



# Atlantic cod stock structure in US waters: Introduction

**The Atlantic Cod Stock Structure Working Group (ACSSWG)**

**Presenter: Richard McBride, NOAA Fisheries**

**New England Fishery Management Council Peer Review**

# Outline – Introduction

Why does stock structure matter?

- Populations vs. monitoring, assessment, or management units

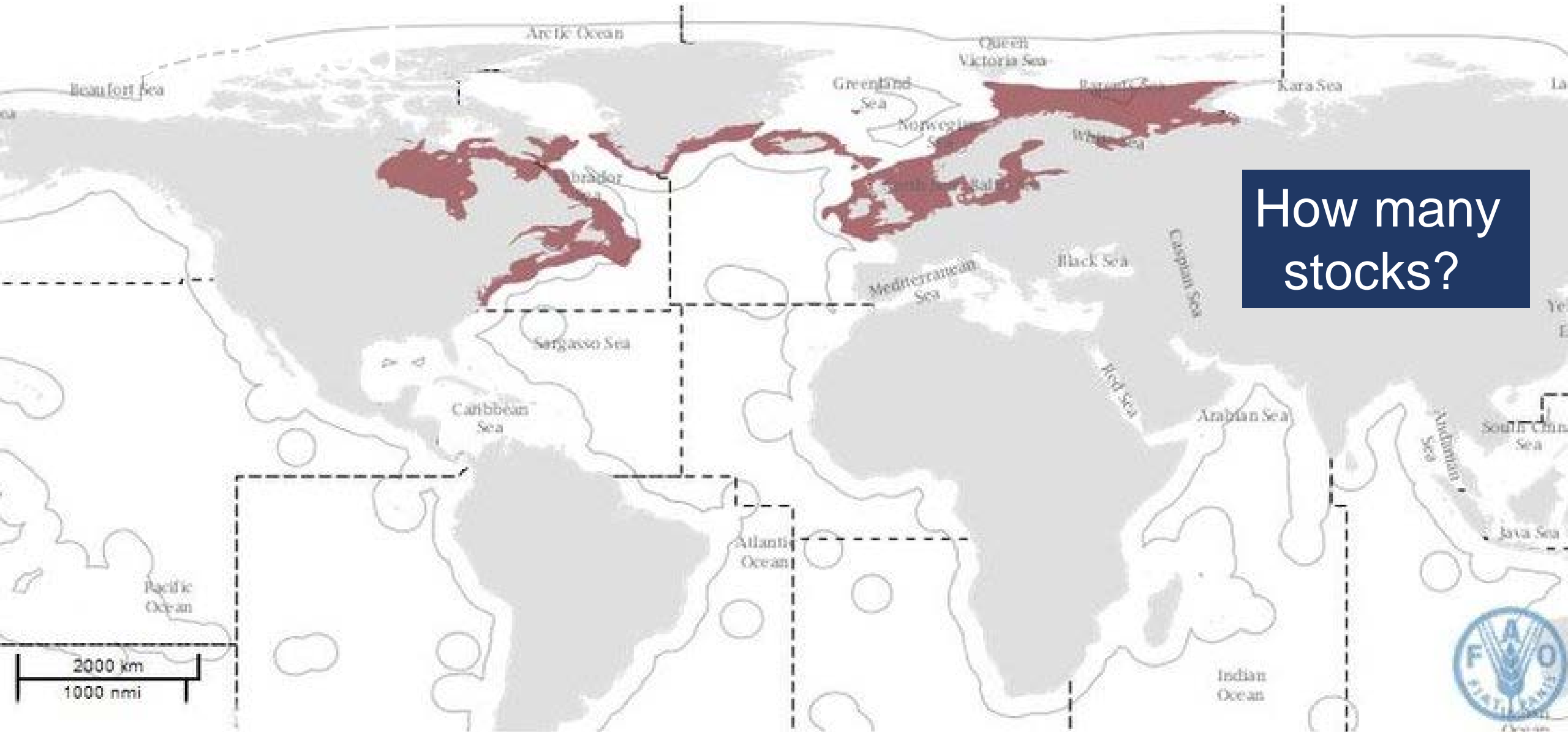
The Atlantic Cod Stock Structure Working Group

- The people, partners and progress

Preview the approach and proposal

- Interdisciplinary as complementary not competing perspectives
- A 5 stock hypothesis in US waters

# Global distribution of cod (*Gadus morhua*)



No, not this kind of fish stock



Instead, a biological stock (= population)

# What is a biological stock?

Consider a group of individuals where...

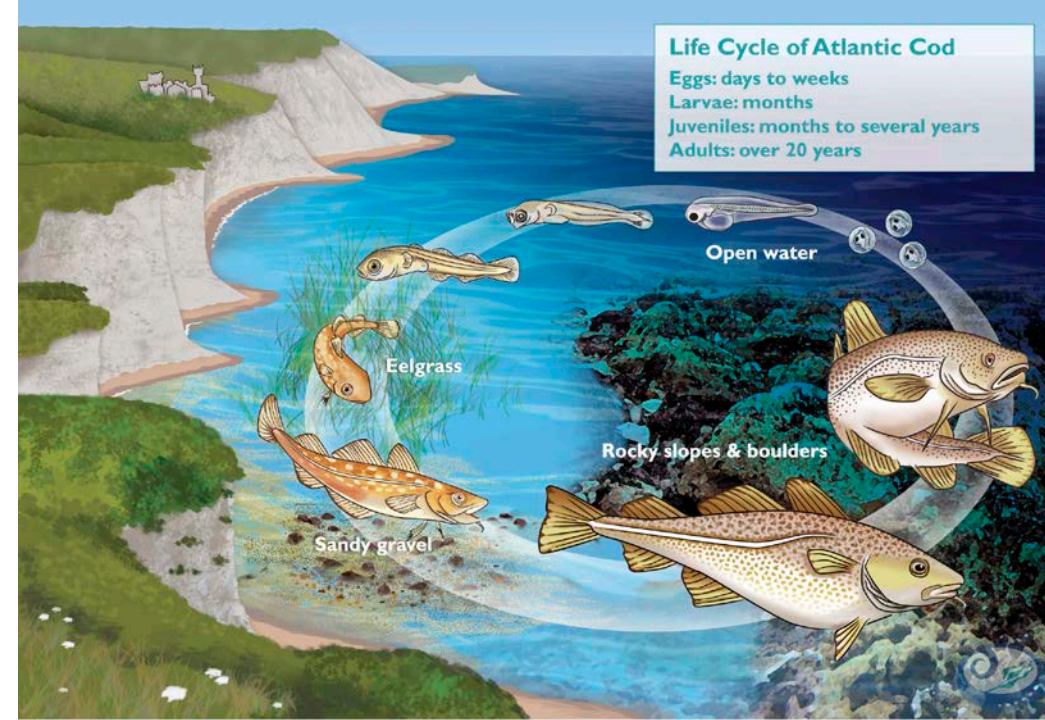
Source of new recruits comes from within

- reproductive isolation

Demographics – growth, mortality, maturity, fecundity –  
are similar by age, size, or sex (i.e., dynamic pool)

Abundance estimates are representative of the stock

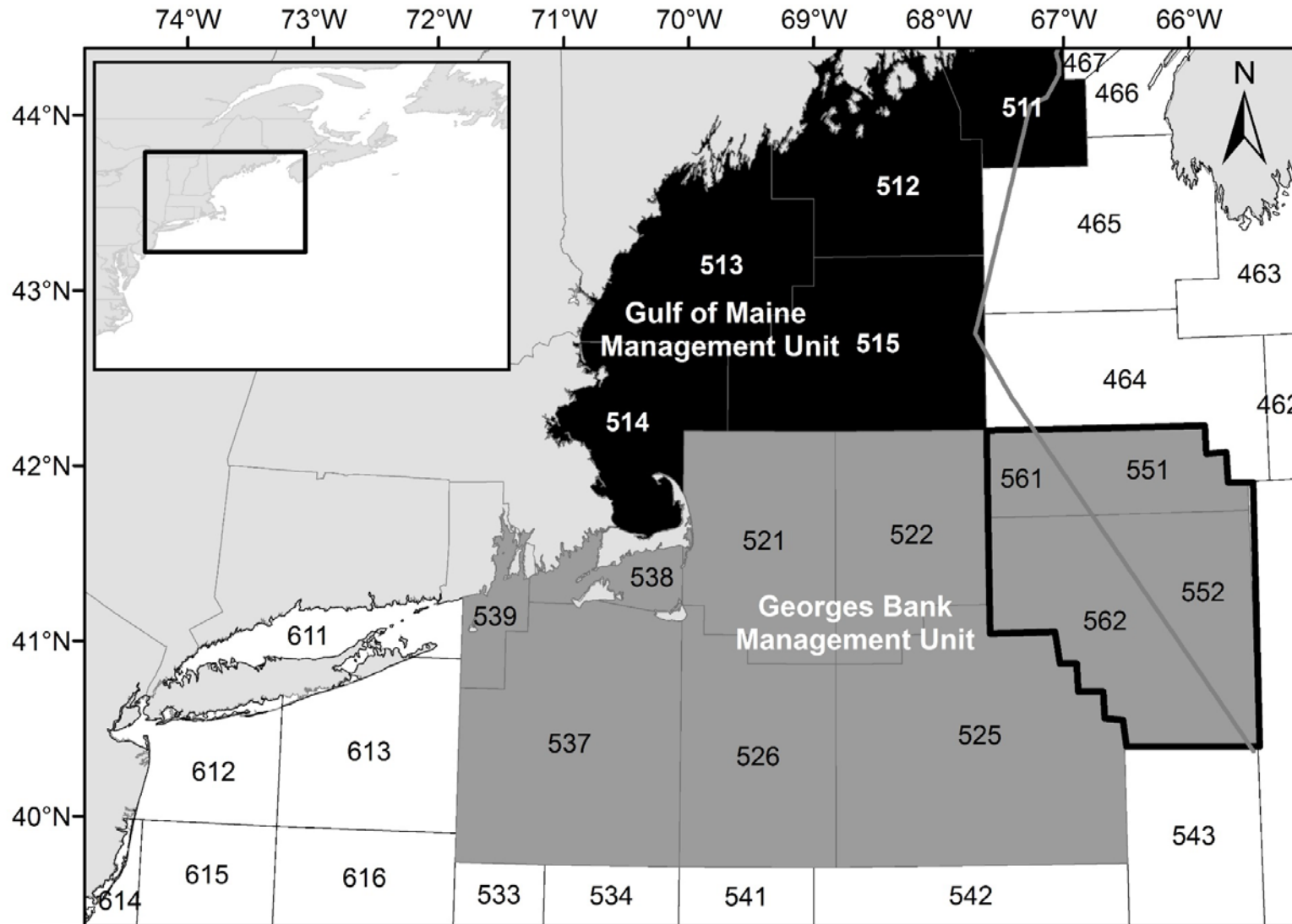
- well mixed



The Atlantic cod uses many habitats throughout its life. Open water, eelgrass beds, sandy and gravel areas, kelp, boulder fields and steep rocky ledges are important for growth and survival during different life stages of this fish.

*Art by Molly Thomson*

# Where are the boundaries of the current US cod management units?



Since ~ 1970s  
(North-South)

- 2 US stock units
- Transboundary
- Subunits (areas)

*The question:*  
How do these  
geographic  
management units  
relate to biological  
stock structure  
of Atlantic cod?

# Wasn't there a stock structure workshop in 2012?

**“The Steering Committee recommends that an inclusive but focused Working Group meeting be held involving a small group of Canadian and US scientists to consider the results of the Workshop.” - Annala, 2012**

## Timeline from WG formation (Feb 2018)

### Conference Calls

- 1 in 2020
- 7 in 2019
- 3 in 2018

### WG workshops (UNH, GMRI)

- Nov 14-15, 2018
- Jun 20-21, 2018

### Outreach symposia

- Mar 7, 2020 (MFF)
- Jun 6, 2019 (UNH)
- Jun 19, 2018 (UNH)

# Working Group members



Ames



Andrushchenko



Cadrin



Cournane



Dean



DeCelles



Kerr



Kovach



McBride (co-chair)



Overgaard  
Therkildsen



Puncher



Smedbol (co-chair)



Wang



Zemeckis



(DFO)

# Other contributors, reviewers, and sponsors

D. Clark (DFO)

D. Goethel (FV Ellen Diane)

R. Brown, A. Miller, M. Palmer, D. Richardson, M. Traver, M. Wuenschel (NEFSC)

G. Sherwood, Z. Whitener (GMRI)

M. Raymond (Maine Fishermen's Forum)

C. Kellogg, T. Nies (New England Fishery Management Council)

E. Chapman, M. Lemos, L. Taylor Singer (NH Sea Grant)

## Attendees at our three symposia



Fisheries and Oceans  
Canada

Pêches et Océans  
Canada



New England  
Fishery Management  
Council



# What is the ACSSWG?



## Atlantic cod stock structure working group

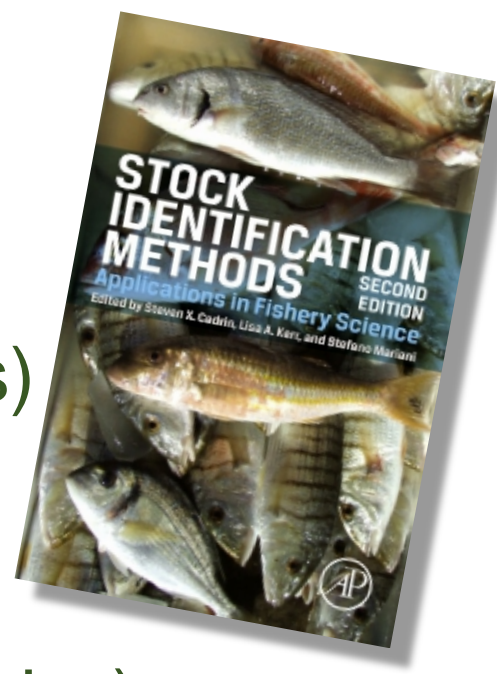
- Experts (members & partners) working collaboratively
- to characterize the biological stock structure of cod
- using interdisciplinary approach
- for eventual consideration in monitoring, assessment and management of US Atlantic cod

# Why interdisciplinary?

Perspective	Information	Population Inference
Distribution	fishery data fishery-independent surveys	spatial and seasonal fishing patterns by fleet; spawning, feeding and nursery areas distribution at early, juvenile and adult life stages
Dispersal	early life stage dispersal conventional tags archival tags active telemetry passive telemetry	connectivity of spawning and nursery areas movement patterns or rates individual movement trajectories individual movement trajectories movement patterns and spawning dynamics
Geographic Variation	selected genetic characters neutral genetic characters life history traits morphology meristics natural tags abundance trends size or age composition	reproductive isolation or local adaptation reproductive isolation limited mixing and possibly reproductive isolation or local adaptation limited mixing and possibly reproductive isolation or local adaptation limited mixing at early stages and possibly reproductive isolation or local adaptation limited mixing and environmental history demographic independence demographic independence or fishery selectivity

# Our interdisciplinary

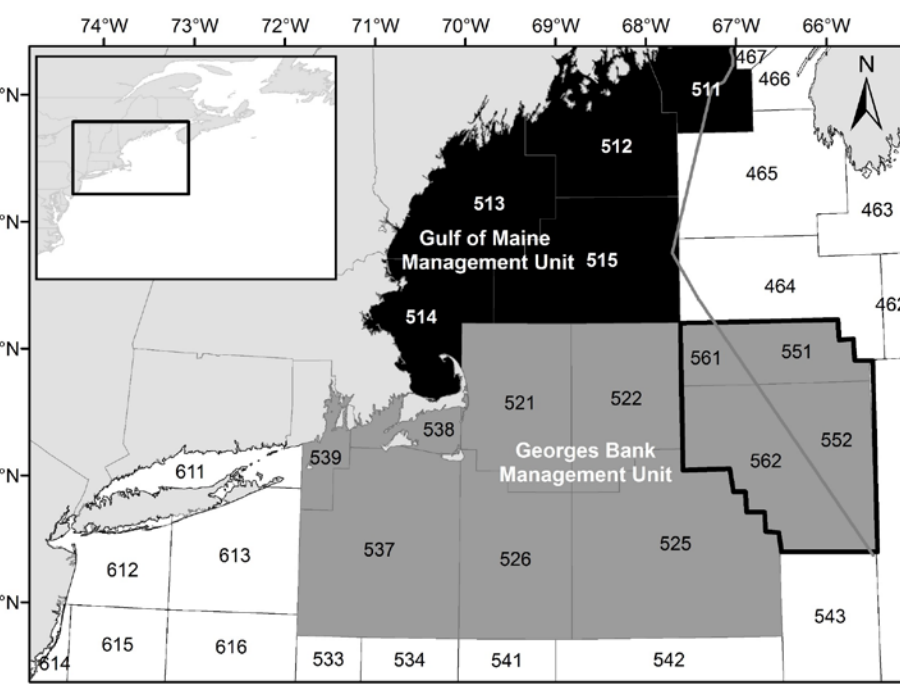
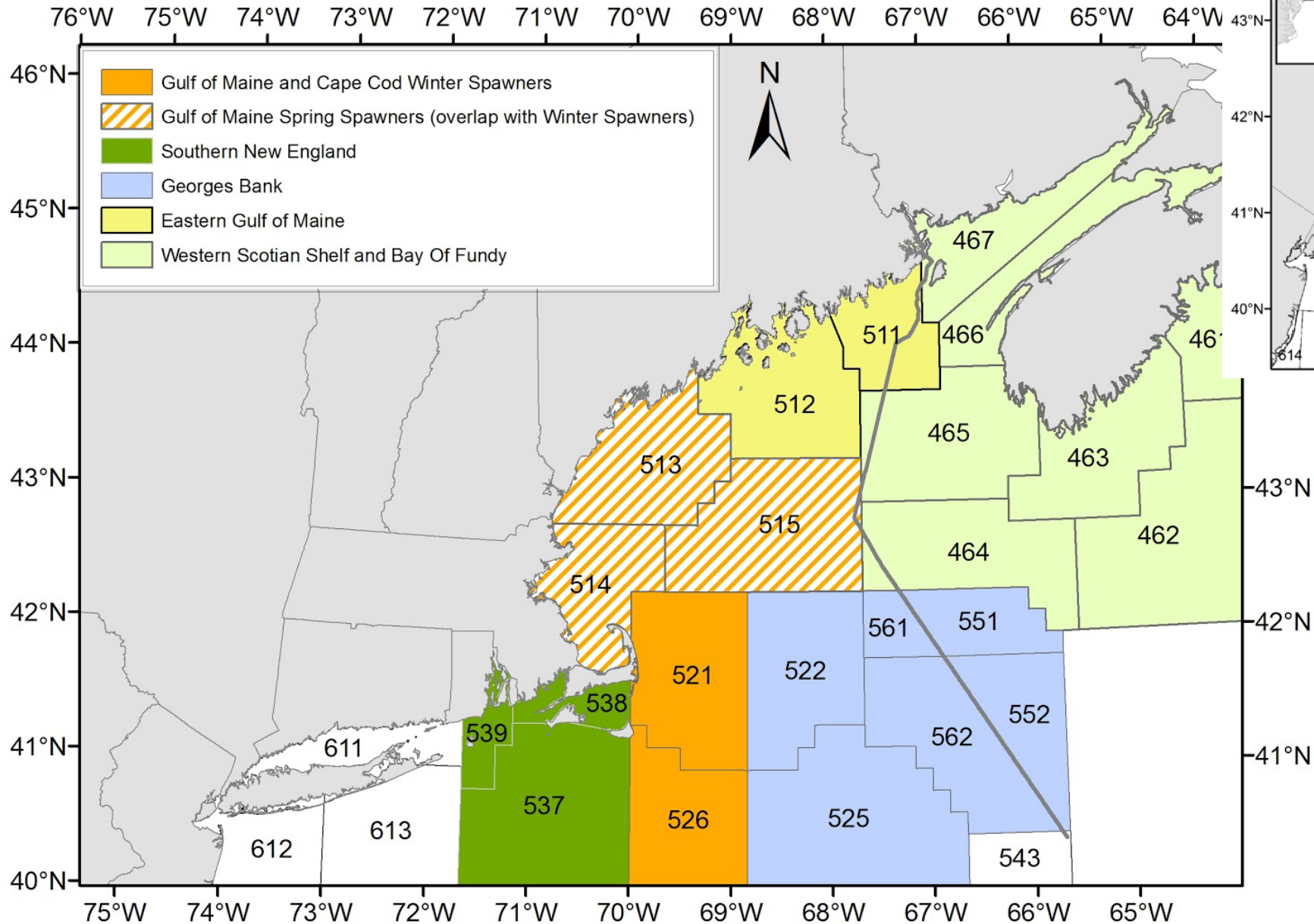
1. Fishermen's ecological knowledge (structured interviews)
2. Early life history (spawning–settlement)
3. Genetic markers (including adaptive markers and genomics)
4. Life history (48 years of the NEFSC bottom trawl survey)
5. Natural markers (otoliths, parasites, color morphs, etc.)
6. Applied markers (200,000 tagged cod; 12,000 recaptures [1923-2013])



# Interdisciplinary highlights

- 1) Notable phenotypic and genetic variability among statistical areas
  - Cod not well mixed in either US management unit
- 2) Extensive movements by adults
  - exchange between US-US management units
  - as well as between US-Canada management units
- 3) Larval dispersal around Cape Cod
  - one-way connectivity between US-US management units
- 4) Two sympatric, genetically differentiated stocks in SW Gulf of Maine
  - adaptive differences between winter- and spring-spawning cod

# 5 US cod stocks proposed

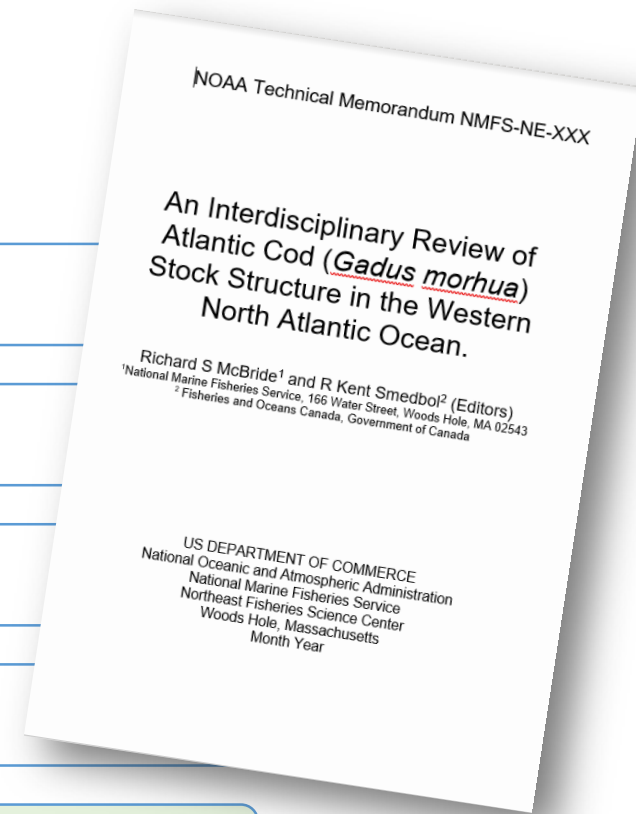
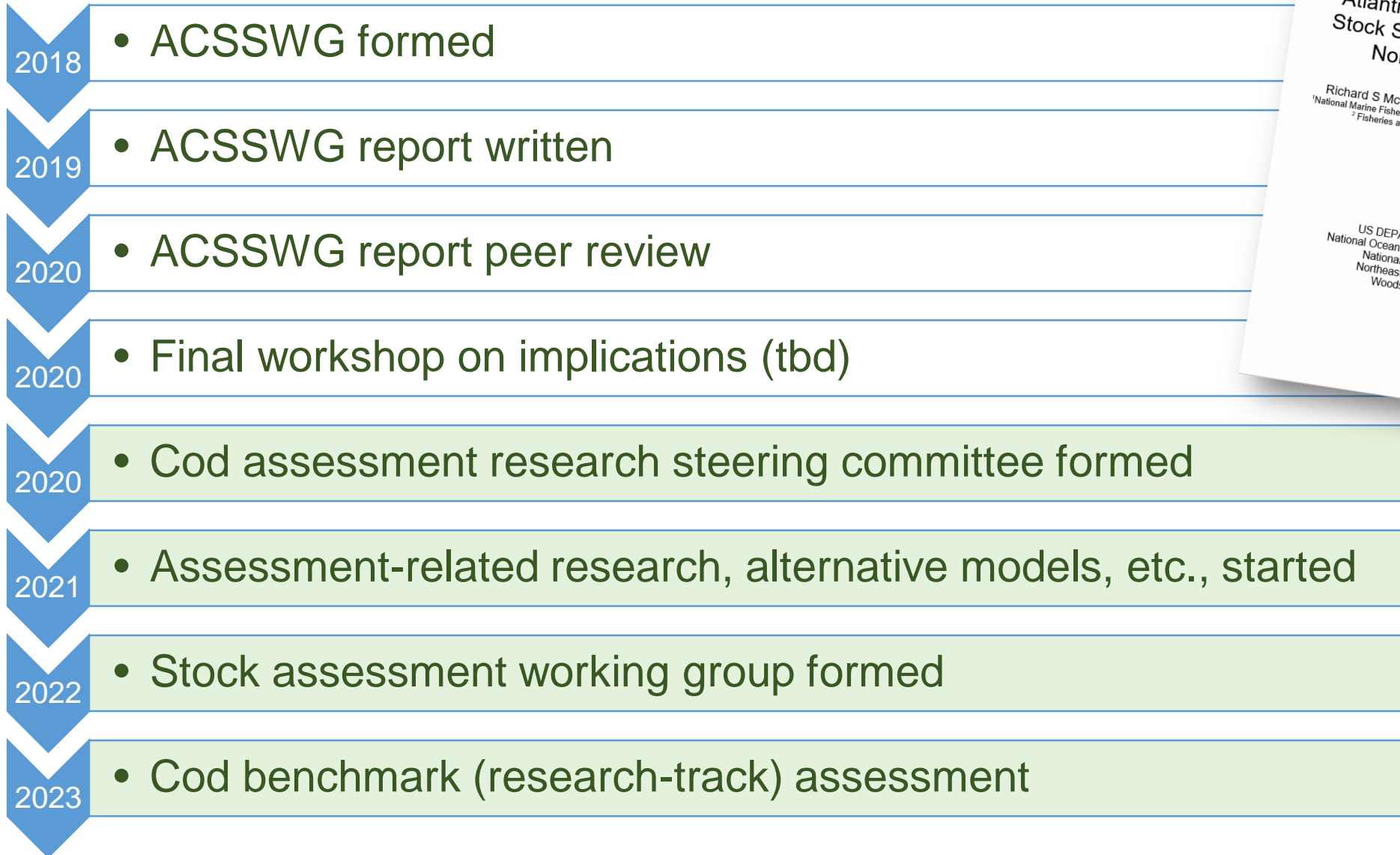


This proposal accounts for:

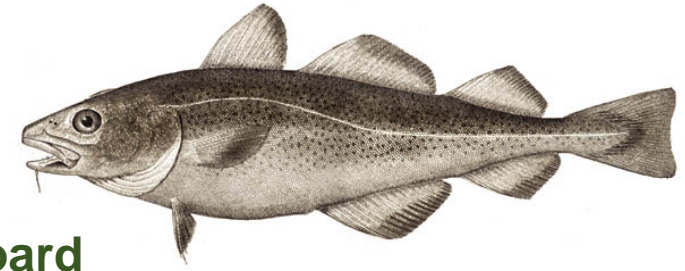
- Within unit variation
- Between unit connectivity
- Winter/spring sympatry

# The broader timeline?

You  
Are  
Here →



# Acknowledgements



## The working group

Ames, Ted  
Andrushchenko, Irene  
Cadrin, Steve  
Cournane, Jamie  
Dean, Micah  
DeCelles, Greg  
Kerr, Lisa  
Kovach, Adrienne  
McBride, Rich (co-chair)  
Overgaard Therkildsen, Nina  
Puncher, Greg  
Smedbol, Kent (co-chair)  
Wang, Yanjun  
Zemeckis, Doug

Bowdoin College & MCCF Founding Board  
Canadian Department of Fisheries & Oceans  
University of Massachusetts Dartmouth, SMAST  
New England Fishery Management Council  
Massachusetts Division of Marine Fisheries  
Massachusetts Division of Marine Fisheries  
Gulf of Maine Research Institute  
University of New Hampshire  
Northeast Fisheries Science Center  
Cornell University  
University of New Brunswick  
Canadian Department of Fisheries & Oceans  
Canadian Department of Fisheries & Oceans  
Rutgers University

New England Fishery Management Council  
NOAA's Northeast Fisheries Science Center  
New Hampshire Sea Grant  
Maine Fishermen's Forum



# Atlantic cod stock structure in US waters: Management Context

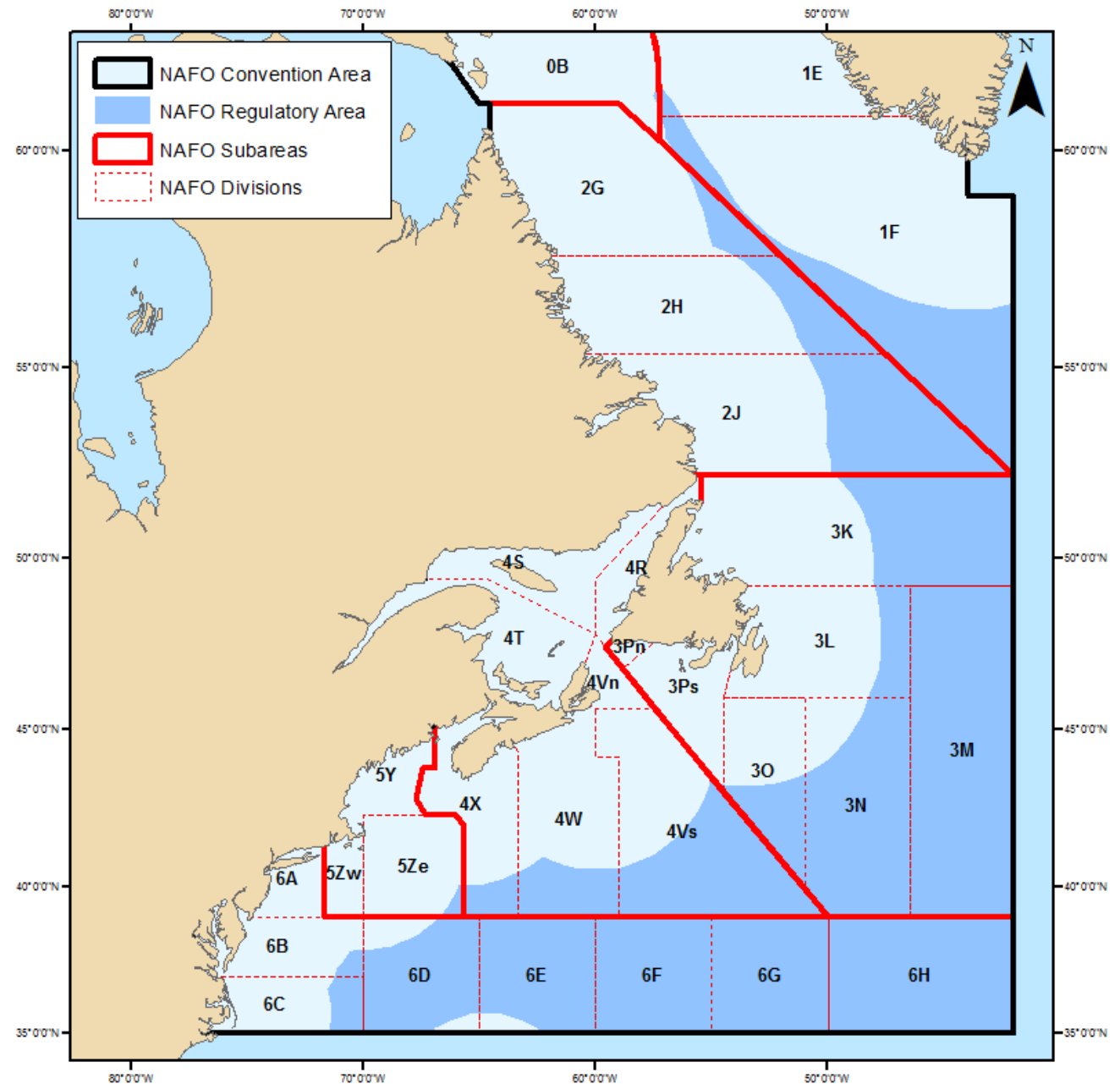
**The Atlantic Cod Stock Structure Working Group (ACSSWG)**

**Presenter: Jamie Cournane, NEFMC**

**New England Fishery Management Council Peer Review**

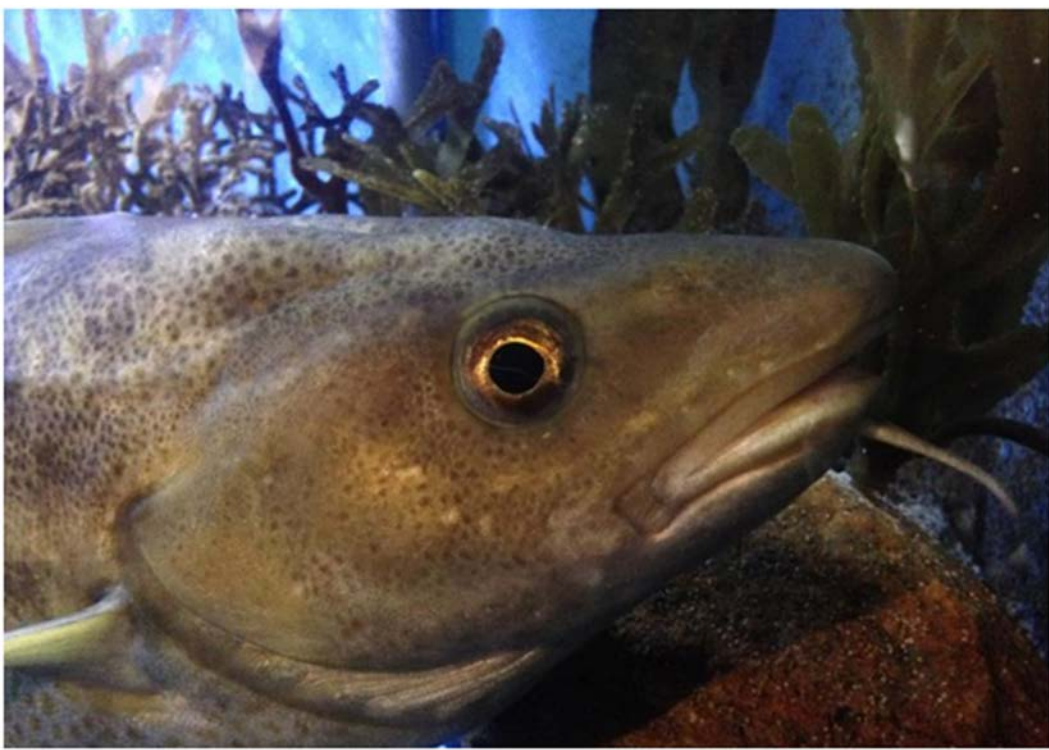
Determine the most appropriate representation of Atlantic Cod stock structure for use in regional stock assessments (**NAFO Divisions 5 and 6 and interactions with 4X**) based on currently available information. “Most appropriate” means having the greatest scientific support and accurately capturing the available data and assessment model frameworks. This determination will not include the running of assessment models.

