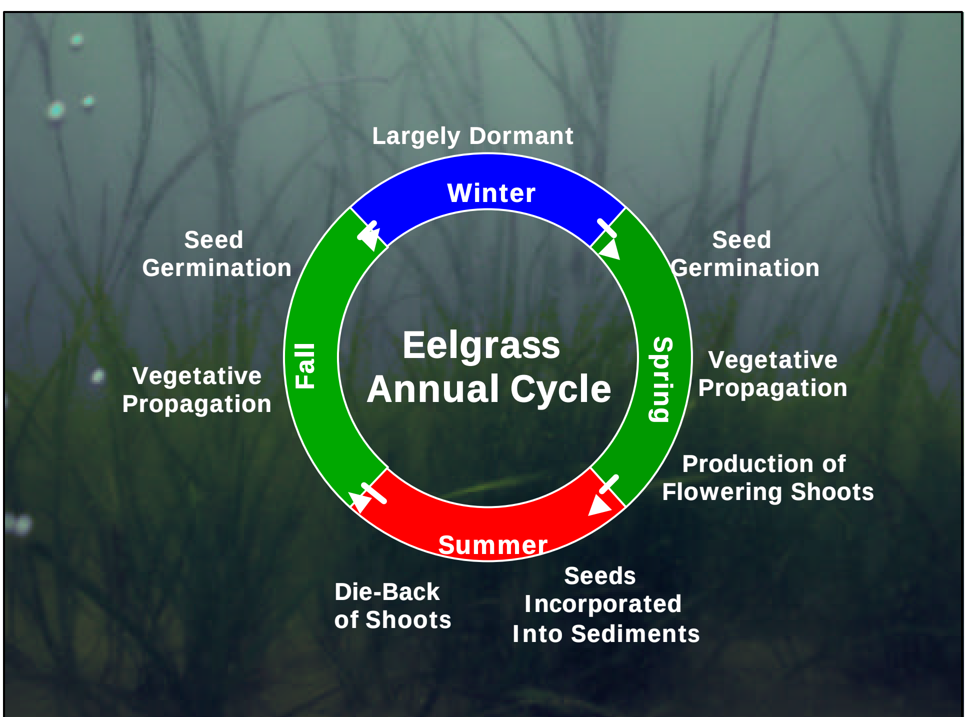

CULTURE OF EELGRASS
(ZOSTERA MARINA)
FOR RESTORATION PROJECTS
Christopher Tanner
St. Mary's College of Maryland

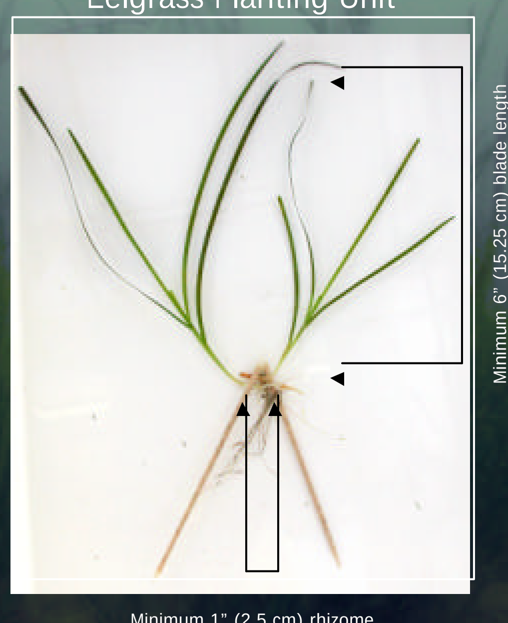

Largely Dormant
Winter
Seed Germination
Seed Germination
Fall
Spring
Eelgrass Annual Cycle
Vegetative Propagation
Vegetative Propagation
Production of Flowering Shoots
Summer
Die-Back of Shoots
Seeds Incorporated Into Sediments

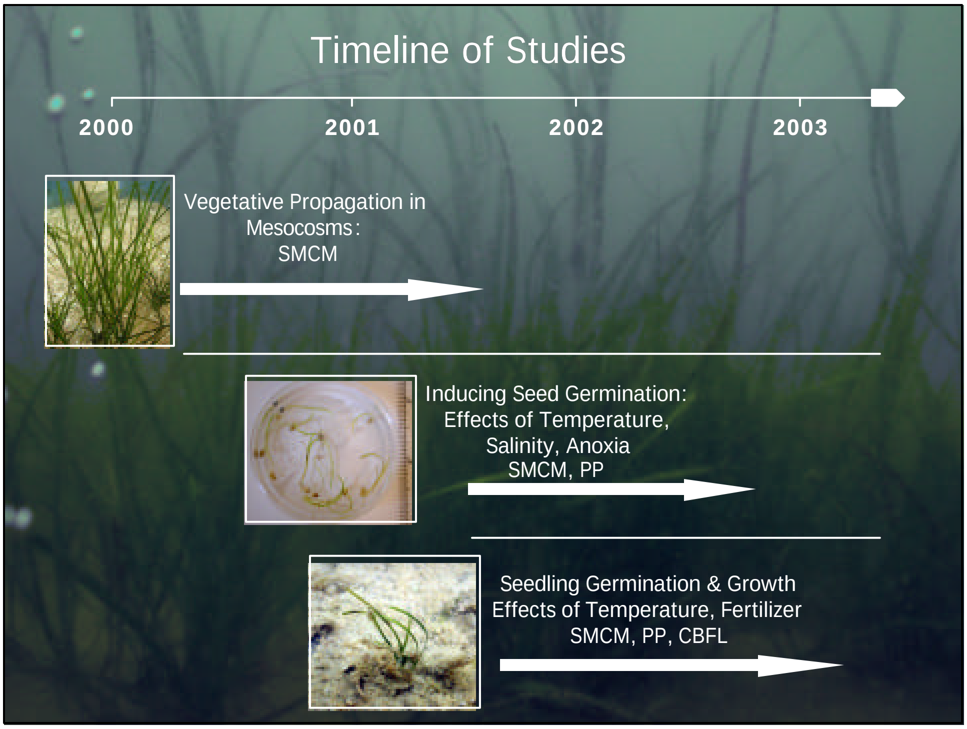
Research Goals

To develop methods for land-based propagation of eelgrass

- Investigate eelgrass vegetative propagation under culture conditions
- Determine whether eelgrass seeds can be induced to germinate early and seedlings grown to size for outplanting

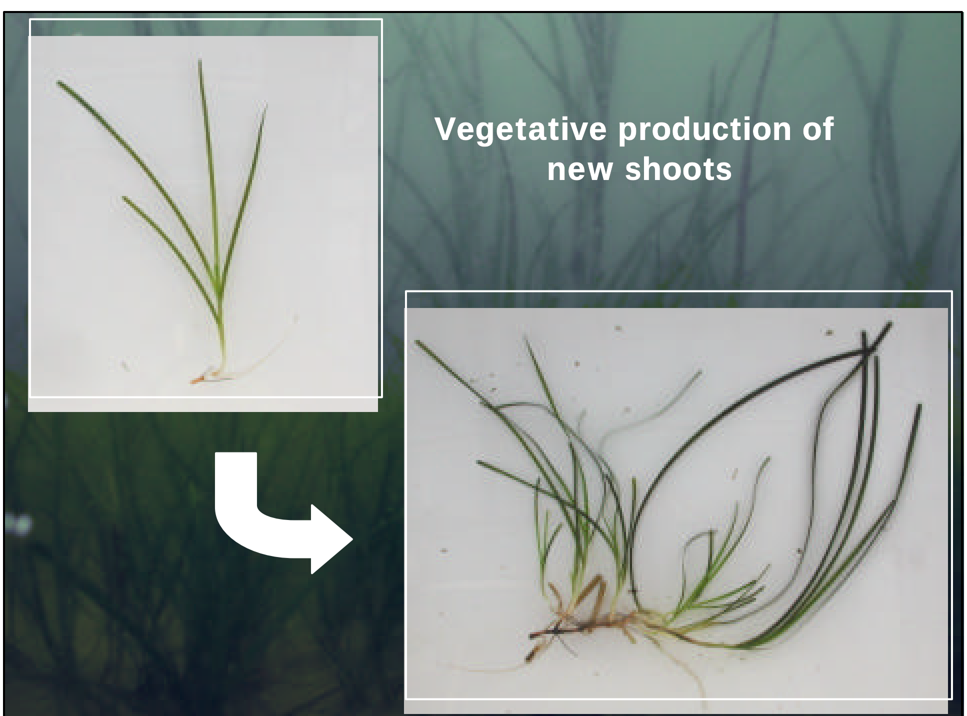
Eelgrass Planting Unit

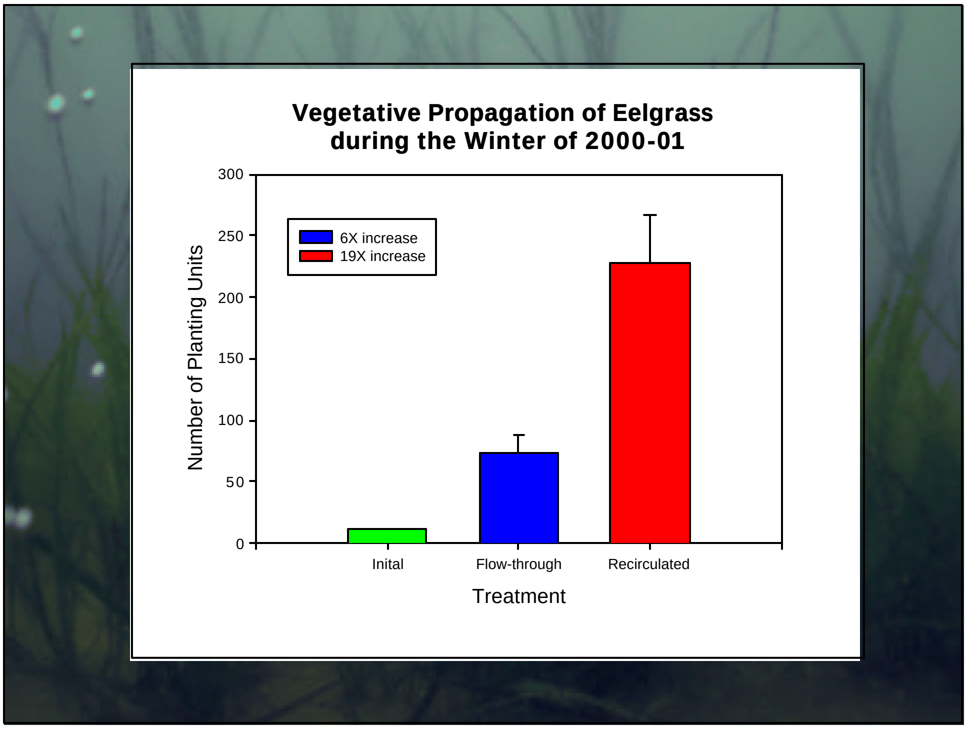



Timeline of Studies
2000
2001
2002
2003
Vegetative Propagation in Mesocosms: SMCM
Inducing Seed Germination: Effects of Temperature, Salinity, Anoxia
SMCM, PP
Seedling Germination & Growth
Effects of Temperature, Fertilizer
SMCM, PP, CBFL

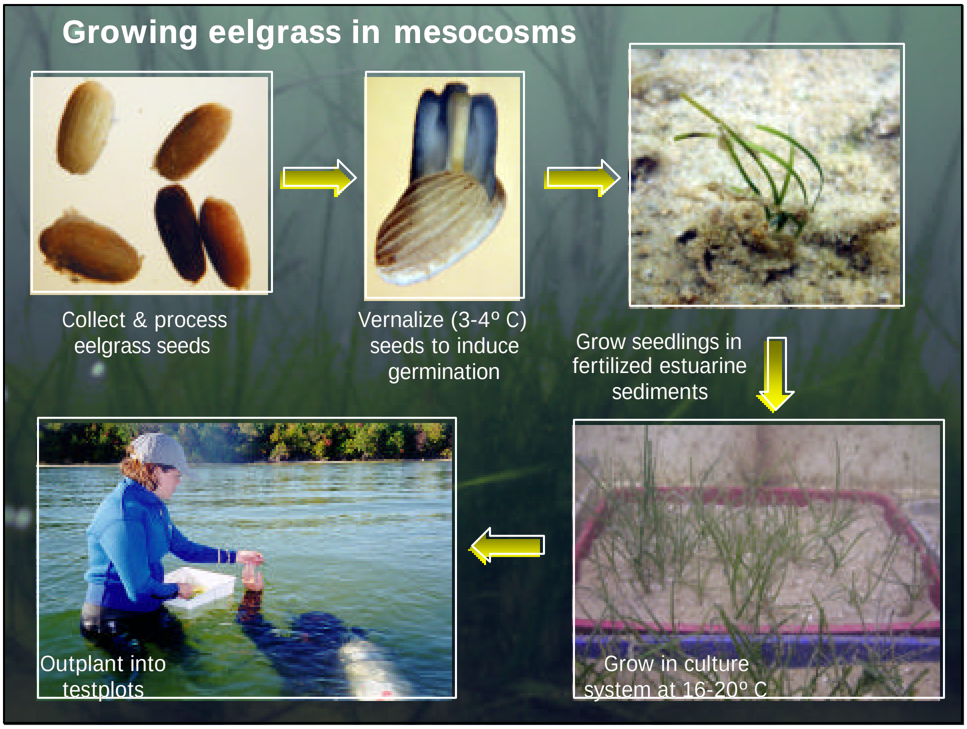

Mesocosms in the St. Mary's College Greenhouse
Mesocosms at the Piney Point Aquaculture Facility
2002


Mesocosms at the Chesapeake Bay Field Laboratory 2002
Mesocosms at the Piney Point Aquaculture Facility 2003


Vegetative production of new shoots


Vegetative Propagation of Eelgrass
during the Winter of 2000-01
6X increase
19X increase
Number of Planting Units
300
250
200
150
100
50
0
Inital
Flow-through
Recirculated
Treatment


Seedling grown under
ambient conditions
Seedling grown under
controlled conditions



Seed Germination Experiment

Soil-free culture held at 14° C (SMCM; July-September, 2001)

Treatment	% Germination	% Seedling Survival	Days to Germination
14-16 ppt	43	20	7-13
Sterilized, 14-16 ppt	27	20	13-27
Scarified, 14-16 ppt	60	27	10-27
Hypoxic, 14-16 ppt	100	100	?-29*
0 ppt	93	50	3-27
5 ppt	87	47	3-27
10 ppt	33	20	10-27
15 ppt	40	13	10-28
20 ppt	7	0	28-29
25 ppt	7	0	27

*Initial germination of scarified seeds was not observed

Seed Germination and Seedling Growth Experiment

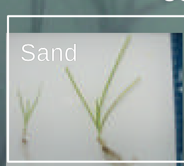
Planted in peat pots with natural sediments and placed in mesocosms with flow-through ambient estuarine water (SMCM, Fall 2001). Results 127 days after planting.

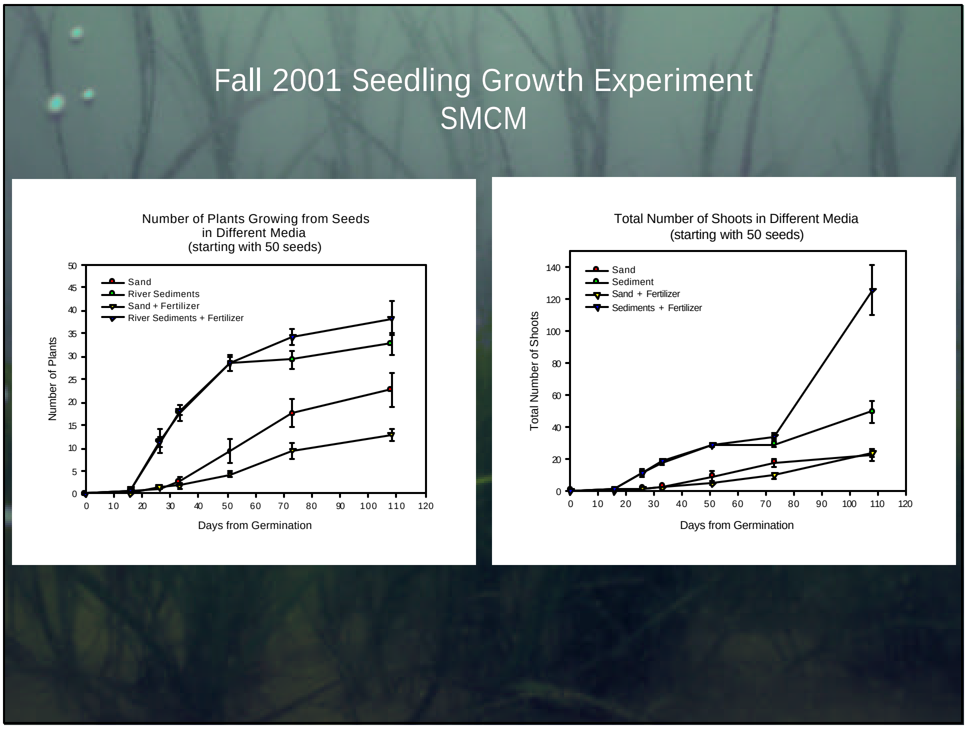
Storage Conditions	% Pots with Seedlings*	% Survival**	Maximum Shoot Height (cm)
4º C	90.3 ± 5.4	61.1 ± 6.6	22.6 ± 1.6
14º C	59.7 ± 4.0	25.0 ± 2.6	22.9 ± 1.1
Ambient Temp	33.5 ± 5.7	10.9 ± 2.1	16.9 ± 1.6
Seedlings	47.2 ± 11.5	59.7 ± 18.7	20.9 ± 3.5

