Ribbed mussel habitat restoration for water quality benefits

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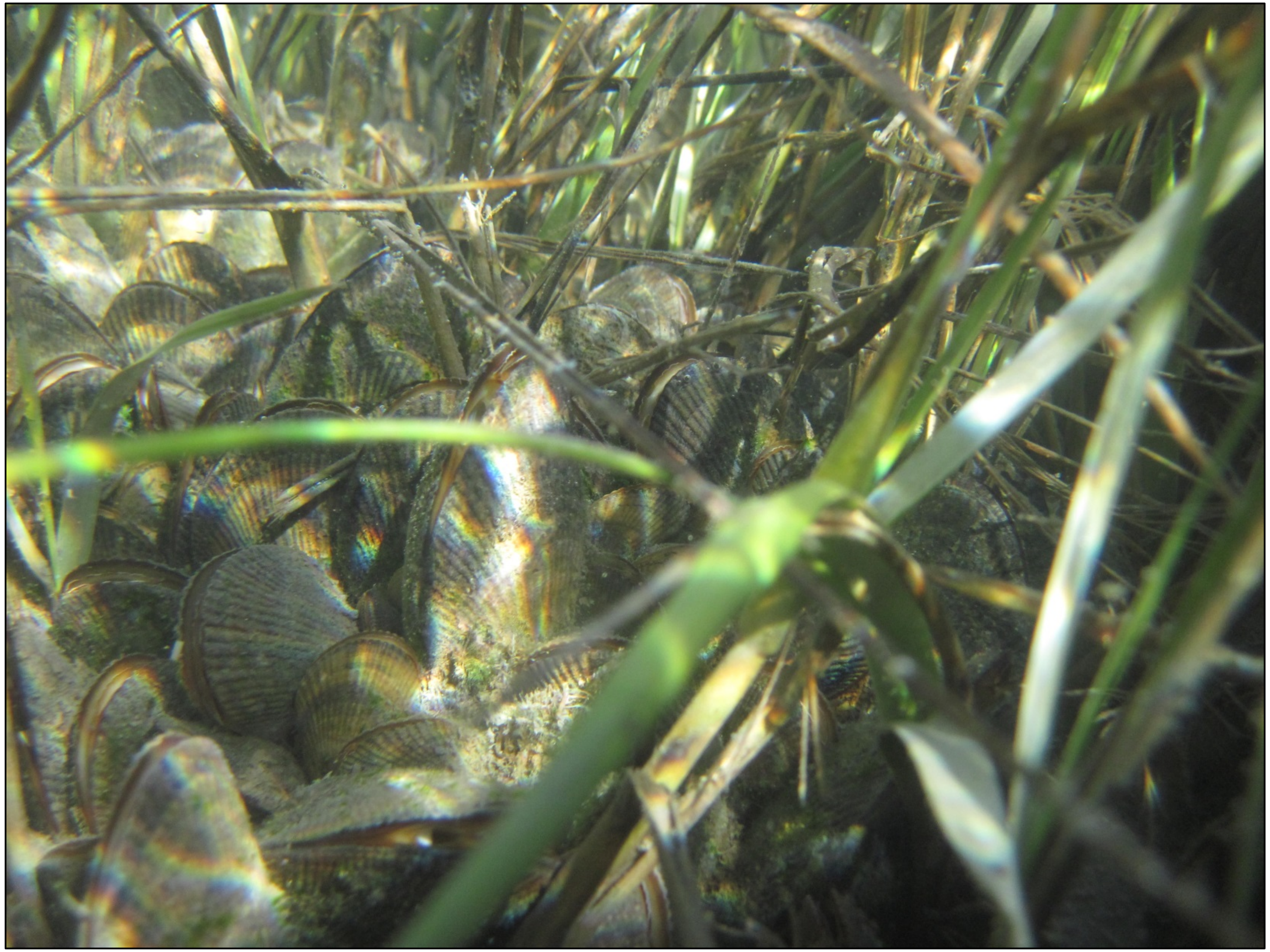
Delaware Center for Inland Bays STAC Meeting

July 27, 2018 Rehoboth Beach, DE

Bivalves of the Delaware Estuary

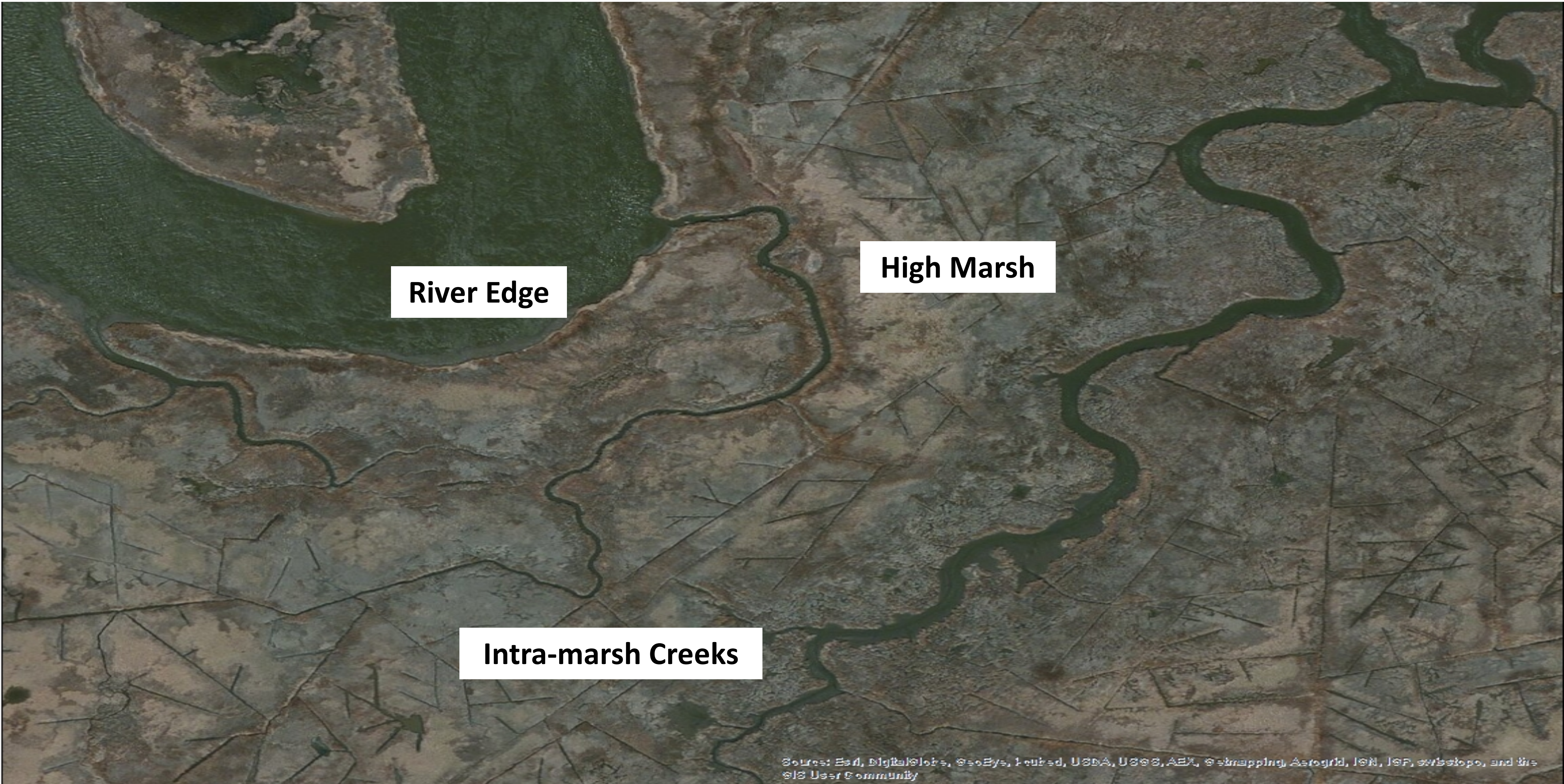
Nature's Benefits (Natural Capital)		Oysters	Marsh Mussels	FW Mussels
Millennium Ecosystem Assessment Categories	***Specific Services/Values***	***Relative Importance Scores***		
Provisioning: Food & Fiber	*Dockside Product*	✓✓✓		✓
Regulating	*Shoreline & Bottom Protection*	✓✓		
	Shoreline Stabilization	✓✓	✓✓✓	✓✓
Supporting	*Structural Habitat*	✓✓✓	✓✓	✓✓
	Biodiversity: Imperiled Species			✓✓✓
	Bio-filtration	✓✓✓	✓✓✓	✓✓✓
	Biogeochemistry	✓✓	✓✓	✓✓
	Prey	✓	✓✓	✓
Cultural/ Spiritual/ Historical/ Human Well Being	*Waterman Lifestyle, Ecotourism*	✓✓		
	Native American	✓✓		✓✓✓
	Watershed Indicator	✓✓✓	✓✓	✓✓✓
	Bio-Assessment	✓✓✓	✓✓	✓✓✓

Ribbed Mussels: Functionally Dominant Bivalve of Eastern US Salt Marshes



Relevant Literature: Kuenzler 1961; Lent 1969; Jordan and Valiela 1982; Bertness 1984