From ACSSWG Objectives



<https://www.nafo.int/Fisheries>

# Outline



For each stock/unit of cod

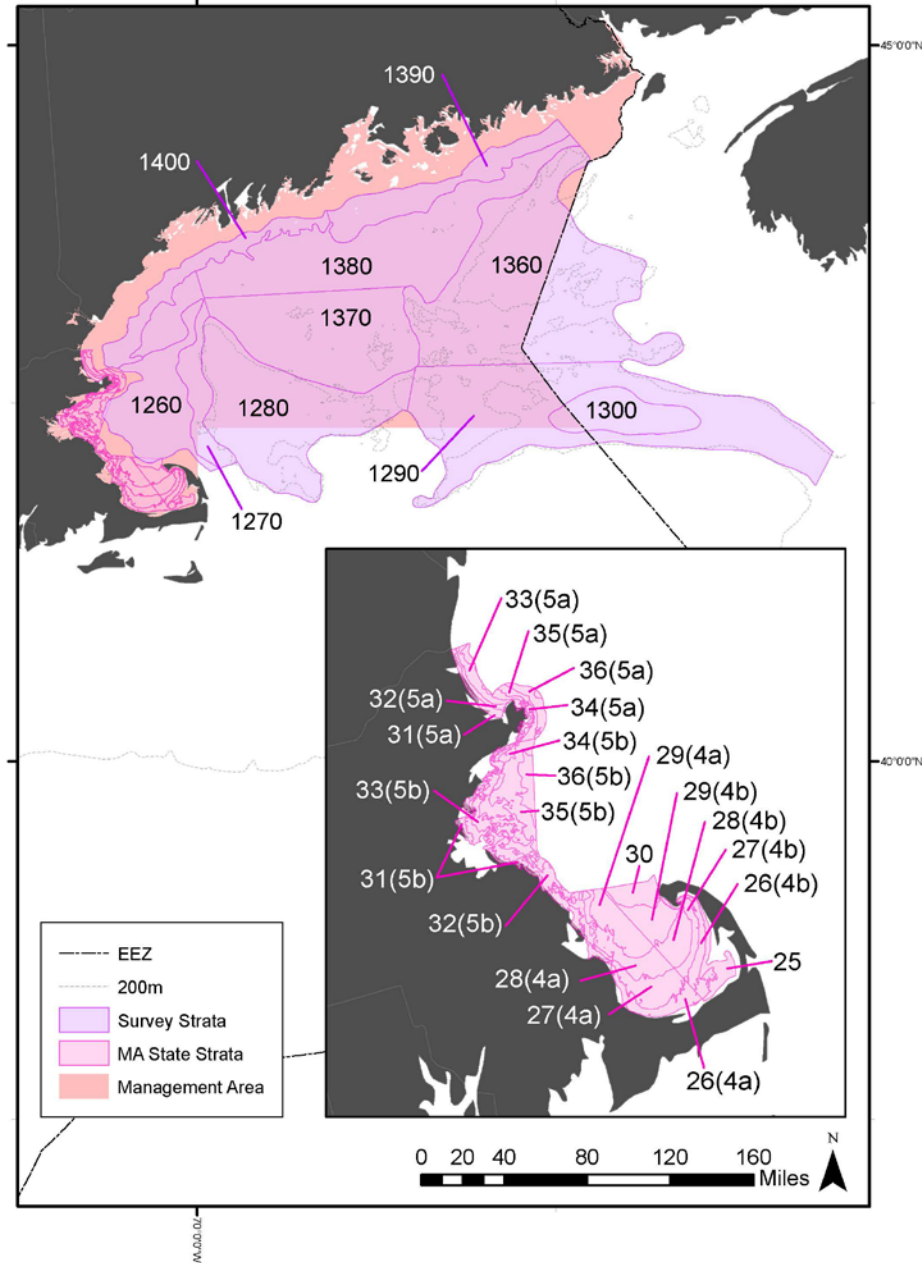
Survey strata – assessment

Management areas – catch monitoring

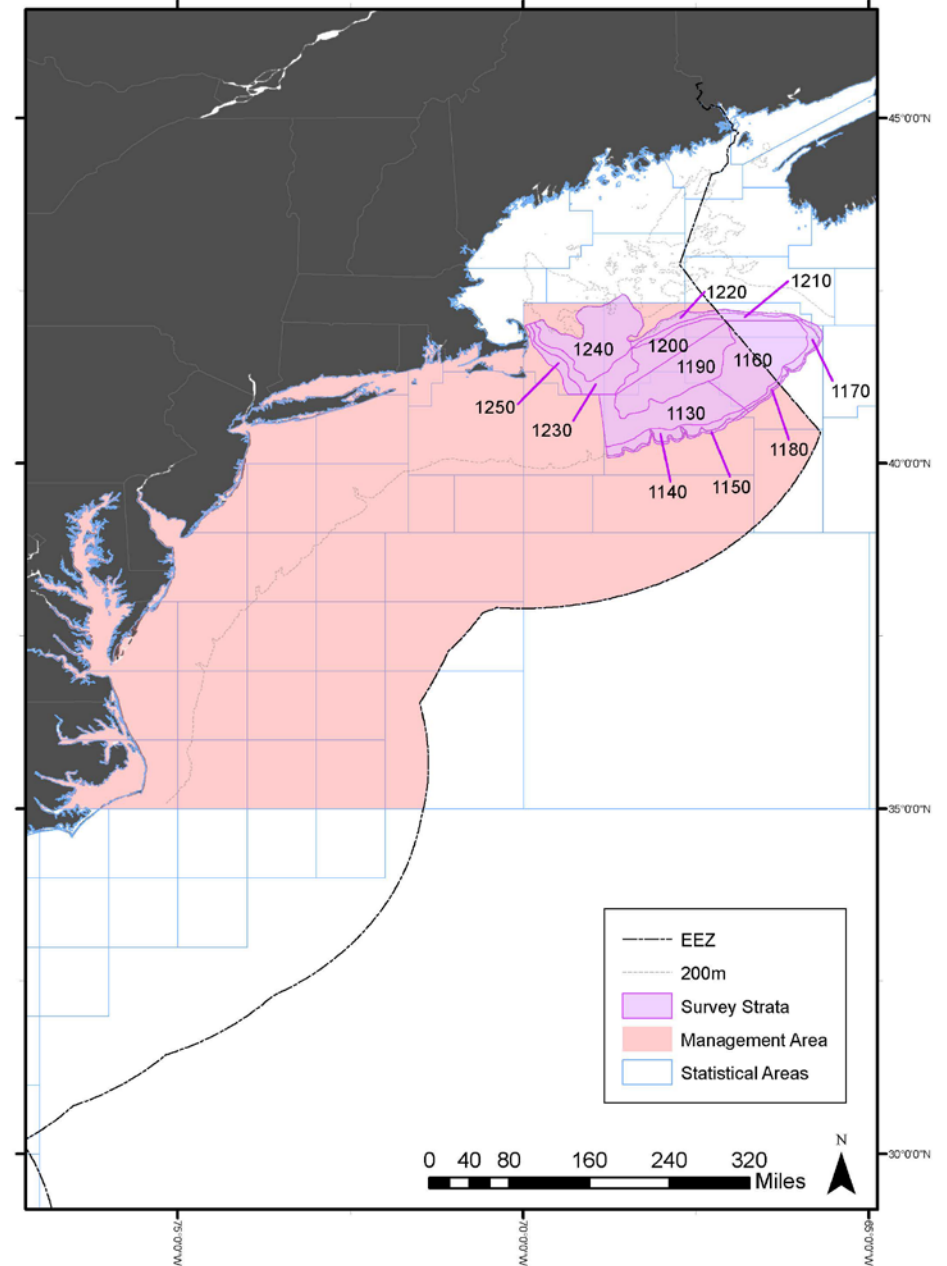
**Sub-Group:** Jamie Cournane (NEFMC), Steve Cadrin (SMAST), Yanjun Wang (DFO), Irene Andrushchenko (DFO), and Ted Ames

**Additional assistance:** Chris Quartararo (NEFMC intern) and Michael Palmer (NEFSC)

## Gulf of Maine Cod Management

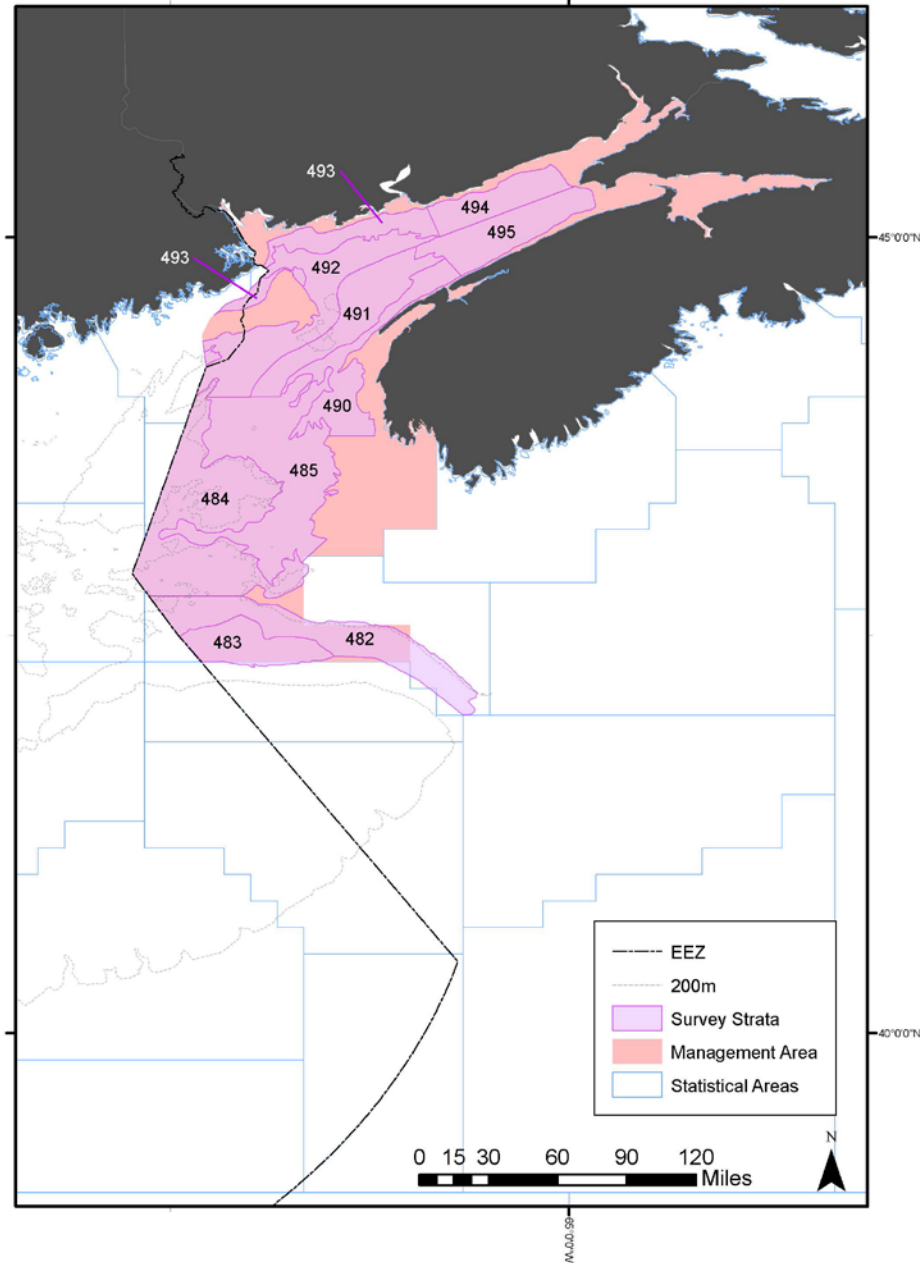


## Georges Bank Cod Management

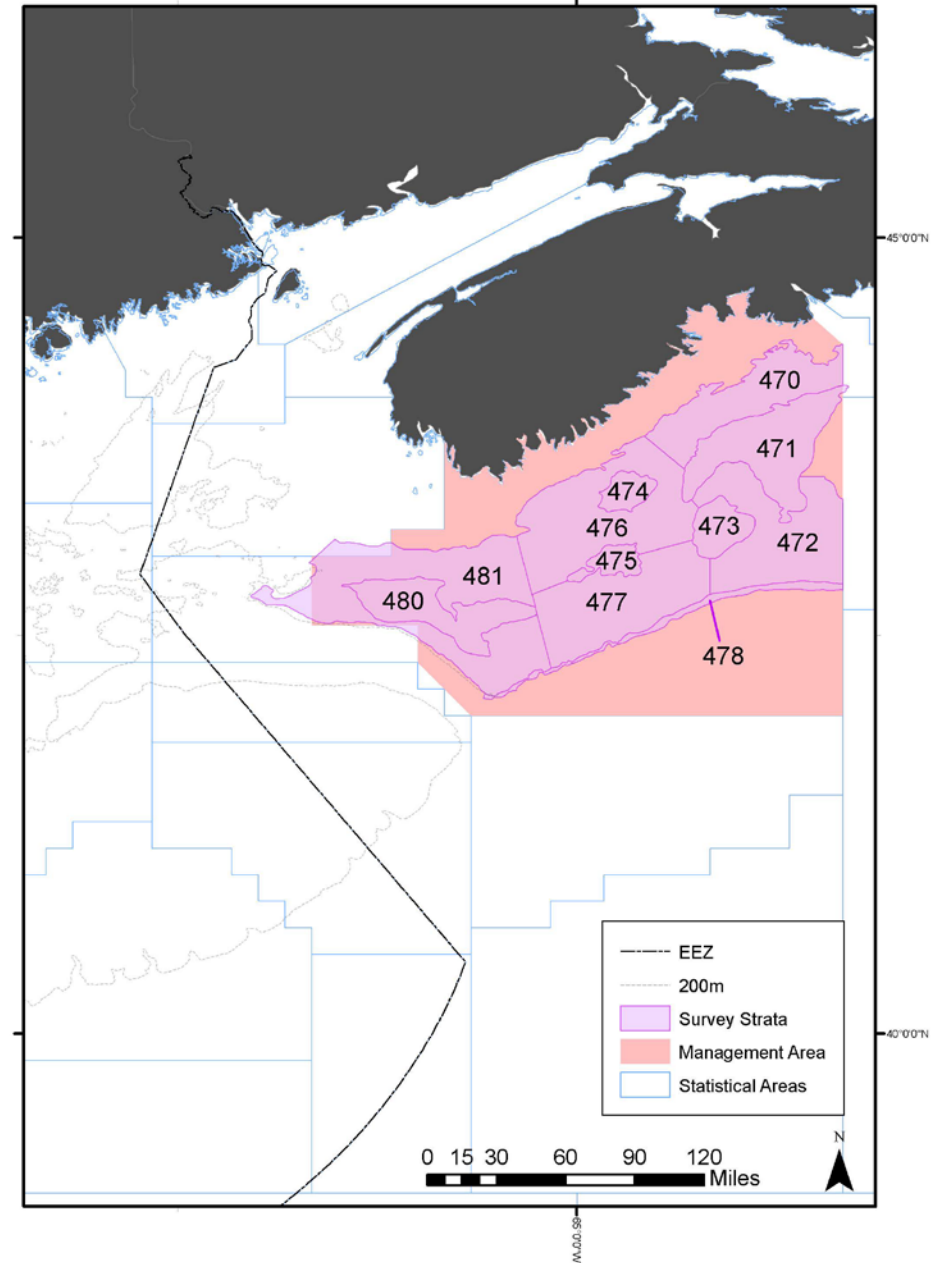


# Canada

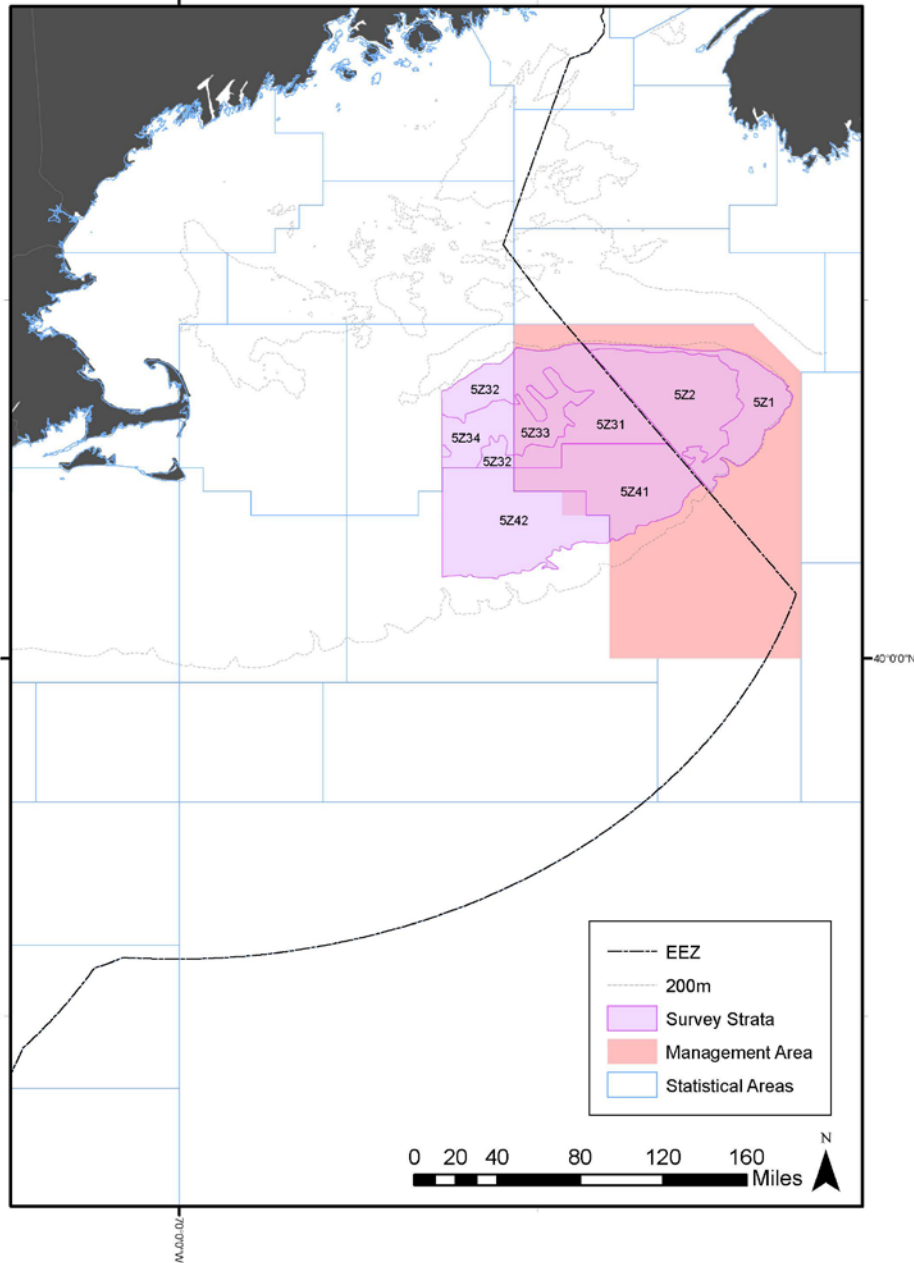
## Bay of Fundy Cod Management



## Scotian Shelf Cod Management

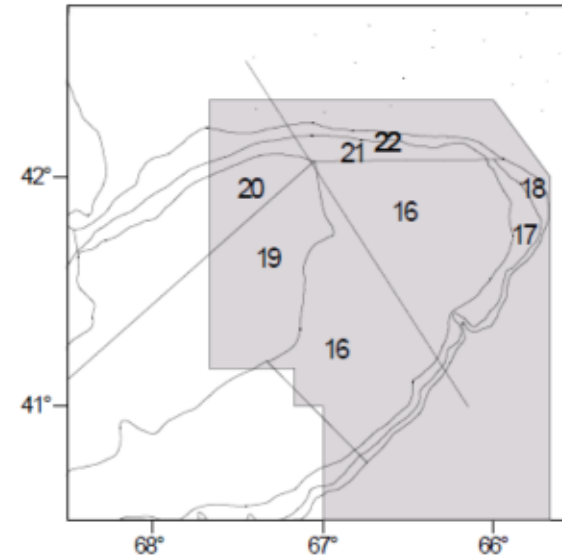


## Eastern Georges Bank Cod Management



# US/Canada

Stratification used for the NMFS surveys. The eastern Georges Bank management unit is indicated by shading.



Stratification used for the DFO survey. The eastern Georges Bank management unit is indicated by shading.

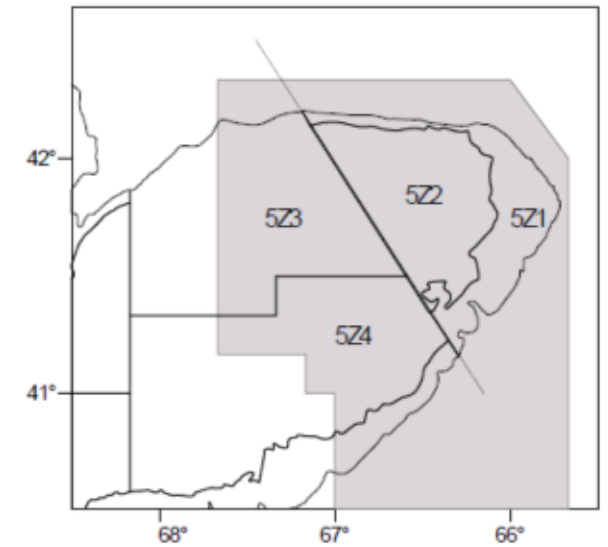


Figure 14 (left) and Figure 15 (right) from the 2016 TRAC assessment of EGB cod  
[https://www.nefsc.noaa.gov/saw/trac/egb\\_cod\\_trac\\_2016.pdf](https://www.nefsc.noaa.gov/saw/trac/egb_cod_trac_2016.pdf)

# United States

## Northeast Multispecies (Groundfish) Fishery Management Plan

NOAA  
Fisheries and  
New England  
Fishery  
Management  
Council

13 species, 20 stocks, 2 management units

Commercial- trawl, gillnet, and hook and line

Recreational – hook and line, private and for-hire

Complex management system – sector program, closed areas, quotas, trip limits, gear restrictions, monitoring



Acadian Redfish  
*Sebastes fasciatus*



# Atlantic cod stock structure in US waters: Fishermen's Ecological Knowledge

**The Atlantic Cod Stock Structure Working Group (ACSSWG)**

**Presenter: Greg DeCelles, Ørsted/MADMF**

**New England Fishery Management Council Peer Review**

# Acknowledgments & Outline

Sub-Group: Greg DeCelles and Ted Ames

Background – Utility of Fishermen's Ecological Knowledge

Objectives and Methods

Discussion

Conclusions

# Background – Utility of FEK

FEK is the experiential knowledge that fishermen accumulate as they interact with the marine environment over an extended period of time (Hind, 2015).

FEK spans a range of spatial and temporal scales.

Growing consensus that FEK is a valuable supplement to traditional scientific data and part of the best available science.



# Background – Utility of FEK

## Timing and location of spawning

- Ames, 1998; Neis, 1999; Johannes et al., 2000; Maurstad, 2002; Silvano et al 2006

## Extirpation of spawning components

- Pedersen and Hall Arber, 1999; Ames, 2004

## Discovery of new spawning grounds

- Maurstad, 2002

## Stock structure

- Neis, 1998; ; Neis et al., 1999; Wroblewski et al., 2005; Murray et al., 2008; Hedeholm et al., 2016

## Changes in abundance

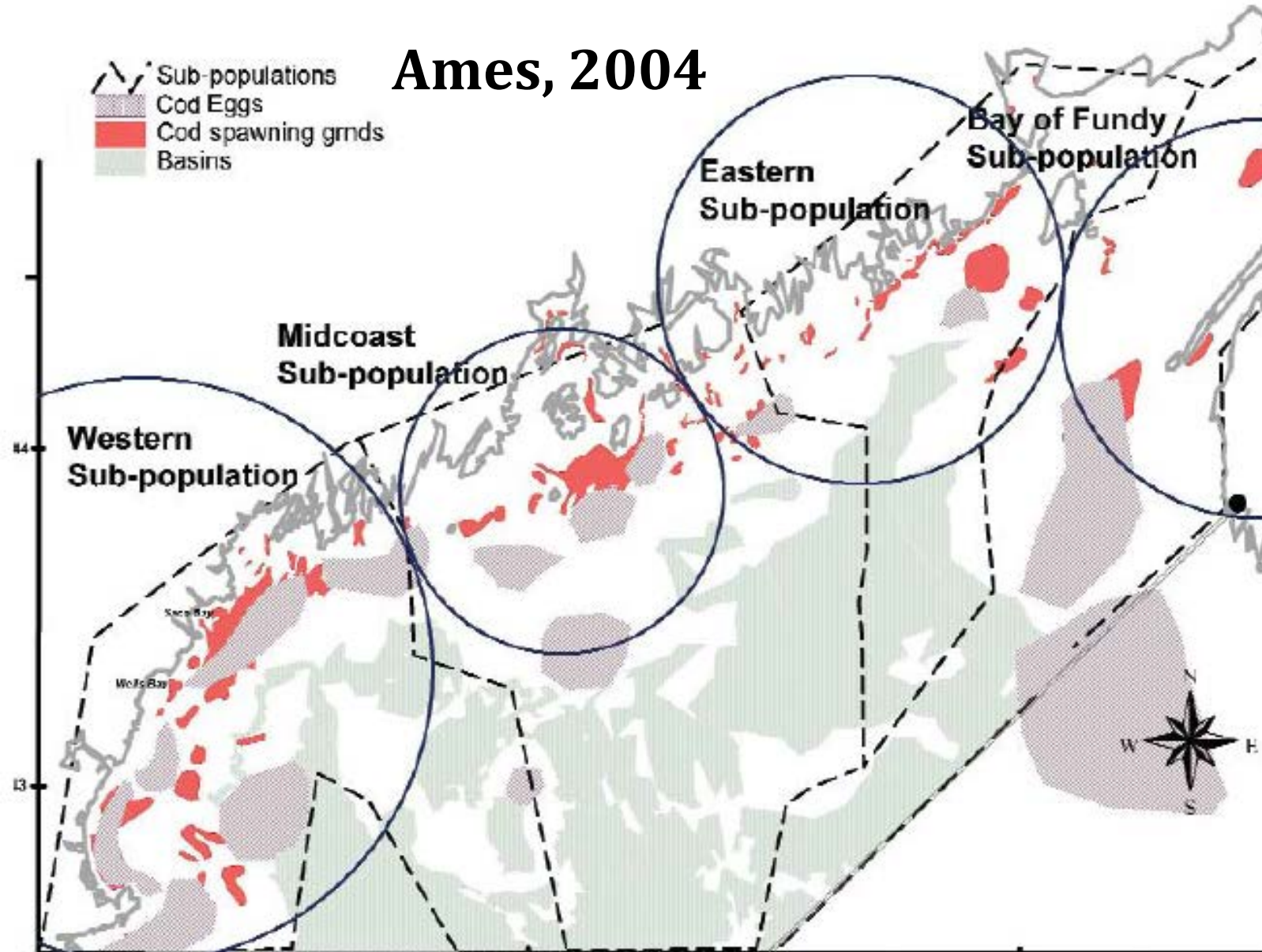
- Neis et al., 1999; Macdonald et al., 2014; Figus et al., 2017; Van Putten et al., 2016

# Objectives

1. Collect FEK to better understand the spatial and temporal distribution of cod spawning activity in the western Gulf of Maine.
2. Gather FEK related to morphometric variation amongst cod spawning groups.
3. Collect FEK related to connectivity amongst cod spawning components.
4. Synthesize the FEK collected during objectives 1-3, to serve as a complement to our traditional scientific knowledge to inform cod stock structure in the region.

This chapter builds off the prior research of Ames (1998; 2004) and DeCelles et al., (2017).

# Background



# Methods – Semi Structured Interviews

Part 1: Demographic questions to document fishing experience

Part 2: Questions related to individual spawning grounds

Part 3: Questions about connectivity, morphology and color.

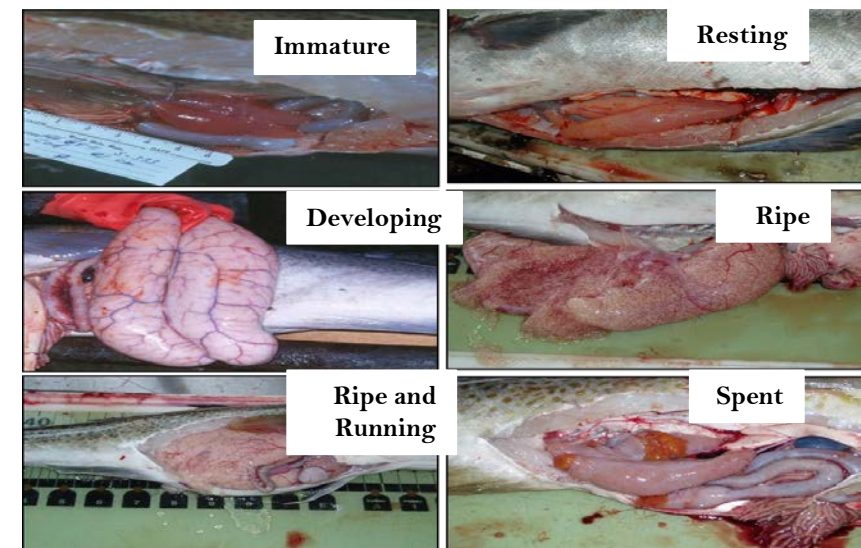
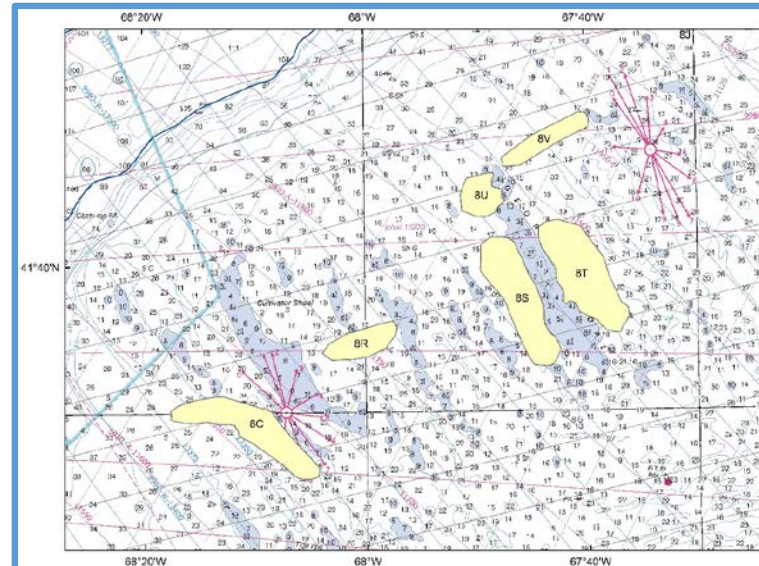


Image courtesy Rich McBride NOAA - NEFSC

# Results

50 fishermen were interviewed.

- 40 as part of the DeCelles et al., (2017) study
- 10 as part of the ACSSWG study

2,000 years of total fishing experience.

1,700 years of experience fishing for cod.

Mean experience targeting cod = 34.7 years.

Home Port	# of Captains
New Bedford, MA	21
Gloucester, MA	6
Chatham, MA	7
Hyannis, MA	1
Scituate, MA	1
Boston, MA	2
Newburyport, MA	1
Montauk, NY	1
Hampton, NH	2
Portland, ME	1
Pubnico, NS	3
Lunenburg, NS	1
Yarmouth, NS	2

Gear Type	# of Captains
Otter trawl	45
Gillnets	10
Longline	8
Rod and reel	4

# Results

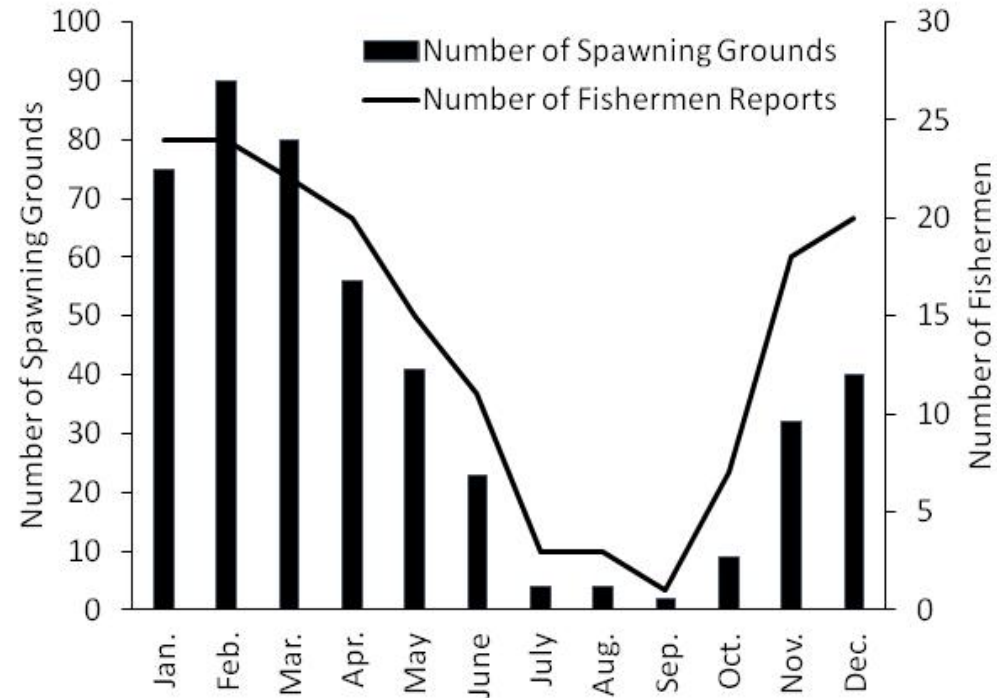
Fishermen were typically attentive to the reproductive condition (and diet) of the cod they caught.

Spawning grounds were often in areas with complex bathymetry (ridges, valleys, deep holes, etc.)

The fishermen identified 210 cod spawning grounds on Georges Bank and Nantucket Shoals.

22 cod spawning grounds were identified in the western Gulf of Maine.

# Results – Georges Bank and Nantucket Shoals



	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.
Nan. Shoals and Channel (n = 27)	1-10%	1-10%	1-10%	20.1-50%	>50%	>50%	20.1-50%	20.1-50%	20.1-50%	20.1-50%	10.1-20%	1-10%
Closed Area 1 (n = 7)							20.1-50%	>50%	>50%	>50%	10.1-20%	10.1-20%
Northern Edge (n = 18)						1-10%	10.1-20%	20.1-50%	20.1-50%	>50%	>50%	20.1-50%
Georges Shoal (n = 20)				1-10%	1-10%	20.1-50%	20.1-50%	20.1-50%	20.1-50%	20.1-50%	20.1-50%	10.1-20%
Southwest Part (n = 8)							10.1-20%	>50%	>50%	>50%	20.1-50%	10.1-20%
Closed Area 2 (n = 12)	1-10%	1-10%				1-10%	>50%	>50%	20.1-50%	1-10%	10.1-20%	10.1-20%
Northeast Peak (n = 12)	10.1-20%	10.1-20%					20.1-50%	10.1-20%	20.1-50%	20.1-50%	20.1-50%	20.1-50%
Eastern Georges (n = 4)							>50%	>50%	20.1-50%	20.1-50%	20.1-50%	

0%

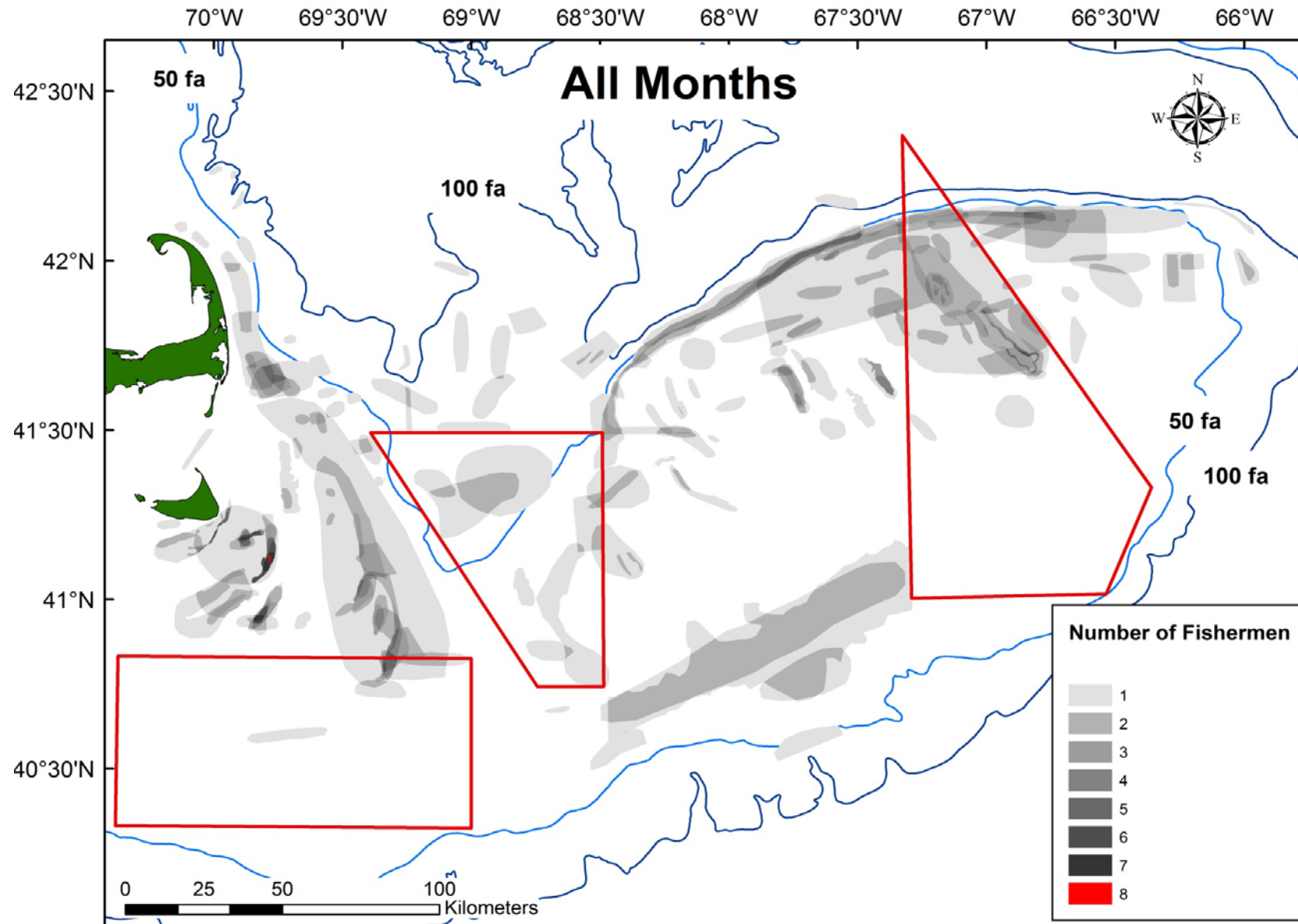
1-10%

10.1-20%

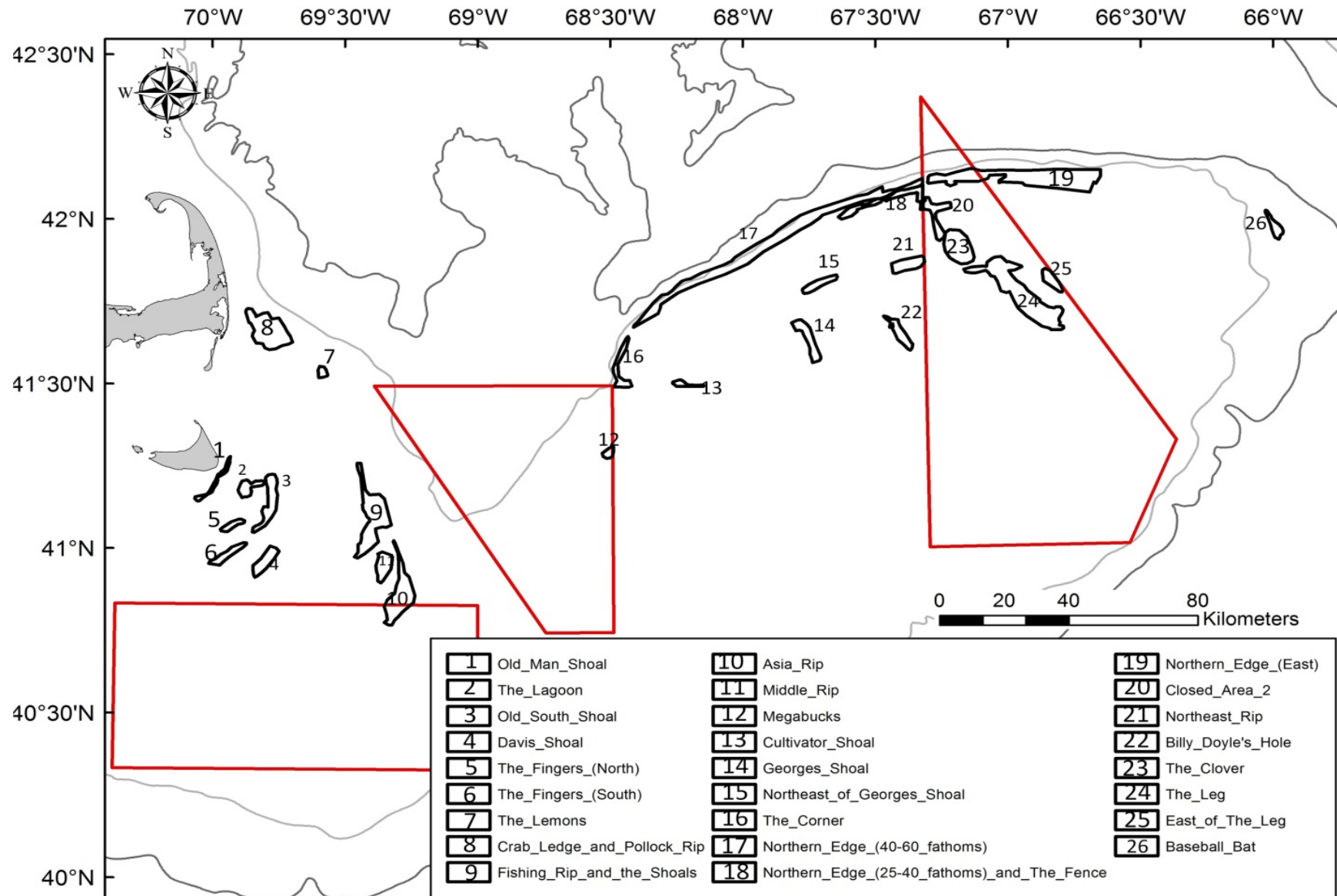
20.1-50%

>50%

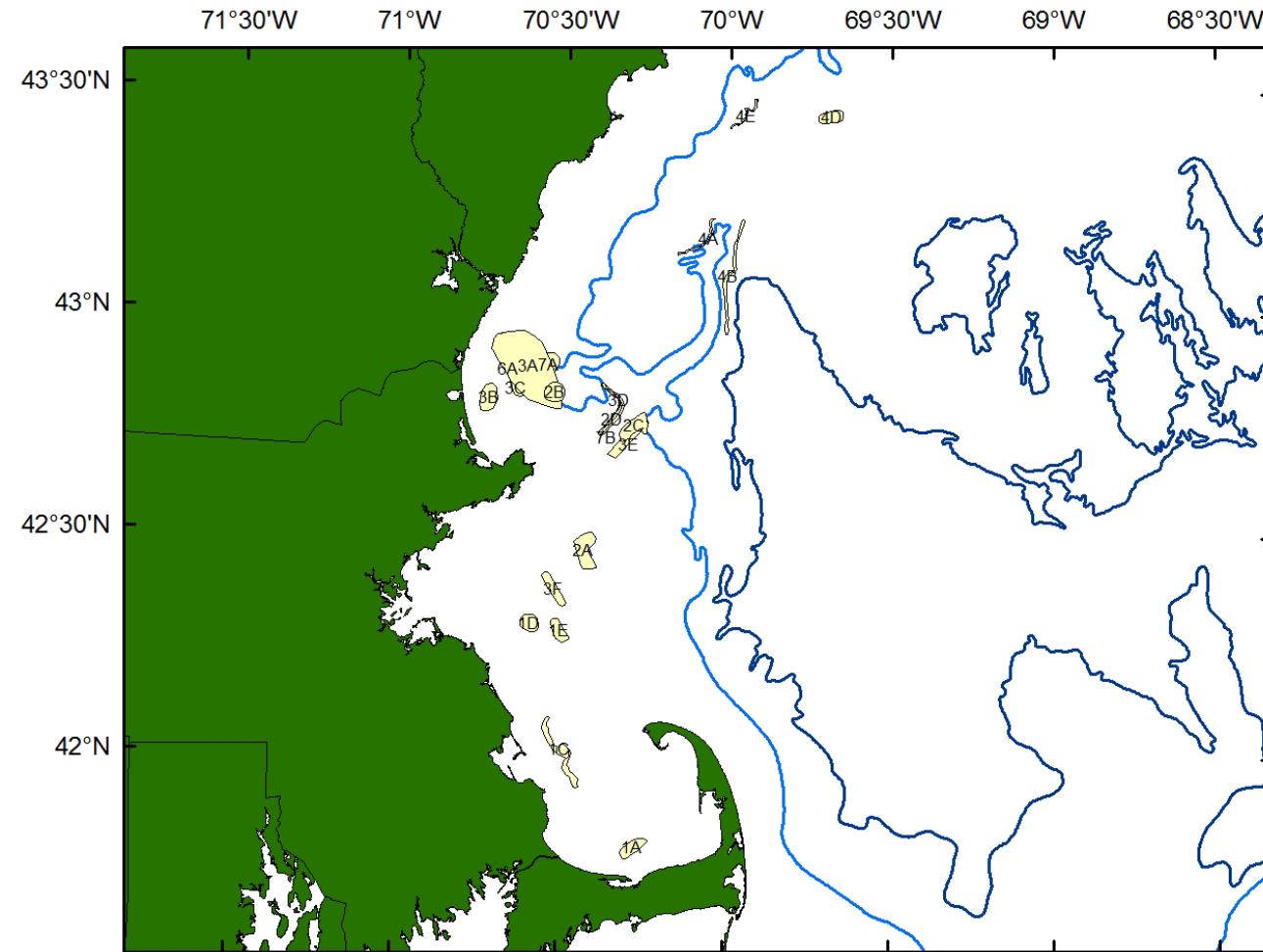
# Results – Georges Bank and Nantucket Shoals



# Results – Georges Bank and Nantucket Shoals



# Results – Western Gulf of Maine



# Results - Connectivity

15 of 16 fishermen remarked that cod on western and eastern Georges Bank are distinct.

