes are transitioning horizontally. That is a good way to track that horizontal effect. However, since its newly developed, it hasn't been used during our time period in question. Any other questions?

Audience: Another approach to monitoring transition zone change is through GIS-based analysis. We've pursued this at Waquoit Bay NERR (as have many of the other NERRs) and the near-IR sensors are quite good at picking up the difference between low and high marsh communities as well as the upland border transition zone. However, *Phragmites* is very hard to distinguish. This approach provides more of a landscape scale analysis of horizontal change (i.e., migration) in the salt marsh zones.

We used drone photography to include and add as a level of analysis.

Audience: Do you have an estimate of sea level rise and how that will shift over time?

We will address that after lunch. Any other questions?

We should jump into the multivariable approach. We used PRIMER as a way of looking at communities that combines all aspects of the data that we are looking at in the field. These tables are a bit complex. Basically, we are looking at three levels of analyses with PRIMER, which is similar to other methods of ordination, but flexible to be applied to non-parametric data since we're looking at ranks instead of absolute values. 1$^{st}$ level of analysis is the non-metric multidimensional scaling plot (NMDS), which is a fancy way of saying ordination plot. Secondly, we can quantify differences in data, in this instance: years, using an analysis of similarity (ANOSIM). An ANOSIM is basically an ANOVA. Lastly, from the similarity analysis we can generate a SIMPER table that answers the question: 'What are the cover types that are driving the differences?'

Audience: So these are your two-dimensional plots?

Yes, the stress level indicates how well the 2D or 3D plot fits in this complicated data matrix. If it's under 0.1 it's really great. Please keep in mind, for this project, we were not only looking at how NERR marshes in New England are faring to SLR in the last 8 years, but we are also looking at developing a template for analysis that can be transferred to people that have data. At Great Bay, NH we see strong significant shifts in the transition between the high and low marsh at 2 of the 3 marshes showing greater *S. alterniflora*, which are reflected in the NMDS, ANOSIM, SIMPER and also reflected in our pie charts. If you look at Great Bay as a whole, it can be much more complicated to interpret but can speak to data trends at the bay scale rather than the marsh scale. At the bay scale, the transition points are also significantly different, that it's driving the whole model to be that way as well. There is also upland shift. It seems to increase in bare, dead and poison ivy and less wrack. When separating by zone, it helps in interpreting community shifts because different zones appear to change in different ways. If you look at the transition here, you can see more clearly the shift that has been moving towards *S. alterniflora*. Now I will quickly review the results from the three remaining reserves.

Wells, ME: Overall, this estuary has less community differences and that's a good thing. But we are seeing the high marsh becoming more alterniflora and less patens. The nature of the transects in Wells, they are short and dispersed, and individual plots are tracking in different directions. It's probably more complex than a straight shift in *alterniflora* to *patens*. I think it's because of the way that they were set up before the vegetation protocols were developed. They are set up to be short and to look at the impact of the buffers, which asks a different question than our other sentinel sites.

At Narragansett, RI there is a lot of bad change. Increases in dead and bare is never a good sign. If you look at the high marsh of Coggeshall, you can not only see that 2010 and 2017 are different but track the change by year. It's driven by greater bare and less plants. This is a pairwise test in the corner here, which compares 2010 vs every other year. At first there is no significant change between years, but then you can see the increasing significance of changes towards a degrading marsh system starting in 2014. The NMDS plot clearly shows this community shift from 2010 to 2014 to 2017. We see a very similar pattern at the other marsh in RI (Nag) using PRIMER, we greater bare and lower plant cover in the low marsh. But even more powerful is the pictures that Kenny took for each year, showing an almost completely vegetated plot shifting to a completed barren plot. And on a whole at Narragansett, the shift in plant community becomes even more apparent in the low and high marsh, shifting towards more bare overall and more *S. alterniflora* in the high marsh.

DB: People ask all the time when can we expect to be able to show significant changes from monitoring efforts? Using this multivariate approach, we can track the number of years leading to demonstration of significance.

Audience: How long is your transect?

KR: About 100 meters or so.

