# Development of Protocols to Monitor Submerged Aquatic Vegetation in North Carolina's Estuaries

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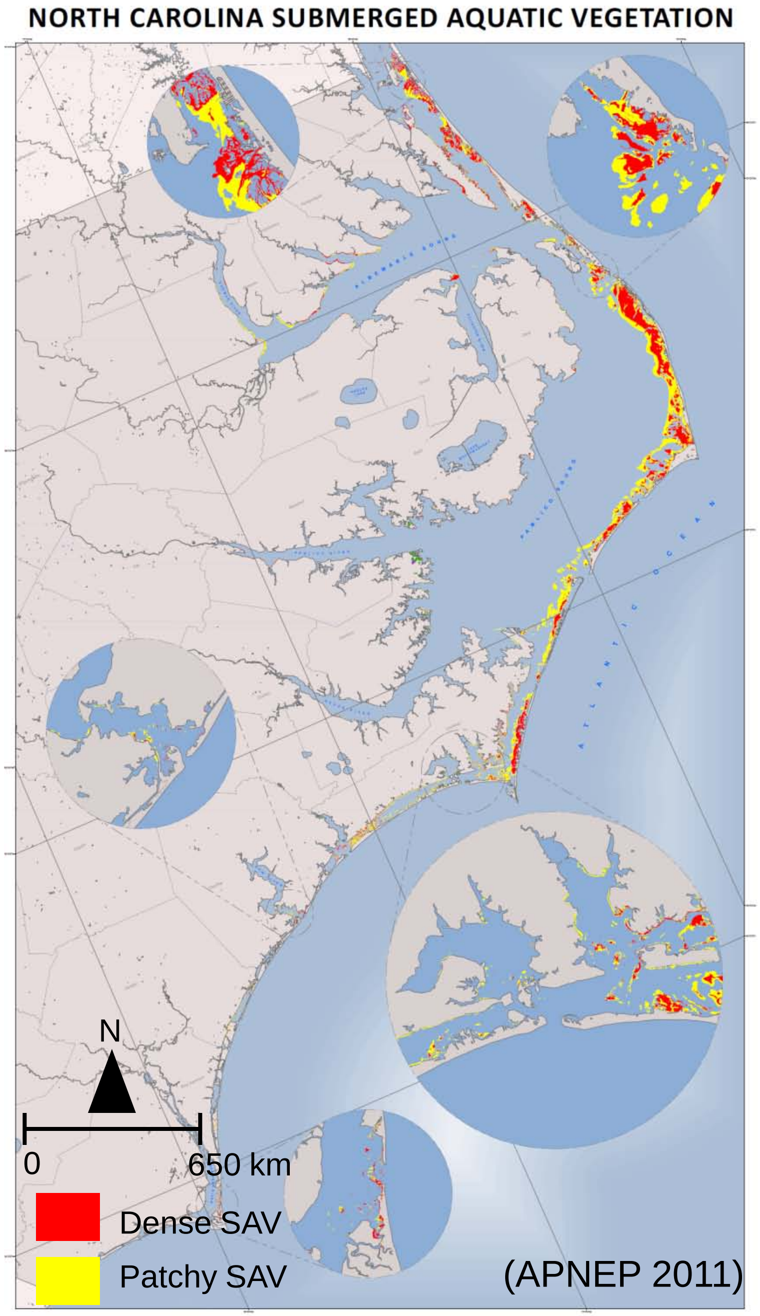
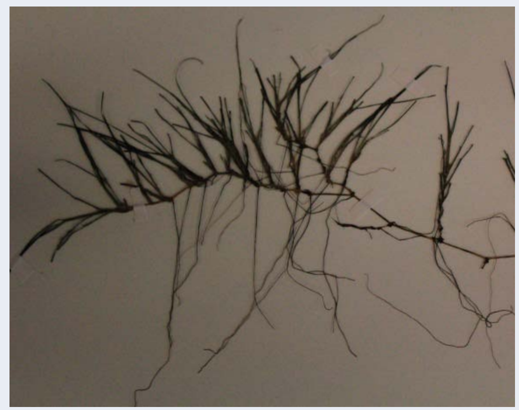
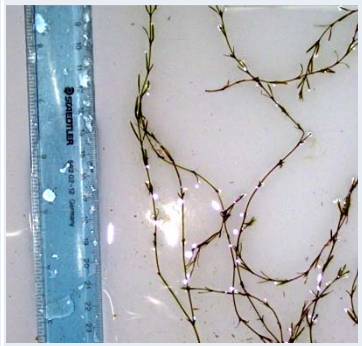
***Wild Celery, Vallisneria americana***
***Sandy Point, Albemarle Sound July 2009***

# SAV in North Carolina

- The Albemarle-Pamlico Estuarine System (APES) is the 2nd largest estuarine system in U.S.
- 3rd largest area of SAV in the U.S.
  - 138,626 acres or 561 km$^2$
  - likely to be underestimated
- Challenges:
  - Aerial surveys only see in clear water (behind OBX)
  - Turbid regions must be surveyed on-the-ground ("invisible grass")
  - SAV is located in high and low salinity areas
  - SAV is highly seasonal
    - N. limit of *Halodule wrightii*
    - S. limit of *Zostera marina*



| Marine species | Photos |
|---|---|
| Saltwater Eelgrass<br>*Zostera marina* |  |
| Widgeon grass<br>*Ruppia maritima* |  |
| Shoal grass<br>*Halodule wrightii* |  |

| Low-salinity species | Photos | Low-salinity species | Photos |
|---|---|---|---|
| Wild celery (Freshwater eelgrass) *Vallisneria americana*, |  | Wideon grass, *Ruppia maritima* |  |
| Southern naiad *Najas guadalupensis*, |  | Eurasian watermilfoil, *Myriophylium spicatum* |  |
| *Redhead grass Potamogeton perfoliatus* |  | Sago Pondweed *Stuckenia pectinata* |  |
| Coontail, *Ceratophyllum demersum* |  | Horned pondweed *Zannichellia palustris*, |  |

# Motivation for the Study

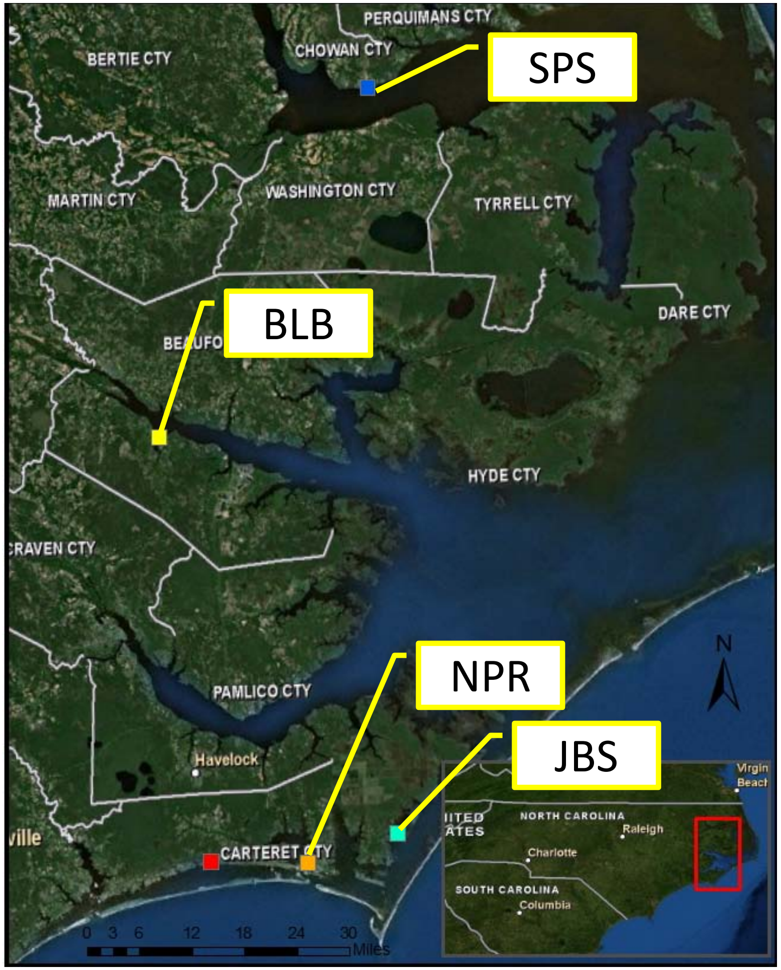
- SAV can be killed or coverage reduced by harmful algal blooms, phytoplankton blooms, nutrient pollution, sediment plumes, dredging events, propellers, pesticides, storms, climate change, and natural agents (birds, rays, manatees).
- How much does the SAV change from year-to year?
- Is it growing, shrinking, or staying the same?
- Areal coverage can be obtained from imagery and ground truth, but what is the variation?
- Probability estimates must be attached to the area estimates to understand a *significant* change.

# Objectives

1) Develop and test a sampling protocol for a long-term, in-the-water probabilistic based method to monitor the distribution and change in SAV habitat in coastal waters statewide, and evaluate the relationship between environmental conditions and SAV distribution.
2) Determine the feasibility of developing a protocol with a performance measure capable of detecting at least a 10% inter-annual change in SAV abundance.
3) Compare a point-intercept visual census technique using low-light underwater cameras with a hydro-acoustical technique to determine the most appropriate method of monitoring and data acquisition.
4) Draft a long-term statewide monitoring plan for SAV.
5) Originally, there was a fifth goal incorporating an outreach effort to disseminate information and educate and inform resource managers and the public on the value and status of SAV and the critical role of monitoring and conserving SAV habitat. This goal was not funded in the first years of the project. This outreach is still needed – people should know the value SAV (at least $12,000 per acre in ecosystem services).
6) SAV is worth about $1.66 billion in NC!

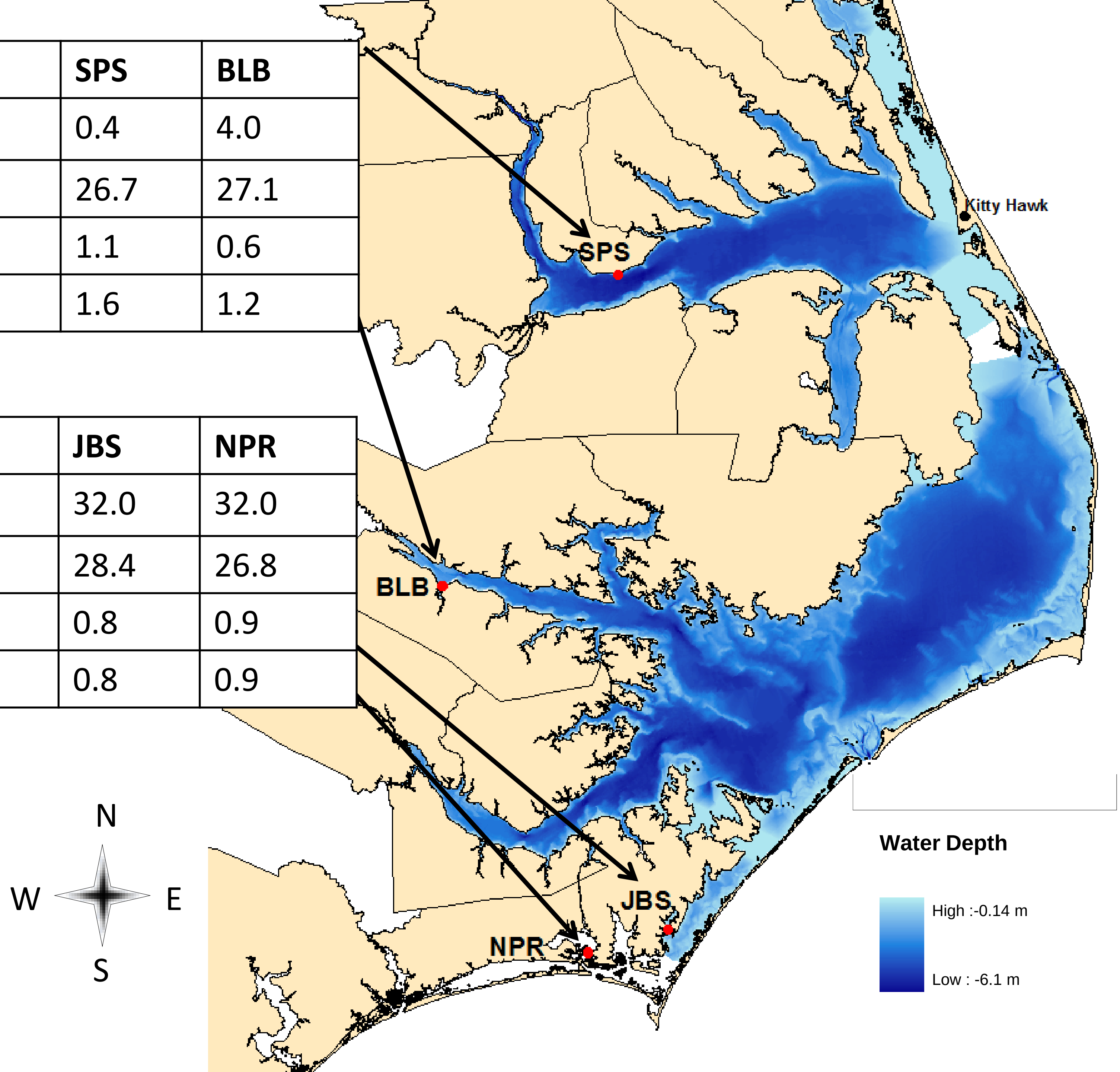
# Methods

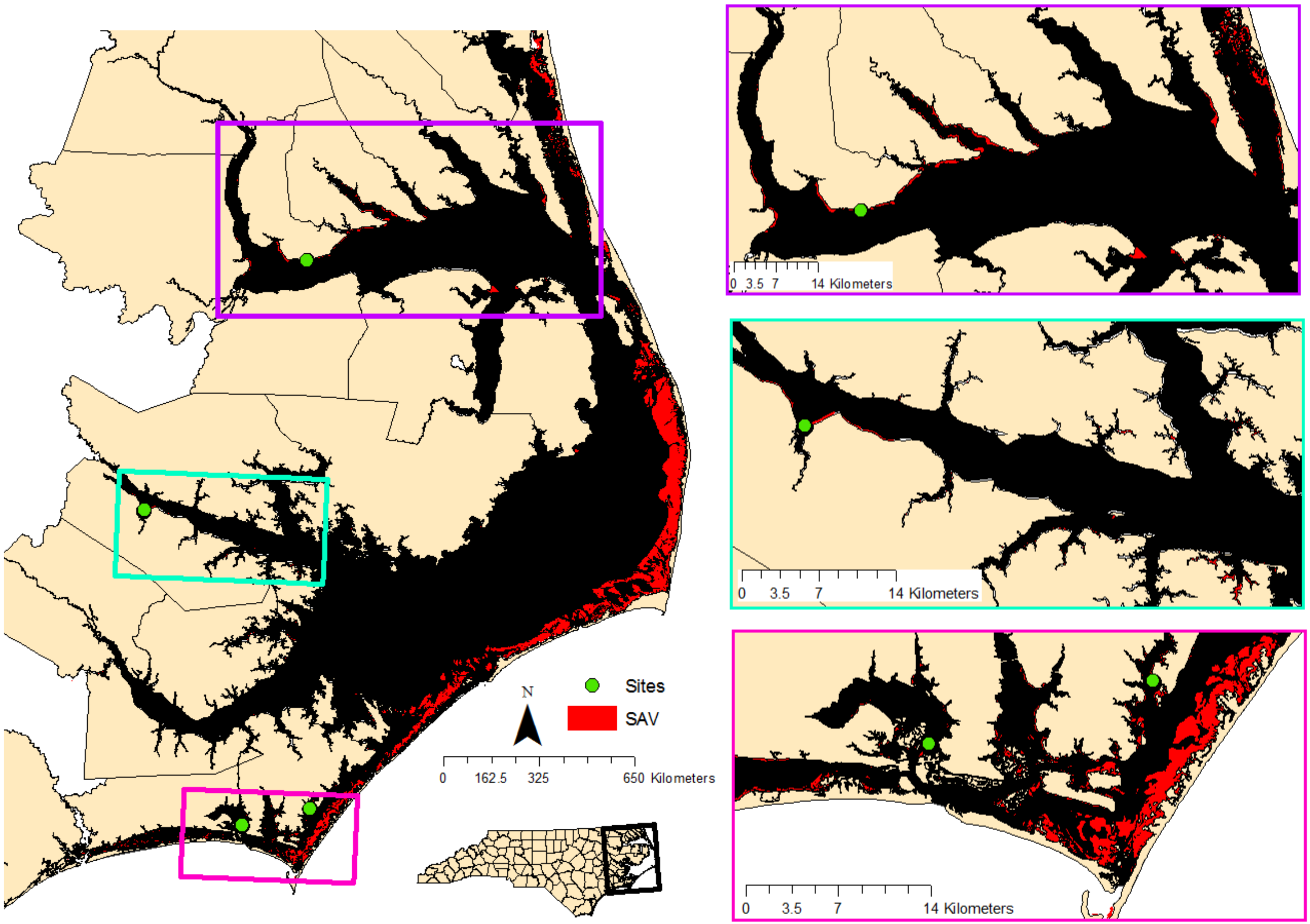
- Seagrass video surveys, acoustic surveys, and quadrat ground-truthing surveys were conducted in May - Sep 2010 at four sites throughout the Albemarle-Pamlico Estuarine System.
- Two of the sites were high-salinity (>30 ppt): located in Newport River (NPR), Jarrett Bay (JBS)
- Two of the sites were low-salinity (<10 ppt), one located at Sandy Point (SPS) and the other at Blount's Bay (BLB).
- One experimental satellite image (WorldView) was ground-truthed at Jarrett Bay



| | SPS | BLB |
|---|---|---|
| Salinity (ppt) | 0.4 | 4.0 |
| Temp (°C) | 26.7 | 27.1 |
| Secchi Depth (m) | 1.1 | 0.6 |
| Average Depth (m) | 1.6 | 1.2 |

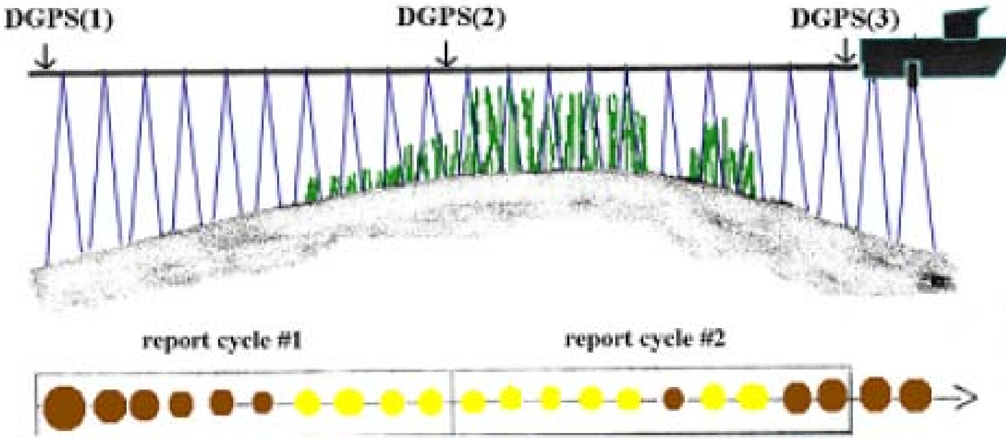
| | JBS | NPR |
|---|---|---|
| Salinity (ppt) | 32.0 | 32.0 |
| Temp (°C) | 28.4 | 26.8 |
| Secchi Depth (m) | 0.8 | 0.9 |
| Average Depth (m) | 0.8 | 0.9 |