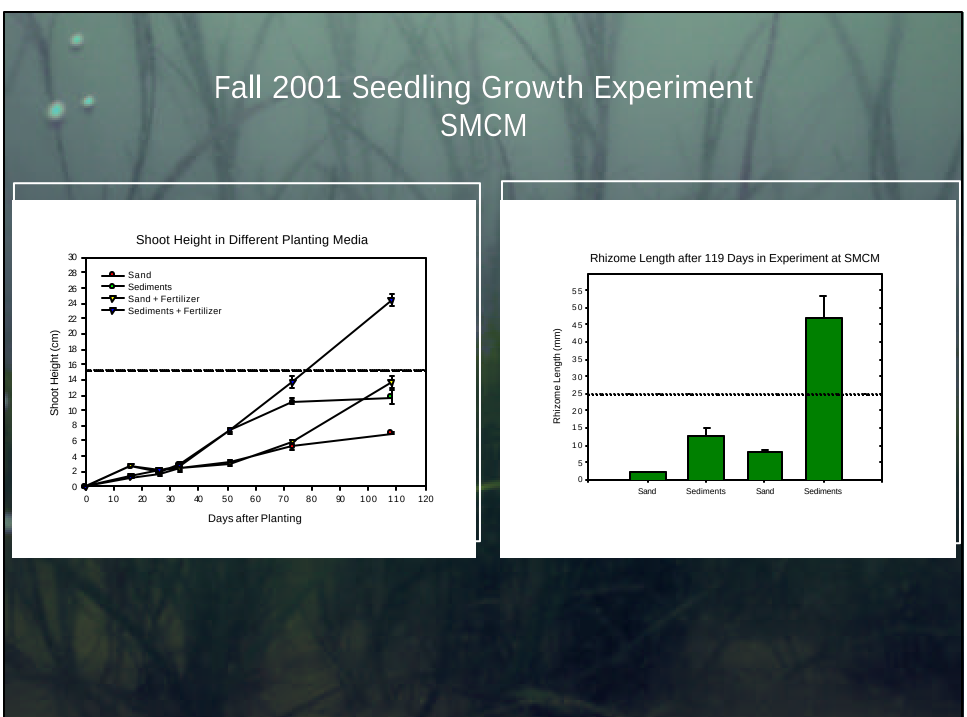
Values respresent means ± the standard error
*Five seeds were planted per peat pot
**Percent survival based on the number of shoots per pot, which could include new turions

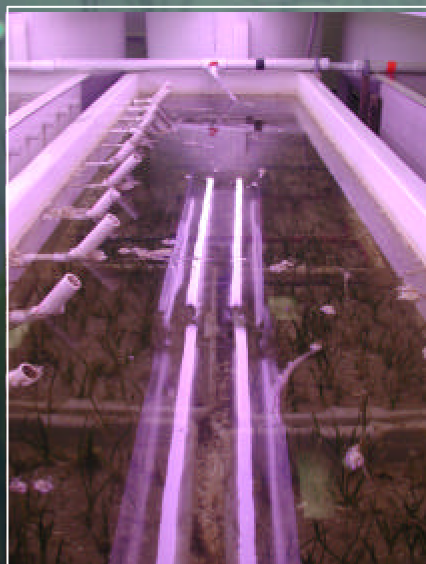
Effects of sediments and fertilizer on seedling growth

(SMCM, Fall 2001)



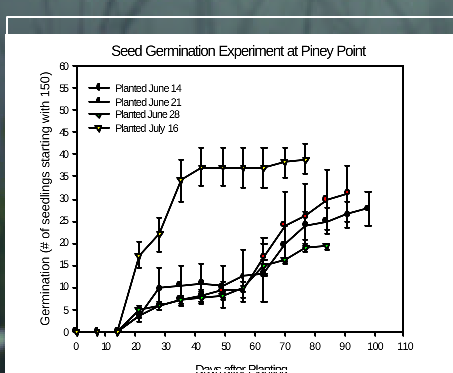

Fall 2001 Seedling Growth Experiment
SMCM
Number of Plants Growing from Seeds in Different Media (starting with 50 seeds)
Sand
River Sediments
Sand + Fertilizer
River Sediments + Fertilizer
Number of Plants
Days from Germination
Total Number of Shoots in Different Media (starting with 50 seeds)
Sand
Sediment
Sand + Fertilizer
Sediments + Fertilizer
Total Number of Shoots
Days from Germination

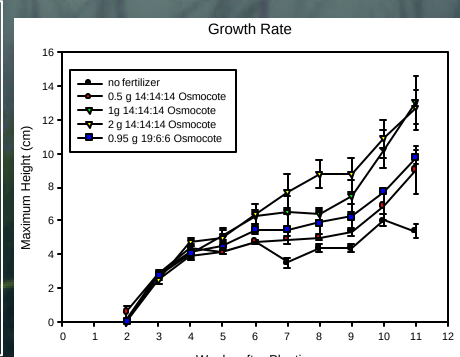

Fall 2001 Seedling Growth Experiment
SMCM
Shoot Height in Different Planting Media
Sand
Sediments
Sand + Fertilizer
Sediments + Fertilizer
Shoot Height (cm)
Days after Planting
Rhizome Length after 119 Days in Experiment at SMCM
Rhizome Length (mm)
Sand
Sediments
Sand
Sediments

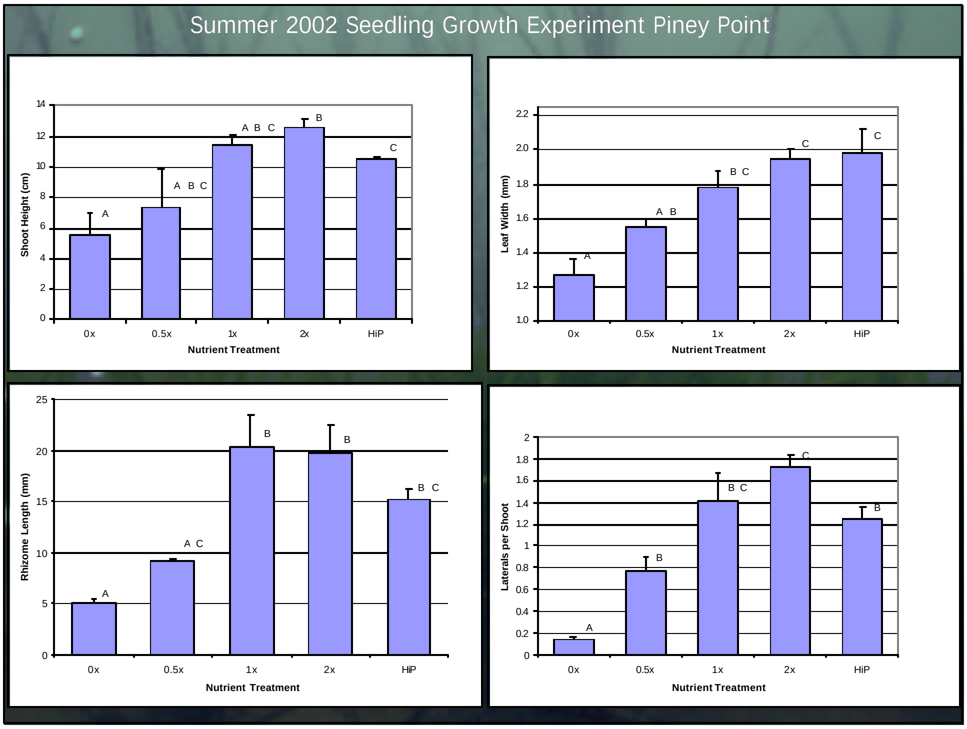


Summer 2002 Seedling Growth Experiment
Piney Point

Summer 2002 Seedling Growth Experiment
Piney Point







Conclusions

- Eelgrass for restoration projects can be either propagated vegetatively or grown from seed in land-based culture systems
- Vegetative propagation does not require the collection of field material after the initial culture stock is established
- Use of seeds lowers culture costs as the system is in operation for approximately 6 months
- Low germination rates this year, possibly due to cooler temperatures and lower salinities

Cost-Effectiveness

1. Investment in culture facilities
   a) Tanks, pumps and chillers (or heat pumps)
   b) Lighting
2. Costs associated with running the system
   a) Electrical costs
   b) Maintaining pumps, chillers and lights
3. Culture costs
   a) Collecting/processing vegetative shoots and/or seeds
   b) Collecting sediments
   c) Planting shoots and/or seeds in tanks
   d) Cleaning tanks and plants
   e) Harvesting plants and preparing for outplanting

Research funded by the Wilson Bridge Mitigation Program and the Chesapeake Bay Trust

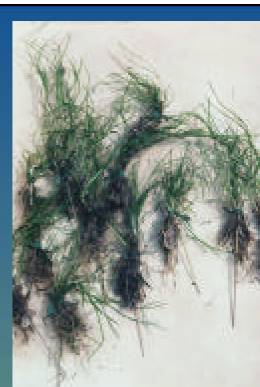
Eelgrass Restoration in Chesapeake Bay:

Are seeds the way to go?

Robert J. Orth

Virginia Institute of Marine Science
College of William and Mary

www.vims.edu/bio/sav



OR

‘Strategy to Accelerate Protection and Restoration of SAV in Chesapeake Bay’

By Dec. 2008,
plant at least 1000 acres
at multiple sites!!


200 acres
EACH year for 5
years!!

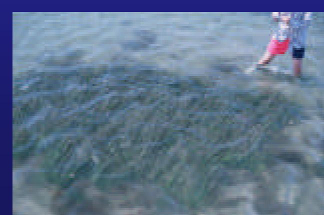

Seagrass Transplants – Variety of Techniques to Plant Adult Plants

Labor intensive

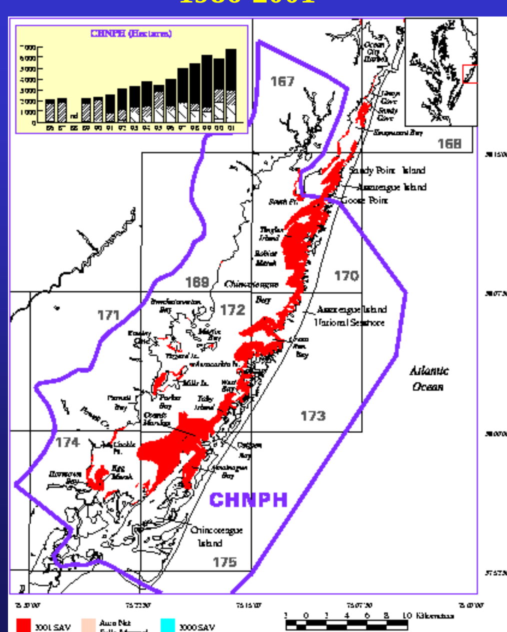
Tedious

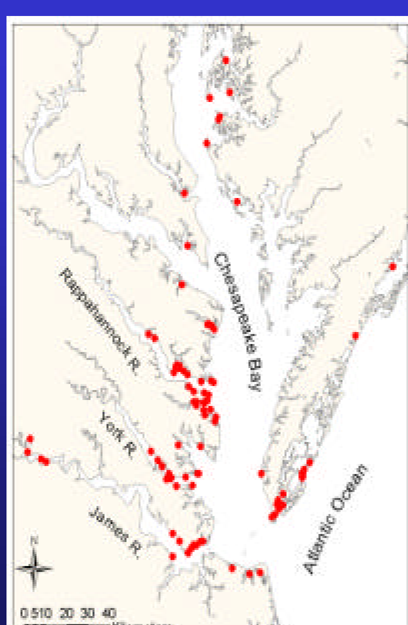
Potential donor bed impacts

Small areas planted



RECOVERY OF SEAGRASS TO CHINCOTEAGUE BAY 1986-2001





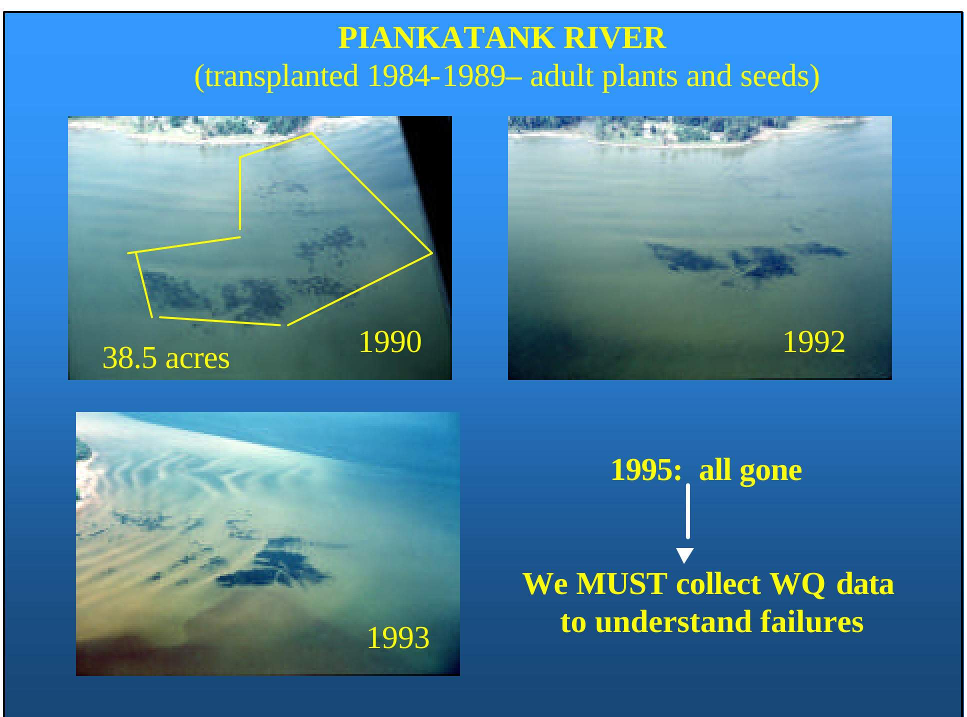
Transplant Sites
1979-2002

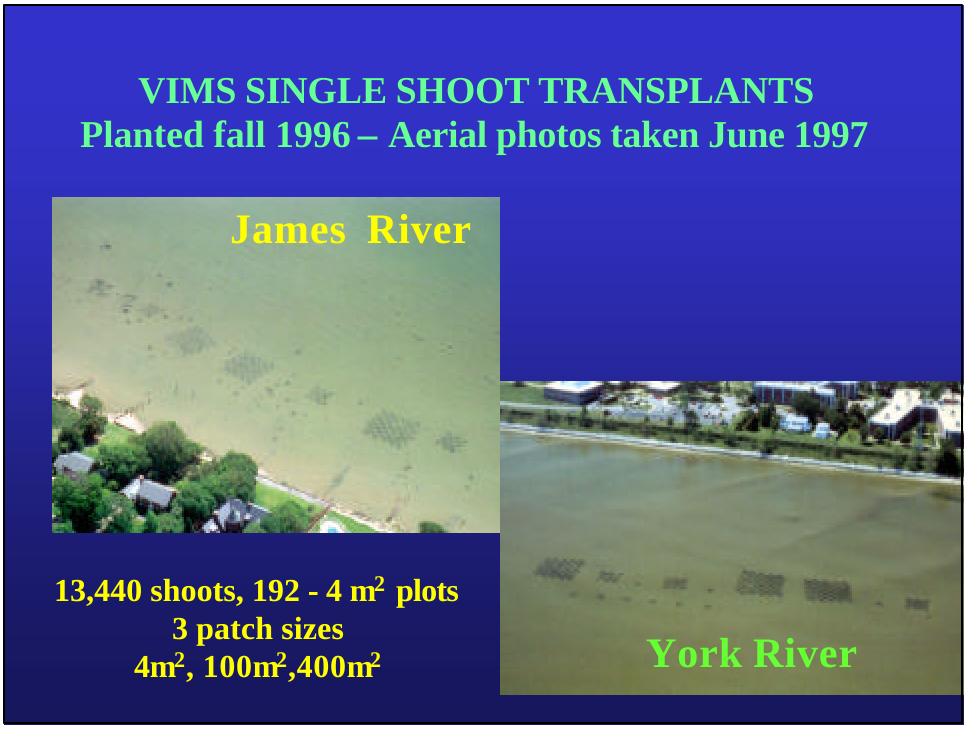
- Nearly 90 sites planted

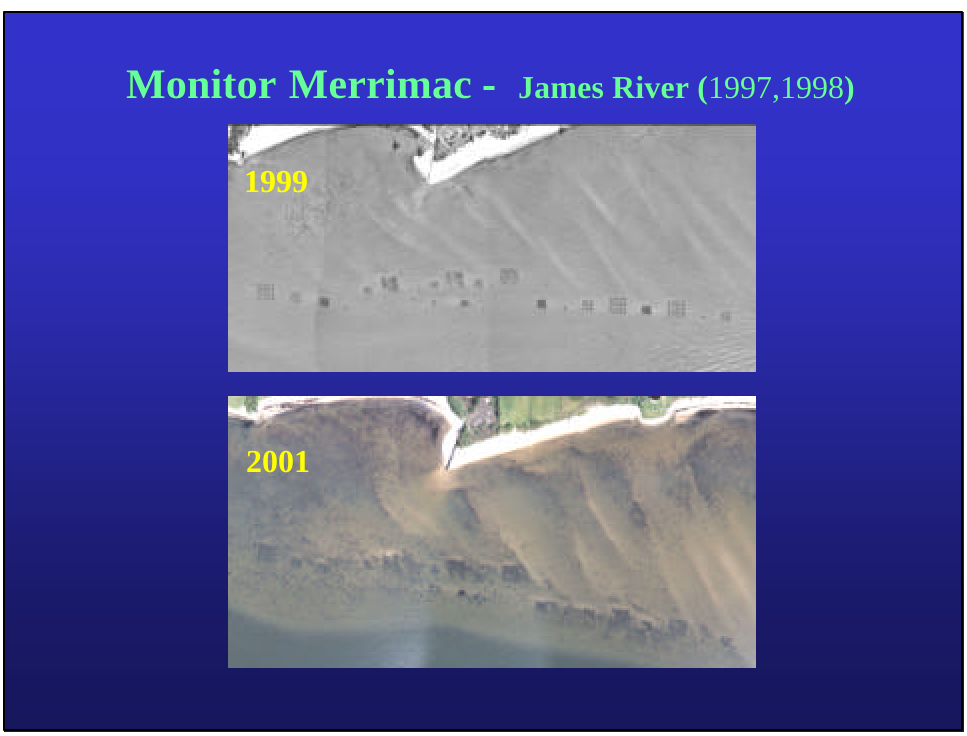
SPECIES USED

- Eelgrass (*Zostera marina*) ******
- Wild celery (*Vallisneria americana*)
- Sago Pondweed (*Stuckenia pectinata*)
- Elodea (*Elodea canadensis*)
- Coontail (*Ceratophyllum demersum*)