Ribbed Mussels Live Across the Salt Marsh Landscape



Research Questions: RARE Grant EPA ORD

1. Where are our current services located?
2. Are they maximized?
3. If not, can they be enhanced, and how?

Task 1: Seasonal Physiological Experiments

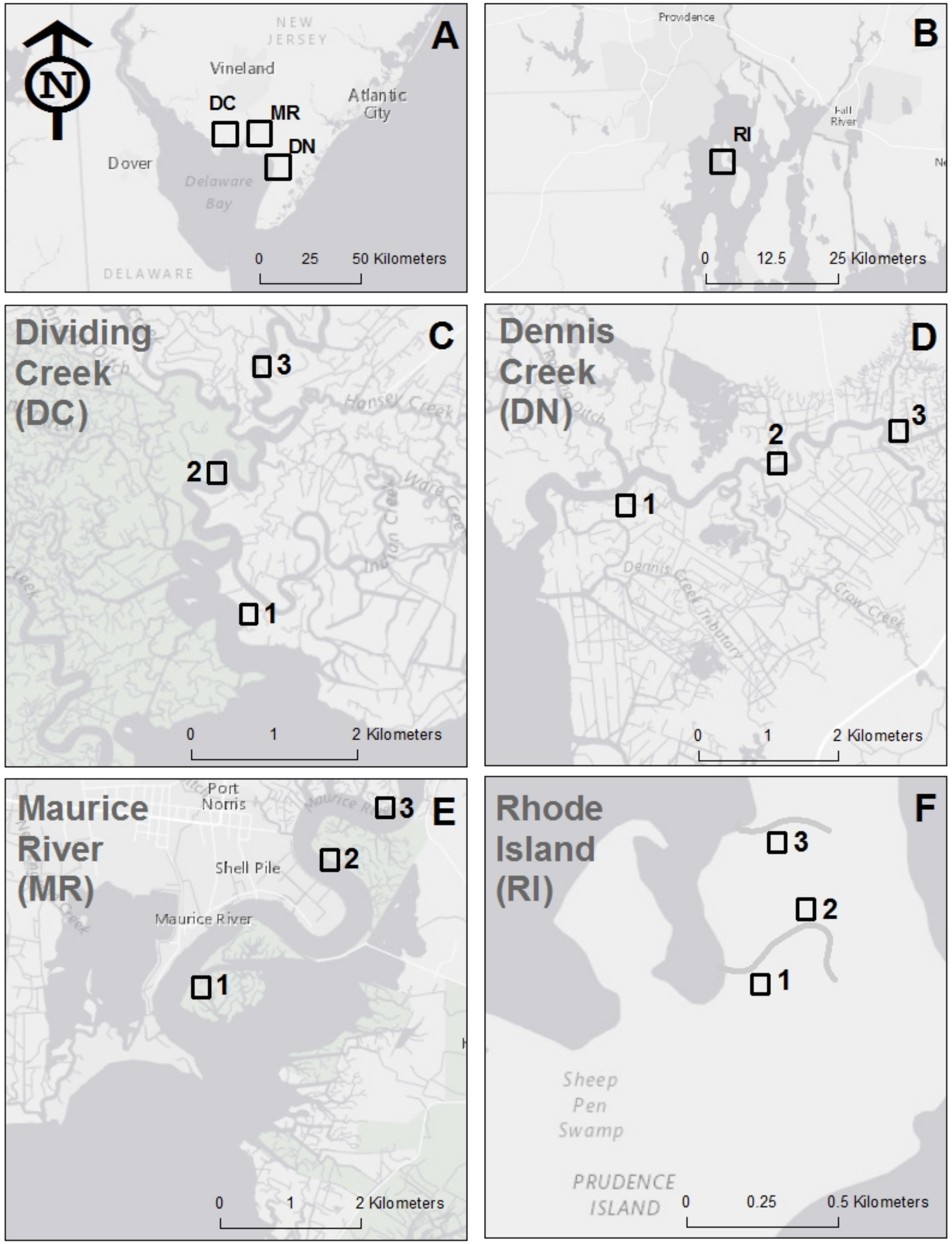
Rate Function on Natural Seston Diets

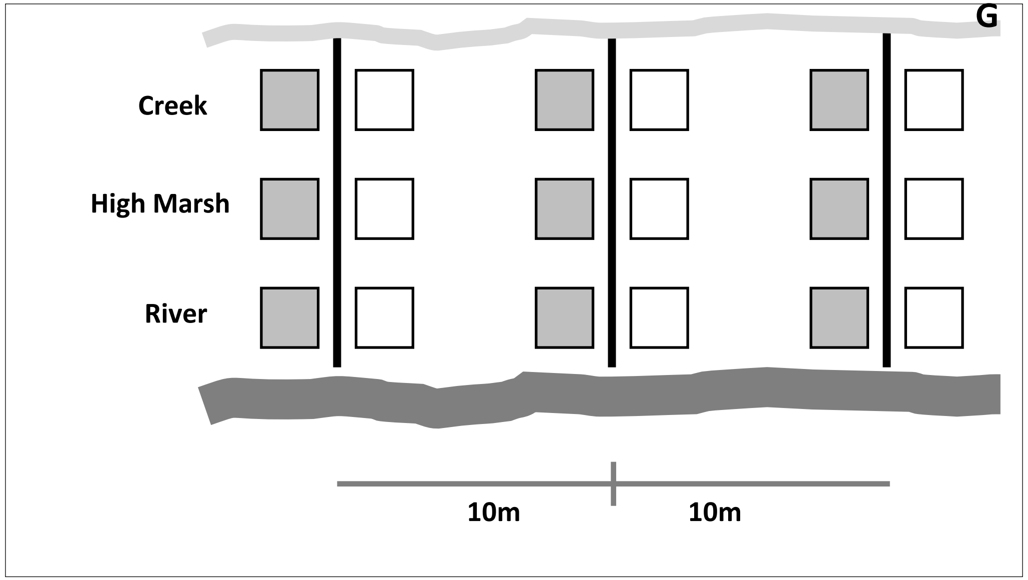
1. Clearance Rate (l hr^{-1} $gDTW^{-1}$):

2. Concentration of TSS or PN (mg l^{-1}):

3. Filtration Rate TSS or PN (mg hr^{-1} $gDTW^{-1}$)
   - Fall: 7.2-8.2°C (6-10°C)
   - Spring: 14.6-16.2°C (14-18°C)
   - Summer: 20.5-25.6°C (>20°C)
     - RI Summer Only

Regional Applied Research Effort (RARE) 2012-2014
TITLE: Importance of Ribbed Mussels for Salt Marsh Climate Adaptation and Water Quality Management in Atlantic Estuaries
REGIONAL CONTACT: Irene Purdy, Kathleen Drake (Division of Environmental Planning and Protection)(DEPP), Region 2
ORD INVESTIGATOR: Suzanne Ayvazian, Elizabeth Watson, Atlantic Ecology Division (AED)

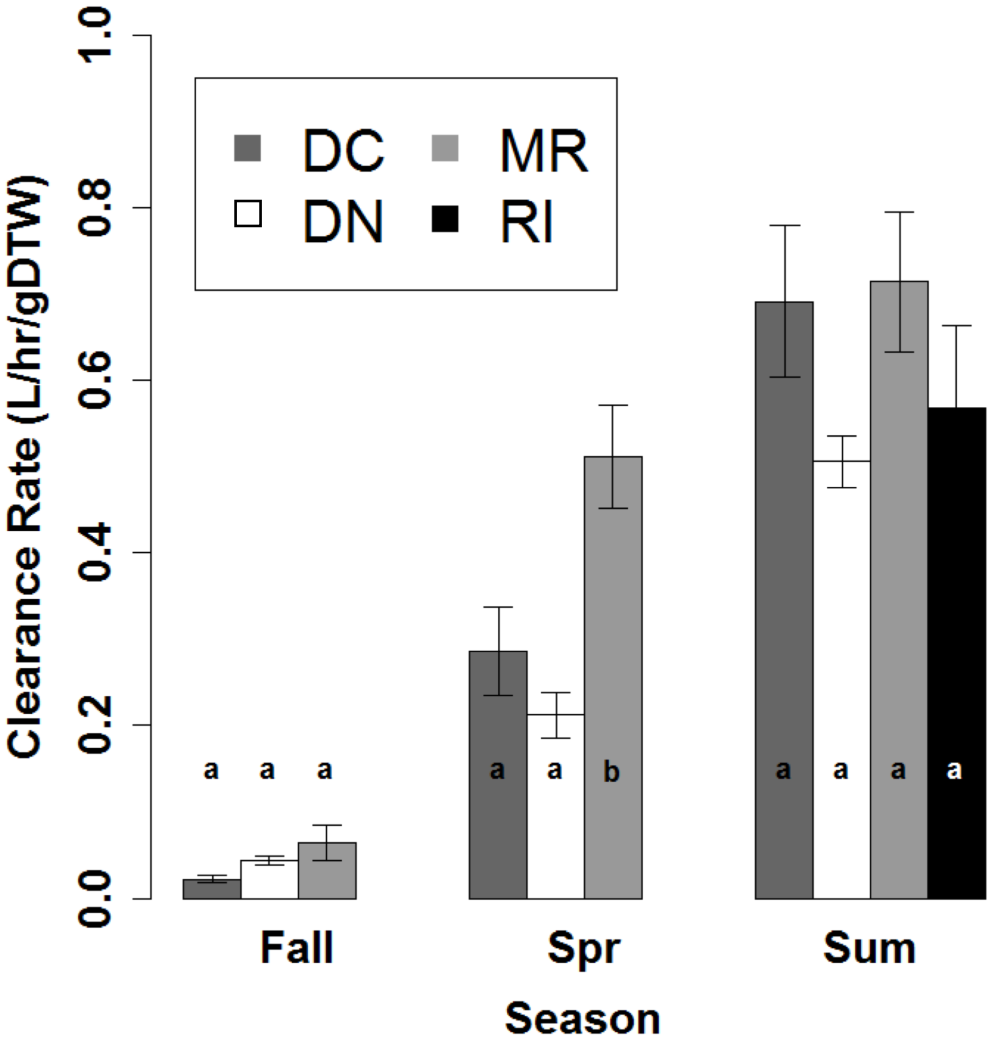




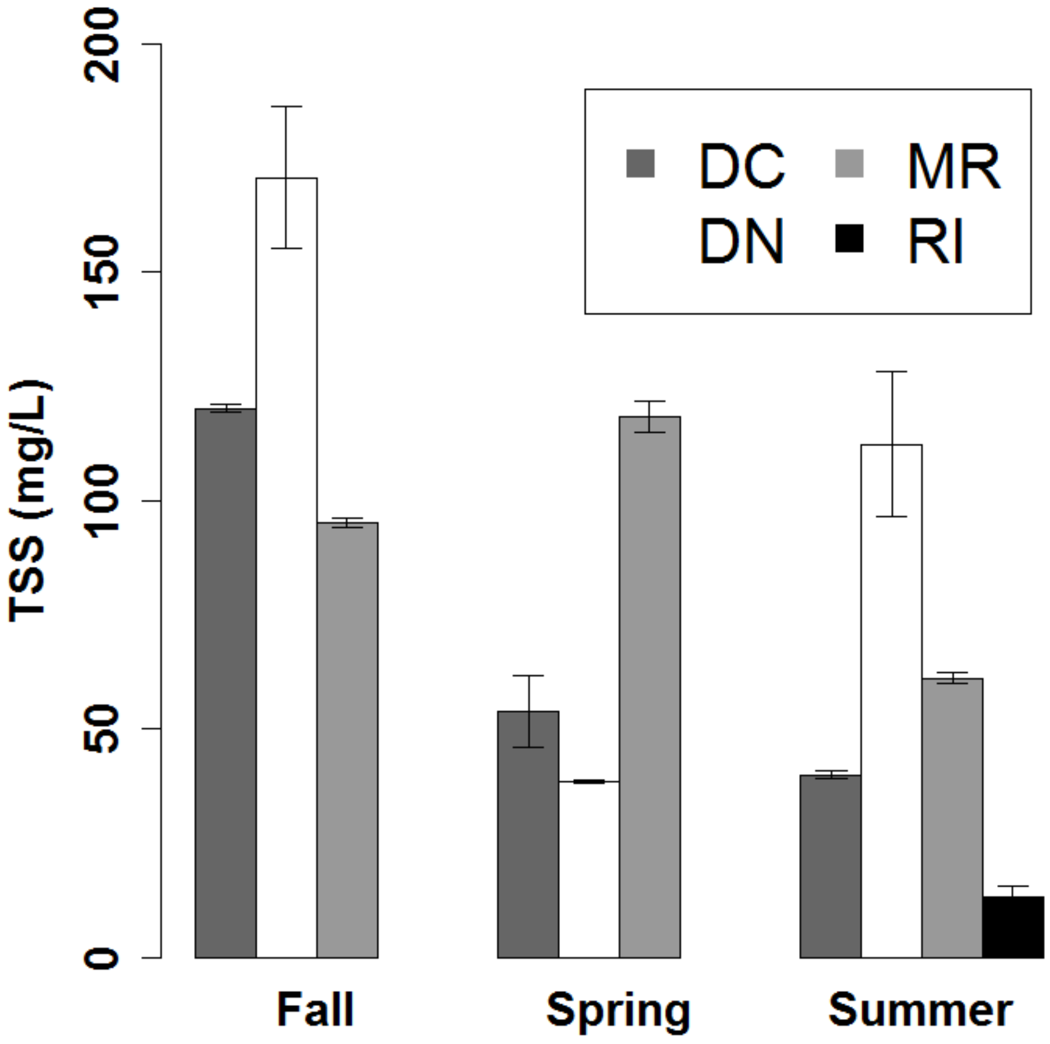
Task 2: Marsh-Specific Data

1. Ribbed Mussel Biomass Across Habitats
2. Relative Percent Habitat Area
3. Inundation Times
4. Local Erosion Rates
5. Existing Living Shoreline Recruitment Data

