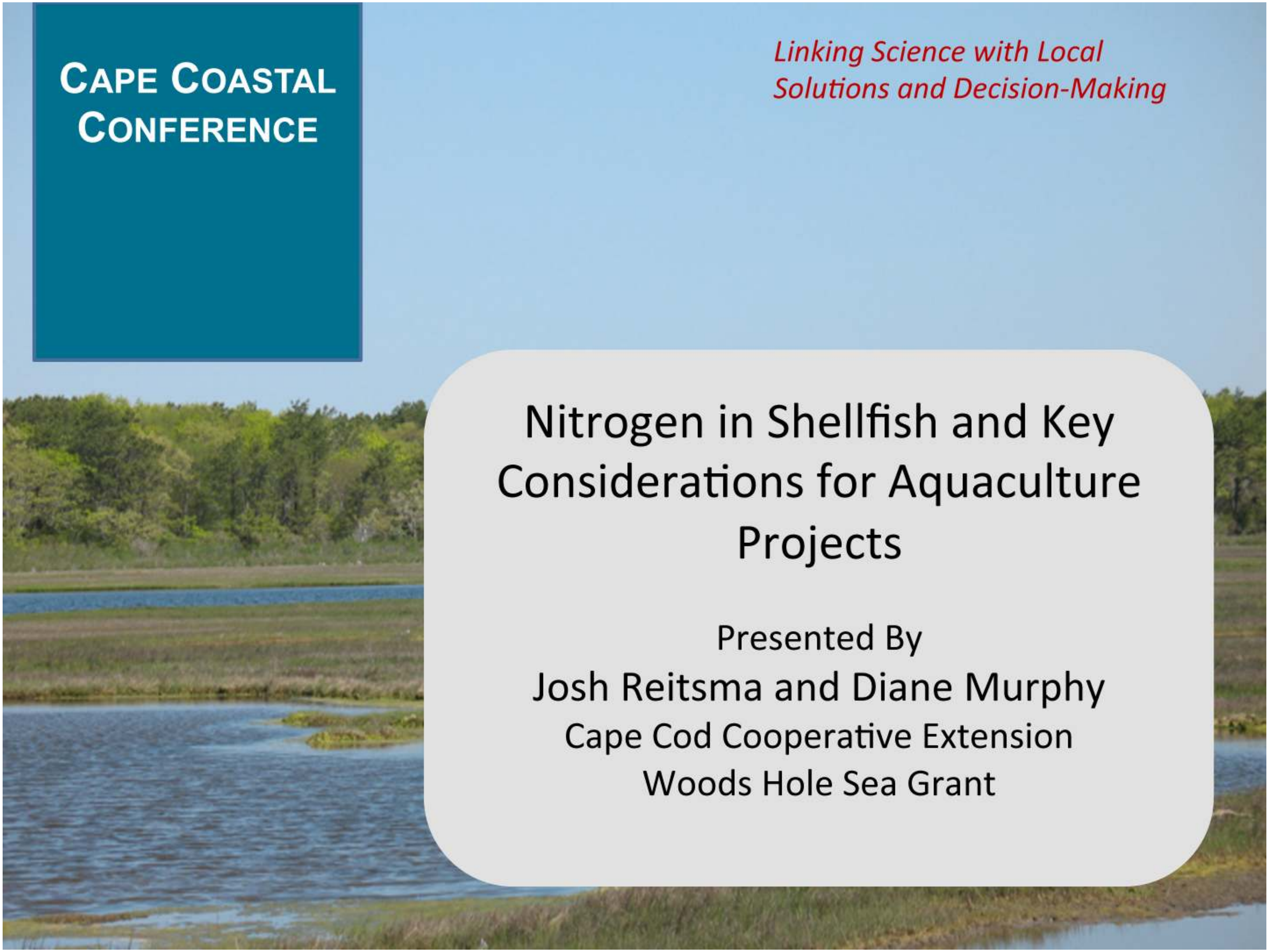


Cape Coastal Conference

Linking Science with Local Solutions and Decision-Making

Nitrogen in Shellfish and Key Considerations for Aquaculture Projects

Presented By

Josh Reitsma and Diane Murphy

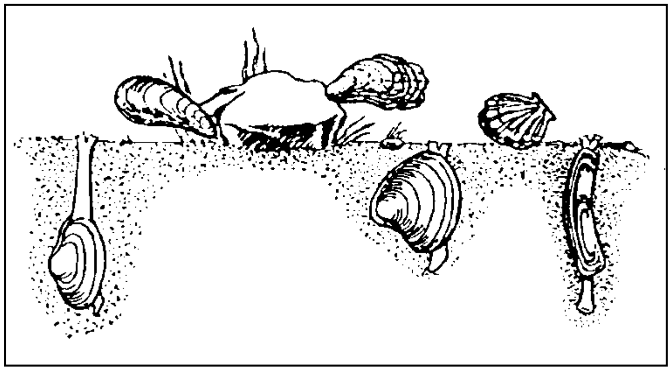
Cape Cod Cooperative Extension

Woods Hole Sea Grant

The Mighty Bivalve

- How do shellfish and nutrients interact?
- How are shellfish involved ecologically?
- How much nitrogen is in our local shellfish?
- How might shellfish be used to encourage water quality improvement?
- Has this been done elsewhere?
- What is limiting developing aquaculture here?
- A potential tool to help with siting?

Shellfish and Nutrients



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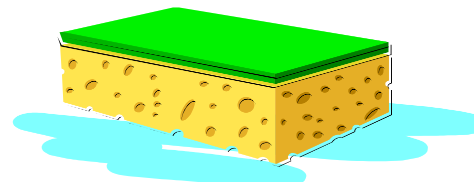

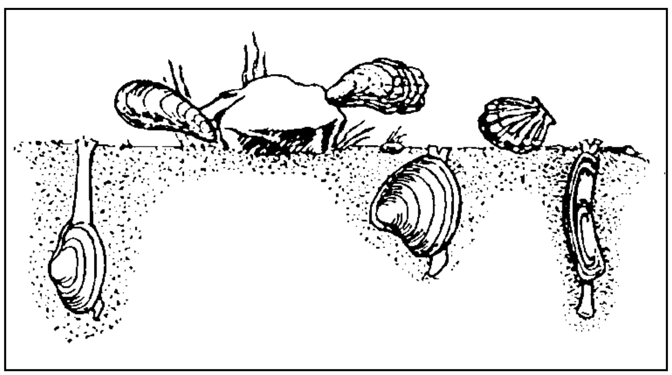

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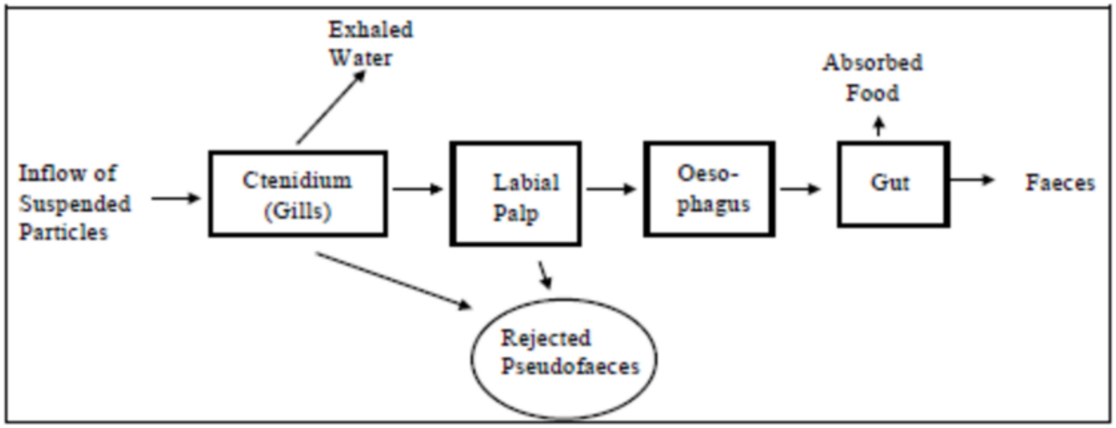
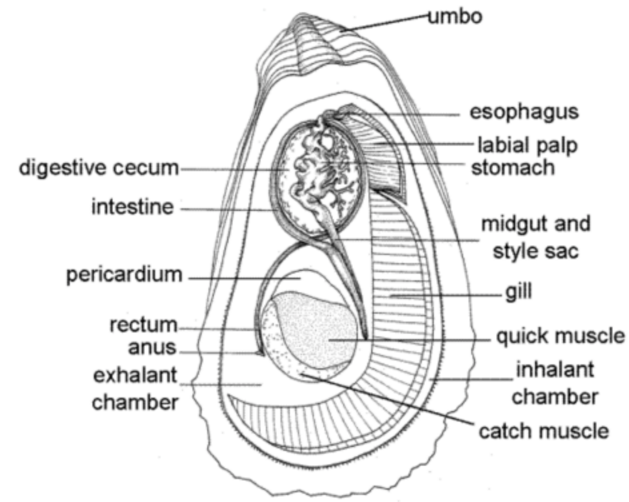
Shellfish Biology/Feeding

Figure 1: Simplified model of filter food processing by bivalves.



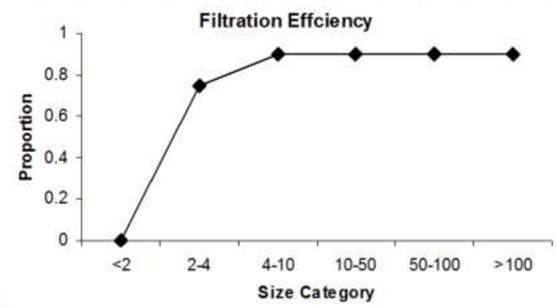


- Water is pumped in and over the gills (the filter)
- Particulate matter is trapped in a mucous coating and transported to the mouth
- Labial palps help sort the mucous coated particles either to be ingested or rejected as pseudofeces

(Beecham, J. 2008, Fox, R. 2005)

Filtering capacity

- Extremely good at capturing particles
- Oysters capture about 100% of particles over 5um (Riisgard 1988)



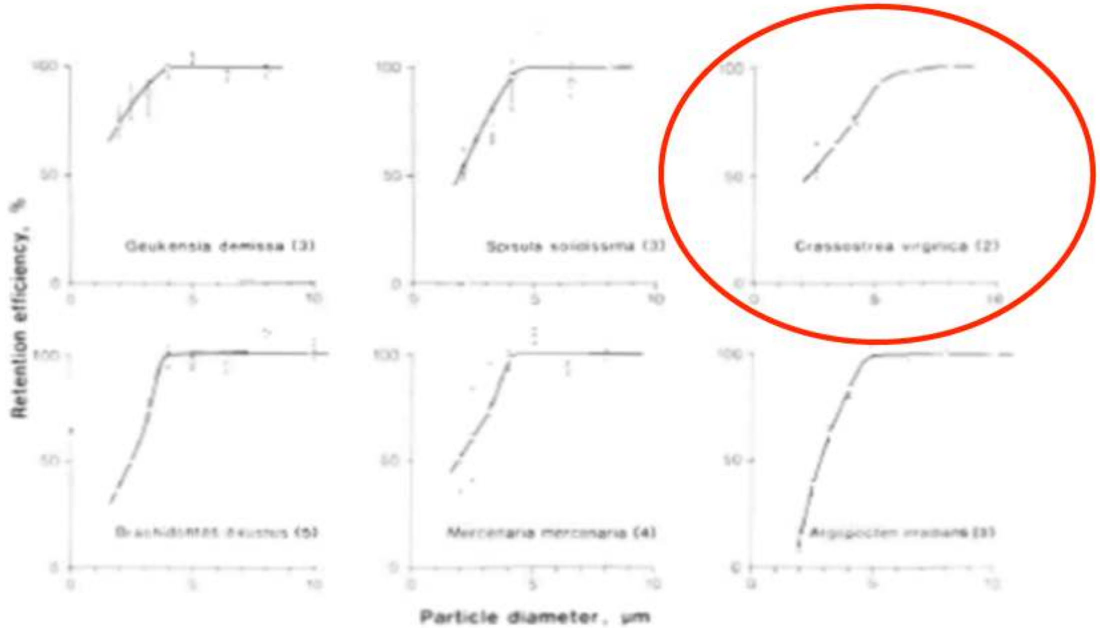
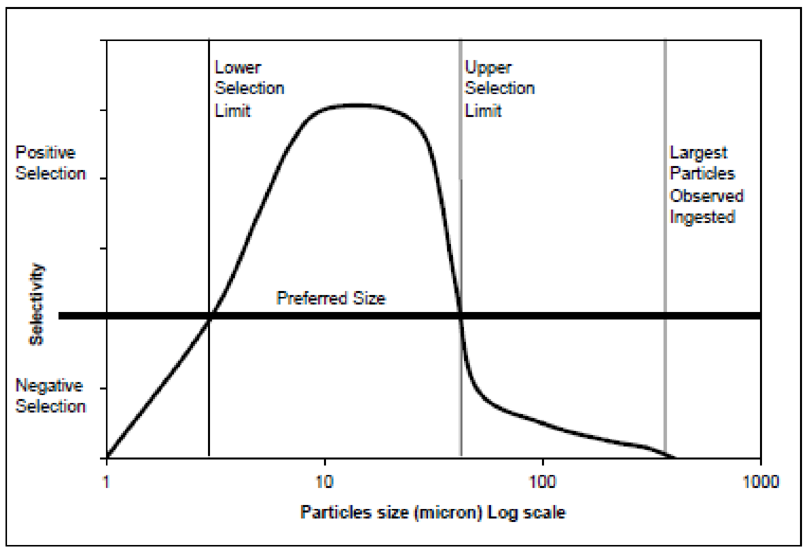


Fig. 1. Particle retention efficiency as a function of particle diameter in 6 species of bivalves. Each value is the mean and range of one measurement on each of 2 to 5 indivduals as indicated by the figures in parentheses

Particle Selection for Ingestion

- Most bivalves seem to select certain particles out of the total filtered
  - Size, 20-30 um preferred (Beecham, 2008)
  - Quality - based on organic content (Newell and Jordan, 1983)
  - Plankton species (Shumway et al. 1985, Ward and Shumway 2004)
  - Cell types? (Waite et al. 1995) or shape?