The analysis for Waquoit doesn't show a lot of change in section one and two. For section 1, the low marsh is significantly shifting towards a more barren, dead and waterlogged area. *S. alterniflora* is likely decreasing due to abiotic factors associated with greater inundation and less drainage. If you combine both sites together at Waquoit, the low marsh is generally shifting to more abiotic habitat, unfortunately.

Examining all the New England reserves together, the output is complex. In the low marsh, there is greater abiotic components and less plants (*S. alterniflora*) over time, but in the high marsh there is more *S. alterniflora*. This pattern reinforces the benefit by examining marshes by zone. These results are similar to the univariate analysis. If you look at it by region, change over time is driven by southern New England reserves, with more abiotic and less biotic cover. In northern New England, plant community patterns a little less clear, thankfully. Overall, there is a significant change showing more *S. alterniflora* and bare, and less *S. patens* and dead, which is likely dominated by low and high marsh transition plots in Great Bay and high marsh in Wells.

Summary: The strongest drivers in our mulitvariate analysis is *S. alterniflora*, which is the strongest driver in marsh shift and the most sensitive indicator to sea level rise. Depending on where you are in the marsh dictates whether it is gaining or losing; low marsh = losing, high marsh = gaining. Bare seems to be increasing overall especially in the low and transitional plots, dead is increasing in the transition zone and decreasing in the low marsh, and waterlogged is also increasing overall. Plants are being replaced by nothing. Transition plots seem to be more sensitive. Lastly, where are we going? Will our northern marshes look more like southern mashes over time and are the southern marshes going to be turning to mudflat?

**Documenting Change Over Time**
**David Burdick**

DB: I want to transition to another topic. Then we will synthesize those thoughts after lunch. We want to talk about another set of data documenting changes in marshes: using Surface Elevation Tables (SETs). Essentially you can see these pins shown in the photo, and we put down clay marker horizons to measure that first day of measurement which is a zero point. At Great Bay, we measured how much this marsh is increasing in elevation as sea levels rise. In Narragansett Bay, some of these marshes are showing positive growth, but some of them are not. The average is only 1mm of growth. That was probably fine before SLR began to increase rapidly, but not right now. In Webhannet, the results are really different. This location was growing at 16 mm/year. Then they dredged and accretion stopped. Before the dredging, the embayment filled with water, but as the tide fell, the last portion of the tide would be effectively trapped within the estuary, leading to less marsh drainage at low tide. Dredging effectively pulled the plug so at low tide the marsh would be better drained, and it seems that the peat would become oxidized and subside.

Audience: Do you know how many sites are in this dataset?

There is only one at Webhannet. Besides dredging leading to oxidation and subsidence of the marsh peat, there are a couple possible explanations for why the marsh SET stopped accreting. If we look at the metonic cycle that could be another possibility. When tidal range goes up, our marshes will be flooded more. Every 19 years, that range gets higher, then lower, than higher again. This whole distance is captured right in this section of the graph on the screen. What is happening with SLR? It's really high, so the marshes that were growing here in 2005 have experienced lots of SLR.

At Waquoit Bay, we have three SETs in each section. For the most part, they are looking good.

In this table I present all the SET data in the context of sea level rise. Global increase for SLR in 1993-2010 was 3.23mm/yr. We don't have any published resources after 2010 that show us SLR rates. Waquoit Bay and Great Bay are equal at one marsh but losing at another. Narragansett is just plain losing it, and it shows will the dramatic changes in marsh vegetation.

You asked us which is more sensitive to SLR, SETs or vegetation and I think we have an answer: vegetation.

**Inundation Model Results from Four Reserves**
**Jenny Allen, Megan Tyrrell**

Megan Tyrrell: What we are doing here is using an inundation tool available in Excel. We do think that it provides similar data. Calculate the frequency of water inundating the marsh. We need to know the elevation of our plant plots, our plant community cover and have a continuous record of water levels for several months.

Some of the questions that they posed to us in Texas, how often does the tide reach the marsh plain? What is the duration for each period of inundation. This is an idea of what the tool looks like, you can have it from a logger. You will see tide station for Narragansett and Wells. Jenny did all of these analyses, and in a few seconds the program spits out the model results. We know that water levels vary daily, monthly and annually.