Ribbed Mussel Water Processing was Consistent Across Space (Habitats and Marshes) but Differed Through Time



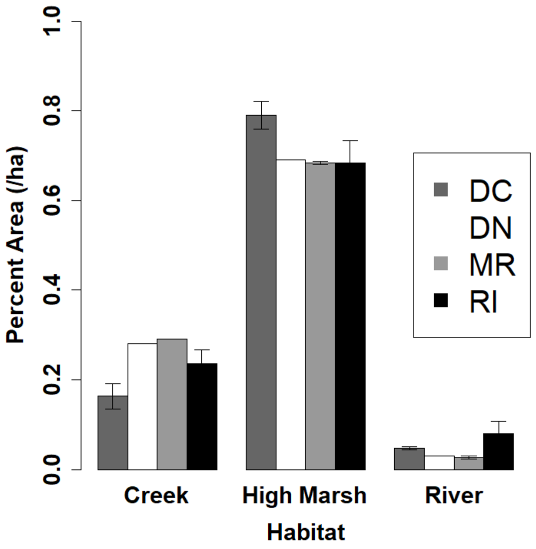
Seston was Variable Across Space and Time

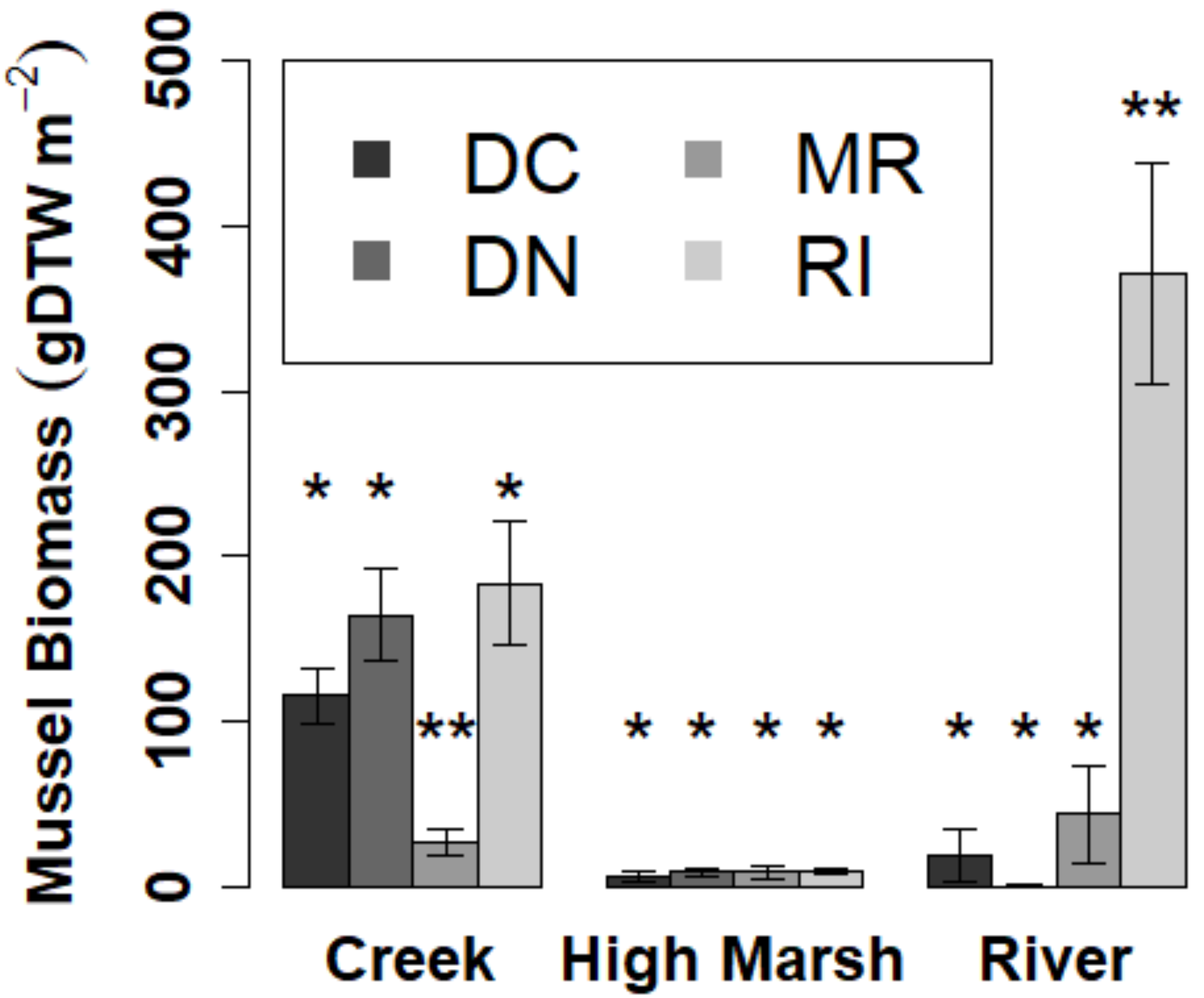


Annual Filtration Rates Dependent on Water Processing and Food Availability

Marsh	n	Annual Clearance Rate (l hr^{-1} $gDTW^{-1}$)	TSS (mg l^{-1})	PN (mg l^{-1})	Filtration Rate TSS (mg hr-^{1} $gDTW^{-1}$)	Filtration Rate PN (mg hr^{-1} $gDTW^{-1}$)
DC	79	0.27 ± 0.04	71.26 ± 8.84	0.59 ± 0.08	19.37	0.16
DN	93	0.29 ± 0.02	107.12 ± 14.83	0.89 ± 0.12	30.95	0.17
MR	79	0.34 ± 0.04	91.44 ± 5.81	0.77 ± 0.04	31.47	0.27
RI	96	0.28 ± 0.03	13.12 ± 2.34	0.11 ± 0.01	2.95	0.02

Assess Habitat and Marsh-Specific Parameters





Mussel Biomass: non-normal but similar distributions; used Kruskal Wallis and Dunn post-hoc test (can accommodate unbalanced design)

Integrate Spatial and Filtration Rate Data

$$\boldsymbol{Gross\ Habitat\ Specific\ Filtration\ Rate\ per\ Site\left(\frac{kg}{yr\ ha}\right) =}$$

$$Average\ Marsh\ Gross\ Filtration\ Rate\left(\frac{mg}{hr\ gDTW}\right) * Immersion\ Time\left(\frac{hr}{day}\right) * Mussel\ Biomass\left(\frac{gDTW}{m^2}\right)$$

$$* \ Percent\ Habitat\ Area * Scaling\ Factor\left(\frac{kg\ m^2 day}{mg\ ha\ yr}\right)$$

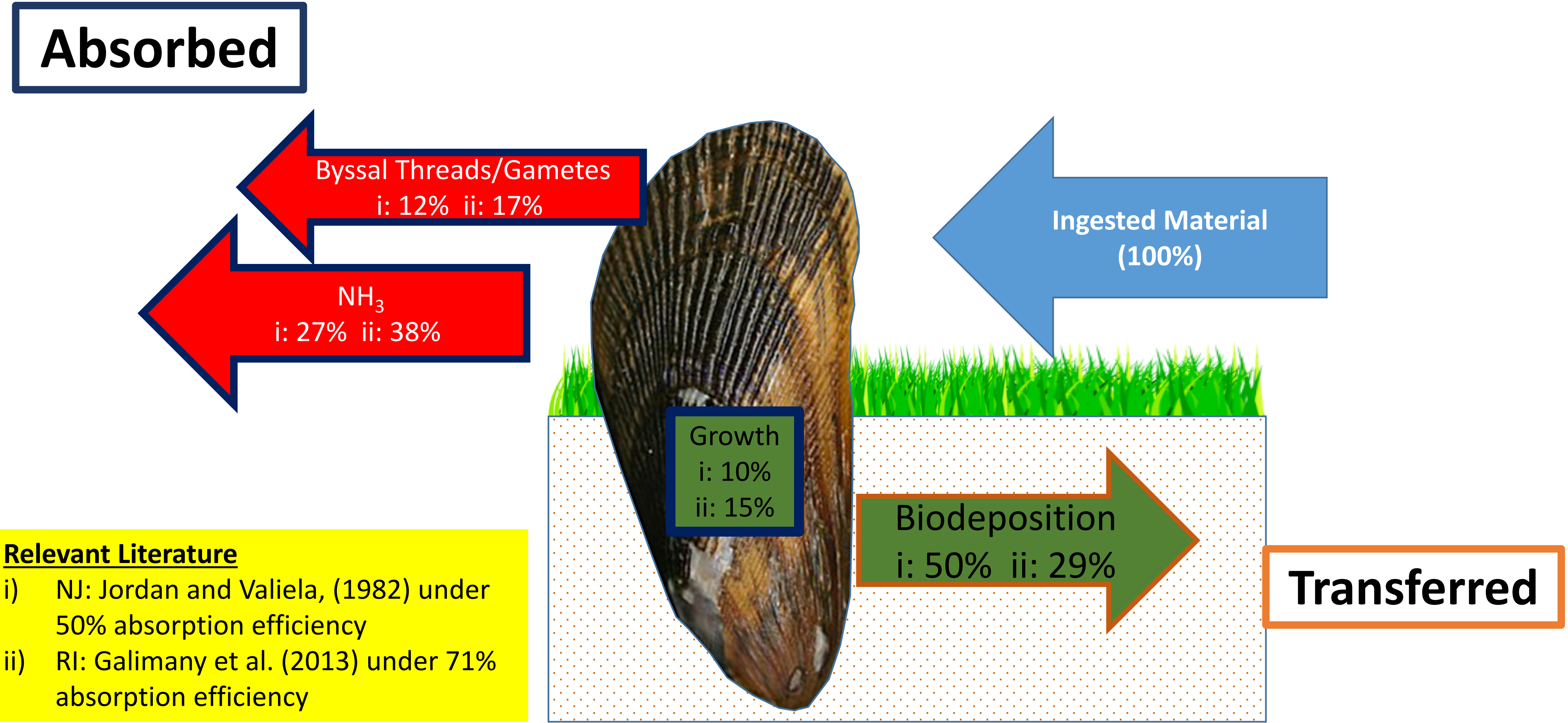
Marsh	Site	Habitat	Filtration Rate TSS mg hr^{-1} $gDTW^{-1}$	Filtration Rate PN mg hr^{-1} $gDTW^{-1}$	Immersion hr day^{-1}	Biomass gDTW m^{-2}	% Habitat Area	Habitat-Specific Filtration Rate TSS kg yr^{-1} ha^{-1}	Habitat-Specific Filtration Rate PN kg yr^{-1} ha^{-1}
DC	1	Creek	19.37	0.16	9.93	71.11	0.22	10,981.71	91.68
DC	2	Creek	19.37	0.16	10.63	86.58	0.14	9,109.19	76.04
DC	3	Creek	19.37	0.16	10.84	190.62	0.13	18,991.21	158.54
DC	1	High Marsh	19.37	0.16	7.59	0.02	0.73	7.84	0.07
DC	2	High Marsh	19.37	0.16	9.59	3.50	0.81	1,922.19	16.05
DC	3	High Marsh	19.37	0.16	10.82	16.59	0.83	10,528.20	87.89
DC	1	River	19.37	0.16	11.38	4.58	0.05	184.27	1.54
DC	2	River	19.37	0.16	13.44	0.70	0.05	33.26	0.28
DC	3	River	19.37	0.16	11.23	52.97	0.04	1,681.64	14.04

Marsh-wide Gross Filtration Rate

Marsh	Gross Filtration Rate-TSS ($kg\ ha^{-1}\ yr^{-1}$)	Gross Filtration Rate-PN ($kg\ ha^{-1}\ yr^{-1}$)
DC	17, 813 ± 6,694	148.71 ± 55.88
DN	33, 359 ± 5,638	277.44 ± 46.89
MR	13,538 ± 6,954	114.14 ± 58.63
RI	11, 504 ± 2,640	92.80 ± 21.30

But what does this mean for ecosystem service provisioning?