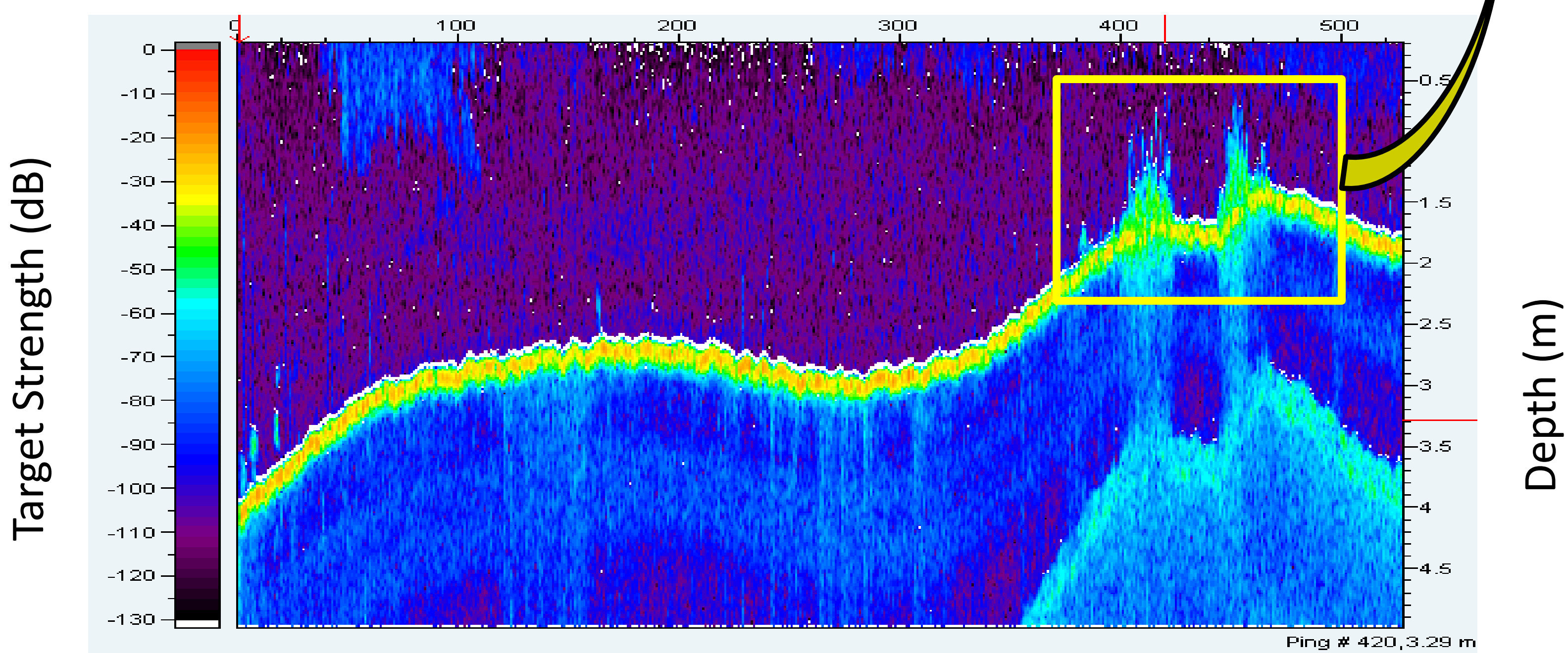


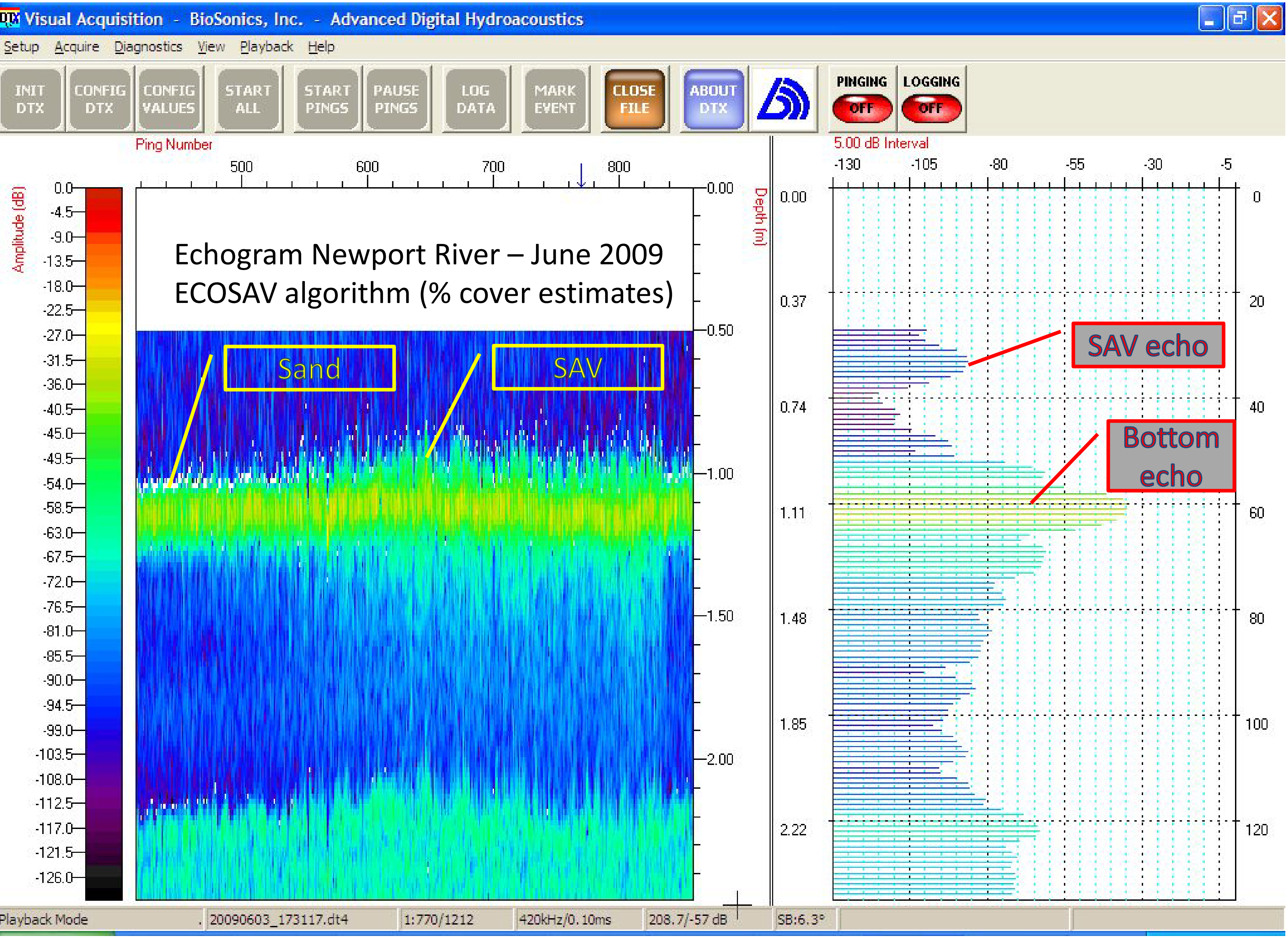


Sites
SAV
N
0 162.5 325 650 Kilometers
0 3.5 7 14 Kilometers
0 3.5 7 14 Kilometers
0 3.5 7 14 Kilometers

# Acoustic (Single-beam SONAR) Method



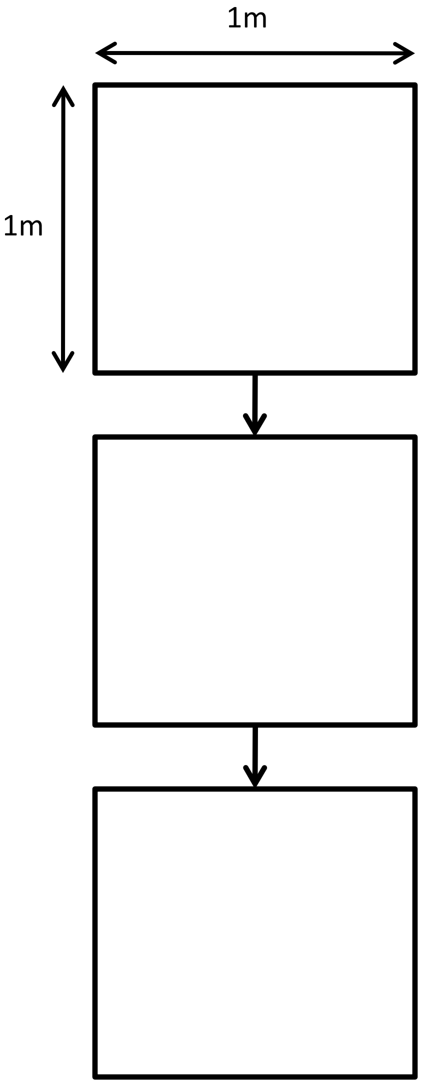




Visual Acquisition - BioSonics, Inc. - Advanced Digital Hydroacoustics
Setup Acquire Diagnostics View Playback Help
INIT DTX
CONFIG DTX
CONFIG VALUES
START ALL
START PINGS
PAUSE PINGS
LOG DATA
MARK EVENT
CLOSE FILE
ABOUT DTX
PINGING OFF
LOGGING OFF
Ping Number
500
600
700
800
Amplitude (dB)
0.0
-4.5
-9.0
-13.5
-18.0
-22.5
-27.0
-31.5
-36.0
-40.5
-45.0
-49.5
-54.0
-58.5
-63.0
-67.5
-72.0
-76.5
-81.0
-85.5
-90.0
-94.5
-99.0
-103.5
-108.0
-112.5
-117.0
-121.5
-126.0
Echogram Newport River – June 2009
ECOSAV algorithm (% cover estimates)
Sand
SAV
0.00
0.50
1.00
1.50
2.00
Depth (m)
5.00 dB Interval
-130
-105
-80
-55
-30
-5
0.00
0.37
0.74
1.11
1.48
1.85
2.22
0
20
40
60
80
100
120
SAV echo
Bottom echo
Playback Mode
20090603_173117.dt4
1:770/1212
420kHz/0.10ms
208.7/-57 dB
SB:6.3°


# Video Method

- High resolution low light camera
- Differential GPS
- Continuous stamped video – date, time & location
- Camera fixed 13cm above bottom
- Frame size ~$0.25 m^2$
- Individual frames classified for SAV presence/absence

# The Quadrat Method



# Satellite Remote Sensing Approach WorldView-2 Imagery

- 9 spectral bands:
  - 5 optical (400-450μm blue band)
  - 3 Infrared bands
  - 1 panchromatic band
- 1.8-m spatial resolution
- 11-bit radiometric resolution
- 1.1-day temporal resolution
- Off-nadir capabilities

# Methods and Analysis

- A 300 x 300 m sampling box was overlain on each seagrass site
  - Shore-normal boat transects with video and sonar methods were obtained on or near the same day
- Data were analyzed as SAV presence/absence for comparison
- Fraction of SAV ($F_{SAV}$) was calculated for video and SONAR

$$F_{SAV} = \frac{N_{SAV}}{N_{Total}}$$

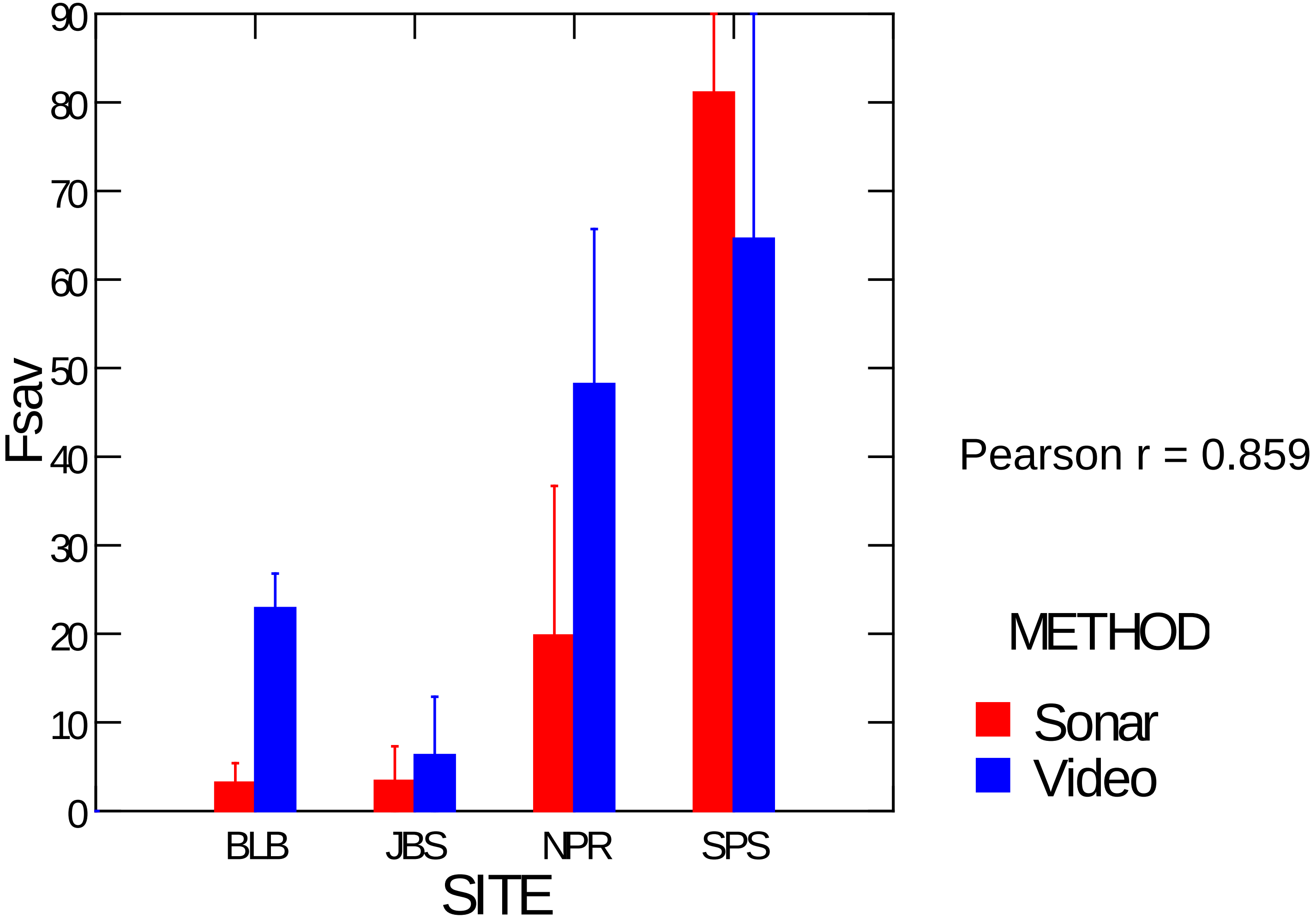
  - $F_{SAV}$ is the fraction of SAV present on a transect
  - $N_{SAV}$ is the number of video images or SONAR report with SAV present
  - $N_{Total}$ is the total number of video images analyzed or SONAR reports
- Mean $F_{SAV}$ and SD's were calculated from transects for each site and method
- Power analyses completed with Systat 13 ($\alpha = 0.05$, 2-sample t-test)
  - Desired: $\Delta = 10\%$, with a power of 0.8

# Co-Kriging applied to SONAR

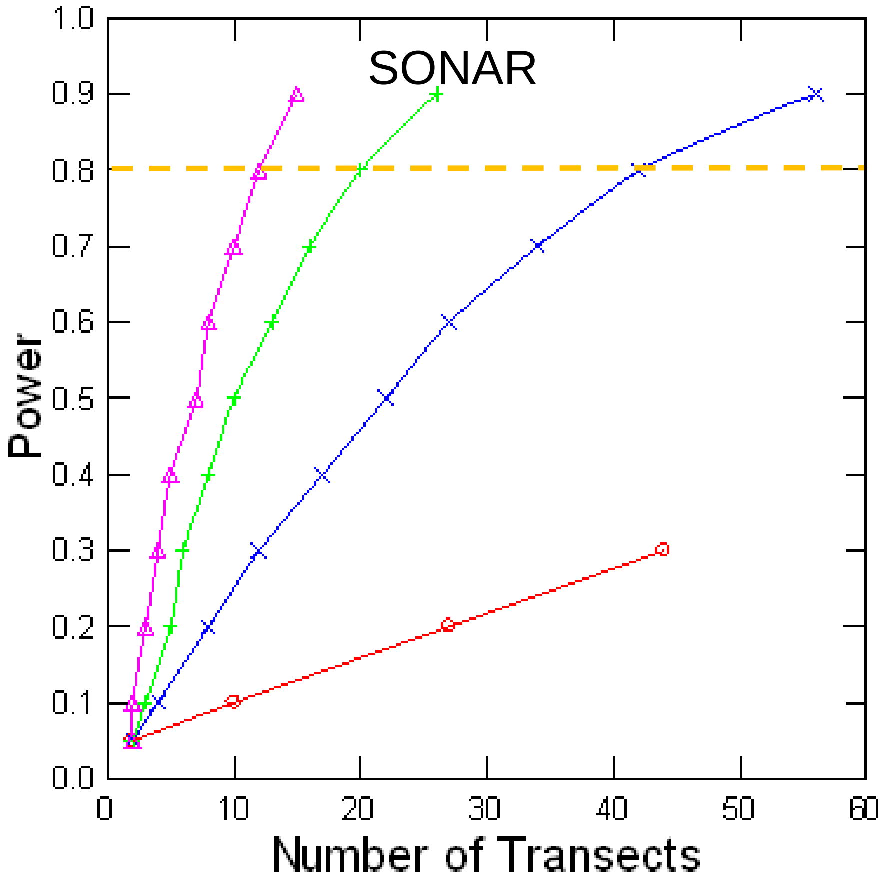
- ARC Map GIS geostatistical software used
- Predicts % cover values at locations where no data exists by using nearby known values
- Uses two correlated variables to improve prediction (% cover and depth)
- Produces Standard Error of predicted surface
- Standard Error increases as distance from known points increases

# RESULTS

# $F_{sav}$ as quantified by Video & SONAR



# All Sites

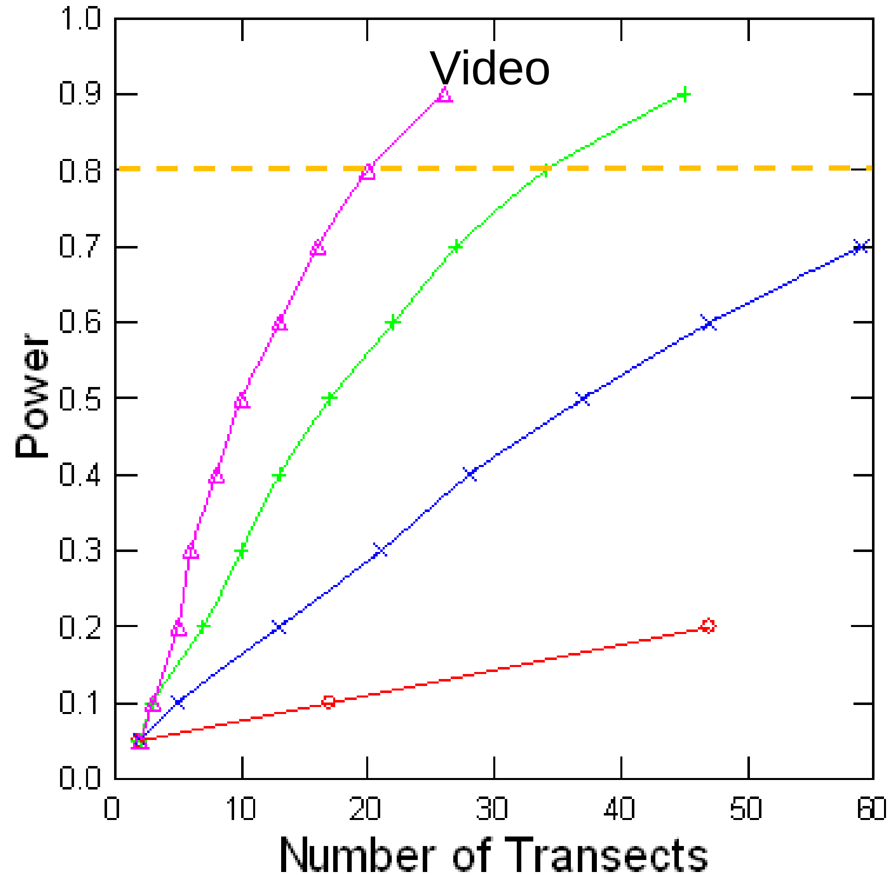



Change in $F_{sav}$

Mean $F_{sav}$ = 26.9

○ 10% $F_{sav}$ = 24.2
× 20% $F_{sav}$ = 21.5
+ 30% $F_{sav}$ = 18.8
△ 40% $F_{sav}$ = 16.1