Found out that not all reserves have elevation measured for their plots. We can't analyze using this tool without having elevation available. The equipment accuracy matters, RTK vs laser. It's important to QA/QC the data. We are fortunate enough because of MGS that we have stable benchmarks for our elevation data. This is a graph showing the plots along our transect and their elevation relative to a benchmark elevation. They could also be pool plots, there are a lot of pool plots in our marsh zones. There is a lot of variability with elevation. For our higher marsh plots, the variability is pretty low, the pool plots can also be very high. We are only using one average point, and we might need to think about other ways to encapsulate the variability in our pools and plots that are low. When you're taking plot elevations going to all four corners and center, it matters if you characterize the elevation in once are where there is *S. alterniflora* vs a bare area. So, there is a lot of variation within a plot. I looked at the version of NE vegetative database yesterday to see what the elevation is of the lowest plot in a particular marsh and the highest plot within a marsh. This conditional formatting shows that Waquoit has really low elevation in our plots probably due to our soft-bodied pools. Wells has really high elevations in their plots.

- Do you have elevations of your lowest veg plots? And they will be flooded 100% of the time?

We do, but they are not available right now. And yes, they will be flooded all the time. We put all of our plots into the inundation analyses. The pools are in. You have to again be very careful with QA/QC. Have a long-term water level record. We have Great Bay water level data, but the plants are responding over a longer period of time. And when you have theoretical data, you can generate curves, but our data didn't quite look like that. We can do this for Wells, Waquoit and Narragansett. How well do our plots represent the area of marsh that is regulated flooded? We can compare that across reserves. For our early surveys, vs more recent, we could look at the percent of plots above mean high water. This was theoretical before I saw how Webhannet plots were arranged.

**Jenny Allen**
JA: The actual data is a bit messier than what Megan presented. In order to do the analysis, you need the local water levels, or as close to a tide gauge that you can get, vegetation and elevation information. Those are the three key components to run the analysis. Also, Waquoit has the most comprehensive information and then there is a reserve comparison of other reserves. Great Bay did not make it into that analysis because of some water data issues. For Narragansett and Wells, I used the NOAA tide gauges. The differences that we see might have to do with the relatively closeness to water level. The first thing I want to look at for Waquoit, is elevation vs percent of flooding. When I refer to early, I mean 2010 and 2013. Some reserves have information from 2010, and others from 2013. Recent will be 2016-2018. When you plot them on top of each other, the elevation relative hasn't really changed much. They overlap a bit and you would see what you expect. But when you look deeper like plot by plot the story changes. It's hard to tease out, but 2018 the percent flooding is decreasing. Not in all cases, but you can see the differences along the way which is not what I was expecting to see. We need to understand what is going on in terms of accuracy of elevation measurements.

There is a little discrepancy in how things are measured for each reserve. There are some interesting things coming out of this. These are still preliminary results. These seem to be consistent with our findings.

- On the right graph you have a peak in the percent cover, does that line up with other researchers' findings?

No, we haven't compared but that would be interesting to look at.

- The water level loggers, are they installed in the tube that are submerged or on the surface?

Right, we are just looking at surface water.

- Can you clarify what you mean by percent flooding?

The percent flooding is the percent over time that the marsh is flooded.
Again, taking these results with a grain of salt, looking at the blue vs the red lines, both the plant cover is decreasing as well as the extent. To summarize, I broke them into categories by flood sensitive species. As you're seeing the kind of shift to less flooded area, you are also seeing *alterniflora* is also shifting into those less flooded areas. Now I'll do a brief comparison by the reserves together. Each reserve has a different color on these graphs. The first thing that pops out when graphed out, Waquoit, the *alterniflora* is spread out across the flooding range. Wells is clustered in this really low flooded area. Narragansett is similar, but perhaps looking at the fact that *alterniflora* is everywhere maybe moving up.

- It's the ecotone.

At the most it's 25% flooded there.

- As a reminder, we had to use Newport tide elevation logger, so the water level data is not actual.

- Do you know if Webhannet is the only system that has transects that go across the roads?

I'm not familiar with all the sites.

- There was a master's student project that looked at water loggers in marshes and she found that *alterniflora* where areas were less frequently flooded.

