Atlantic Cod Population Structure

Phenotypic characters: what they can tell us?

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June 19, 2018

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Science. Education. Community.
What is genotype? What is phenotype?

- **Genotype** is the genetic identity of a fish.
- **Phenotype** is a description of fish’s observable characteristics.
- Not all phenotypes are a direct result of genotype; oftentimes result of interaction of genotype with environment experienced.

*Donax variabilis* with diverse coloration and patterning in their phenotypes.

Atlantic cod color morphs

- a
- b
- c
- d

*Wroblewski et al 2005 Sherwood and Grabowski 2010*
Phenotypic Characters

- Many different phenotypic characters have been used to identify fish populations.
  - Life history traits
  - Meristics

- Some are more useful for describing differences between populations and some are useful for differentiation of populations (i.e. natural markers)

Otoliths

Body Morphometrics
Phenotypic Characters

- Phenotypic characters alone do not provide direct evidence for genetic differences.
- Best when applied in conjunction with genetics and movement information.
- Provide information on life history type.
- Provide knowledge on mixing of fish populations which can aid fisheries management decisions.

Stock mixing of Cod Populations in the Baltic Sea

Hussey et al. 2016
Outline

- Overview of phenotypic markers
  - Morphometrics
  - Otolith chemistry
  - Otolith structure
    - Life history traits (reviewed in the next presentation)
- Recent work applying phenotypic markers to Atlantic cod.
Morphometrics

- They may look the same, but...
- Subtle differences in body shape often occur among populations.
- Differences in life history (e.g. growth, diet), migratory behavior, and environment among regions may drive differences in body shape.
Cod Morphometrics in US Waters

Western and Eastern GoM (Red)
- Suggests high degree of structuring within the GoM
- Classification accuracy = 91%

Eastern and Western GB (Blue)
- Important structure on Georges Bank
- Classification accuracy = 77%

- Is Platt’s Bank the boundary between the western and mid-coast sub-populations?

Sherwood and Grabowski 2012
Otolith Chemistry

- Otoliths retain record of water chemistry.
- Otolith chemistry can be used as a natural tag to discriminate among groups of fish.

Pathway of Incorporation

- Ca, Sr, Mg, Mn, Ba
Cod Otolith Chemistry in US-Canadian Waters

- Atlantic cod collected at 7 spawning grounds in NW Atlantic
- Elemental fingerprinting
- Demonstrated the ability to discriminate between spawning sites (83-94% accuracy)

Campana et al. 1994
Campana and Gagne 1995
Otolith Structure

- Otoliths retain a record of past growth.
- Difference in otolith growth reflects:
  - Physiological and developmental status (age, sex)
  - Physical environment (temperature, upwelling)
  - Biological environment (competition, food availability)

North Sea Herring – Otolith Patterns

Clausen et al. 2007
Cod Otolith Structure in Norwegian Waters

- Size of year-one otolith growth used to differentiate between Northeast Arctic cod and Norwegian Coastal cod.

Northeast Arctic cod

Norwegian Coastal cod
Recent Collaborative Cod Research

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Capt. David Goethel
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Steve Cadrin
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Doug Zemeckis
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Adrienne Kovach
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Overarching Goal

The goal of this research was to characterize cod spawning complexes in the Gulf of Maine and how they interact with the fishery.

Can morphometrics be used to discriminate between winter and spring spawners?

Can otoliths be used to discriminate between winter and spring spawners?

How does the modern and historical fishery interact with spawners?

Note: this is unpublished work
Data Collection

Spawning fish: 2012-2015; Spring=63, Winter=68
Modern commercial collections: 2015-2016; n=187

Sampling with Industry Partner

Archived Otoliths
Results: Differences in Body Morphometrics

• Significant differences in 8 of 17 morphometrics variables (p< 0.01).

• Body morphometrics can classify fish as winter or spring spawners with ~82% accuracy.
Results: Differences in Otolith Structure

- Significant differences in year-1 growth between winter and spring spawners ($p < 0.001$).
- Enables classification of fish based on year-1 growth alone (~78% accuracy)
Otolith Structure: Mixed Stock Composition

Winter and Spring Spawners by Year

<table>
<thead>
<tr>
<th>Year</th>
<th>Winter Spawner</th>
<th>Spring Spawner</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>S = 51%</td>
<td>W = 49%</td>
</tr>
<tr>
<td>1998</td>
<td>S = 57%</td>
<td>W = 43%</td>
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<tr>
<td>1999</td>
<td>S = 14%</td>
<td>W = 86%</td>
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<tr>
<td>2000</td>
<td>S = 53%</td>
<td>W = 47%</td>
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<tr>
<td>2001</td>
<td>S = 74%</td>
<td>W = 25%</td>
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<tr>
<td>2002</td>
<td>S = 41%</td>
<td>W = 59%</td>
</tr>
<tr>
<td>2003</td>
<td>S = 7%</td>
<td>W = 93%</td>
</tr>
<tr>
<td>2004</td>
<td>S = 43%</td>
<td>W = 57%</td>
</tr>
<tr>
<td>2005</td>
<td>S = 23%</td>
<td>W = 77%</td>
</tr>
</tbody>
</table>

Micah Dean, MDMF
Results: Differences in Otolith Chemistry

- Significant differences in year-1 otolith chemistry.
- Otolith chemistry can classify fish as winter or spring spawners with ~74% accuracy.
Results: Otolith Chemistry Mixed Stock Composition

Increase in the proportion of winter spawners in fishery samples during recent time period.

1980s (n=116) 49% Winter
1990s (n=154) 46% Winter
2010s (n=187) 64% Winter
Spatial Shifts in the Resource and Fishery

H1: Spatial shift in fishery has increased catch of winter spawners.
• Otolith chemistry suggests Atlantic cod are experiencing the warming trend in the Gulf of Maine

H2: Winter fish are doing “better” in current thermal environment resulting in a shift in relative abundance of spawners.
Findings

• Otolith structure, chemistry & morphometrics all show differences between winter and spring spawners in western Gulf of Maine.

• Provides tools to discriminate between winter and spring spawners and assign fish of unknown origin to their source population.

• Provides knowledge on mixing of fish populations which can aid fisheries management decisions.
What do you see on the water?

- Do you experience cod with different colors and shapes (where and when)?

- Have you noticed changes in spawning seasons (or areas) over time?
Project Acknowledgements

- Funding: NOAA Saltonstall Kennedy Program
- Massachusetts Division of Marine Fisheries: Lots of help in sampling cod over past years
- Northeast Fisheries Science Center:
  - Data: Commercial landings
  - Archived samples