- Discontinuous distribution
- Biomass of cod is larger on eastern GB
- Differences in the size of the fish (white cod more common on eastern GB)
- Differences in filet quality (related to diet)
- Differences in the shape of the fish (different mouths)
- Differences in the timing of spawning
- Longitudinal boundary (68°, 69°, or Great South Channel)

# Results - Connectivity

- Many fishermen observed that there is connectivity between Nantucket Shoals/Great South Channel and the Gulf of Maine.
  - Several fishermen - “follow the cod” from Chatham in March, to Nauset in April, and Stellwagen in June
  - One fishermen – “42° line was a “joke”, because they would steam over fish to get into the GB stock area
  - Chatham fisherman – “When there were no cod on Stellwagen they were ass deep down our way, and vice versa”
- Some fishermen observed that cod on Stellwagen Bank and Ipswich Bay have different diets.
  - Sand eels vs. herring & shrimp
  - “the fish smell different”

# Results – Morphology and Color

Gulf of Maine fishermen noted differences in the size and shape of spawning cod during the different seasons.

- Spring spawning fish were “meatier” ( i.e., better yield)
- Whale cod were more common in spring spawning aggregations

Red cod are common throughout the Gulf of Maine

- Associated with hard bottom, across a range of depths (nearshore to 70 fathoms)
- Only caught in feeding aggregations, never observed in spawning condition
- Red cod were generally smaller than olive cod



# Conclusions

FEK provided valuable insights into the spatial and temporal distribution of spawning, regional connectivity, and natural markers.

## **Observations from FEK support revised stock boundaries:**

1. Eastern GB cod are distinct from those on Nantucket Shoals and the Great South Channel
- 2: Connectivity between Great South Channel and western Gulf of Maine
- 3: Eastern Gulf of Maine cod or distinct from other groups

FEK is largely congruent with information from applied markers, genetics, and natural marks.

# Semi-Structured Interview Questions (Part 1)

## Fishing Experience

- How old are you?
- How many years of experience do you have commercial fishing?
- How many years of experience do you have fishing specifically for cod in the Gulf of Maine?
  - Of those years, how many were you a deckhand, mate, or captain?
- What gear types did you use when targeting cod?

# Semi-Structured Interview Questions (Part 2)

## Spawning Grounds

- Name
- Timing
- How did you define spawning?
- ~~Sex Ratio~~
- Habitat
- Magnitude
- Fish Size
- Predictability
- Active (?)

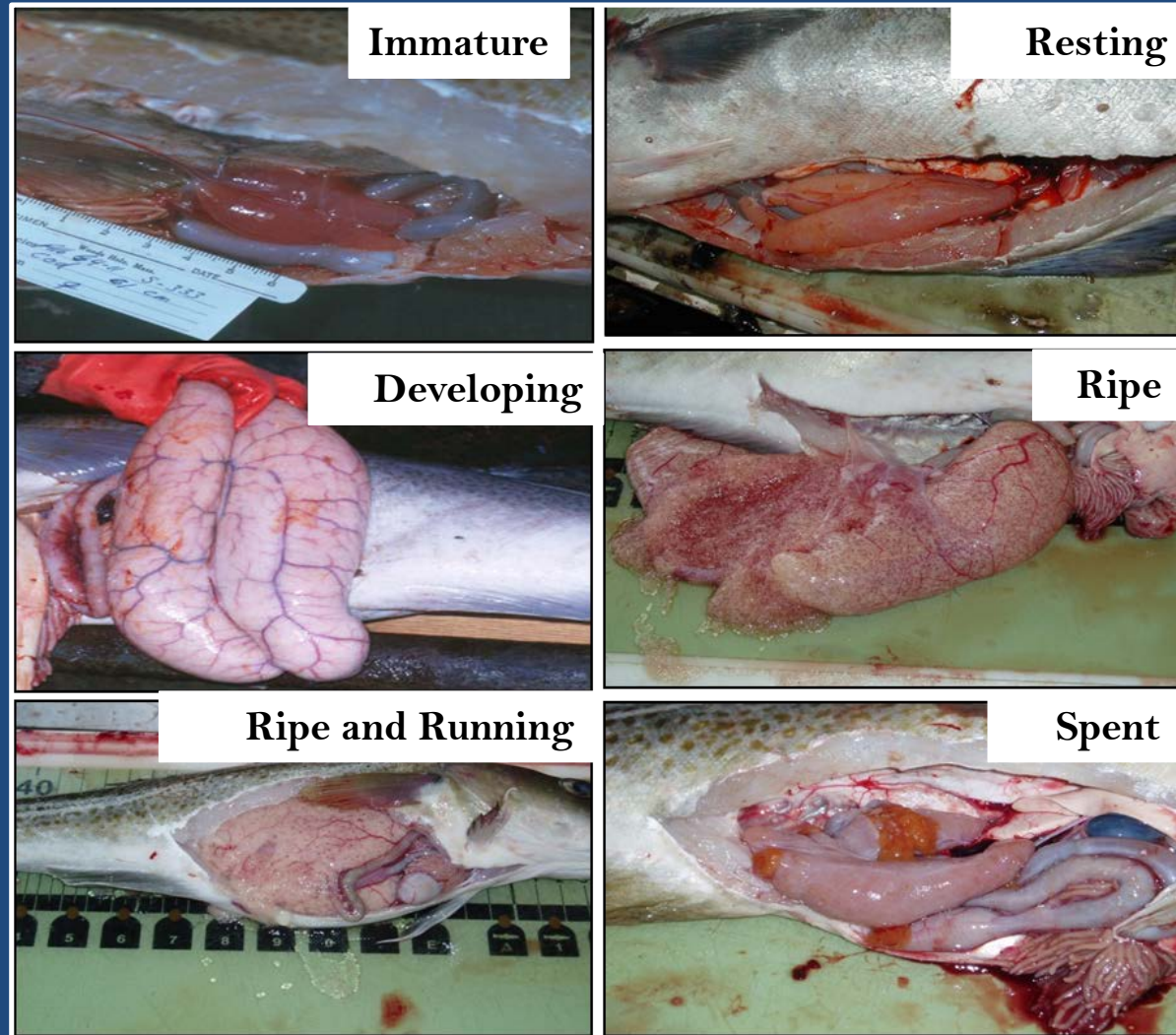
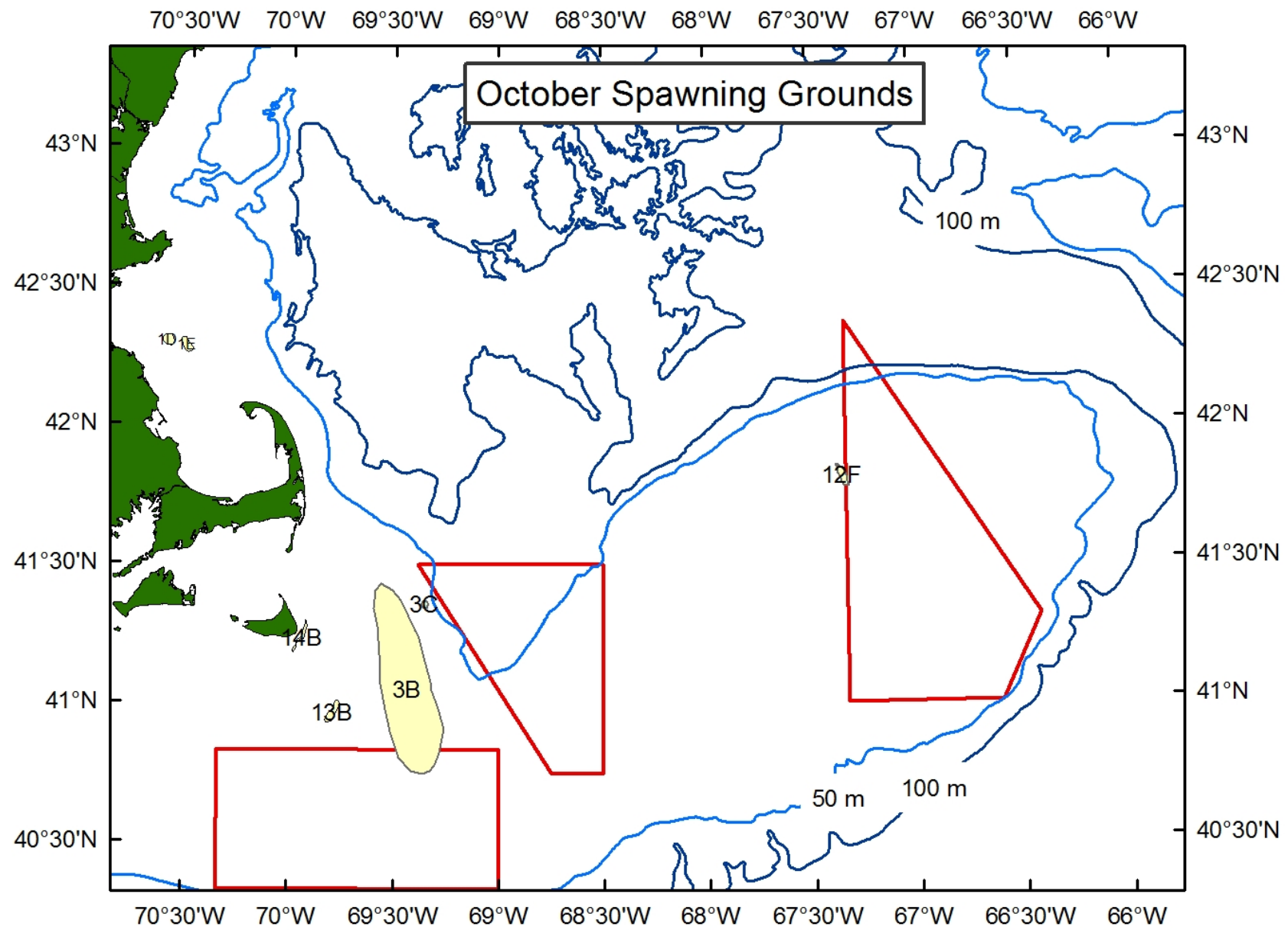


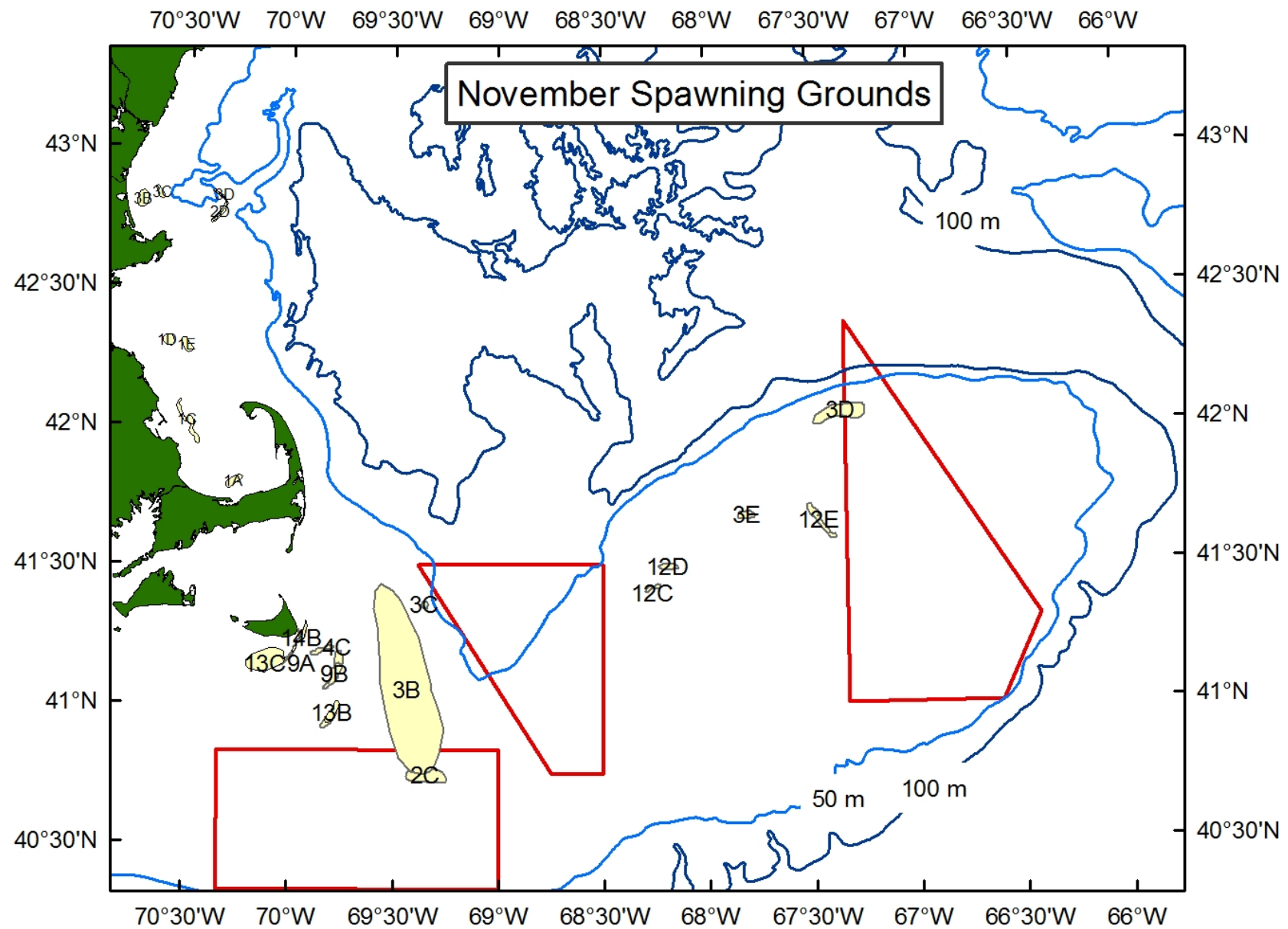
Image courtesy Rich McBride NOAA - NEFSC

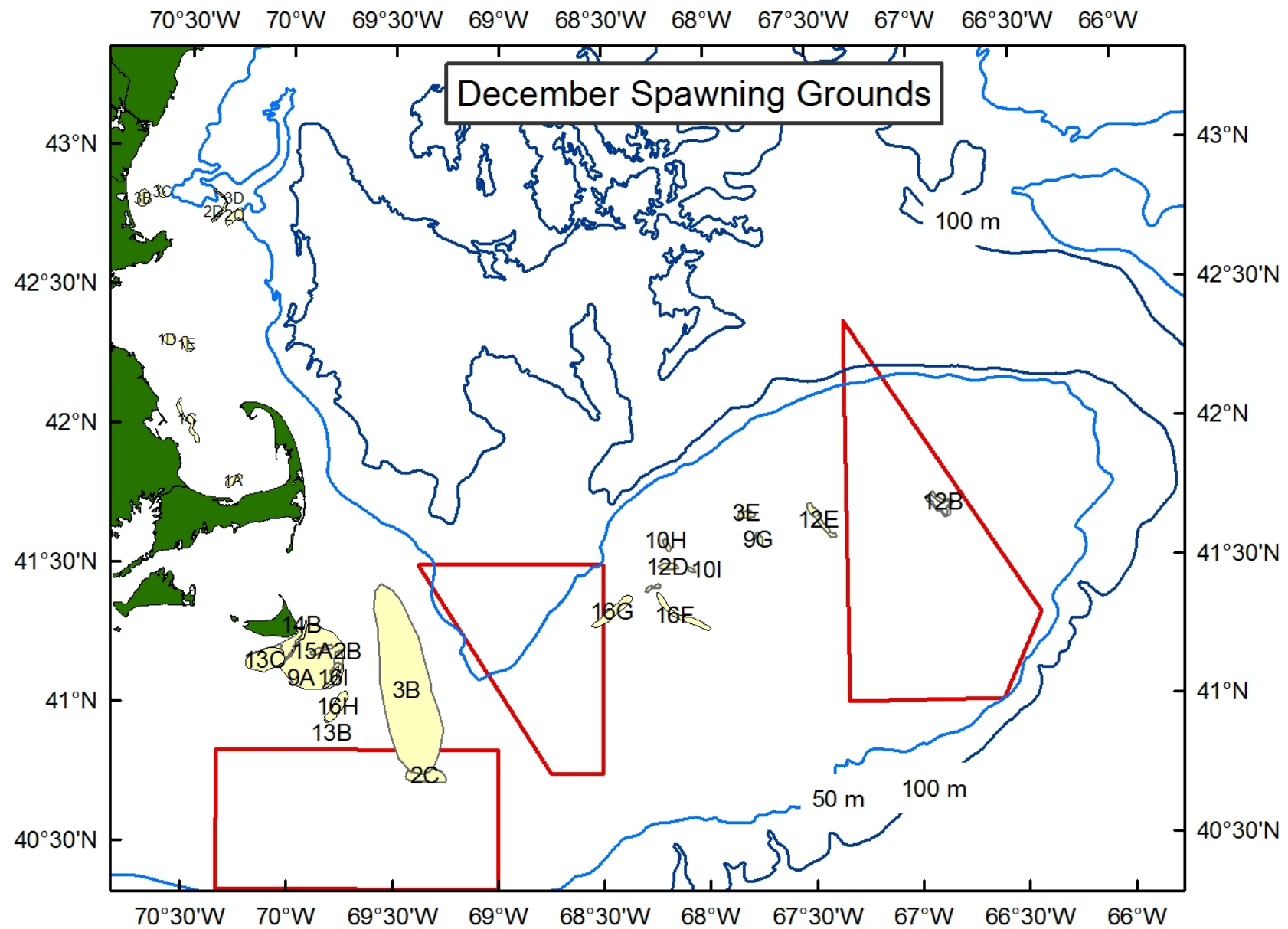
# Semi-Structured Interview Questions (Part 3)

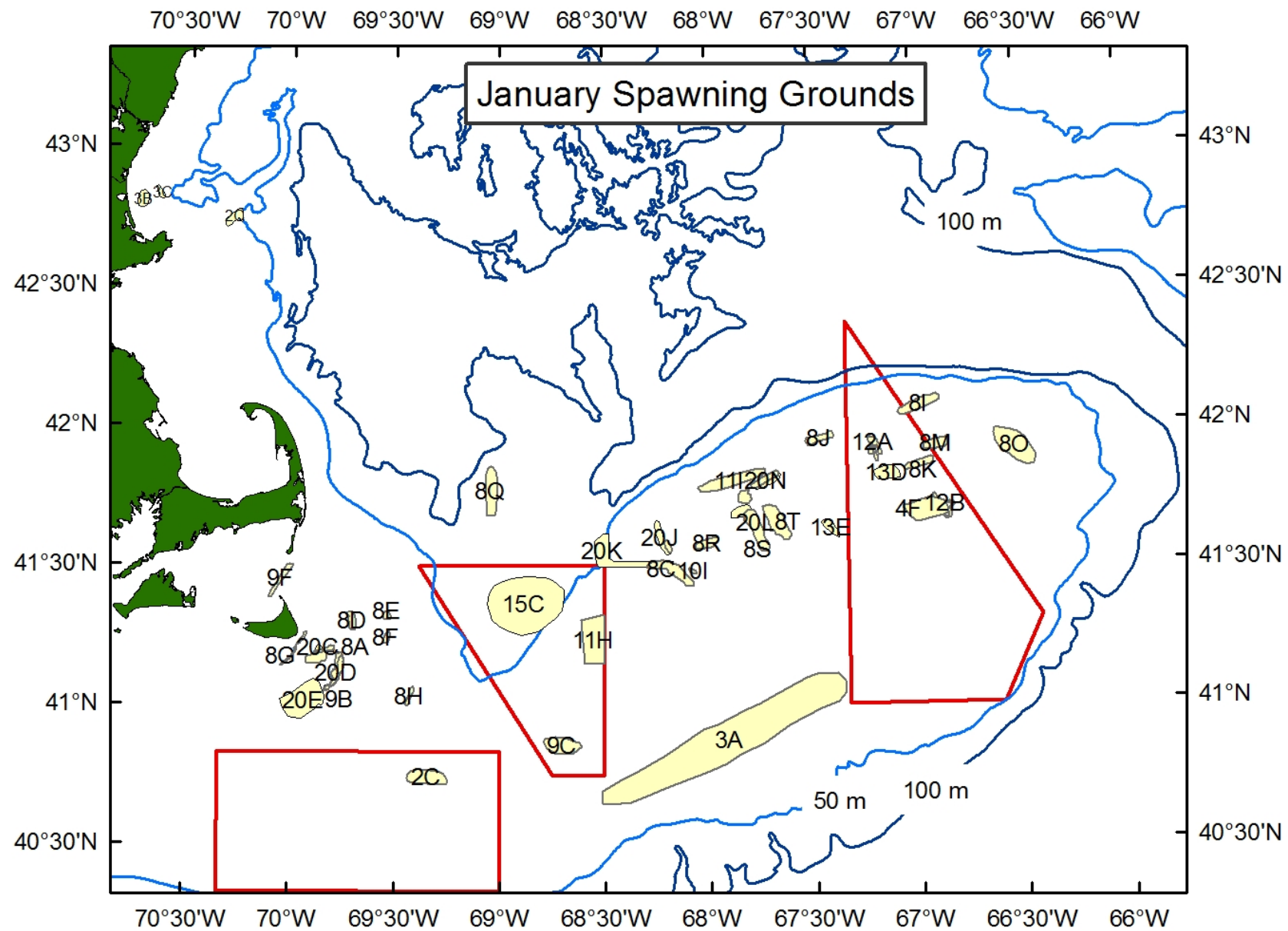
## Stock Structure

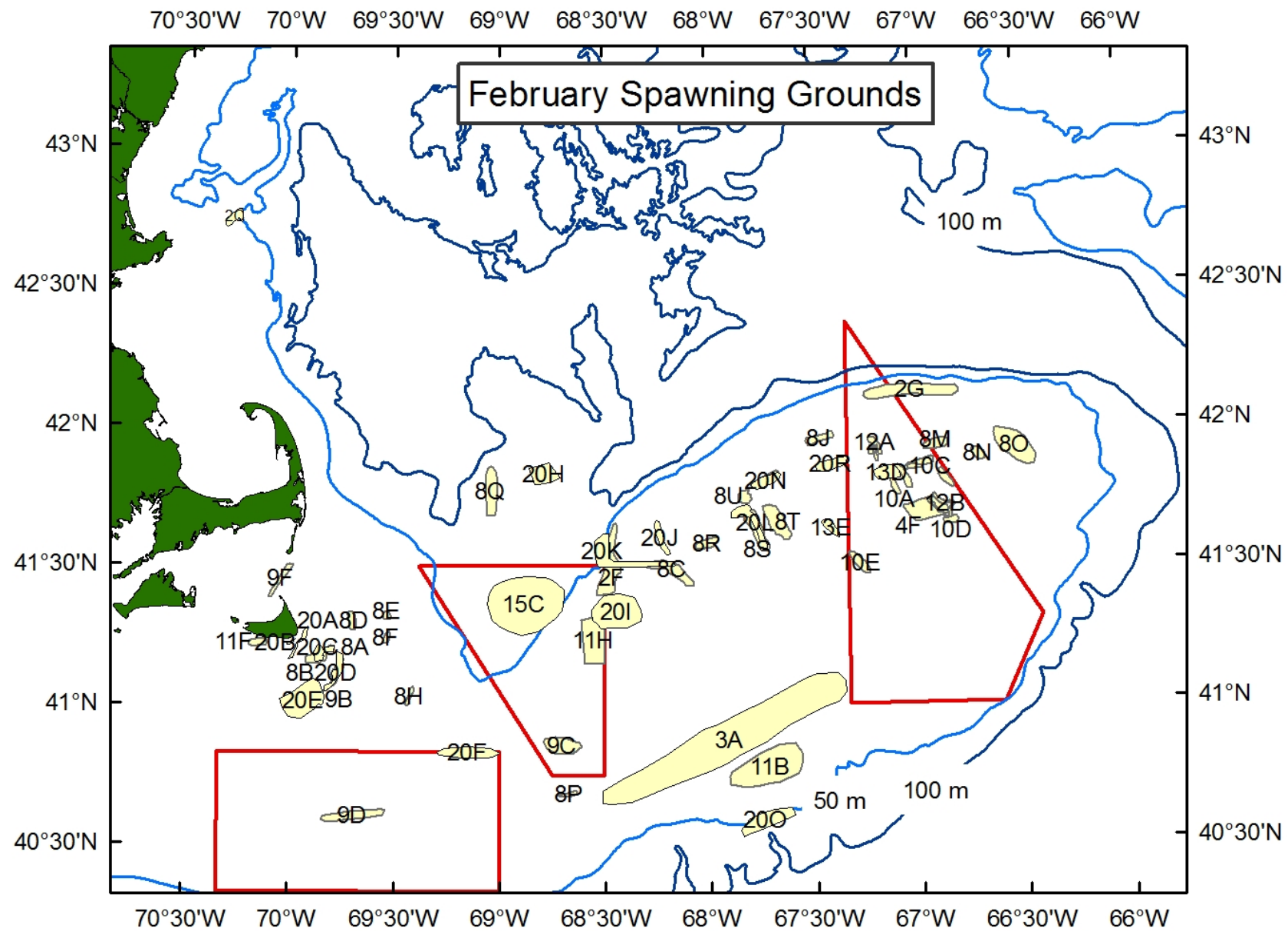
- Is there connectivity between the spawning sites you identified within the larger spawning grounds?
- Was there anything unique about the color of cod at any of the spawning grounds?
- Was there anything unique about the shape of cod at any of the spawning grounds?
- Is there anything else that you think is important?
- ~~• Do you think there is a boundary between inshore and offshore cod?~~
- ~~• Were cod feeding during the spawning season?~~
- ~~• Was spawning related to the time of day?~~