So then looking at recent, it looks like *alterniflora* is shifting to less flooded areas, and if you draw in the lines it gives you a little more insight as to what is happening. For Waquoit, the cover is decreasing, Wells in slightly increasing in cover, but again these lines are to be taken lightly. It's just meant to help gauge out the changes that are happening. Looking at the bare class looking at all the sites, only Waquoit has bare, dead and algae. The general trend is that percent of cover is increasing across the reserves. For flood sensitive species across the reserves, for both Narragansett and Wells, they had more than 100% cover of species. With Waquoit, you're getting the shift in expanse where things are getting smaller. The trends are the same, but if you look over 100%, you get a lot more stuff going on. When you look at it in more recent time, everything is shifting down. That could be due to changes in the way that readings are done, counting percent cover, or that cover is increasing.

- I'm trying to understand the model. So your model is taking the surface level water and against elevation right? So you're mapping surface water inundation against elevation, not taking into account micro-elevation around your veg plots?

Right. It's crude, but it works.

- In this case where *alterniflora* is growing in high elevations, they actually might be inundated since you're using elevation as a surrogate for inundation.

Right. I think together they can show very valuable information. Kate pointed into also that this analysis does not take into account a rainy season from last year.

- Or a high-water table.

Right, there are a lot of variables.

- Are those loggers coming out during the winter?

They are taken out for a 2-week period for ice.

- And they are tied into RTK?

The recent elevation levels were taken by a ….. those benchmarks are deep and long established.

- What is the name of those cheap water level loggers?

We'll send you the brand. They are less than 100 bucks. You have to go and check on them though. They are cheap and they are installed with a stake and an arm that floats. You need to make sure that they are checked on.

- Are these the HOBO loggers? I think we tested them here, and just walking around the marsh…

You're thinking of the marsh elevation marsh level, these were installed in the creek. It's not a pressure transducer, so the accuracy of these loggers are much better.

**Presentation - Discussion of Management Implications**
**Christine Feurt and David Burdick**

CF: This is where we hear from other people about how what we've heard today makes sense to them. How do we care about the changes being seen in our marshes? What is the connection between this research and other research, and what are the connections that you are making, the take home messages? I did have people write their challenges down.

- Bri B: We are losing high marsh platform, but there seem to be other areas that are experiencing more flooding as well.
- Jason G: Site selection and modification questions: I think from some of the talks this morning, there are folks that might want to set up monitoring sites at their marshes, in our case, we may want to modify how we monitor our sites. What are our research questions that will lead to better management practices? We had a formal workshop back in June and we are more likely to alter our transects either add or create new ones that better encompass our area. The Webhannet marsh is a huge marsh. It's complicated, it has tidal creeks and a few roads running through it, different water features. They all weigh into the discussion of how we decide which criteria to use to monitor.
- --: CT is also looking to set up a monitoring program as well as Maine.
- --: MA CZM has one. We established ours in 2018. We will be collecting our next year of data soon.
- Jake A: Predicting restoration outcomes: studying anthropogenic impacts to saltmarsh. Finding ways that the data we collect can improve these impacts.
- Sue A: A lack/need to map prior to agriculture alterations that still persist today, such as embankments.
- Russ H: In 85 acres of MA, we are looking to restore marshes by using the ditches to seal them up. Using hay and other materials to plug them up and restore the natural hydrology. As a part of that, we mapped all historical embankments.
- Sue A: The challenge when using elevation as a surrogate for inundation, you are missing certain elements.
- Kate O: How did you map all this out? What did you use? We don't have a continuous system-wide method.
- Dave B: Geoff is using ground survey.
- Christine F: It seems that we are talking about something bigger than one project.
- Kate O: It seems that we will need to address it at a scale that we are losing marshes. How do you monitor so intensely without throwing money down the drain.? How do we decide to add certain sediment to areas, but not others? I don't know how to make those types of decisions.
- Dave B: We don't know how to answer that.
- Kevin L: Do you differentiate between short and low marsh form of alterniflora? When ditch density is highest, you have … Why does this data show this?
- Russ H: Because there are twice as many ditches as needed, the tide is so dissipated, that a lot of ditches are getting blocked, there isn't enough flow to keep the marshes clean. Some areas are totally saturated.
- Sue A: short form is an indicator of saturation and peat formation.
- Ruth I: There's a marsh in Georgetown that is pretty much unditched, and that is a lot of patens.
- Kevin L: It seems there is a management implication if we manage short and tall form alterniflora.
- --: As someone who is collecting this data, at a lot of our marshes we see a lot of short form too and we had someone come and RTK our marshes. This has not management implication, but it's more data and moving forward. I think of how we collect data and it's shown me that we will be collecting whether it's short or tall form alterniflora.
- --: We also added a metric for short and tall form maybe that they could act as transition indicators from low to high marsh. The challenge was what is short vs tall? No one has the answer really. It just seems like that needs to be a consistent method for what we call short and tall.
- Dave B: there is a paradigm that we are proposing, most of our marshes have been ditched, mosquito ditching was done 40 years ago, while these ditches heal, we are driving water towards main creeks. We get the high marshes around the main creeks. We want main creeks with high marsh around it, and if we also get short form to help create the thatch, that is okay. So we have metonic cycles and SLR, but we also have areas where marshes are being lost to open water. One of the things that people wanted to know was, 'Can we look at