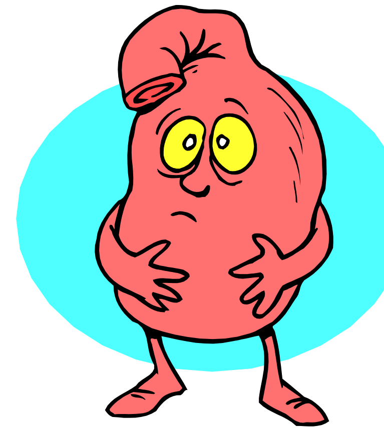
Figure 2: General pattern of size selectivity by bivalves, showing positive selection for particles above a lower limit of a few microns, which peaks for mid-sized particles, typically 20-30μm, and then falls off above 40μm, but with a few large particles nevertheless being ingested. The absolute magnitude of selection depends on concentration, species and type of particle.



(Ward and Shumway, 2004)

- Not selected? Packaged in mucus and sent out as "pseudofeces"

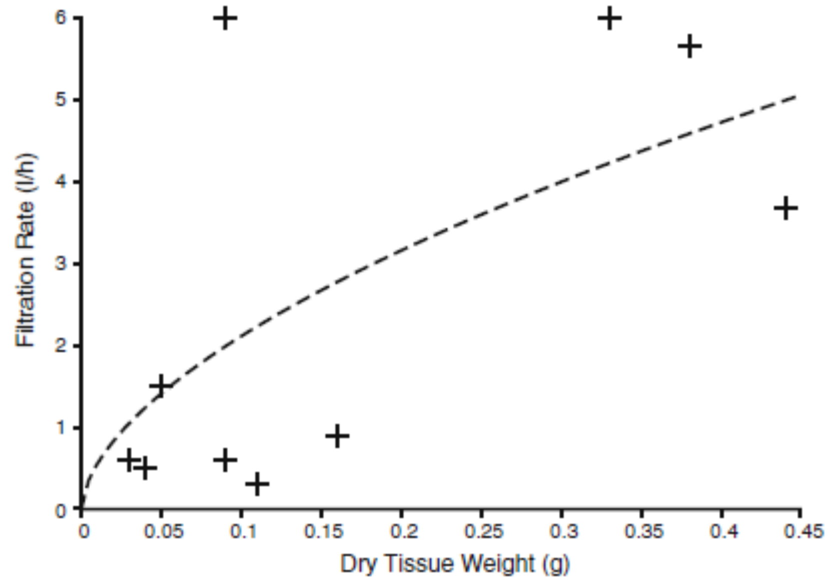
Feeding Efficiency



- Depending on quality and quantity up to 100% of particles filtered may be ingested (Cerca & Noel 2005)
  - In some cases a lot is sorted out and discarded as pseudofeces
- ~20-90% of ingested may be assimilated to tissue (Newell et al. 2005)
  - Rest goes out as fecal material, or metabolites
- Pseudofeces & feces – “biodeposits”
  - Release of heavier particulates

Filtration Rates

- Size dependent
- Temperature dependent
  - Shuts down around 8C (Cerca & Noel 2005, Newell and Mann 2012)
- Also dependent on available food, salinity, dissolved oxygen, etc.
- A harvestable oyster (2.4g dry weight) could be filtering about 13 l/h under ideal conditions (zu Ermgassen et al. 2013)



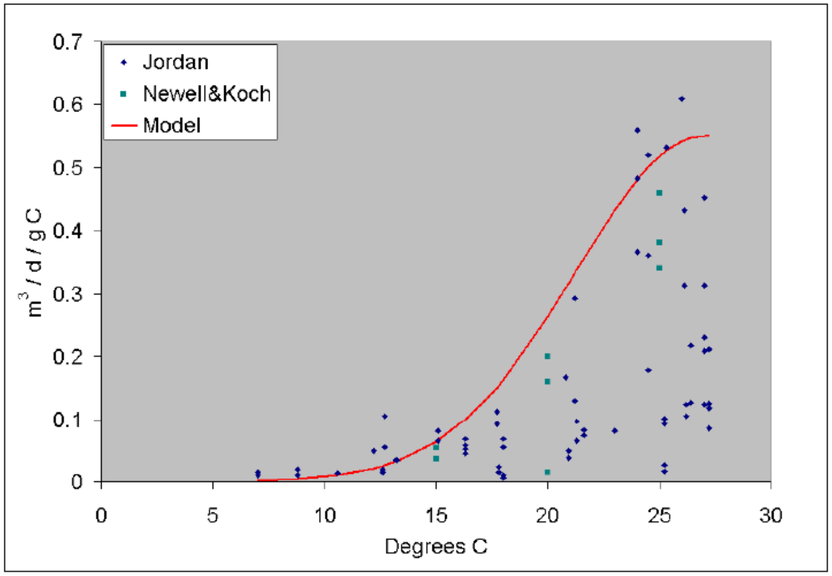


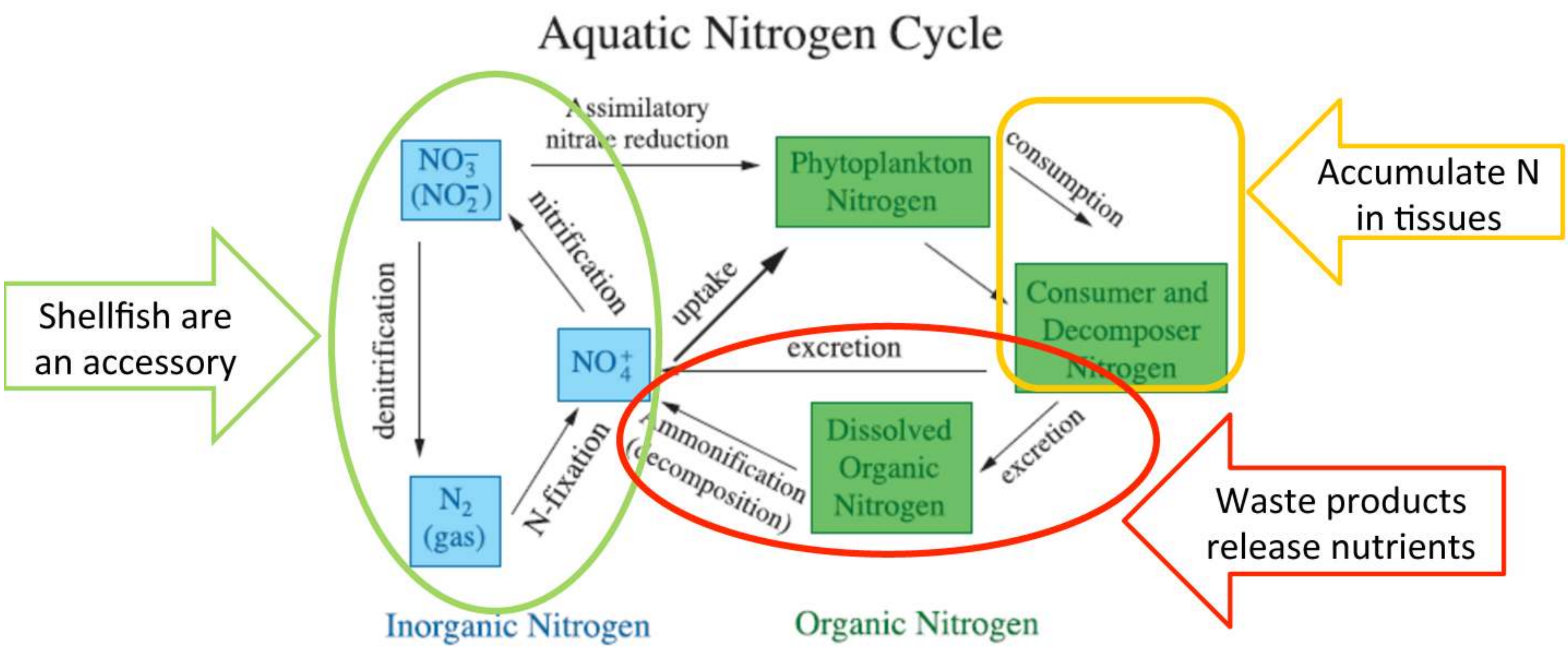
Figure 3. Effect of Temperature on filtration rate.

Filtration – Effect on Water Quality

- Often difficult to measure in the field, but there has been some success locally
- 200 oysters in a pipe fed by a tidal creek were able to reduce Chlorophyll (algae) by 28% and Turbidity by about 22%
- Similar measurements have been associated with oyster reefs (Cressman et al. 2003, Grizzle et al. 2008)

Shellfish and Marine Nitrogen Cycling

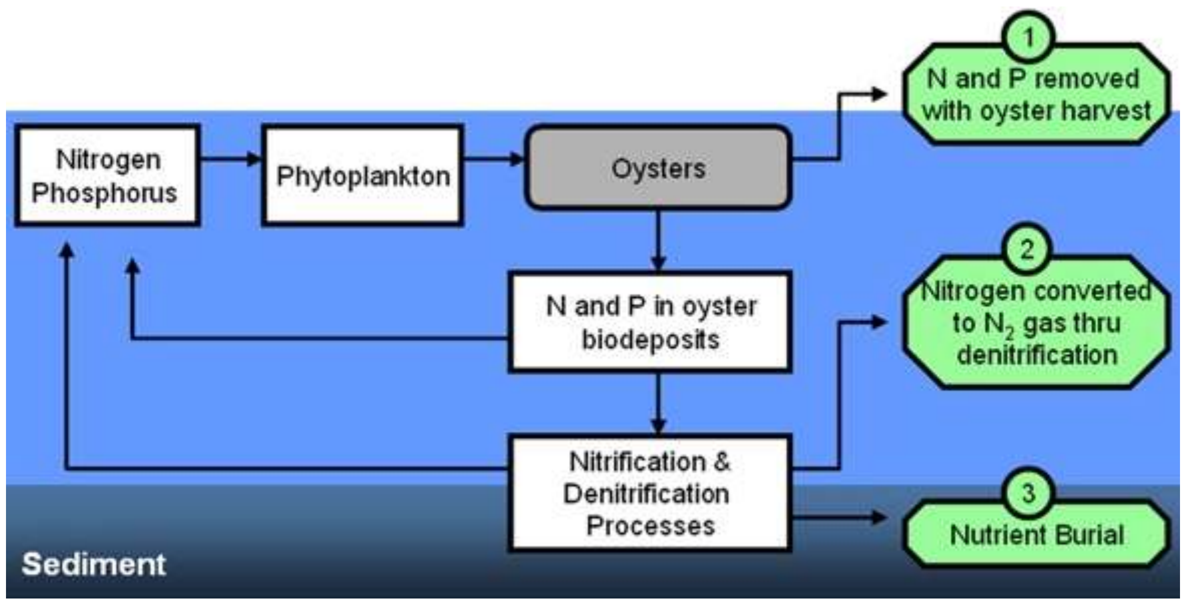
- Areas where shellfish can potentially remove nutrients
- Areas where nutrients are regenerated



Nitrogen Cycle from: Rice 2008

Important Areas of Cycle for Potential Nutrient Remediation

- Direct removal – oyster tissues (1)
- Removal in conjunction with the nearby sediment and microbial community (2 &3)
  - Oysters stimulate removal