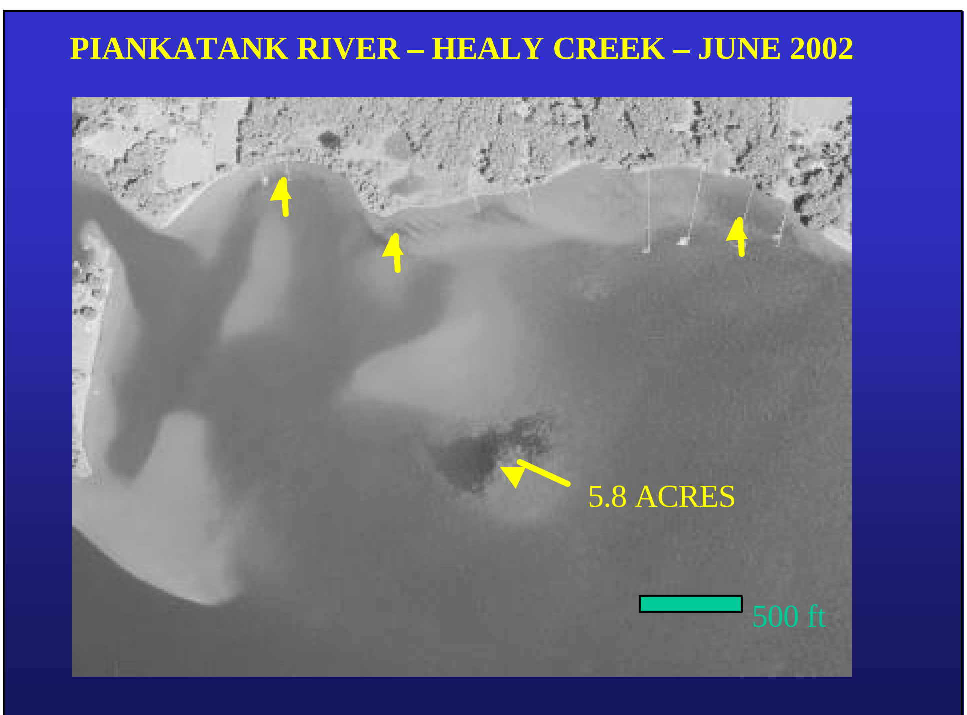

VIMS - BUNDLE TRANSPLANTS
0.5, 1.0 and 2.0 m centers in 1982 and 1983
1984
1985
1987
1988
1990-2002

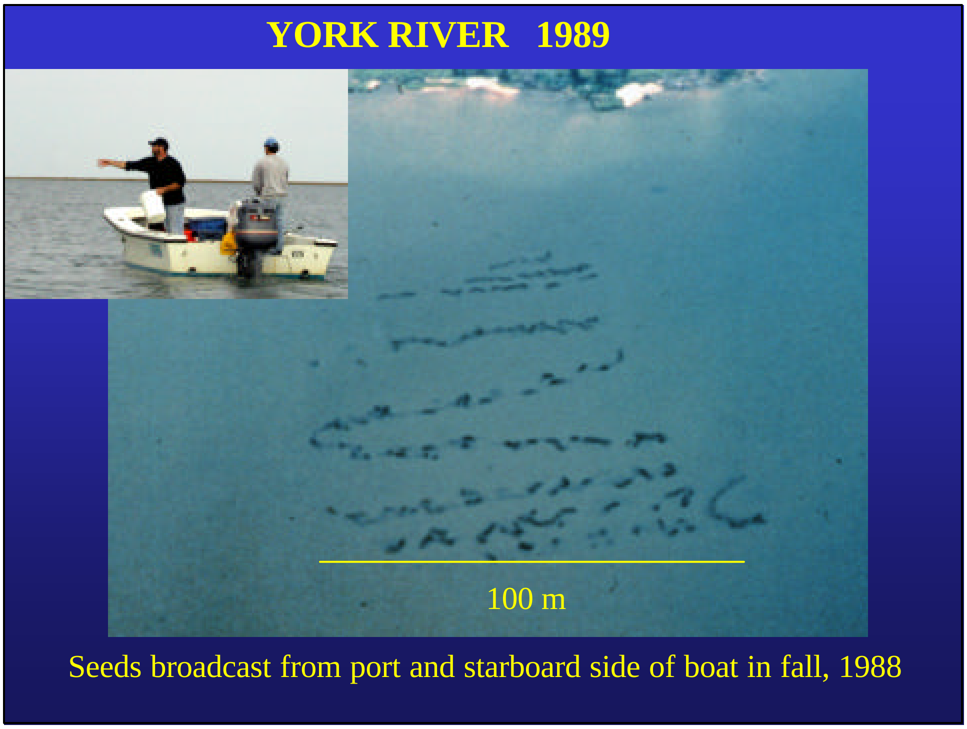

PIANKATANK RIVER
(transplanted 1984-1989– adult plants and seeds)
38.5 acres
1990
1992
1993
1995: all gone
We MUST collect WQ data
to understand failures

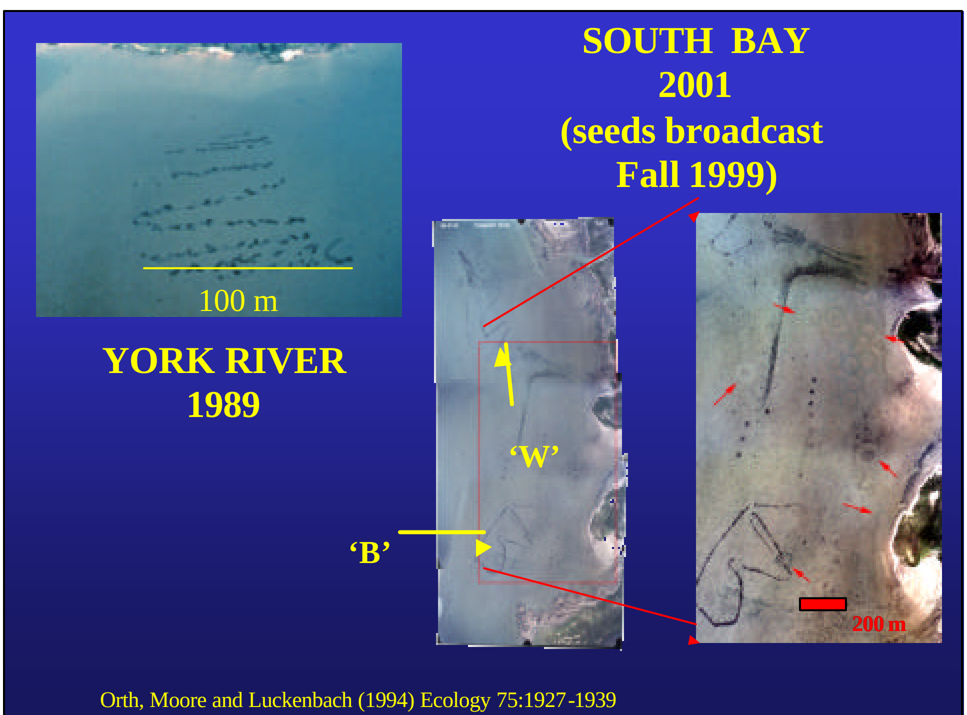

VIMS SINGLE SHOOT TRANSPLANTS
Planted fall 1996 – Aerial photos taken June 1997
James River
13,440 shoots, 192 - 4 m2 plots
3 patch sizes
4m2, 100m2,400m2
York River


Monitor Merrimac - James River (1997,1998)
1999
2001

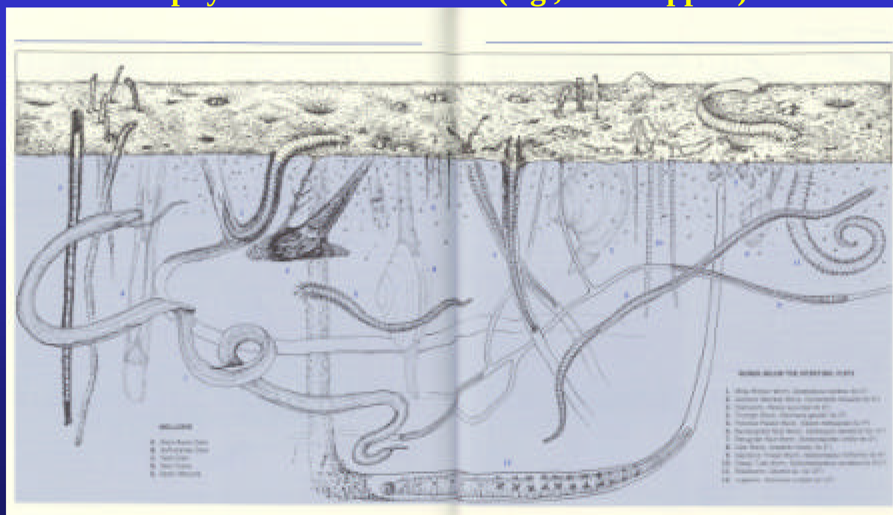

Healy Creek
Stingray Point
6 km
Burtons Point
Gwynn's Island
Cobb's Creek
5 km


PIANKATANK RIVER – HEALY CREEK – JUNE 2002
5.8 ACRES
500 ft

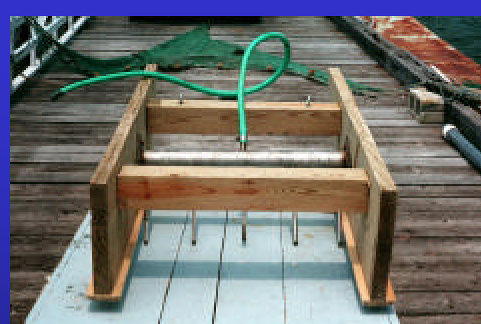

YORK RIVER 1989
100 m
Seeds broadcast from port and starboard side of boat in fall, 1988


SOUTH BAY
2001
(seeds broadcast
Fall 1999)
100 m
YORK RIVER
1989
'W'
'B'
200 m
Orth, Moore and Luckenbach (1994) Ecology 75:1927-1939

Seeds retained where they settle because of topographic complexities of sediment surface due to bioturbation or physical discontinuities (e.g., sand ripples)



Luckenbach and Orth (1999) Aquatic Botany 62:235-247



SEED COLLECTION
LATE MAY – MID-JUNE

2001
6.6 million seeds in 204 collecting hours = 32,500 seeds/hour
2002
2.5 million seeds in 246 collecting hours = 10,000 seeds/hour
2003
5.2 million seeds in 310 collecting hours = 16,800 seeds/hour

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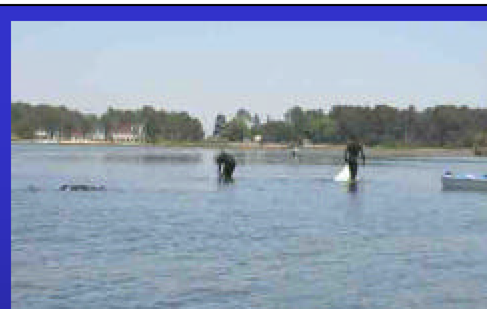
Broadcast in August to October prior to seed germination in mid Nov.



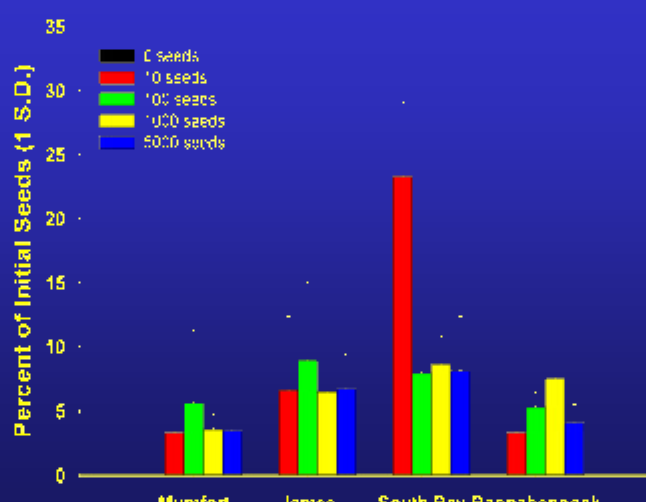
SEEDS- 1989 to present

PRO

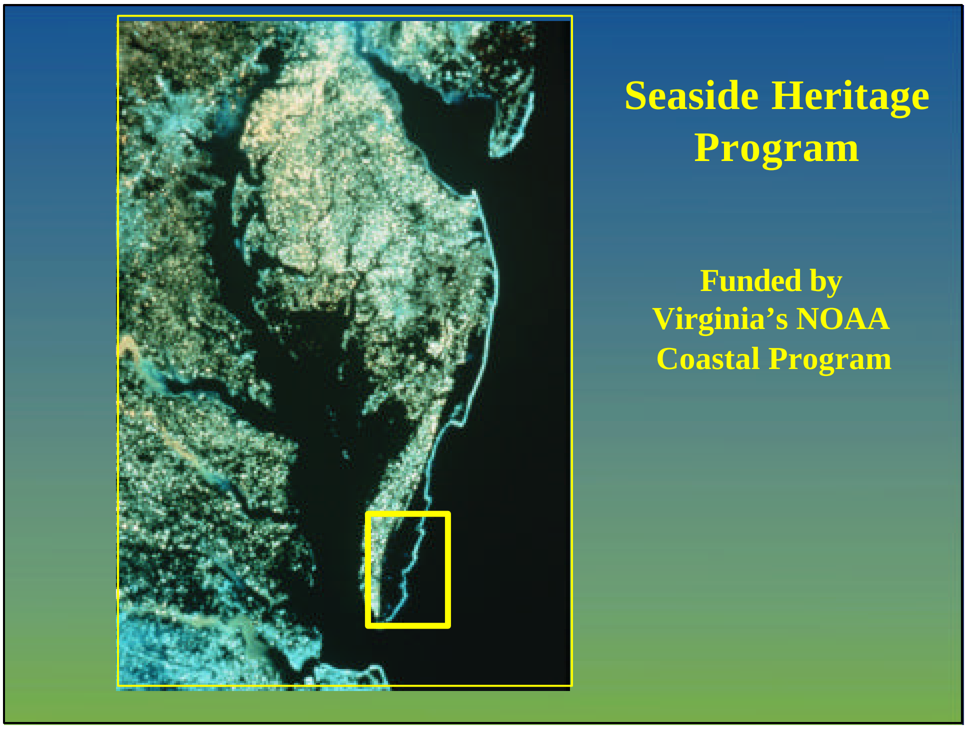
- Low donor bed impact
- Can collect ‘heaps’ of seeds!
- Easy for volunteers to collect and disperse

- **CON**
  - Only 5-15% of seeds germinate and survive

Seedling Abundance vs. Initial Seed Density



Orth, Fishman, Harwell and Marion (2003) Mar. Ecol. Prog. Ser. 250:71-79


Seaside Heritage Program
Funded by Virginia's NOAA Coastal Program


Atlantic Ocean
400 acre set aside
Wreck Island
South Bay
0 300 600 1,200 1,800 2,400
Meters

SEED DISPERSAL

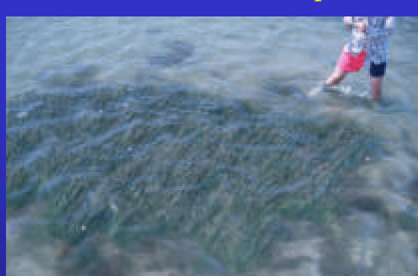
2001 - 42 acres @ 100K and 200K per acre
2002 - 32 acres @ 50K and 100K per acre