Ribbed Mussel Mediated Ecosystem Services: Net Particulate Nitrogen Removal



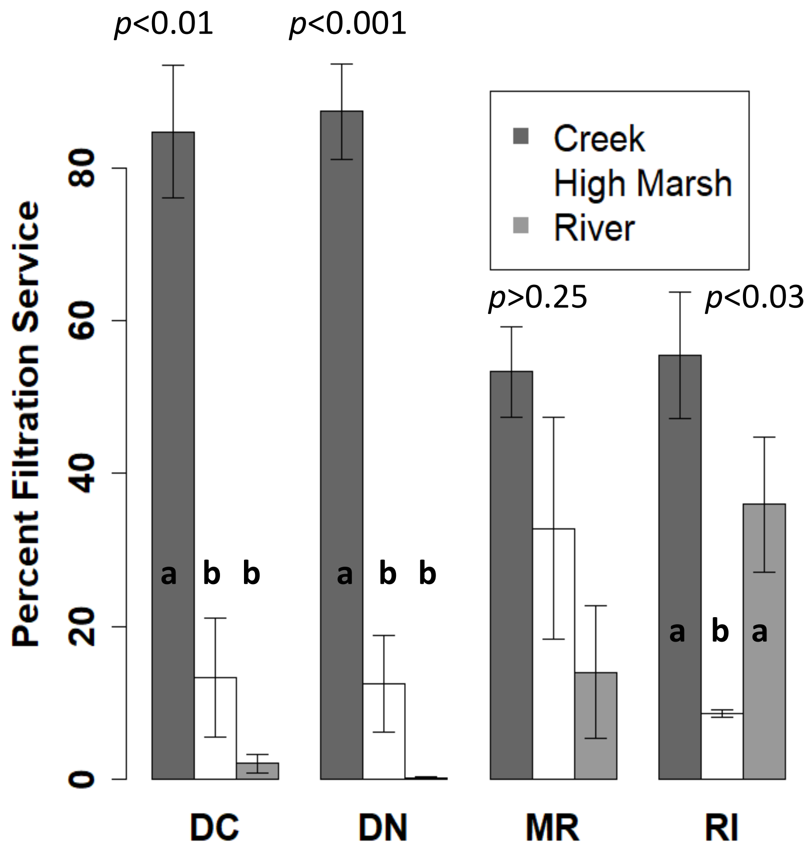
Relevant Literature

i) NJ: Jordan and Valiela, (1982) under 50% absorption efficiency

ii) RI: Galimany et al. (2013) under 71% absorption efficiency

NJ: Services Concentrated in Creeks
RI: Services Concentrated in Creeks and Rivers

Marsh	Estimated Net PN Removal ($kg\ ha^{-1}\ yr^{-1}$)		
	Total	**Biodeposit**	**Growth**
DC	89.22 ± 33.53	74.35 ± 27.94	14.87 ± 5.59
DN	166.46 ± 28.13	138.72 ± 23.45	27.74 ± 4.69
MR	68.49 ± 35.18	57.07 ± 29.32	11.41 ± 5.86
RI	39.90 ± 9.16	26.91 ± 6.18	12.99 ± 2.98



Ribbed Mussel Filtration Services were Vastly Underrepresented along NJ River Habitat

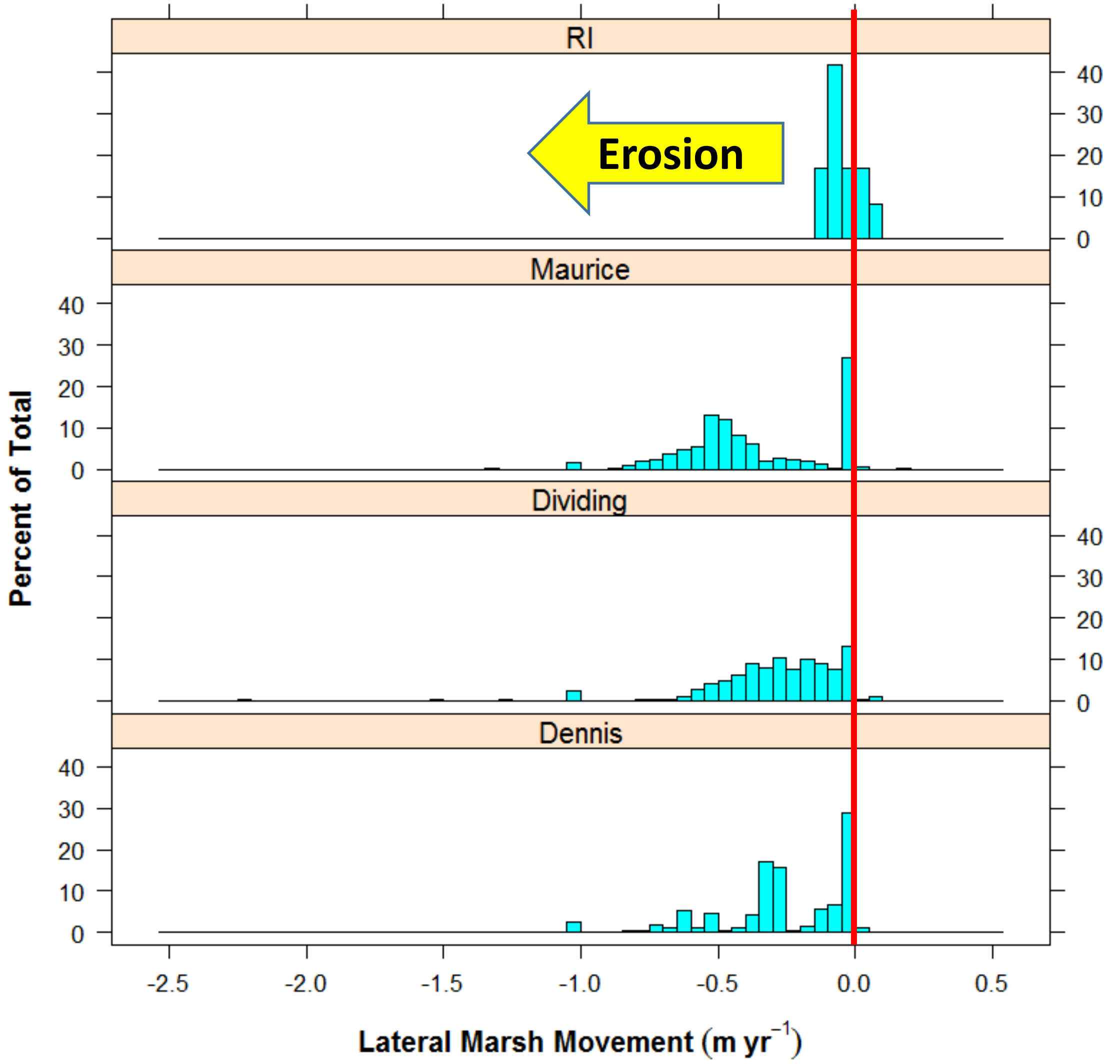
Habitat	Region	Percent Area (ha^{-1})	Mussel Biomass (g DTW m^{-2})	Gross Annual TSS Removal (Kg ha^{-1} yr^{-1})	Net Annual PN Removal (Kg ha^{-1} yr^{-1})	Percent of Services (Regional Habitat^{-1})
High Marsh	NJ	72.11±0.02*	8.56±1.91*	4,823±1,489	24.21±14.82	22%
	RI	68.33±0.05*	9.60±1.94*	339±73	1.18±0.26	3%
Creek	NJ	24.44±0.02*	102.99±13.44*	16,040±3,740	80.28±19.90	74%
	RI	23.67±0.03*	183.87±37.00**	7,901±1,843	27.40±16.40	69%
River	NJ	0.03±0.01*	21.63±11.10*	705±485	3.56±3.33	3%
	RI	0.08±0.03*	371.20±66.48**	3,263±1,568	11.32±5.44	28%

Net Particulate Nitrogen Removal
River:Creek

RI: 0.41 DC: 0.05 DN: <0.01 MR: 0.21

Percent Area: normal and similar distributions: linear mixed effects model (marsh/site) as random effects;
Used lme which can handle unbalanced designs

NJ River Habitat Experience High Rates of Erosion



RI Coastal Resources Management Council (1939-2003) http://www.crmc.ri.gov/maps/maps_shorechange.html

NJ Partnership for the Delaware Estuary (1970-2014): Haaf, L., S. Demberger, A. Padeletti, D. Kreeger. 2017. Mid Atlantic Tidal Rapid Assessment: Development of the Shoreline Attribute Using Historical Change Analyses. Partnership for the Delaware Estuary. PDE Report No. 17-##.

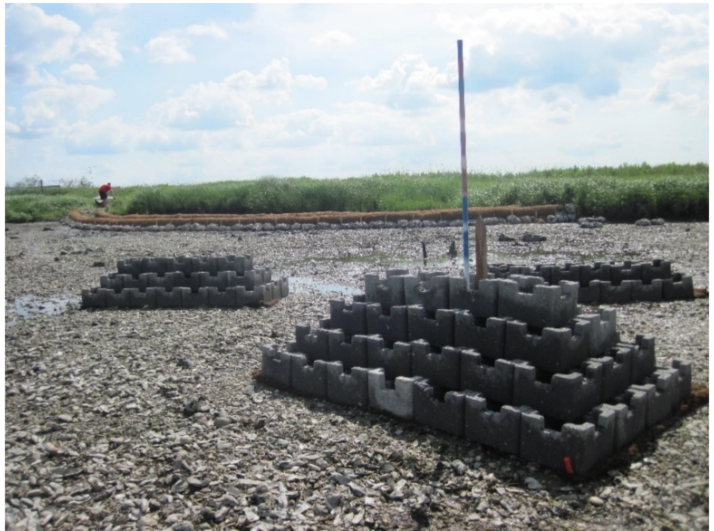
What Can We Do?