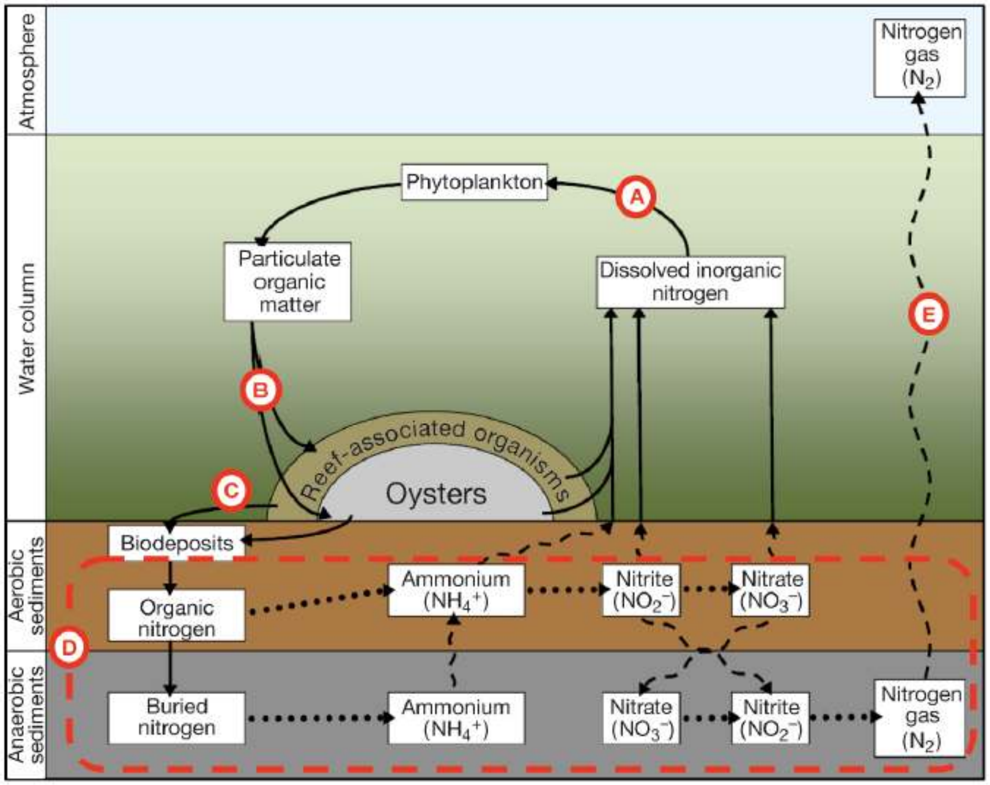
Importance of Cycling Nutrients

- Filtering bivalves graze down phytoplankton and a portion of those nutrients go back into the water column
- Phytoplankton bloom is regenerated (Gilbert et al. 1997, Newell 2005, Gibbs 2005)
- Never more than what original N content was
  - Some assimilated or buried/removed
- If bloom left unchecked, could crash – anoxia and fish kills

http://www.nbcnews.com/id/40947831/ns/us_news-environment/t/millions-fish-wash-dead-chesapeake-bay/#.UbeBL5y1uHs

Denitrification – an Ecosystem Service

- Process in which nitrogen is processed and transformed in sediment – can result in net removal through N gas
- Has been variable and difficult and expensive to quantify
- Most often studied with oyster reefs



Source of figure: Kellogg et al. 2013

N Removal - Denitrification or Burial

- May be stimulated by bivalves, may not be
- Rates associated with oysters may be up to 0.5g N per (Newell 2005)
  - Coupled with N burial - removal may be up to 0.75g of N per oyster
    - 0.25g of N buried
- Recent study showed shellfish aquaculture did not influence dentrification in sediment (Higgins et al. 2013)
  - Floating cage culture 1-3m off the bottom
- Under mussel farm in NZ showed signs of reduced denitrification compared to control sites (Christensen et al. 2003)
- Clam farming has been associated with increased denitrification in Italy (Nizzoli et al. 2006)
- Less is known about shellfish and denitrification rates in our area

Denitrification by Habitat Type

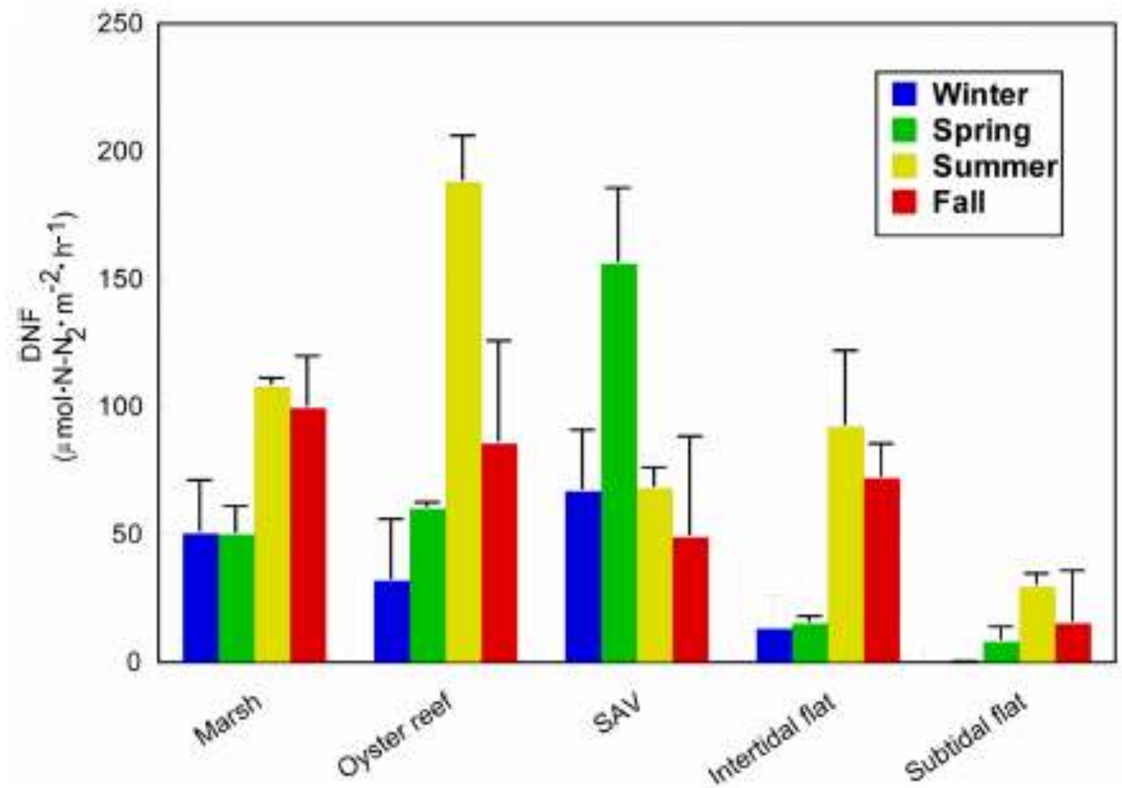
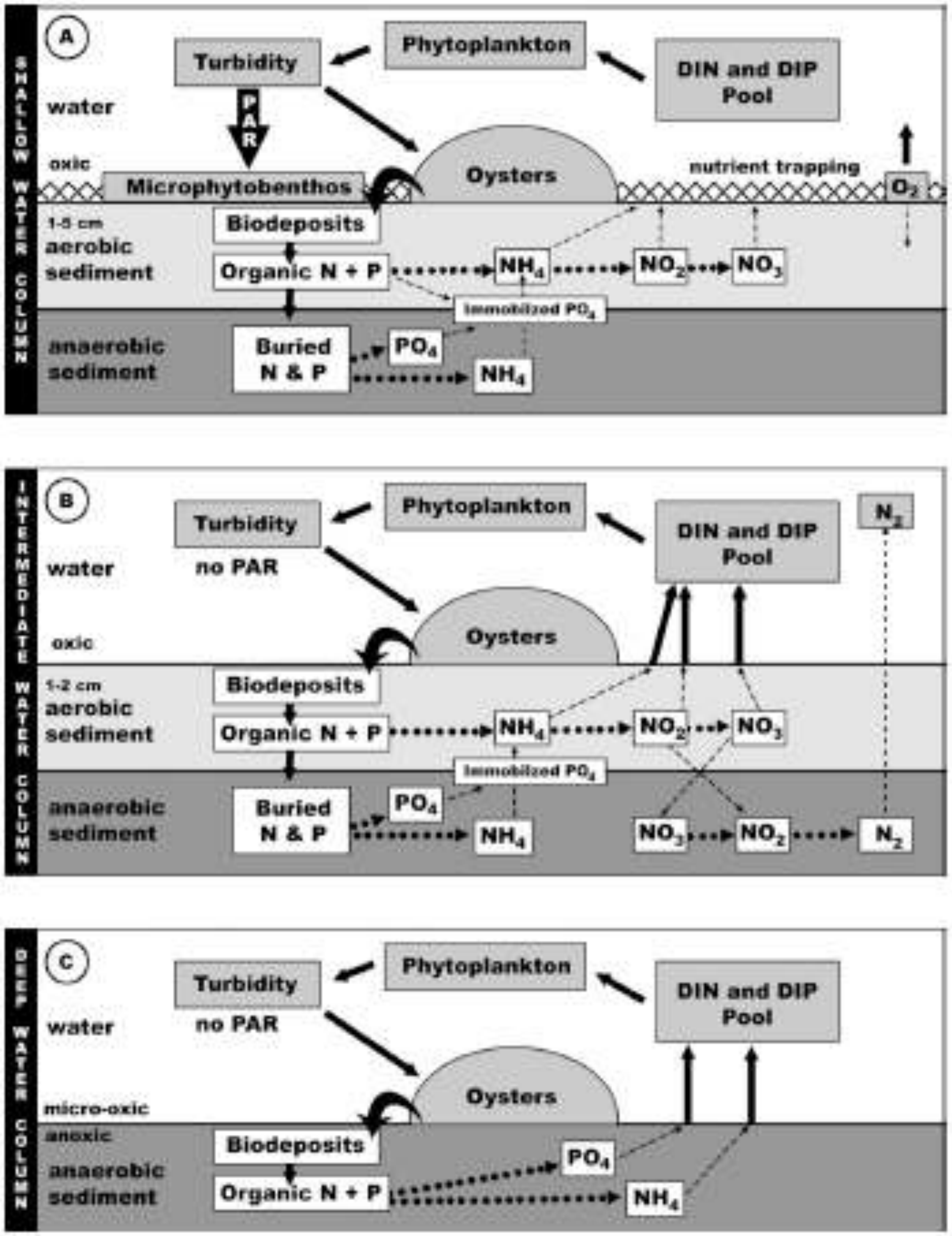


Fig. 1. Mean rates of denitrification by habitat for each season. Error bars are one standard error.

- Structure seems to help promote the denitrification process (Piehler and Smyth 2011)
- Aquaculture may do the same through added structure

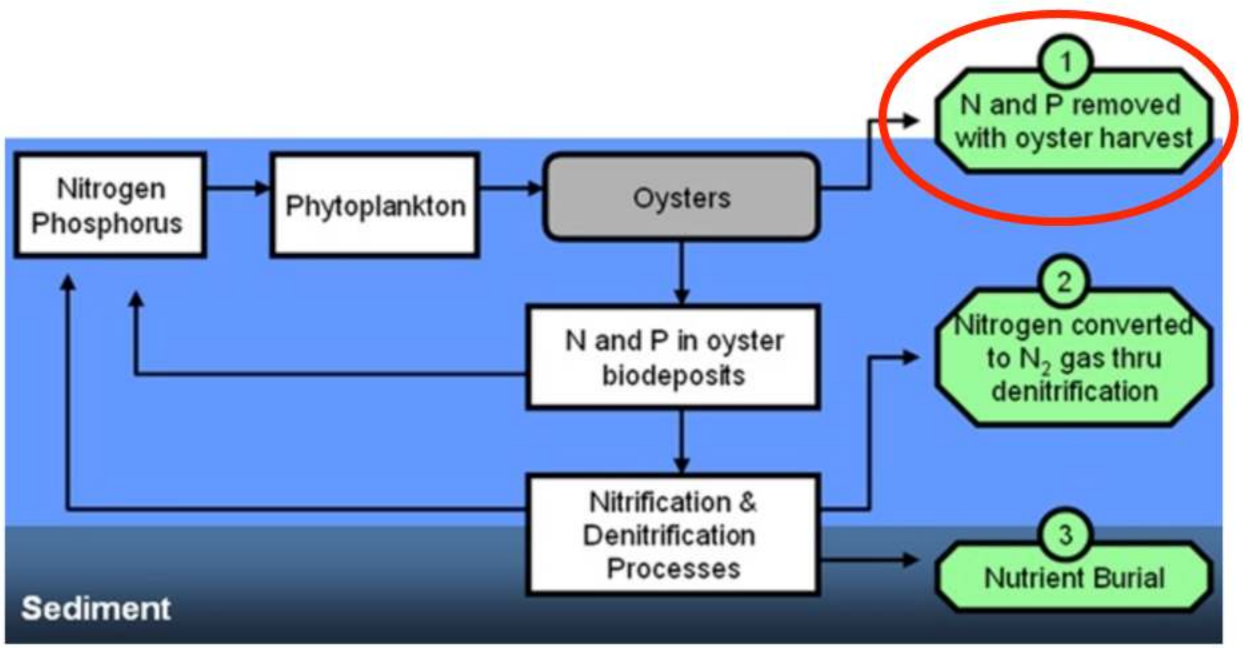
Denitrification and Sediment Type



- Characteristics of sediment an shellfish population may dictate denitrification
  - (Newell 2005, 2012)
- Flow may also make a difference (Porter et al. 2004)

Where do we start?

- 3 areas of potential removal
- 1 is more easily measured and likely to have more consistent numbers
  - Also can provide economic activity



Shellfish Nitrogen Content

- Some of values in literature (% nitrogen) all from elsewhere:
  - Oyster
    - Soft tissues – 7 to 9.3%
      - 7% (Newell 2004), 7.9% (Higgins et al. 2011), 8.6% (Carmichael et al. 2012), 9.27% (Sisson et al. 2011)
    - Shell – 0.2 to 0.3%
      - 0.2% (Higgins et al. 2011), 0.21% (Sisson et al. 2011), 0.3% (Newell 2004)
  - Quahogs
    - Soft tissues – 5.96% (Sisson et al. 2011)
    - Shell – 0.15% (Sisson et al. 2011)
- Challenges or questions
  - different morphologies - growing conditions
  - location variability
  - seasonal variation
- Need some local values!