100K = 25 seeds/m²

******TIME TO SET UP PLOT AND BROADCAST SEEDS = 1 HOUR FOR THREE PEOPLE******

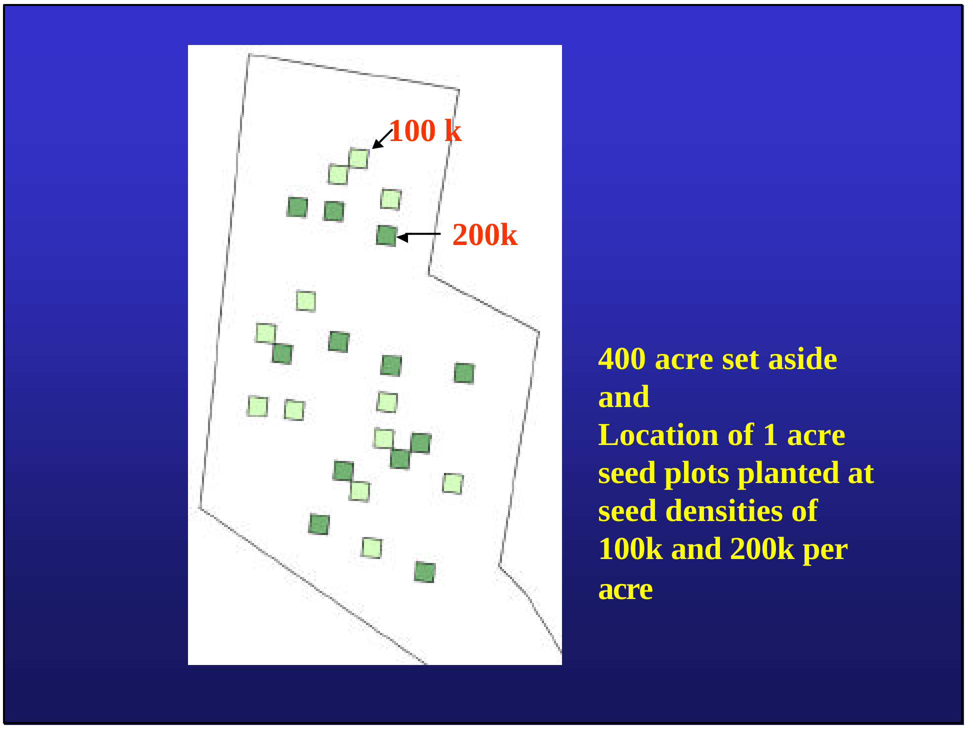
SOUTH BAY EELGRASS IN DIFFERENT TREATMENTS - 2002

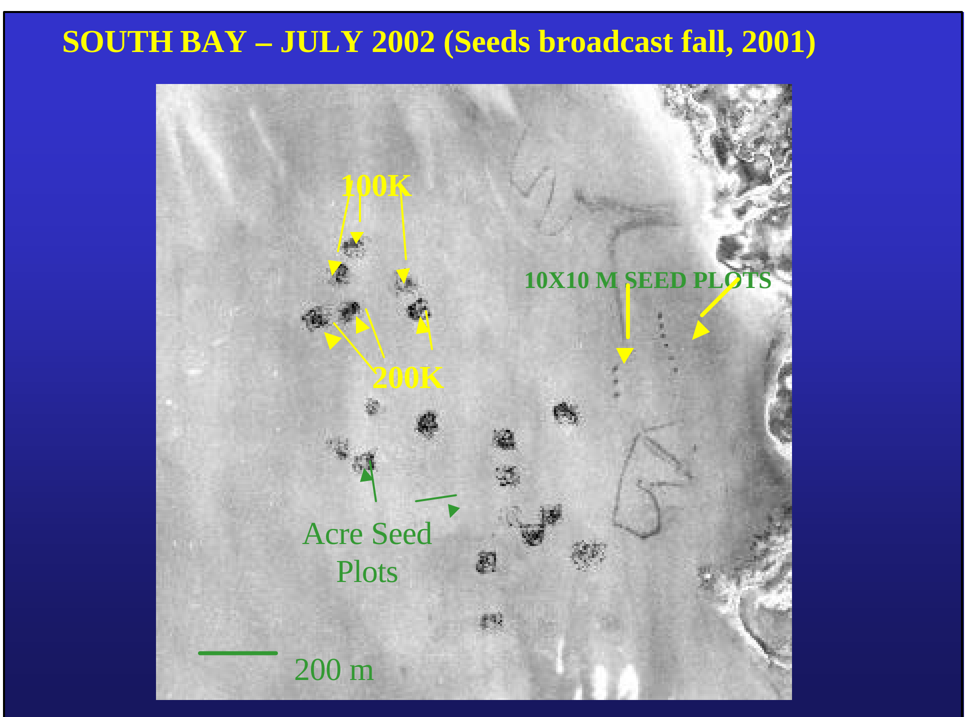
1998 – small test plot

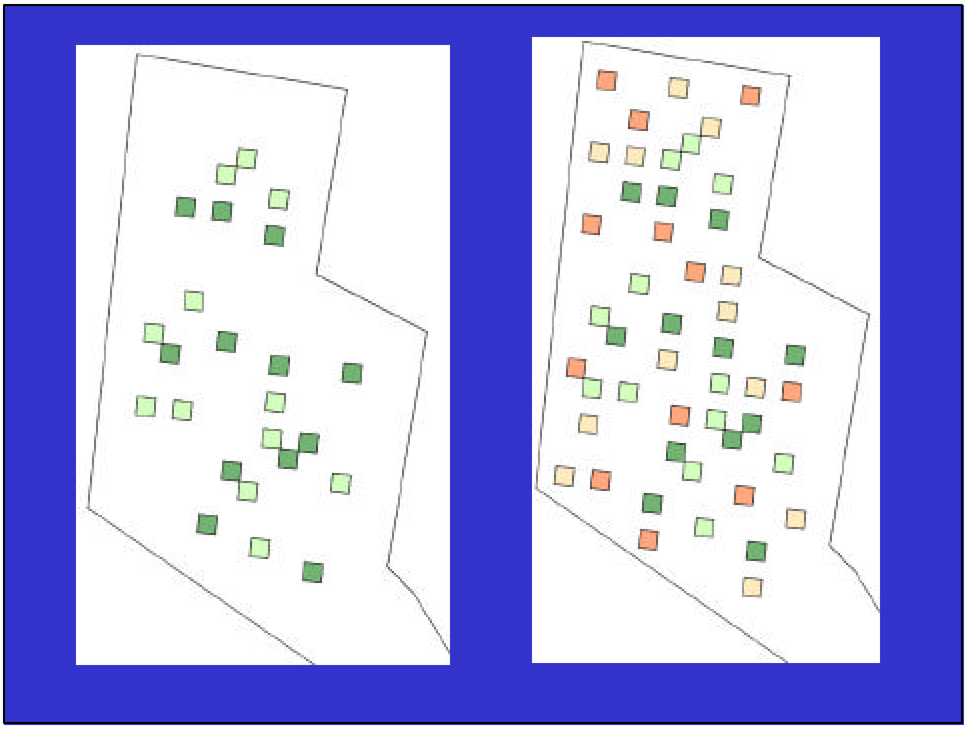


1999 – seed broadcast

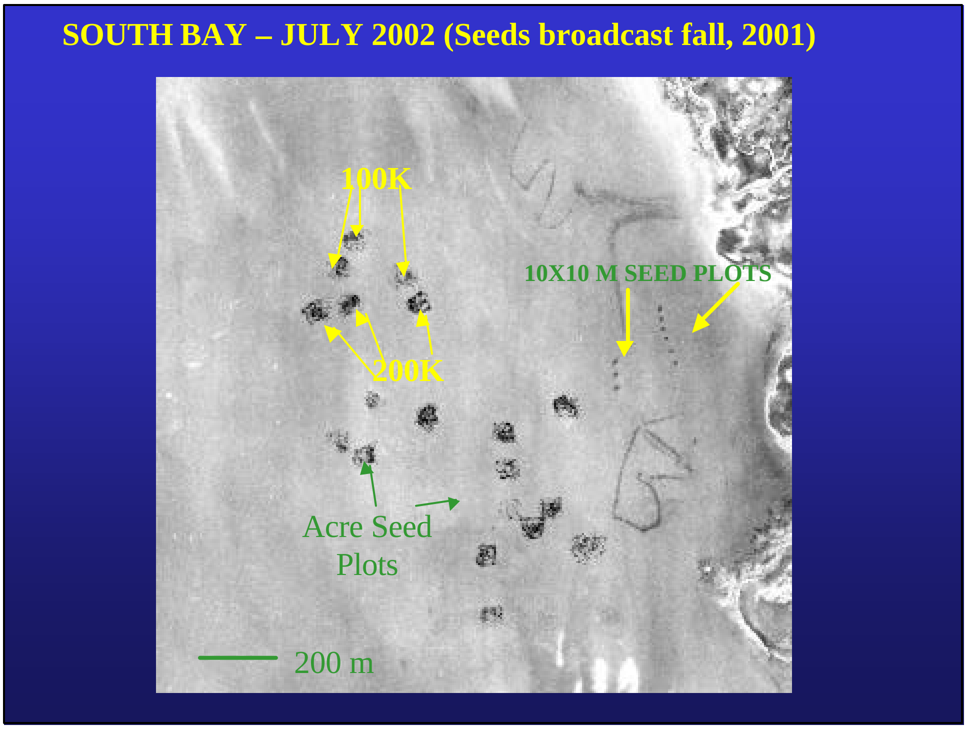
2000 – 10x10 m seed plot

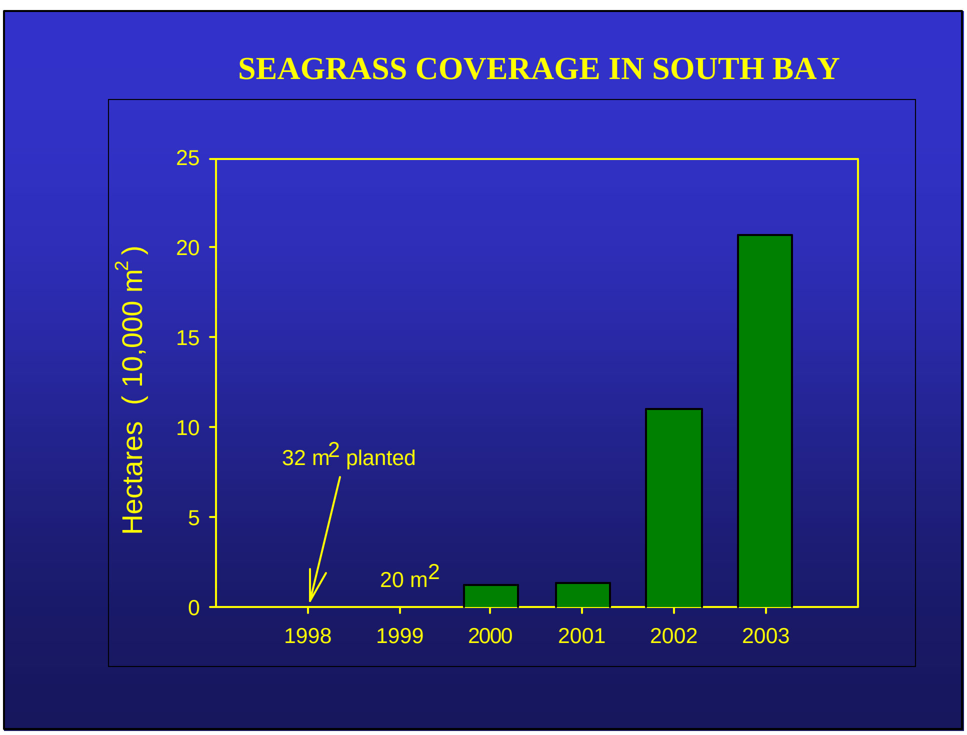

100 k
200k
400 acre set aside
and
Location of 1 acre
seed plots planted at
seed densities of
100k and 200k per
acre


SOUTH BAY – JULY 2002 (Seeds broadcast fall, 2001)
100K
10X10 M SEED PLOTS
200K
Acre Seed
Plots
200 m




SOUTH BAY – JUNE 2003 (Seeds broadcast fall, 2001)


SOUTH BAY – JULY 2002 (Seeds broadcast fall, 2001)
100K
10X10 M SEED PLOTS
200K
Acre Seed Plots
200 m


SEAGRASS COVERAGE IN SOUTH BAY
Hectares (10,000 m2)
25
20
15
10
5
0
32 m2 planted
20 m2
1998
1999
2000
2001
2002
2003

TRANSPLANT METHODS*

METHOD	# Plants or Seeds/ PU	TIME* (min)
ADULT PLANTS		
Woven Mats	15	30.0 PU^{-1}
Turf	~40	6.4 PU^{-1}
Cores	~15	5.7 PU^{-1}
Bundles	5-12	4.9 PU^{-1}
Single Shoots	1	0.4 PU^{-1}
SEEDS		
Burlap/Wire	550 m^{-2}	32.8 m^{-2}
Peat Pots	10 seeds	3.8 PU^{-1}
Seed Bags	10 seeds	3.3 PU^{-1}
Broadcast	12-50 m^{-2}	0.3 m^{-2}

*Includes:
Collection
Preparation
Planting

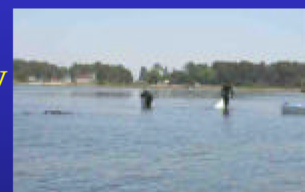
TIME PER SUCCESSFUL PLANTING UNIT AT 24 WEEKS* AVERAGED FOR BOTH SITES

- Machine 40.6 sec
- Manual 22.4 sec
- Seed 4.5 sec

* only includes time to plant

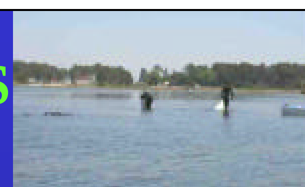
TAKE HOME LESSONS

- Seed production – narrow window but generally large numbers produced for many species

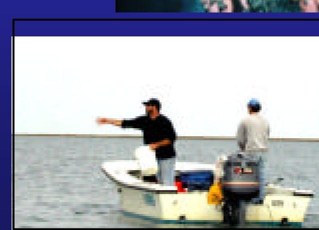


- Reproductive shoots with seeds easy to harvest and store

TAKE HOME LESSONS

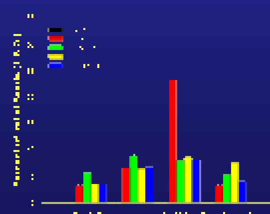


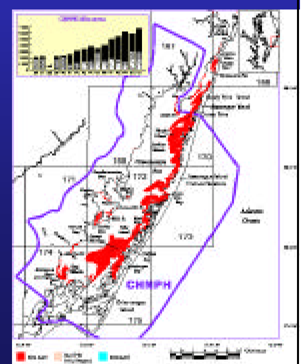
- Low donor bed impact
- Easier than using adult plants
- Genetic issues
- MUST conduct basic experiments



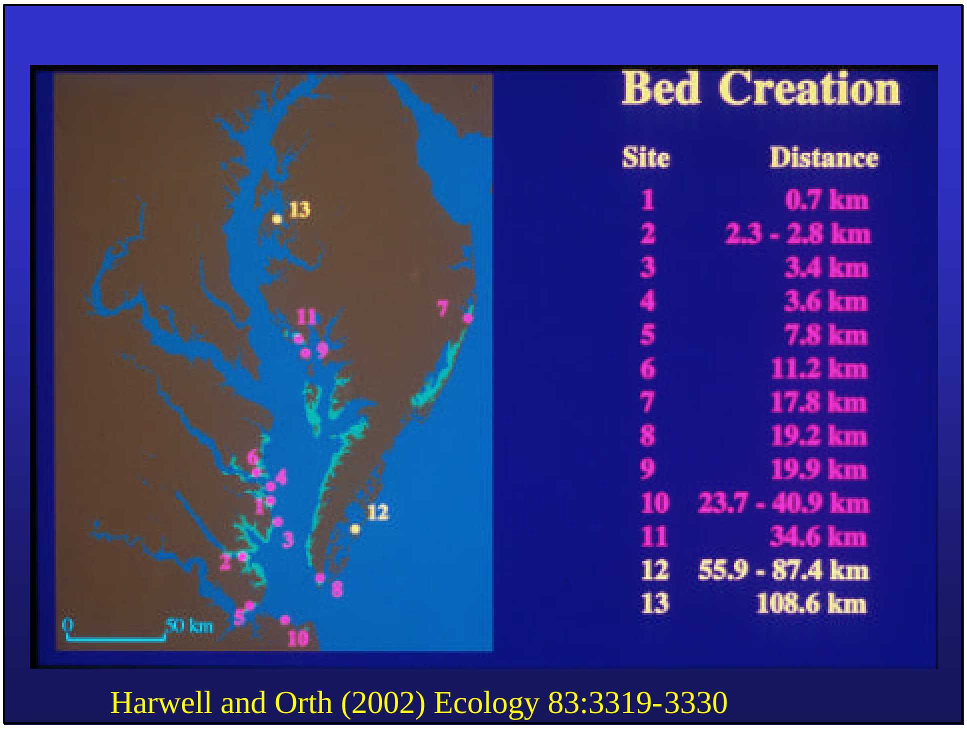
TAKE HOME LESSONS

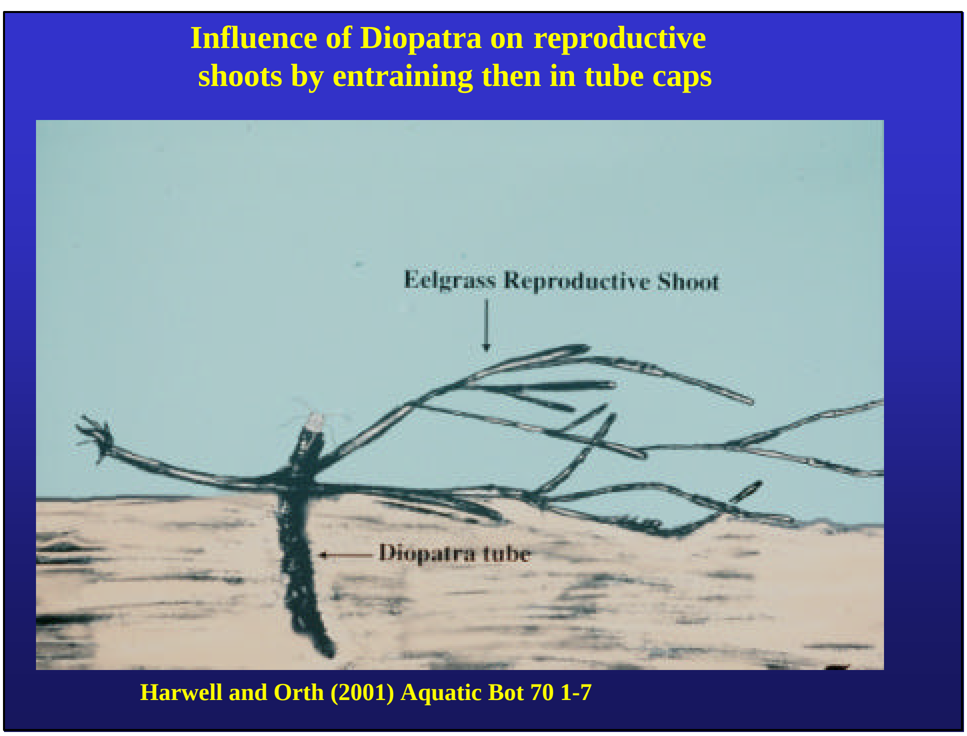
- WATER QUALITY!!!!
- Natural variation can dwarf human efforts
- Large increases in seagrass populations most likely due to seed input not vegetative spread