Living Shorelines Provide Ribbed Mussel Habitat Over Time

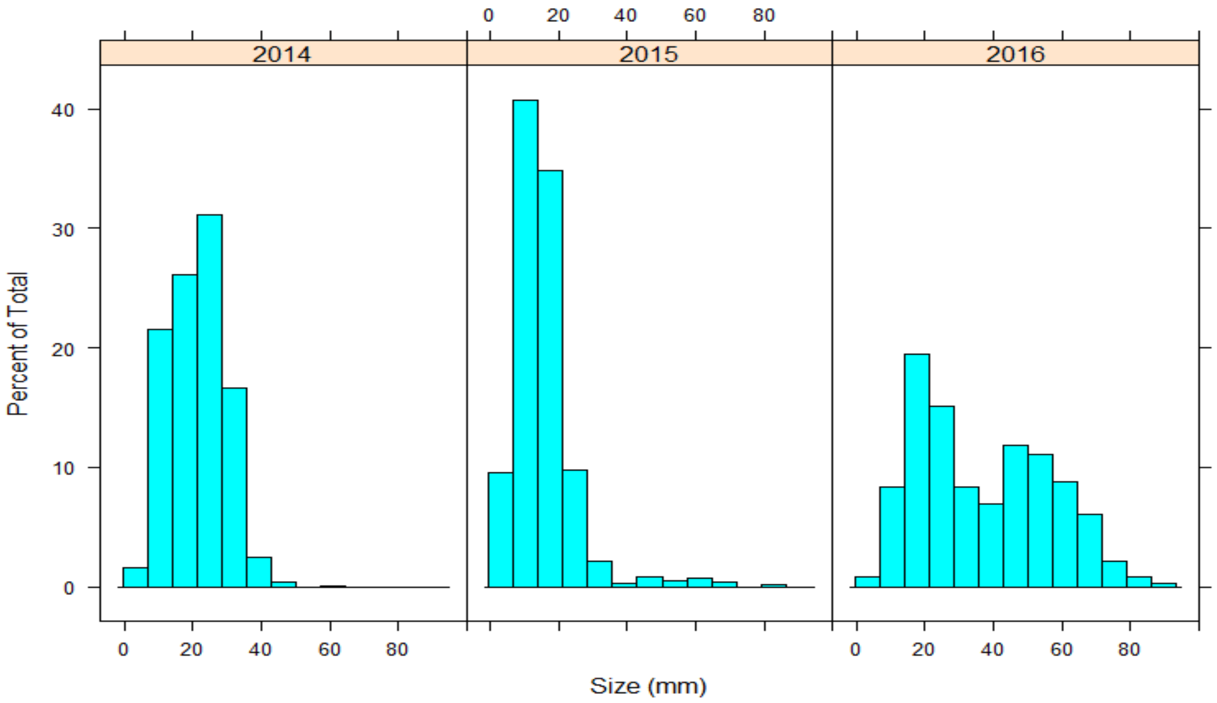
Mispillion Living Shoreline: Materials installed 04/2014

	Oyster Castles	Shellbags	Cusps	Total
11/2014 Oysters	1,146	1,273	-	2,419
11/2015 Oysters	7,510	2,038	-	9,548
11/2016 Oysters	16,927	6,408	1,205	24,540
11/2014 Ribbed Mussels	0	0	0	0
11/2015 Ribbed Mussels	107	N/A	26	133
11/2016 Ribbed Mussels	193	898	485	1,576

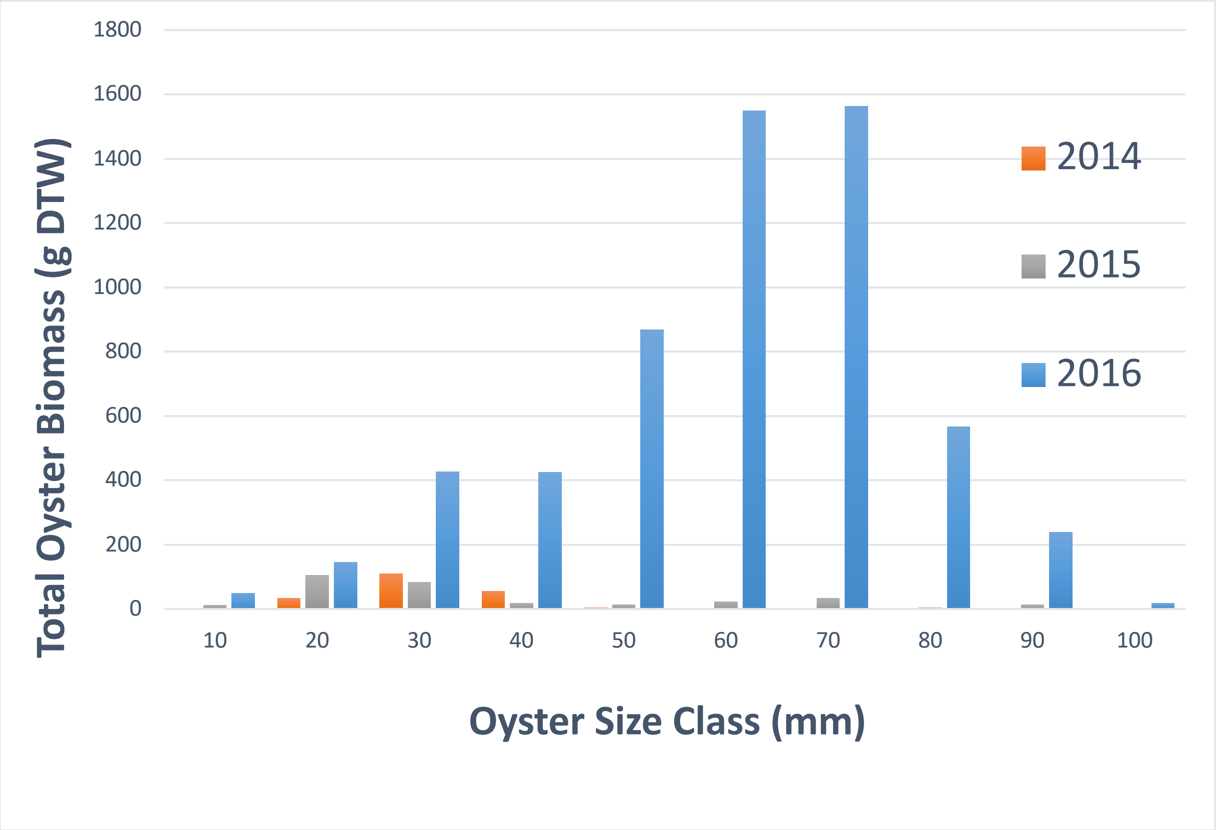


Changes in Population Structure and Biomass Drive Changes in Services

Size Structure of Population



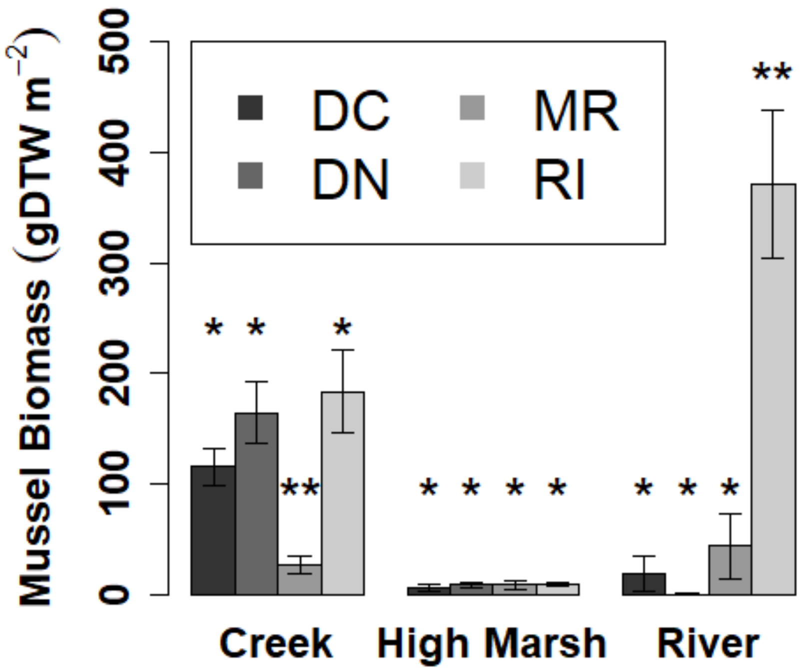
Biomass: Non-Linear Δ/Time



Older Oysters = Bulk of Physiological Services

Potential Uplift from Enhanced Ribbed Mussel Populations

Density	Living Shoreline Length (m)	Annual Filtration Rate (mg hr^{-1} $gDTW^{-1}$)	Mussel Biomass (g DTW m^{-2})	Gross Annual FR-TSS (kg yr^{-1})	Gross Annual FR-PN (kg yr^{-1})	Net FR-PN (kg yr^{-1})	Increase
Current NJ River	100	23.93 (TSS) 0.20 (PN)	21.63	226.71	1.89	1.14	



Potential Uplift from Enhanced Ribbed Mussel Populations

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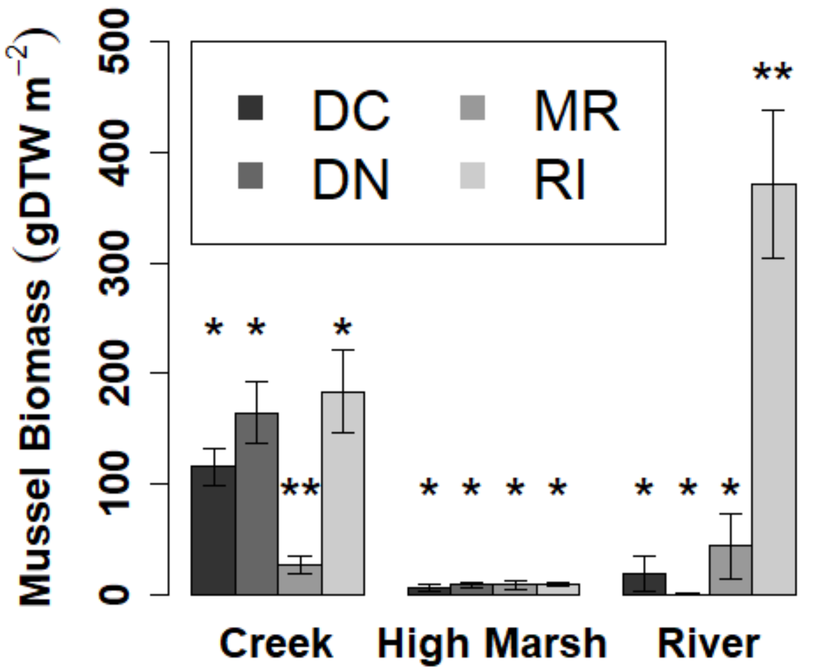
Current NJ River	100	23.93 (TSS) 0.20 (PN)	21.63	226.71	1.89	1.14	
NJ Creek			102.99	1,079.41	9.02	5.41	371%