What’s in our local shellfish?

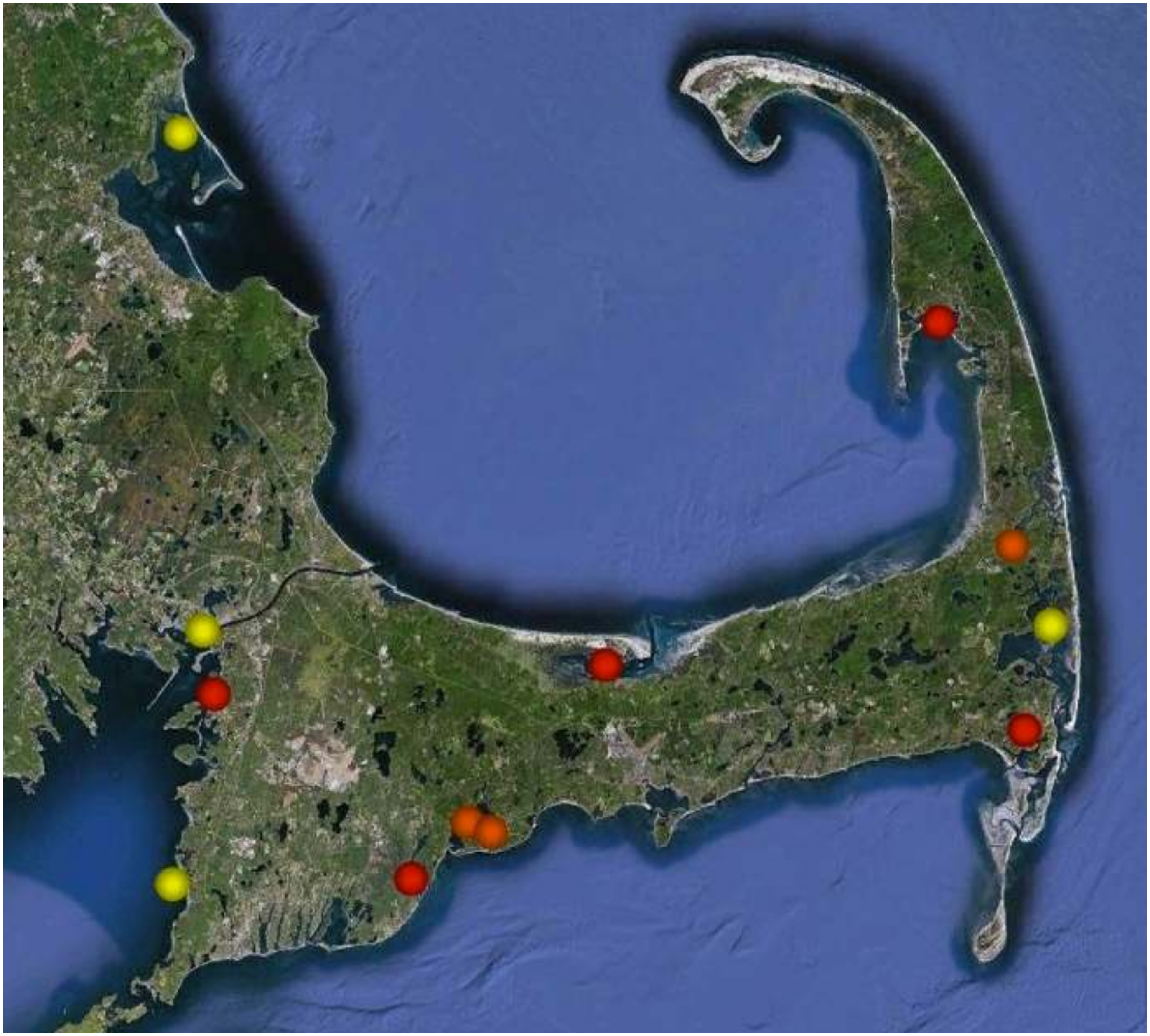
- Sampled June and Oct 2012
- Selected 4 per group, at typical harvest size
- Quahogs: 1-1.5” hinge width - littlenecks
  - Wild – 6 sites
  - Cultured – 5-6 sites
- Oysters: 3-3.5” if at all possible
  - Wild – 4 sites
  - Cultured, on-bottom – 6 sites
  - Cultured, off-bottom (any gear) – 8 sites
- Cooperation from a lot of folks to get samples
  - Town shellfish programs and private growers
- We collected and measured them, Boston University did the shell and tissue analyses (the hard part)

Sample Sites

Yellow: just oysters

Orange: just quahogs

Red: both



Summary and Comparison

Cape Cod Oyster and Quahog Data Summary

	Shell Length (mm)	Shell DW (g)	Tissue DW (g)	Tissue %N	Shell %N	Total N (g)	Total % N (DW)
Overall average from Cape Cod							
oysters	83.8	40.9	2.43	8.01	0.24	0.28	0.69
quahogs	56.1	31.2	2.22	7.69	0.18	0.22	0.67
Oysters from Cape Cod							
wild	82.7	46	2.42	8.2	0.26	0.31	0.67
Cultured On	84.9	47.4	2.7	7.89	0.26	0.32	0.65
Cultured Off	83.1	35.7	2.36	7.95	0.21	0.26	0.7
C Off Triploid	86.5	22.3	1.36	8.5	0.32	0.19	0.82
Quahogs from Cape Cod							
Wild	57.1	32.6	2.43	7.5	0.18	0.24	0.67
Cultured	54.95	29.6	1.99	7.9	0.17	0.21	0.66
Wild oysters from reefs in Chesapeake (Newell 2004)							
	76	150	1	7	0.3	0.52	0.34
Cultured floating cage oysters - Chesapeake (Higgins et al. 2011)							
	85.5	37.6	1.58	7.28	0.17	0.18	0.45

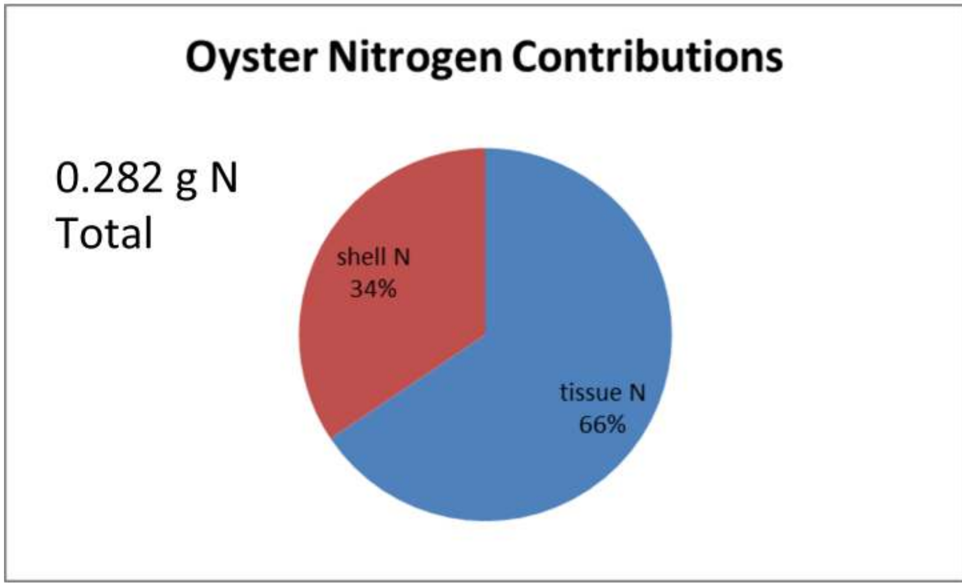
Adapted from: Newell and Mann 2012

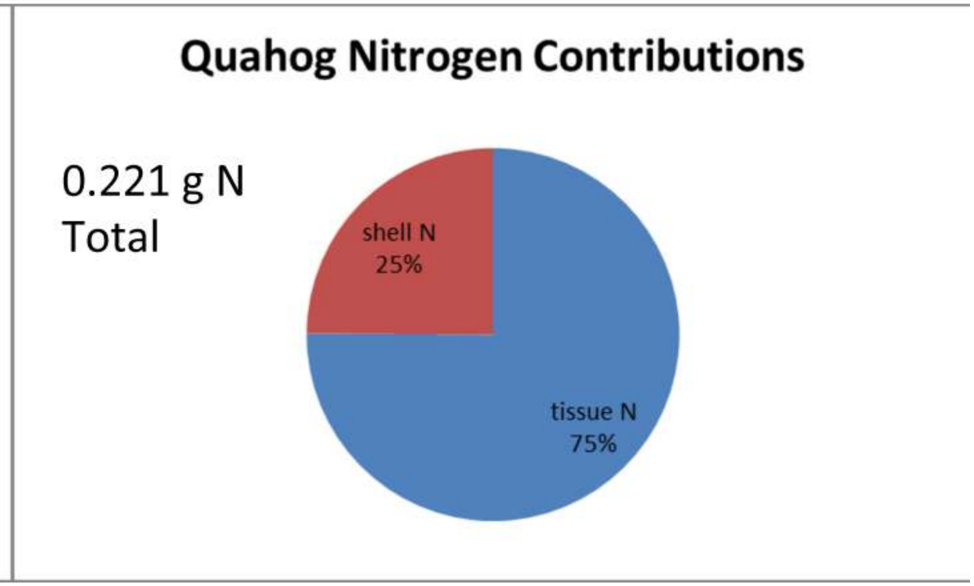
- Summary of Cape Cod data in comparison with the most often quoted Chesapeake oyster data

Quahogs and Oysters

Cape Cod Oyster and Quahog Data Summary							
	Whole Wt (g)	Shell DW (g)	Tissue DW (g)	Tissue %N	Shell %N	Total N (g)	Total % N (DW)
oysters	66.1	40.9	2.43	8.01	0.24	0.282	0.686
quahogs	51.7	31.2	2.22	7.69	0.18	0.221	0.665
Difference	*Yes	*Yes	No	*Yes	*Yes	*Yes	No

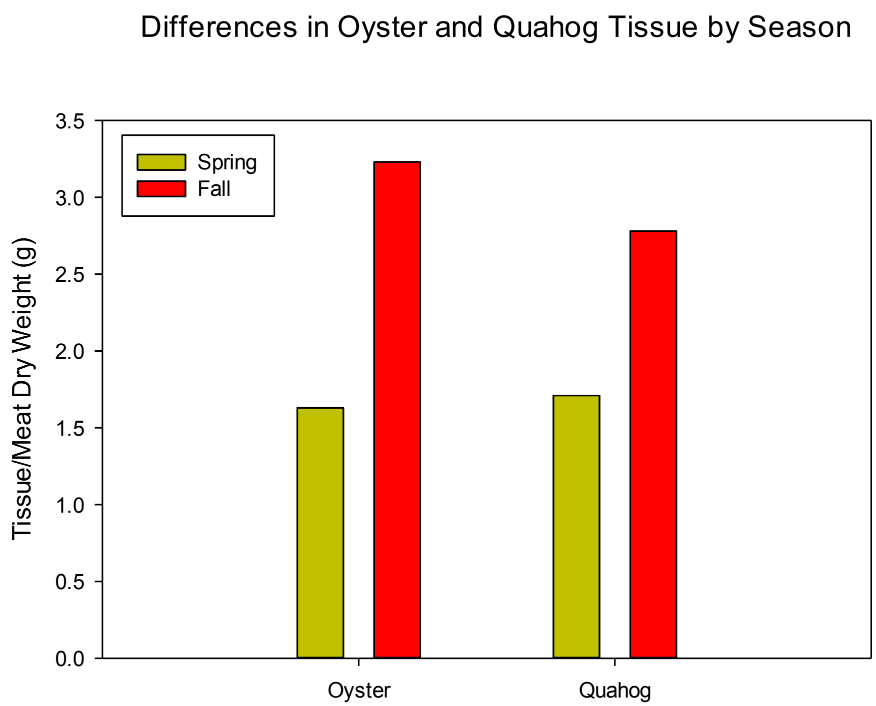
- Different animals
- Size is the biggest difference
- Oysters averaged higher %N in tissue and shell

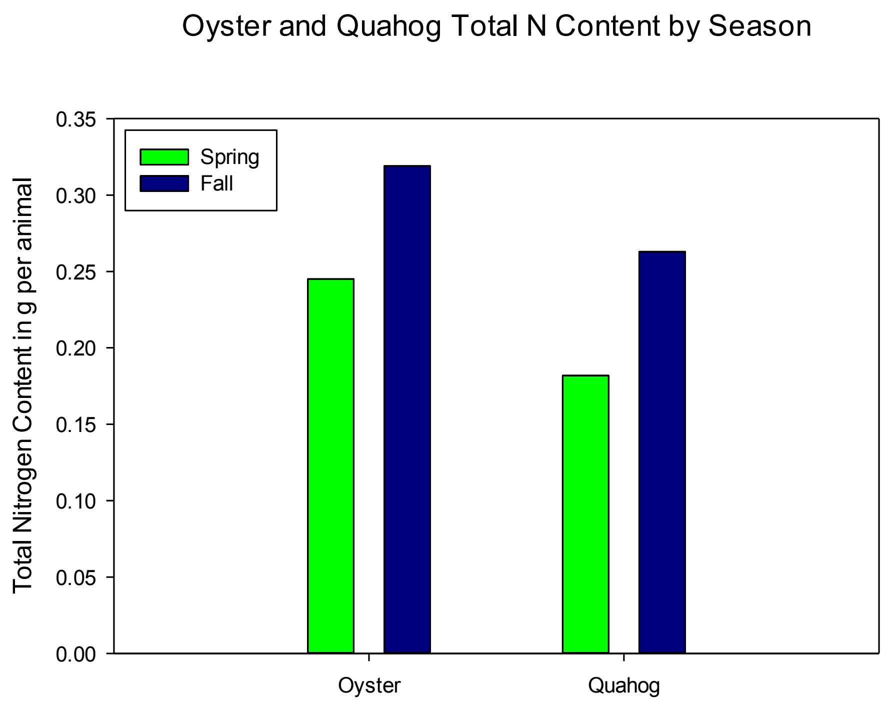




Difference by Season

- Tissue or meat content was much higher in Fall
  - 98% and 63% more for oysters and quahogs respectively
- %N in the meat dropped a bit in fall
  - Tissues have more glycogen reserves, less % protein in fall
- Shell was similar, spring to fall