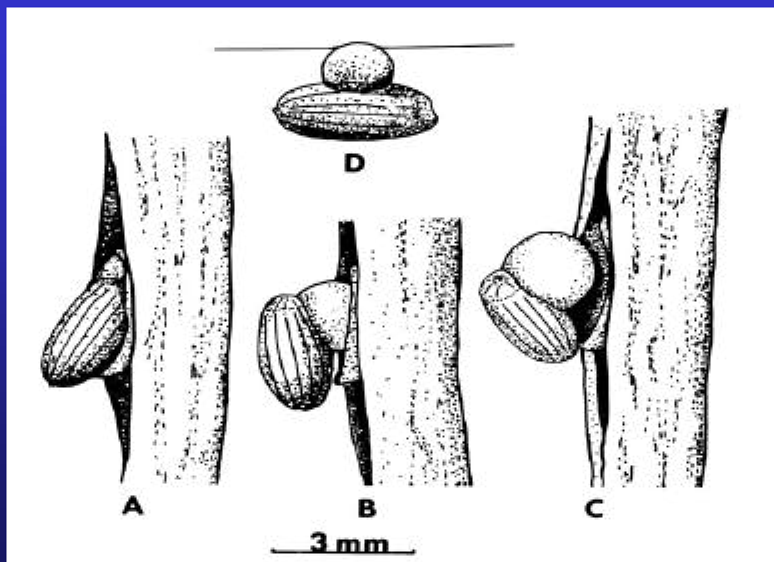





LIBERTY

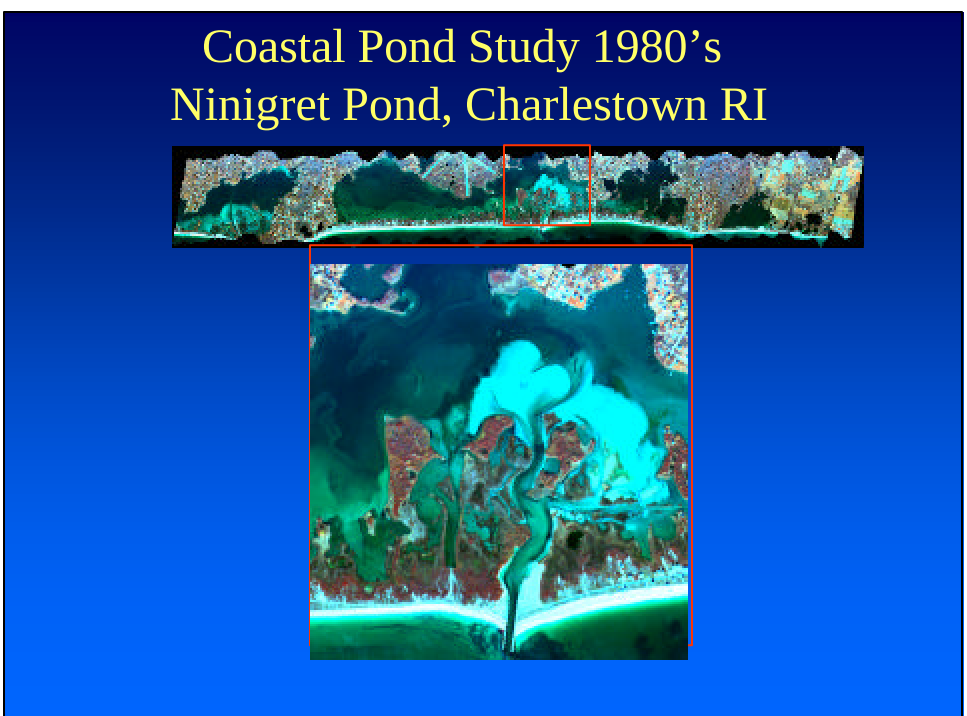

Bed Creation
Site Distance
1 0.7 km
2 2.3 - 2.8 km
3 3.4 km
4 3.6 km
5 7.8 km
6 11.2 km
7 17.8 km
8 19.2 km
9 19.9 km
10 23.7 - 40.9 km
11 34.6 km
12 55.9 - 87.4 km
13 108.6 km
0
50 km
Harwell and Orth (2002) Ecology 83:3319-3330


Influence of Diopatra on reproductive shoots by entraining then in tube caps
Eelgrass Reproductive Shoot
Diopatra tube
Harwell and Orth (2001) Aquatic Bot 70 1-7



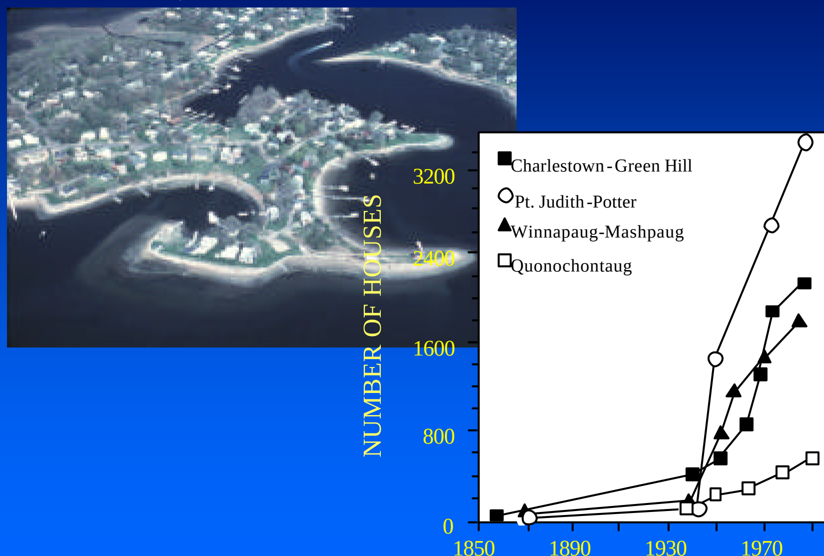
from Churchill, et al., 1985


Seagrass Ecology and the Use of
Eelgrass Seeds for Restoration
Stephen Granger, Scott Nixon,
Mike Traber and Betty Buckley
University of Rhode Island, GSO
METRIC 1 2 3 4 5 6

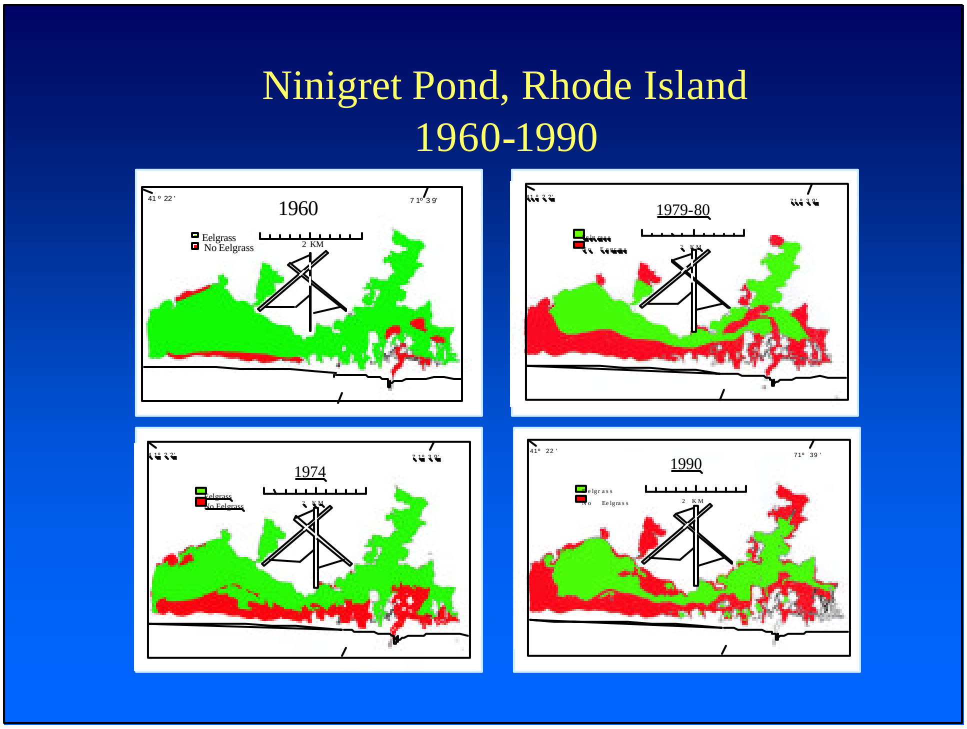

Coastal Pond Study 1980's
Ninigret Pond, Charlestown RI

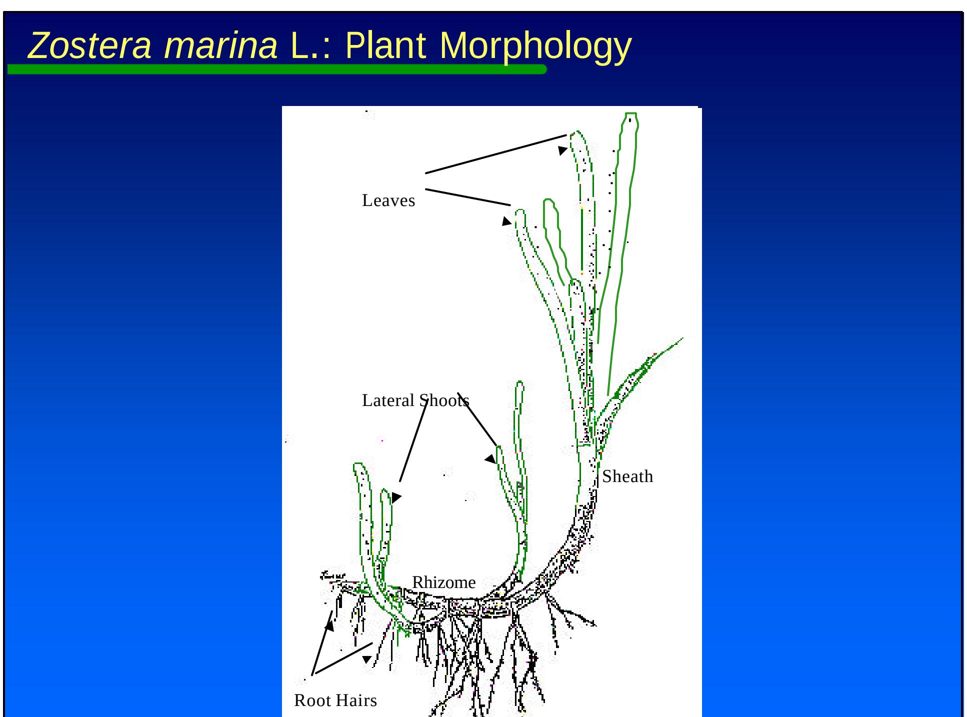
Residential Development

Point Judith Pond, Rhode Island

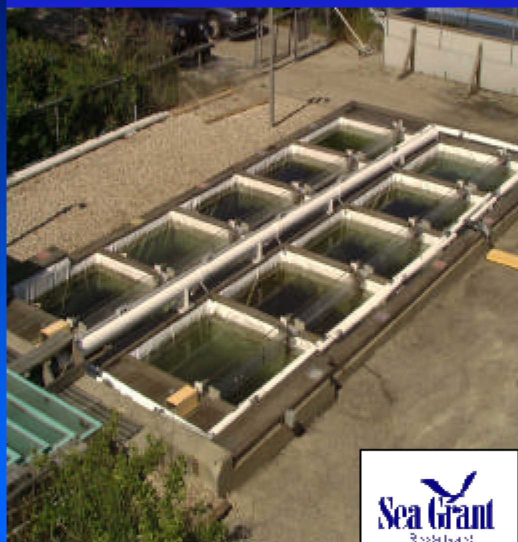


Groundwater Infiltration


Ninigret Pond, Rhode Island
1960-1990
1960
41° 22'
71° 39'
Eelgrass
No Eelgrass
2 KM
1979-80
1974
1990


Zostera marina L.: Plant Morphology
Leaves
Lateral Shoots
Sheath
Rhizome
Root Hairs

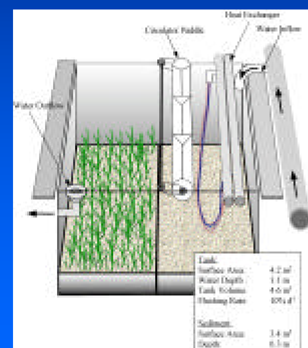
Coastal Lagoon Mesocosms at the URI Graduate School of Oceanography



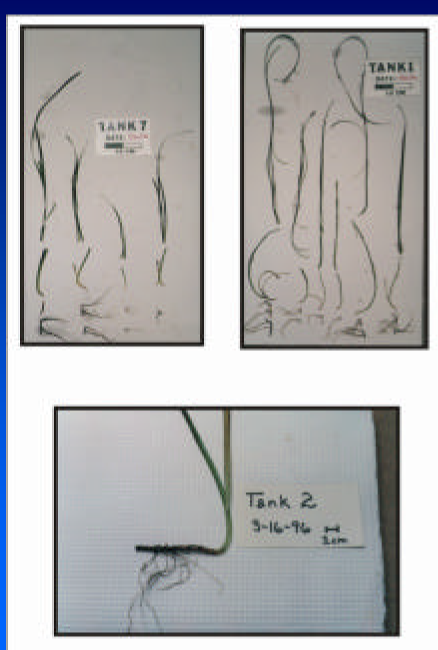
1990

First Experiments

in Enclosures



Chronic Nutrient Enrichment in Coastal Embayments



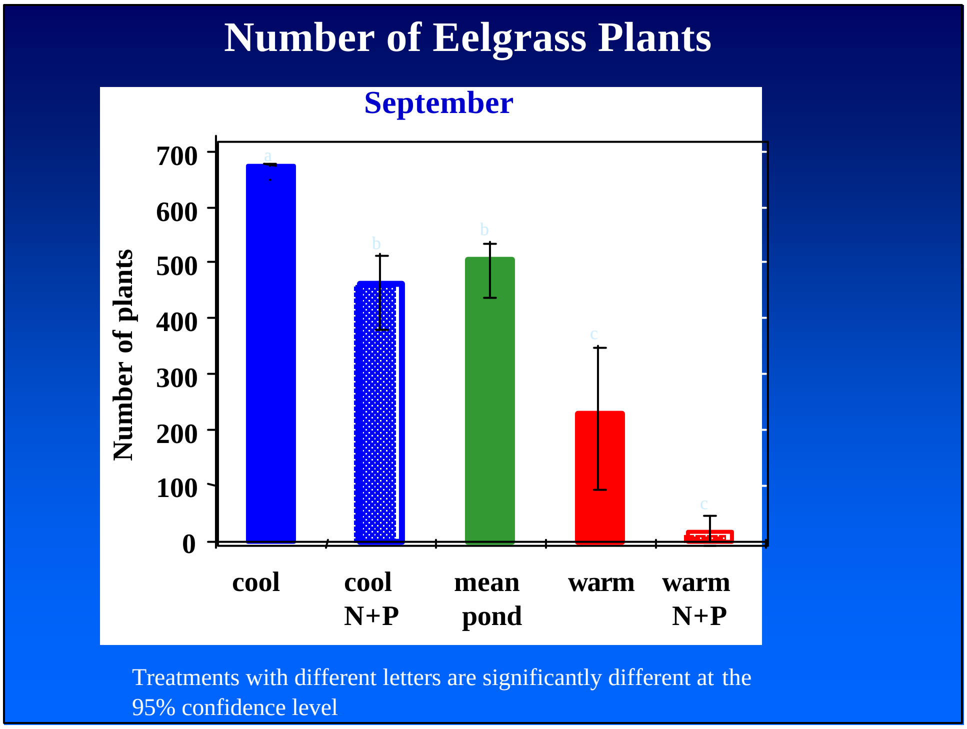
- Elongation of seagrass canopy with nitrogen enrichment; independent of water clarity.
- Higher above-ground/below-ground ratio.
- Greater time required to create a new leaf.

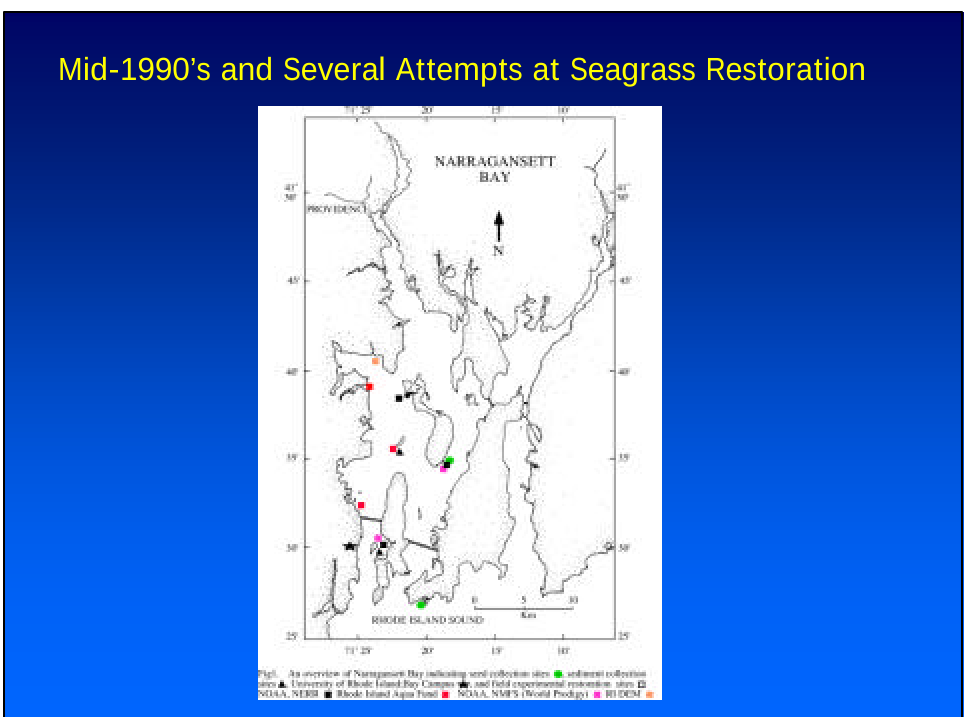
SUMMARY TABLE

Treatment	Shoot/Root Ratio	n	ANOVA grouping
Control	6.7 (0.9)	12	A
Low	8.2 (3.6)	12	A
Low + filter feeders	13.9 (2.0)	12	B
High + filter feeders	11.2 (3.3)	5	B

Treatments withANOVA grouping A are significantly different than group B (95% confidence).

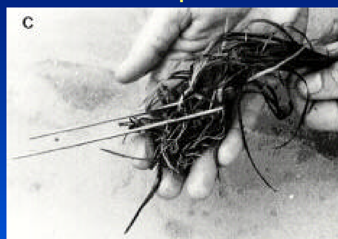
Shoot/Root ratios were determined from the g. dry weight of above ground biomass divided by the g. dry weight of th first two rhizome nodes with root hairs (see photo to left). Standard deviations are shown as ( ).