Potential Uplift from Enhanced Ribbed Mussel Populations

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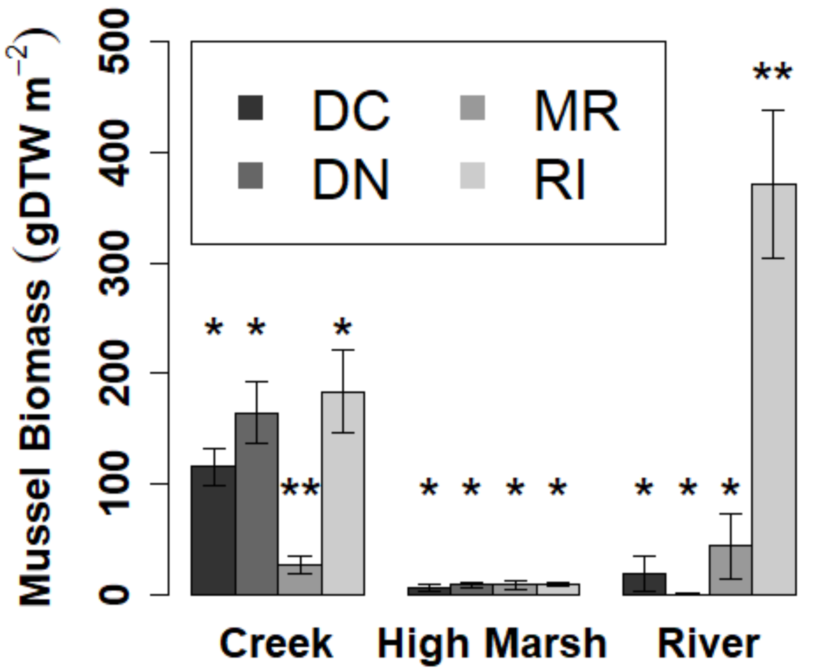
NJ Creek			102.99	1,079.41	9.02	5.41	371%
Mean RI River/Creek			237.10	2,485.13	20.77	12.46	991%



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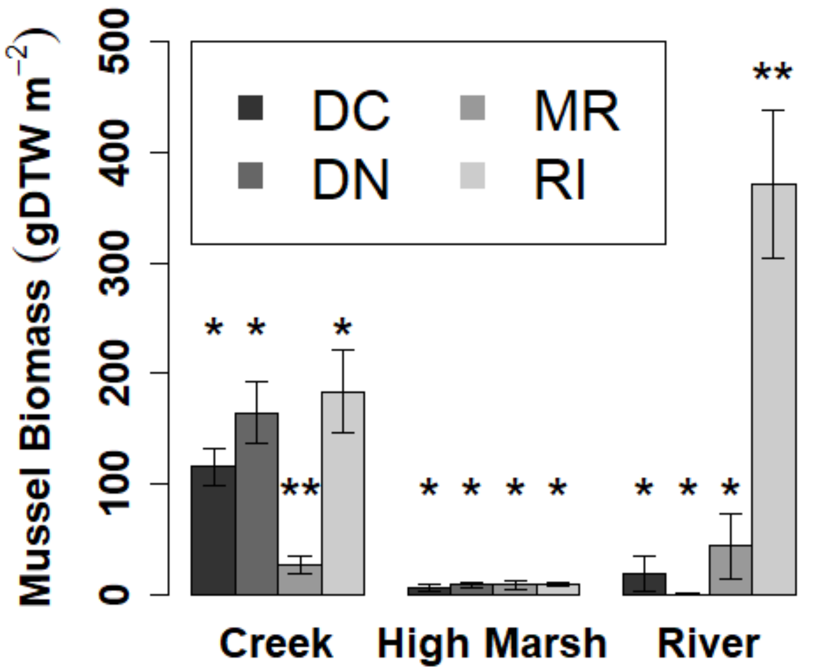
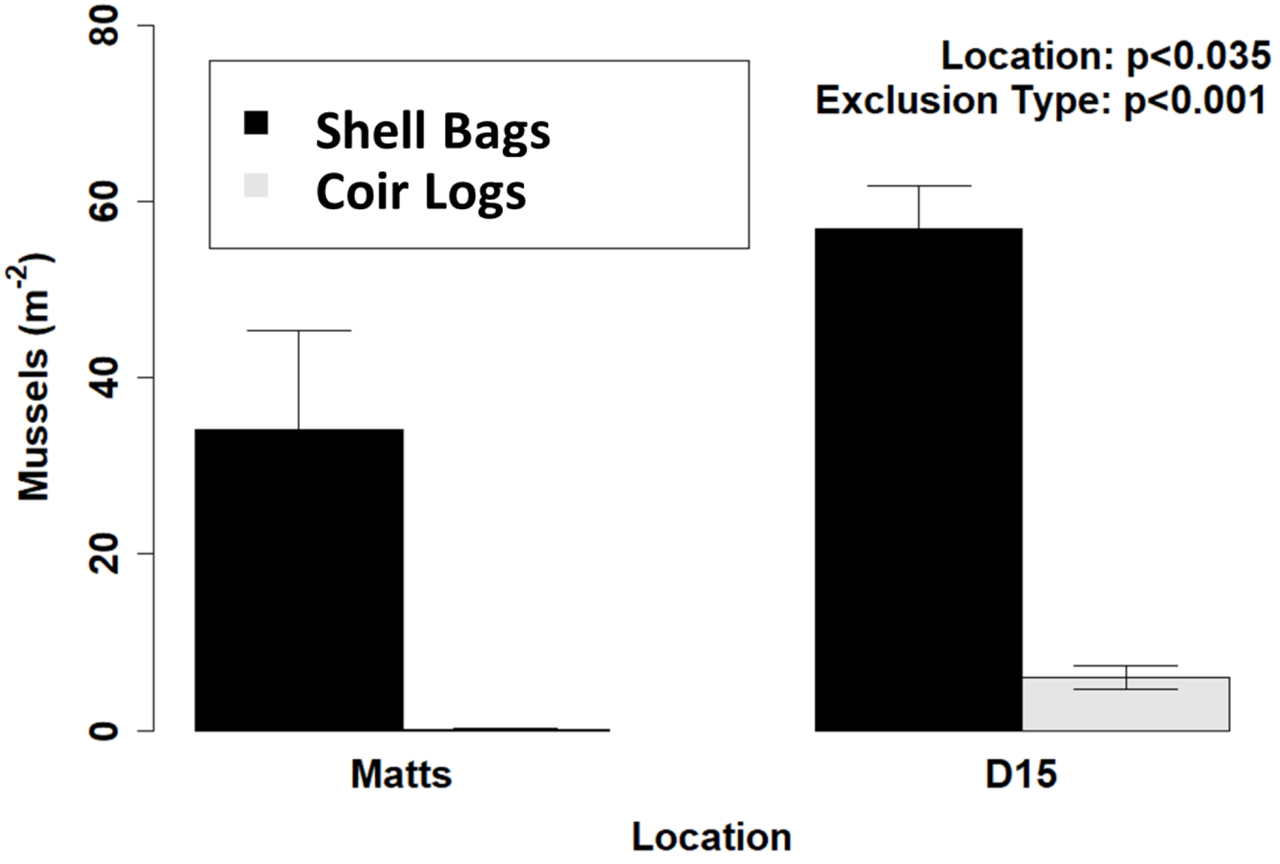
NJ Creek			102.99	1,079.41	9.02	5.41	371%
Mean RI River/Creek			237.10	2,485.13	20.77	12.46	991%
RI River			371.20	3,890.67	32.52	19.51	1,615%



New Efforts are Focusing on Enhancing Ribbed Mussel Recruitment in Living Shorelines

Questions

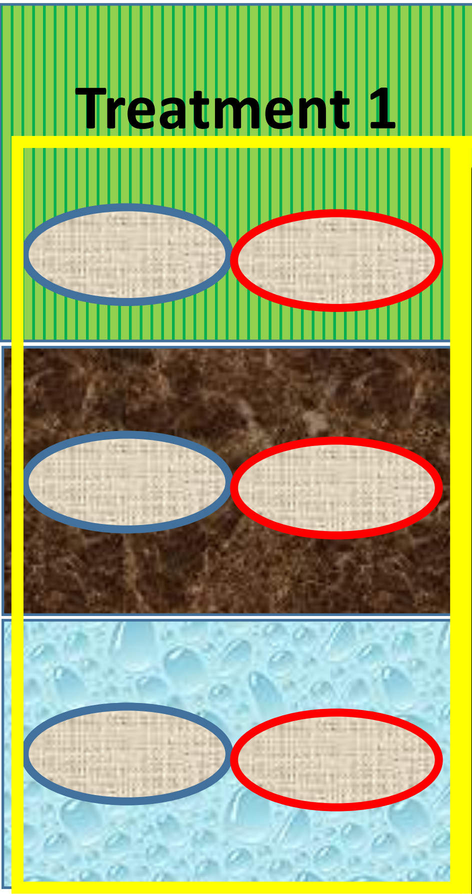
1. **Is mussel density greater in shell bags than on coir-fiber logs in our older living shorelines?**
2. **Is mussel density greater in materials that exclude predators than those that allow access to predators?**



2016 EPA Region 2 Regional Applied Research Efforts (RARE) Grant

Project Title: Enhancement of Ribbed Mussel Populations in Mid-Atlantic Salt Marshes and Living Shorelines for Water Quality Ecosystem Services

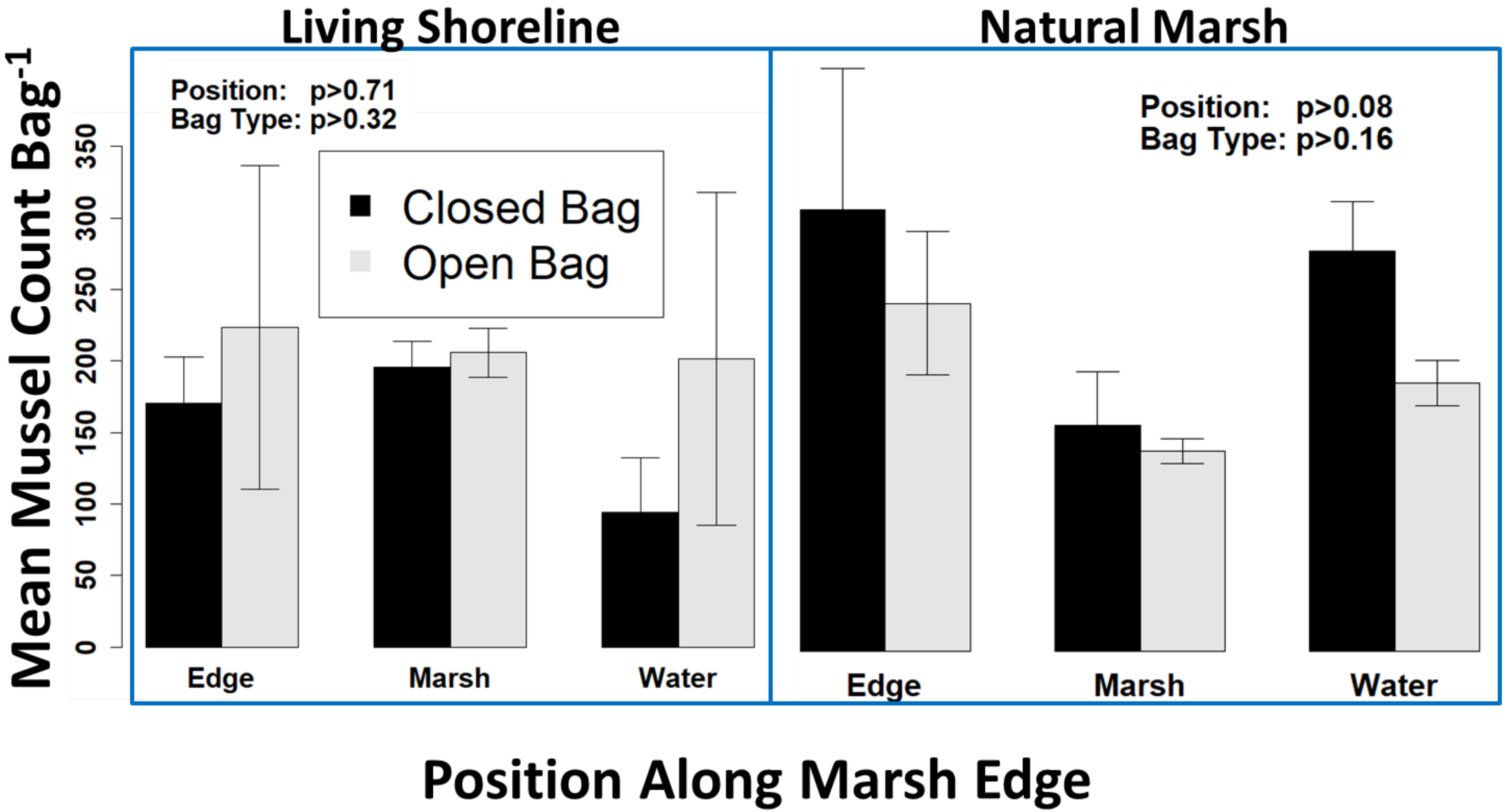
Is mussel density greater in shell bags that exclude predators than those that allow access to predators?



