Restoring Oysters Sustainably Requires
Good Genes: Genomic Evidence from
Delaware Bay and Hudson River

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photo by Josef Galatioto
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What we say to dogs
Okay, Ginger! I've had it! You stay out of the garbage! Understand, Ginger? Stay out of the garbage, or else!

What they hear
blah blah GINGER blah
blah blah blah blah
blah blah GINGER blah
blah blah GINGER blah
blah blah blah blah...
Eastern Oyster Natural History

**Crassostrea virginica**
- Canada to Mexico
- High fecundity
- Larval dispersal
- Phenotypic plasticity
  - Shell morphology
  - Depth
  - Euryhaline
Osmoregulatory Plasticity

Swannack et al. 2014 JSR

Oyster Suitability Index

Mean salinity during spawning season
Questions for Today

- How much does oyster population fitness depend on phenotypic plasticity vs. evolutionary mechanisms that depend on genetic diversity?
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* How much does oyster population fitness depend on phenotypic plasticity vs. evolutionary mechanisms that depend on genetic diversity?

* Is larval dispersal limited in the upstream direction, allowing some measure of local adaptation?

* Do hatchery produced cohorts have reduced genetic diversity and if so, does it matter?
Questions for Today

* How much does oyster population fitness depend on phenotypic plasticity vs. evolutionary mechanisms that depend on genetic diversity?
  - Delaware Bay adaptive gene expression plasticity

* Is larval dispersal limited in the upstream direction, allowing some measure of local adaptation?
  - Hudson River oyster population structure

* Do hatchery produced cohorts have reduced genetic diversity and if so, does it matter?
  - Wild broodstock vs. aquaculture strain vs. wild
Why Restore Oysters?

* Legacy of oysters in NYC
Ecosystem Services

* Water quality from filter feeding (1-3 liters / hr / oyster)

* Habitat provisioning

* Coastal protection
  ➢ Attenuation of wave strength

Illustration from BOP Oyster Gardening Manual
NY/NJ Oyster Restoration

* Billion Oyster Project, Harbor School
NY/NJ Oyster Restoration

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* Oyster Research Restoration Project, HRF & partners
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* Tappan Zee Bridge Reconstruction Mitigation, AKRF Inc. with partners
* The River Project, Pier 40
* Naval Weapons Station Earle, NY/NJ Baykeepers
* Rebuild by Design competition – Staten Island living oyster fringe reef, SCAPE landscape architects
* Jamaica Bay by NYCDEP
Oyster Restoration Goals?

- NOT for consumption in Hudson/Raritan Estuary

- Short-lived eco-services from hatchery plantings
  - Local benefits, high maintenance, research pilot
Oyster Restoration Goals?

- NOT for consumption in Hudson/Raritan Estuary

- Short-lived eco-services from hatchery plantings
  - Local benefits, high maintenance, research pilot

- Jump-start population recovery (stock enhancement)

- Rebuild self-sustaining reefs
Just How Plastic are Oysters?

Swannack et al. 2014 JSR
Just How Plastic are Oysters?

Tappan Zee Daily Mean Salinity at 2 m depth

Salinity

days between 3/31/14 & 07/29/14

Swannack et al. 2014 JSR
Delaware Bay Oysters
Gene Expression Methods

Delaware Bay Source Reefs
Low salinity (10)  Mod. salinity (25)

9 week salinity acclimation, then RNAseq adults
EdgeR testing for differential expression

http://www.dnr.state.md.us/
Response to environmental variation

- Reaction Norms

(A) Genetic

(B) Plasticity

(C) G x E
Differential Expression Results

Reef by Treatment
n= 5,848 (13.9%)

1892

72

146

21

13

4039

Reef
n=252 (0.6%)

Treatment
n=7,936 (18.9%)

Plasticity
Differential Expression Results

Reef Effect

Reef by Treatment
n= 5,848 (13.9%)

Reef
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Plasticity
Differential Expression Results

Reef Effect
- Reef by Treatment
  - n= 5,848 (13.9%)

G x E
- 1892

Plasticity
- Reef
  - n=252 (0.6%)
- Treatment
  - n=7,936 (18.9%)
Gene expression plasticity is not the whole story

Evolutionary processes also important
Single Nucleotide Polymorphisms

Transcript 1
AAACCAGCGCA..... TTTCGGGCTC..... AGTCGACCG.....

Transcript 2
AAACCAGCGCA..... TTTCGAGCTC..... AGTCAACCG.....

Transcript 3
AAACATGCGCA..... TTTCGGGCTC..... AGTCAACCG.....

Transcript 4
AAACCAGCGCA..... TTTCGGGCTC..... AGTCGACCG.....