α = 0.05




Change in $F_{sav}$

Mean $F_{sav}$ =35.5

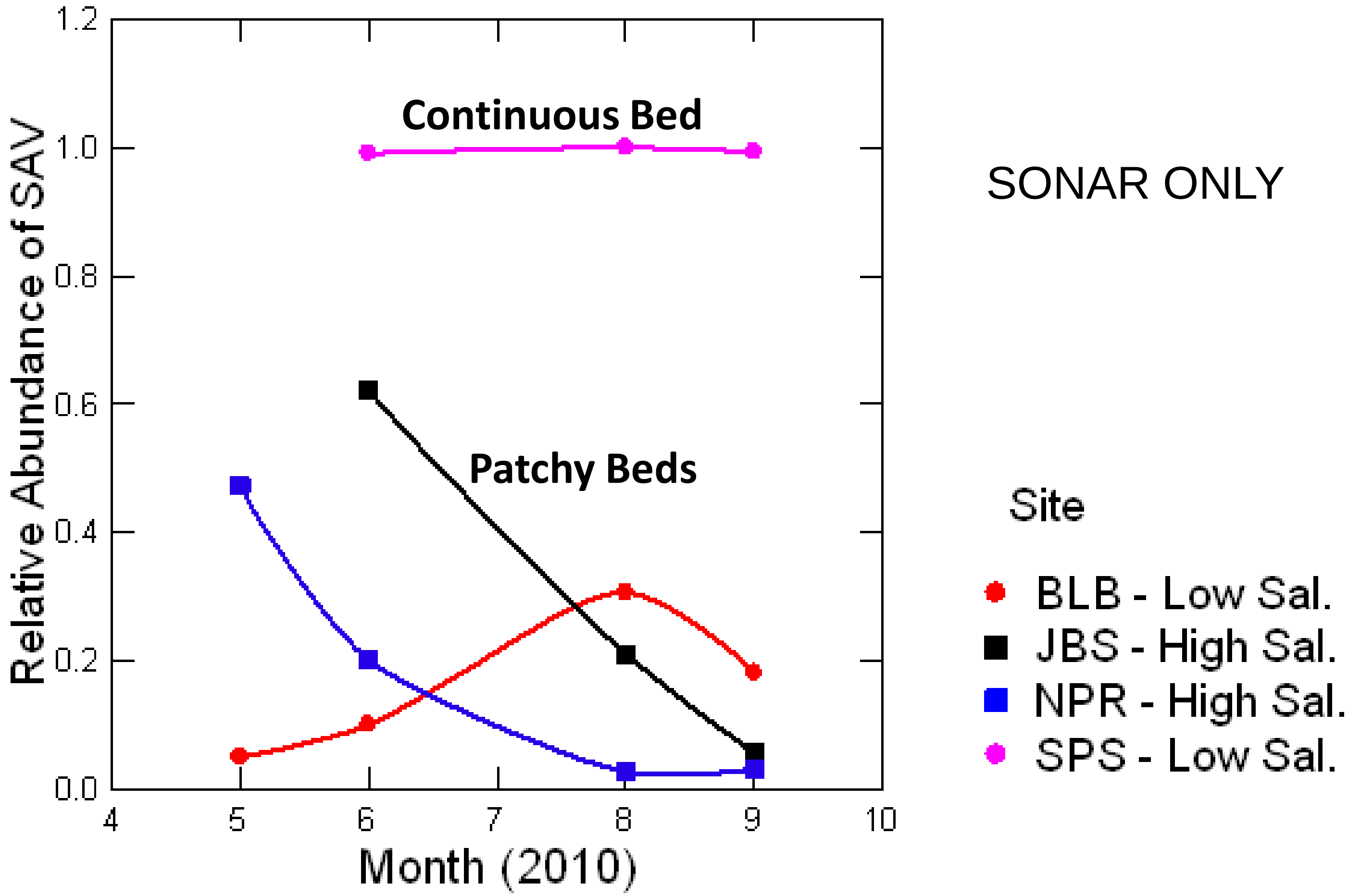
○ 10% $F_{sav}$ = 32.0
× 20% $F_{sav}$ = 28.4
+ 30% $F_{sav}$ = 24.9
△ 40% $F_{sav}$ = 21.3

| Site | type | Date | Original Transect # | # Transects Needed $\beta$ = 0.9 | | |
|---|---|---|---|---|---|---|
| | | | | 10% | 20% | 30% |
| BLB | SONAR | 20100626 | 44 | 992 | 249 | 112 |
| BLB | Video | 20100609 | 5 | 62 | 17 | 8 |
| SPS | SONAR | 20100827 | 44 | 46 | 13 | 7 |
| SPS | Video | 20100824 | 7 | 551 | 139 | 63 |
| JBS | SONAR | 20100730 | 34 | 2762 | 691 | 308 |
| JBS | Video | 20100729 | 9 | 2303 | 576 | 257 |
| NPR | SONAR | 20090603 | 15 | 1527 | 384 | 171 |
| NPR | Video | 20090608 | 15 | 278 | 71 | 32 |
| ALL | SONAR | NA | 137 | 221 | 56 | 26 |
| ALL | Video | NA | 36 | 390 | 99 | 45 |

High-salinity sites

Low-salinity sites

# Seasonal Change in SAV Area



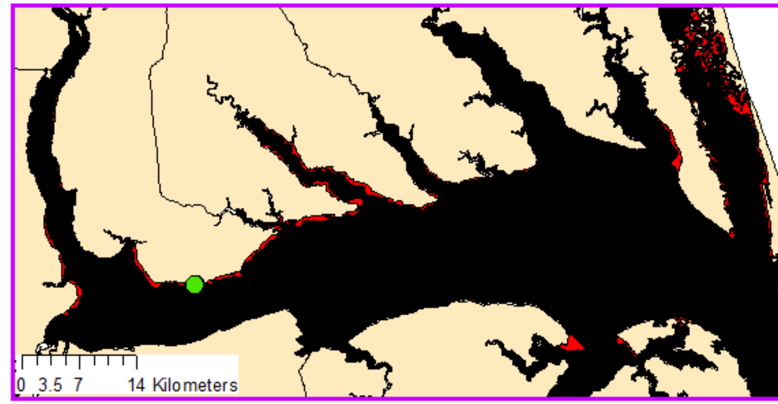

SONAR ONLY

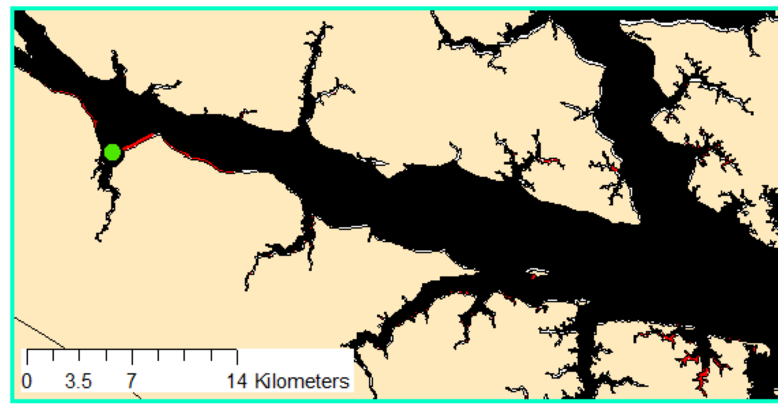
Sonar,  video, quadrat remote sensing methods

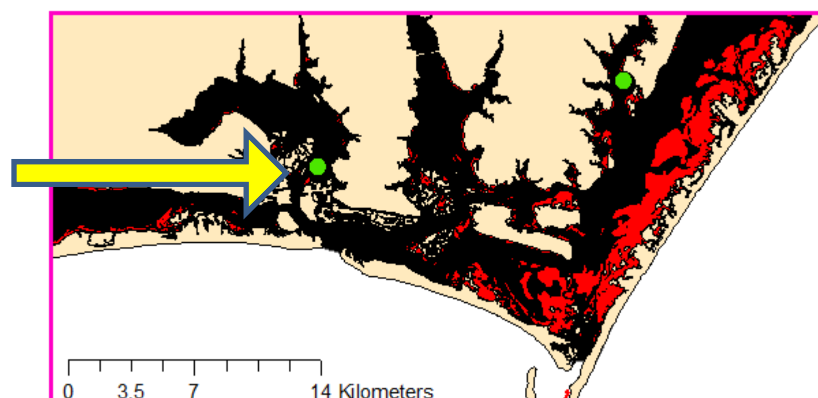
# HIGH SALINITY AREAS

Beaufort NC

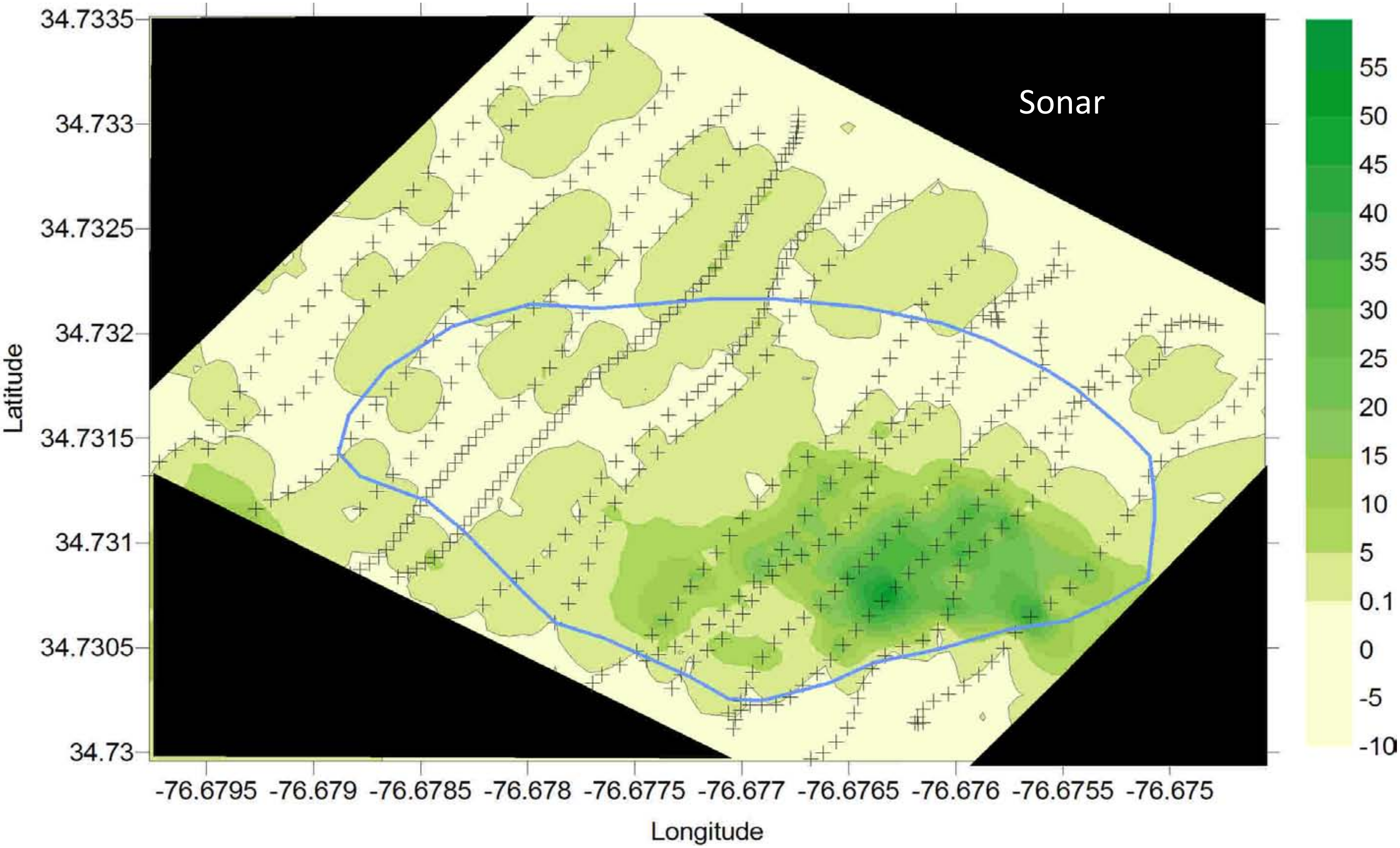
# NEWPORT RIVER

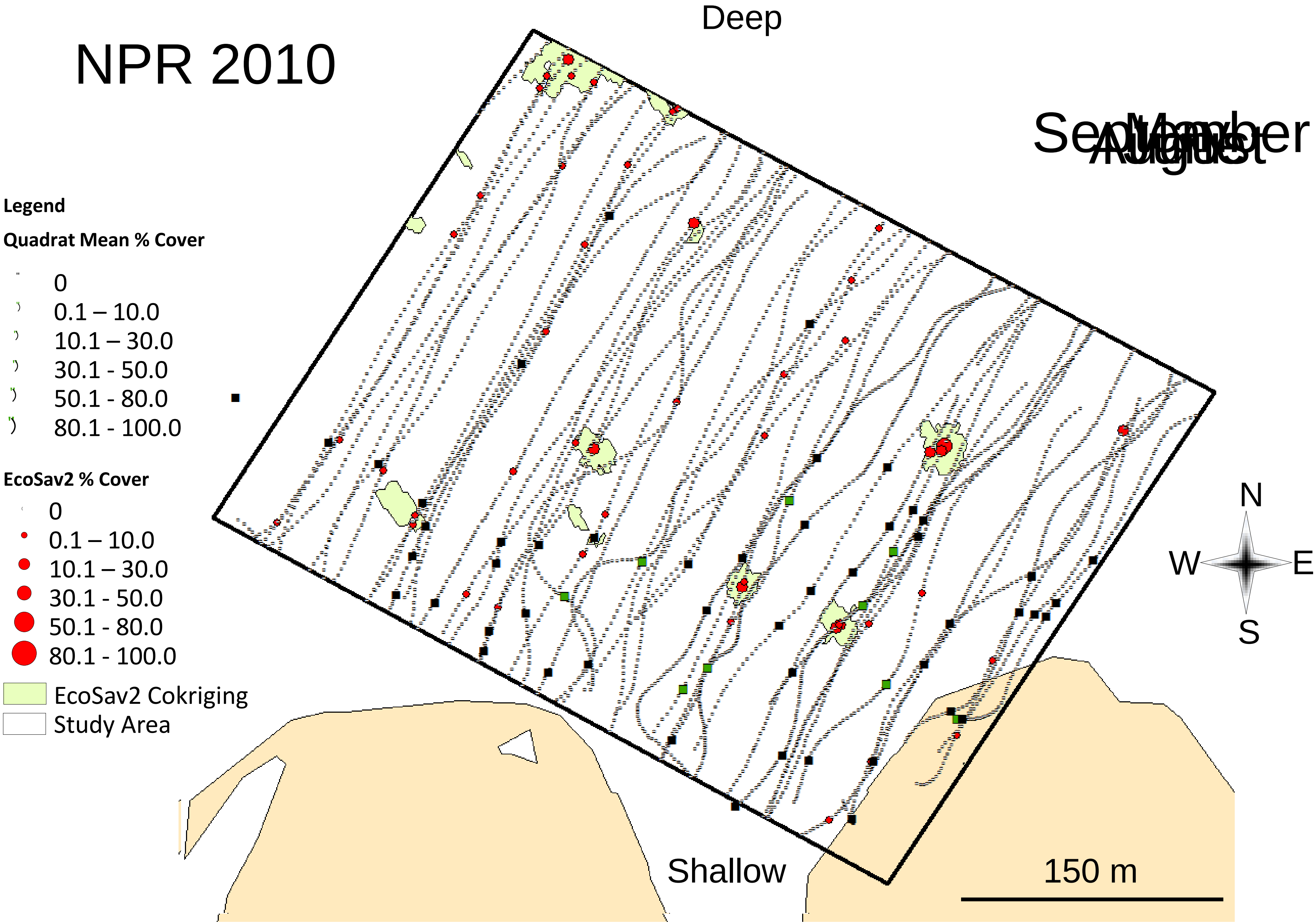


# NPR Shore-Normal June 2009




NPR 2010
Deep
September
August
Legend
Quadrat Mean % Cover
0
0.1 – 10.0
10.1 – 30.0
30.1 - 50.0
50.1 - 80.0
80.1 - 100.0
EcoSav2 % Cover
0
0.1 – 10.0
10.1 – 30.0
30.1 - 50.0
50.1 - 80.0
80.1 - 100.0
EcoSav2 Cokriging
Study Area
N
W
E
S
Shallow
150 m

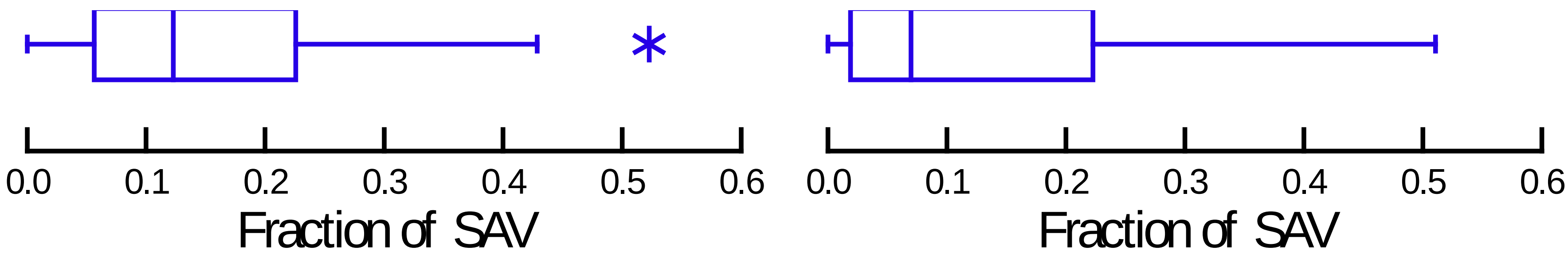
# NPR Comparison of 2009 and 2010 SONAR data