Number of Eelgrass Plants
September
Number of plants
700
600
500
400
300
200
100
0
cool
cool N+P
mean pond
warm
warm N+P
Treatments with different letters are significantly different at the 95% confidence level


Mid-1990's and Several Attempts at Seagrass Restoration
NARRAGANSETT BAY
N
RHODE ISLAND SOUND

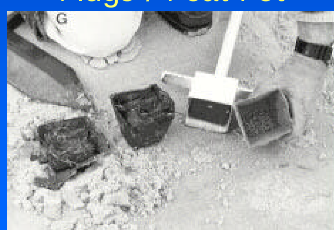
Common Restoration Techniques

Staple



TERF

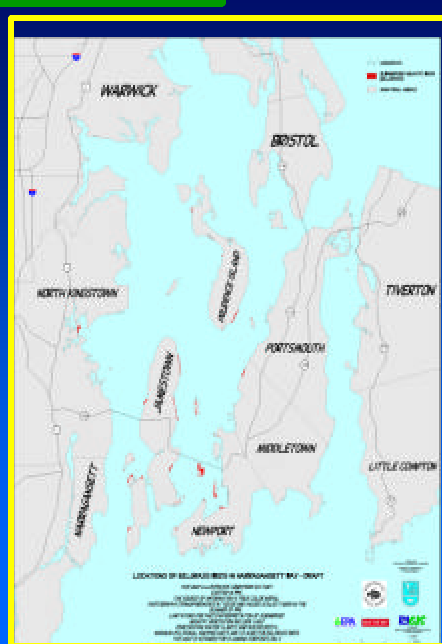
Plugs / Peat Pot

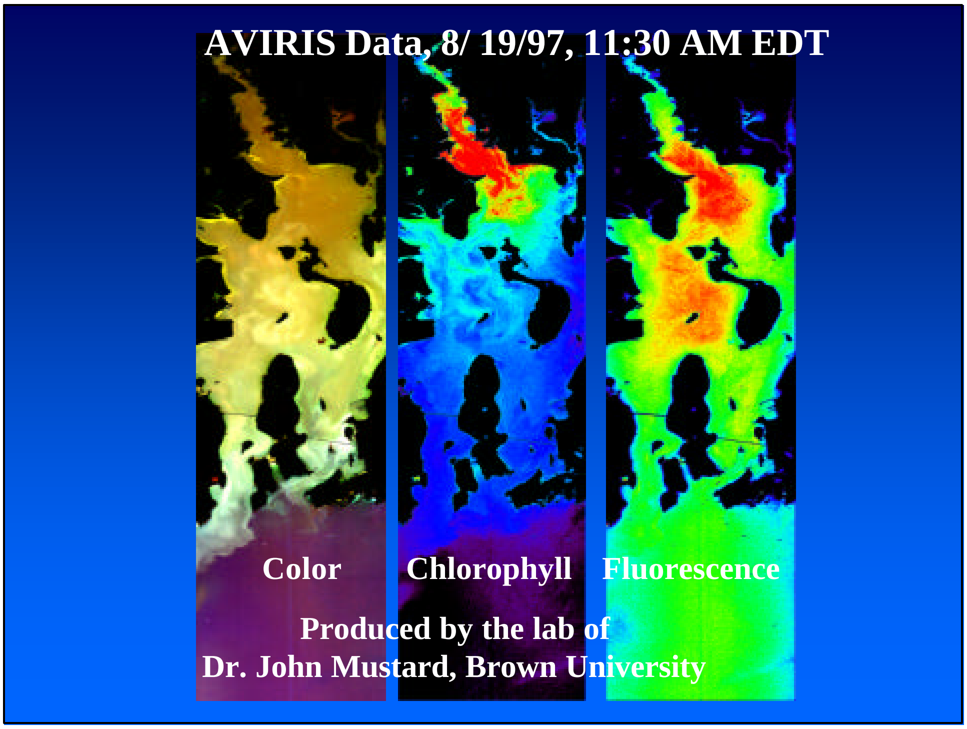


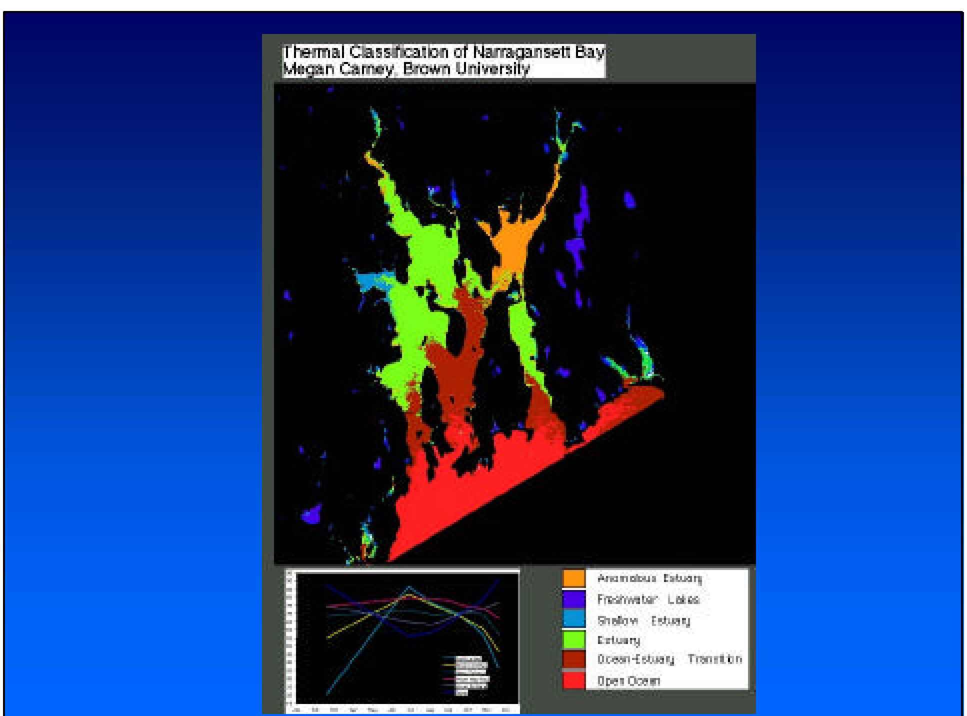
Seeds

Present Day Seagrass Distribution

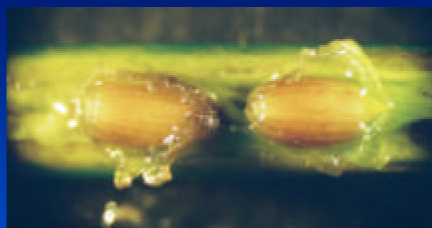
1995
Aerial Photo-
Interpretation




AVIRIS Data, 8/ 19/97, 11:30 AM EDT
Color
Chlorophyll
Fluorescence
Produced by the lab of
Dr. John Mustard, Brown University


Thermal Classification of Narragansett Bay
Megan Carney, Brown University
Anomalous Estuary
Freshwater Lakes
Shallow Estuary
Estuary
Ocean-Estuary Transition
Open Ocean

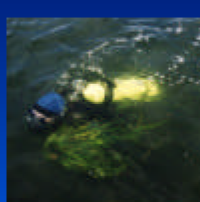
NOAA CICEET and NERRS Funded Research; Why Use Seeds ?



- Less labor intensive to collect and distribute
- Less destructive to the donor site
- Increased genetic diversity at restored site
- Can be held for a period time before planting

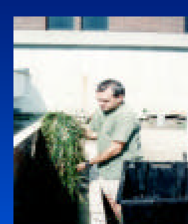
Seed Collection Process

Flowering plant Collection



Plants are held while seeds release

Vegetative material are removed

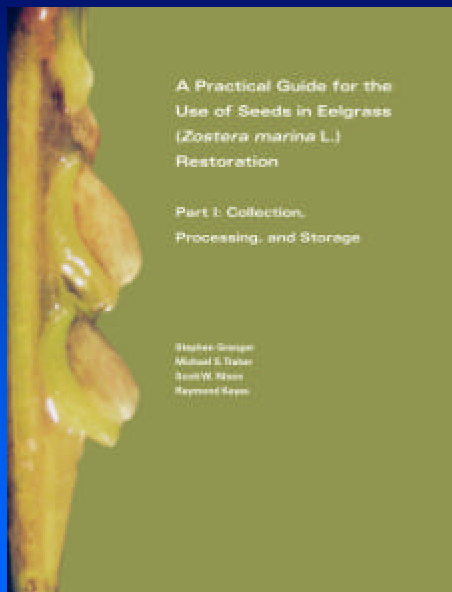


Tank Wash Down

Seed Recovery

Seed Holding

Seed Collection Process

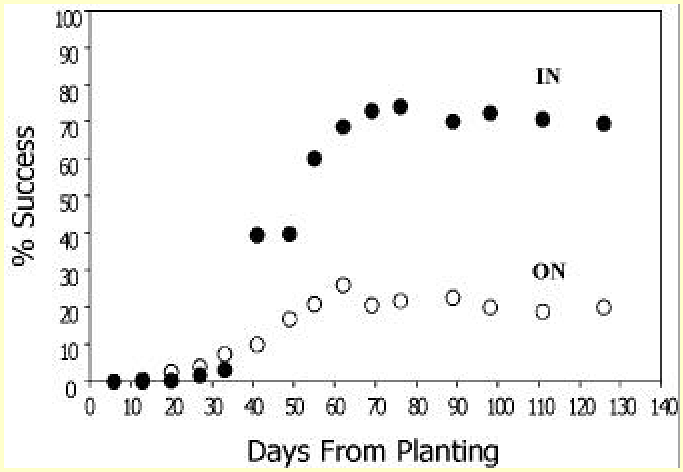


Available at Rhode Island Sea Grant Publications Office

Seed Planting Strategies

- Planting In vs. scattering On the sediment
- What is the optimal density for seeding?
- How will the sediment type effect seedling growth?

Seed Planting Strategies

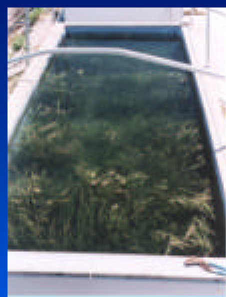


Increasing seed density by applying an outer layer of clay while maintaining high moisture content.


Seeds Distribution Techniques
Hand Casting
Or
Mechanized

Experiments on Seeding Density & Sediment Type

High Organic

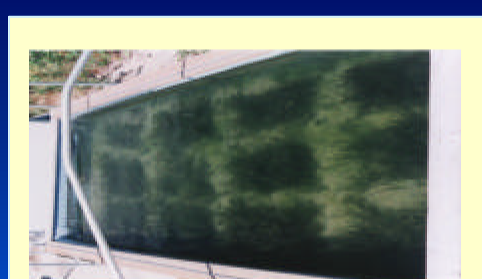


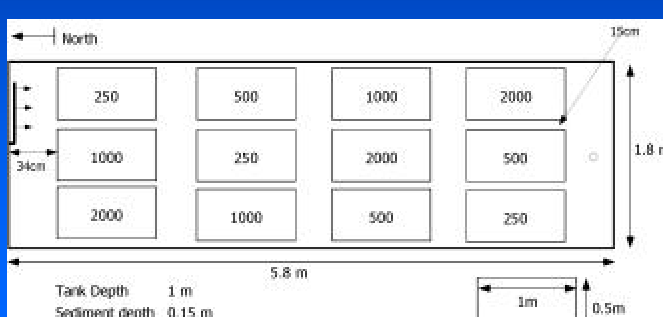
Low Organic

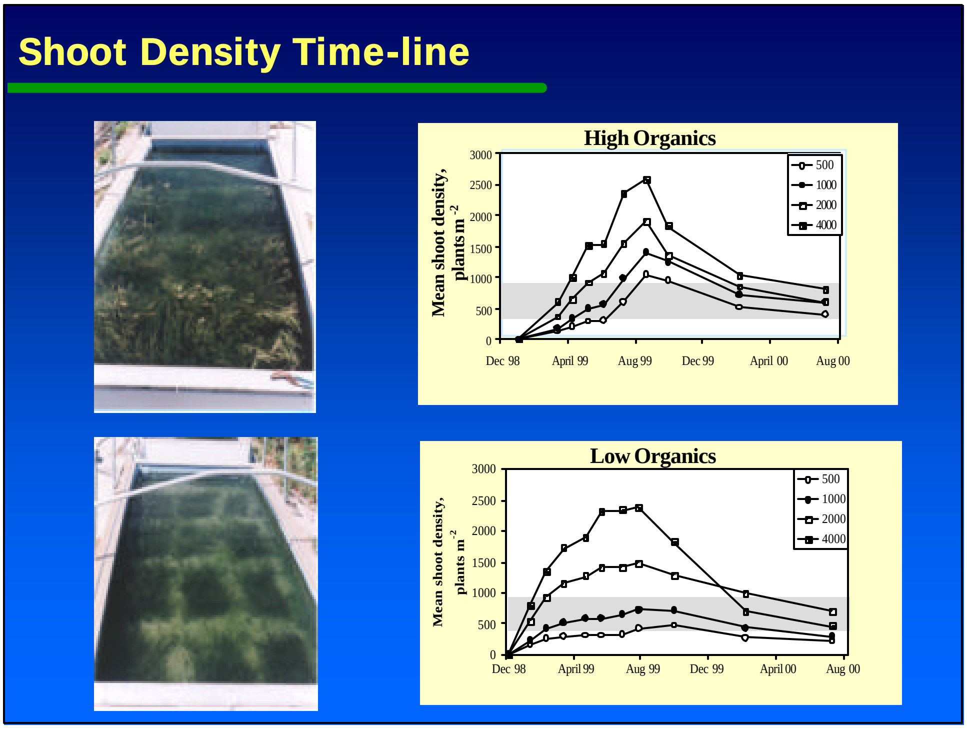
Sediment Characteristics

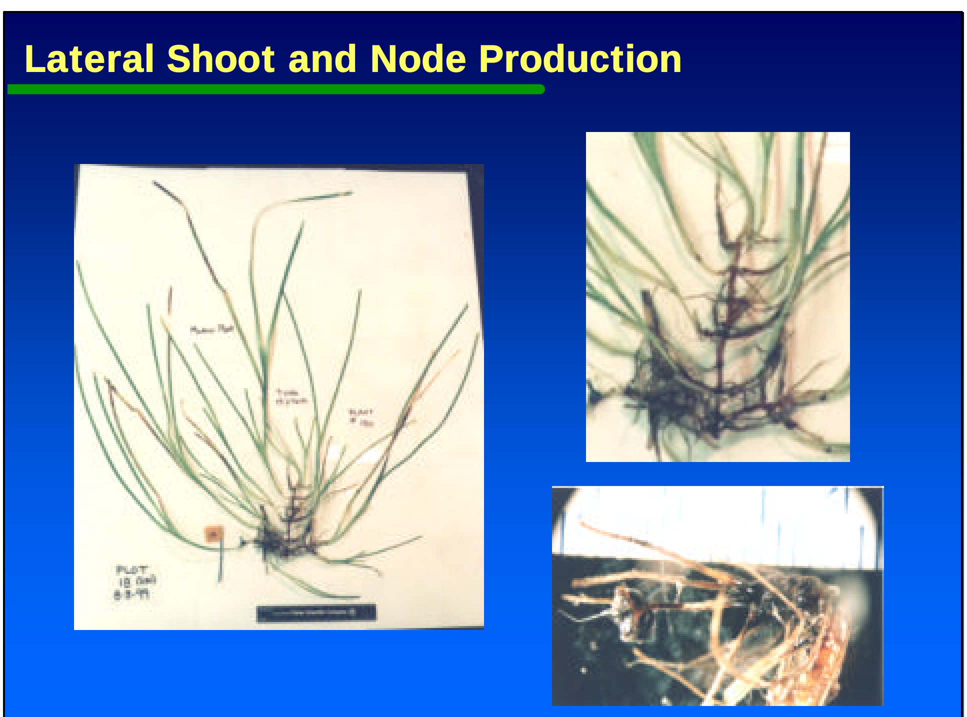
	High Organic Narragansett Bay	Low Organic Rhode Island Sound
Location		
Latitude	41° 30'	41° 21'
Longitude	71° 24'	71° 32'
% Organic Content		
0-2cm	1.7	0.56
2-6cm	1.63	0.51
Redox Layer		
Depth, cm	1.3	2.5

Experimental Design



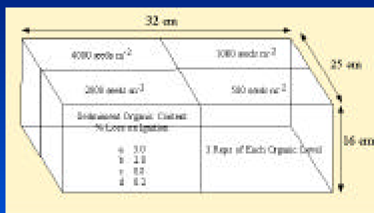


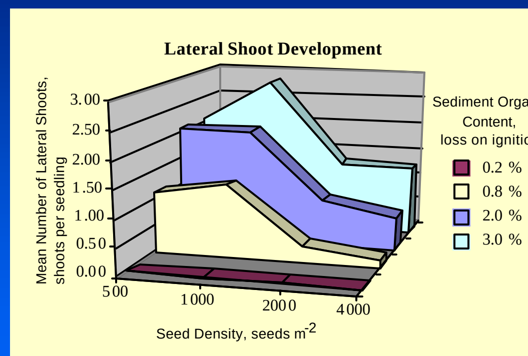

Shoot Density Time-line
High Organics
Mean shoot density, plants m -2
3000
2500
2000
1500
1000
500
0
Dec 98
April 99
Aug 99
Dec 99
April 00
Aug 00
500
1000
2000
4000
Low Organics
Mean shoot density, plants m -2
3000
2500
2000
1500
1000
500
0
Dec 98
April 99
Aug 99
Dec 99
April 00
Aug 00
500
1000
2000
4000


Lateral Shoot and Node Production

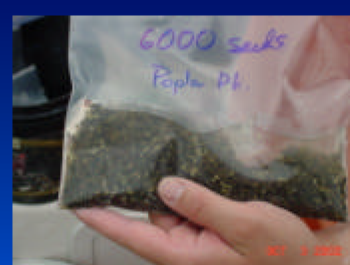
Stephen Granger, Scott Nixon,
Mike Traber, and Betty Buckley