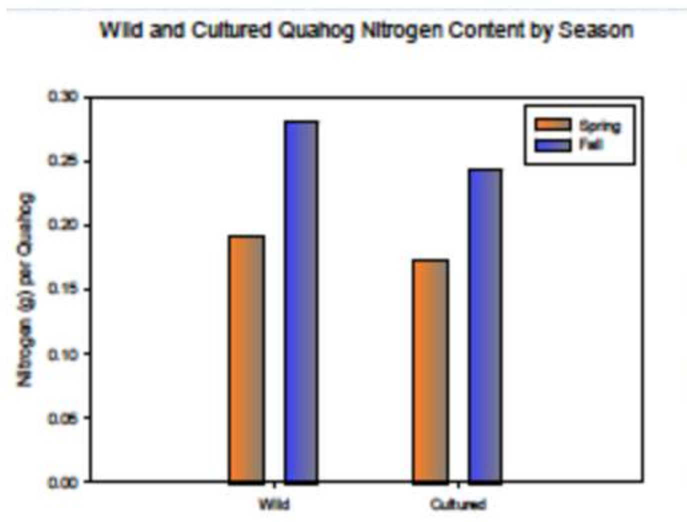




Closer Look: Quahogs Wild and Cultured

Quahogs	Shell Length (mm)	Shell DW (g)	Tissue DW (g)	Tissue %N	Shell %N	Total N (g)	Total % N (DW)
Wild	57.1	32.6	2.43	7.5	0.18	0.236	0.672
Cultured	54.95	29.6	1.99	7.9	0.17	0.205	0.657
Difference	*yes (sampling)	no	*yes	*yes	no	*yes	no

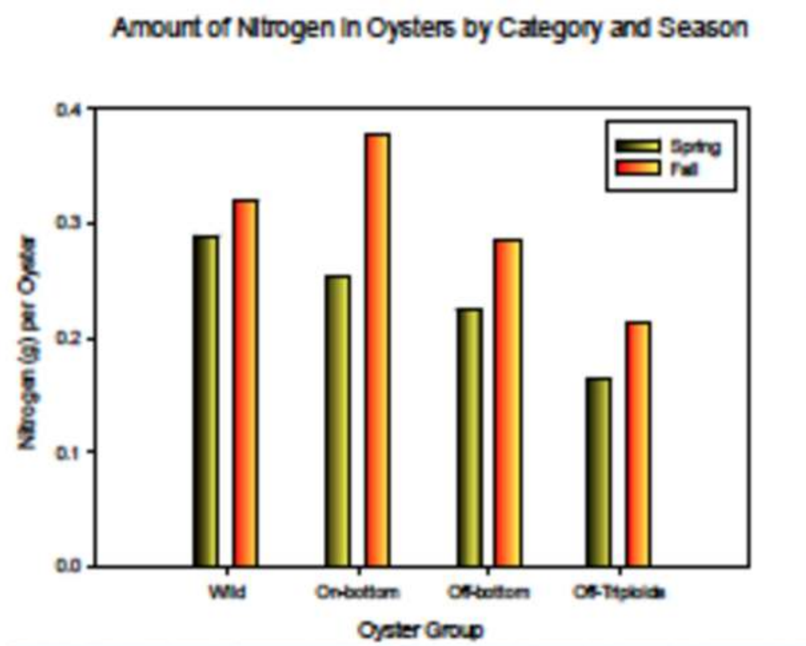
- Differences between wild and cultured mostly related to size
  - Our attempt to sample the same size was off
- Nitrogen content up in the fall over spring (more tissue)



Closer Look: Categories of Oysters

Oyster Groups		Cultured			
	Wild	On-bottom	Off-bottom	Off-Triploids	Difference
Shell Length (mm)	82.7	84.9	83.1	86.5	no
Shell DW (g)	46	47.4	35.7	22.3	*yes
Tissue DW (g)	2.42	2.7	2.36	1.36	*yes
Tissue %N	8.2	7.89	7.95	8.5	no
Shell %N	0.263	0.26	0.21	0.316	no
Total N (g)	0.306	0.317	0.255	0.189	*yes
Total % N (DW)	0.666	0.653	0.704	0.82	no

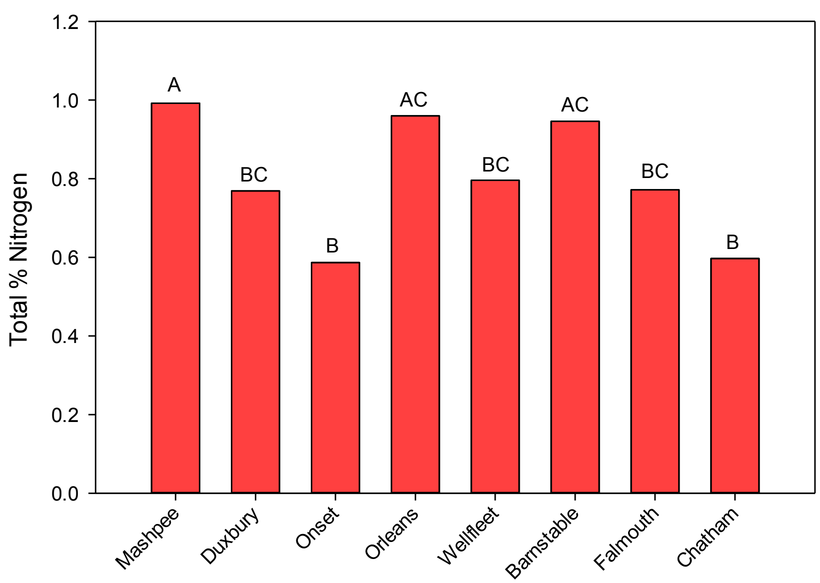
- Oysters cultured off-bottom had lower shell weights
  - Lower shell weights influence total N
- Off-bottom triploids much younger than other groups sampled
  - fast growers



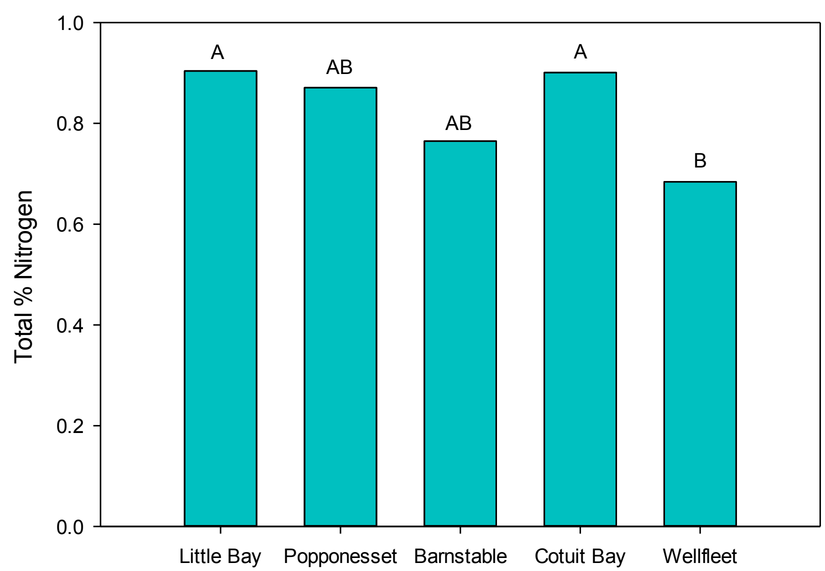
Site Differences

- Some differences between sites
  - Could partly be due to sampling – size, age, etc.
  - Probably some inherent differences by site
- Health or condition of animals can make a big difference too

Fall Sampled Cultured Oysters Across Sites



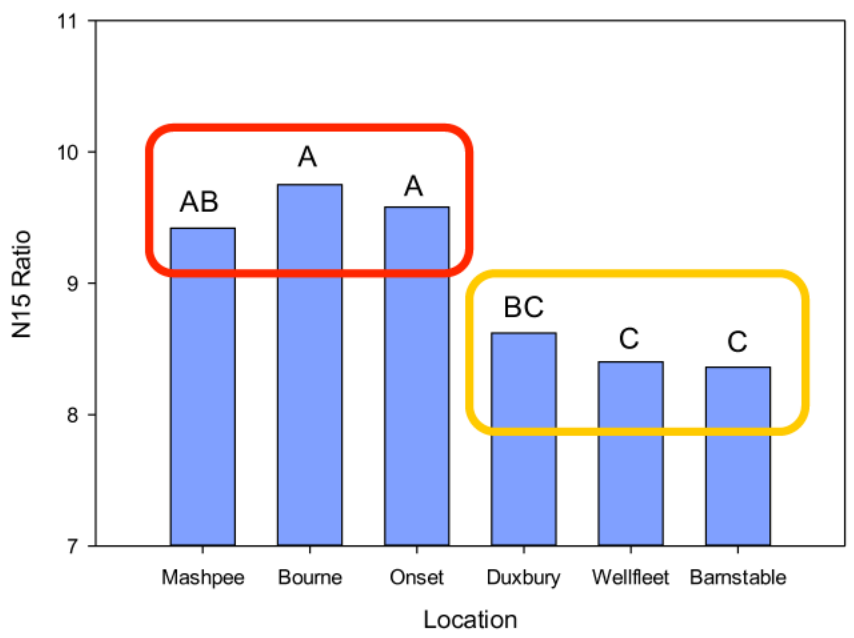
Fall Sampled Cultured Quahogs Across Sites



Isotope Signature Data

- Quahogs a bit different from oysters
  - Feeding in different areas of water column?
- Not much difference whether wild or cultured
- Heavier N15 ratio with increased N from human sources – waste water (Carmichael et al. 2008)

Isotope Profiles of Oysters Cultured On-Bottom



- Differences by site
- Seem to differ by water body
  - Cape Cod Bay
  - Buzz Bay/South Cape

Summary

- Oysters contain about 0.282g N (0.69% of DW)
  - Less in animals off-bottom due to less shell
- Quahogs contain about 0.221g N (0.67% of DW)
  - Not much difference wild or cultured
- Size and time of year make the biggest difference in amount of N contained
  - Fall more than spring
  - Bigger means more N – more tissue
- Associated forms of removal – denitrification/ burial are variable and would need more investigation

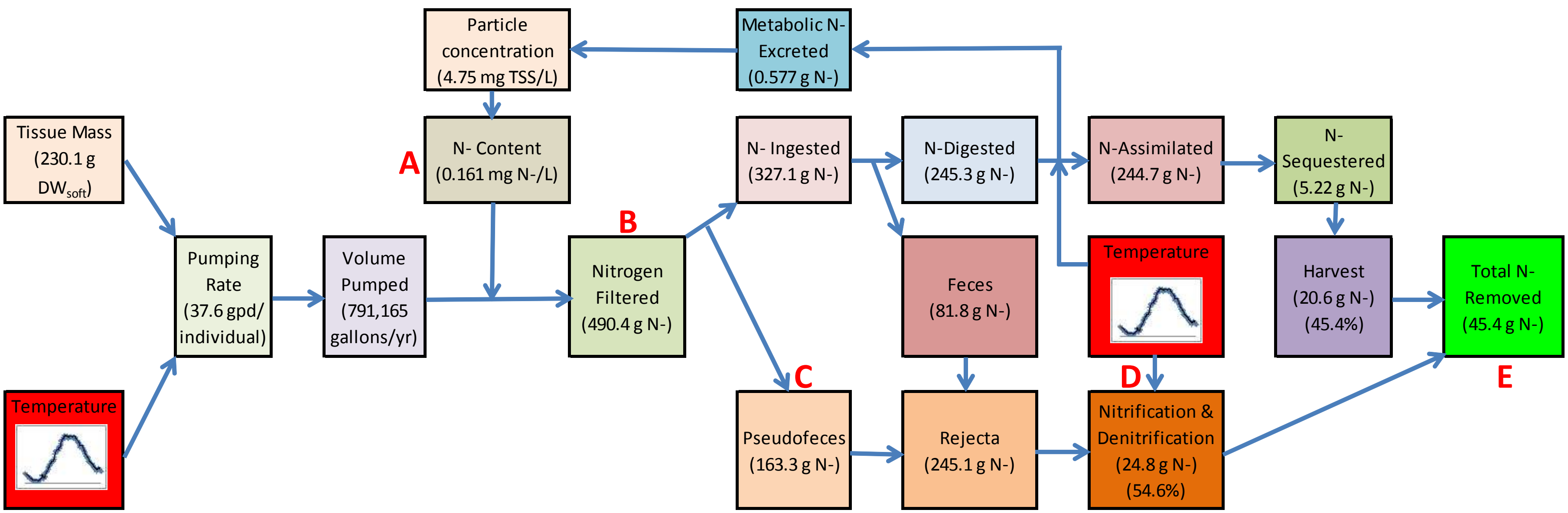
Extraction Potential???