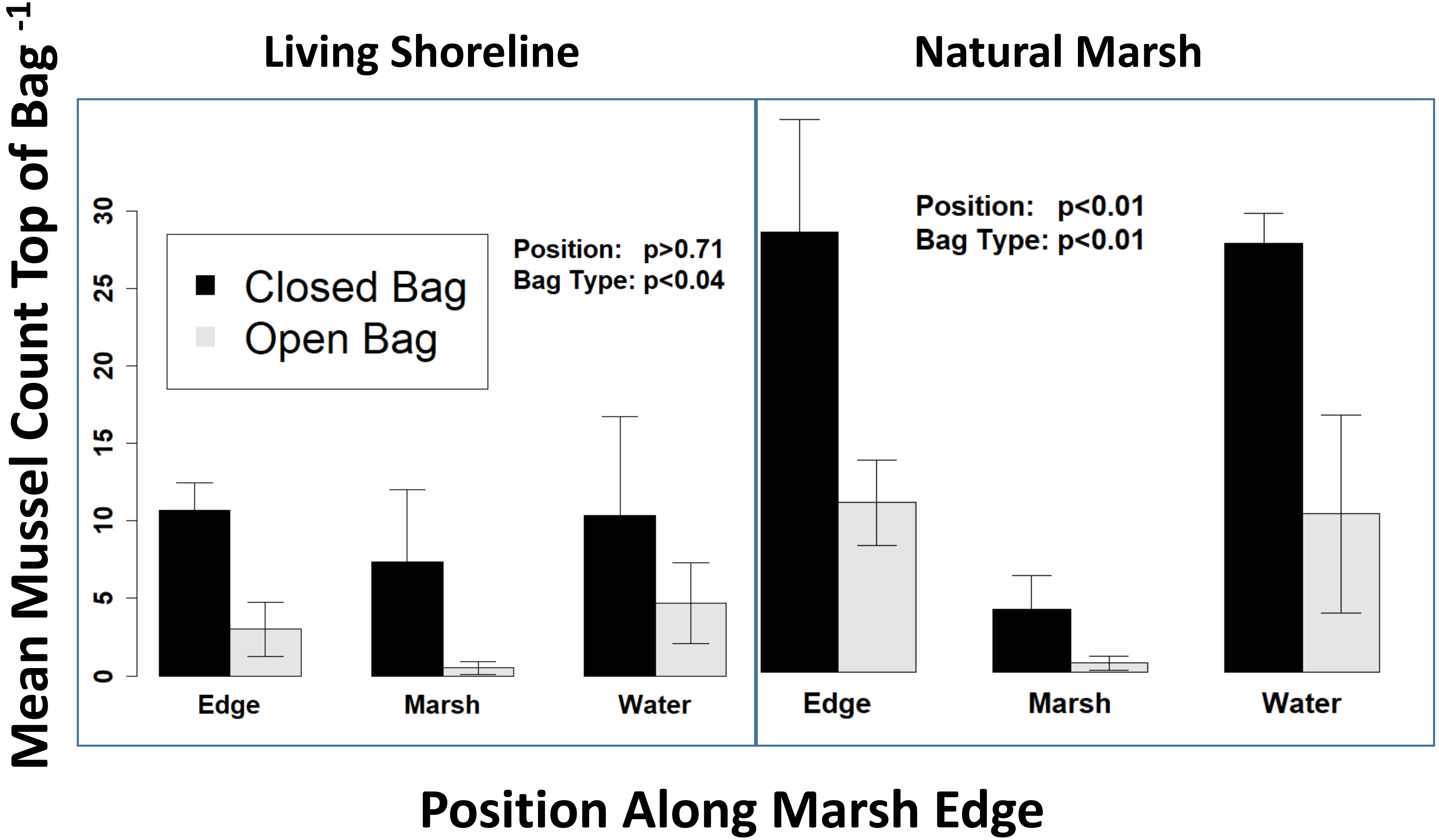
Shell bag **open** to predation

Shell bag **closed** to predation

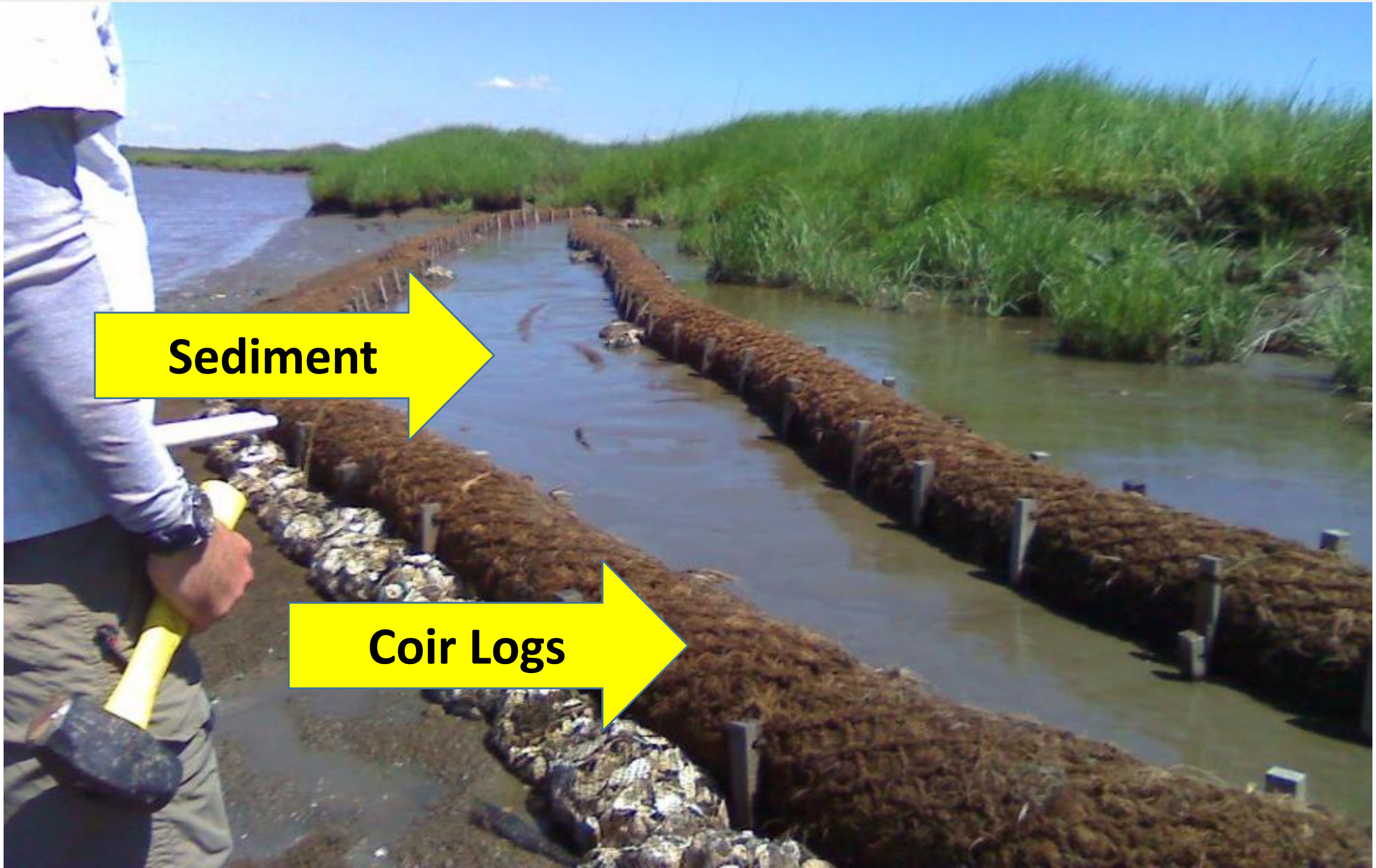
There was No Difference in Total Bag Recruitment Between Open and Closed Bags



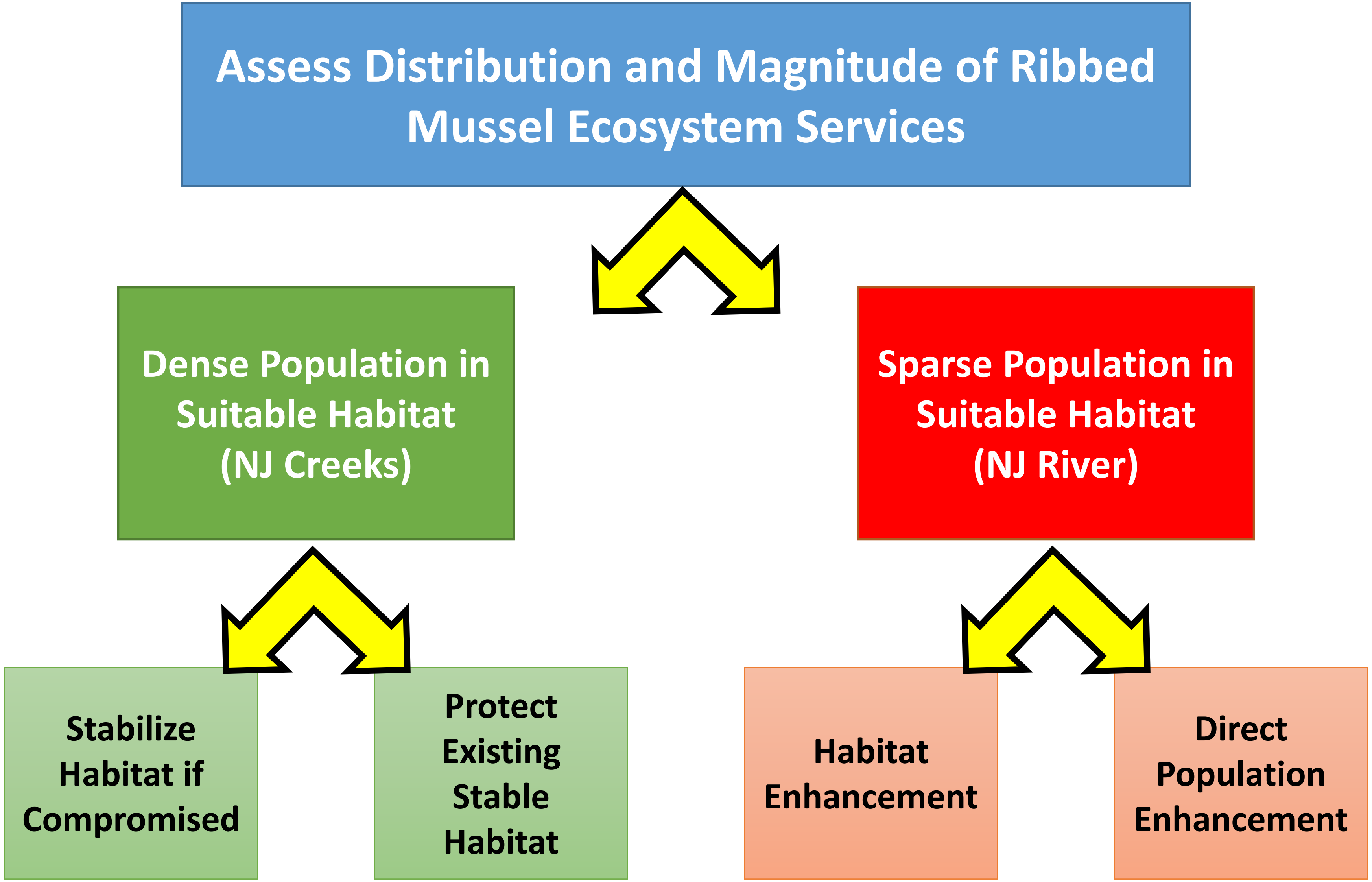
Only 6%-8% of Total Recruitment was to Bag Surface