Mean $F_{sav}$ = 16.2
N = 25 transects

3 June 2009

Mean $F_{sav}$ = 12.1
N = 72 transects

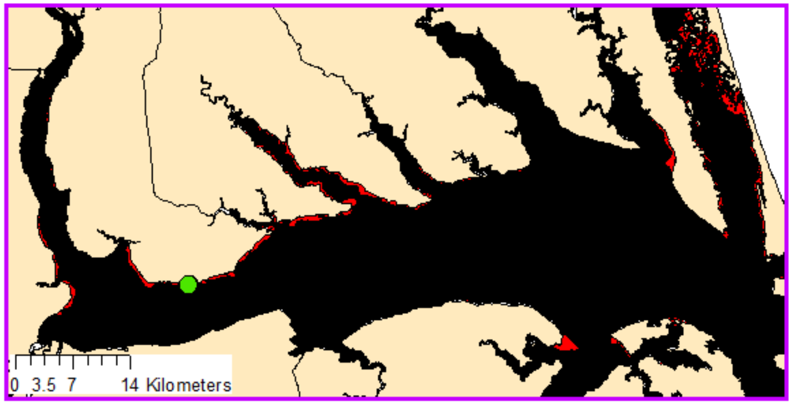
27 May 2010

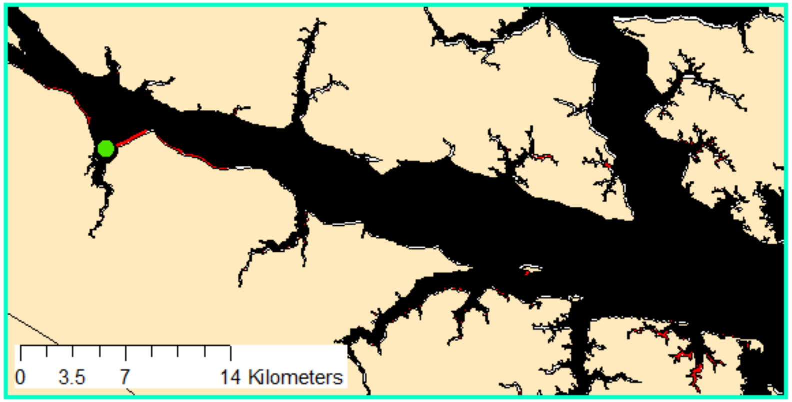


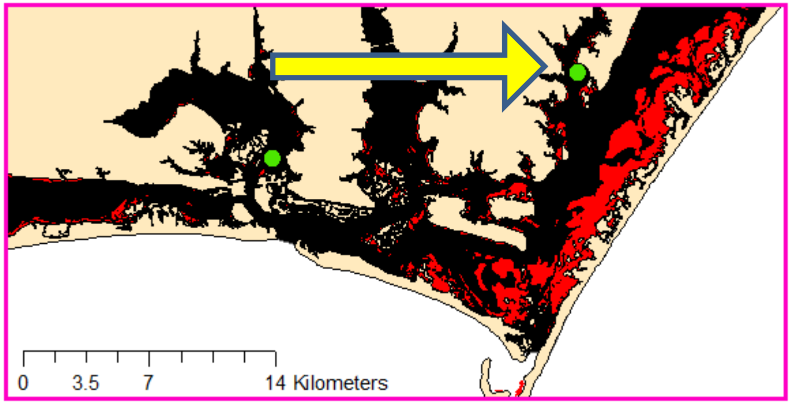

Two-sample t-test:
t=1.309, df=95, P = 0.194

Sonar, video, quadrats, remote sensing

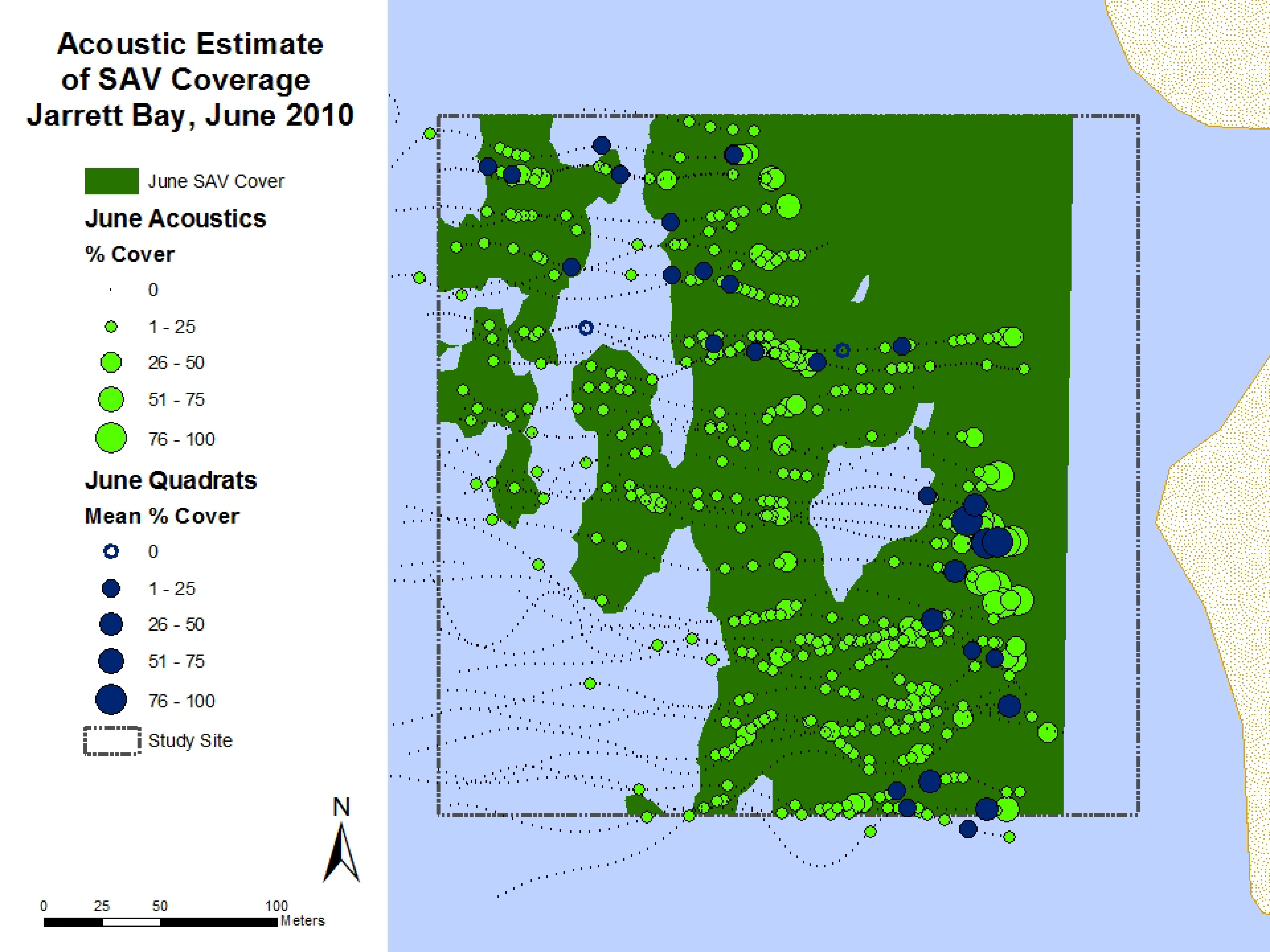
# JARRETT BAY



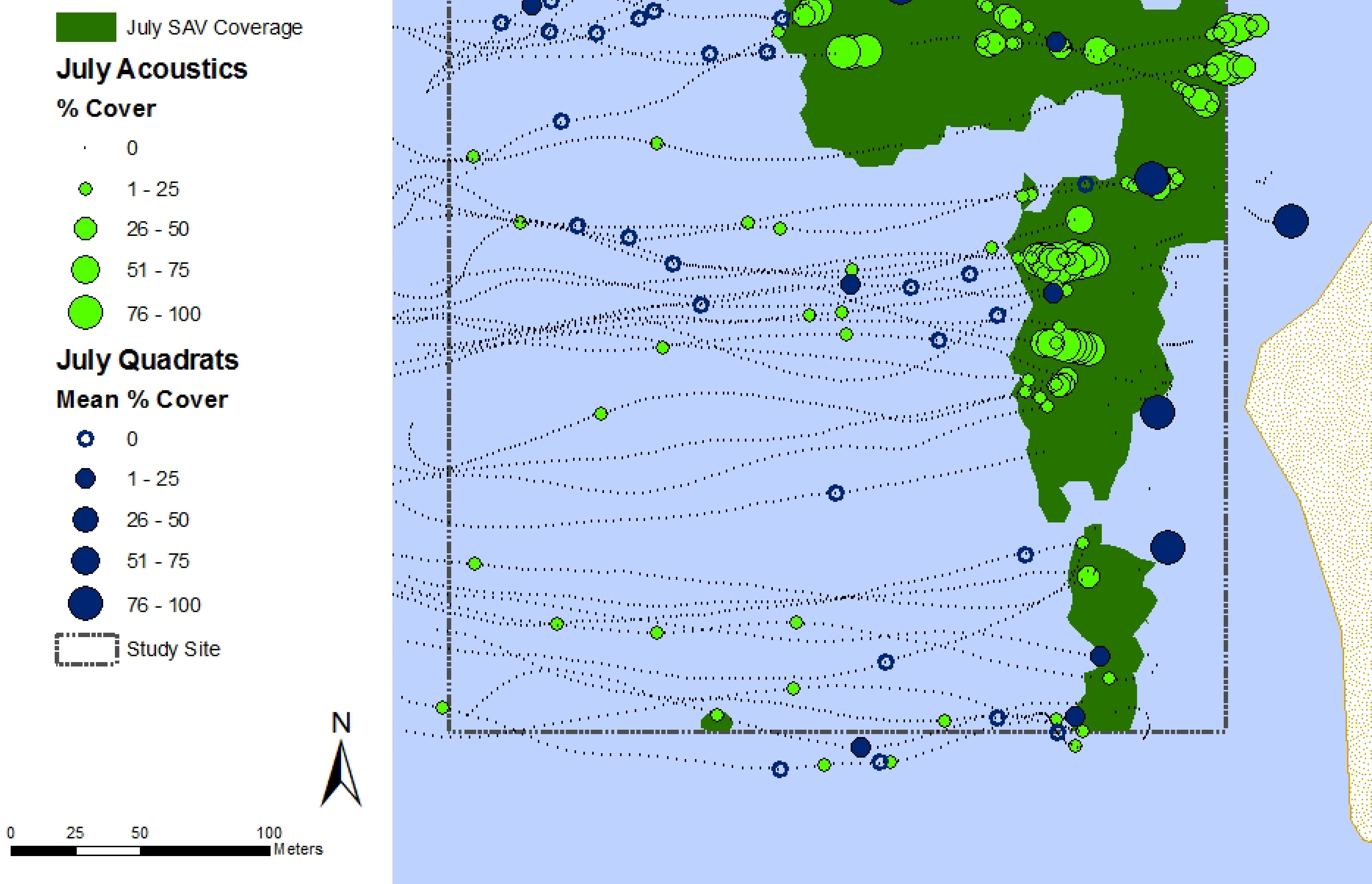



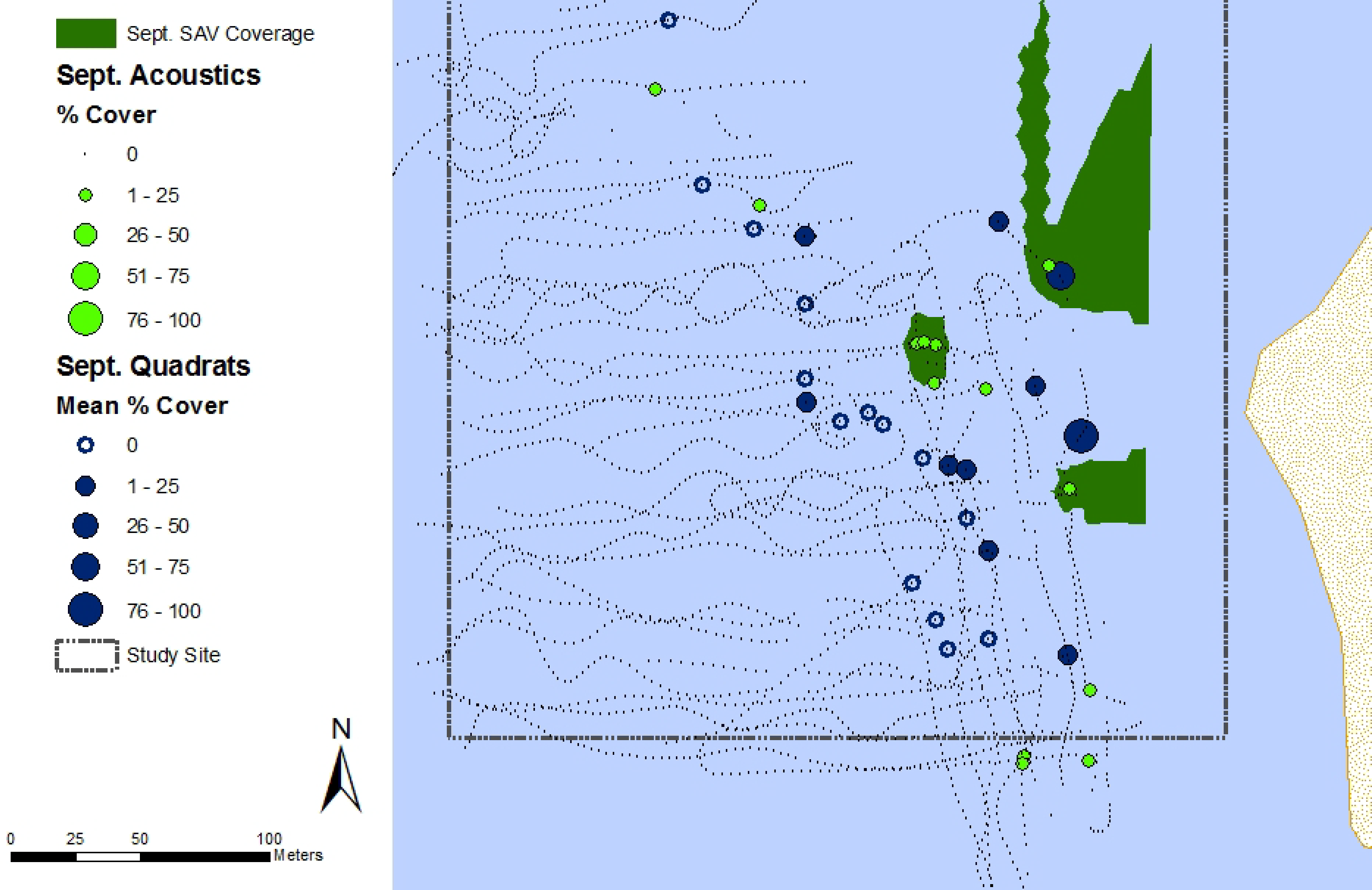

WorldView-2 Image
September 2010
0
150
300
600
Meters
N

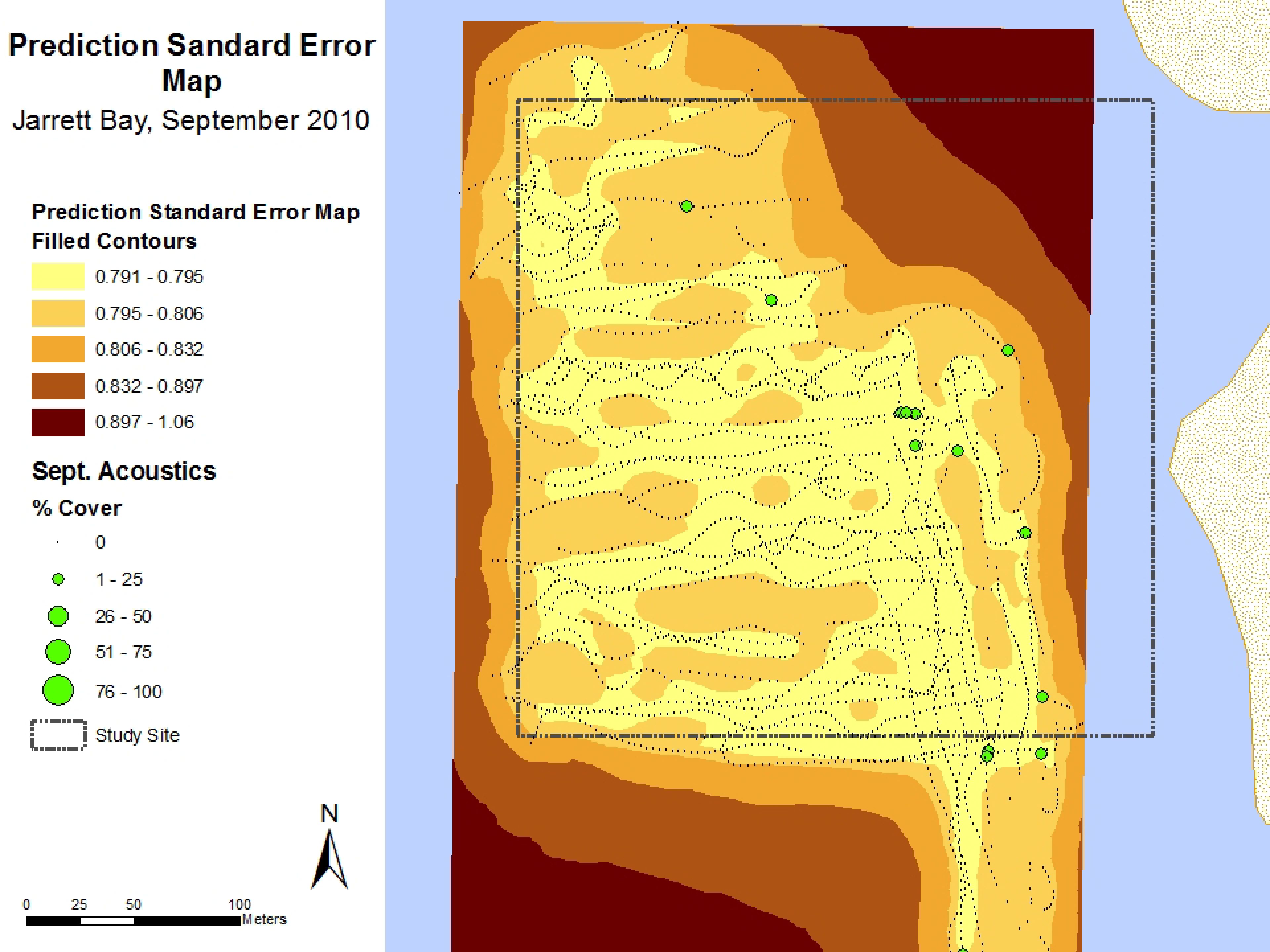

Acoustic Estimate of SAV Coverage Jarrett Bay, June 2010
June SAV Cover
June Acoustics
% Cover
0
1 - 25
26 - 50
51 - 75
76 - 100
June Quadrats
Mean % Cover
0
1 - 25
26 - 50
51 - 75
76 - 100
Study Site
N
0
25
50
100
Meters

# Acoustic Estimate of SAV Coverage Jarrett Bay, July 2010

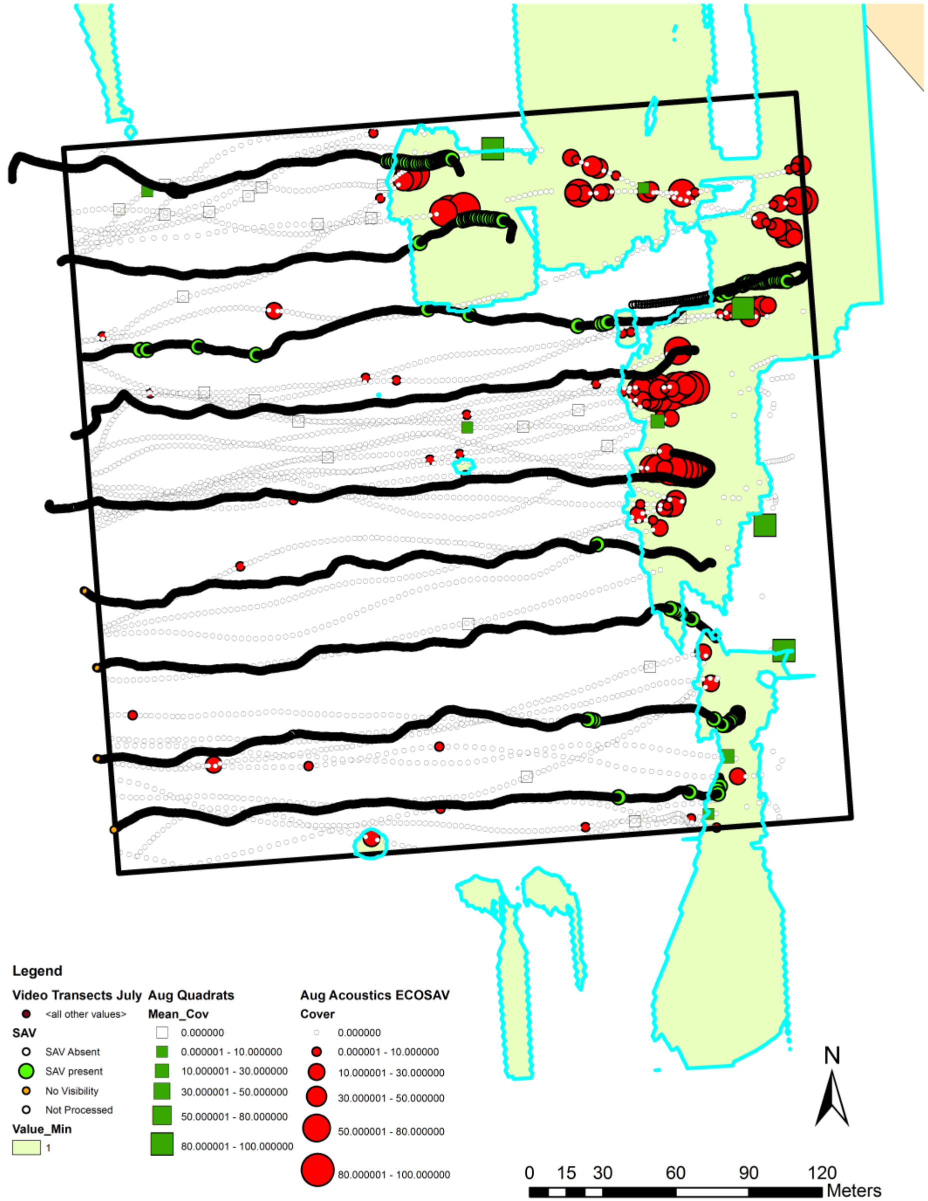


# Acoustic Estimate of SAV Coverage
## Jarrett Bay, September 2010





Prediction Sandard Error Map
Jarrett Bay, September 2010
Prediction Standard Error Map
Filled Contours
0.791 - 0.795
0.795 - 0.806
0.806 - 0.832
0.832 - 0.897
0.897 - 1.06
Sept. Acoustics
% Cover
0
1 - 25
26 - 50
51 - 75
76 - 100
Study Site
N
0
25
50
100
Meters