- Oyster estimate:
  - Oysters average 0.28g N per harvestable oyster
- Commercial oyster harvest in Wellfleet estimated conservatively at 6,000,000 oysters
  - Would remove 1680 Kg of N at 0.28g N per oyster
  - Combination of culture and wild harvest
- A small shellfish farm harvesting 200,000 oysters
  - Extractive benefit of 56 Kg N per year at 0.28g N/oyster
  - Conservative estimate

Extraction Potential???

- Quahog estimate:
  - Total per quahog 0.22g N - harvestable "littleneck"
    - Bigger quahogs, much more N (less $ value)
- Recent commercial quahog harvest in Chatham approx. 2,600,000 pieces
  - 572 Kg (1258 lbs.) N, conservatively

N- Budget for an oyster bed in Wellfleet Harbor (1 m²/yr)



- N- removal by a single oyster = 0.77 g N-/yr

Estimates done by Dr. Dale Leavitt - Roger Williams University, applying theoretical values

Have shellfish been credited elsewhere?

- Many nutrient offset trading programs exist (Breetz et al. 2004), examples:
- Maryland trading offsets between land based farmers who follow conservation practices and WWTF (http://www.mdnutrienttrading.com/)
  - Or even private purchase of offset credits from NGO's
- NC similar, also fund Ecosystem Enhancement Program of the state (http://portal.ncdenr.org/web/eep/in-lieu-fee-programs#Nutrient)
- There are rules and oversight
- $13-50/lb of nitrogen
  - How many oysters for a lb. of N - ~1620, incentivize growers?
  - Waste water programs could fund town shellfish programs as an offset?

Shellfish and Nutrient Offset Credits

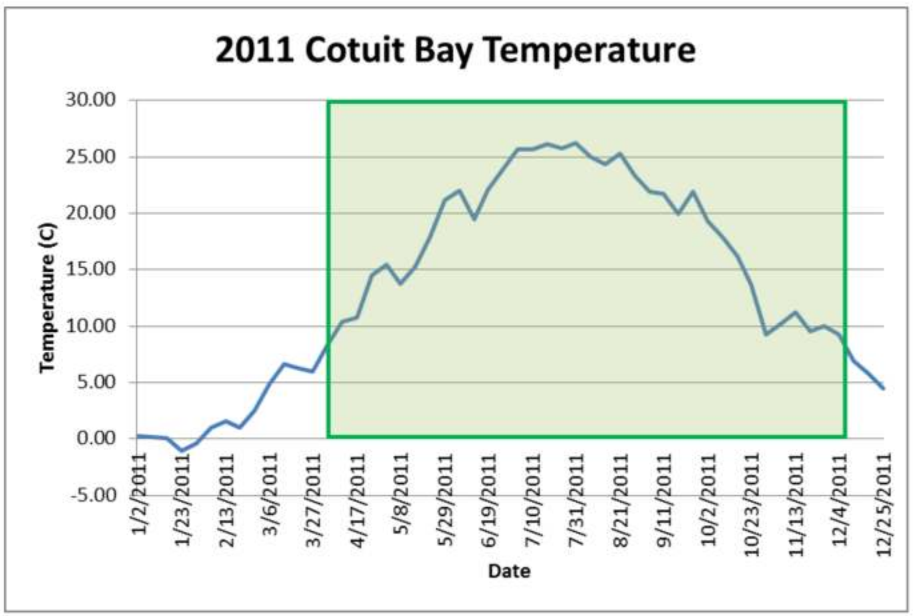
- Other areas shellfish nutrient credits are being seriously considered:
- Virginia (Newell and Mann 2012) working out the best approach in the Chesapeake region
  - Do you credit harvested tissue and/or denitrification?
- Mussel farming proposed in Sweden (Lindahl et al. 2005)
- Integrated Multi-Trophic Aquaculture (IMTA) is being used to improve fish culture environmental interactions and economic outputs

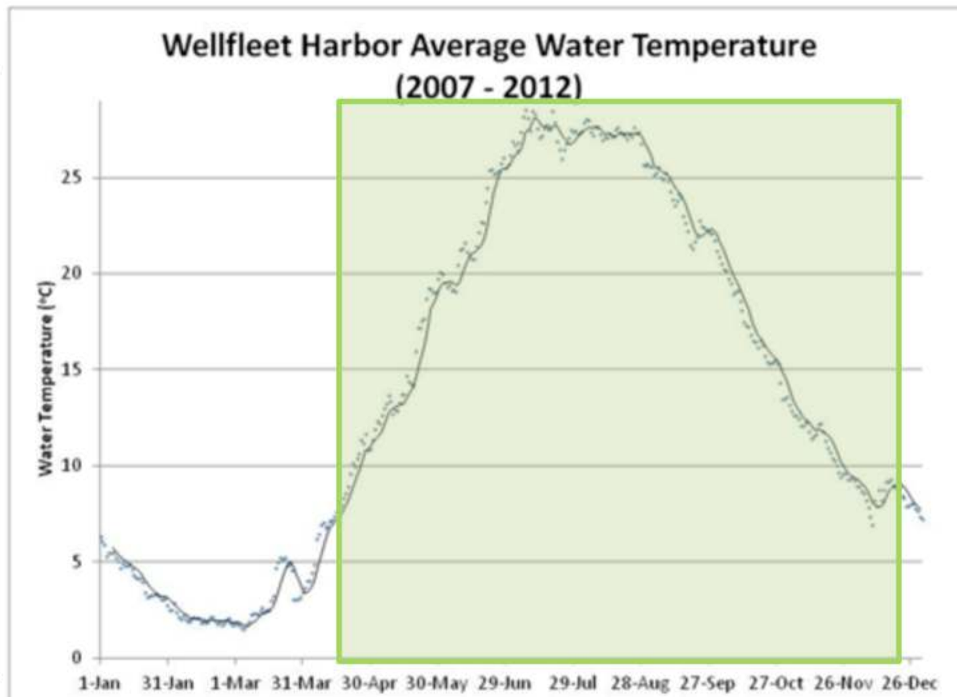
WHAT'S NOT TO LIKE?

Growing large amounts of shellfish is not always simple

Limitations – Seasonality of Activity

- Temperature regulates activity
- >8C for oysters, optimum 20-28C
  - Quahogs optimum 20C
- Roughly early April through early December
- 4-5 months of inactivity depending on year





Limitations - Predators






Limitations

Weather

Disease

Limitations – Available Space?

- State approved waters
- Non productive bottom (no current fisheries)
- Not infringing on protected species
- Limited/no user conflicts
- Where can you grow shellfish???

Shellfish N-Vis

Visualization of Oyster Aquaculture for N-Removal in Local Waters

Woods Hole Sea Grant & Cape Cod Cooperative Extension Marine Program:

- Diane Murphy
- Joshua Reitsma
- Abigail Franklin

Aquaculture

- NOAA: "aquaculture is defined as the propagation and rearing of aquatic organisms for any commercial, recreational, or public purpose. This definition covers all production of finfish, shellfish, plants, algae, and other marine organisms."
  – Public/Private
    - restoration & enhancement (NGO's, County, etc.)
  – Municipal
    - resource enhancement
    - recreational & commercial
  – Commercial
    - licensed through the State and Town
    - non-productive ground
    - open waters
    - non-competing uses

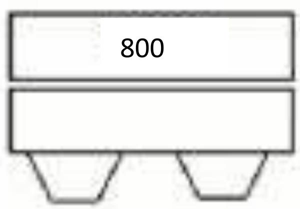
Faces of Local Aquaculture

Bottom Gear

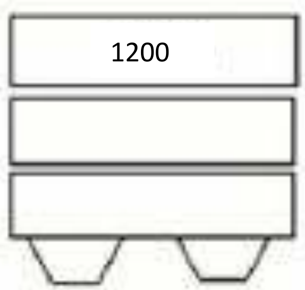
Oyster Trays
(36x36” = .84m²)

400 oysters
= 112g N

800 oysters
= 224g N

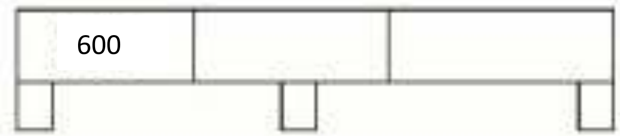


1,200 oysters
= 336g N

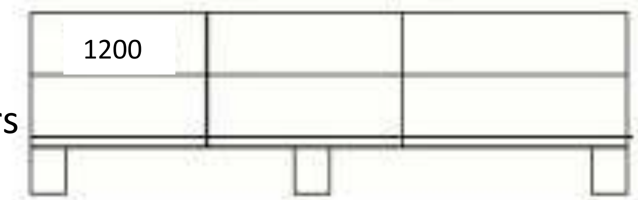


Oyster Cages
(36x63” = 1.5m²)

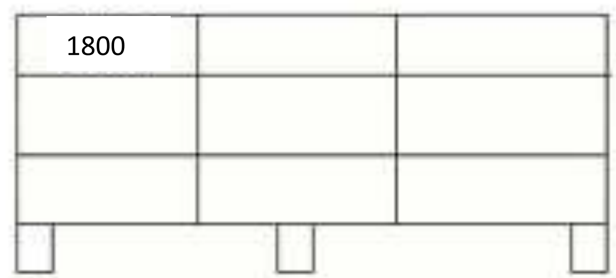
600 oysters
= 168g N



1,200 oysters
= 336g N



1,800 oysters
= 504g N

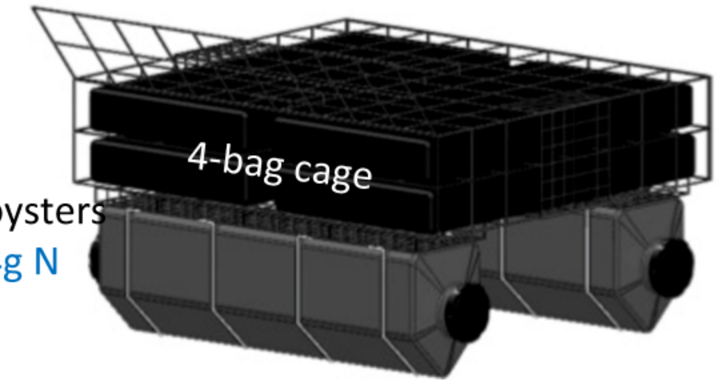


Floating Gear

Floating Bags
(18x36” = .42m^2)

200 oysters/bag
= 56g N
20 bags/line = 4,000 oysters
=1,120g N or 2.7 lbs. N

Floating Cages
(range .84m^2 to 1.5m^2)



800 oysters
= 224g N

1,200 oysters
= 336g N

<u>Recommend100 cages/acre</u>
6bags/cage x 100 = 600 bags
600bags x 200oys/bag = 120,000 oysters
120,000 x .28g N/oyster
= 33,600g or 74 pounds N

Visualization Tool

- Municipal Use
  - Siting
    - Competing uses (mooring fields, eelgrass beds, water quality, etc.)
  - Gear configurations
  - Nitrogen values

- Private Use
  - Siting
    - Competing uses (mooring fields, eelgrass beds, water quality, etc.)
  - Gear configurations
  - Nitrogen values