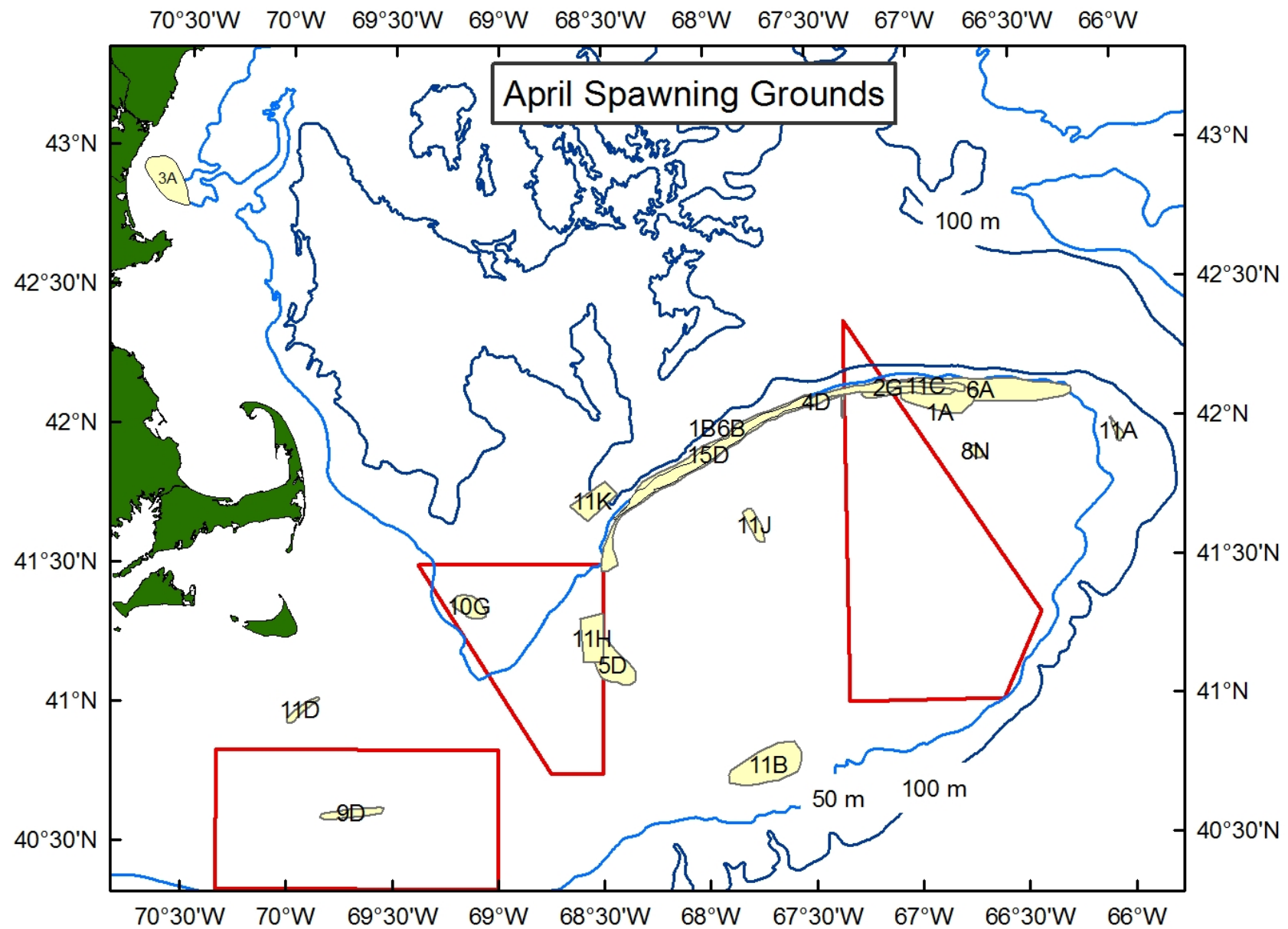


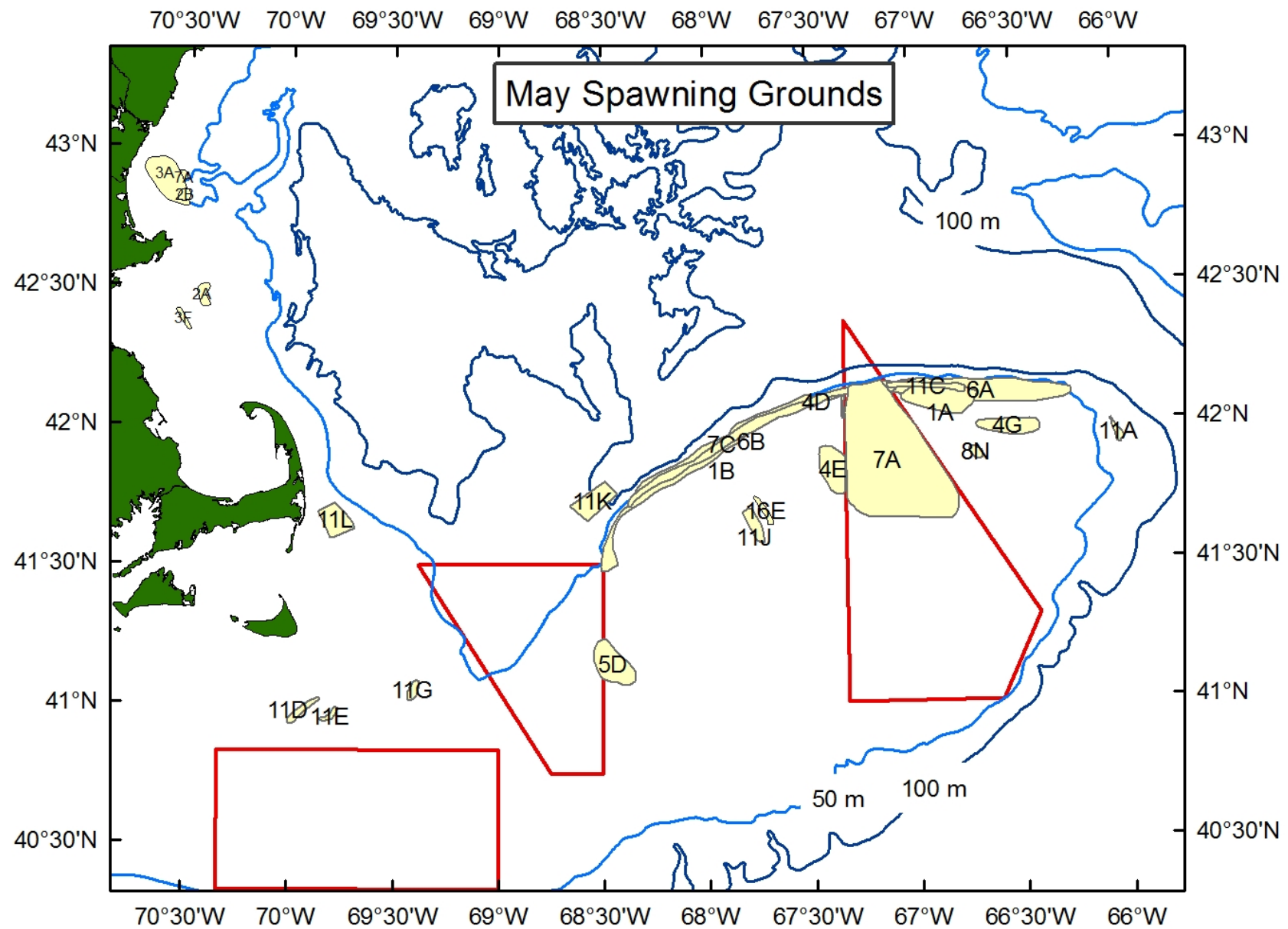


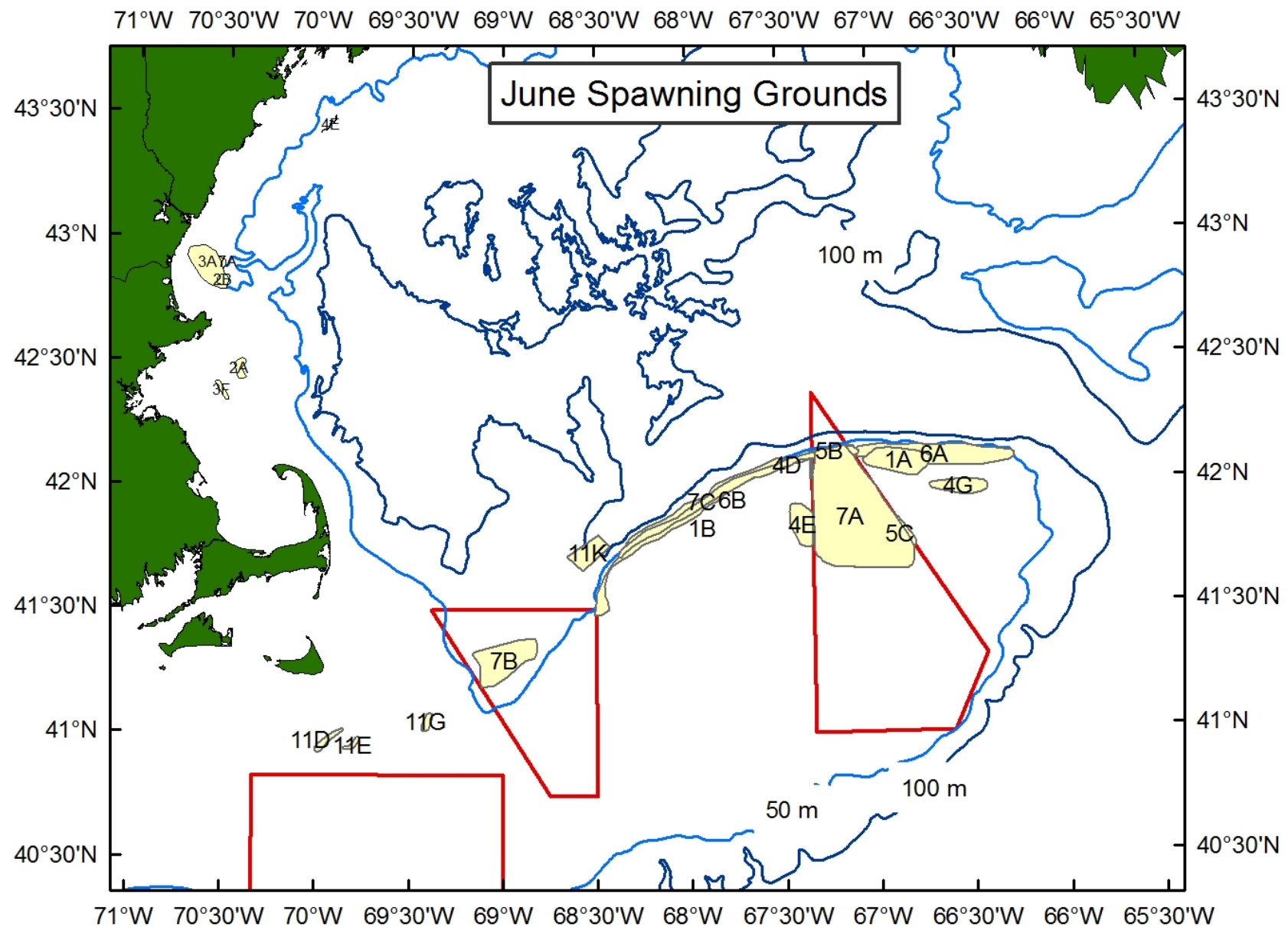


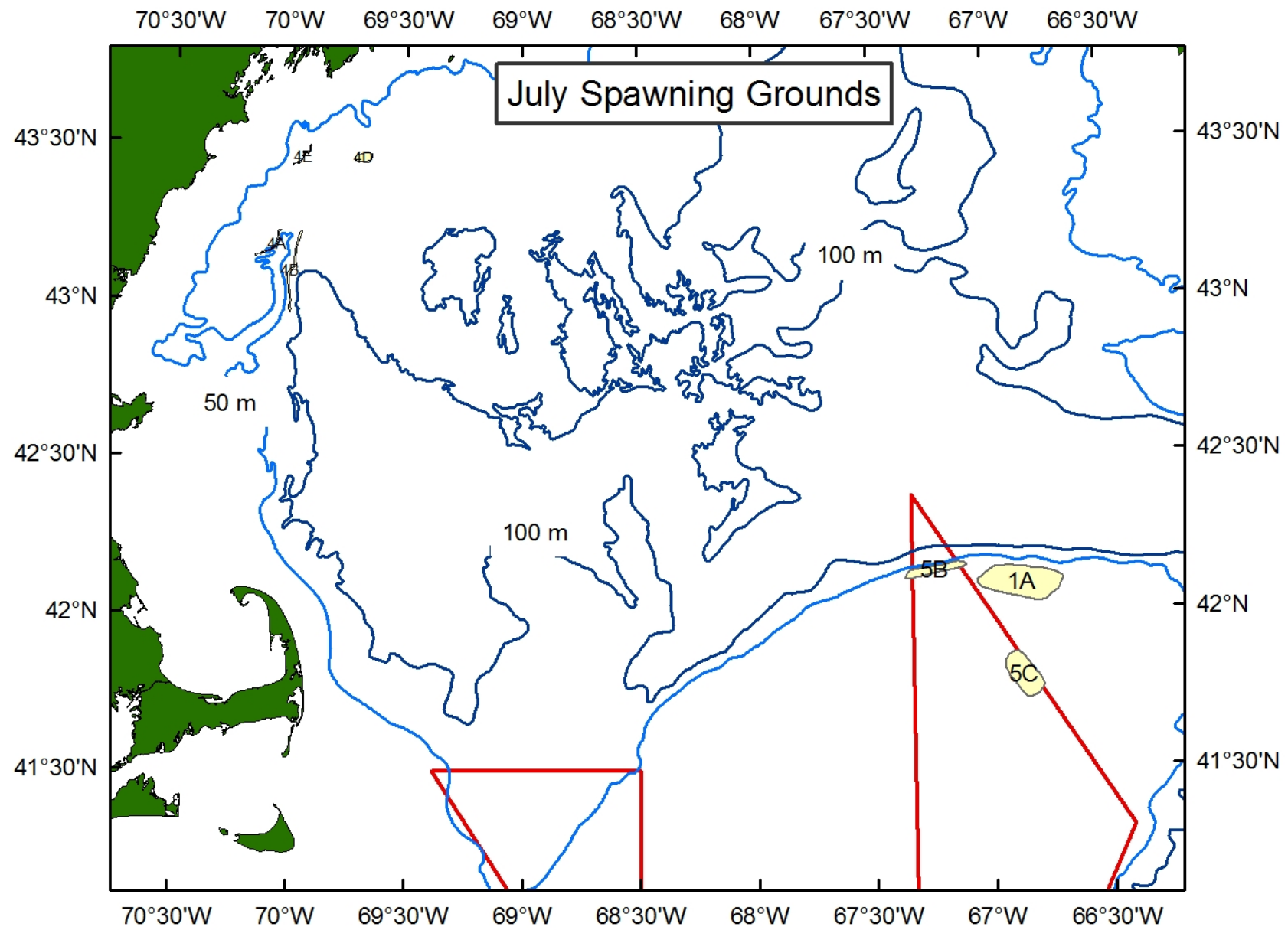


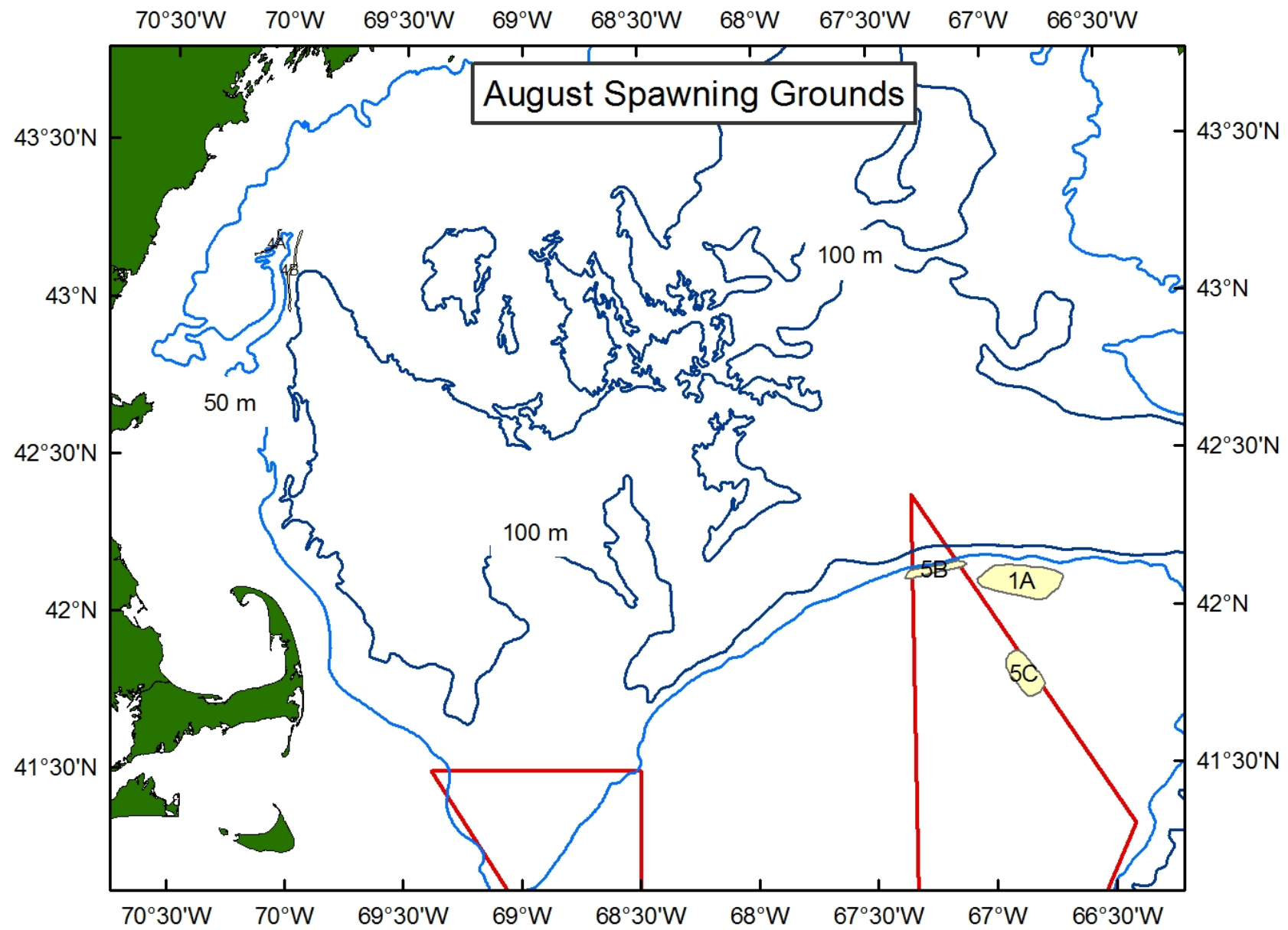


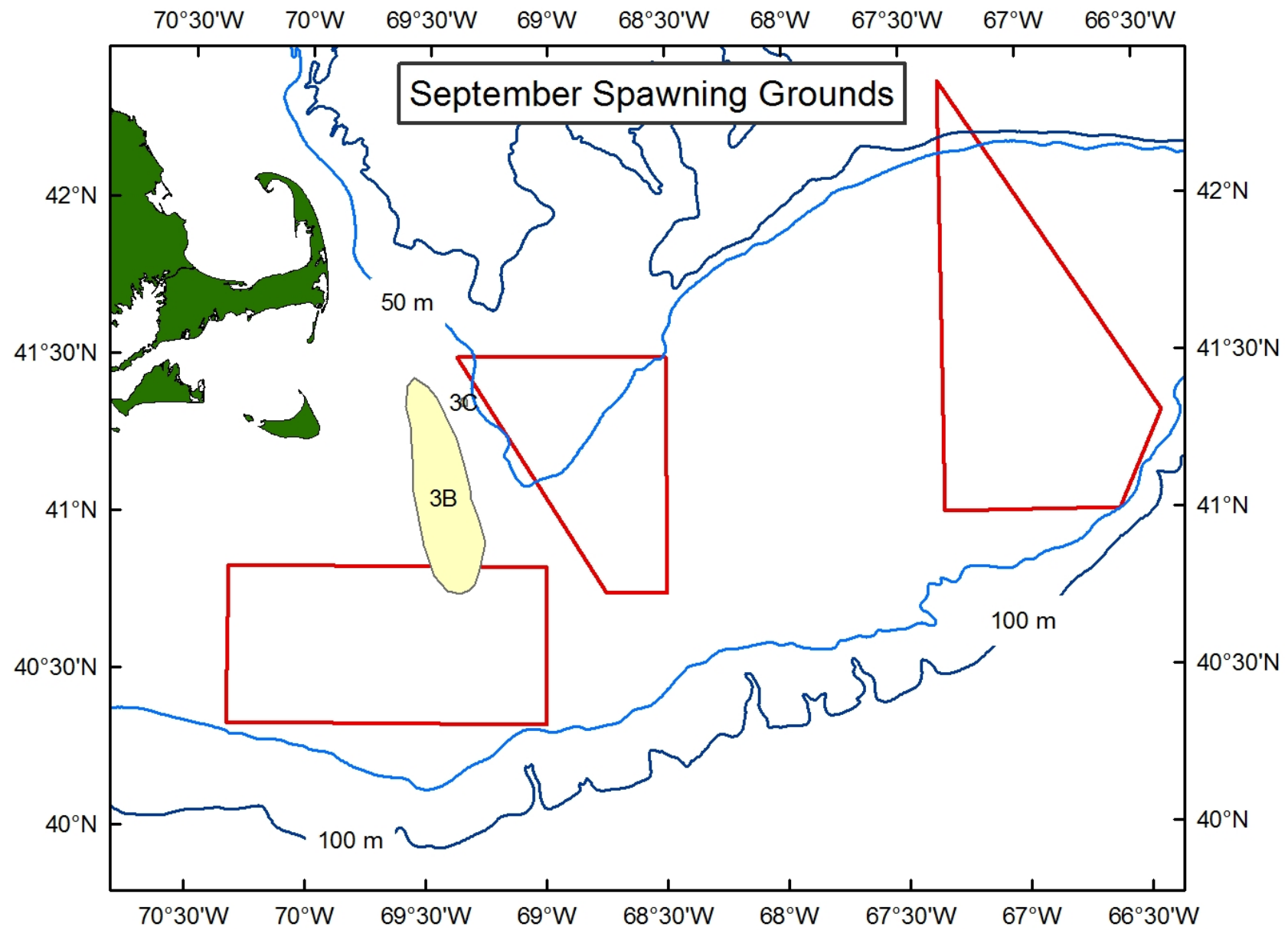














Atlantic cod stock structure in US waters:

## Early Life History

**The Atlantic Cod Stock Structure Working Group (ACSSWG)**

**Presenter: Micah Dean, MA Division of Marine Fisheries**

**New England Fishery Management Council Peer Review**

# Acknowledgements & Outline

Sub-Group: Micah Dean, Greg DeCelles, Doug Zemeckis, Ted Ames

External Reviewers: Dave Richardson (NOAA), Yanjun Wang (DFO)

## Introduction

## Distribution of Early Life Stages

- Spawning

- Larvae

- Settlement

## Evaluation of Connectivity

- Larval Transport

- Timeseries Correlations

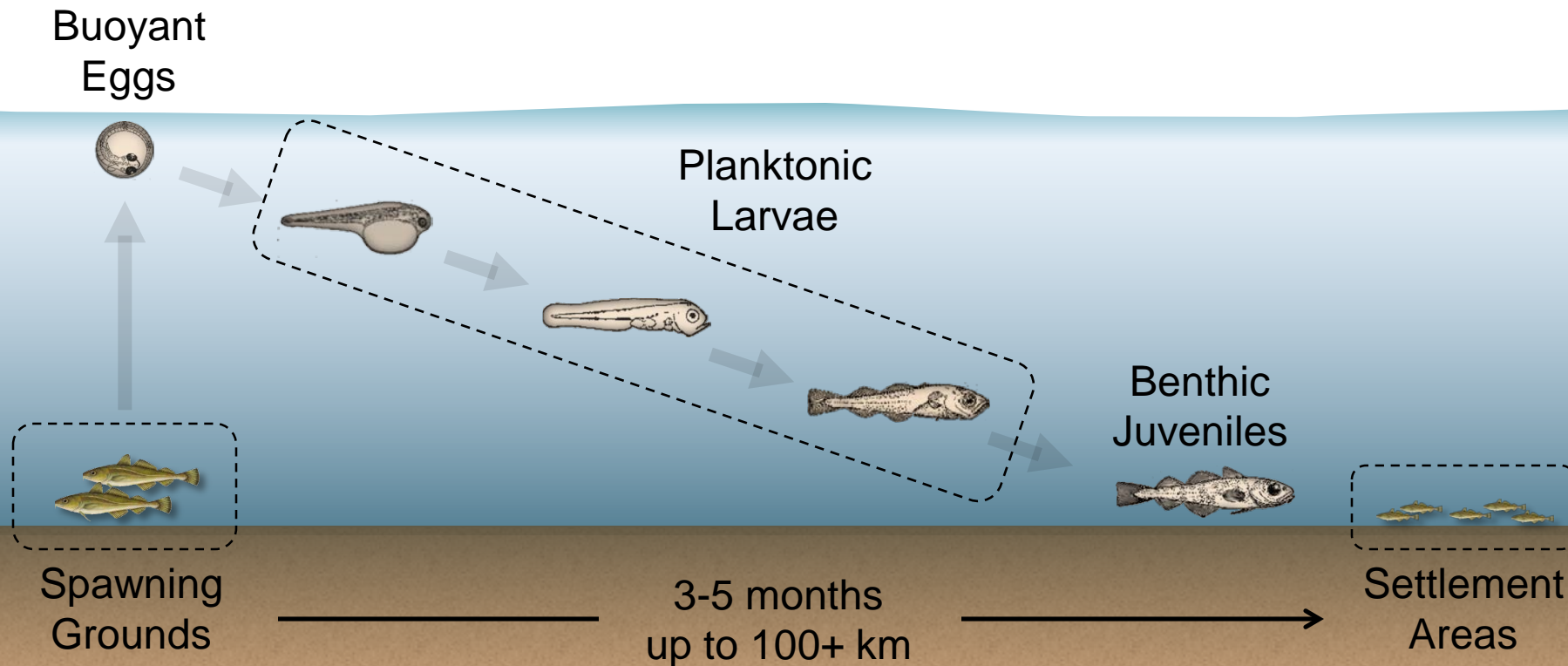
## Conclusions

# Cod Early Life History

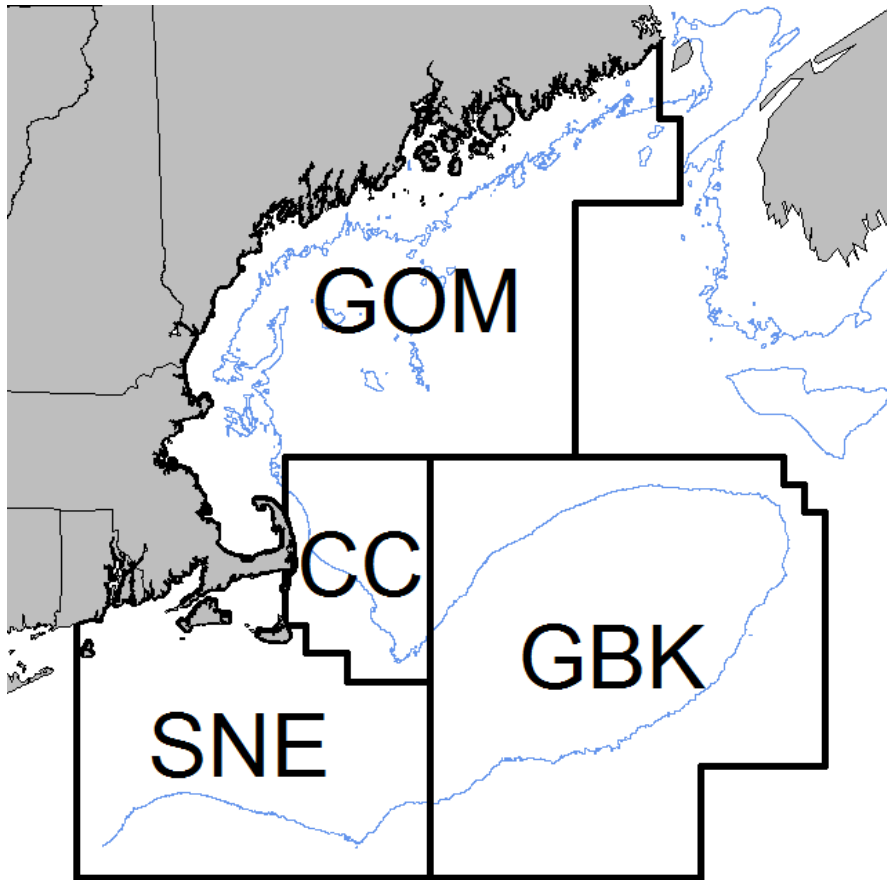
Spawning grounds – specific locations

Pelagic eggs/larvae – drift with currents

Settlement areas – specific habitats



# Spatial Strata



		Settlement Area			
		GOM	CC	SNE	GBK
Spawning Area	GOM Spring				
	GOM Winter				
	CC				
	SNE				
	GBK				

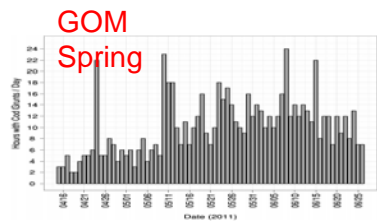
**Objective** - fill out the matrix with...

C = major connectivity  
c = minor connectivity  
X = unlikely connectivity

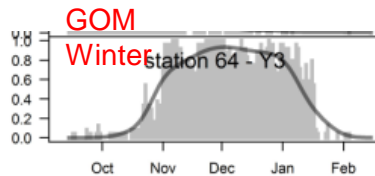
# Distribution of Spawning

## Data Sources – Spawning Seasons

### Passive Acoustics

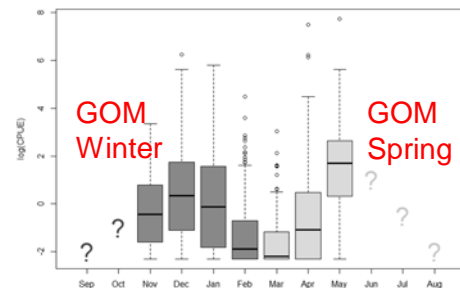


Hernandez et al, 2010

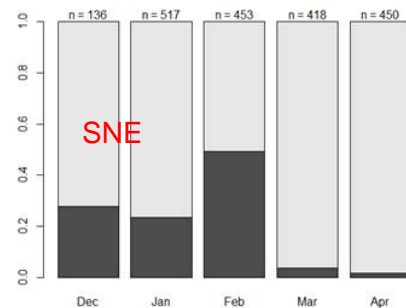


Zemeckis et al, 2019

### Maturity Data

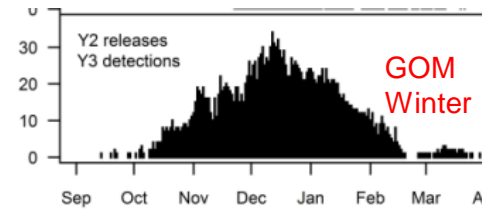
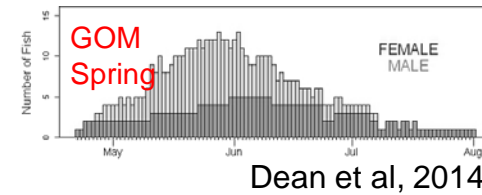


Hoffman et al, 2012



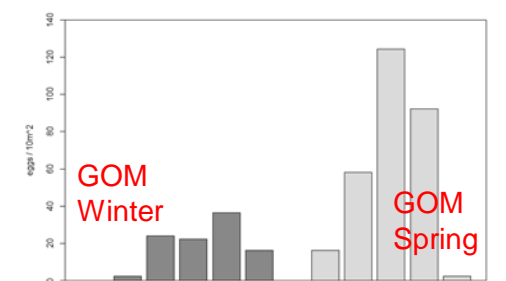
SMAST tagging, 2007-2011

### Acoustic Telemetry



Zemeckis et al, 2019

### Egg Density



Berrien and Sibunka, 1999

### Fishermen Ecological Knowledge

	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.
Nantucket Shoals and Channel												
Closed Area I												
Northern Edge												
Georges Shoal												
Southwest Part												
Closed Area II												
Northeast Peak												
Eastern Georges												

DeCelles et al, 2017

# Distribution of Spawning

## Data Sources – Spawning Grounds

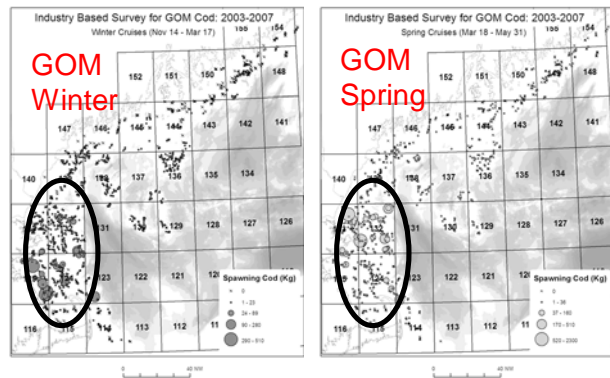
Passive Acoustics

Fishermen

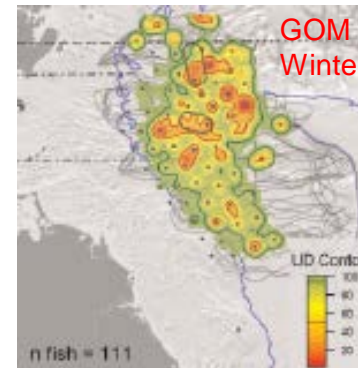
Ecological Knowledge

Maturity Data

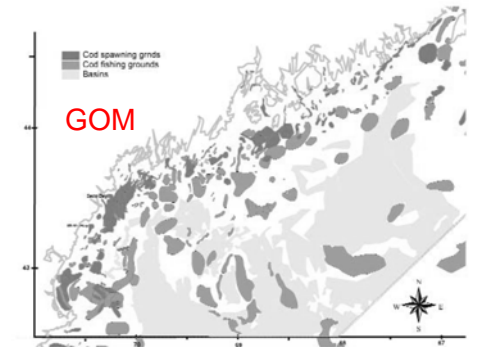
Acoustic Telemetry



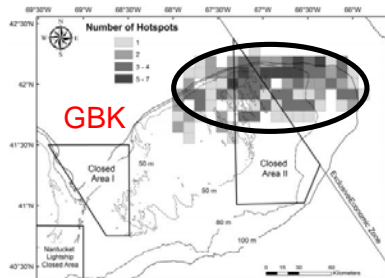
Hoffman et al., 2012



Zemeckis et al, 2019



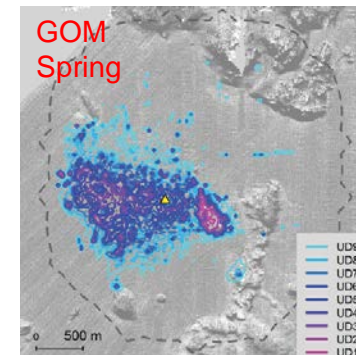
Ames 2004



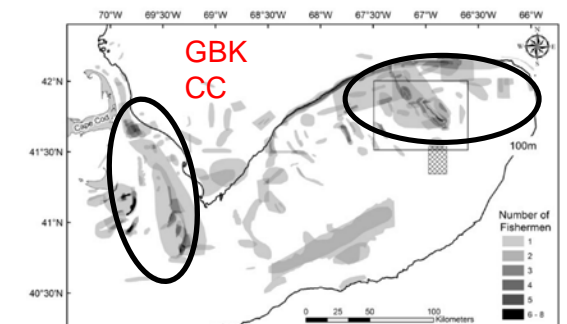
DeCelles et al, 2017



SMAST tagging, 2007-2011



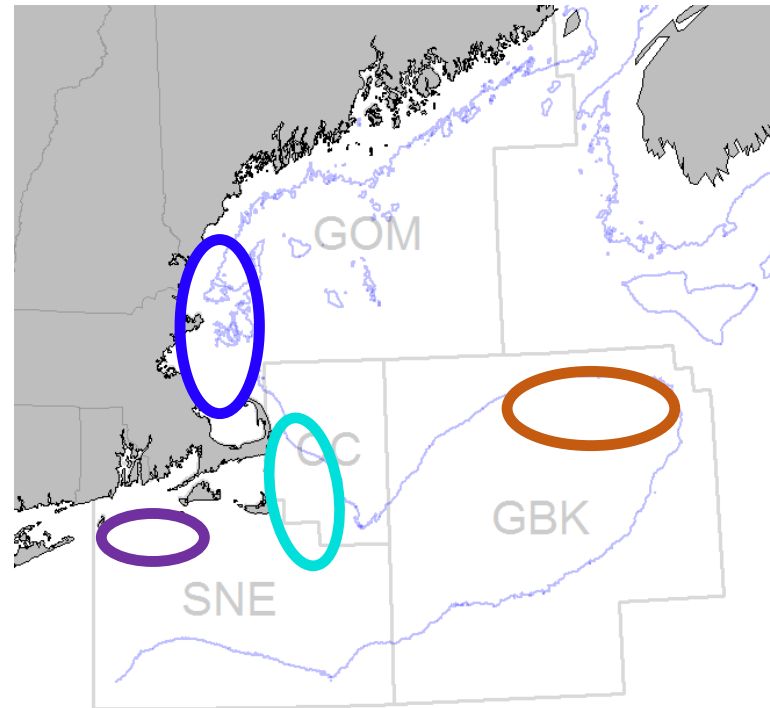
Dean et al, 2014



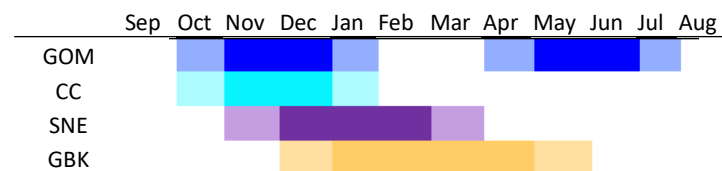
DeCelles et al, 2017

# Distribution of Spawning

## Spawning Grounds



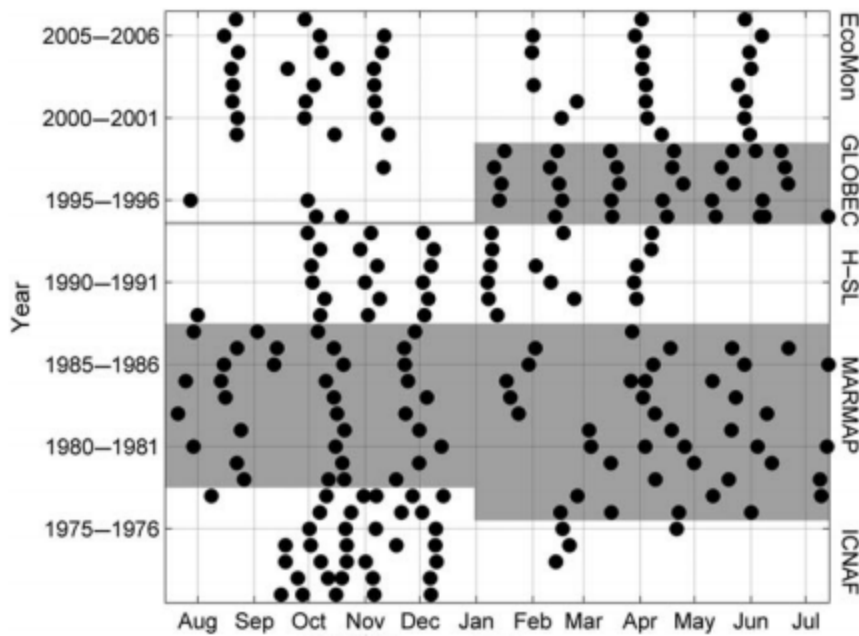
## Spawning Seasons



# Distribution of Larvae

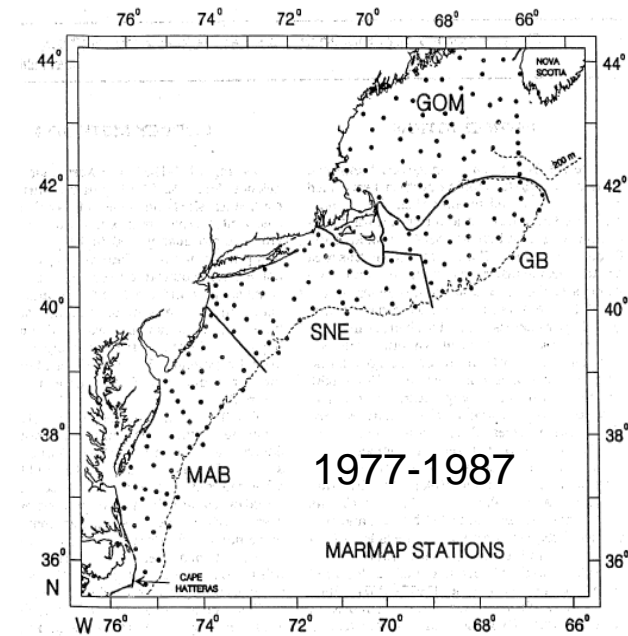
## Ichthyoplankton Sampling Programs

Broad Seasonal Coverage



Richardson et al., 2010

Broad Spatial Coverage

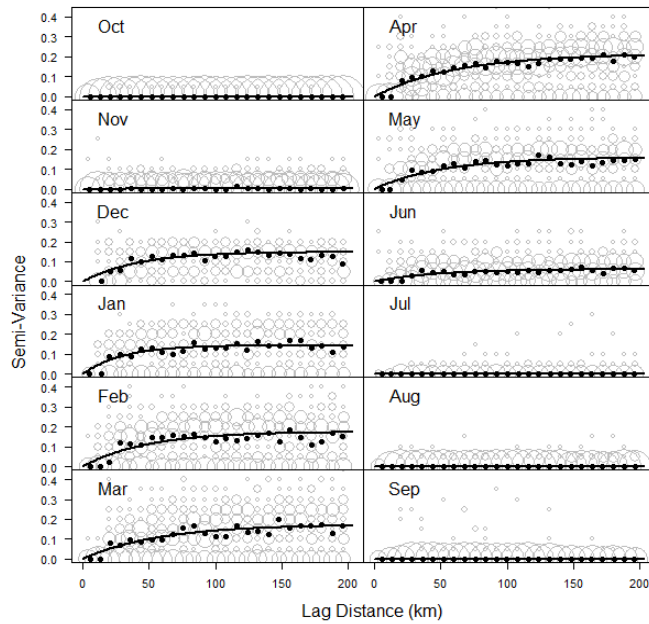


Morse 1994

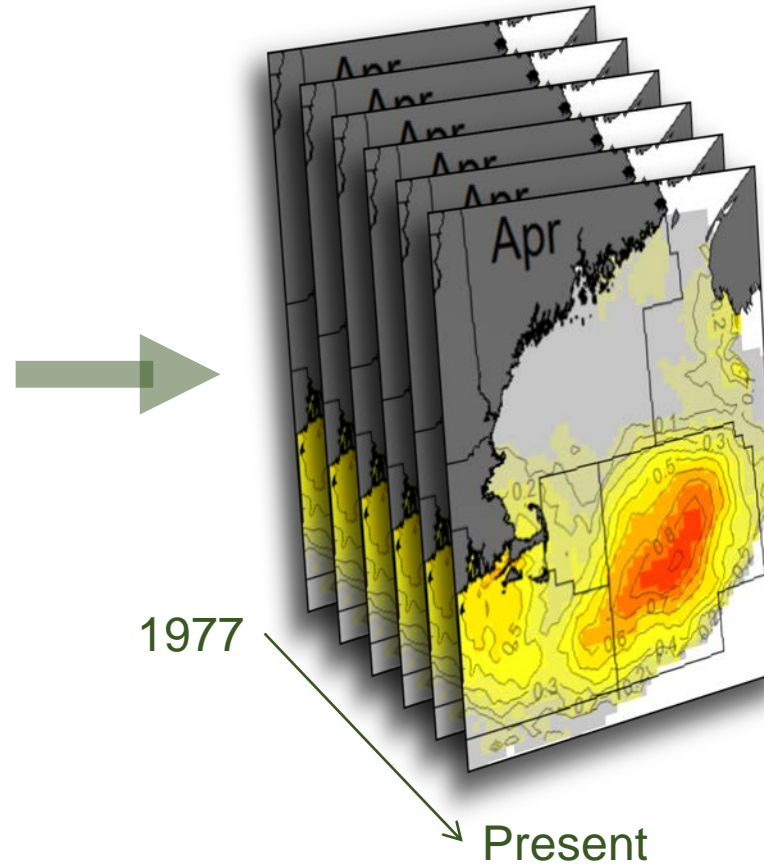
# Distribution of Larvae

## Aggregation of Kriging Predictions

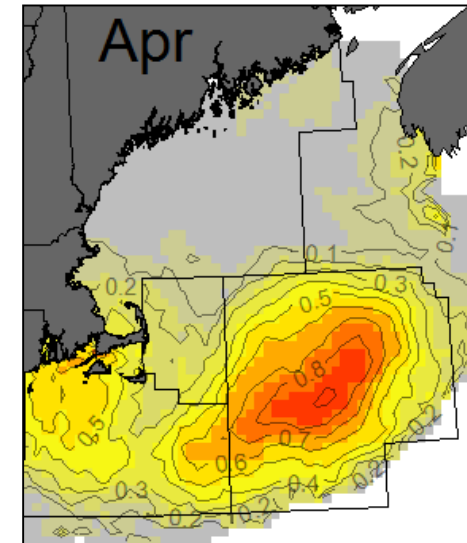
Variograms by Month



Monthly Predictions by Year



Average Predictions by Month across All Years

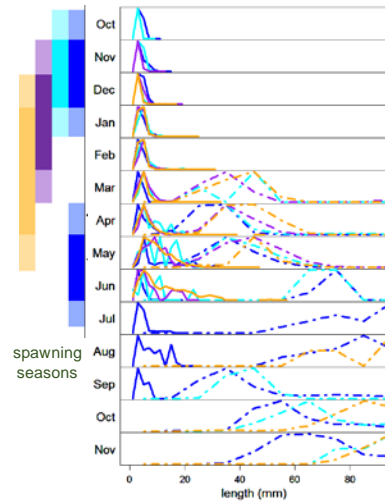


# Distribution of Larvae

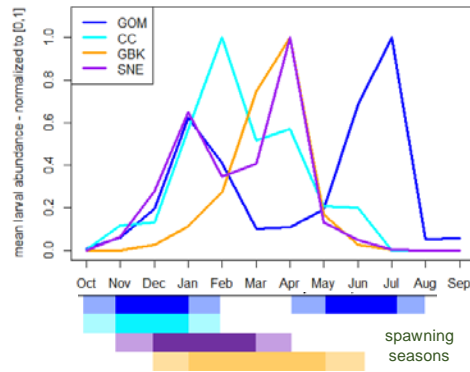
## Ichthyoplankton Surveys

MARMAP + GLOBEC + ECOMON - 1977-2017

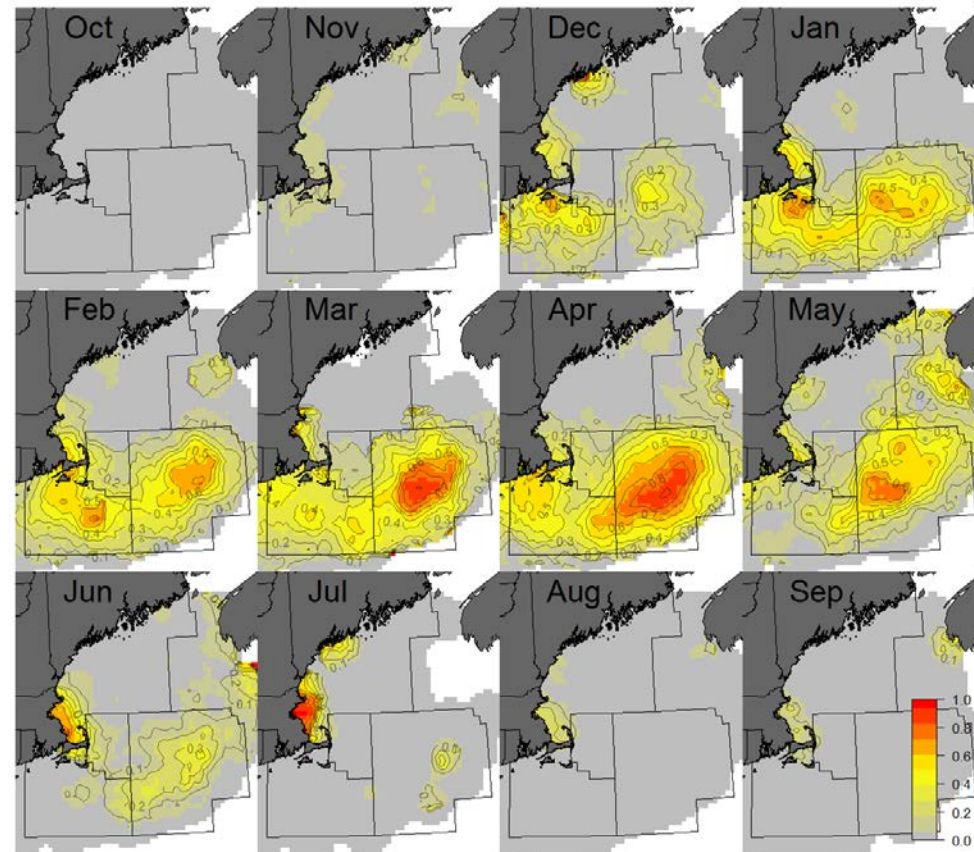
### Size Frequency



### Seasonal Abundance



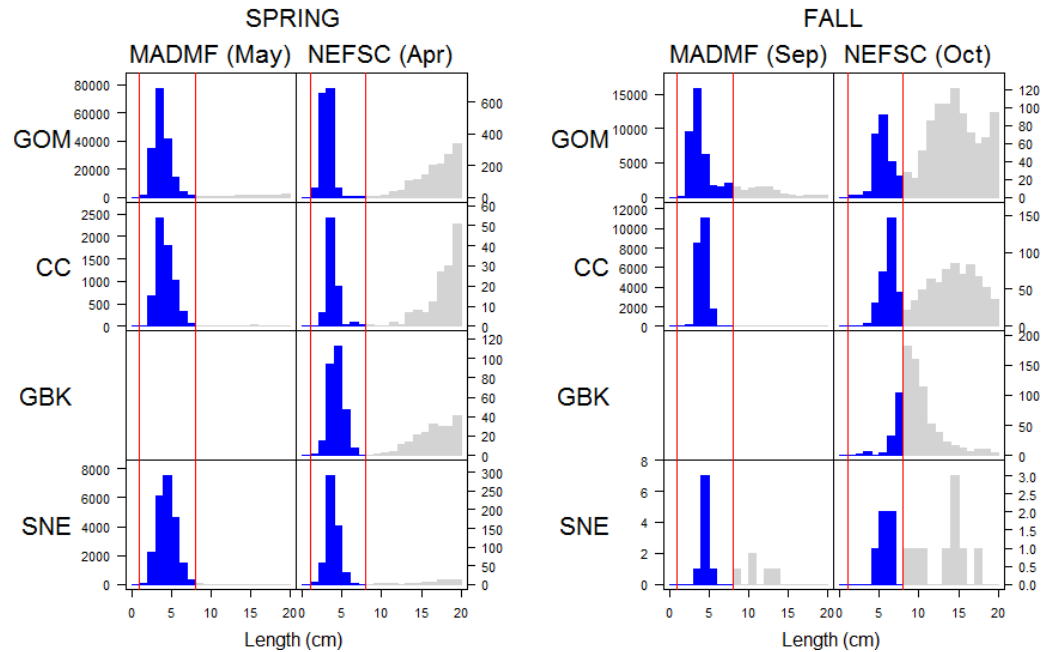
### Spatial Distribution



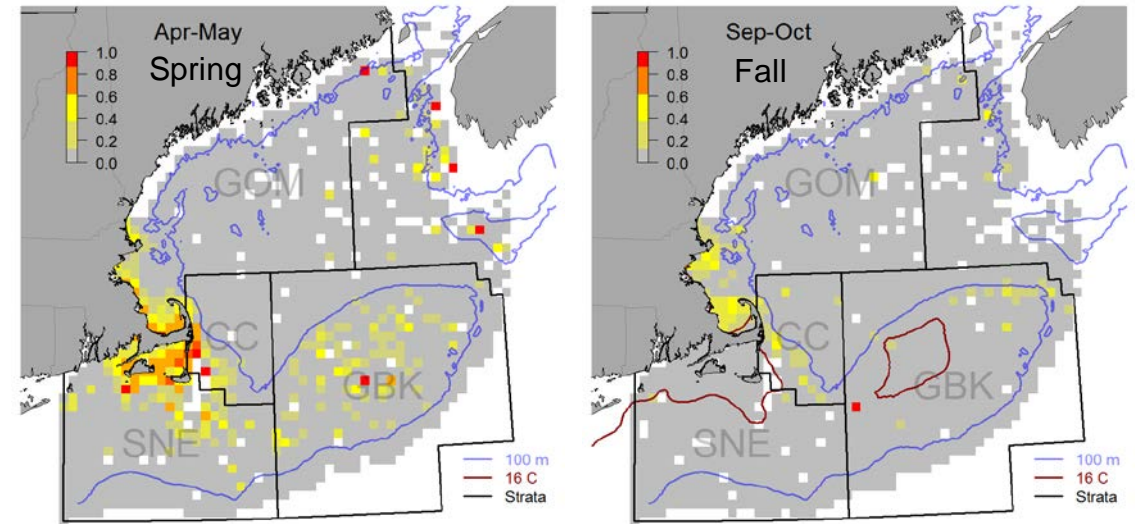
Average probability of presence

# Distribution of Settlement

## Length Frequency of 1<sup>st</sup> Mode



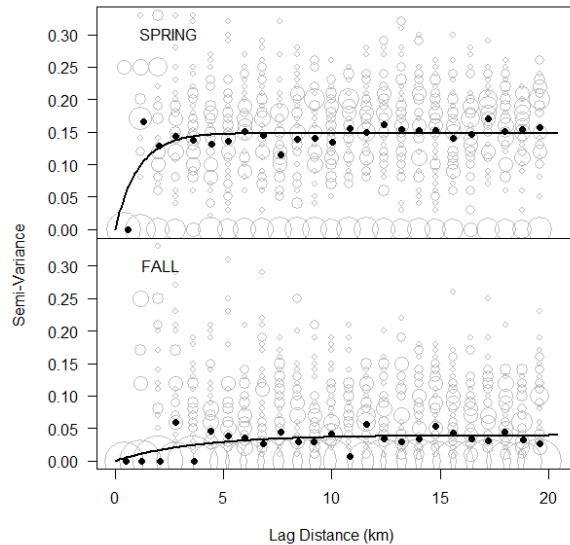
## Observed Occurrence, < 8 cm (MADMF + NEFSC)