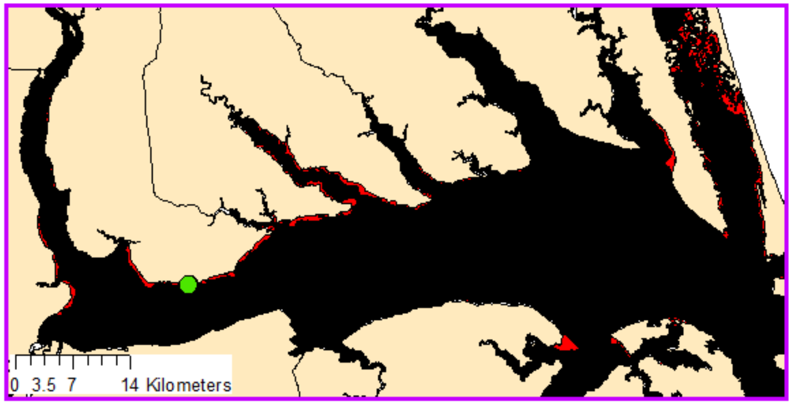
Legend
Video Transects July
<all other values>
SAV
SAV Absent
SAV present
No Visibility
Not Processed
Value_Min
1
Aug Quadrats
Mean_Cov
0.000000
0.000001 - 10.000000
10.000001 - 30.000000
30.000001 - 50.000000
50.000001 - 80.000000
80.000001 - 100.000000
Aug Acoustics ECOSAV
Cover
0.000000
0.000001 - 10.000000
10.000001 - 30.000000
30.000001 - 50.000000
50.000001 - 80.000000
80.000001 - 100.000000
N
0 15 30 60 90 120
Meters