Haplotypes

Haplotype 1
CTCAAAAGTACGTTTCAGGCA

Haplotype 2
TTGATTGCGCAACACGTAATA

Haplotype 3
CCCCGATCTGTGATACTGGTG

Haplotype 4
TCGATTTCGCCTCTGACGAC
Allele Frequency Differentiation Between Reefs Estimated with Fst

Genomic mean Fst across 79,660 SNPs = 0.0025 (minor allele freq. > 0.25)
Allele Frequency Differentiation Between Reefs Estimated with Fst

Genomic mean $Fst$ across 79,660 SNPs = 0.0025 (minor allele freq. > 0.25)

797 SNPs in the top 1% of distribution, contained within 627 transcripts
With strong selection for one sequence (allele) among many variant sequences at a locus, expect that locus to show:

- Reduced nucleotide diversity
  - Low-salinity reef mean = 0.34
  - High-salinity reef mean = 0.41
  - paired t-test, $p = 0.035$
With strong selection for one sequence (allele) among many variant sequences at a locus, expect that locus to show:

- Reduced nucleotide diversity
- Elevated allele frequency correlations (linkage disequilibrium)
Signature of Selection at Low Salinity Reef only

For 627 transcripts that contained one or more high-Fst SNPs:

Pearson correlation test, $p=0.019$
What is the timescale for this natural selection?

* Recurrent within-generation selection
  - Similar to patterns described for blue mussels and barnacles
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- Recurrent within-generation selection
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- Multigenerational Darwinian adaptation
  - Only likely if gene flow is limited
  - Biophysical larval tracking models suggest dispersal asymmetry
  - Quantitative genetic simulations ongoing to test these distinct mechanisms
HRE Oysters

* 2012 and 2013 collections
* Spat and adults
* Thanks to
  - Jeff Levinton, Stonybrook U.
  - Paul Cooper, PrincetonHydro
  - NYCDPR (Pralls Island)
  - NY/NJ Baykeepers
  - NY oyster gardeners
  - HRF & ORRP
Eight Microsatellite Markers, 2012 samples

- Bayesian assignment test clustering using STRUCTURE
- Best support for K=2 differentiated populations
Population Genomic Methods

* Double-digest RADseq
  - Barcoded individuals
  - Single-end sequencing
  - 100 bp reads
  * n = 13 – 24 per sample
* SNPs or haplotypes
* Filters:
  - 89 bp trimmed reads
  - No missing data
  - Minor allele freq. > 0.01
Limited Connectivity?

Wild oyster samples

- n = 13 each, no missing data allowed at 430 loci
- Bayesian assignment test clustering using STRUCTURE
- Best support for K=2 differentiated populations
Limited Connectivity?

Upper Hudson and lower Hudson samples have different level of historical admixture
Fisher’s Island
Introgression?
Does Hatchery Production Reduce Diversity?

**Percent Polymorphic Loci**

- N=13 individuals per sample
- 430 loci with no missing data
Oyster performance comparisons

Compare hatchery-produced and wild across diverse natural environments:
- Growth rate
- Survivorship
- Fecundity
Rock Oyster Survivorship after 3 months
(Summer)

**P < 0.05**

Dominic McAfee
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Macquarie University
Sydney, Australia
How much does oyster population fitness depend on phenotypic plasticity vs. evolutionary mechanisms that depend on genetic diversity?

For gene expression, plasticity & evolutionary mechanisms both contribute to broad realized niche
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Is larval dispersal limited in the upstream direction, allowing some measure of local adaptation?

- Yes in Hudson River, but don’t know degree of isolation yet
How much does oyster population fitness depend on phenotypic plasticity vs. evolutionary mechanisms that depend on genetic diversity?
- For gene expression, plasticity & evolutionary mechanisms both contribute to broad realized niche

Is larval dispersal limited in the upstream direction, allowing some measure of local adaptation?
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Do hatchery produced cohorts have reduced genetic diversity and if so, does it matter?
- Bottlenecks, yes. We need tests of whether bottlenecked and ‘specialist’ oysters are less reliable for building sustainable reefs
Thanks

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For this Talk:
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Hare Lab
Best Management Practices for Shellfish Restoration

Prepared for the ISSC Shellfish Restoration Committee

2011
Best Management Practices for Shellfish Restoration

Prepared for the ISSC Shellfish Restoration Committee

2011

Kennedy et al. JSR 2011

Figure 2. Number of sites that had a restoration activity in MD 1990-2007.
A PRACTITIONERS GUIDE TO THE

Design & Monitoring
of Shellfish Restoration Projects

2012 update
Recommendations (in recruitment-limited systems):

- Transplant broodstock when possible
- For hatchery-based stock enhancement use locally collected broodstock for spawning
- Use pair-wise crosses of broodstock to maximize parental contributions, minimize genetic bottleneck
- Characterize the genetics of broodstock and the hatchery-produced cohort