Sediment Organic-Seeding Density Experiment

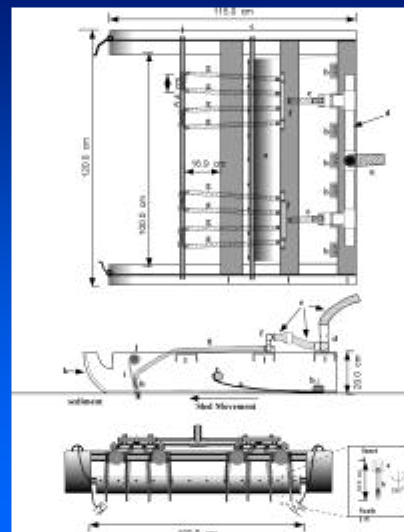




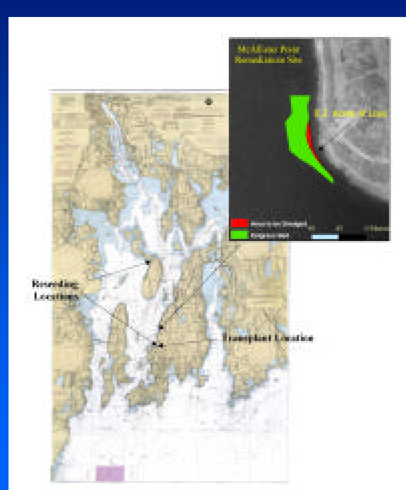
Gel-Injection Seeding



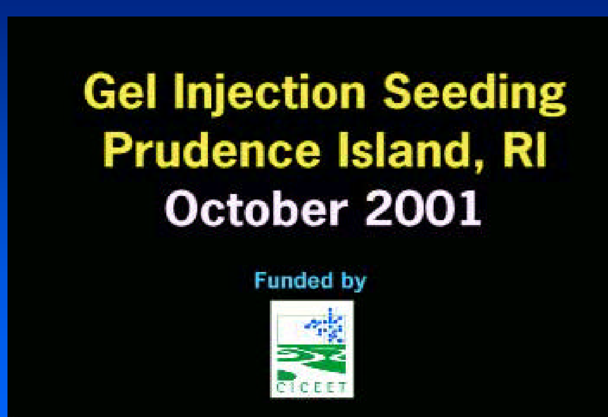
Gel-Injection Seeding



McAllister Point Remediation and Restoration

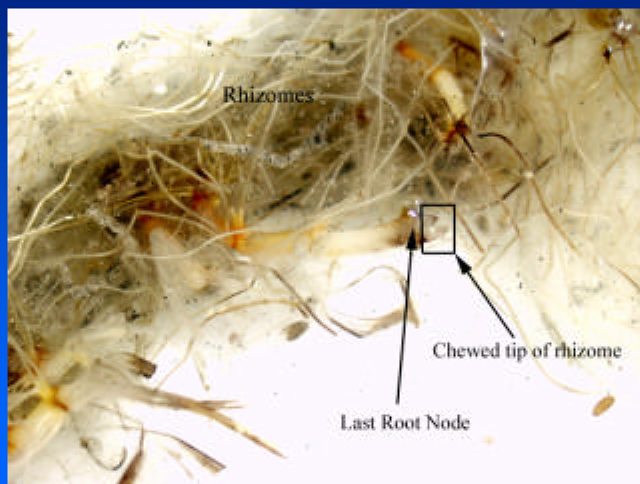


2001-2002 Seeding



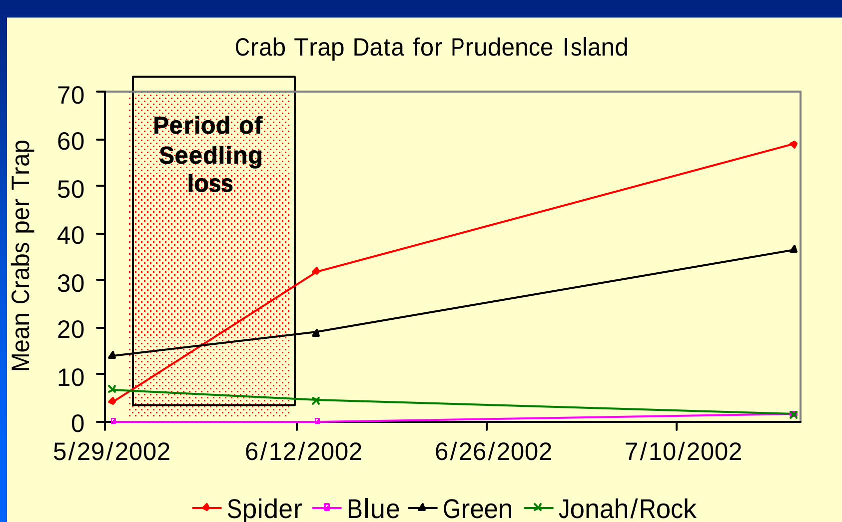
Potential Hurdles, Bioturbation

Damage to Seedling observed, June 2002



Potential Hurdles, Bioturbation

Damage to Seedling observed, June 2002



Potential Hurdles, Bioturbation

Damage to Seedling observed, June 2002

Present Research Efforts Funded by SeaGrant

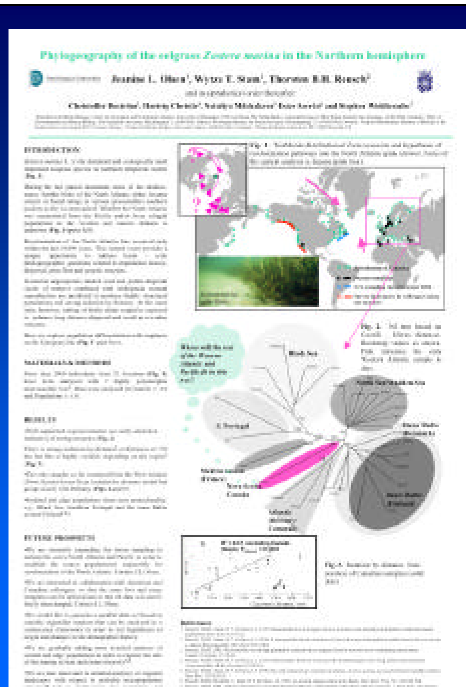
- Investigating alternative suspension media to reduce or enhance sediment respiration. Adjusting the redox layer to optimize seed germination.
- Testing more heat tolerant seedlings propagated from seed stocks collected in Chesapeake Bay.
- Planting strategies to overwhelm seedling loss from grazing.
- Fall meeting of geneticists and plant propagators/breeders to consider the implications of interbreeding between Narragansett Bay and Chesapeake Bay populations.

Gel-Injection Seeding

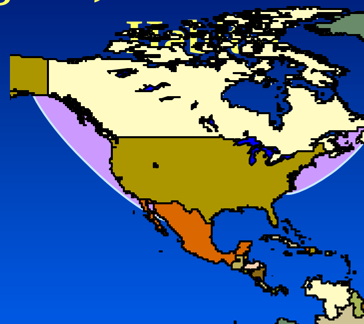
Gelling Agents Tested

Gel Type	% Germination		
	Mean	(Stdev)	n
Sodium Bentonite (Clay)	59**	(11.7)	3
Cab-O-Sil (Silica Based Thickener)	53**	(6.9)	3
Agri-gel, (Organic gel used in terrestrial seeding)	39	(9.4)	3
Knox Gelatin (Food Gelling agent, Pig Skin)	12	(4.8)	3
No Gel, Hand planting	33	(4.8)	3

** Significantly higher, ANOV($P<0.05$)


Phylogeography of the eelgrass *Zostera marina* in the Northern hemisphere

North American Eelgrass, *Zostera marina* L.



Eelgrass thrives in a broad range of environmental conditions from coarse sands and gravel in exposed locations to fine grained mud in quiescent embayments.

The North Atlantic *Zostera marina* population was nearly decimated during the 1930's by a virulent outbreak of a marine slime mold. Since the 1960's *Zostera marina* has successfully repopulated much of its former habitat.

Conclusions

- Planting seeds below the surface increases germination.
- Increasing seeding density had a negative effect on lateral shoot development.
- Increasing sediment organic content had a positive effect on lateral shoot development.
- All seeding densities came to a similar shoot density by the end of year 2, indicating a carrying capacity might be achieved.
- Gel-injection seeding looks promising but still in its infancy.

Acknowledgments

- Mike Traber, URI GSO
- Scott Nixon, URI GSO
- Malia Swartz, RI Seagrant
- Chris Deacutis, RI DEM
- Susan Adamovicz, RI DEM

Buoy-Deployed Seeding: A New Approach to Restoring Seagrass Using Seed

Chris Pickerell, Stephen Schott, and
Sandy Wyllie-Echeverria

SAV Propagation Workshop
Maritime Institute, Baltimore, MD
September 3-4, 2003

Peconic Estuary, Long Island, New York

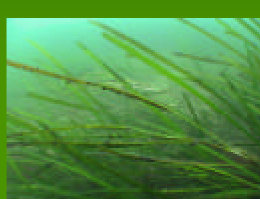
- Average salinity: ~27ppt
- Mean tidal range: 0.75m
- Depth range for eelgrass (*Zostera marina*): 1-5m
- Existing eelgrass : 1551 acres
- Historic eelgrass: ~6240 acres
- ~75% lost since 1930

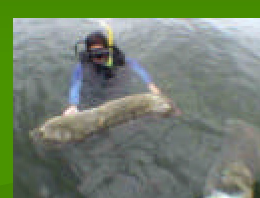
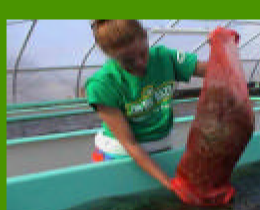
Eelgrass Restoration Efforts to Date

- Work began in 1996-1997 using the staple method (Fonseca, et al., 1982) and harvested adult shoots.
- TERFS (Burdick & Short, 2002) was adopted in 2000 utilizing floating and beach-cast shoots.
- Broadcast seeding (Orth, personal communication) began in 2001 after visiting VIMS.
- Development of the Buoy Deployed Seeding System (BuDSS) began soon after broadcast seeding (2001).

Seed Collection, Processing and Storage

(Churchill and Riner, 1978; Orth, et. al. 1994 and Granger et. al., 2002)



Our Goal

To design a planting method that closely mimics the natural ability of floating and rafting reproductive shoots of *Zostera* to disperse seeds long distances from a donor meadow. In so doing we would eliminate the need for flower storage and handling and the labor associated with it as well as provide a greater opportunity for the public to get involved with the process of seagrass restoration.

Basic Requirements

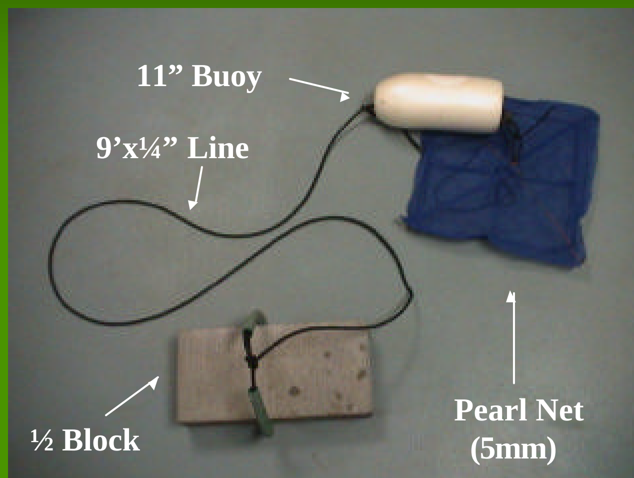
- Some means of holding reproductive shoots.
- Floatation to hold the shoots near the surface of the water to maximize spread.
- Anchor and line to hold the shoots over a defined area.

Prototype I

Design Considerations

- Reliable
- Inexpensive
- Easy to construct and deploy.
- Sturdy enough to be reused over multiple seasons.
- Adaptable to different planting densities, depths and energy environments.
- Use off-the-shelf components.

Prototype II



The Buoy Deployed Seeding System (BuDSS)

2002 BuDSS Deployment Locations

- Red Cedar Bluff: sandy, open bay
- Southold Bay: sandy, open bay
- Jessups Cove: muddy, shallow cove
- Sag Harbor Upper Cove: muddy, cove
- Sag Harbor Causeway: sand/mud, cove

Sag Harbor Causeway

Restoration Site

- This site supported eelgrass as recently as 1994.
- Broadcast seeding “successful” in 2001.
- Depth: 1.3m
- Tidal Range: 0.75m
- Sediment Type : 0% gravel/96% sand/4% clay with 6% Organic Matter

Sag Harbor Causeway
Restoration Site Deployment

- Our goal was to plant 2 - 0.10acre (0.04 hectare) plots at density of 200 seeds/m^2.
- Each buoy arc covered 29m^2 and was stocked with flowers that were expected to yield 5,800 seeds.
- 15 buoys were set in a 3x5 grid with 15ft OC spacing.
- Collected and deployed flowers on June 26, 2002.
- Conducted side-by-side broadcast seeding in September.

Sag Harbor Causeway
Restoration Site Monitoring

April 2003

June 2003

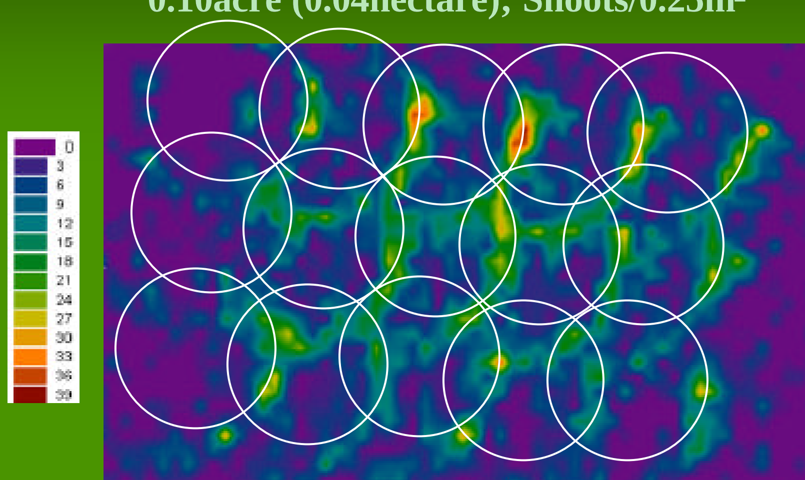
Results

- Seedling distribution closely corresponded to the arc of each buoy indicating minimal transport following release.
- Counts within plots (June) indicated at least 4% recruitment from predicted* seed fall.
- A mean of 2.8 laterals per genet were observed for all plots (BuDSS and Broadcast).
- There was a consistent, but different seedling distribution signature for the BuDSS and broadcast plots.

*Predicted seed fall was less than actual in subsequent tests.

Seedling Density Contour Plot

0.10acre (0.04hectare); Shoots/0.25m^2

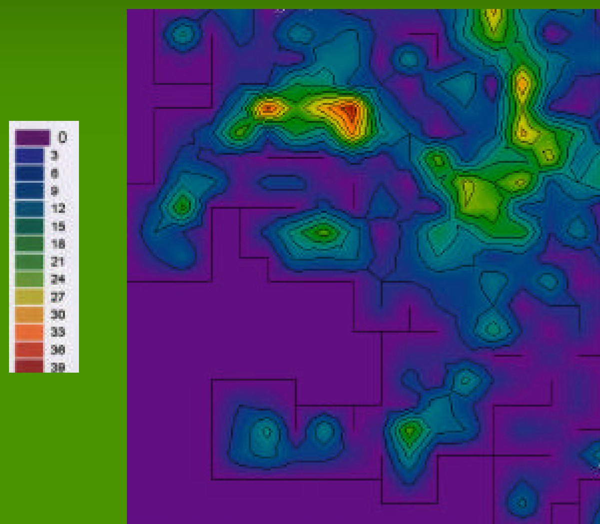


16 m

29 m

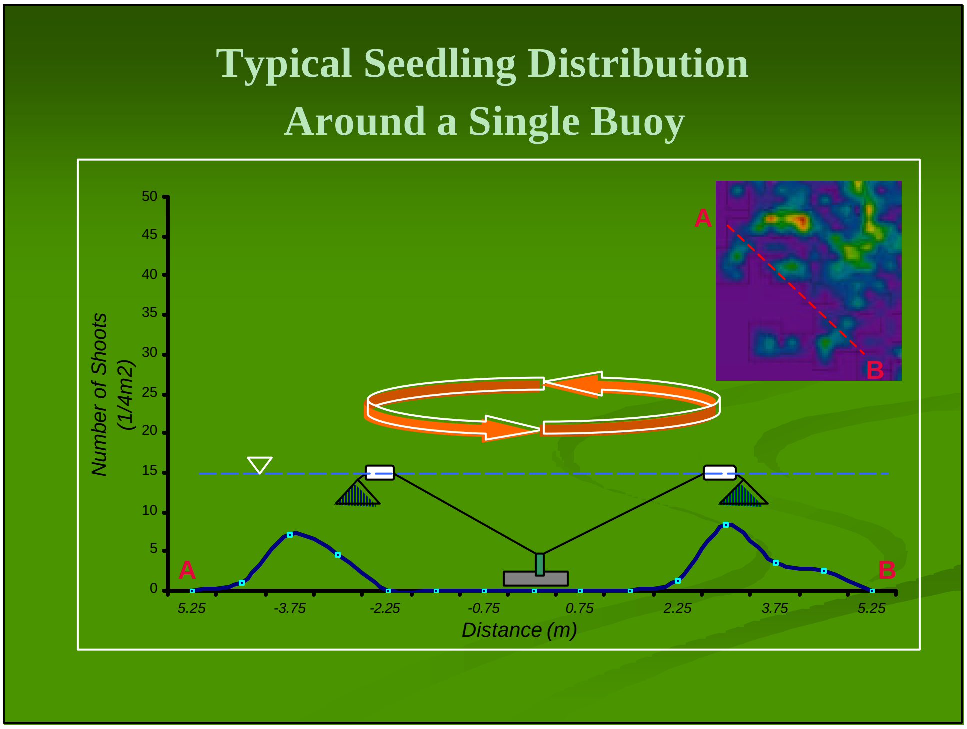
Single Buoy Arc

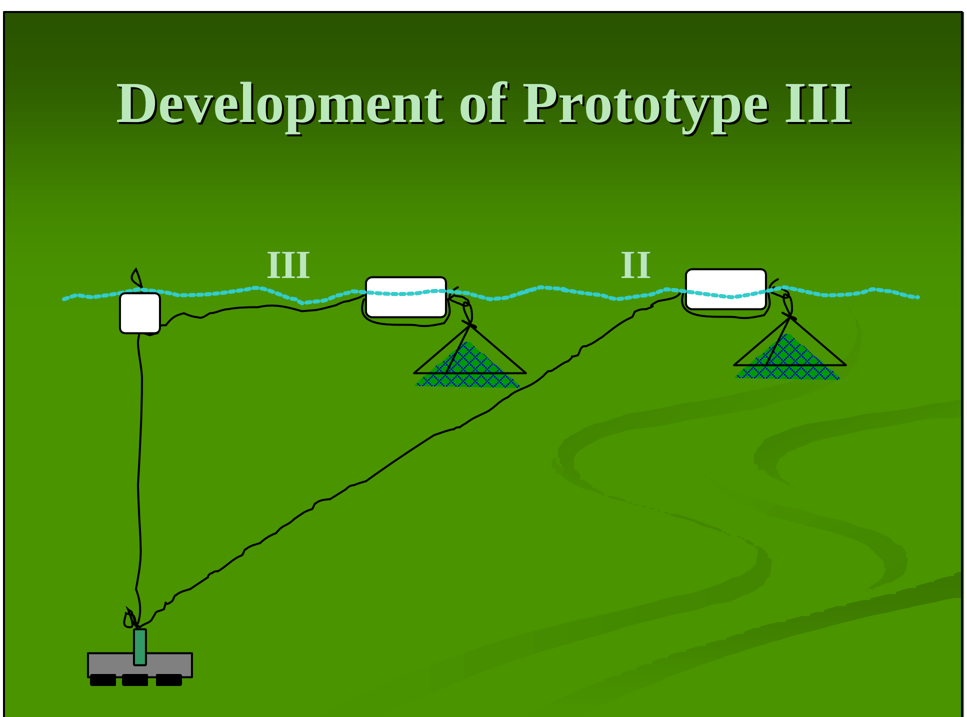
(Shoots/0.25m^2)