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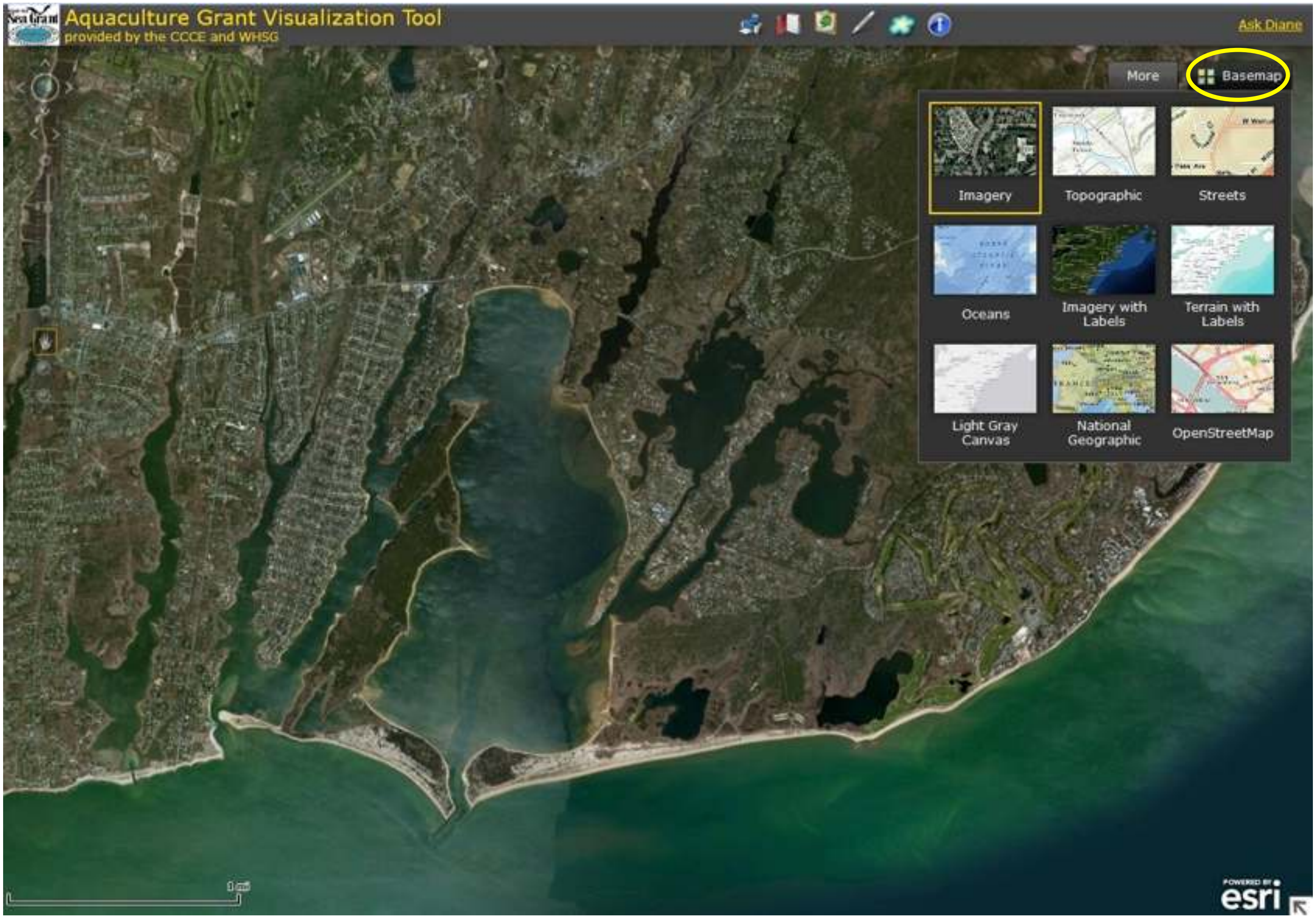
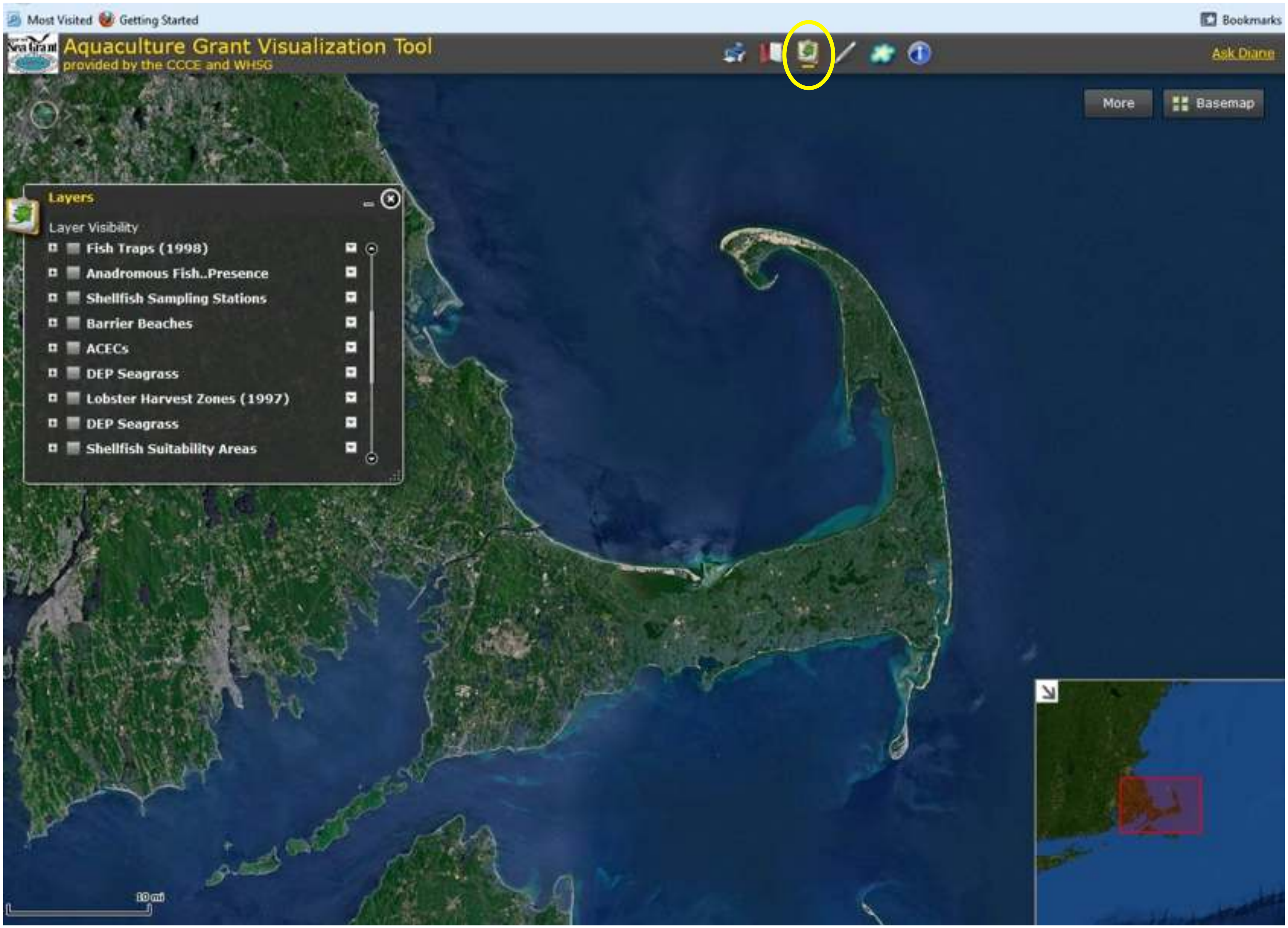
Basemap Options



Layers



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Barrier Beaches
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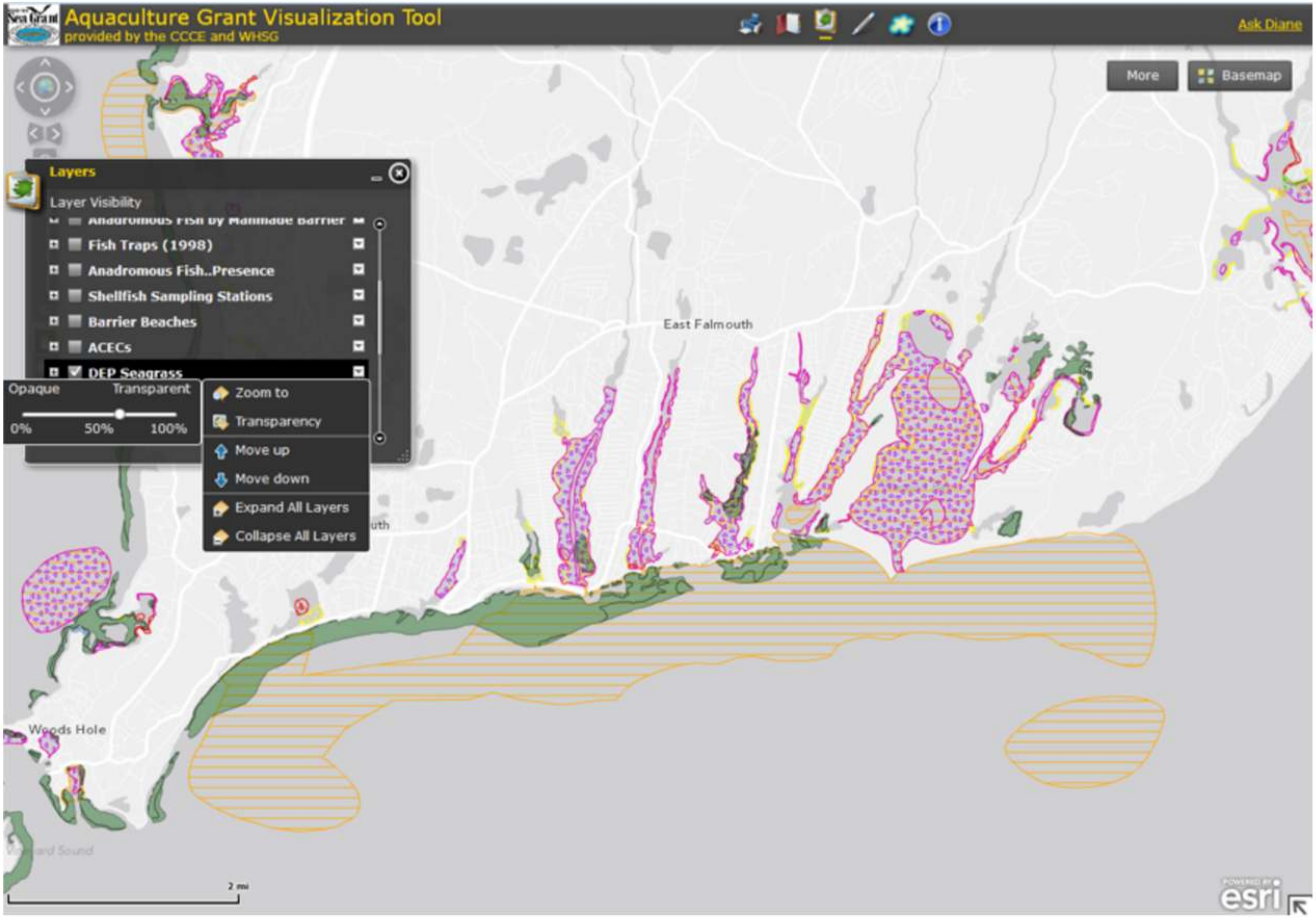
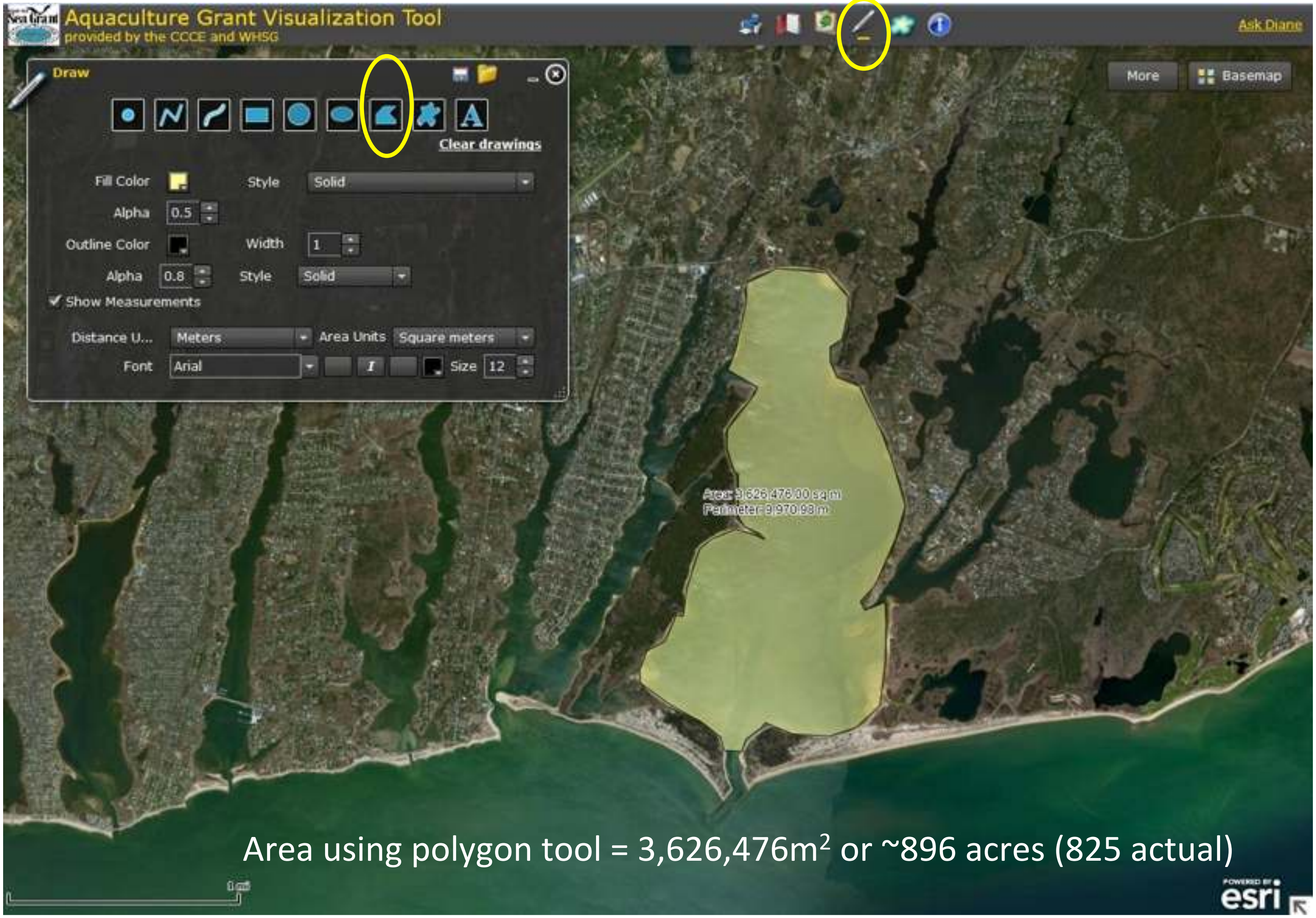
Lobster Harvest Zones (1997)
DEP Seagrass
Shellfish Suitability Areas
10 mi