# Distribution of Settlement

Predictions by Season, Year

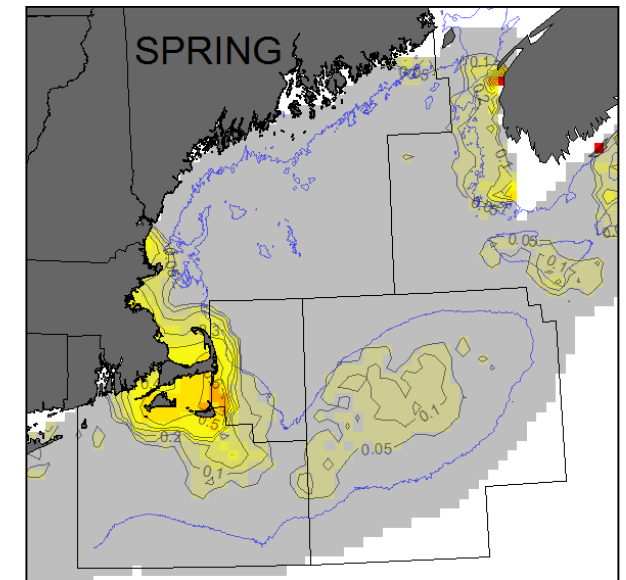
Variograms by Season



1963

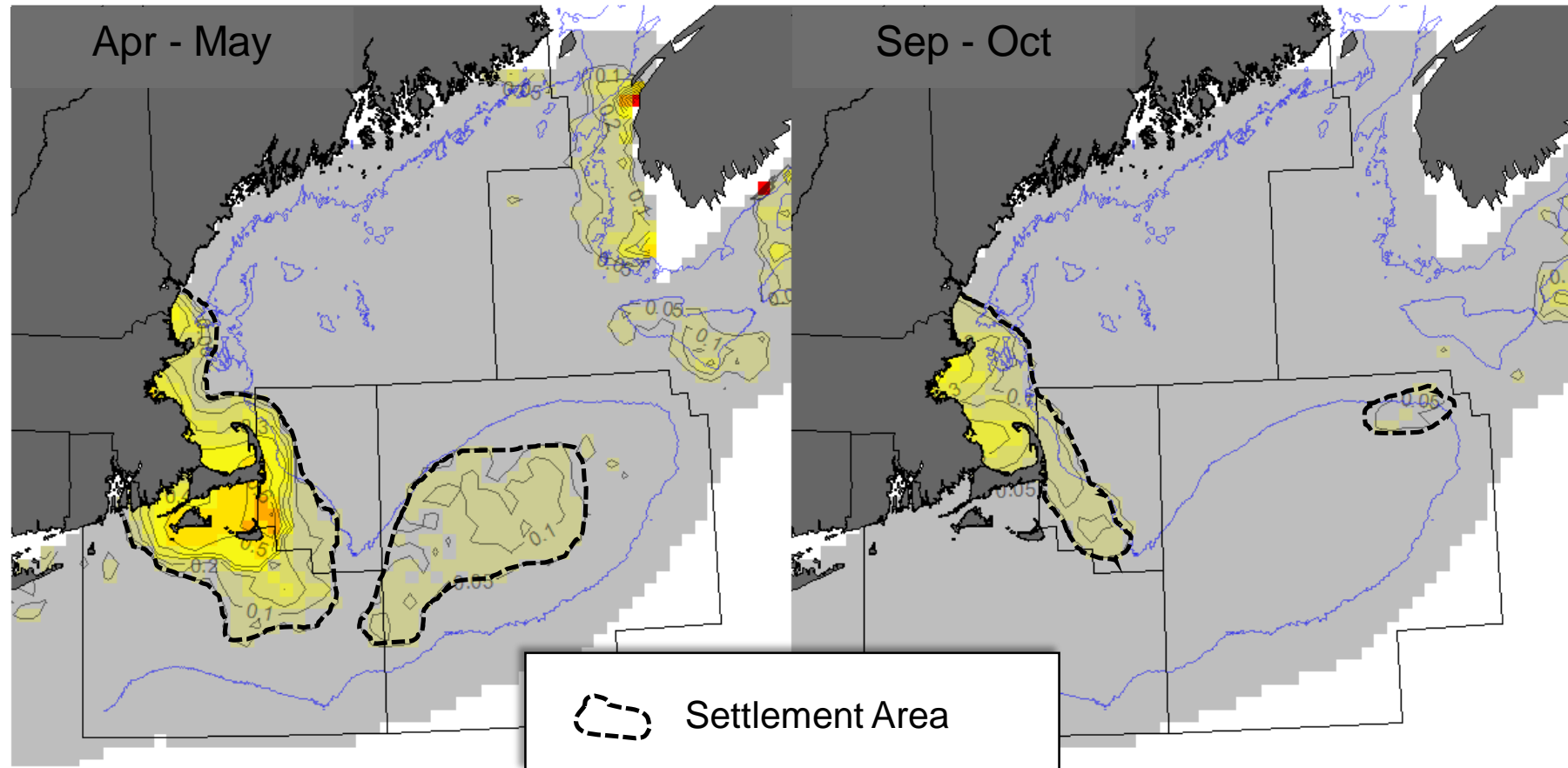
Present

Average Predictions by Season  
across All Years



Average probability of presence

# Distribution of Settlement

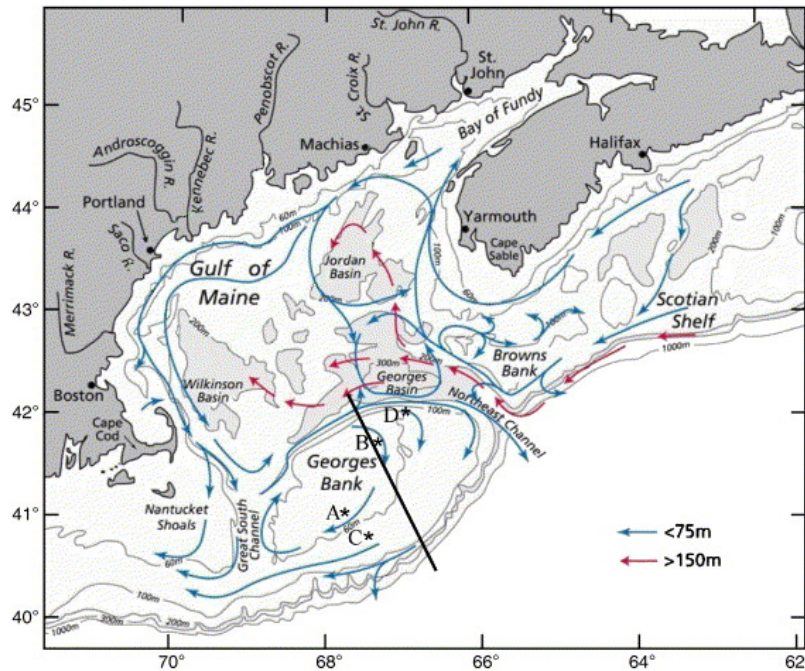


Average Krigged Occurrence of Age-0 Cod < 8 cm

# Evaluation of Connectivity

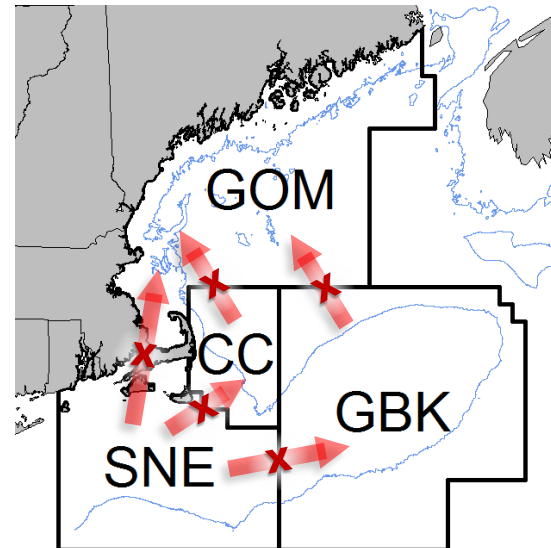
## Larval Transport

### Regional Circulation Patterns



Tian and Chen, 2006

Planktonic larvae cannot move “upstream”



Spawning Area

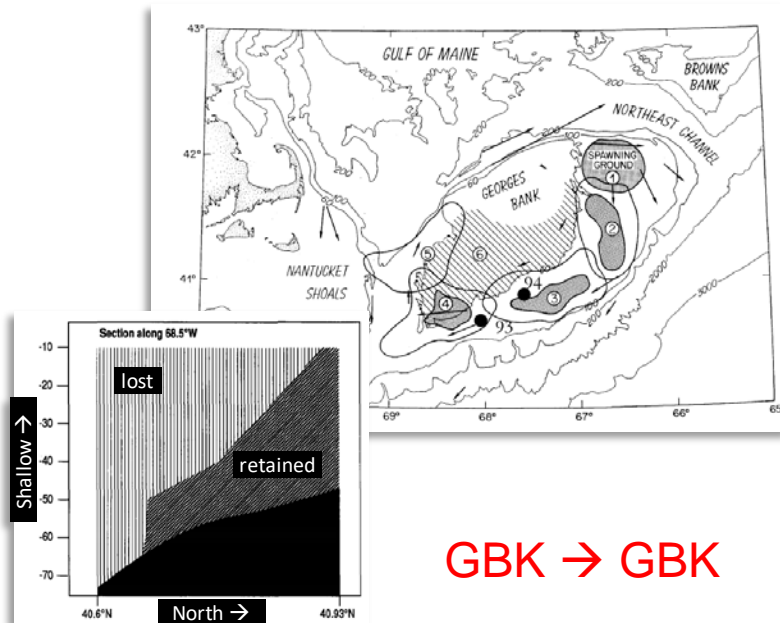
Settlement Area

	GOM	CC	SNE	GBK
GOM Spring				
GOM Winter				
CC	X	X		
SNE	X	X	C	X
GBK	X			

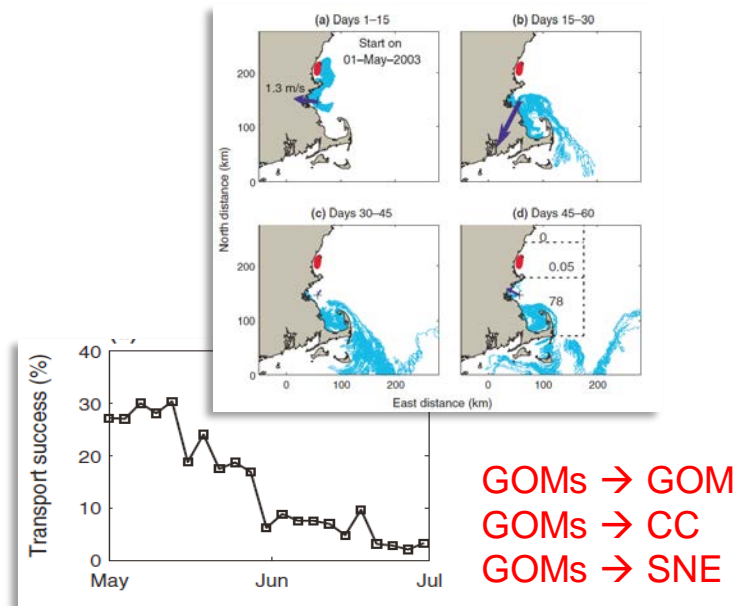
# Evaluation of Connectivity

## Larval Transport

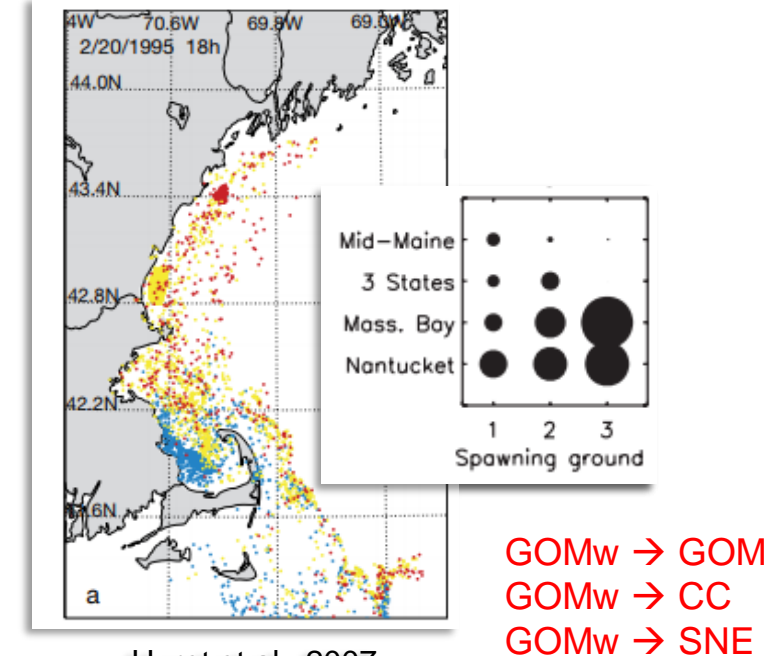
### Dispersal Modeling



Werner et al., 1993; Werner et al., 1996; Lough et al., 2005



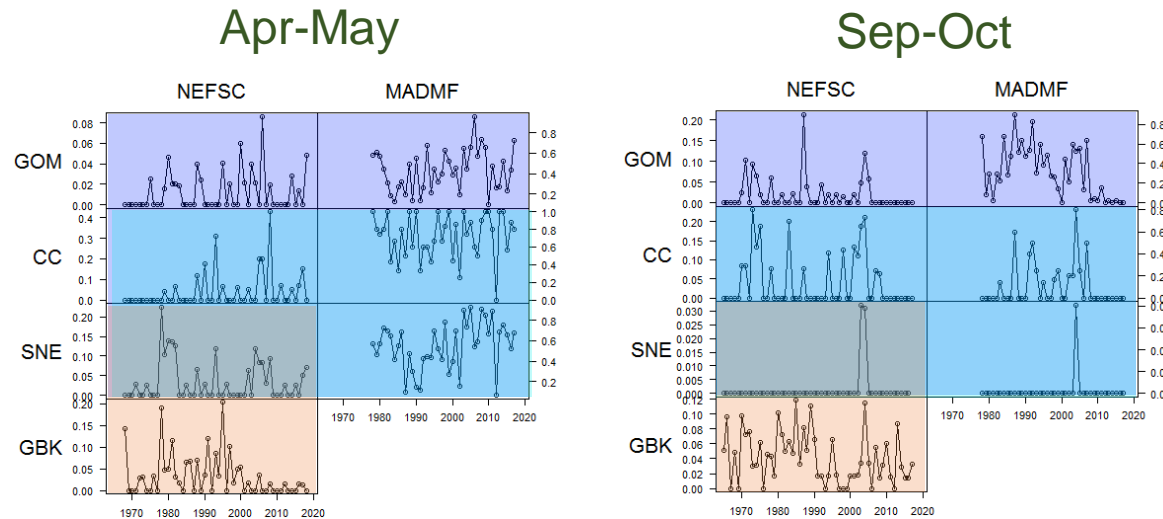
Churchill et al., 2011



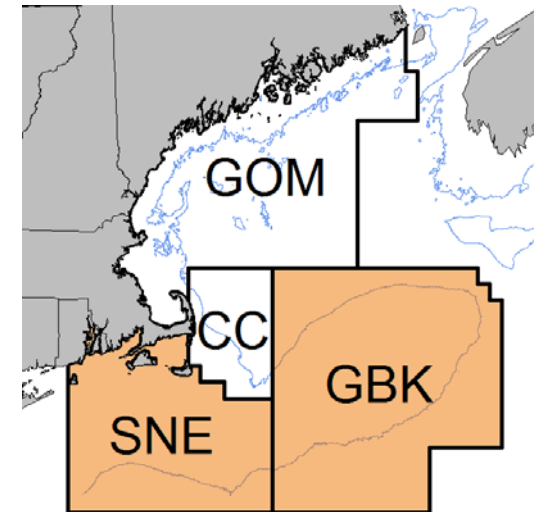
Huret et al., 2007

# Evaluation of Connectivity

## Settlement Timeseries Correlations



% of survey tows with < 8cm cod



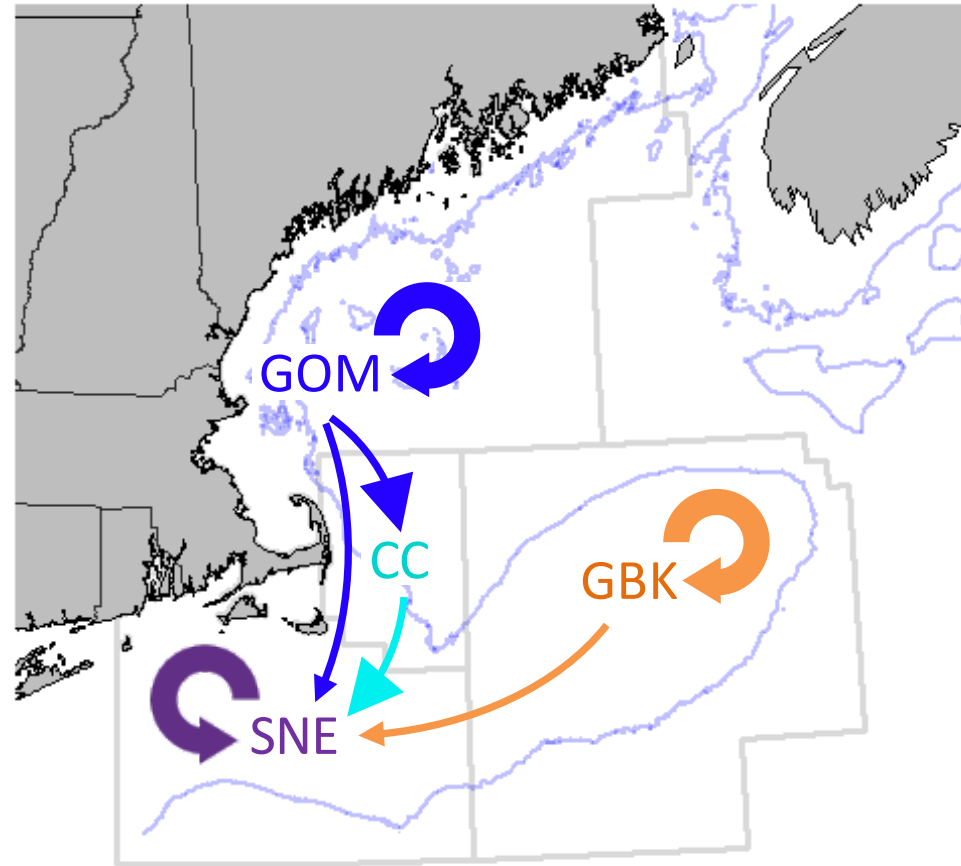
### Significant Correlations

- GOM → SNE; GOM → CC
- CC → SNE
- GBK → SNE

# Conclusions - Early Life History

Spawning Area	Settlement Area			
	GOM	CC	SNE	GBK
GOM Spring	C	C	X	X
GOM Winter	C	C	c	X
CC	X	X	C	X
SNE	X	X	C	X
GBK	X	X	c	C

C = major connectivity  
c = minor connectivity  
X = unlikely connectivity



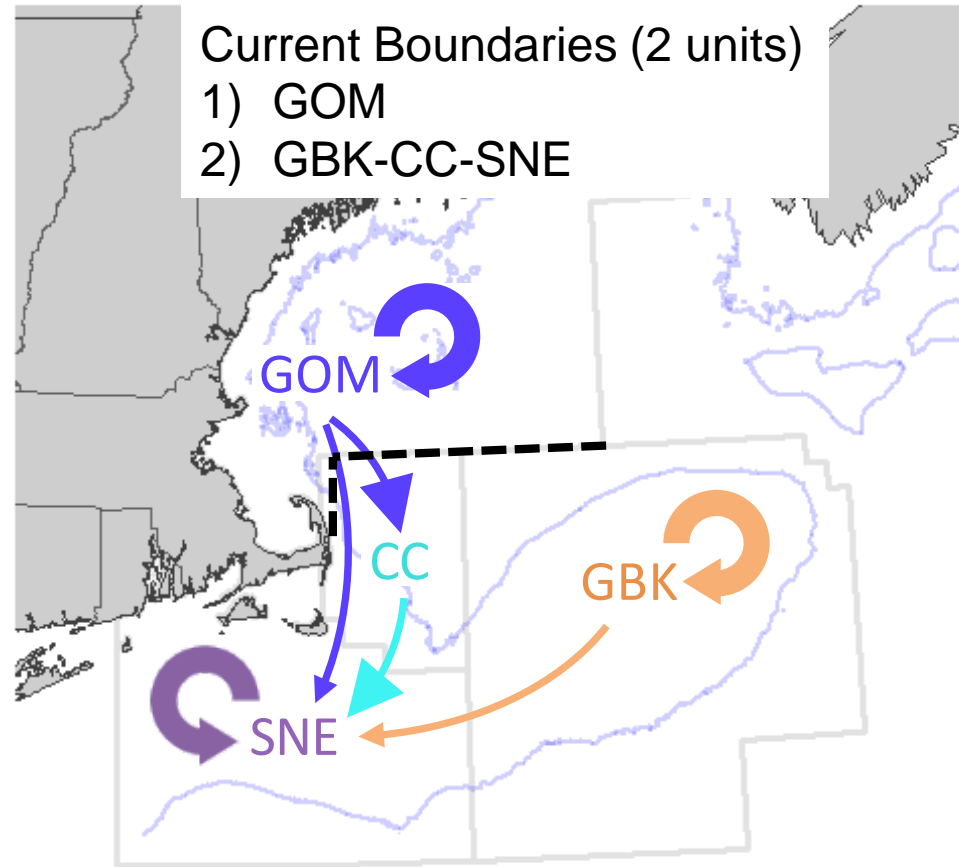
# Conclusions - Early Life History

## Which Boundaries are Most Congruent with ELH?

Does not account for  
3 connectivity links

Spawning Area	Settlement Area			
	GOM	CC	SNE	GBK
GOM Spring	C	C	X	X
GOM Winter	C	C	c	X
CC	X	X	C	X
SNE	X	X	C	X
GBK	X	X	c	C

C = major connectivity  
c = minor connectivity  
X = unlikely connectivity

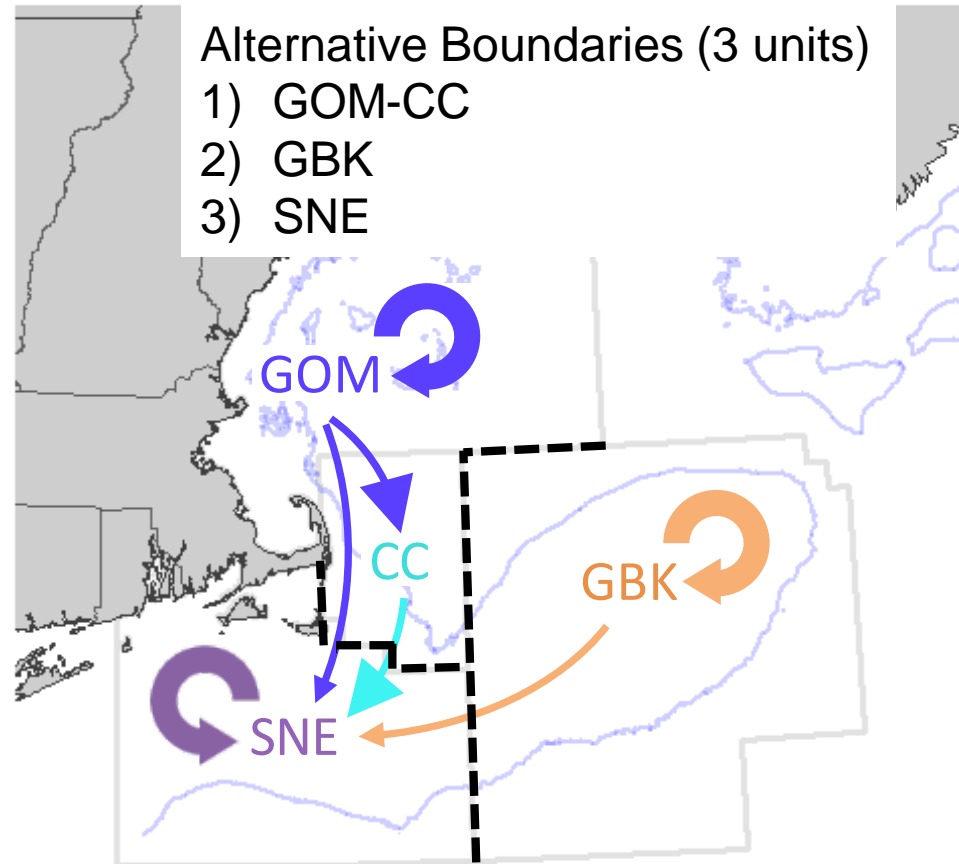


# Conclusions - Early Life History

## Which Boundaries are Most Congruent with ELH?

Spawning Area	Settlement Area			
	GOM	CC	SNE	GBK
GOM Spring	C	C	X	X
GOM Winter	C	C	c	X
CC	X	X	C	X
SNE	X	X	C	X
GBK	X	X	c	C

C = major connectivity  
c = minor connectivity  
X = unlikely connectivity

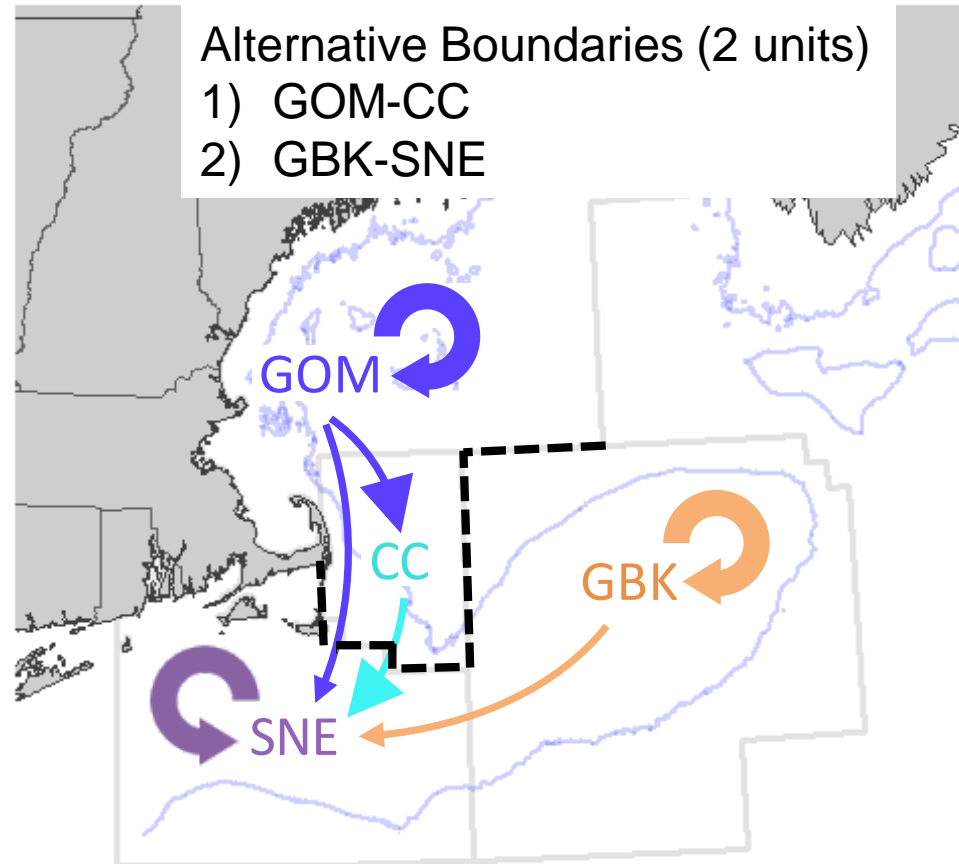


# Conclusions - Early Life History

## Which Boundaries are Most Congruent with ELH?

Spawning Area	Settlement Area			
	GOM	CC	SNE	GBK
GOM Spring	C	C	X	X
GOM Winter	C	C	c	X
CC	X	X	C	X
SNE	X	X	C	X
GBK	X	X	c	C

C = major connectivity  
c = minor connectivity  
X = unlikely connectivity

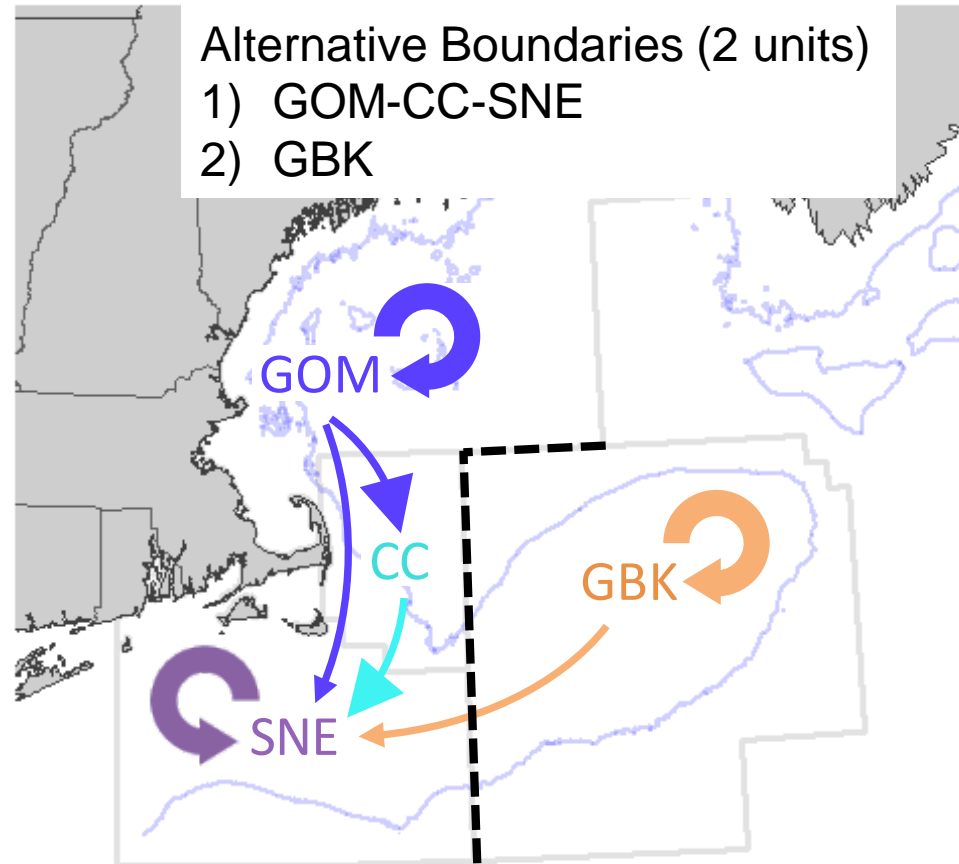


# Conclusions - Early Life History

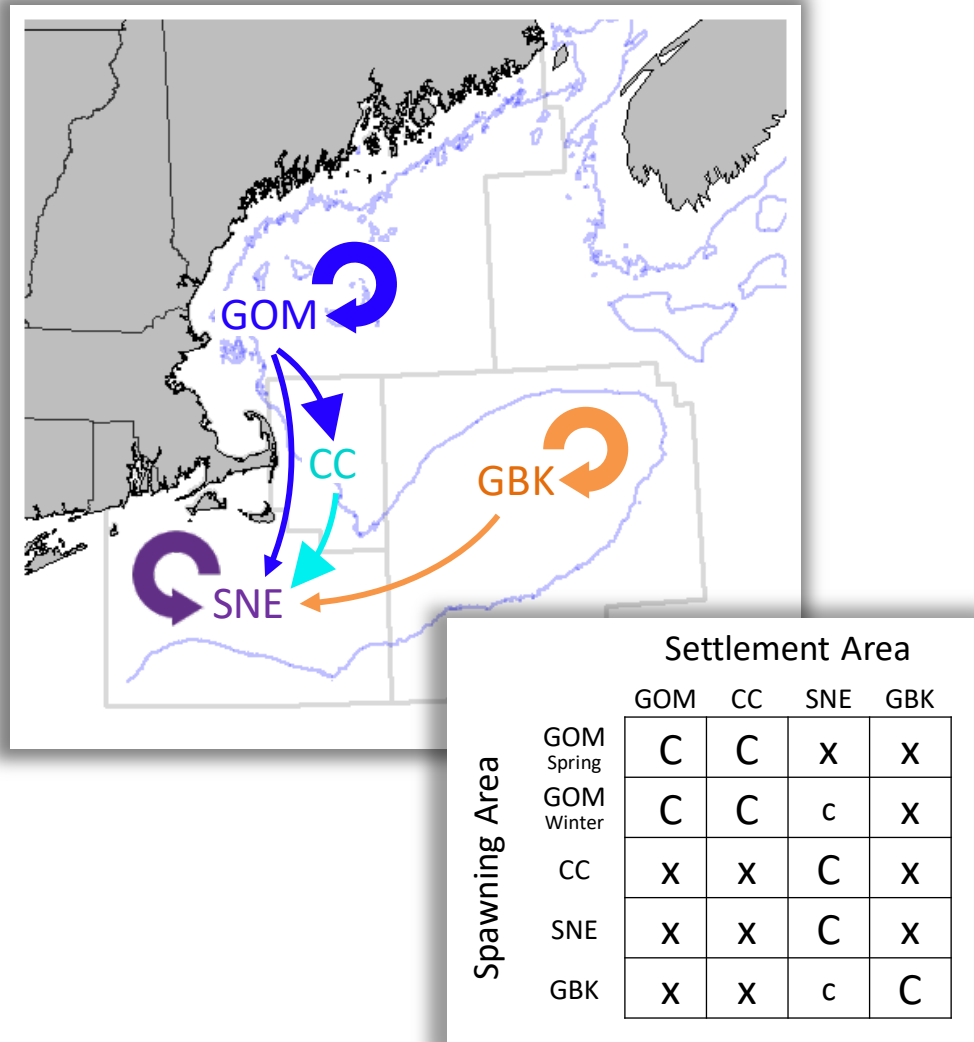
## Which Boundaries are Most Congruent with ELH?