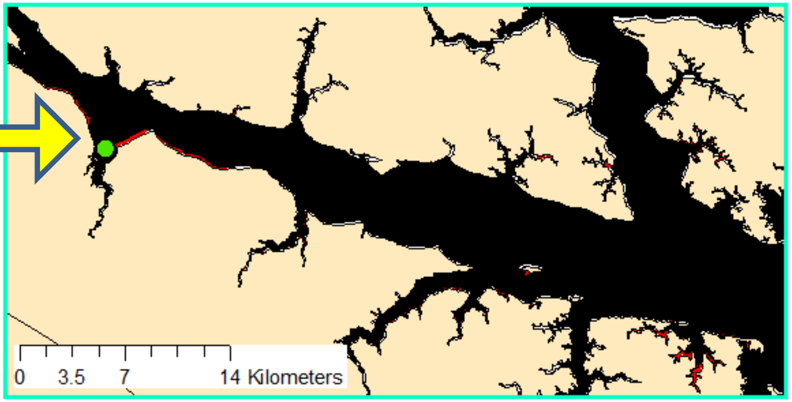
Sonar, video, and quadrats

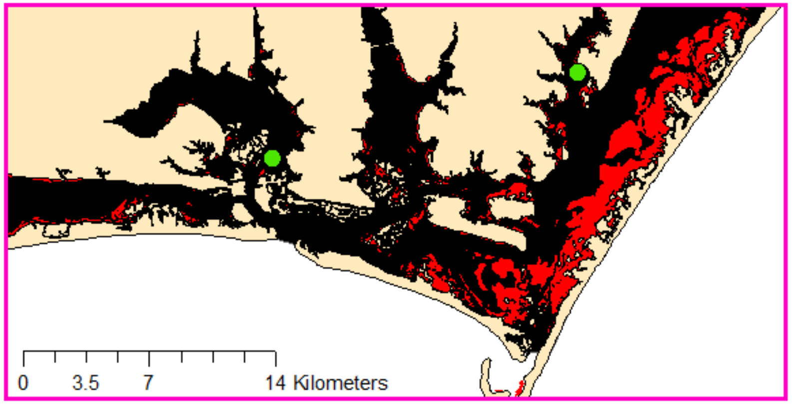
# LOW SALINITY AREAS

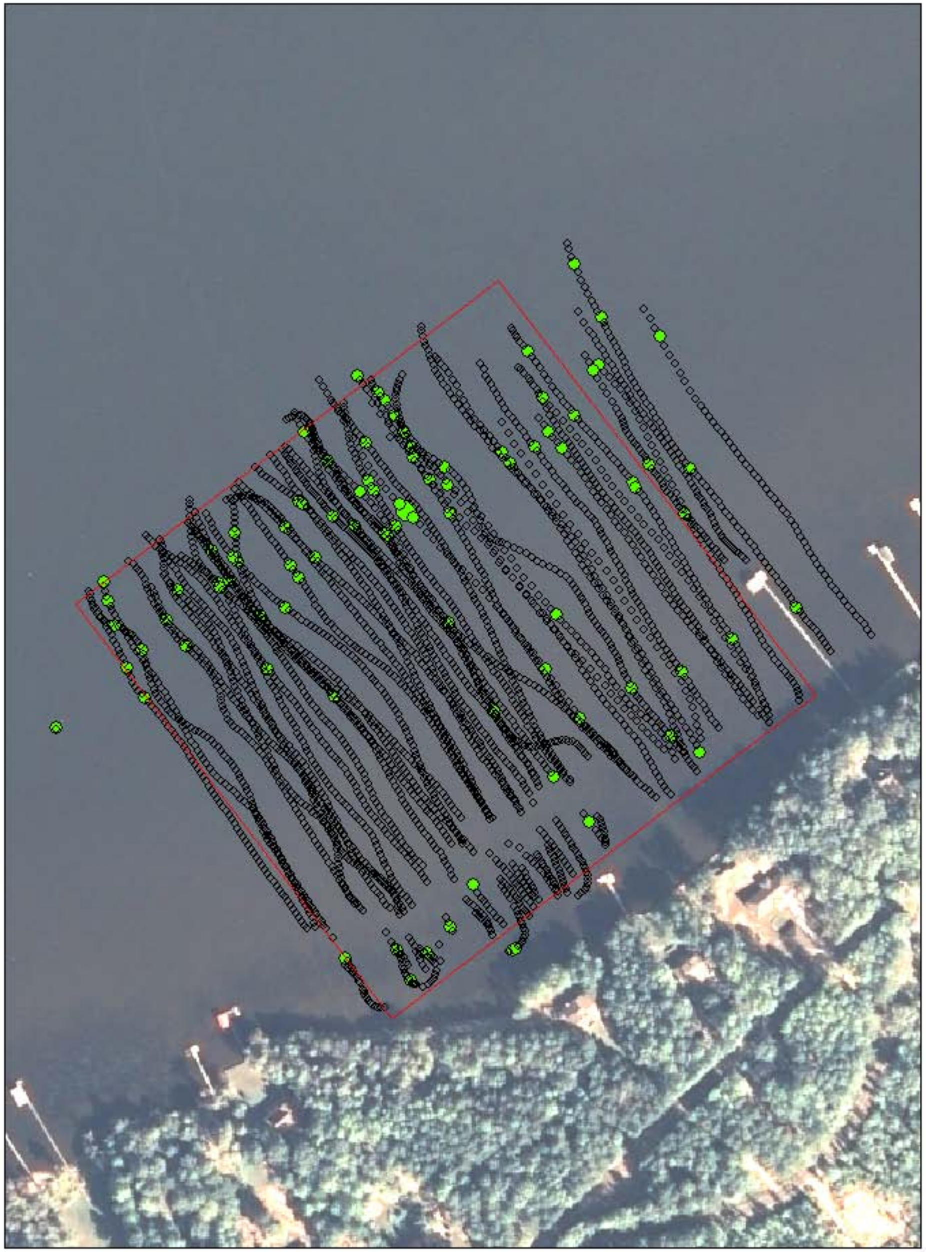
Pamlico River

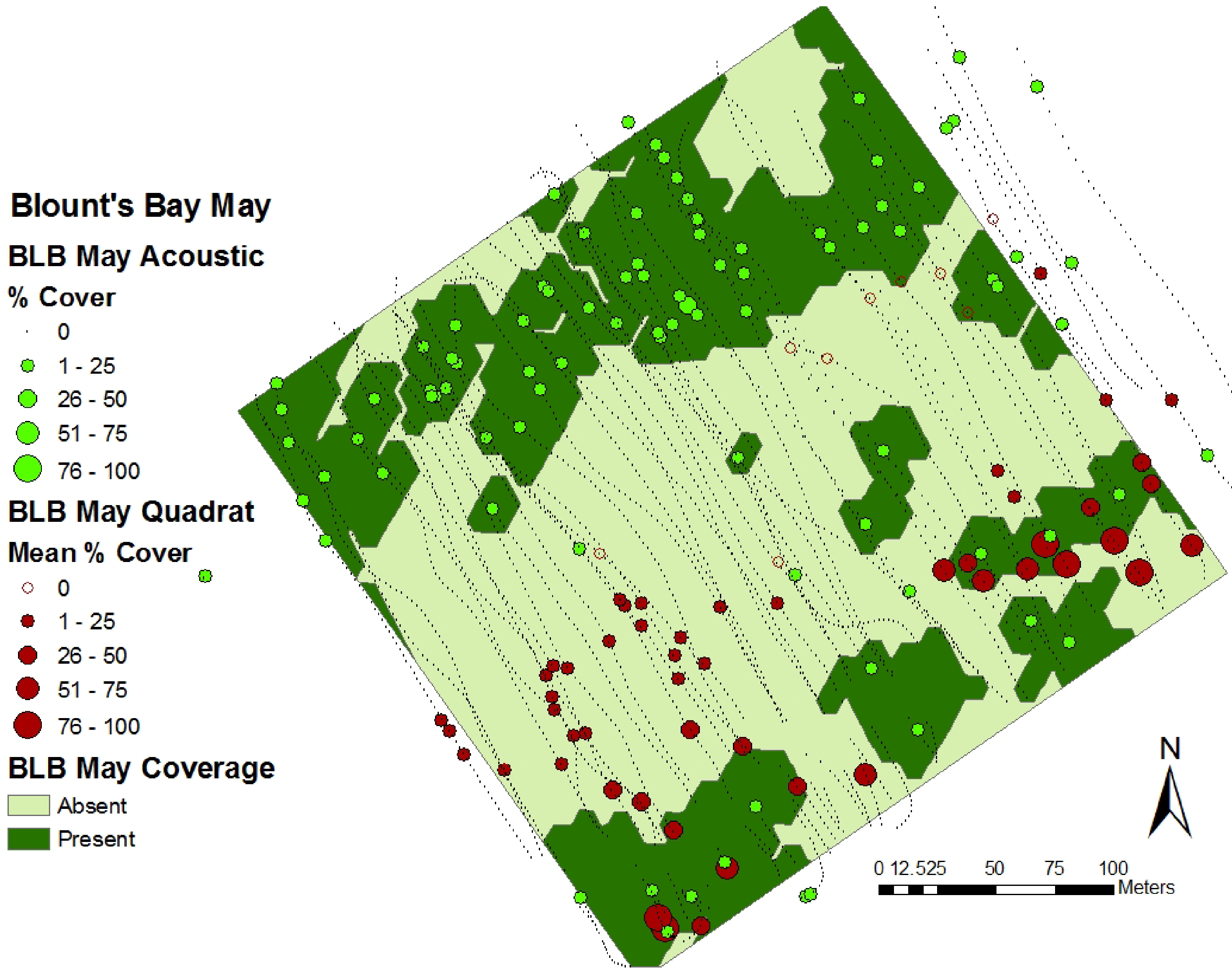
# BLOUNT’S BAY

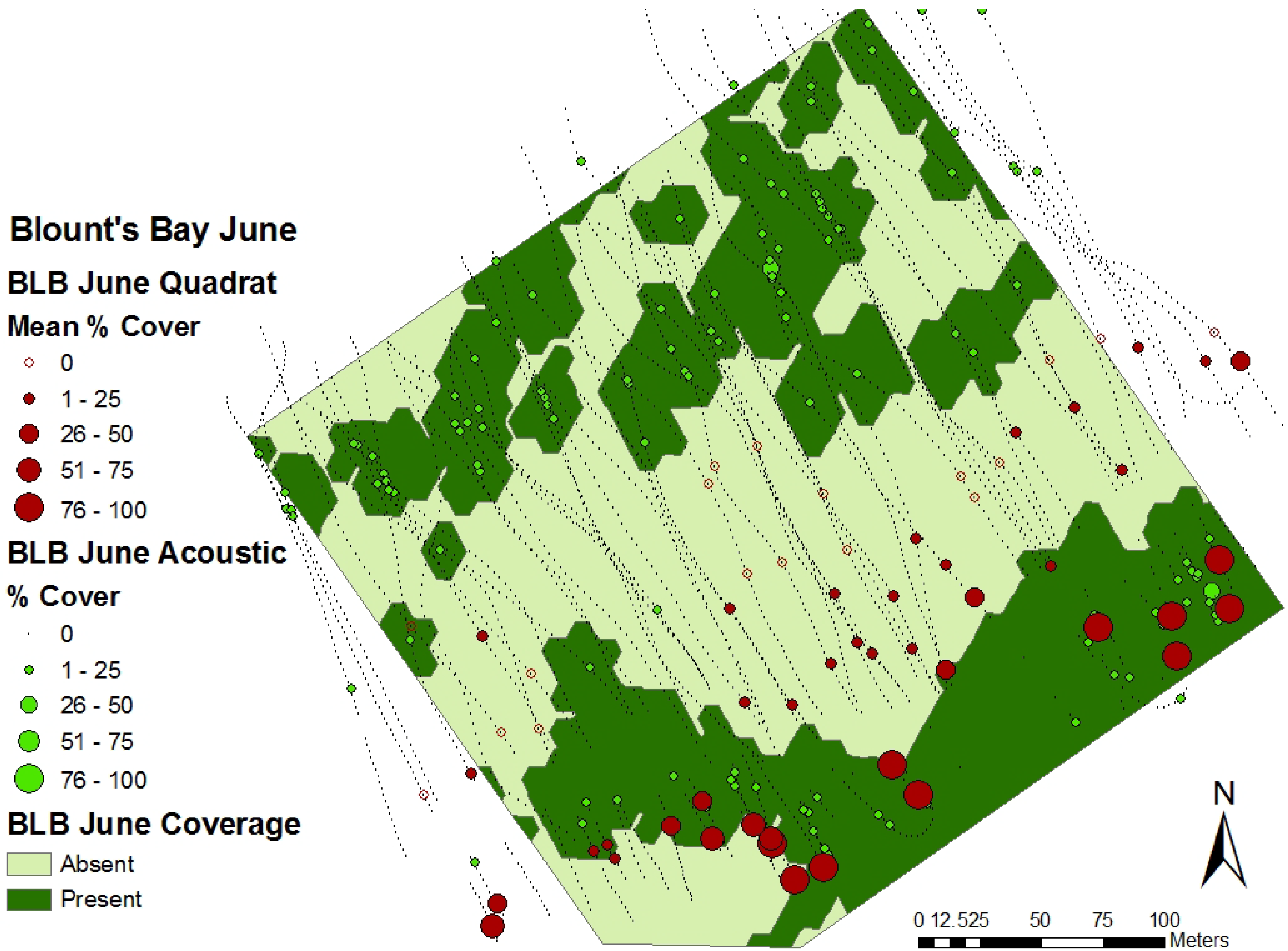


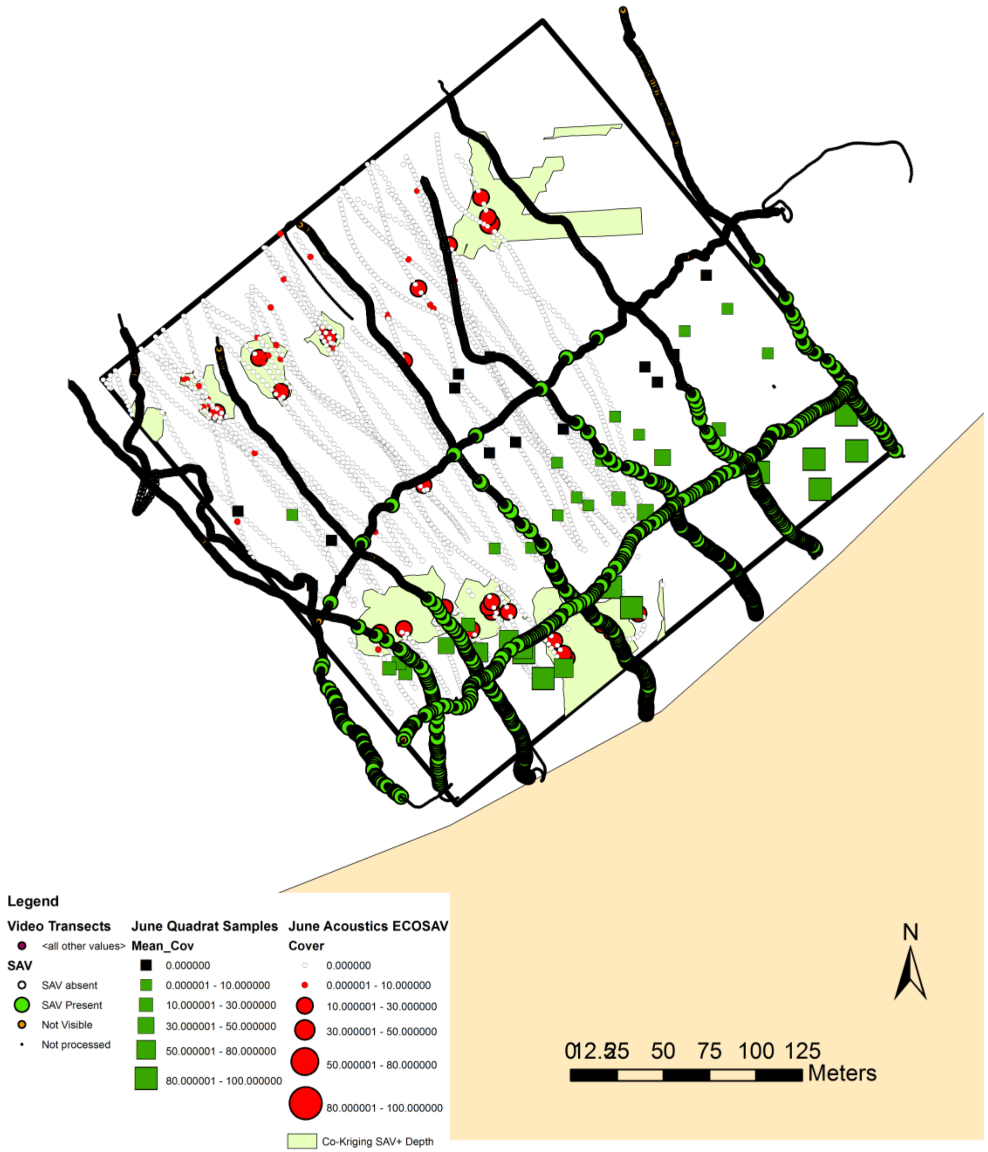



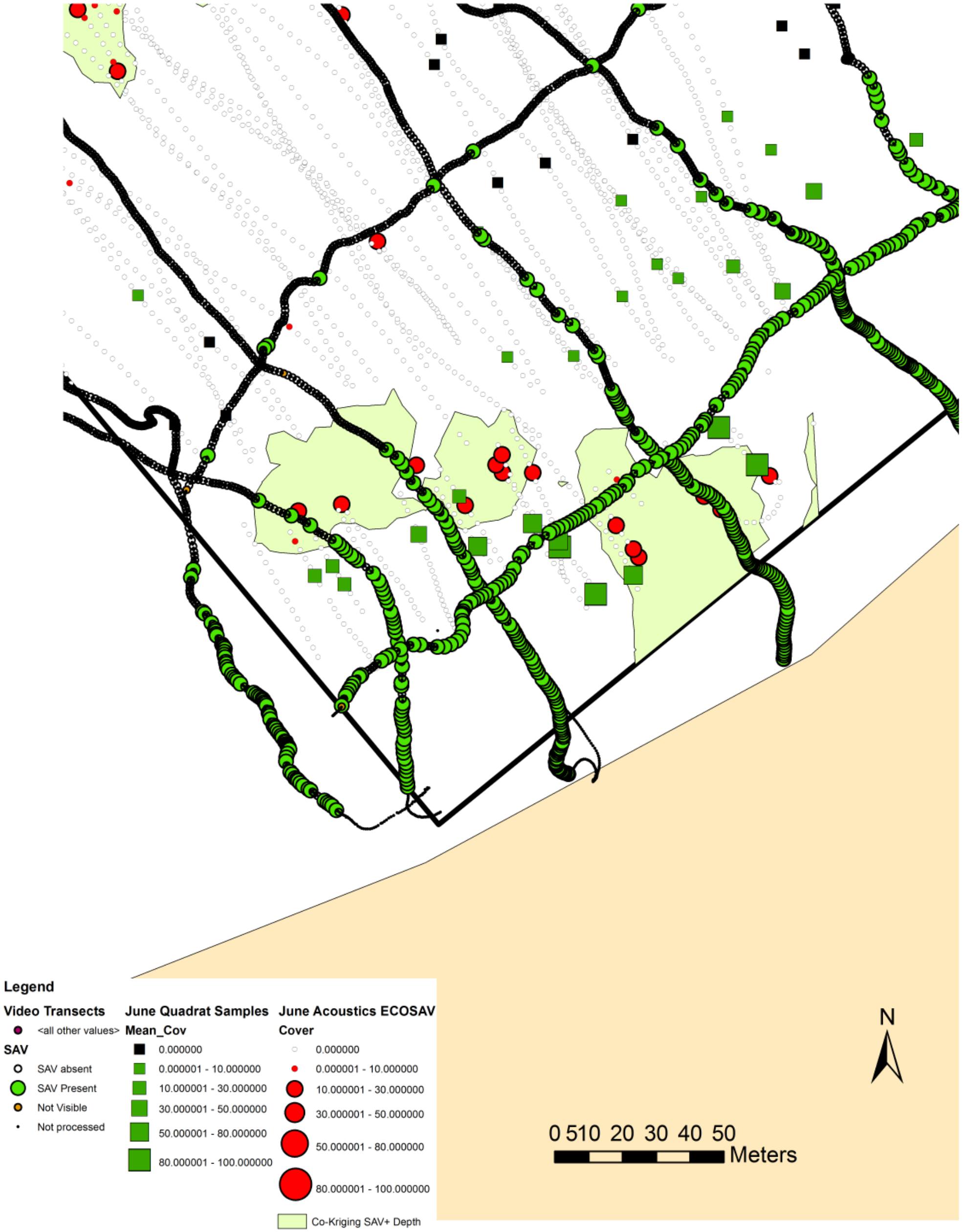



Blount's Bay May
BLB May Acoustic
% Cover
0
1 - 25
26 - 50
51 - 75
76 - 100
BLB May Quadrat
Mean % Cover
0
1 - 25
26 - 50
51 - 75
76 - 100
BLB May Coverage
Absent
Present
N
0 12.525 50 75 100
Meters



Blount's Bay June
BLB June Quadrat
Mean % Cover
0
1 - 25
26 - 50
51 - 75
76 - 100
BLB June Acoustic
% Cover
0
1 - 25
26 - 50
51 - 75
76 - 100
BLB June Coverage
Absent
Present
N
0 12.525 50 75 100
Meters

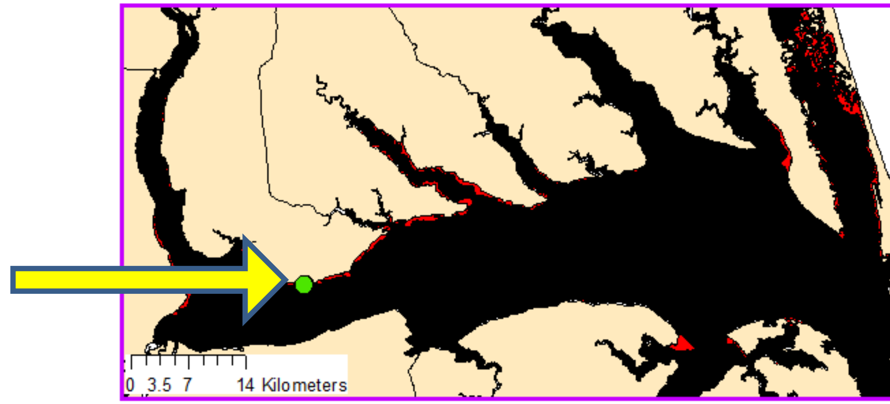

Legend
Video Transects
<all other values>
SAV
SAV absent
SAV Present
Not Visible
Not processed
June Quadrat Samples
Mean_Cov
0.000000
0.000001 - 10.000000
10.000001 - 30.000000
30.000001 - 50.000000
50.000001 - 80.000000
80.000001 - 100.000000
June Acoustics ECOSAV
Cover
0.000000
0.000001 - 10.000000
10.000001 - 30.000000
30.000001 - 50.000000
50.000001 - 80.000000
80.000001 - 100.000000
Co-Kriging SAV+ Depth
N
0 12.5 25 50 75 100 125
Meters

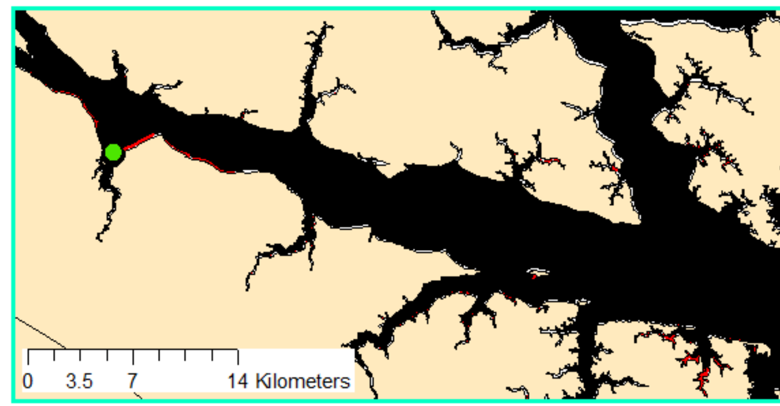


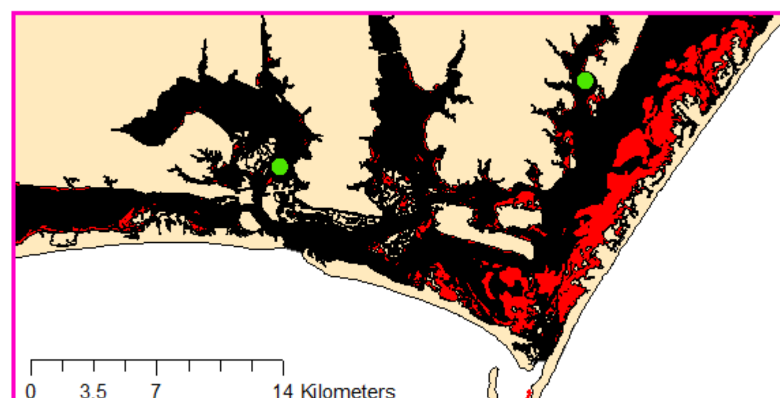
Legend
Video Transects
<all other values>
SAV
SAV absent
SAV Present
Not Visible
Not processed
June Quadrat Samples
Mean_Cov
0.000000
0.000001 - 10.000000
10.000001 - 30.000000
30.000001 - 50.000000
50.000001 - 80.000000
80.000001 - 100.000000
June Acoustics ECOSAV
Cover
0.000000
0.000001 - 10.000000
10.000001 - 30.000000
30.000001 - 50.000000
50.000001 - 80.000000
80.000001 - 100.000000
Co-Kriging SAV+ Depth
N
0 510 20 30 40 50
Meters

Albemarle Sound

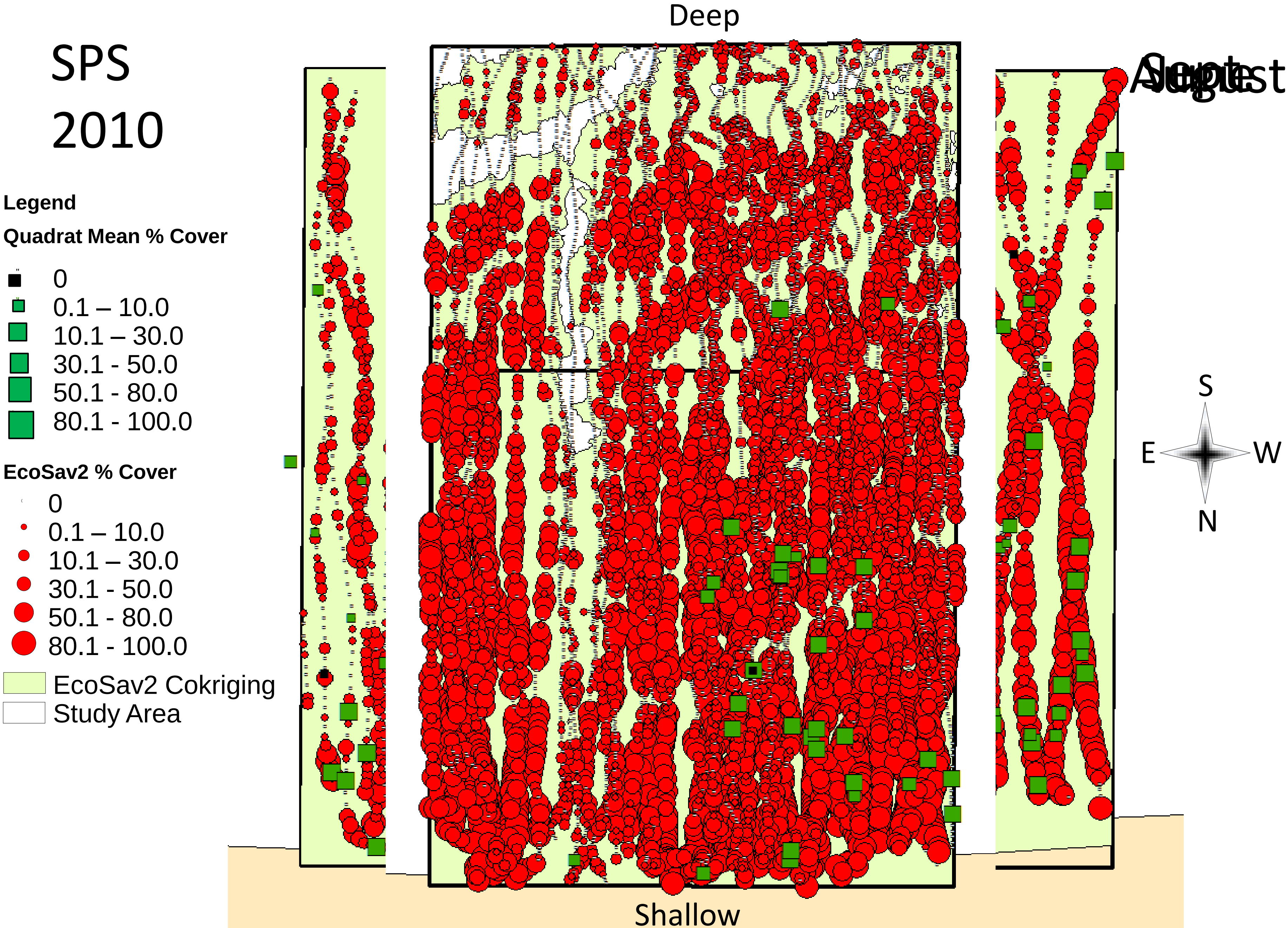
# SANDY POINT



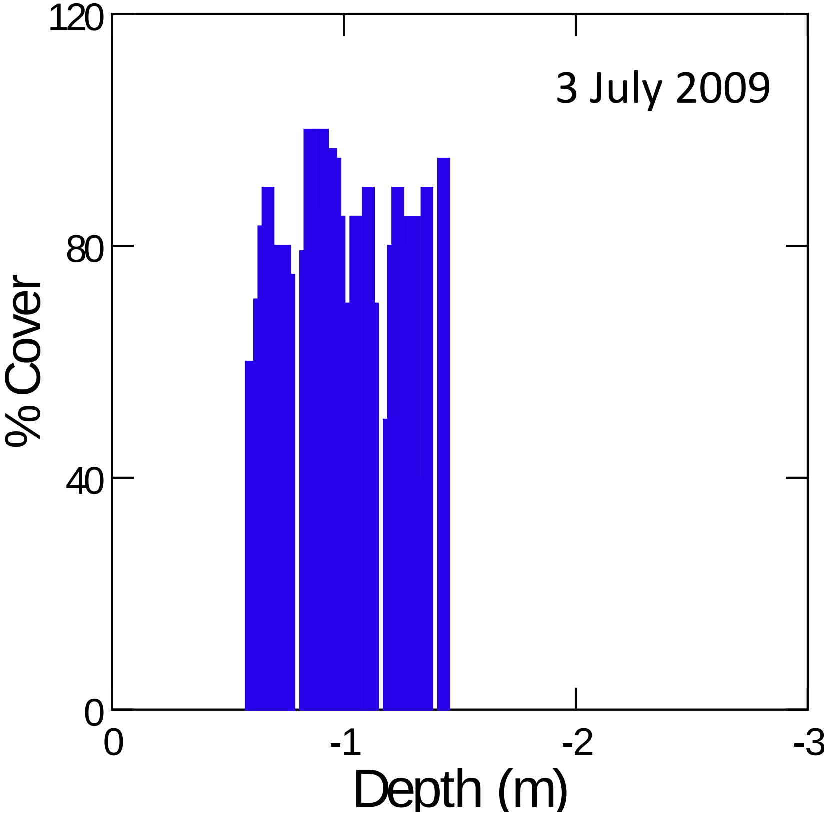



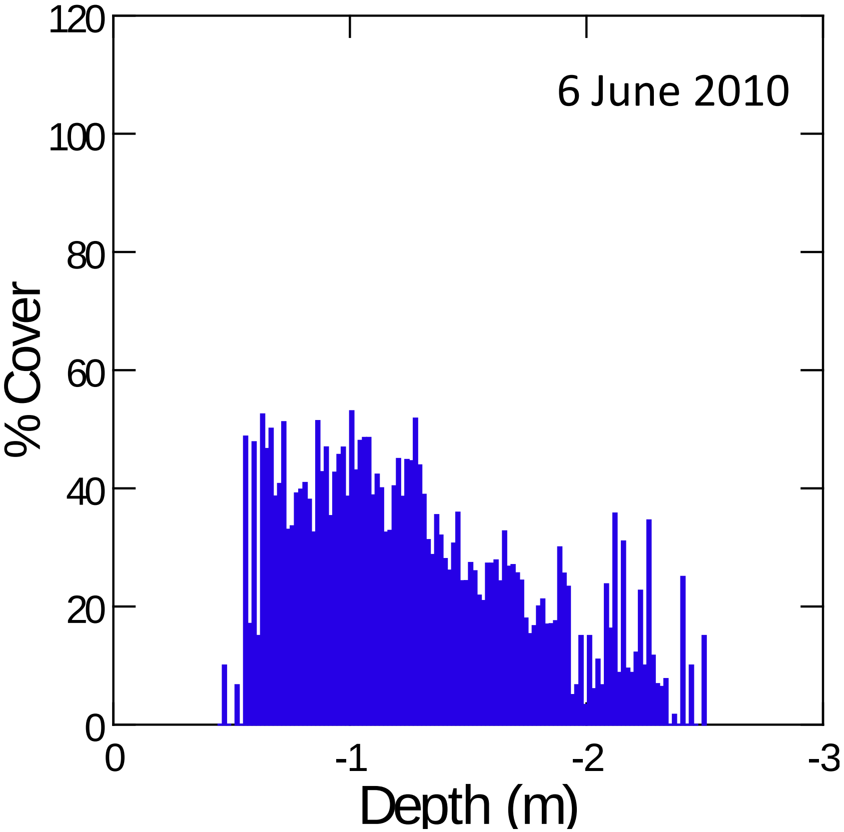
# SPS 2010



Deep
August
Sept.
Legend
Quadrat Mean % Cover
0
0.1 – 10.0
10.1 – 30.0
30.1 - 50.0
50.1 - 80.0
80.1 - 100.0
EcoSav2 % Cover
0
0.1 – 10.0
10.1 – 30.0
30.1 - 50.0
50.1 - 80.0
80.1 - 100.0
EcoSav2 Cokriging
Study Area
S
E
W
N
Shallow

# SPS Comparison 2009 and 2010



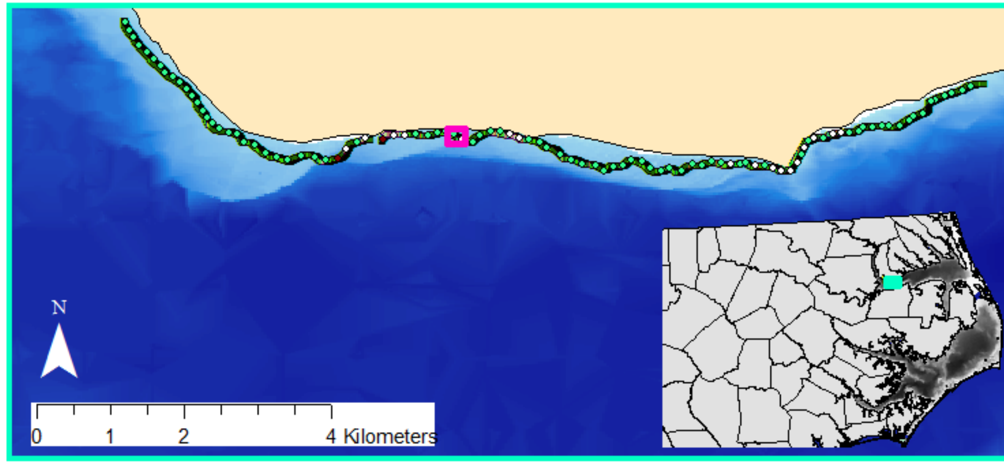



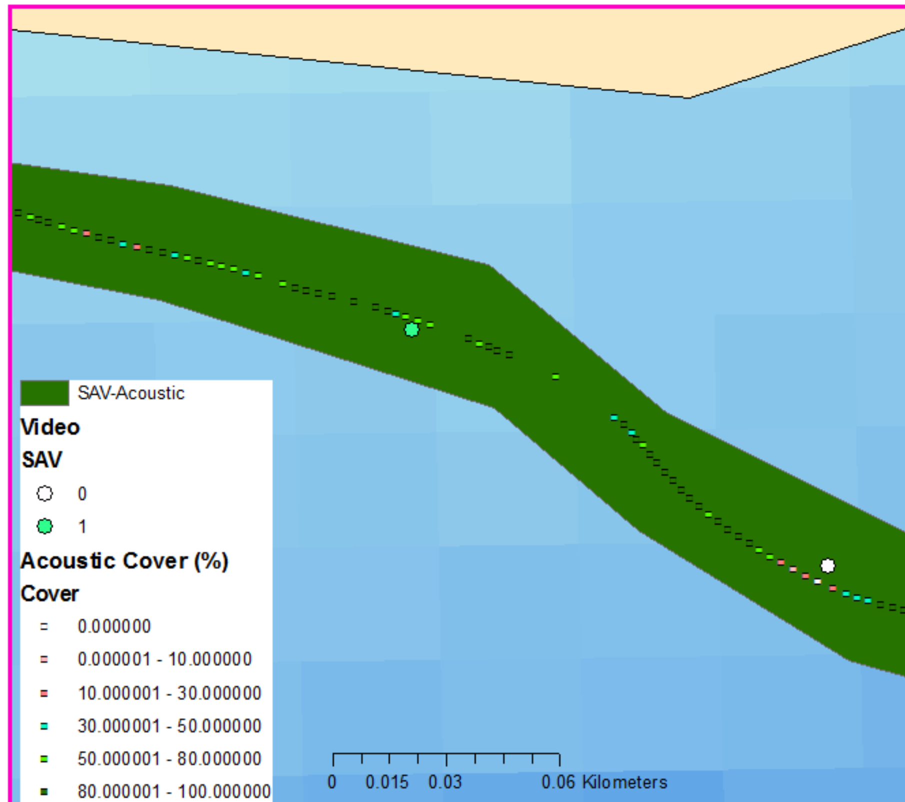
# Accuracy of SONAR

- 6 sites (Percent Accuracy)
  - 2 in the Albemarle Sound (82%, 98%)
  - 2 in the Pamlico River (78%, 98%)
  - 1 in the Bay River (96%)
  - 1 in the Neuse River (95%)