sentinel site data and relate it to ecological data?' So, what we do may hurt one group of species and help another. We aren't saying one is more important than the other, it's just based on what we try first.

- Kevin L: I guess the management of using *alterniflora* is using it as an indicator for…
- Kenny R: We just published a paper that talked about the different metrics and compared six different marshes across the country. Best indicators to use to determine the state of a marsh are using elevations of tidal water and elevation of marsh platform from lowland to upland.
- Kate O: We have pools and pannes that come and go on the marshes, some are natural, how much water is too much water? The second question is are there other ways that we can create sediment?
- Dave B: I look for pools that have unnatural edges. And yes, there are ways to dump large quantities of sand and let the waves spread the material on the marshes.
- --: SLR and metonic cycles, I was hoping that alterniflora would catch up and revegetate some of these areas that have become bare as the sea levels rise.
- Sue A: If you can restore the hydrology, then perhaps that can work.
- Dave B: But, you'd also have to wait until the interstitial space was filled with material so that the marsh can build on itself.
- Kate O: What seems to be missing is a time scale of species survivability. Is there a realistic timescale for alterniflora?
- Dave B: It can take up to 5 years to build a thatch layer. I think we need to tighten up our protocols, I also think we can use our data to inform people about ecological management.
- Jason G: Have we normalized any of our data to….? Can you make a correctional factor knowing certain metrics? The data that we look at is relative to our local tides. If metonic cycle is a factor, can we tease those out because we can't even tease though out from a multivariable method, right?
- Bri B: What if you use annual precipitation? That would be more localized.
- Sue A: You could, but the challenge is that if you don't get rain in one town, but you do in the neighboring town, that could change the results. I want to add that you can add mussels to the surface of the marsh and it usually means that the areas is wetter than other marshes. It could mean inundation.
- Russ H: For the rest of us, we sometimes don't have the staffing to be able to do this. Can volunteers be trained to do this kind of work? Our communities are saying that they want to be involved in this work, but if there is something that our people can do, that would be great given our lack of staffing.
- --: One great salt marsh citizen science project I have heard of is property owners that have docks that cross the marsh, there are markers that are attached and monitored over time.
- --: When you get crabs and can dispose of them, then that's a great way to get citizens involved.
- Dave B: Volunteer monitors can broaden your dataset for sure.

CF: The last thing that I want to talk about are next steps. Is there something that you will do next or that you'd like to see the NERRS do next, please give us your ideas. We will have to compile a report for this project and November 30th is the final date for our project. The evaluation has two sides, your responses will be very valuable. Are there next steps you are thinking about now?

- Jason G: Though we all have different ways of collecting data, the trends are pretty much all the same. A nice output is a portfolio to managers that include recommendations for decision makers and managers.
- Chris P: We do have this regional dataset that we have given to every reserve, but it would be nice to adopt a database that standardizes the data.
- --: With ocular vs point intercept, are there people that will change their methods or stay the same?
- Great Bay is going to stay the same and we're ocular cover.
- Kate O: Both methods tell the same story, but when you publish it it's important.
- Chris P: There are regional and local consistencies that need to be considered as well. The most important is local. There is one protocol change that Wells is doing.