		Settlement Area			
		GOM	CC	SNE	GBK
Spawning Area	GOM Spring	C	C	X	X
	GOM Winter	C	C	c	X
	CC	X	X	C	X
	SNE	X	X	C	X
	GBK	X	X	c	C

C = major connectivity  
c = minor connectivity  
X = unlikely connectivity



# Conclusions - Early Life History



## Relevant Stock Structure Perspectives

Perspective	Population Inference
Distribution	Surveys provide seasonal-spatial pattern of spawning, larvae, and settlement - revealing multiple <b>distinct groups</b>
Dispersal	Larval transport studies provide evidence of <b>connectivity</b> between spawning grounds and nursery areas
Geographic Variation	Timeseries correlations and early growth trajectories demonstrate <b>demographic independence</b> between groups



# Atlantic cod stock structure in US waters: Genetic Markers

**The Atlantic Cod Stock Structure Working Group (ACSSWG)**

**Presenter: Adrienne Kovach, University of New Hampshire**

**New England Fishery Management Council Peer Review**

# Outline

## Genetic Variation & Genetic Markers

- Types of inference that can be made from different markers

## Summary of Genetic Studies

- Studies 1998-2018
- New research conducted during this process

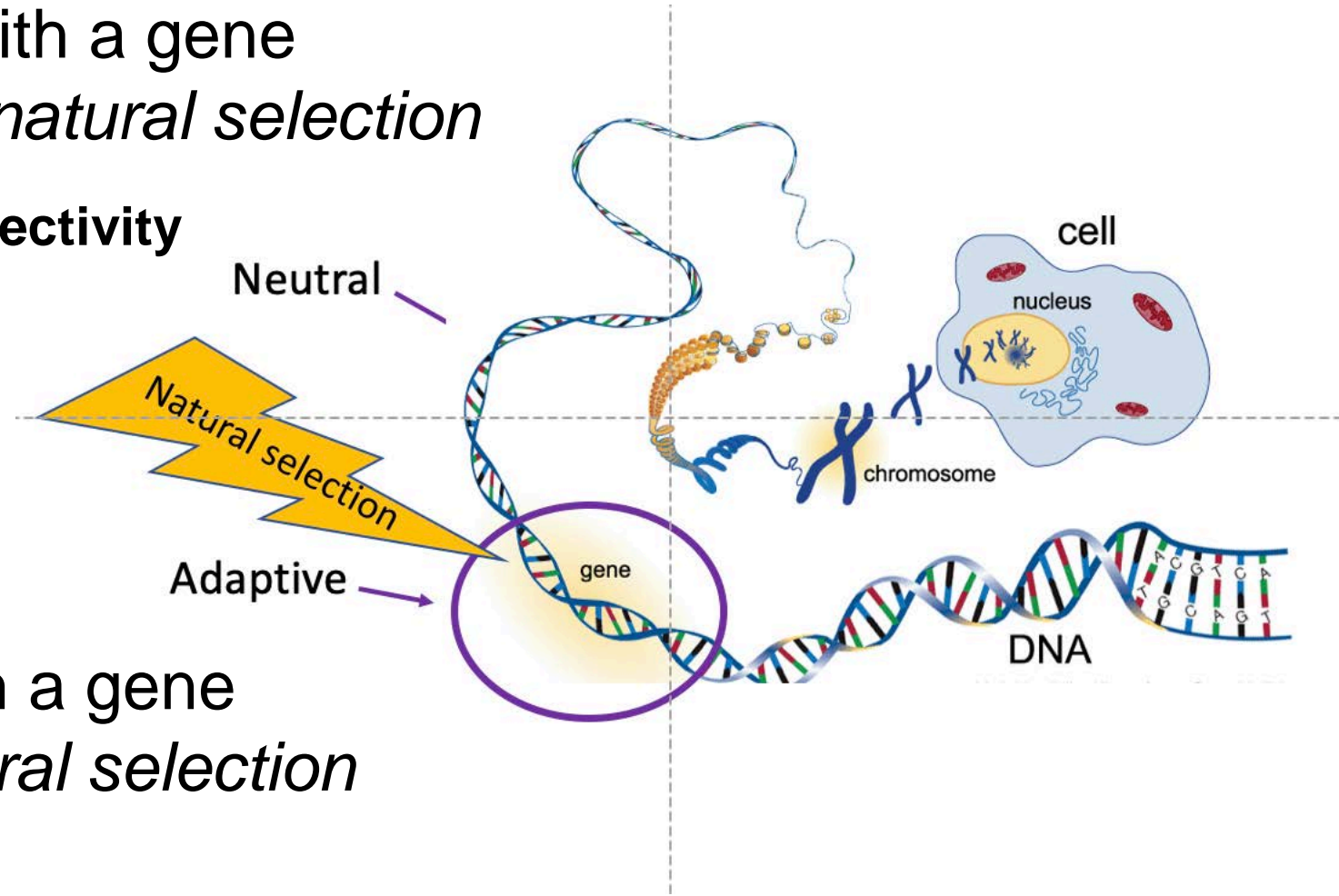
## Conclusion

- Highlights
- Perspective
- Resolution

# Two kinds of genetic variation

**Neutral** – **not** associated with a gene  
***not under the influence of natural selection***

- **Indicate demographic connectivity**

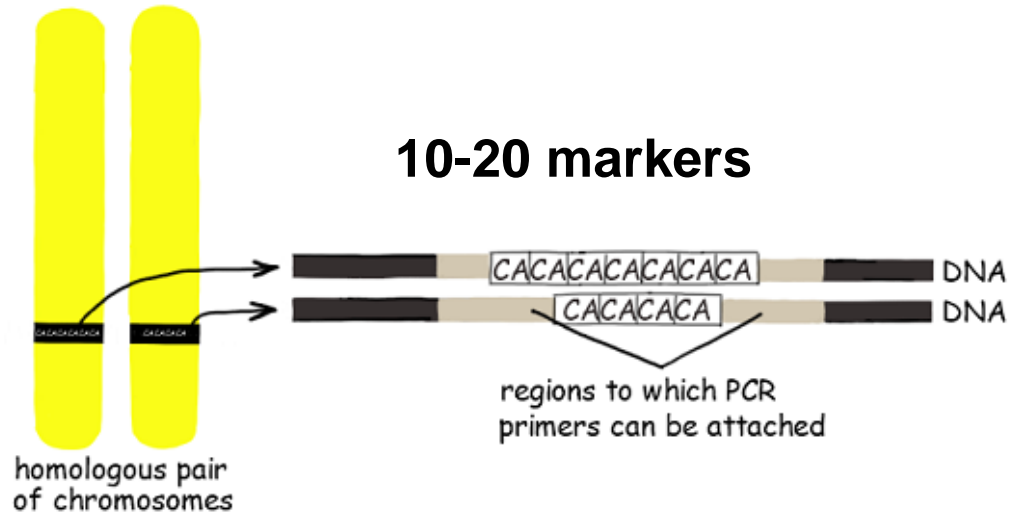


**Adaptive** – associated with a gene  
***under the influence of natural selection***

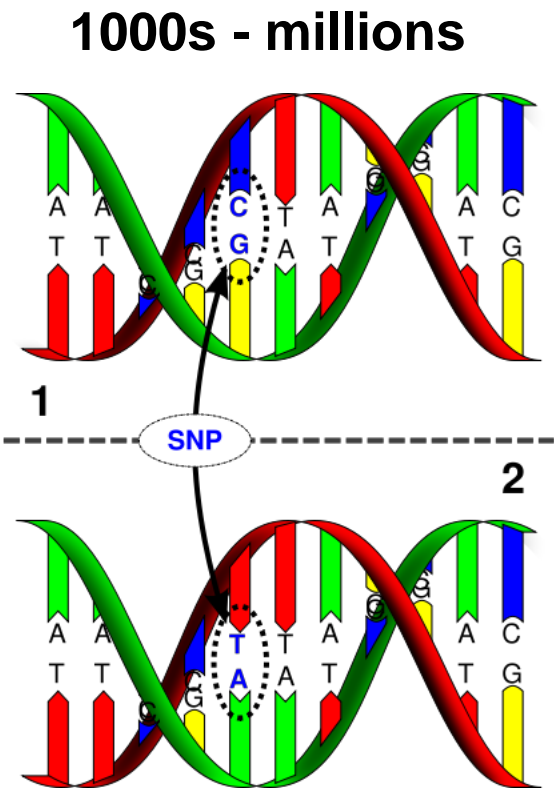
- **Ecological adaptation to local environmental conditions**

# Genetic Markers

## Microsatellites

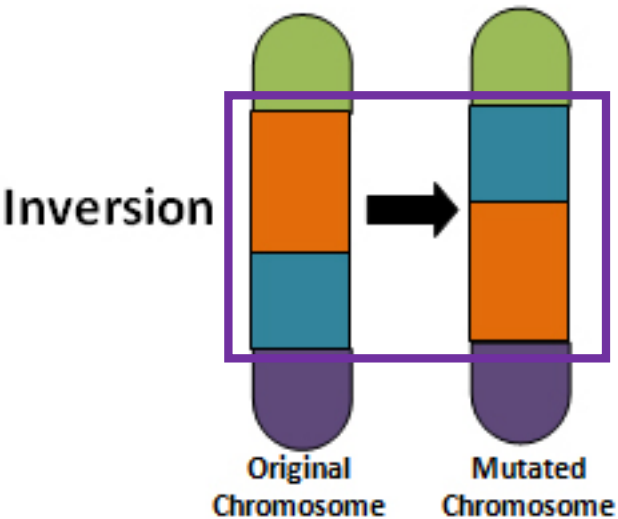


## Single Nucleotide Polymorphisms (SNPs)



## Chromosomal Rearrangement

Inverted region is inherited as a linked block



# Summary of Population Genetic Studies 1998-2018

## Comprehensive Review

### **Studies with Microsatellite Markers & Pan I**

Western Gulf of Maine, Southern New England & NE Georges Bank

- Wirgin et al. 2007, Kovach et al. 2010

Western Georges Bank/Great South Channel – eastern Georges Bank

- Weiss et al. (2005 unpublished report)

Georges Bank – Browns Bank

- Lage et al. 2004, Ruzzante et al. 1998

### **Studies with SNP markers (single nucleotide polymorphisms)**

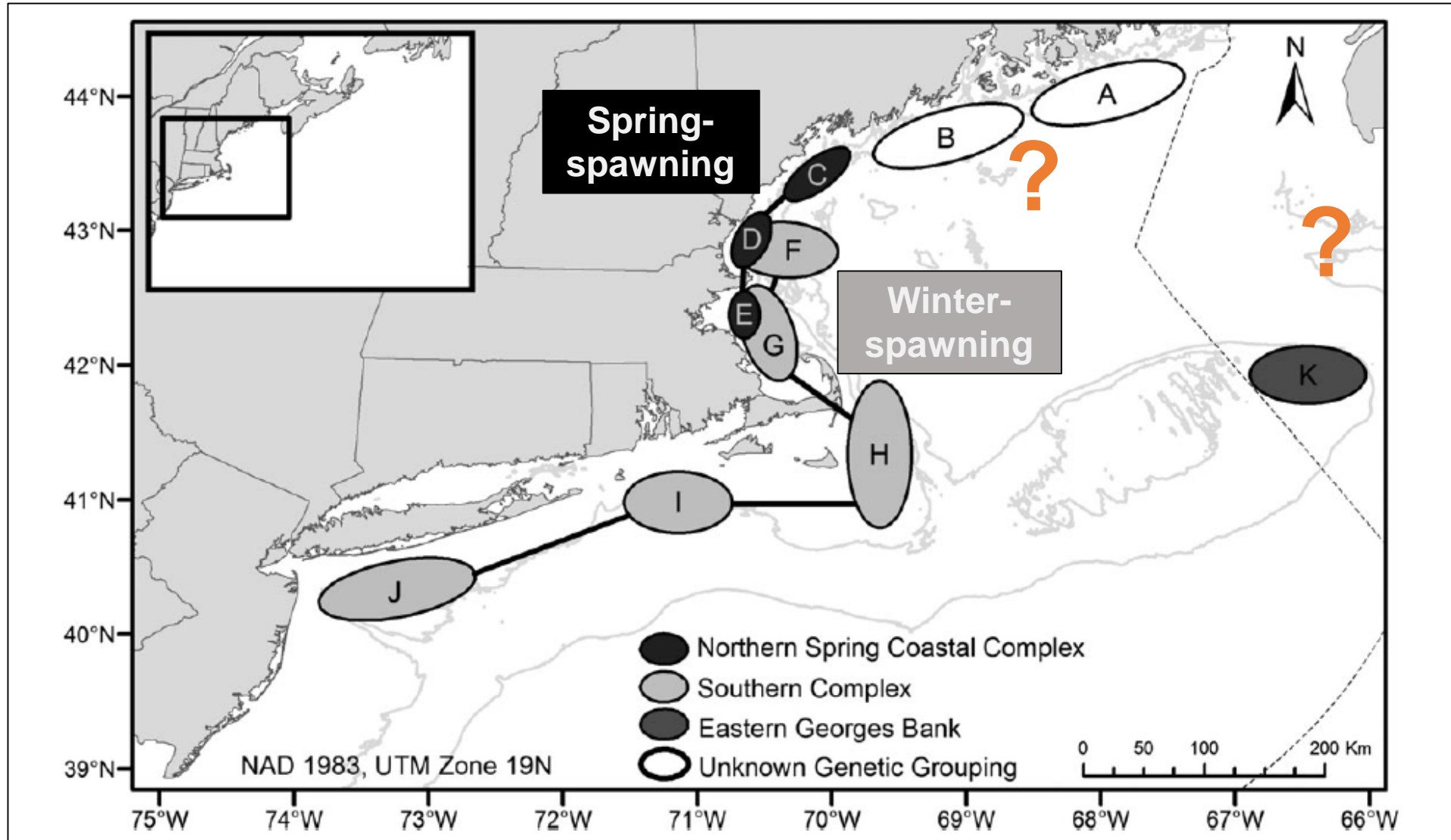
wGoM + Georges Bank – whole genomes (3 chromosomes)

- Barney et al. 2017

Western GoM, eastern GoM, NE Georges Bank – SNP (& microsat) markers

- unpublished NOAA report - Kerr, Cadrin, Kovach et al

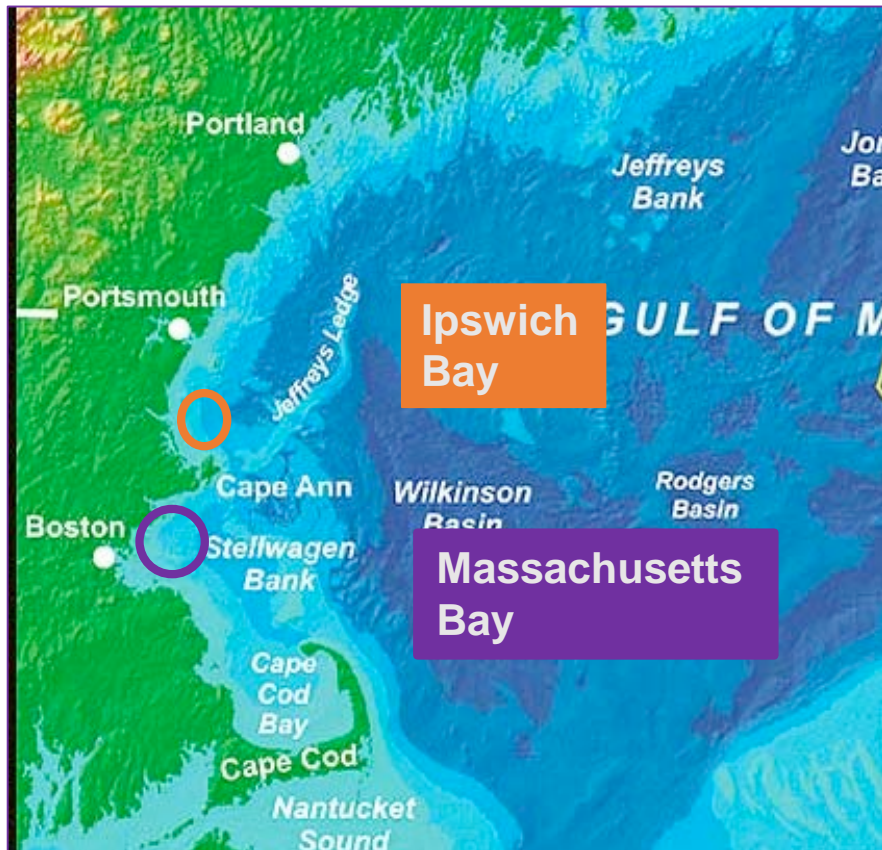
# State of Knowledge Prior to ACSSWG Effort



*Kovach et al. 2010; Zemeckis et al. 2014*

# Focus on western Gulf of Maine – Spring vs. Winter

Adaptive genetic variation drives the difference



Dec -Jan



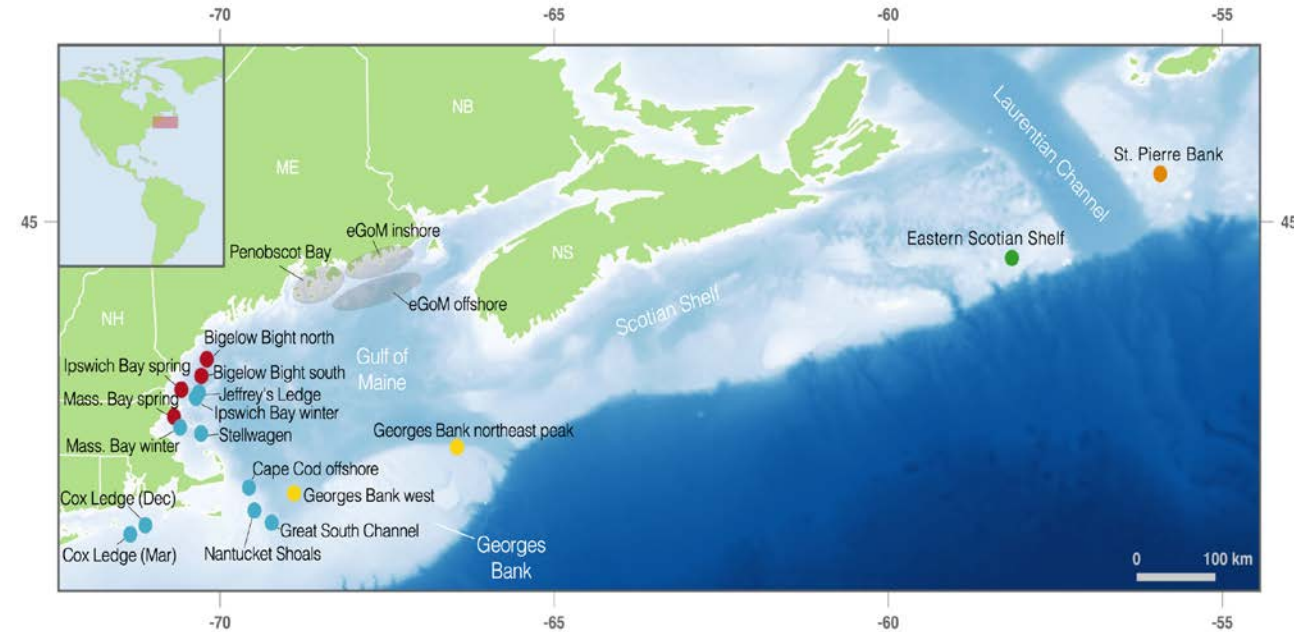
April -May

- Temporal stability of differentiation across 10 years
- Corroborates Otoliths & Morphometrics
- Working hypothesis: winter and spring are distinct ecological units with adaptive life history differences

# New Studies Yield New Information

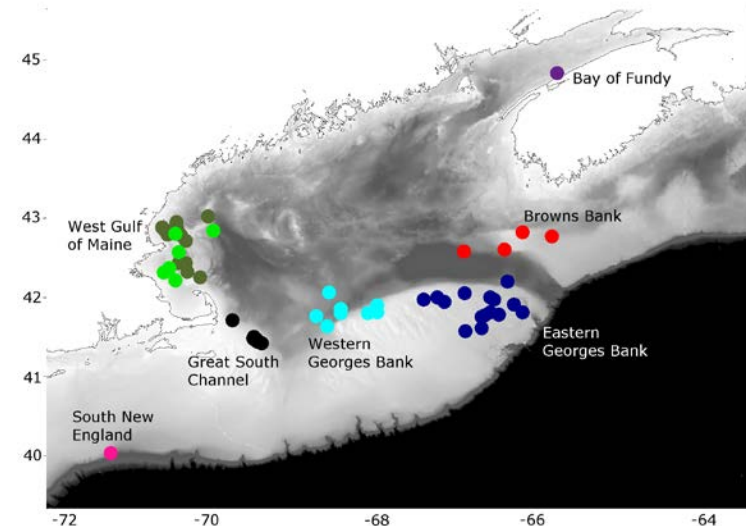
## Clucas et al. 2019

- 306 cod from 20 pops
  - 11 million SNPs
  - whole genome sequencing
  - 11 million SNPs
- 3 *a priori* US groups and
  - 2 Canadian pops
- 11-24 fish per pop
  - spawning except eGoM = Sentinel Fishery



## *Puncher, et al. in prep.*

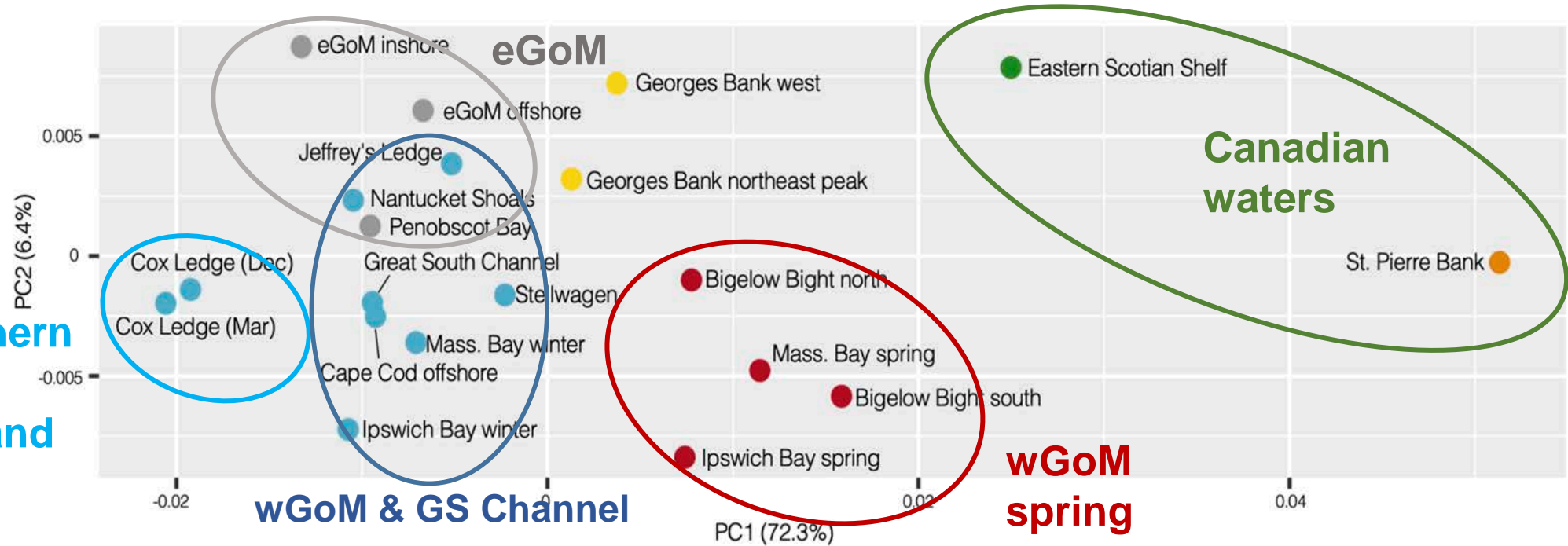
10,000+ genome-wide SNPs



# Genome-wide Genetic Differentiation

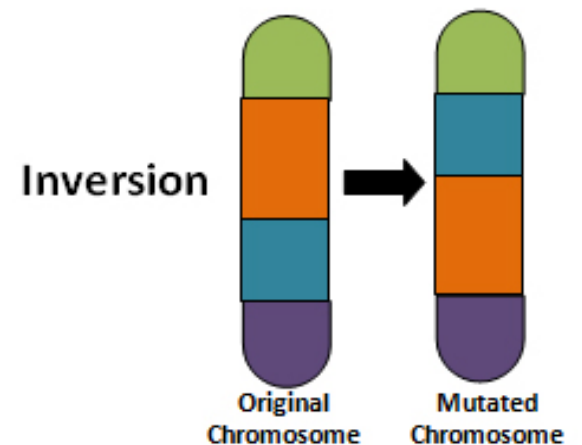
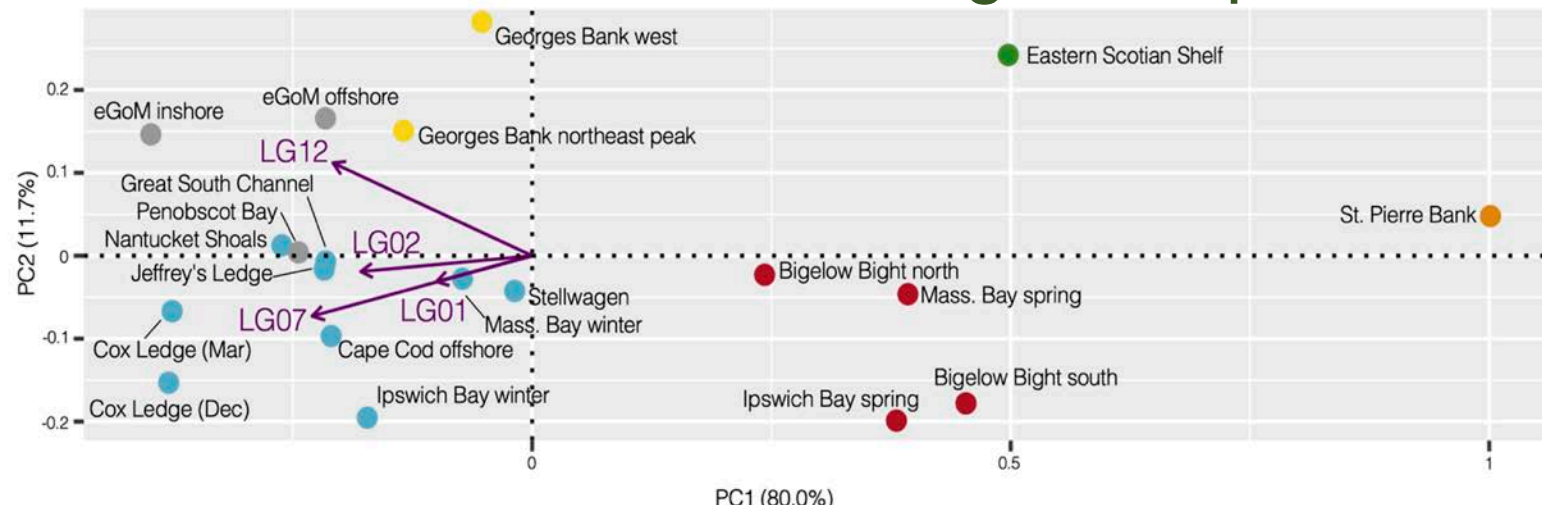
ALL LOCI  
11 million  
SNPs

Southern  
New  
England



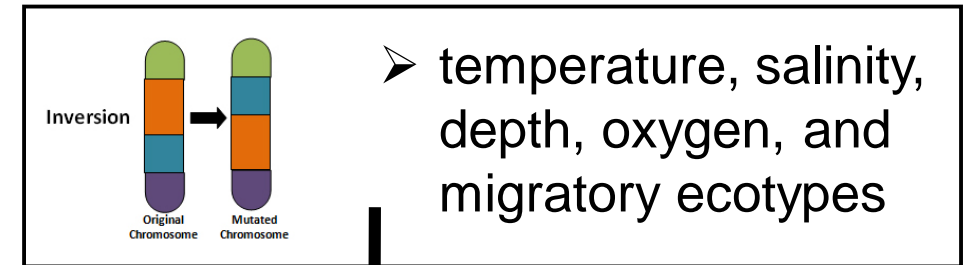
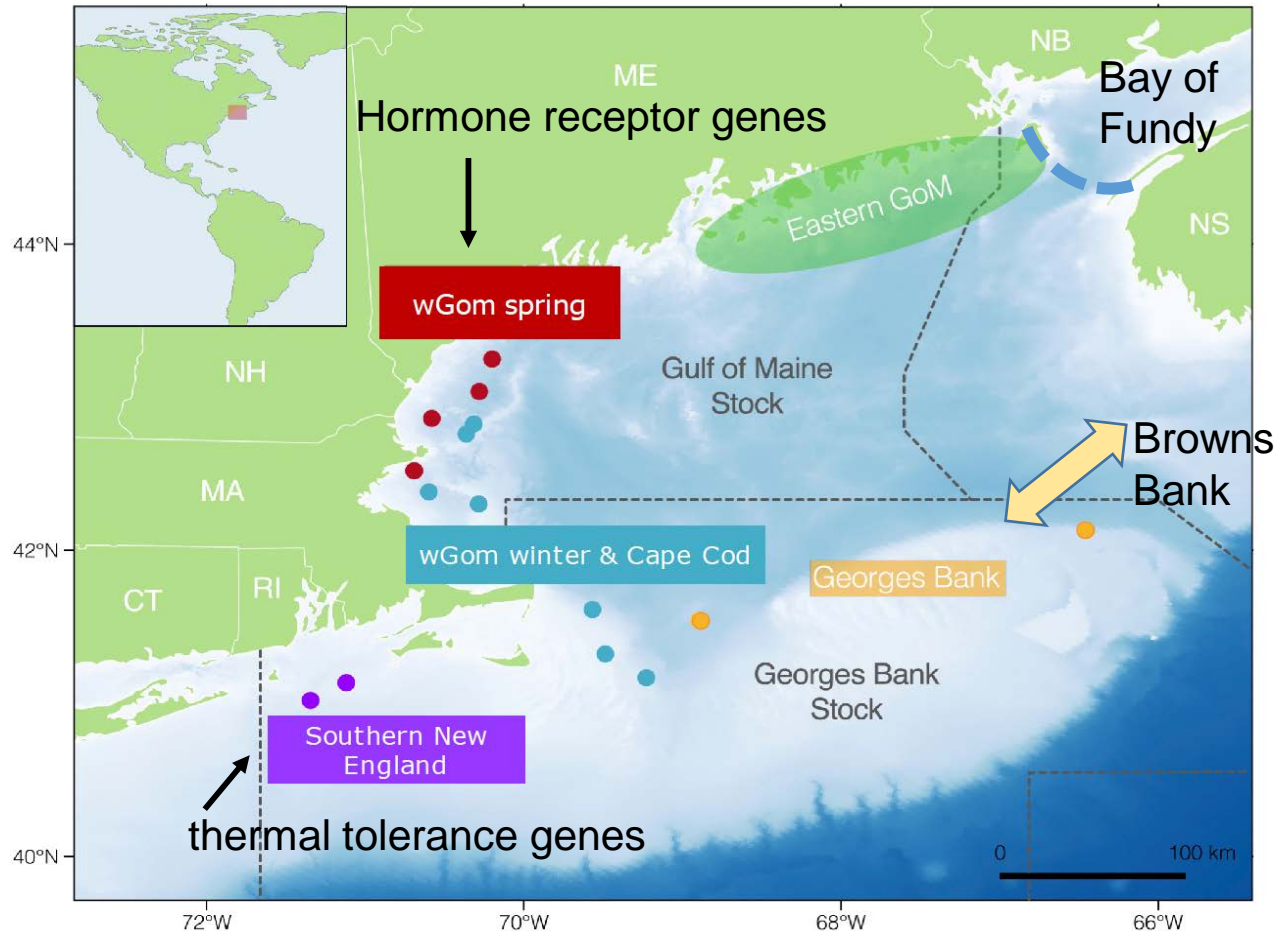
Chromosomal inversions drive the genetic patterns

LGs 1, 2, 7,  
12 only



# Summary of Genomic Results

## Four genetically distinct groups in US waters + eastern GoM



- **wGoM spring** shares similarity with northern Canadian waters
- unique component of biodiversity

- Reproductive genes separate wGoM spring
- Thermal genes separate southern New England

Connections to Canadian Waters

# Conclusions

Genetic studies provide perspectives from neutral and adaptive variation

Adaptive variation largely drives the patterns of genetic differentiation, suggesting ecological, life history, physiological or behavioral differences.

Neutral variation among populations is slight, suggesting adaptation in the face of some ongoing or recent gene flow.

# Highlights from Genetic Markers Studies

Heterogeneity within wGoM: 2 genetically distinct groups of cod spawn in 513 & 514 in spring and winter

Eastern GoM has some connectivity with wGoM winter and Georges Bank; may be an area of mixing.

High connectivity between western GoM (winter) and Cape Cod/Nantucket Shoals

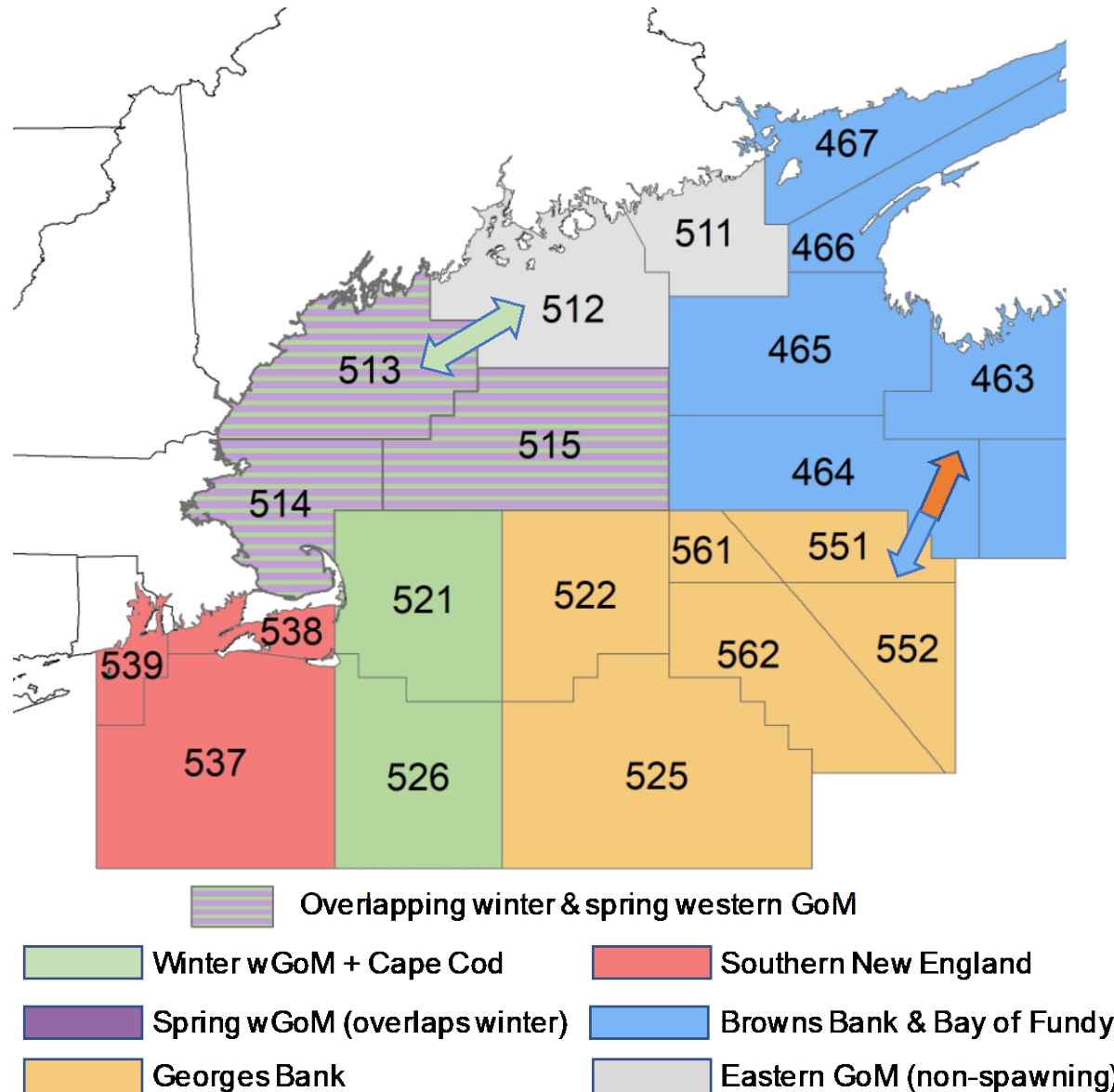
Differentiation of Southern New England from other areas

Differentiation of Georges Bank from Cape Cod and Southern New England

Connectivity between Georges Bank and Browns Bank & Bay of Fundy

# Resolution of Stock Structure from Genetic Markers

5 stocks



## Remaining Uncertainties

- Where is the geographic separation of Cape Cod from western Georges Bank (68 or 69 W boundary)?
- Was the eastern GoM a genetically distinct spawning location? What is the composition of the mixed stock in eGoM today?

# Acknowledgments

Genetics Working Group

Nina Therkildsen

Greg Puncher

Yanjun Wang

Steve Cadrin (internal review)





# Atlantic cod stock structure in US waters: Life History

**The Atlantic Cod Stock Structure Working Group (ACSSWG)**

**Presenter: Richard S. McBride, NOAA Fisheries**

**New England Fishery Management Council Peer Review**

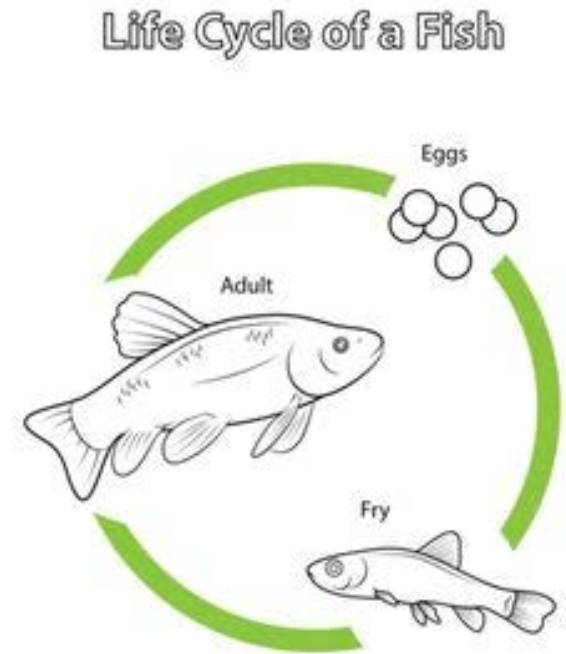
# Acknowledgements & Outline

Sub-Group: McBride, RS, DR Zemeckis, GR DeCelles, T Ames, I Andrushchenko, L Kerr, AS Miller, and S Cadrin

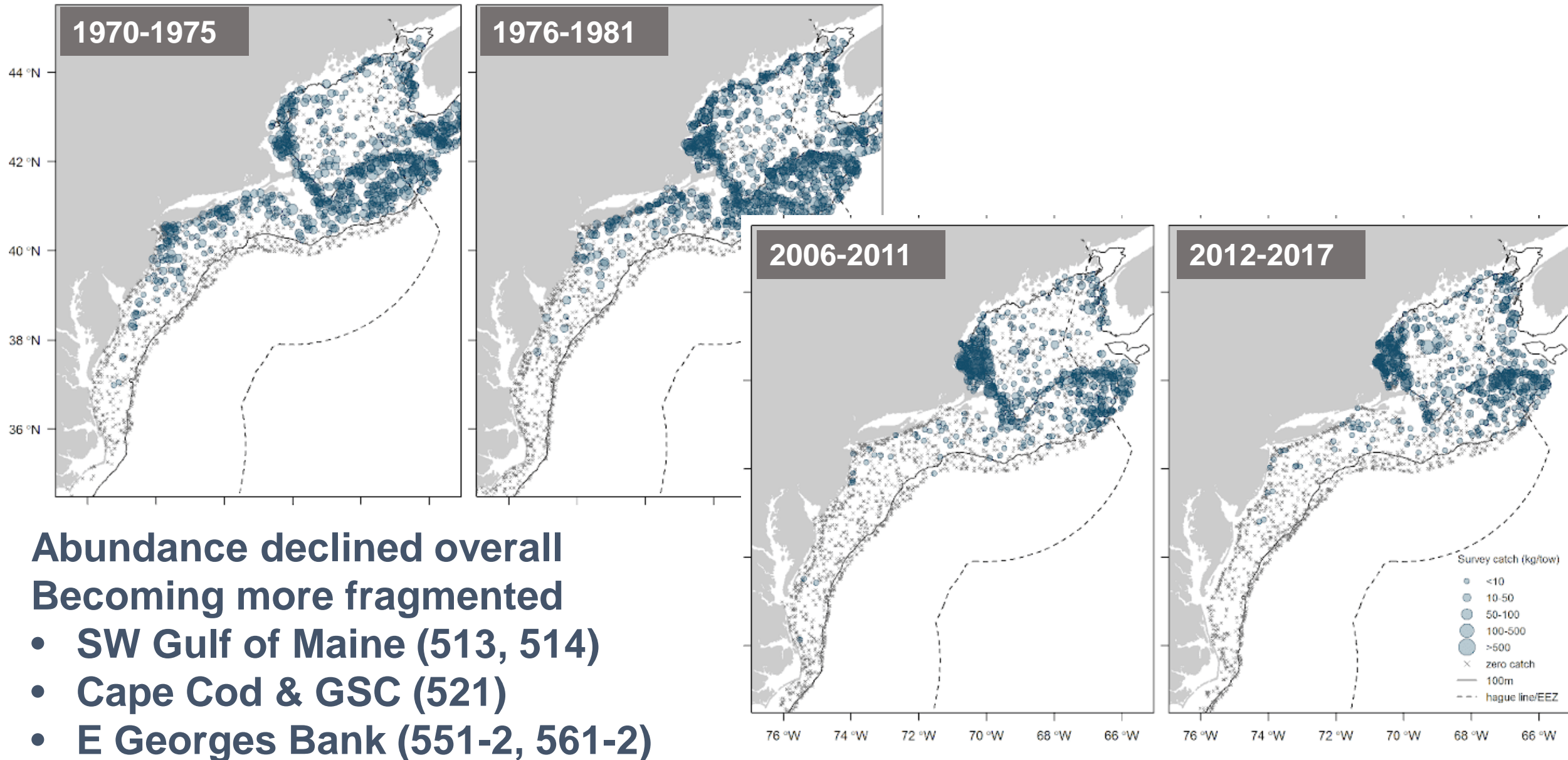
External Reviewers: M. Wuenschel, M. Traver (NOAA)

- 1) Abundance and distribution
- 2) Size at age 2, by sex
- 3) Size and age at maturity (females)

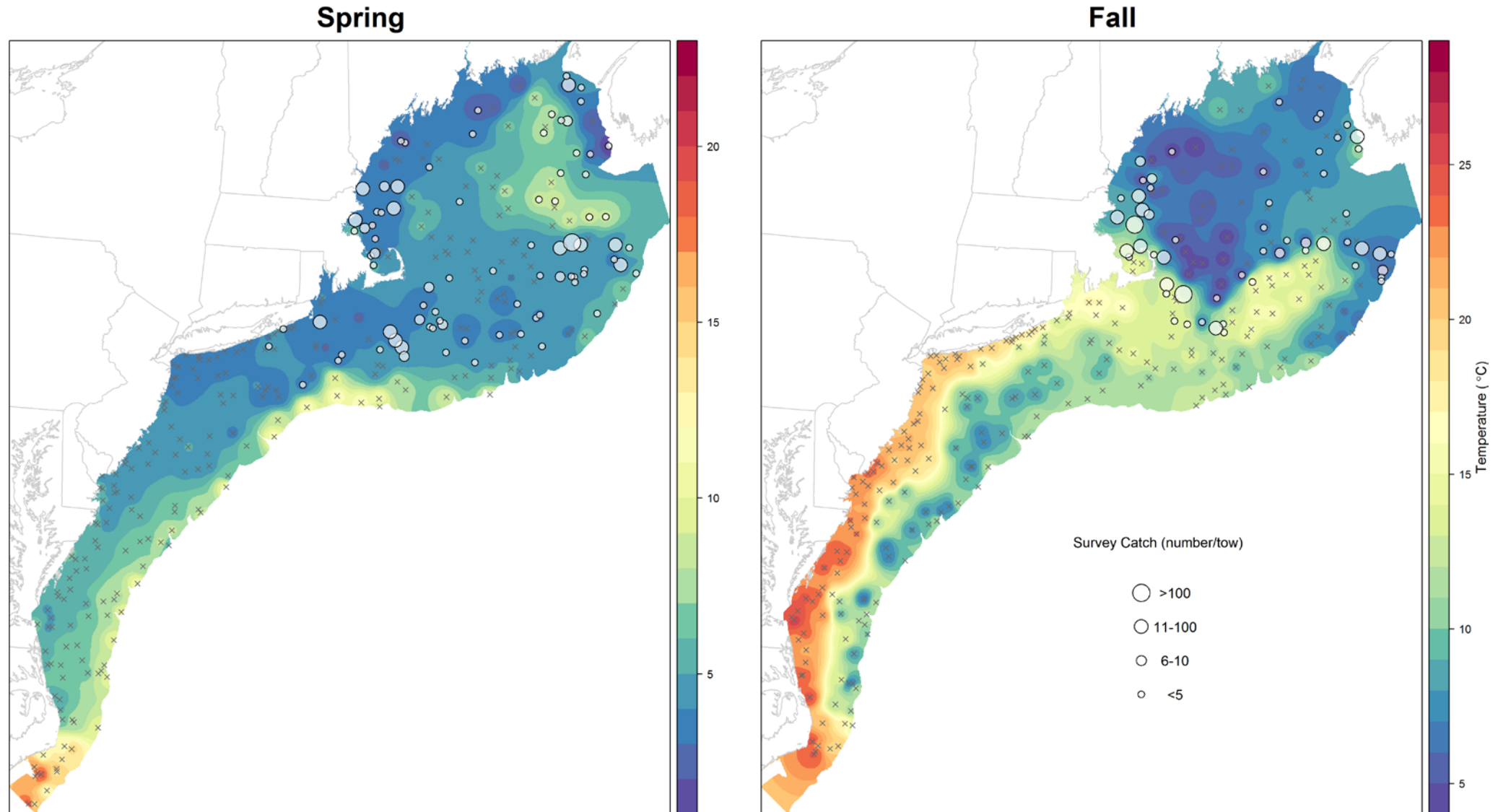
**Data source: NEFSC bottom trawl survey  
spring, fall (1970-2017)**