**Overall Accuracy**

| | SAV-Absent | SAV-Present |
|---|---|---|
| **SONAR** | 520 | 218 |
| **Video** | 574 | 164 |
| **Accuracy** | | 93% (684/738) |



# Discussion

- Tremendous seasonal and between-year variability
  - Will require high sampling effort to detect a 10% change, may be unrealistic
  - Up to 70% change within a year is natural
- All sites with current effort, to detect a change:
  - SONAR: 20% change in $F_{sav}$ ($\alpha$ = 0.05, power ≥ 0.8)
  - Video: 40% change in $F_{sav}$ ($\alpha$ = 0.05, power ≥ 0.8)
- May need to stratify sampling by bed-type: continuous vs. patchy
  - Continuous: we can detect a 10% change with our current sampling effort ($\alpha$ = 0.05, power = 0. 9)
  - Patchy: With current sampling effort, we can detect 20-40% change in $F_{sav}$ ($\alpha$ = 0.05, power ≥ 0.8)
- Video and SONAR methods show similar trends in $F_{sav}$
  - Differences in methods related to depth, SAV density, plant height
  - Sparse SAV not easily detected with SONAR
  - SONAR has plant height threshold (SAV ≥ 4 cm) limit
  - Video may under-sample tall plants (SPS area)

# SONAR Pros and Cons

- Cons of SONAR:
  - Water depth limit: > 0.8 m
  - SAV height limit: > 4 cm but does detect smaller
  - Can’t tell species of SAV
  - Bottom type: mud, algae may give false positives
- Pros:
  - Fast (90,000 $m^2$ area, set-up acquisition and analysis is do-able in 1 d/site, 30 transects/site)
  - Good for finding deep edge of SAV
  - Bathymetry is obtained simultaneously
  - Can estimate SAV change over a large area on a short (weeks/months) or long (years) time scale

# Video Pros and Cons

- Cons of Video:
  - Water depth limit: > 0.5 m
  - Turbidity is a problem is some areas
  - Acquisition and analysis takes a long time (~120 h/site (3 weeks), 30 transects/site)
  - Will limit sampling  to fewer transects/site
  - Presence/absence data
- Pros:
  - Good accuracy, larger estimates of SAV area
  - Species identification possible (algae vs. SAV)
  - Sensitive to sparse and small plants

# Final Protocol for SAV Monitoring

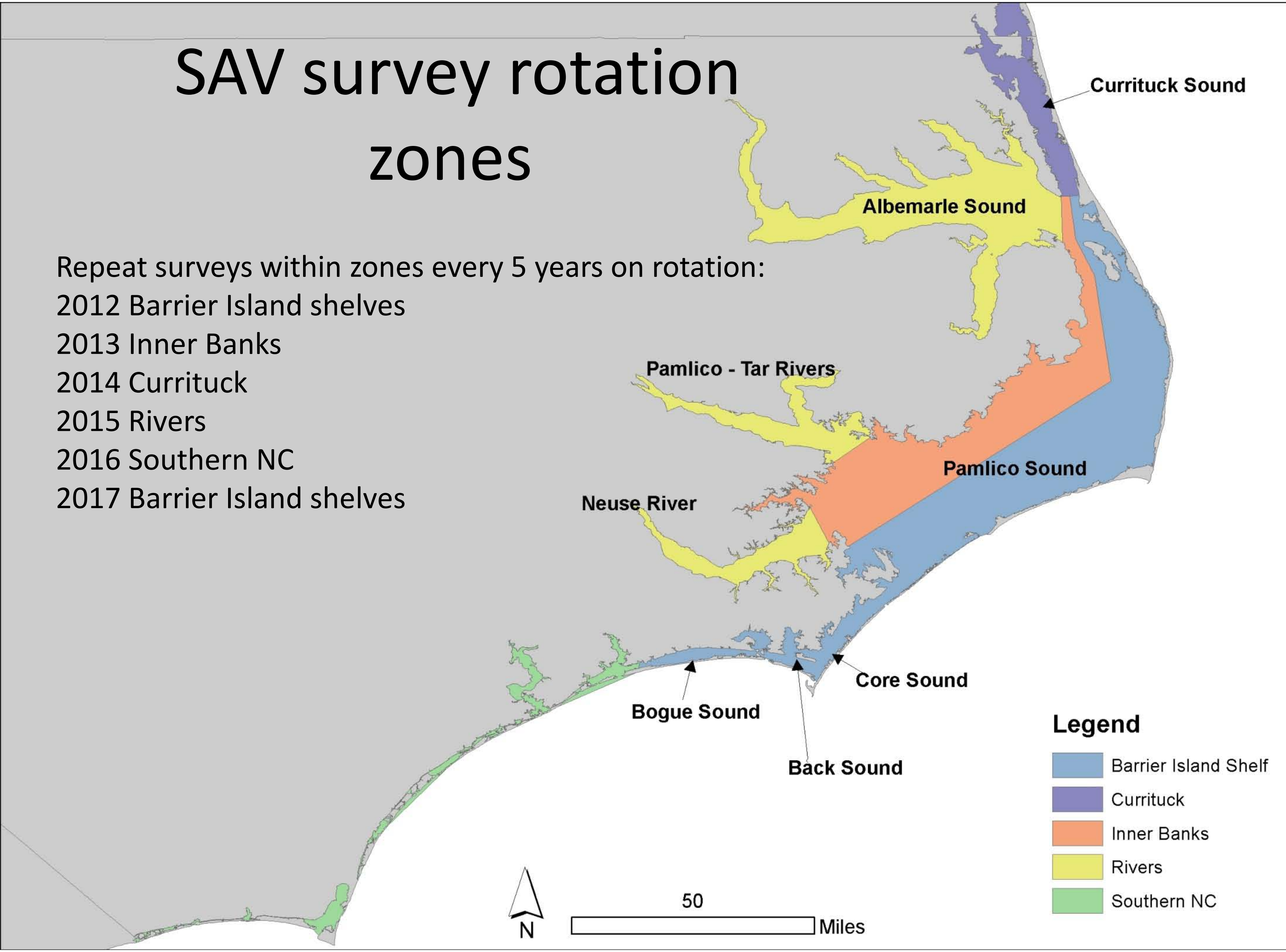
- **We suggest using multiple methods:**
  - Aerial digital imagery (DMC) is best for shallow (≤ 1m) water environments
    - Large area of coverage (whole NC coast)
    - Still problems with turbid areas, sun angle, and cloud cover
    - Will miss the “invisible grass” in rivers
  - SONAR and video together can be used to ground truth digital imagery at water depths ≥ 1 m at **sentinel sites**
    - Smaller total area, with 50 sites/region
    - Monitor in peak biomass season
    - May, June for high-salinity regions
    - Sep for low-salinity regions

# Stratify by Geographical Regions

- Five regions, with *X* sites/region
  - Barrier Islands (polyhaline 18-35 ppt)
  - Southern NC (polyhaline 18-35 ppt)
  - Rivers and sounds (oligohaline 0-10 ppt: Albemarle, Pamlico R., Neuse R.)
  - Currituck Sound (oligohaline 0-10 ppt)
  - Inner Banks (mesohaline 10-18 ppt)
- *X* will be determined from new power analysis based on site-to-site variation (shore-parallel transects).
- Randomly select *X* new 300 m x 300 m polygons from each strata every 5 years.
- OR select sentinel *X* sites within each region, visit once every 5 years

# SAV survey rotation zones

Repeat surveys within zones every 5 years on rotation:
2012 Barrier Island shelves
2013 Inner Banks
2014 Currituck
2015 Rivers
2016 Southern NC
2017 Barrier Island shelves



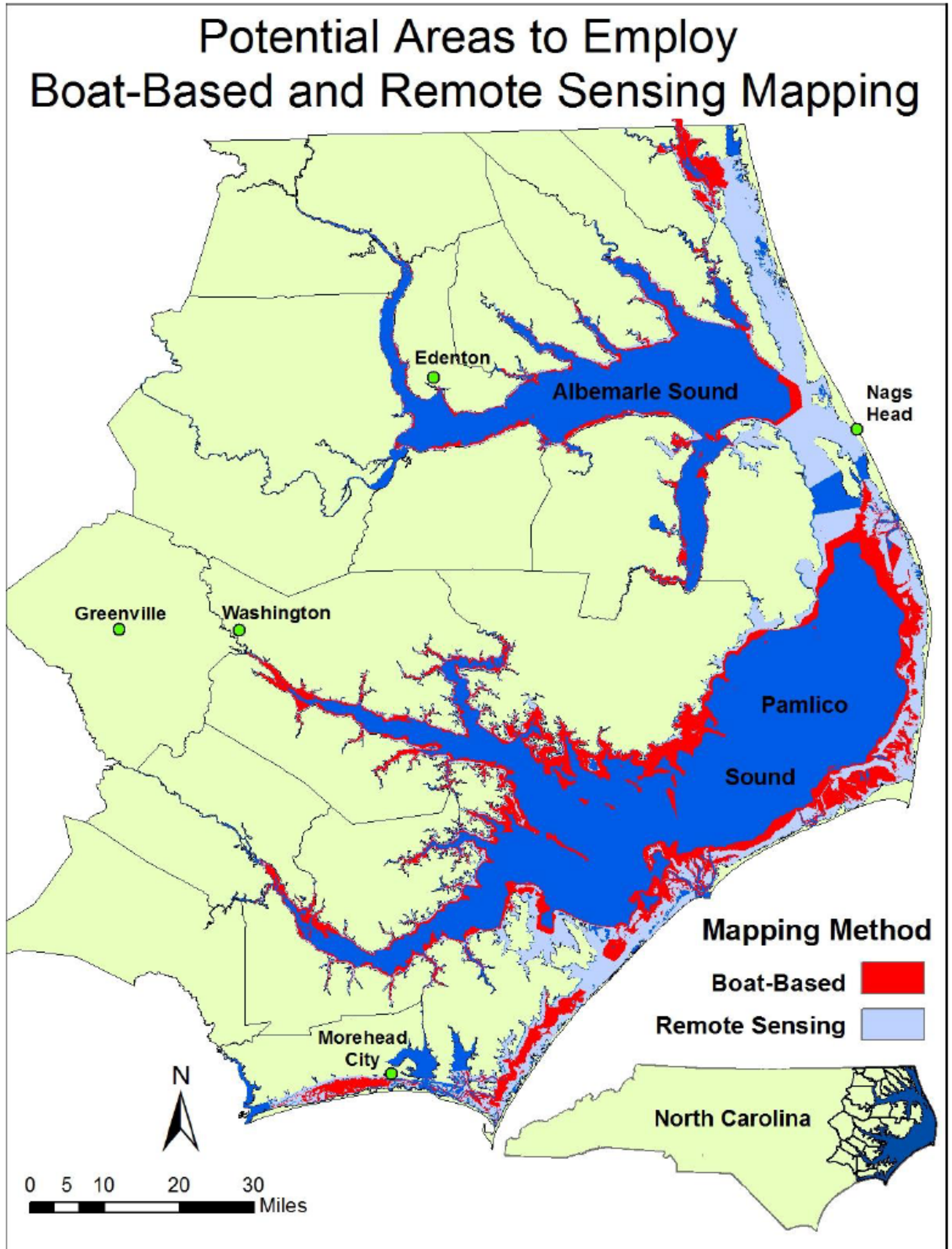
# Make new GIS Map for site selection

- Depths < 0.8m is do-able by optical remote sensing (either World-View 2 or DMC)
- Depths > 0.8 m must be visited by boat and video or acoustic survey done, with diver quadrat surveys
- Video transects with 10 shore-normal transects/300 m (30 m spacing)
- Sonar transects with 30 transects/300 m (10 m spacing)

This map is based on
Rich Curran's thesis
Figure 13
Boat-based
Min = 0.8 m
Max = 2.0 m

Remote sensing had
High accuracy  < 0.8 m
(90% accuracy)

Boats can't easily work in
< 0.8 m (true for video and
acoustic methods)



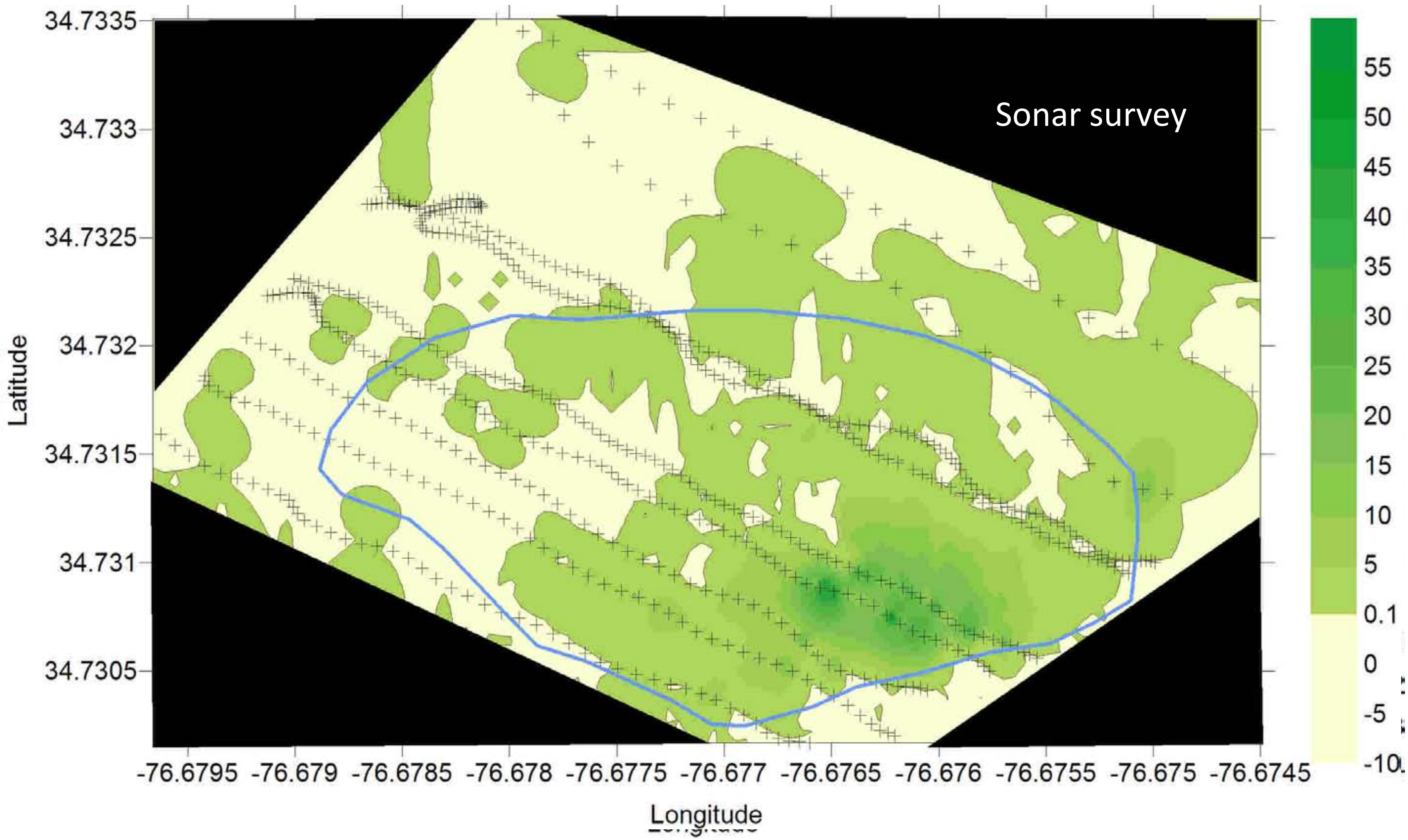
# Cost estimates

- Aerial photography costs:
  - Digital Mapping Camera of entire NC coast: ~$250,000 (every 5 years)
  - Photo interpretation: ~$90,000 (every 5 years)
  - Total: ~$340,000 (~$68,000 per year)
- Cost Per site (set up, acquisition, analysis):
  - Video: $1500, if *X* = 50 sites/region, ~$75,000
  - SONAR: $500, if *X* = 50 sites/region, ~$25,000
- **$168,000 per year (Aerial + Boat-based)**

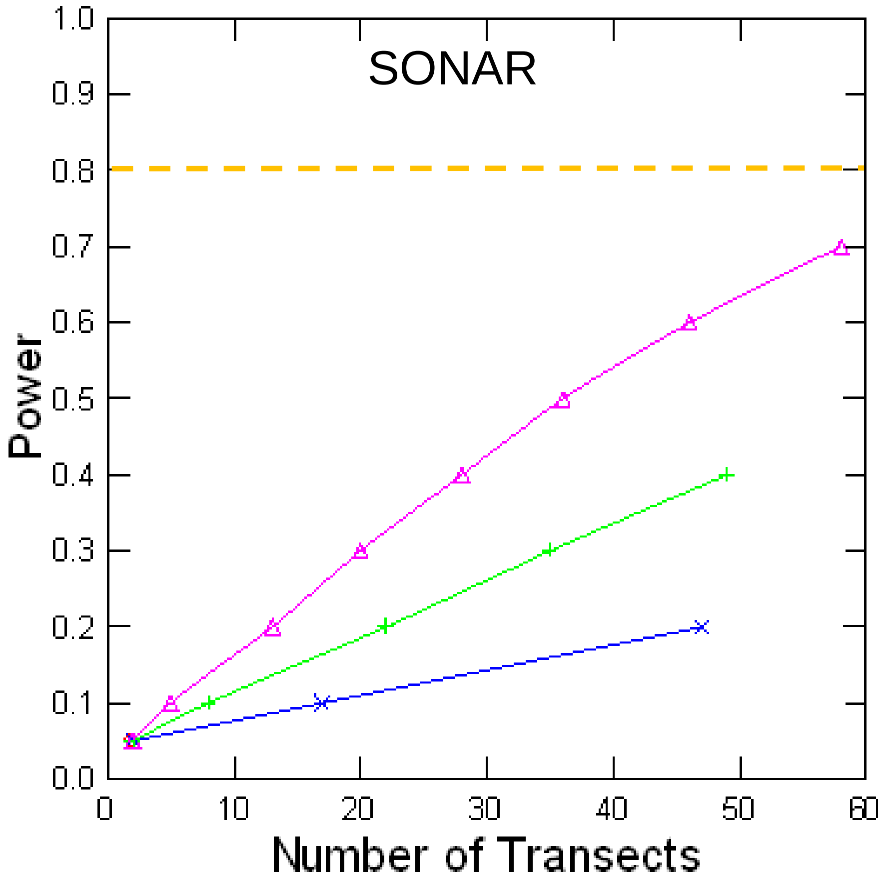
# Thank You!