Implication: Substrate with only surface recruitment options may suffer from low ribbed mussel persistence without protection



Management Approach: Conserve and Enhance



Conclusions: Considering Ribbed Mussels for Water Quality Uplift

1. Capable of filtering large quantities of TSS and particulate nitrogen
2. Services are largely concentrated in intra-marsh creek networks
3. Prime mussels habitat along primary channel edges are under-performing due to low mussel biomass
4. Living shoreline tactics can help to stem loss and rebuild populations
5. Maximize biomass enhancement likely by protecting developing populations
6. Two-pronged approach to ribbed mussel-mediated service maximization: Conserve and Enhance

Questions or Comments

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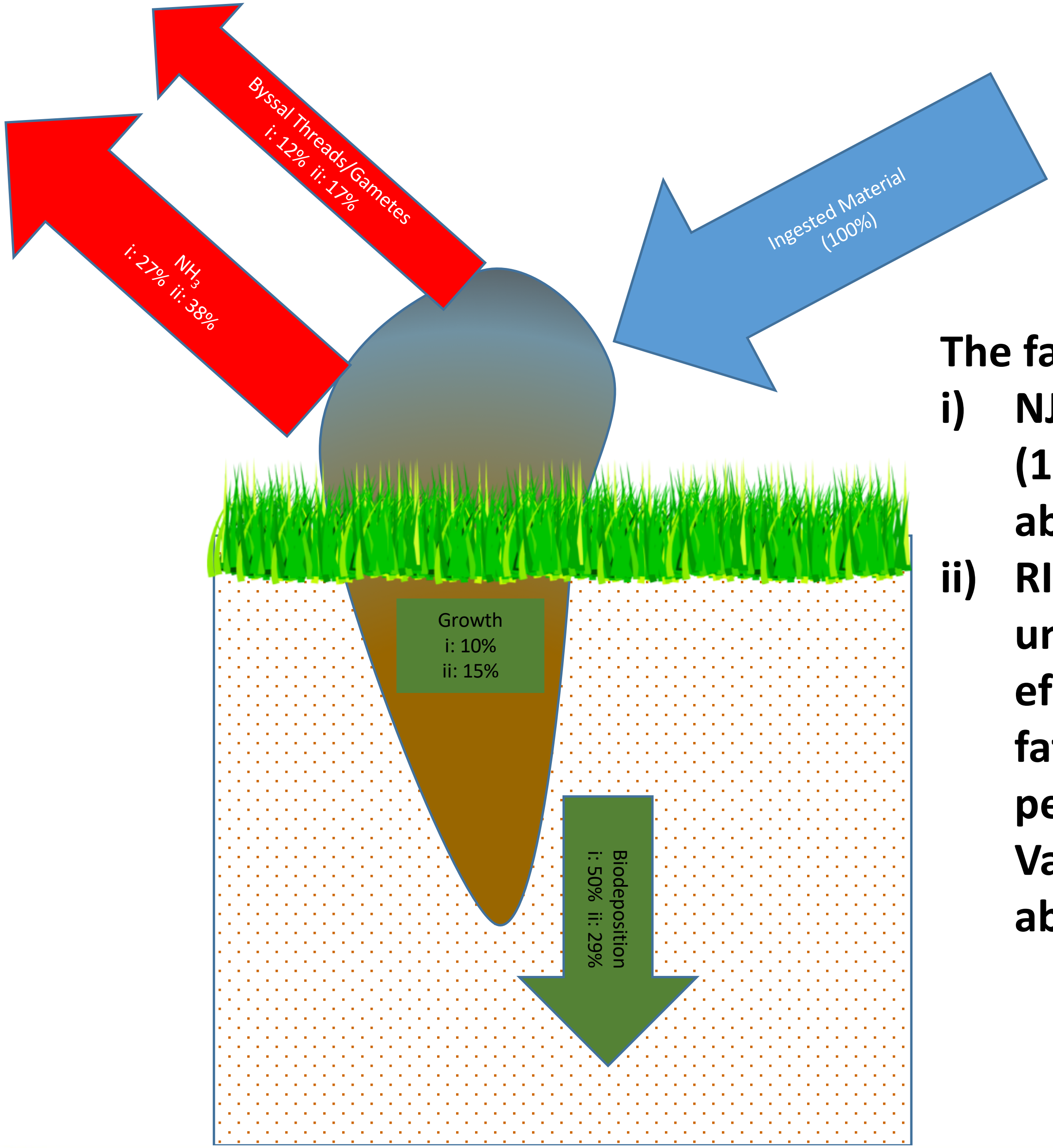
Partnership for the DELAWARE ESTUARY

Connecting people, science, and nature for a healthy Delaware River and Bay

Delaware Estuary-wide Scaling: 32,000 ha of Salt Marsh Habitat

	River	High Marsh	Creek
Annual Filtration Rate PN ($mg\ hr^{-1}\ gDTW^{-1}$)	0.2	0.2	0.2
Mussel Biomass ($g\ m^{-2}$)	20	10	100
Immersion Time ($hr\ day^{-1}$)	12	8	10
Scaling Factor ($kg\ ha^{-1}\ yr^{-1}$)	3.65	3.65	3.65
Area of 32,000 ha (%)	1,600 (5%)	22,400 (70%)	8,000 (25%)
Gross Filtration ($tons\ yr^{-1}$)	309	1,441	6,172
Particulate Nitrogen Removal (60%) ($tons\ yr^{-1}$)	185	865	3,703
Net Estuary-wide Ribbed Mussel Particulate Nitrogen Filtration			**4,753 tons yr^{-1}**



The fate of ingested nitrogen:

i) **NJ: Jordan and Valiela, (1982) under 50% absorption efficiency**

ii) **RI: Galimany et al. (2013) under 71% absorption efficiency assuming equal fate partitioning percentages as Jordan and Valiela (1982) for the absorbed nitrogen.**

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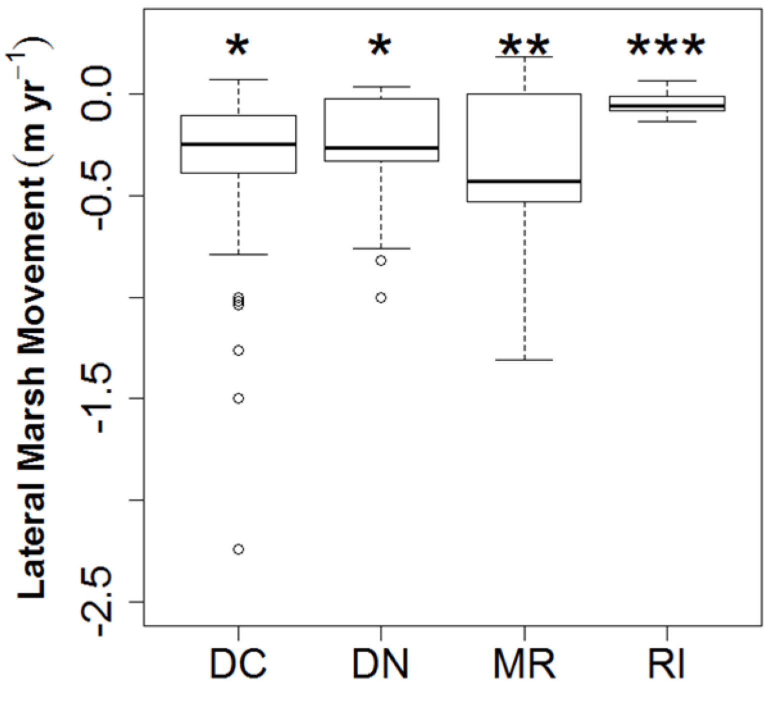

Lateral Marsh Movement (m yr⁻¹)
0.0
-0.5
-1.5
-2.5
*
*
**
***
DC
DN
MR
RI

Marsh	Habitat	TSS (mg l^{-1}) (n=18 NJ; n=6 RI)	Potential Net PN Removal ($kg\ ha^{-1}\ yr^{-1}$) Total	Biodeposit	Growth
DC	Creek	71.26 ± 8.84	65.25 ± 15.18	54.38 ± 12.65	10.88 ± 2.53
	High Marsh		20.80 ± 16.21	17.33 ± 13.50	3.47 ± 2.70
	River		3.17 ± 2.64	2.64 ± 2.20	0.53 ± 0.44
	Marsh-wide		**29.74 ± 11.27**	**24.78 ± 9.39**	**4.96 ± 1.88**
DN	Creek	107.13 ± 14.83	140.34 ± 24.98	116.95 ± 20.82	23.39 ± 4.16
	High Marsh		25.93 ± 14.02	21.61 ± 11.68	4.32 ± 2.34
	River		0.19 ± 0.11	0.16 ± 0.10	0.03 ± 0.02
	Marsh-wide		**55.49 ± 23.07**	**46.24 ± 19.22**	**9.25 ± 3.85**
MR	Creek	91.44 ± 5.81	35.26 ± 19.54	29.38 ± 16.28	5.88 ± 3.26
	High Marsh		25.91 ± 14.24	21.59 ± 11.87	4.32 ± 2.37
	River		7.32 ± 7.24	6.10 ± 6.04	1.22 ± 1.21
	Marsh-wide		**22.83 ± 8.36**	**19.02 ± 6.97**	**3.80 ± 1.39**
RI	Creek	13.12 ± 2.34	27.41 ± 6.40	18.48 ± 4.31	8.92 ± 2.08
	High Marsh		1.18 ± 0.26	0.79 ± 0.17	0.38 ± 0.08
	River		11.32 ± 5.44	7.64 ± 3.67	3.69 ± 1.77
	Marsh-wide		**13.30± 4.52**	**8.97 ± 3.05**	**4.33 ± 1.47**

Estimated Particulate Nitrogen Removal River: Creek

RI: 0.40

DC: 0.05

DN: <0.01

MR: 0.21

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