# Abundance (cod biomass/tow [spring])

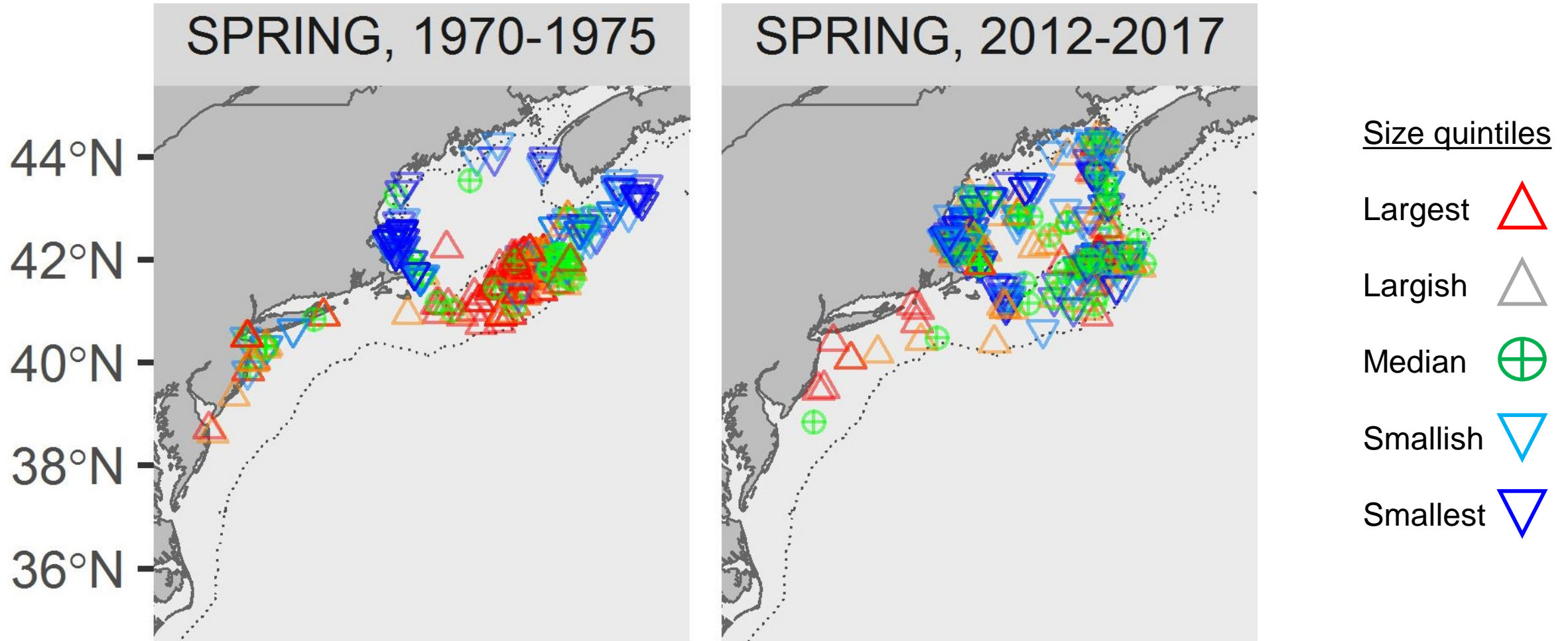


# Seasonal distributions (2004)



**Cod migrate from southern latitudes to stay in cooler water year-round**

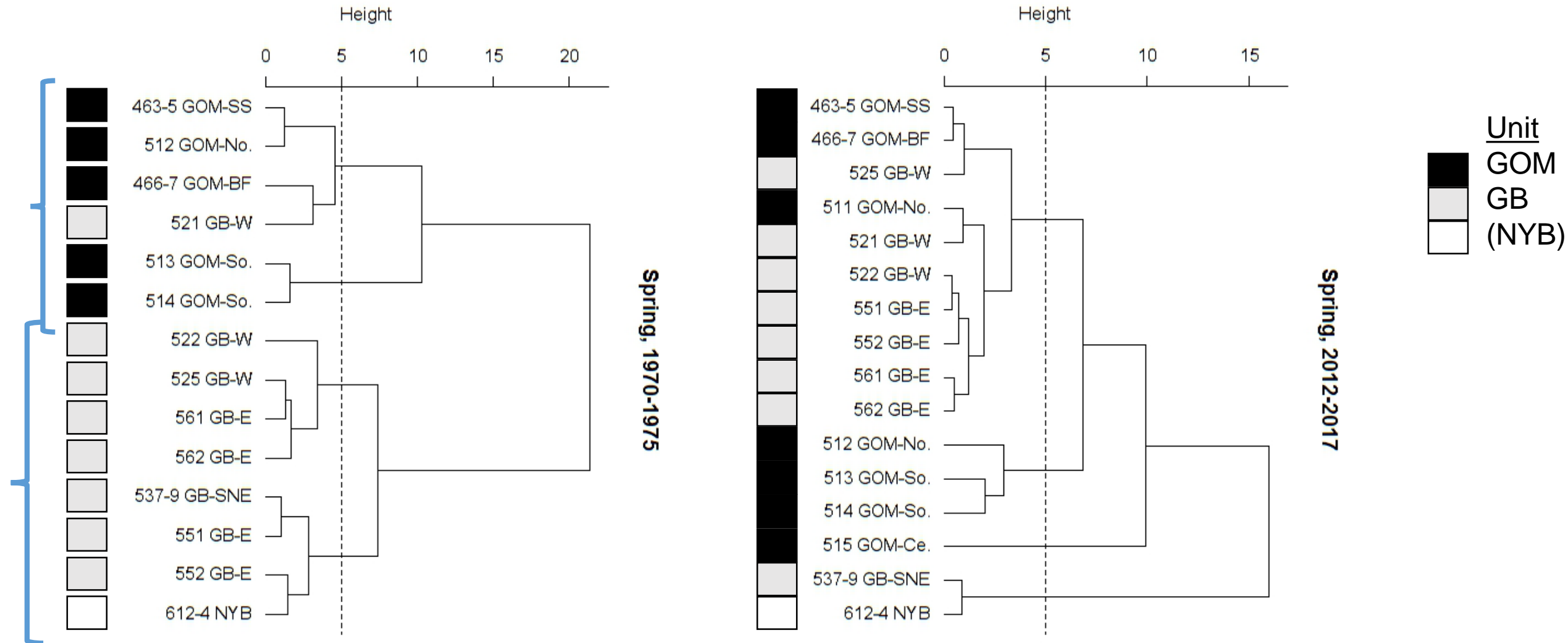
# Size at age 2 (females shown)



1970s: differences roughly by latitude, between GOM and GB

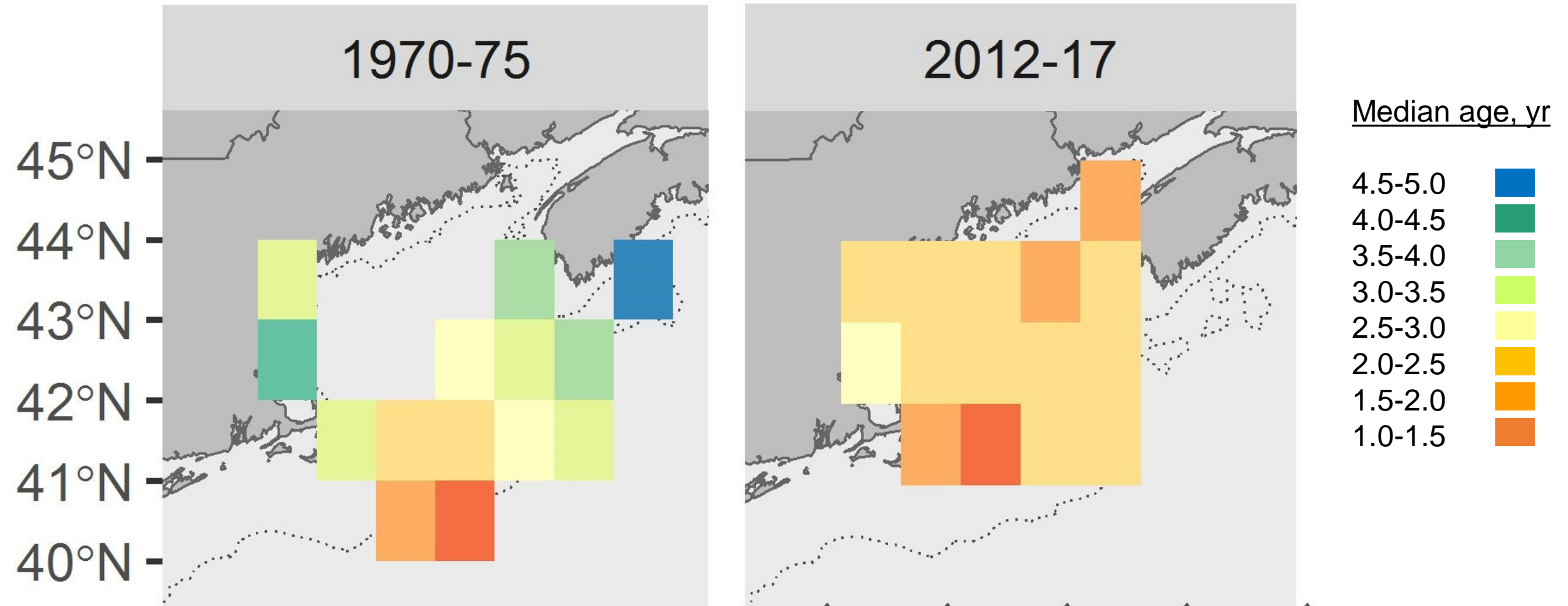
However, by the 2010s, difference between GOM – GB have diminished

# Divisive cluster analysis of size at age 2 data



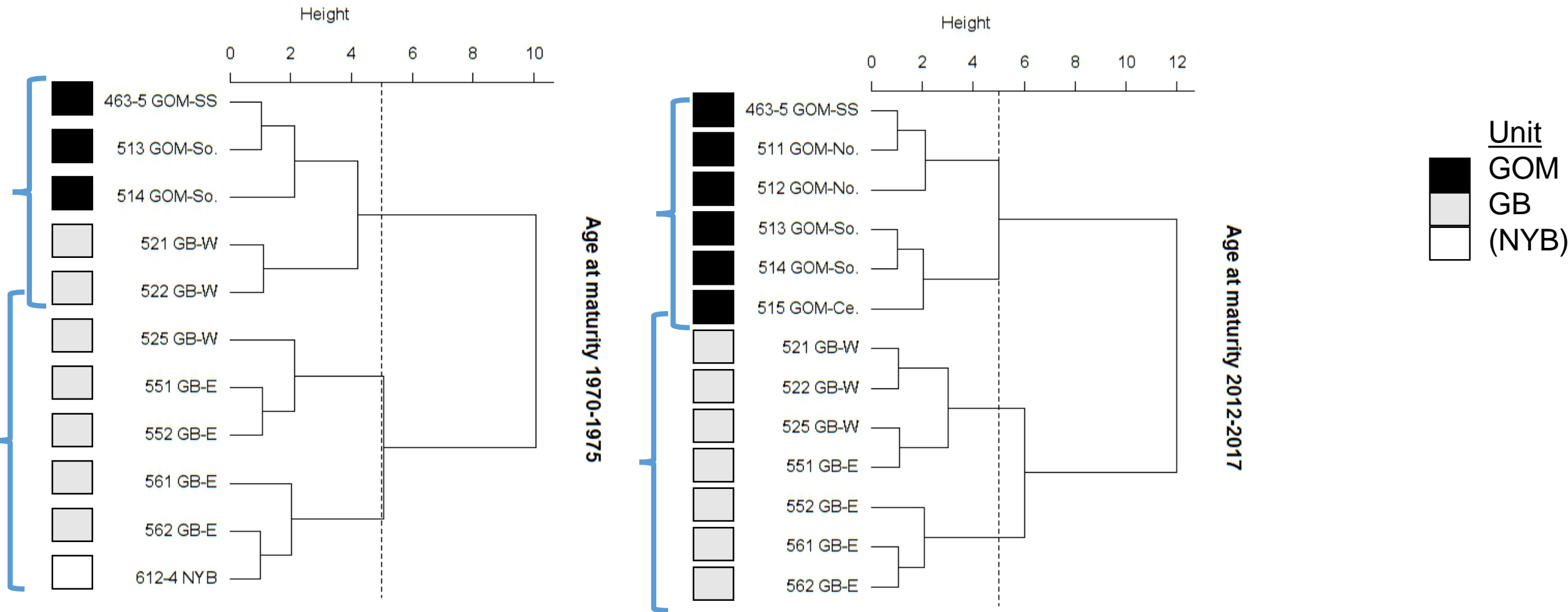
**1970s: Strong difference, except Cape Cod (521) clusters w/ GOM**  
**2010s: Signal lost; GOM fish bigger, GB smaller, than in the 1970s**

# Age at female maturity ( $A_{50}$ )



**1970s: earlier maturation in GB unit; small samples downeast Maine**  
**By the 2010s, maturity comes at a younger age in both areas**

# Divisive cluster analysis of female $A_{50}$ (spring)



**Despite declines over decades,  $A_{50}$  largely supports spatial units, except that part of GB (521 & 522) clusters w/ GOM in the 1970s**

# Conclusions

## Perspective

- Distribution: entire distribution in US waters covered by 1 survey
- Size at age: a 2-stock signal evident early but lost after the 1990s
- Maturity: a 2-stock signal largely evident early and recently

## Highlights

- This evidence was important in the 1970s stock identification
- Loss of size-at-age signal indicates geno-/phenotypic change

## Resolution of stock structure from this discipline

- Resolution at 2 largely-latitudinal stocks, roughly GOM and GB
- except unit mismatch off Cape Cod (521 & 522) in 1970s, and
- some suggestive within unit variation



# Atlantic cod stock structure in US waters: Natural Markers

**The Atlantic Cod Stock Structure Working Group (ACSSWG)**

**Presenter: Lisa Kerr, Gulf of Maine Research Institute**

**New England Fishery Management Council Peer Review**

# Outline

- Background on natural markers.
- Review of natural markers application to Atlantic cod.
- Conclusions on natural markers application to Atlantic cod.

The Team:

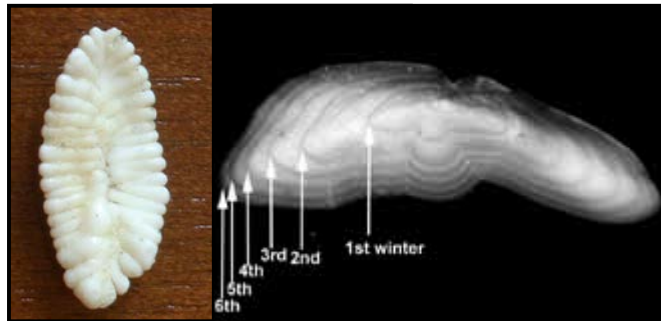
L. Kerr, G. DeCelles, G. Puncher, S. Cadrin, R. McBride



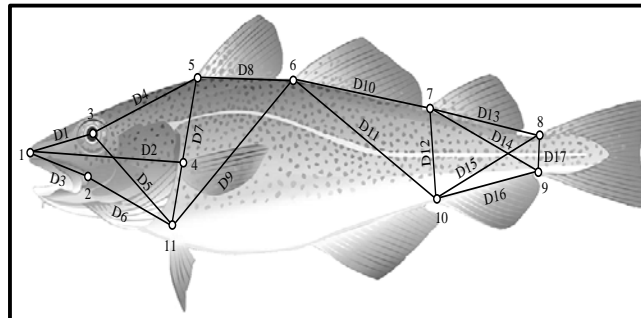
# Natural Markers

- Natural markers are naturally-induced characteristics that can be used to identify members of a population or more discrete grouping.
- Phenotypic traits reflect genetic and environmental influences.
- Many different natural markers have been used to identify fish populations.
  - Body characteristics
    - Tissue characteristics
    - Other features, such as parasites.
  - Otolith characteristics

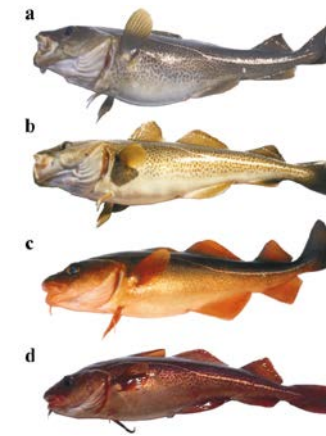
**Otoliths**



**Body Shape**

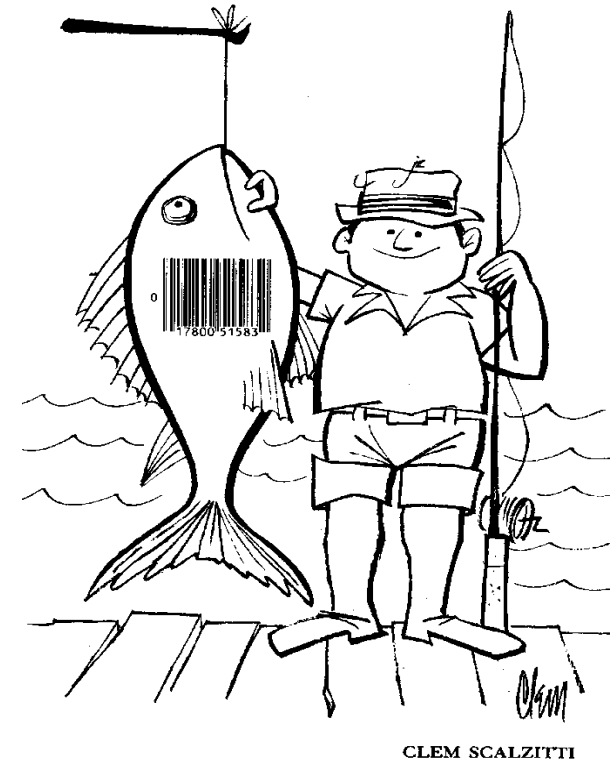
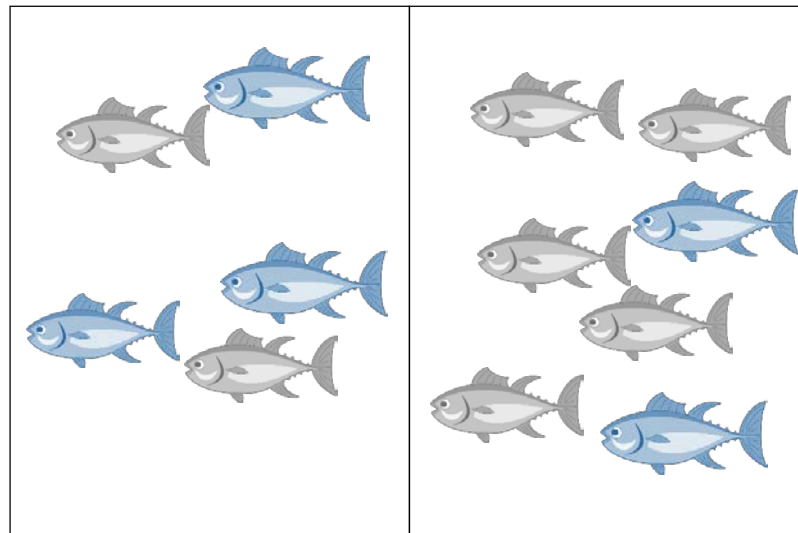


**Color Variation**



# What can we learn from Natural Markers

- Once we establish that a natural marker “works”, we can apply the marker in mixed stock analysis.
- Mixed stock analysis: provides estimates of origin of fish in mixed catch.
- This information has been used in assessment and management of other species.



# Application of Natural Markers to Atlantic Cod

Application of natural markers to the study of Atlantic cod stock structure in the northwest Atlantic.

## **Otolith characteristics:**

Structure

Chemistry

Shape

## **Tissue characteristics:**

Stable isotopes concentrations

Fatty acid profiles

## **Body characteristics:**

Color type

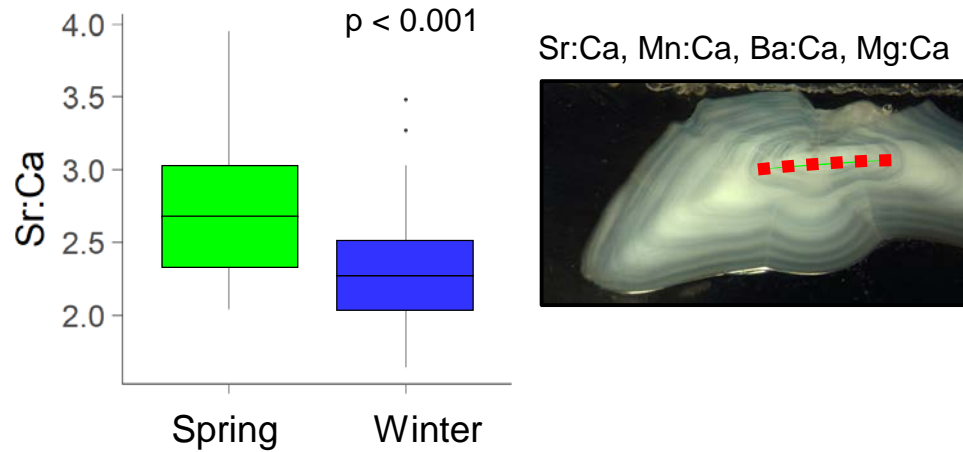
Morphometrics

Meristics

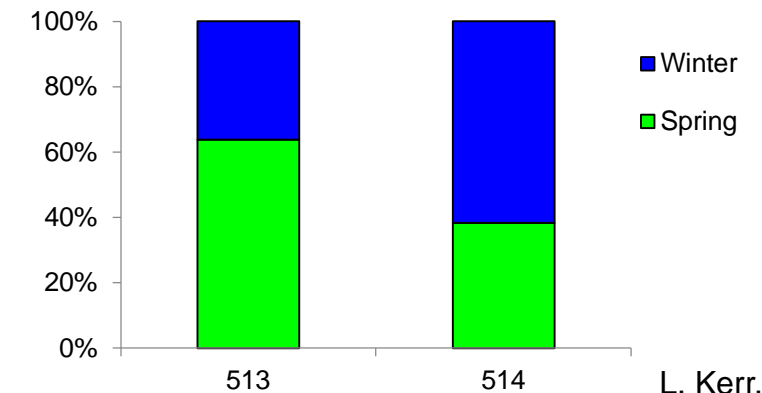
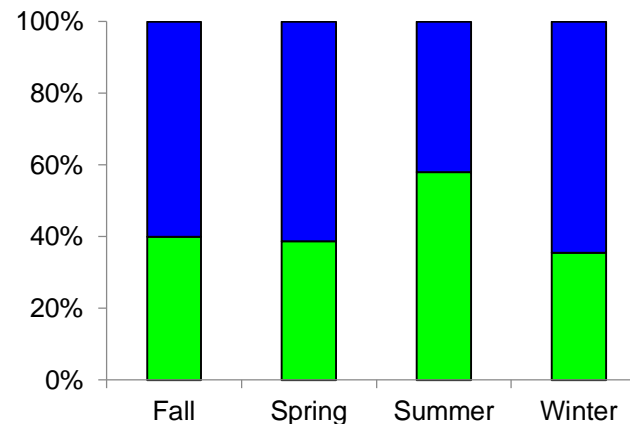
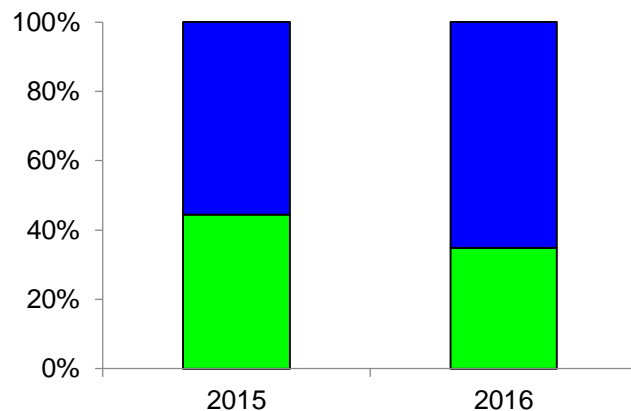
Parasites

# Otolith Chemistry

Chemical composition of year one otolith growth

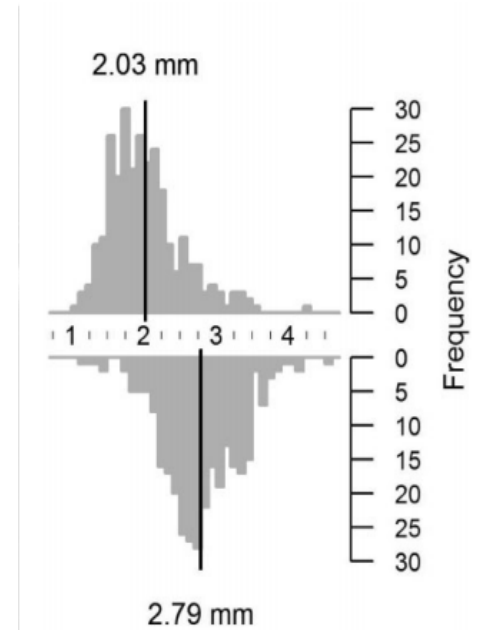
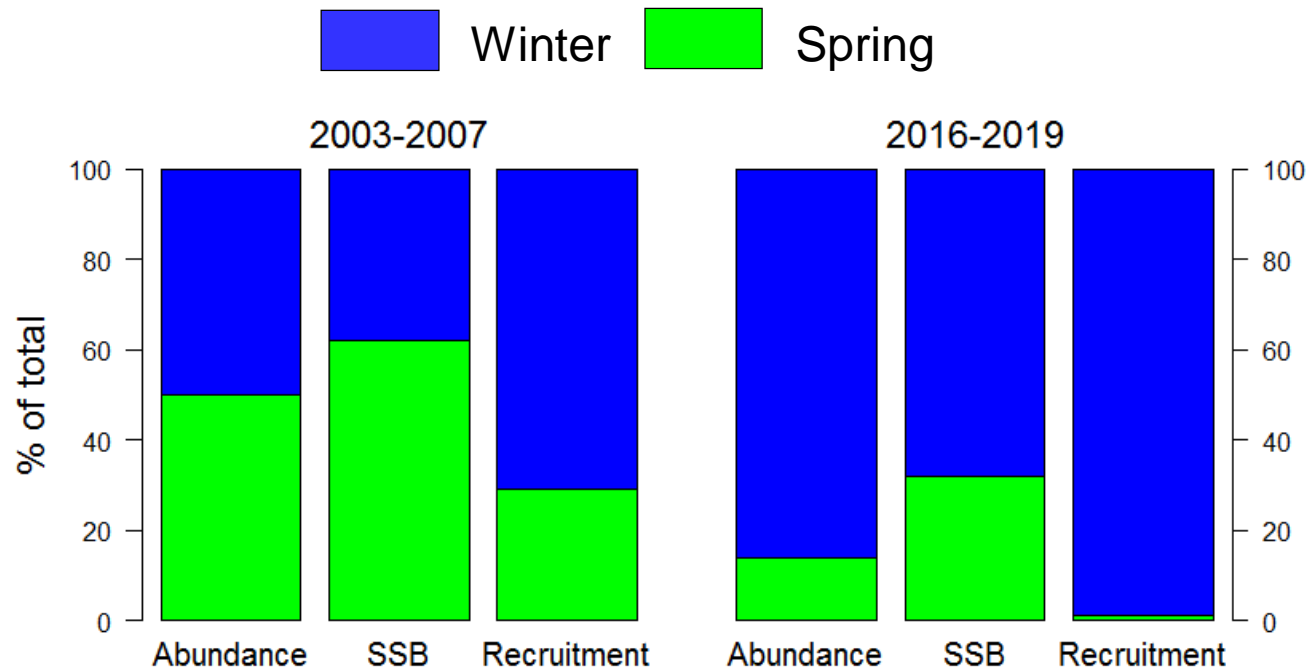


- Several examples of past applications of otolith chemistry to cod, primarily in Canadian waters, support the utility of this natural marker.
- Recent application indicated significant differences in elemental ratios of winter and spring spawners in western Gulf of Maine (74% accuracy, Kerr et al 2018).
- Mixed stock analysis revealed the recent composition of fish was dominated by winter spawners.



# Otolith Structure

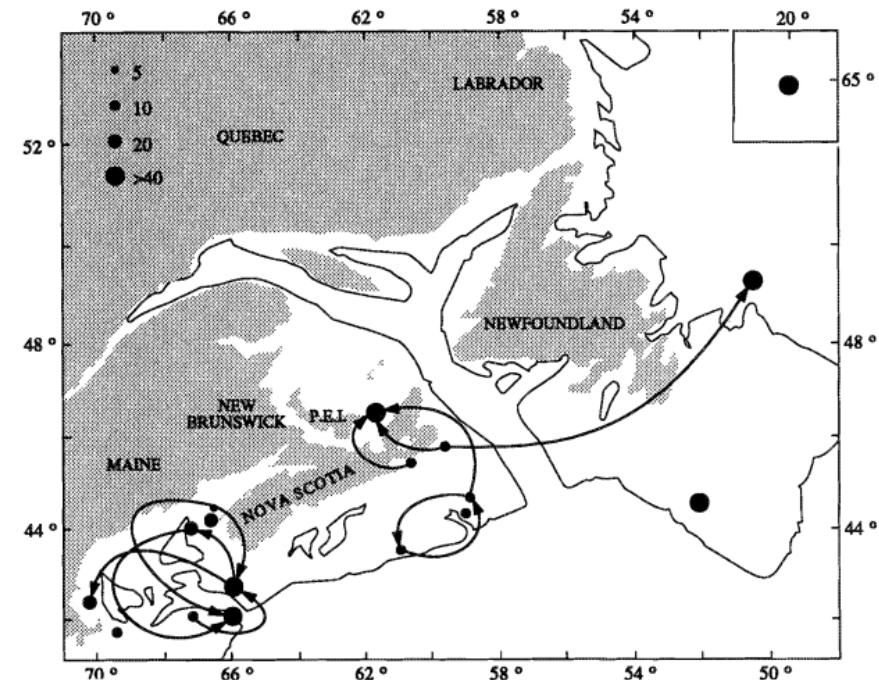
- Otoliths “growth signatures” have been established as a powerful tool for stock identification.
- Analysis of otoliths from spring and winter spawning cod in the Gulf of Maine identified distinct early growth patterns between the two spawning populations (81% accuracy; Dean et al. 2019).
- Mixed stock analysis revealed the recent composition of fish was dominated by winter spawners.



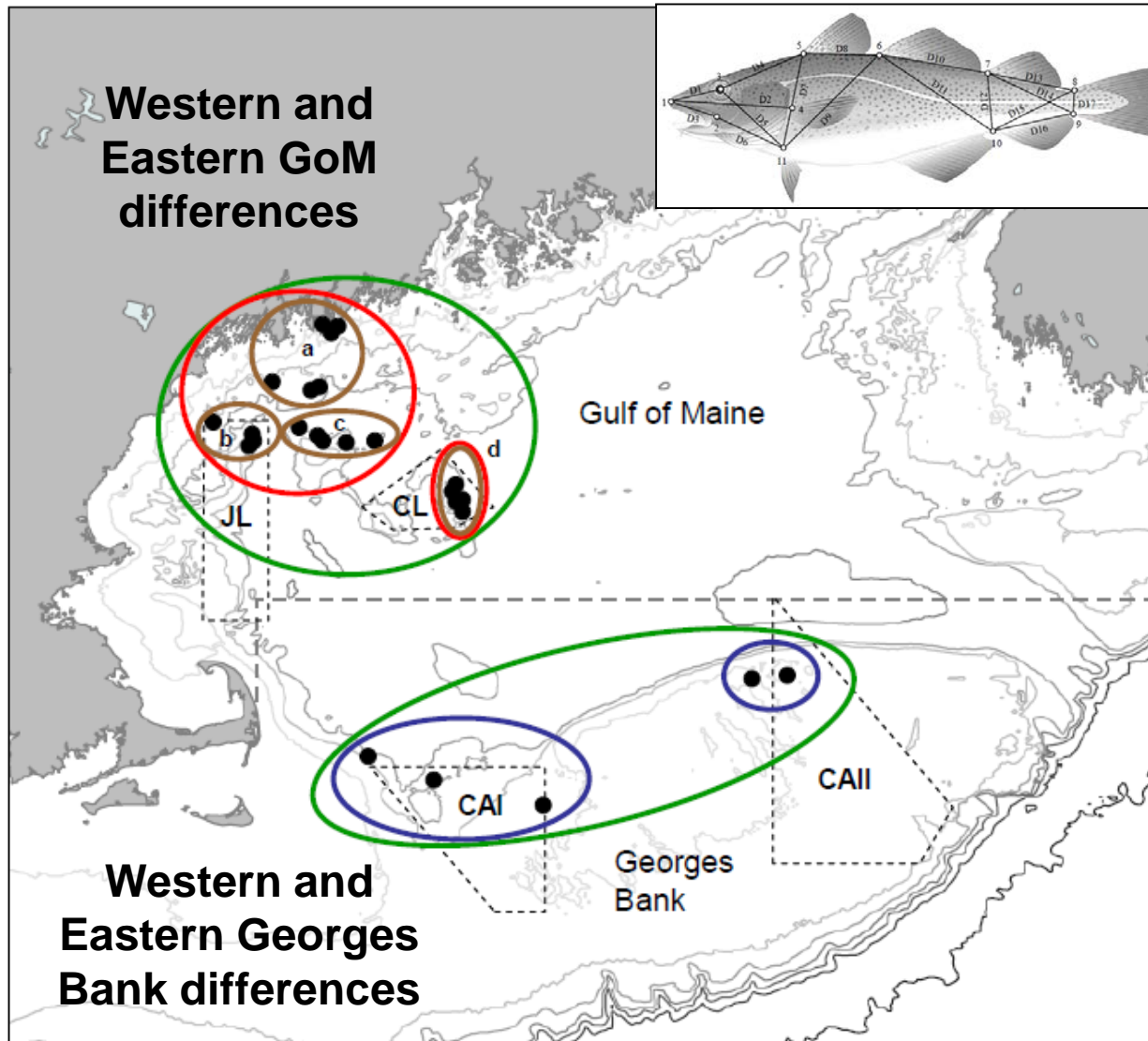
# Otolith Shape

- Otolith shape has been shown to have utility in stock discrimination.
- Campana and Casselman 1993 applied otolith shape analysis to classify cod populations in the northwest Atlantic.
- Classification accuracy was wide ranging, with higher classification to Gulf of Maine region.

1. **Gulf of Maine** (61-80% accuracy)
2. Eastern Scotian Shelf
3. St. Lawrence
4. Newfoundland
5. Iceland

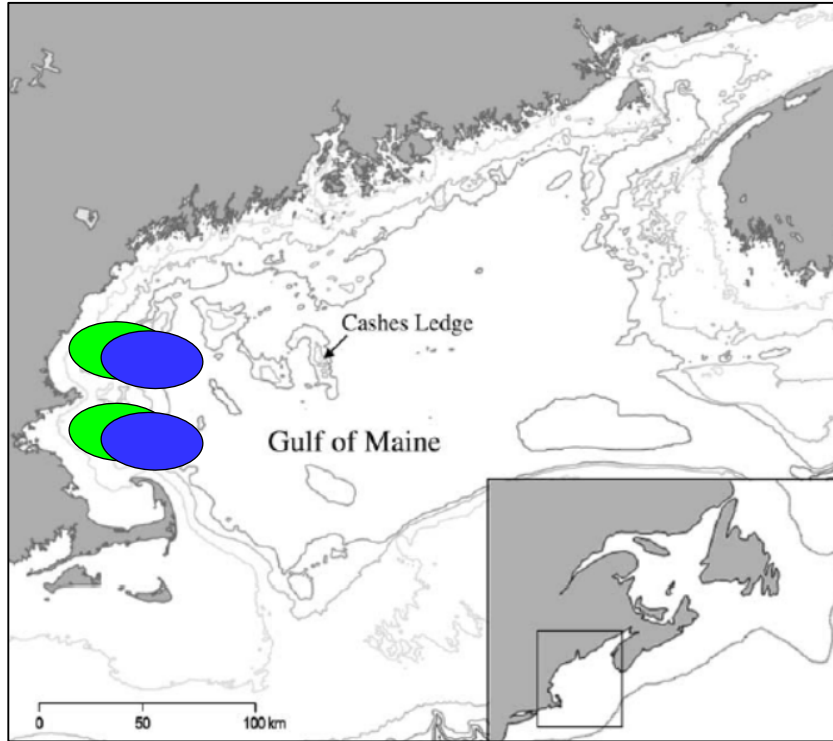


# Morphometrics



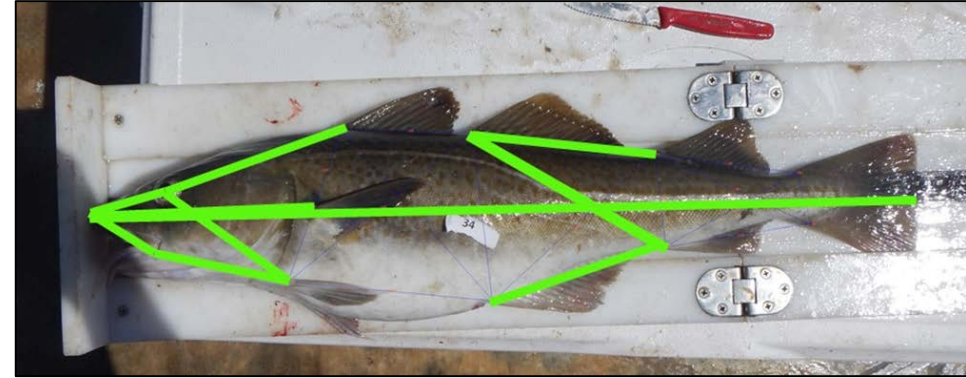
- Morphometrics (i.e., body shape analysis) has long been used to aid in identification of stock structure in fish.
- Sherwood and Grabowski (2012) examine morphometrics of cod in Gulf of Maine and Georges Bank (70% accuracy).
- Identified differences between eastern and western Georges Bank (77% accuracy).
- Identified differences between eastern and western Gulf of Maine (91% accuracy).