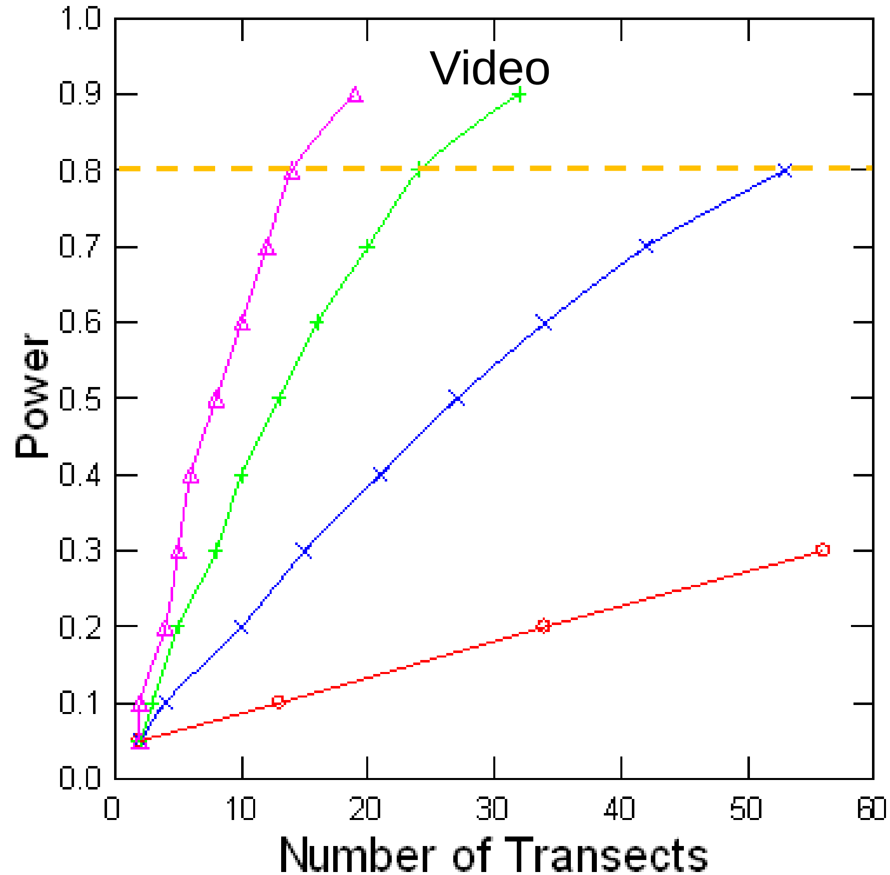
Allison Ballance
Lyndell Bade
Jill Paxson
Casey Smith
Becky Deehr
Devon Eulie
Kay Evans
David Knowles
Greg Meyer
Katherine Spears

# NPR Shore-Parallel June 2009



# High Salinity (Patchy) - June NPR 2009




**SONAR**

Change in $F_{sav}$

Mean $F_{sav}$ = 19.8

- ○ 10% $F_{sav}$ = 17.8
- × 20% $F_{sav}$ = 15.8
- + 30% $F_{sav}$ = 13.9
- △ 40% $F_{sav}$ = 11.9

α = 0.05

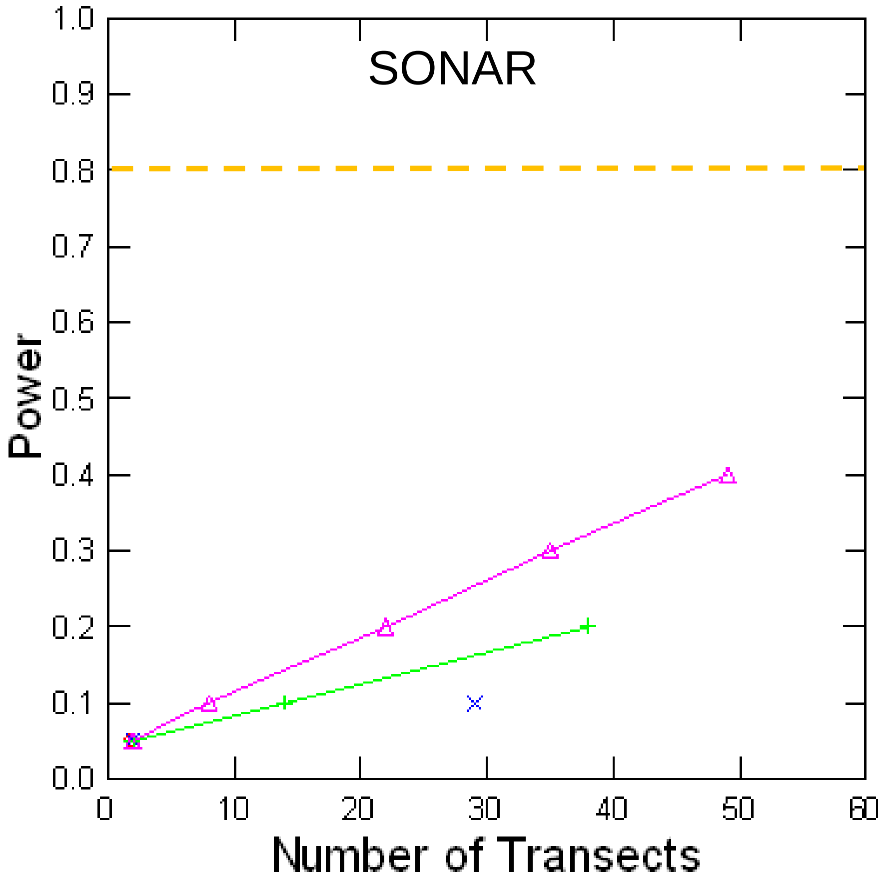
**Video**

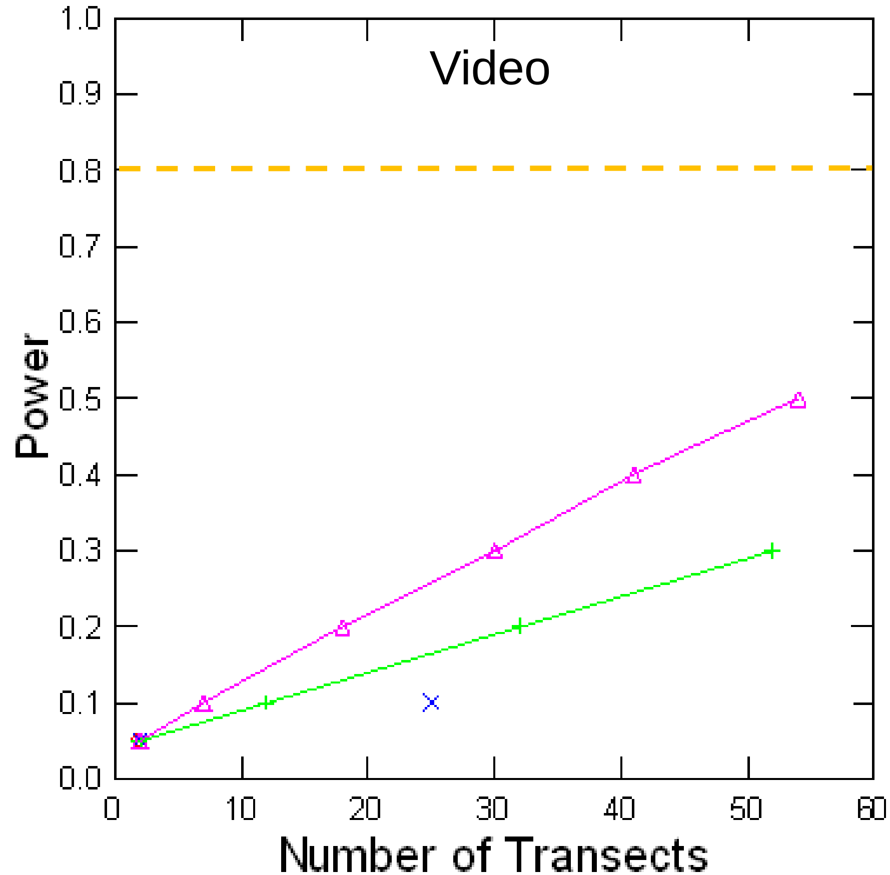
Change in $F_{sav}$

Mean $F_{sav}$ = 48.2

- ○ 10% $F_{sav}$ = 43.4
- × 20% $F_{sav}$ = 38.6
- + 30% $F_{sav}$ = 33.7
- △ 40% $F_{sav}$ = 28.9

# High Salinity (Patchy) - July JBS 2010




Change in $F_{sav}$

Mean $F_{sav}$ = 3.4

- ○ 10% $F_{sav}$ = 3.1
- × 20% $F_{sav}$ = 2.7
- + 30% $F_{sav}$ = 2.4
- △ 40% $F_{sav}$ = 2.0

Change in $F_{sav}$

Mean $F_{sav}$ = 6.3

- ○ 10% $F_{sav}$ = 5.7
- × 20% $F_{sav}$ = 5.0
- + 30% $F_{sav}$ = 4.4
- △ 40% $F_{sav}$ = 3.8

α = 0.05

# JBS Accuracy Assessment

## Confusion Matrix

| | | Predicted | | |
|---|---|---|---|---|
| | Classification | Present | Absent | Row Total |
| Actual | Present | 15 | 11 | 26 |
| | Absent | 3 | 60 | 63 |
| | Column Total | 18 | 71 | 89 |

## Overall Accuracy: 84%

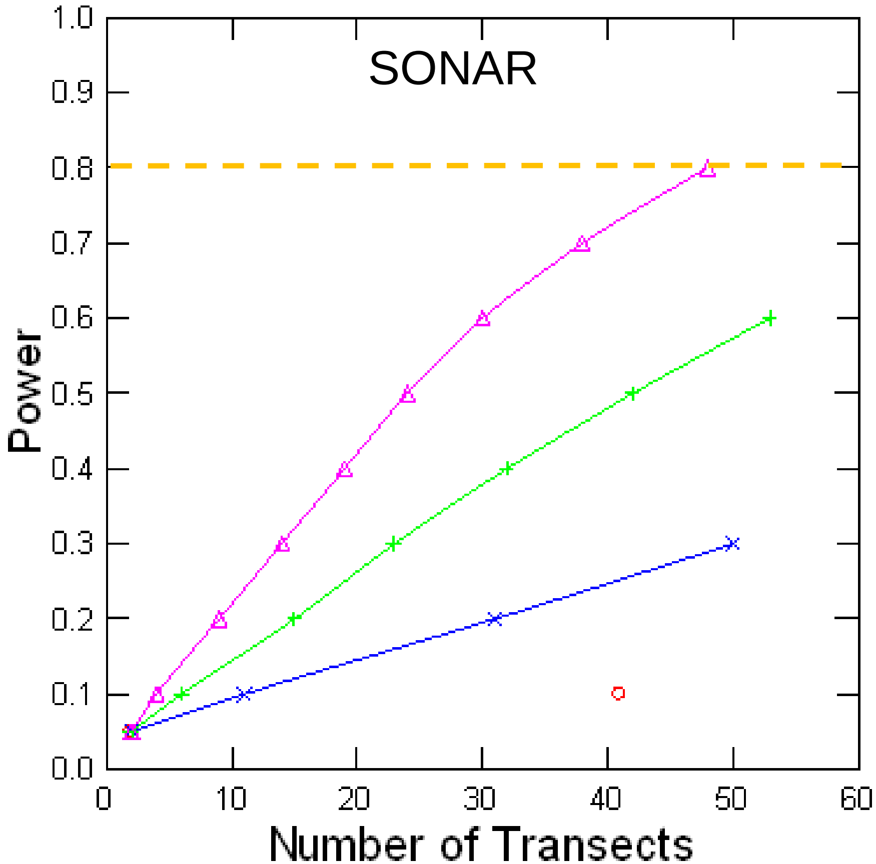
| Producer's accuracy and omission error | User's accuracy and commission error |
|---|---|
| **Present (accuracy) = 83%**<br>**17% omission error** | **Present (accuracy) = 58%**<br>**42% commission error** |
| **Absent (accuracy) = 85%**<br>**15% omission error** | **Absent (accuracy) = 95%**<br>**5% commission error** |

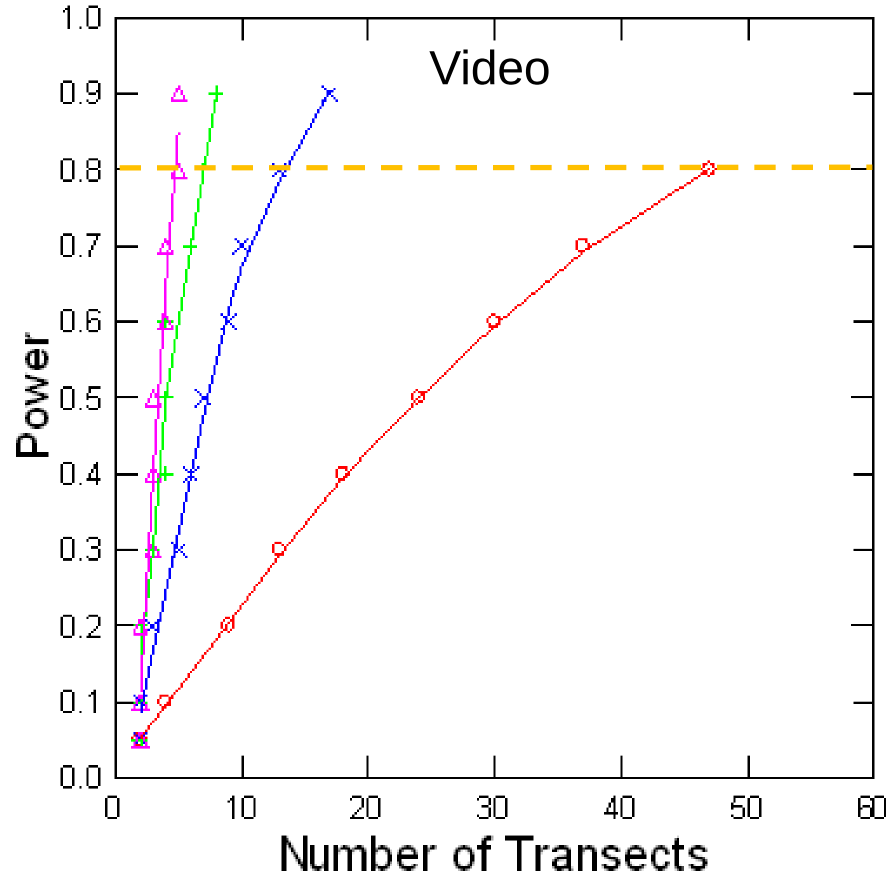
K hat Coefficient of Agreement: 28%

# JBS Comparison

- Acoustic September
  - Area Cover: 4,752 sq. m
  - % Cover: 5.3%
  - % Change: 76.3% decrease
- Satellite RS Classification September
  - Area Cover: 17,577 sq. m
  - % Cover: 19.5%
  - % Change: 12.4% decrease

# Low Salinity (Patchy) - June BLB 2010




Change in $F_{sav}$

Mean $F_{sav}$ = 3.2

○ 10% $F_{sav}$ = 2.9
× 20% $F_{sav}$ = 2.6
+ 30% $F_{sav}$ = 2.2
△ 40% $F_{sav}$ = 1.9

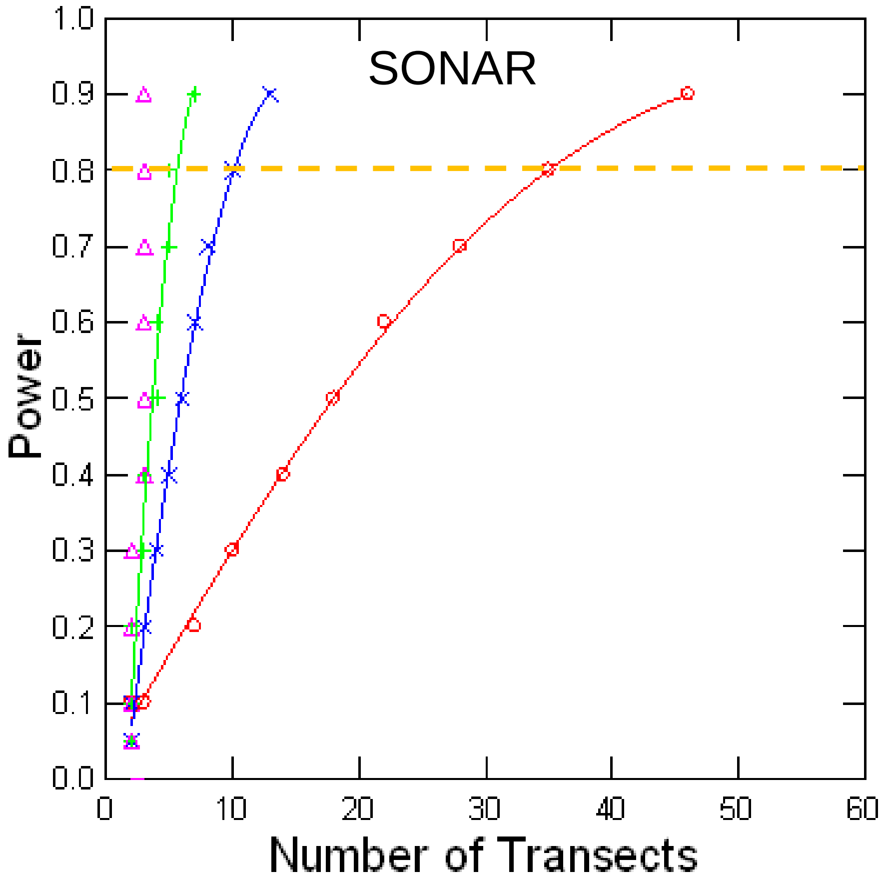
α = 0.05

Change in $F_{sav}$

Mean $F_{sav}$ = 22.9

○ 10% $F_{sav}$ = 20.6
× 20% $F_{sav}$ = 18.3
+ 30% $F_{sav}$ = 16.0
△ 40% $F_{sav}$ = 13.7

# Low Salinity (Continuous) - August SPS 2010

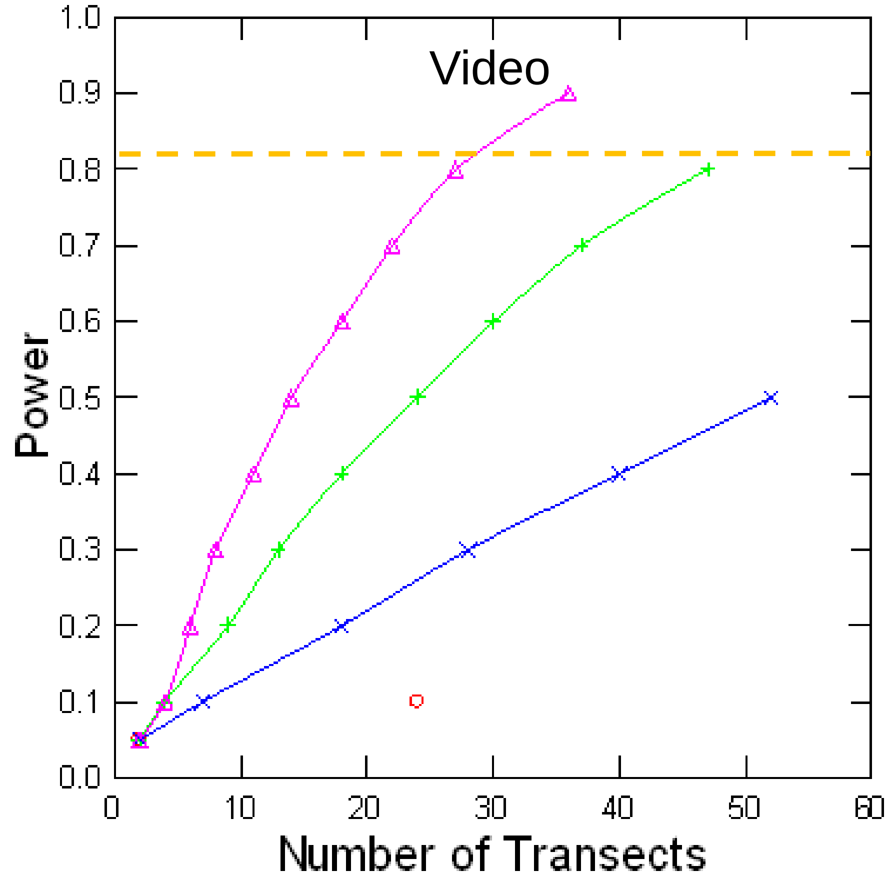



Change in $F_{sav}$

Mean $F_{sav}$ = 81.1

- 10% $F_{sav}$ = 73.0
- 20% $F_{sav}$ = 64.9
- 30% $F_{sav}$ = 56.8
- 40% $F_{sav}$ = 48.7

α = 0.05




Change in $F_{sav}$

Mean $F_{sav}$ = 64.6

- 10% $F_{sav}$ = 58.1
- 20% $F_{sav}$ = 51.7
- 30% $F_{sav}$ = 45.2
- 40% $F_{sav}$ = 38.8