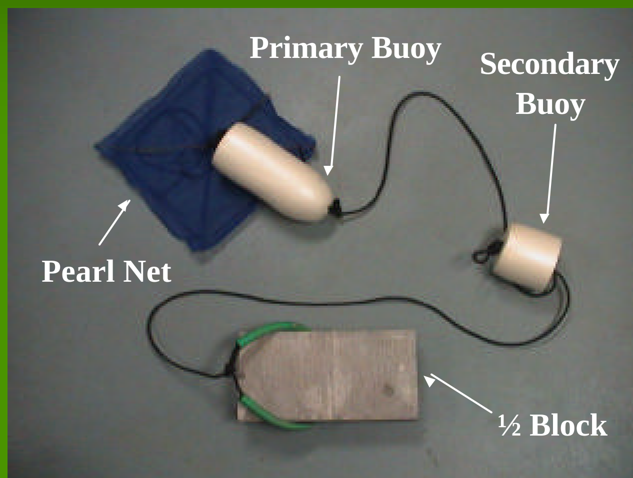
Lessons Learned

1. Seedling recruitment below each buoy was predictable, but not as evenly distributed as desired.


Typical Seedling Distribution
Around a Single Buoy
Number of Shoots
(1/4m2)
50
45
40
35
30
25
20
15
10
5
0
A
B
5.25
-3.75
-2.25
-0.75
0.75
2.25
3.75
5.25
Distance (m)
A
B


Development of Prototype III
III
II

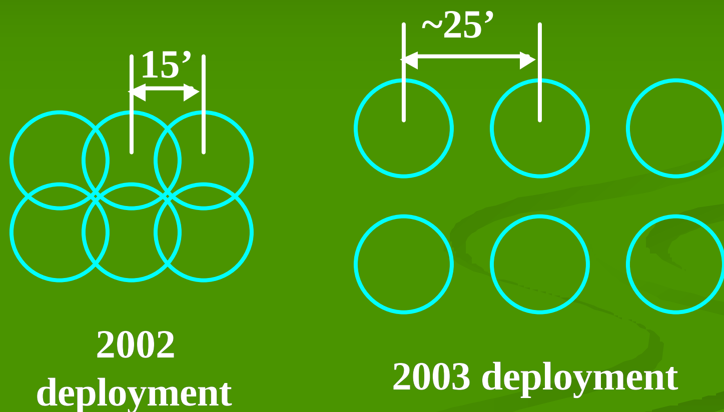
Prototype III



Lessons Learned

2. It would be possible to plant a larger area with the same number of buoys with a greater OC spacing between buoys.

Modified Buoy Spacing



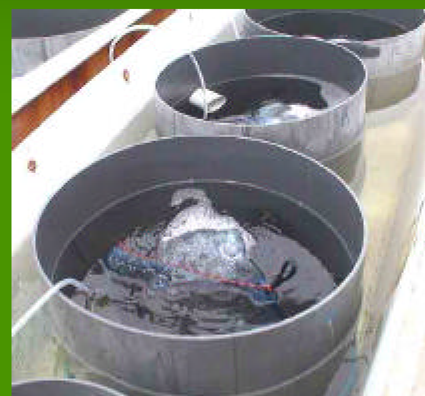
Lessons Learned

3. Our seed(ling) yield was not as high a expected based on preliminary counts of Stage IV seeds (DeCock, 1980) in spathes.

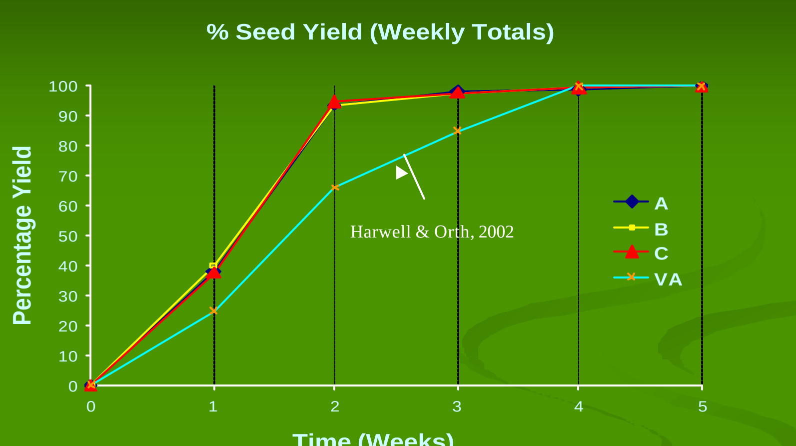
Seed Release Estimates

(How many and when?)

- Weekly counts from nets (Noyack Cr.)
- Data from the literature (Virginia; Harwell and Orth 2002.)
- Daily counts from nets (Mulford Pt.) Data not presented.



Seed Yield of Harvested Flowers



- Predicted total yield = ~5000 seeds per net, based on estimates of ~50 seeds/reproductive shoot and a stocking rate of 100 shoots/net
- Observed total yield (mean) = 2353 seeds per net

Costs

- Seed Collection (20 diver hrs./acre)
  - A well trained diver at a productive site can collect ~300 reproductive shoots/hour; enough to stock 3 nets. A 15 buoy deployment (0.25 acre at the wider OC spacing) would require 5 diver hours.
- Materials ($400/acre)
  - Each buoy/net/anchor combination costs $6.50.
  - Total materials cost for a 0.25 acre planting would be ~ $100.
- Deployment ($0-?)
  - Depending on the location of the planting site relative to collection site and whether a boat is used during seed collection, there may be no additional cost associated with deployment.
- Monitoring
  - Monitoring costs vary considerably with need. Cost would involve dive time, boat and/or travel time.

Advantages and Disadvantages

- ADVANTAGES:
  - Practical:
    - Minimal handling of flowers and seeds required
    - No need for storage and handling facility and the energy and labor necessary to maintain it
    - Visible to the public
  - Theoretical:
    - Mimic's natural phenological schedule
    - May reduce predation by staggering seed dispersal over time
    - May yield a more even distribution of seeds given the combination of time and natural forces at work
- DISADVANTAGES:
  - Practical
    - Visible to the public (could be an attractive nuisance)
    - Navigation issues
  - Theoretical
    - Mimic's natural phenological schedule (seed predators still active)
    - May allow more time for predation, export, or over burial

What's Next?

- Further refine method to improve seedling distribution and buoy spacing.
- Develop a modified version for high-energy and deeper water environments.
- Test with additional species.

Acknowledgements

- New York State Department of State, Long Island Community Foundation and The National Fish and Wildlife Foundation for funding this ongoing work.
- The Peconic Estuary Program
- The Towns of Southold and Southampton
- Bob Orth, VIMS
- Steve Granger, URI
- Jerry Churchill, Adelphi University
- Jon Semlear, Bayman and Southampton Town Trustee
- Mallory Delany for preparation of the Power Point presentation.
- Kim Petersen, Matt Parsons, and Mallory Delany for their assistance in the field.

References

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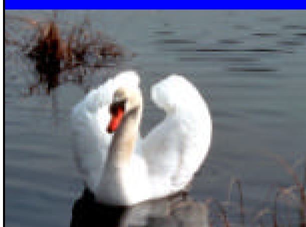
Reproductive Potential of Natural Populations of *Ruppia maritima* and *Potamogeton perfoliatus* by Seed in the Mid-Chesapeake Bay



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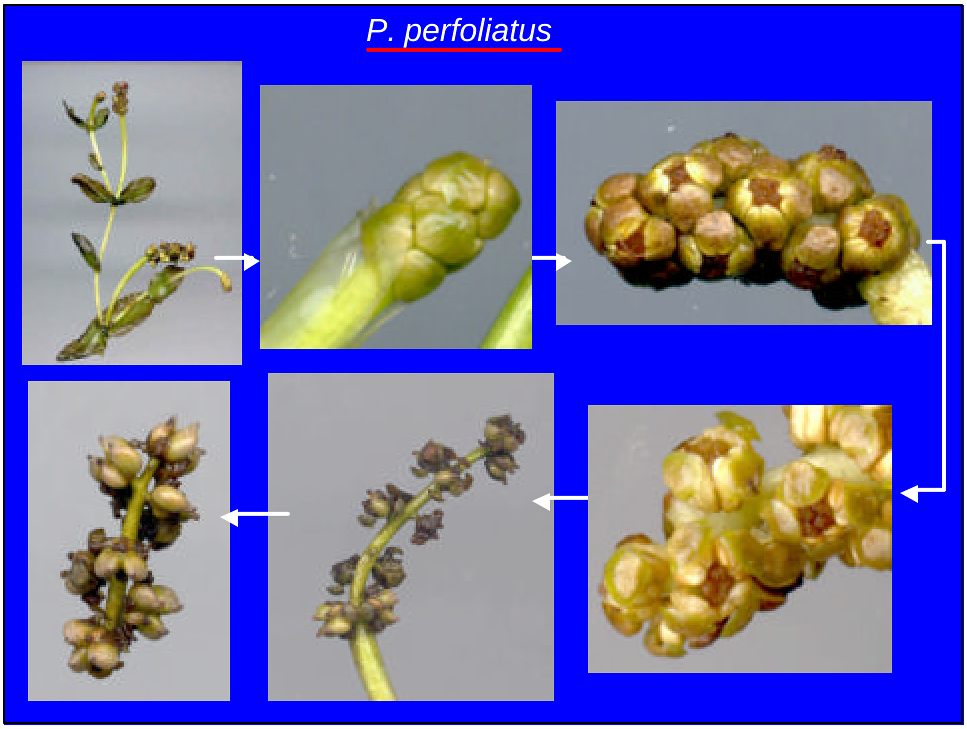
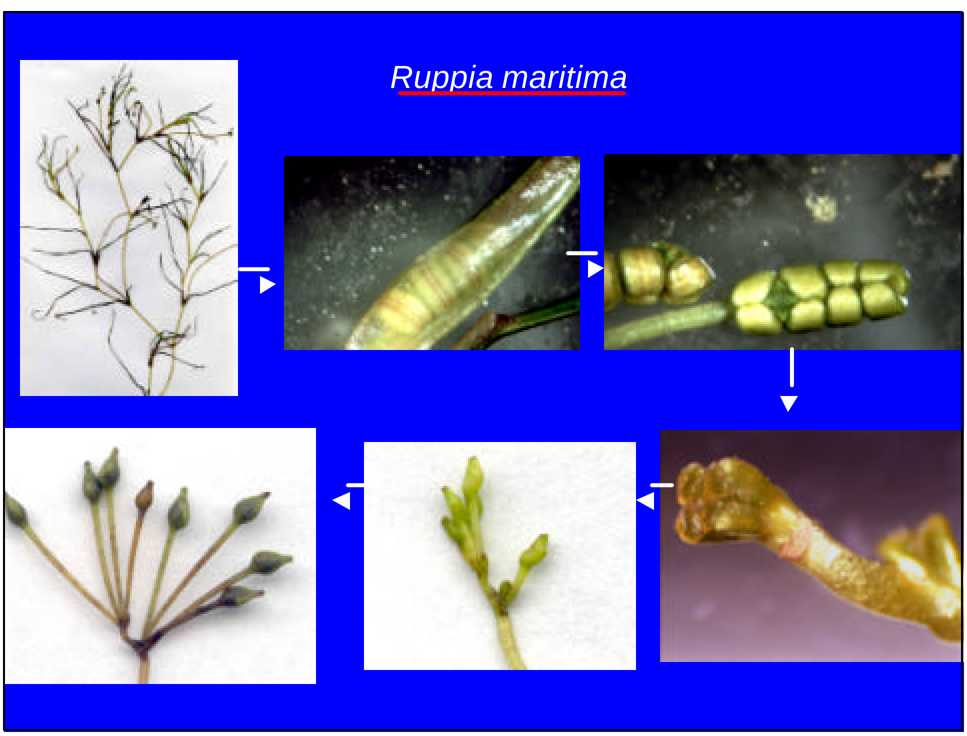
Reproductive Potential	*Potamogeton perfoliatus*	*Ruppia maritima*
1) Plants/unit area	Highly variable	Highly variable
2) Stems/plant	Highly variable	Highly variable
3) Inflorescences/ stem		
4) Flowers/ inflorescence		
5) Carpels/flower		
6) Ovules/carpel		
Seeds/ inflorescence		
Seeds/stem		


P. perfoliatus


Ruppia maritima

Reproductive Potential	*Potamogeton perfoliatus*	*Ruppia maritima*
1) Plants/unit area	Highly variable	Highly variable
2) Stems/plant	Highly variable	Highly variable
3) Inflorescences/ stem	2.4	2.6
4) Flowers/ Inflorescence	5-12 (9)	2
5) Carpels/flower	4	4
6) Ovules/carpel	1	1
Seeds/ inflorescence	20-48	8
Seeds/stem	48-115	20.8

~~Redhead – Location Eastern Bay~~

*Average ranges of three, 1/4lb. Samples					
Date:	Immature Inflorescence	Mature Inflorescence	Inflorescence with Immature Seed	Inflorescence with Mature Seed	Potential Seeds per lb. (Inflorescences x36x4)
07/29/03	10-48	18-54	3-28	32-81	9072-30384
08/07/03	20-40	30-40	14-19	60-93	17856-27648
08/14/03	5-8	7-15	5-15	42-130	8496-24192
^Averages of three, 1/4lb. Samples					
Date:	Immature Inflorescence	Mature Inflorescence	Inflorescence with Immature Seed	Inflorescence with Mature Seed	Potential Seeds per lb. (Inflorescences x36x4)
07/29/03	25	32	12	52	17424
08/07/03	31	35	16	72	22176
08/14/03	7	10	10	77	14976
**Counts per 25 individual stems					
Date:	Immature Inflorescence	Mature Inflorescence	Inflorescence with Immature Seed	Inflorescence with Mature Seed	Seeds/stem (Inflorescences x36/25)
07/29/03	17	20	6	19	89
08/07/03	18	15	2	39	107
08/14/03	8	4	1	31	63

Ruppia – Location Taylor's Island

*Ranges of three, 1/4lb. Samples.

Date:	Immature Inflorescence	Potential Seed Production	Mature Inflorescence	Potential Seed Production	Immature Seed	Mature Seed	Total Potential Seeds for one, 1/4lb.	Potential Seeds per lb. (Seedsx4)
07/28/03	0-6	0-48	0-2	0-16	460-669	78-100	538-833	2152-3332
08/01/03	7-11	56-88	1-5	8-40	291-619	84-138	439-885	1756-3540
08/05/03	3-7	24-56	1-2	8-16	134-234	49-65	215-371	860-1484
08/20/03	0	0-64	0	0	0-9	14-17	14-90	56-360

^^ Averages of three, 1/4lb. Samples.

Date:	Immature Inflorescence	Potential Seed Production	Mature Inflorescence	Potential Seed Production	Immature Seed	Mature Seed	Total Potential Seeds for one, 1/4lb.	Potential Seeds per lb. (Seedsx4)
07/28/03	3.66	29.28	1.33	10.64	535.33	86.66	661.91	2647.64
08/01/03	8.66	34.64	2.66	21.28	405.66	107.66	569.24	2276.96
08/05/03	5.33	42.64	1.66	13.28	188.33	54.33	298.58	1194.32
08/20/03	0	0	0	0	5.66	15	20.66	82.64

**Counts per 25 individual stems

Date:	Immature Inflorescence	Potential Seed Production	Mature Inflorescence	Potential Seed Production	Inflorescence with immature Seed	Inflorescence with Mature Seed	Total Potential Seeds for 25 stems	Potential Seeds/stem (Inflor. x8/25)
07/28/03	2	16	1	8	48	11	496	19.8
08/01/03	5	40	1	8	57	15	624	24.9
08/05/03	4	32	2	16	57	14	616	24.6

Factors Affecting Reproductive Potential

1) **Plant vigor** - Photosynthesis - Ambient environment

2) **Plant growth** - Physical damage - Bioturbation

3) **Flowering** - Plant vigor - Plant growth - Stage of growth

4) **Floral abortions** - Miscarriages

5) **Seed set** - Pollination - Plant density - Habitat stability

6) **Seed maturation** - Plant vigor - Plant growth - Habitat stability

7) **Seed dispersal** - Water currents - Waterfowl

8) **Overwintering success** - Habitat stability - Bioturbation

Effects of Waterfowl Classes on Factors Affecting Reproductive Potential

Factor	Resident Waterfowl	Migrating Waterfowl
1) Plant vigor	Direct continuous	Indirect sporatic (overwintering structures)
2) Plant growth	Direct continuous	None - Favorable (Apicial dominance)
3) Flowering	Direct continuous	None
4) Floral abortion	N.A.	N.A.
5) Seed set	N.A.	N.A.
6) Seed maturation	Direct continuous	None
7) Seed dispersal	None	Significant
8) Overwintering success	?	?

Effects of Mute Swans on the Reproductive Potential of *Potamogeton perfoliatus* and *Ruppia maritima* (30 days)

R. maritima

1,550 seeds/lb x 2.2 lb/kg x *3.8 kg/day/swan x 30 days = 388,740 potential seeds/swan

P. perfoliatus

18,192 seeds/lb x 2.2 lb/kg x *3.8kg/day/swan x30 days = 4,562,553/seeds/swan

*Willey and Halla 1972

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