Basemap & Layers

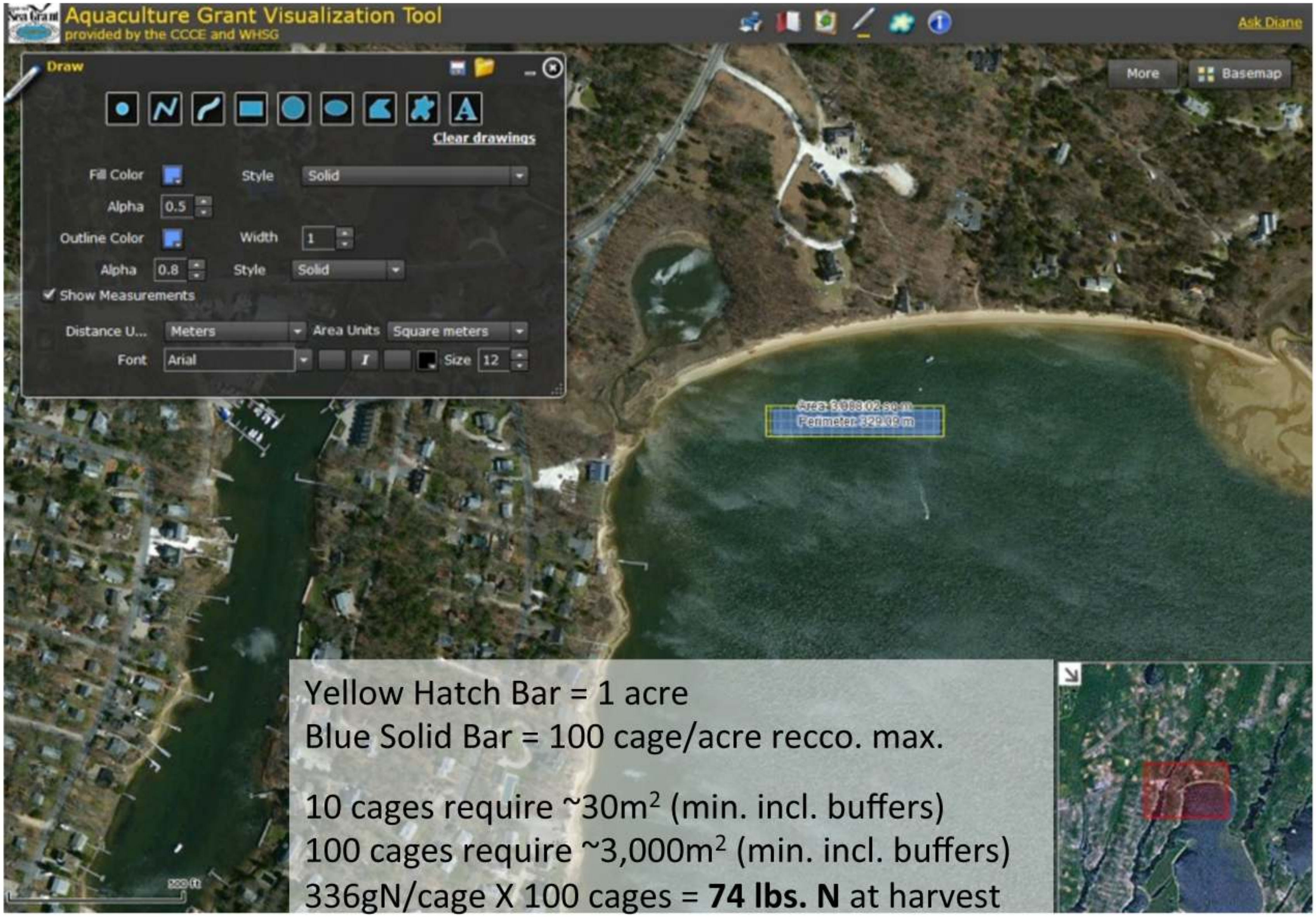


Drawing Tool



Area using polygon tool = 3,626,476m^2 or ~896 acres (825 actual)

N-Removal – Gear Footprint



Yellow Hatch Bar = 1 acre
Blue Solid Bar = 100 cage/acre recco. max.

10 cages require ~30m^2 (min. incl. buffers)
100 cages require ~3,000m^2 (min. incl. buffers)
336gN/cage X 100 cages = **74 lbs. N** at harvest

Floating Bags

Cape Cod, MA

Area = 2,459.09m^2 or .61 acre

1,000+/- floating bags (assume 200 oysters/bag and 56gN/bag)
56g N/bag X 1,000 bags = **123.7 lbs. N** at harvest

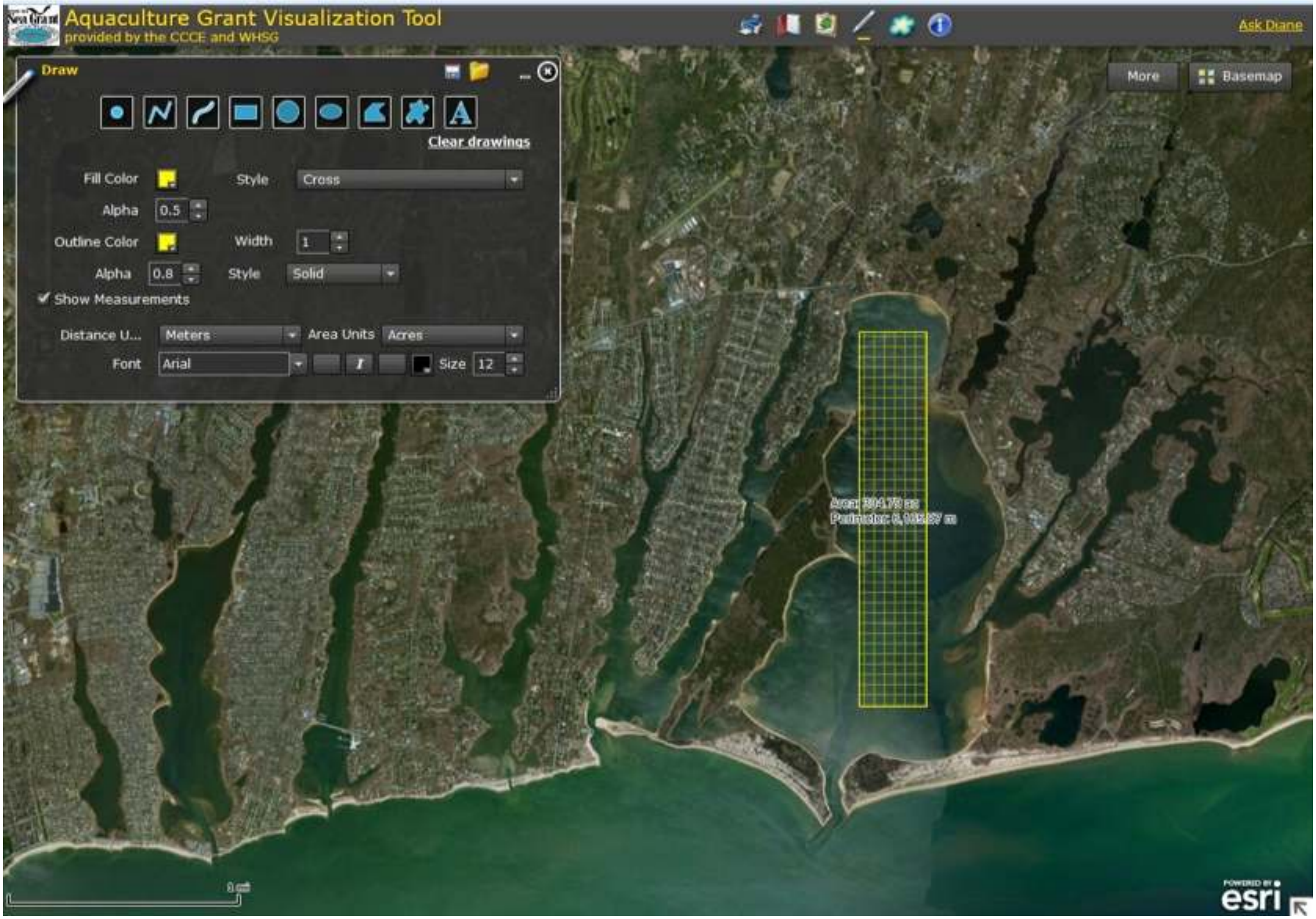
Example: Waquoit Bay

- Estimated 23,000 kg N (50,706 lbs) per year enters Waquoit Bay system
- Assume floating oyster cages
  - 100 cages/acre, 1,200 oysters/cage X 100 cages = 120,00 oysters/acre in floating cages
  - Would require 35,675,674 oysters to remove *22,000 pounds N (over 300 acres)

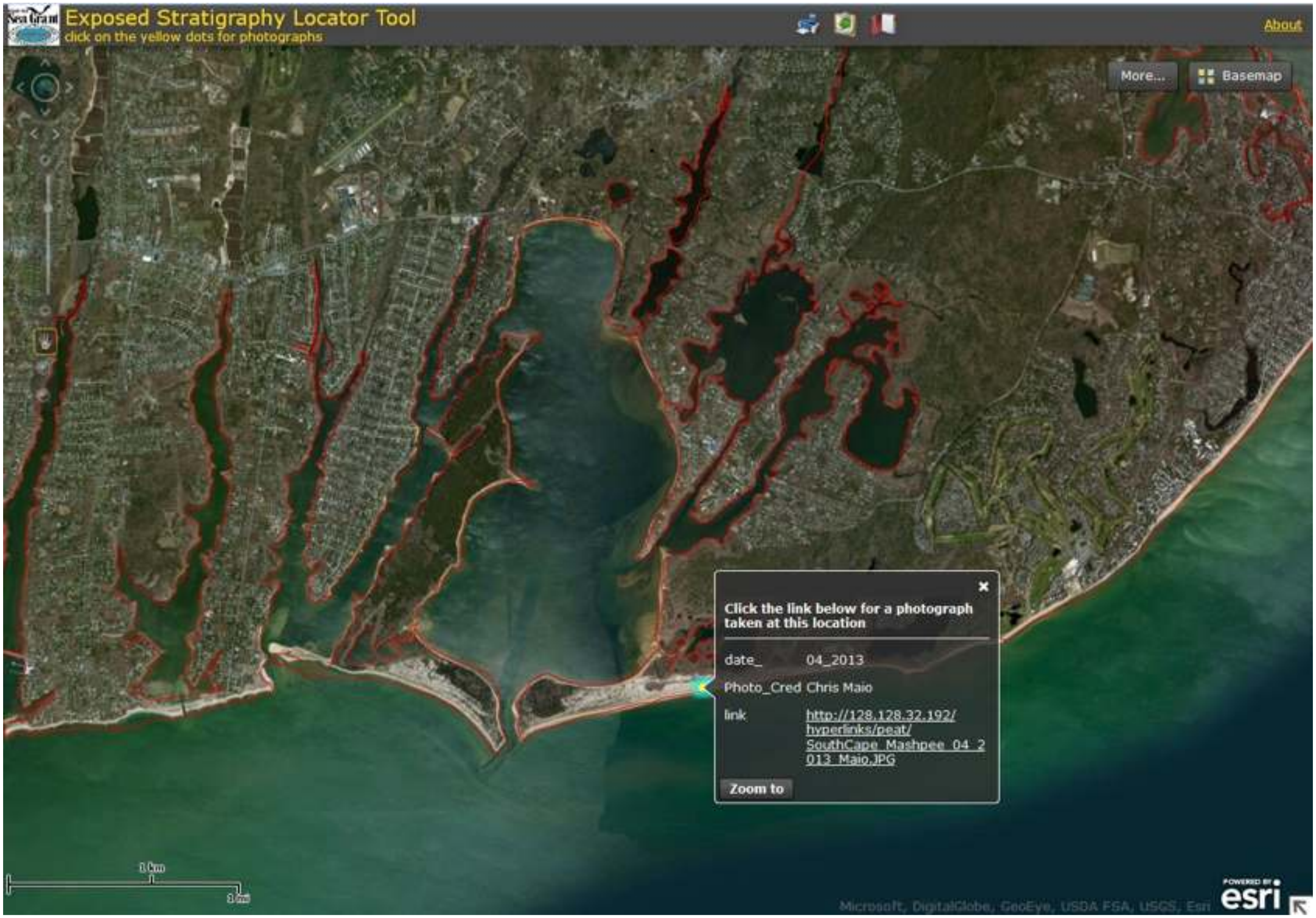
Acres	Oysters/Acre	Pounds N Removed/Acre
1	120,000	74
5	600,000	370
100	12,000,000	7,400
200	24,000,000	14,800
300	36,000,000	22,200
500	60,000,000	37,000

*less than half 50,706 lbs yearly N input

300 Acre Footprint



Stratigraphy Tool



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  - Woods Hole Sea Grant & Cooperative Extension jreitsma@barnstablecounty.org

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  - N-analysis of quahog and oyster samples

- Towns and growers who helped obtain shellfish samples