# Morphometrics



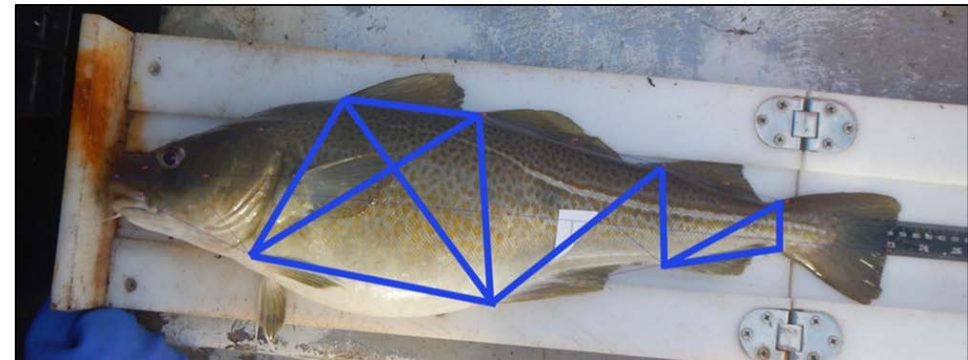
## Spring Spawner

*Spring spawners: More slender streamlined bodies*



## Winter Spawner

*Winter spawners: More robust bodies*



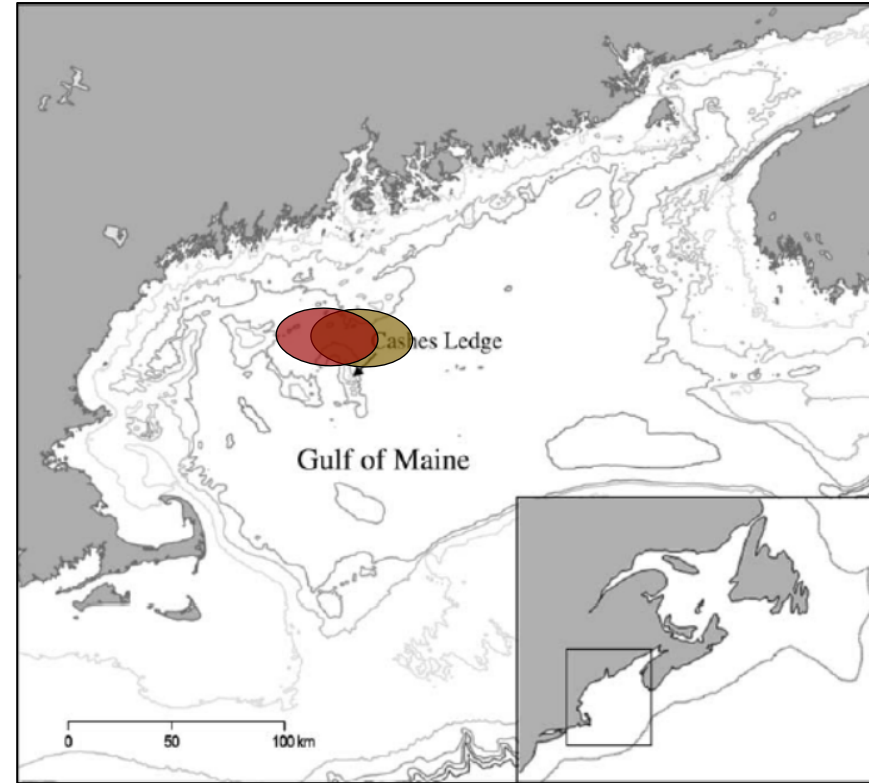
- Morphometric methods were applied to winter and spring spawners in the western Gulf of Maine (Ipswich and Mass. Bay).
- Morphometric differences were identified between Massachusetts and Ipswich Bays and between spring and winter spawning groups (82 % accuracy).

# Color Morphs

Red and Olive cod, Cashes Ledge



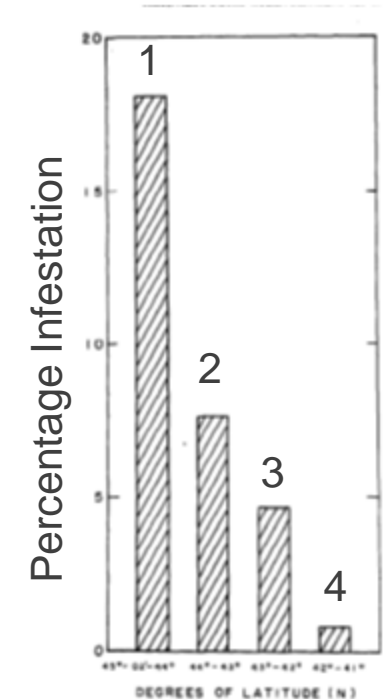
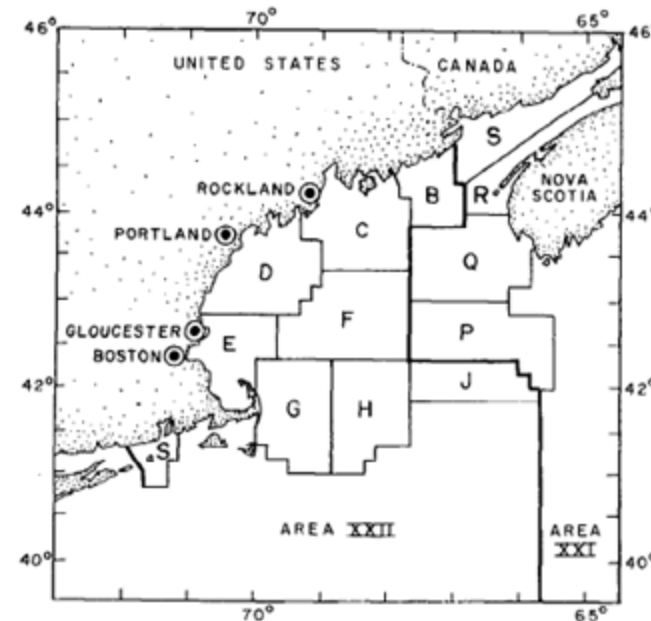
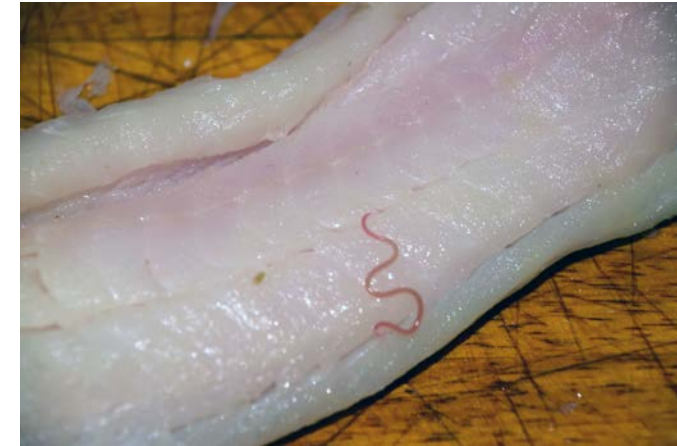
Sherwood and Grabowski 2010



- Coloration in cod is strongly influenced by diet, but can be used as part of interdisciplinary stock composition analysis.
- Sherwood and Grabowski (2010) reported that “red cod” are commonly observed near Cashes Ledge and the presence of red cod in the Gulf of Maine was also noted by Bigelow and Schroeder (1953) and confirmed by Conroy (2016).
- Based on the observed differences in growth, morphometry, habitat, and diet, red cod may exhibit a unique life history strategy in the Gulf of Maine (i.e., more sedentary and shallow-living).

# Parasites

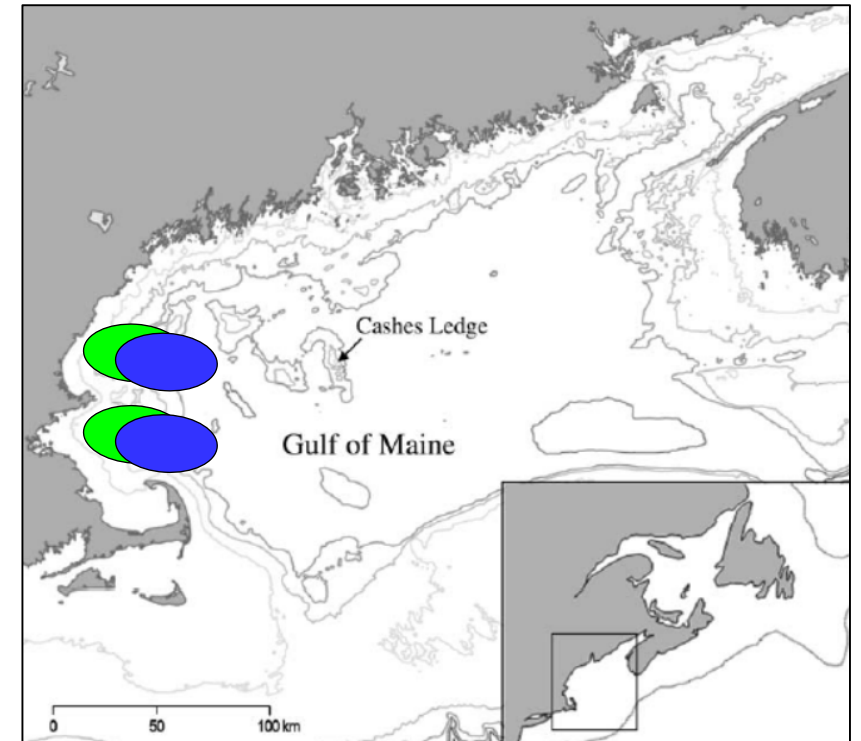
- Parasites have been shown to be useful natural tags to identify connectivity and stock structure.
- Atlantic cod are rich in parasites across their range.
- Sherman and Wise (1961) examined infestation rates of the parasitic copepod, *Lernaeocera branchialis*, in Gulf of Maine.
- Infestation rates were interpreted to represent four stocks of cod:
  - 1) Northern Gulf of Maine (a heavily infested)
  - 2) Central and southern Gulf cod (moderately infested)
  - 3) Georges Bank (lightly infested)
  - 4) Southern New England (free of infestation)



Sherman and Wise (1961)

# Multiple Natural Markers

- A combination of genetics, genomics, otolith chemistry, otolith structure, morphometric, and color analysis was applied to winter and spring spawning fish from the two main spawning locations in the Gulf of Maine (Ipswich and Massachusetts Bays).
  - *Genetic analysis* indicated significant neutral and adaptive genetic differentiation between winter and spring spawners.
  - *Otolith chemistry analysis* indicated significant differences in elemental ratios of winter and spring spawners.
  - *Morphometric analysis* indicated that winter and spring spawning cod exhibit significant differences in body shape.
- 
- Methods provided largely congruent results and support winter and spring spawners as unique groups in the Gulf of Maine.



# Conclusions on Cod Natural Markers

- Morphometric results (Sherwood and Grabowski 2012) suggest that **cod on eastern and western Georges Bank may comprise unique groups**. These results are in broad agreement with genetics (e.g., Kovach et al. 2010), tagging studies (Wise 1963; Hunt et al. 1999; Tallack 2011), and Fishermen's Ecological Knowledge (Section 7).
- Natural markers (otolith chemistry, structure and morphometrics) support **winter and spring spawners as unique groups**. This finding is supported by otolith chemistry, otolith structure, morphometrics, and genetics (Kerr et al 2018, Dean et al 2019, Kovach et al. 2010).
- Parasite infestation rate suggests separation between the northern Gulf of Maine, central Gulf, Georges Bank, and Southern New England cod.

# Tissue Characteristics

- Fatty acid profiles and stable isotope concentrations have not been routinely applied to investigate cod stock structure in US waters.
- Sherwood and Grabowski (2016) investigated the body shape, condition, diet, age and size structure, and stable isotopes of cod inside and outside of the groundfish closed areas (Closed Areas I and II, Cashes Ledge, and Jeffreys Ledge) in US waters.
- This study was not specifically designed to investigate stock structure, they did find differences in the  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  ratios of cod inside and outside of the closed areas, suggesting that cod within closed areas consumed a wider range of prey items.

# Meristics

- Despite the utility of meristic characters for investigating the stock identity of Atlantic cod, this technique has not been routinely applied in U.S. waters or the Bay of Fundy.
- In an early study, Schmidt (1930) investigated vertebral counts of cod taken from Nantucket Shoals (mean = 51.9) and Mt. Desert Island (mean = 53.0).
- Later, Templeman (1962) reported similarities in vertebral counts between cod taken from the Northeast Peak of Georges Bank (mean = 52.7) and Browns Bank (means ranged from 52.5 to 53.0), although the sample sizes were not reported.
- Given the utility and cost effectiveness of this approach, the Working Group notes that analysis of meristic characters may be informative for future multidisciplinary stock identification studies in the region.



# Atlantic cod stock structure in US waters: Applied Marks (i.e., Tagging)

**The Atlantic Cod Stock Structure Working Group (ACSSWG)**

**Presenter: Steve Cadrin, UMass School for Marine Science & Technology**

**New England Fishery Management Council Peer Review**

# Acknowledgments & Outline

Sub-Group: Steve Cadrin (SMAST), Doug Zemeckis (Rutgers),  
Greg DeCelles & Micah Dean (MADMF) & Jamie Cournane (NEFMC)  
Contributors: Don Clark (Canada DFO), David Goethel (FV Ellen Diane)

Review of Tagging Studies in the Region

Analysis of Available Data from Conventional Tagging

Conclusions

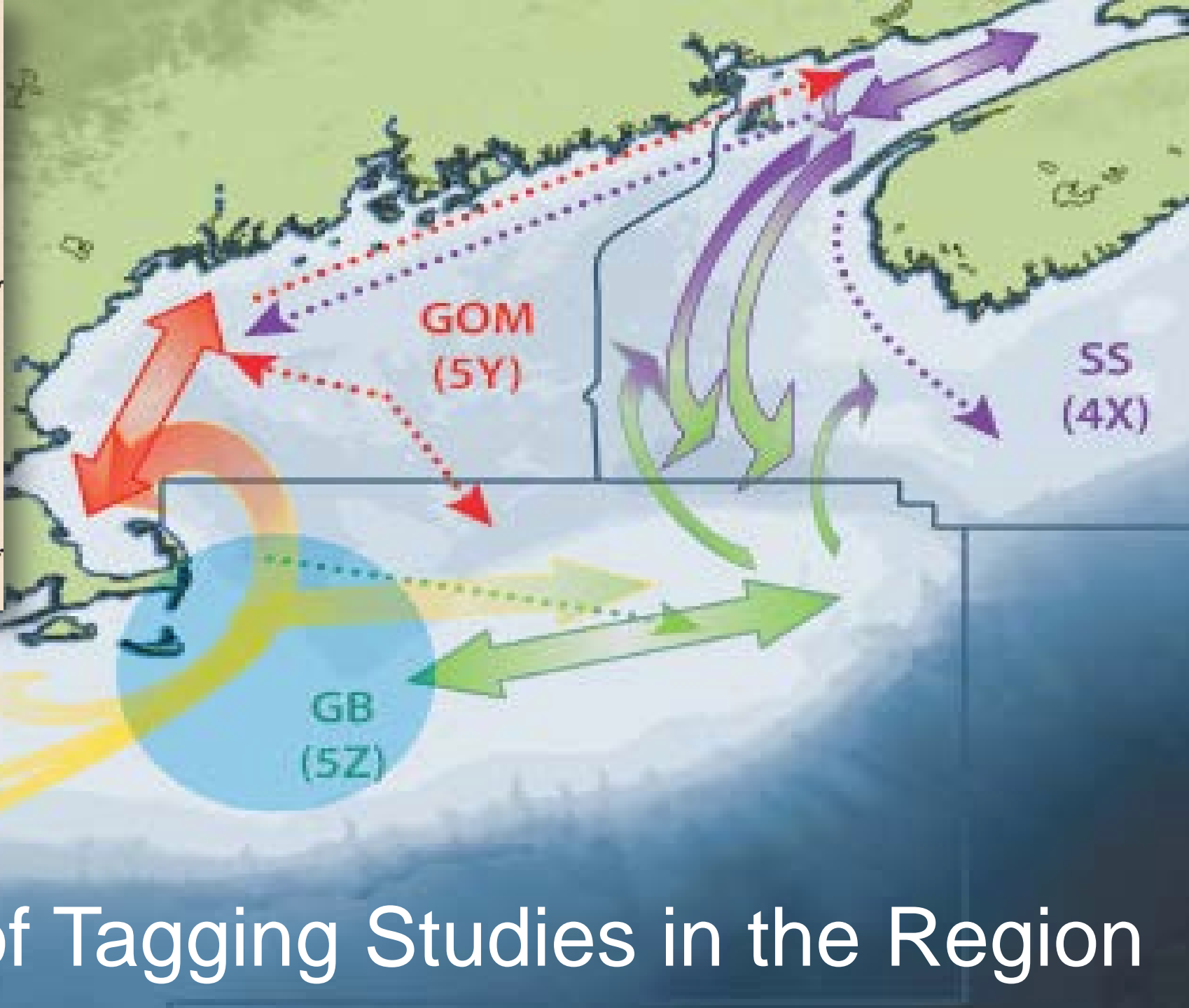
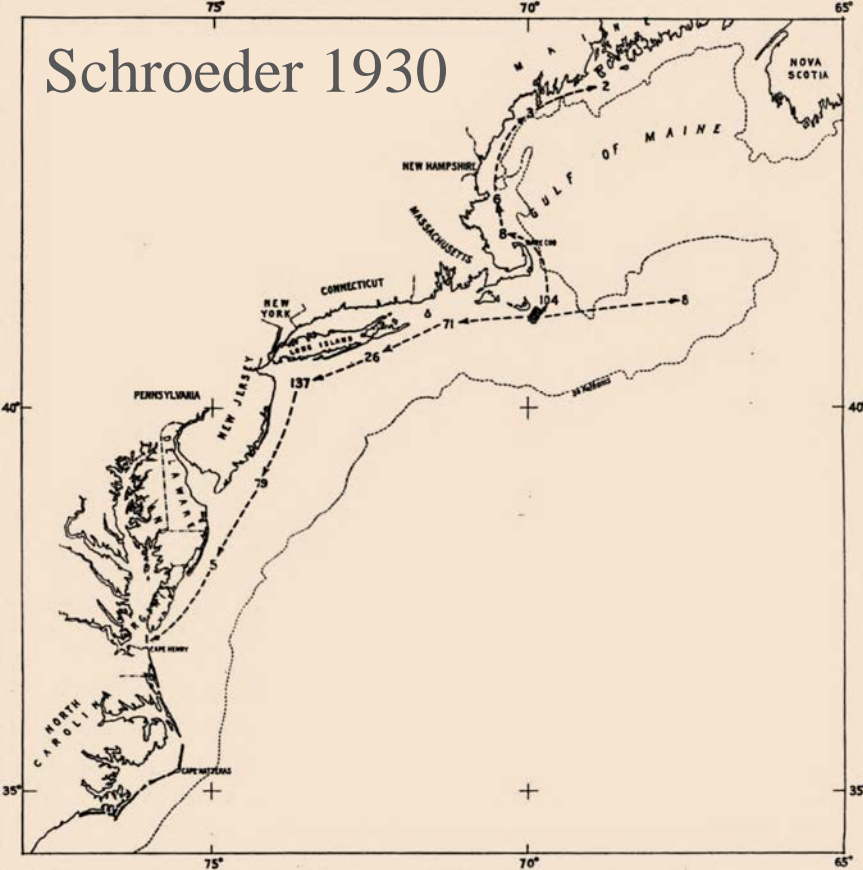


RUTGERS

Fisheries and Oceans  
Canada



Schroeder 1930



# Review of Tagging Studies in the Region

Tallack 2011

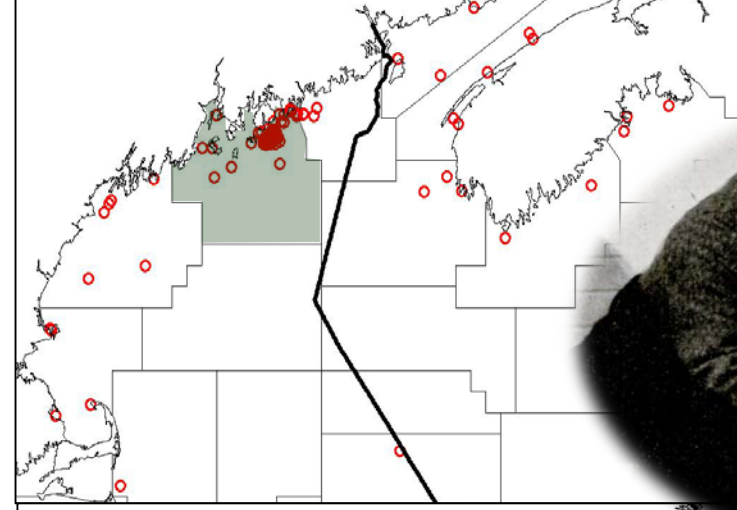
# Analysis of Available Tagging Data

Reference	Release Area(s)	Years	Months	Releases	Recaptures
Schroeder 1930	all US areas	1923-1927	Jan-Oct	30,149	2,150
Hunt et al. 1999	Georges Bank & Gulf of Maine	1994-1996	Mar-Dec	5,067	262
Tallack 2011	all areas	2002-2003	Jan-Dec	114,473	6,784
Loehrke 2014	all US areas	2000-2014	Jan-Dec	37,460	1,900
Clark & Emberley 2008	Scotian Shelf	2001-2004	Jan-Dec	10,000	472
Zemeckis et al. 2017	Massachusetts Bay	2010-2013	Apr-Jul	2,368	223
			<b>Totals</b>	<b>199,517</b>	<b>11,791</b>

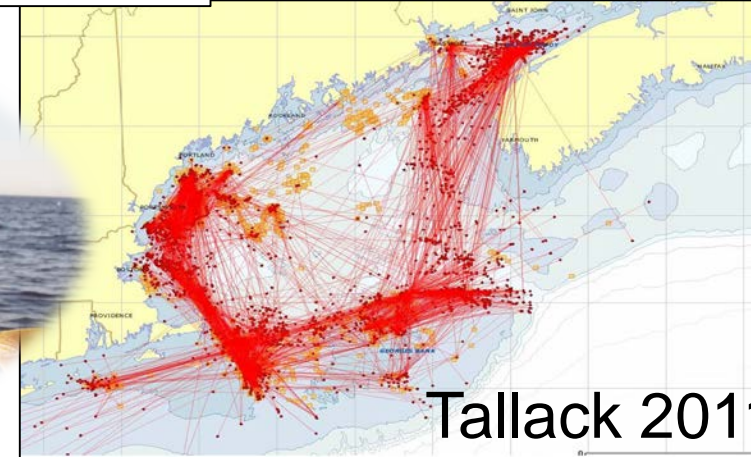
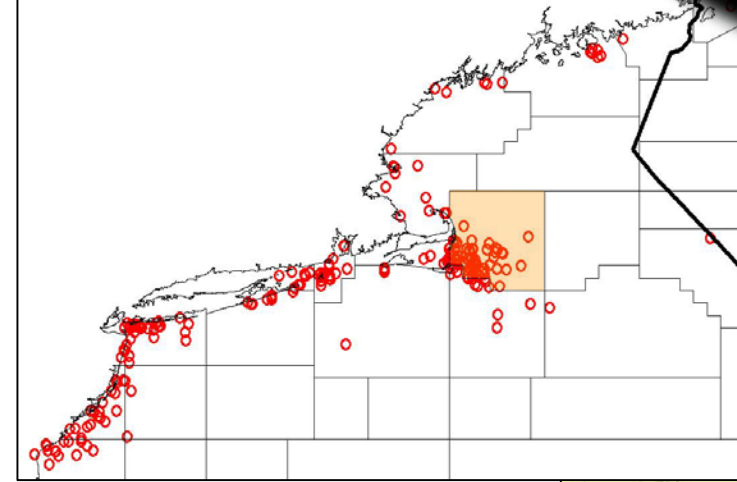
- Movement among fishing grounds (i.e., statistical reporting areas)
- Seasonal dispersal patterns of spawning groups from conventional, archival and acoustic tagging.

# Multi-Decadal Patterns

- Different patterns in the early 1900s
  - many more releases and recaptures from mid-coast Maine (area 512)
  - more movement from the Great South Channel (area 521) and southern New England to the Mid Atlantic Bight
  - more movement from Georges Bank to the Gulf of Maine and to the Mid Atlantic Bight
  - less movement from Georges Bank to the western Scotian Shelf
- Similar general patterns since the 1990s
  - Current inferences based on 1994-2013 tagging data



Schroeder 1930



Tallack 2011

	Recapture Area																															
Rel.	461	462	463	464	465	466	467	511	512	513	514	515	521	522	525	551	552	561	562	526	537	538	539	611	612	613	614	615	616	621	626	Sum
462	94	11	2	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	108
463	6	35	148	22	9	2	1	1	0	0	0	0	0	0	1	5	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	233
464	1	3	7	28	3	2	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41
465	0	2	19	14	25	0	0	0	0	0	0	0	0	0	0	4	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	75
466	0	1	0	9	19	172	224	6	0	3	0	0	0	4	0	9	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	449
467	0	0	1	22	28	15	23	16	3	8	3	0	1	4	1	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	436
511	0	0	0	17	30	10	7	40	0	2	2	0	0	1	0	8	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	121
512	0	0	0	0	1	0	0	0	1	10	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18
513	0	0	0	3	1	2	1	0	0	13	13	30	1	19	32	14	0	3	1	1	1	0	1	0	0	0	0	0	0	0	0	1693
514	0	0	0	0	0	0	0	0	3	1	1	18	13	78	2	6	0	0	0	0	1	32	0	0	0	0	0	0	0	0	0	1581
515	0	0	0	5	1	0	1	0	1	16	11	76	6	14	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	134
521	0	0	0	3	1	2	1	0	0	40	349	3	1588	100	39	20	0	12	6	42	21	5	33	2	6	7	0	2	1	2	0	2285
522	0	1	0	35	4	2	7	3	0	1	2	0	11	72	5	107	0	17	11	2	0	0	0	0	0	0	0	0	0	0	0	280
525	0	0	0	2	0	0	0	0	0	1	0	0	3	2	3	17	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	31
551	0	0	0	0	4	0	1	0	0	0	0	0	1	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
552	3	8	20	14	19	4	0	2	0	0	1	1	1	2	0	77	23	3	0	0	0	0	0	0	0	0	0	0	0	0	0	178
561	0	1	9	54	9	4	10	2	1	5	0	1	25	77	14	177	0	157	32	0	0	2	0	0	0	0	0	0	0	0	0	580
562	0	1	0	19	3	1	6	0	0	0	0	0	2	16	6	61	5	24	43	0	0	0	0	0	0	0	0	0	0	0	0	187
526	0	0	0	0	0	0	0	0	0	1	1	0	9	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	22
537	0	0	0	0	0	0	0	0	0	1	0	0	8	0	0	1	0	0	0	0	76	0	110	1	1	2	0	0	0	0	0	200
539	0	0	0	0	0	0	0	0	0	0	0	0	7	1	0	0	0	0	0	0	3	1	4	1	1	1	0	0	0	0	0	94
621	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	2	20
625	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	3
626	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	0	5
Sum	3	12	35	185	125	334	469	69	9	1563	1960	114	1772	310	76	496	28	222	94	52	134	42	191	4	8	10	1	2	1	26	4	8351

Scotian Shelf

Bay of Fundy

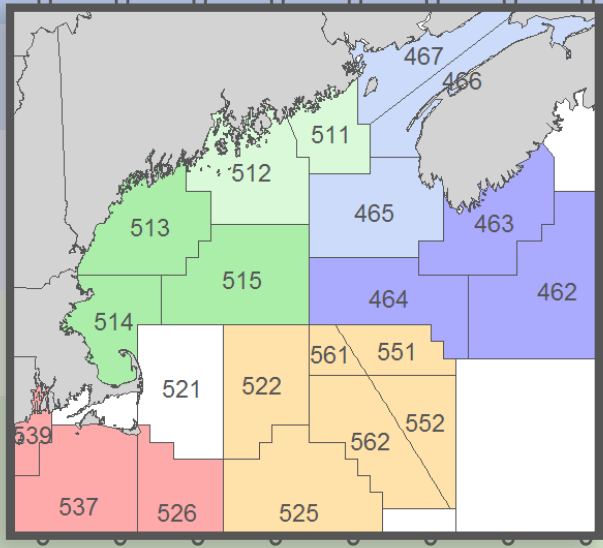
Gulf of Maine

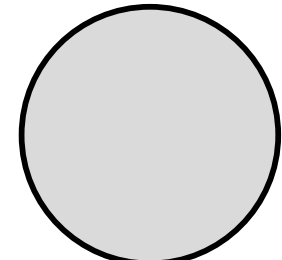
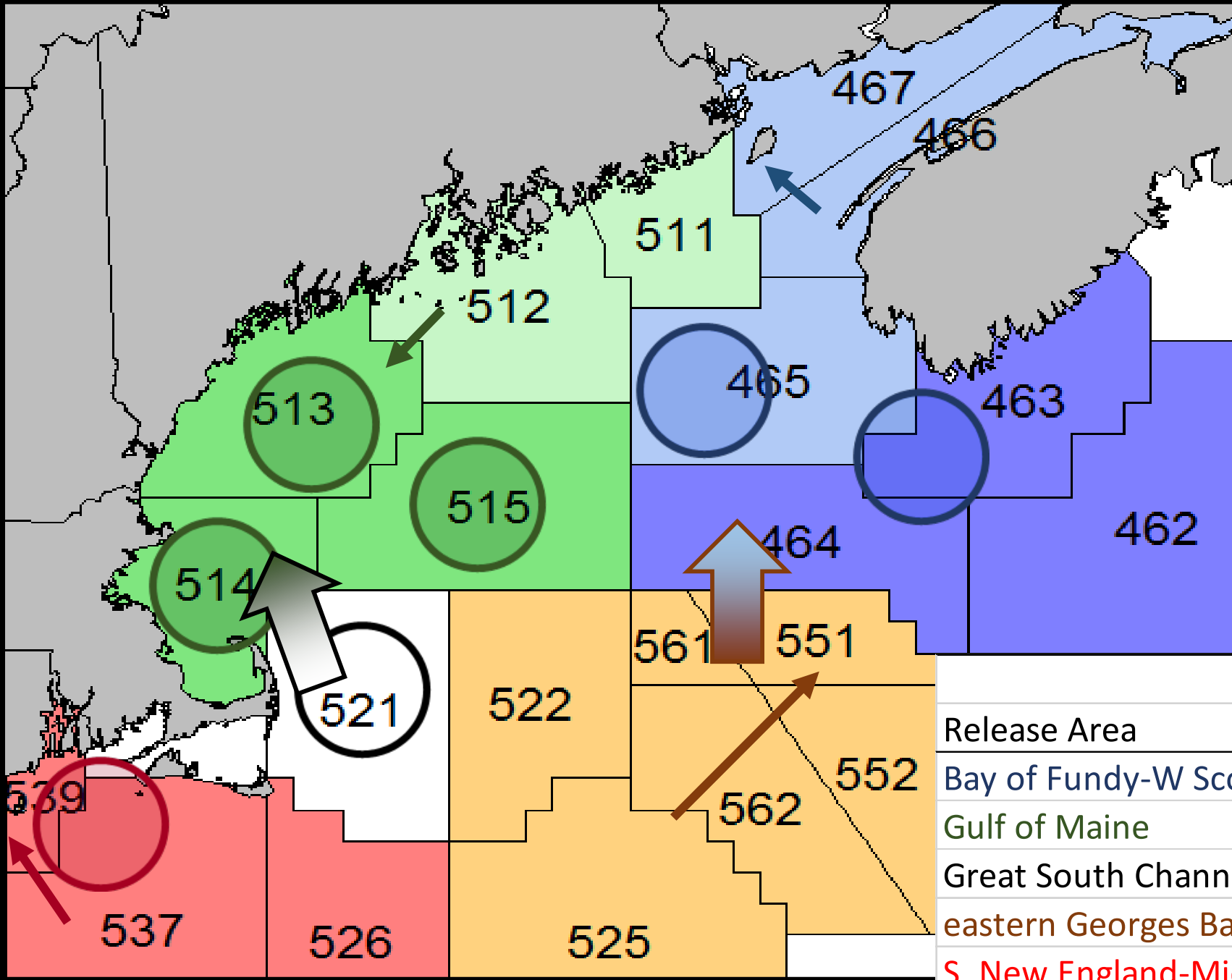
Great South Channel

Georges Bank

Southern New England

Mid-Atlantic Bight





>50% residence in statistical area

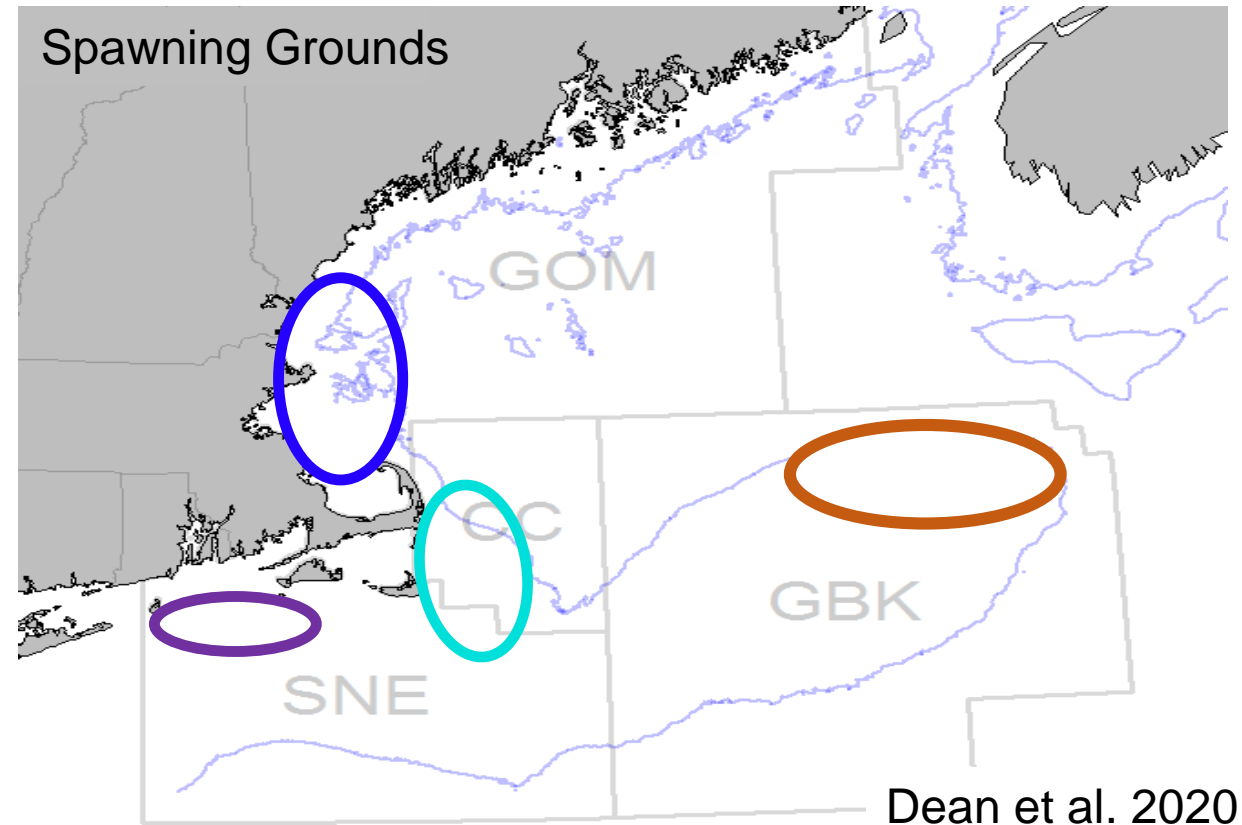
>50% movement among statistical areas

>10% movement among regions

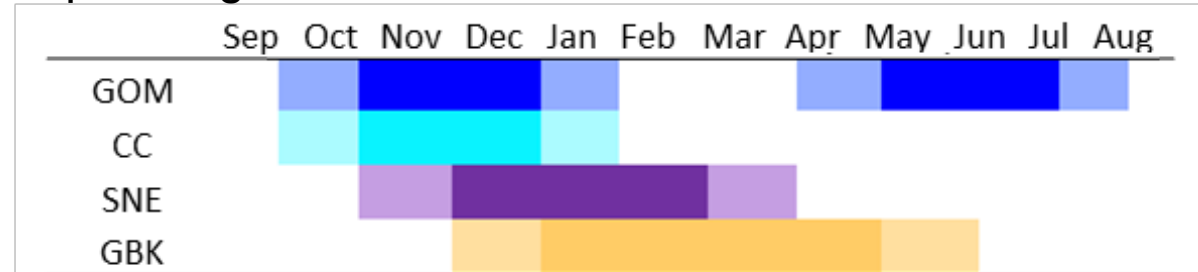
	Recapture Area				
Release Area	BOF	GOM	GSC	EGB	SNMA
Bay of Fundy-W Scotian Shelf	0.93	0.03	0.00	0.04	0.00
Gulf of Maine	0.02	0.92	0.03	0.02	0.01
Great South Channel	0.00	0.17	0.69	0.08	0.04
eastern Georges Bank	0.19	0.02	0.03	0.76	0.00
S. New England-Mid Atlantic	0.00	0.01	0.08	0.01	0.92

# Inter-Disciplinary Analyses

- Genetics information helped to identify reproductively isolated spawning groups.
- Information from early life history, reproductive biology, and fishermen's knowledge as well as otolith microstructure and chemistry helped to define seasonal spawning groups and spawning grounds.
- In return, information on movement patterns and spawning site fidelity help to inform mixing and isolation mechanisms.

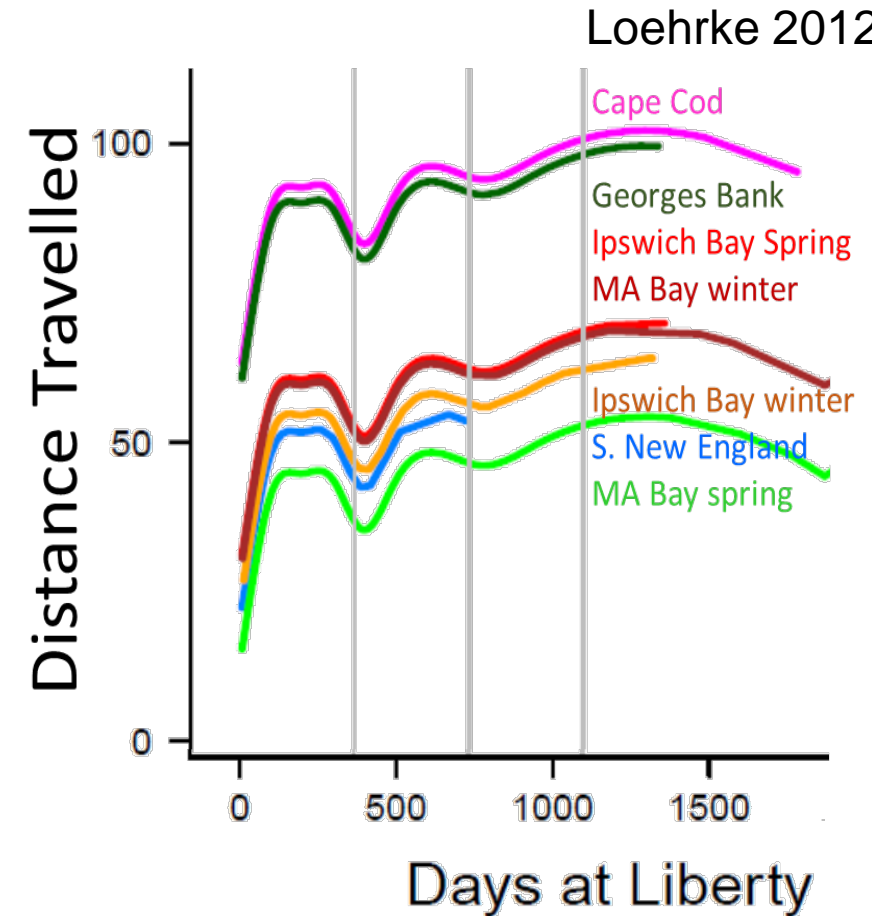


## Spawning Seasons



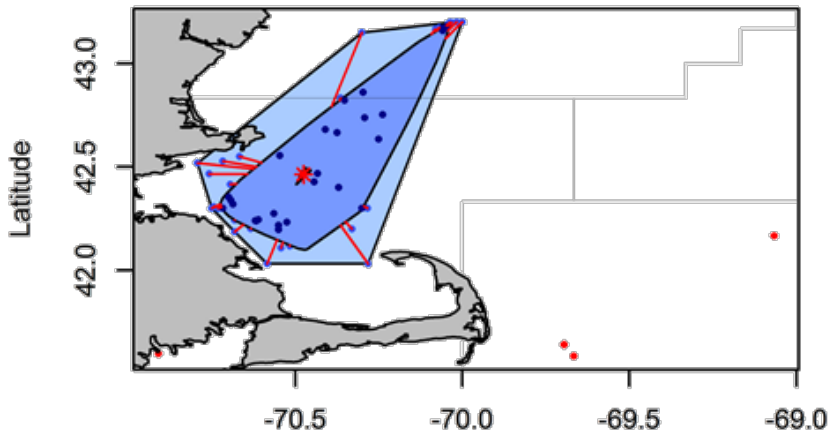
# Multi-Year Seasonal Recaptures of Spawning Cod

- High Spawning Site Fidelity
  - Bay of Fundy-western Scotian Shelf – **92%** (n=159)
  - Western Gulf of Maine spring – **95%** (n=501)
  - Western Gulf of Maine winter – **92%** (n=61)
  - Southern New England – **95%** (n=19)
- Moderate Spawning Site Fidelity
  - Eastern Georges Bank – **72%** (n=274, 22% recaptured in Bay of Fundy-western Scotian Shelf)
- Low Spawning Site Fidelity
  - Cape Cod (Great South Channel) – **59%** (n=68, 28% recaptured in the Gulf of Maine)

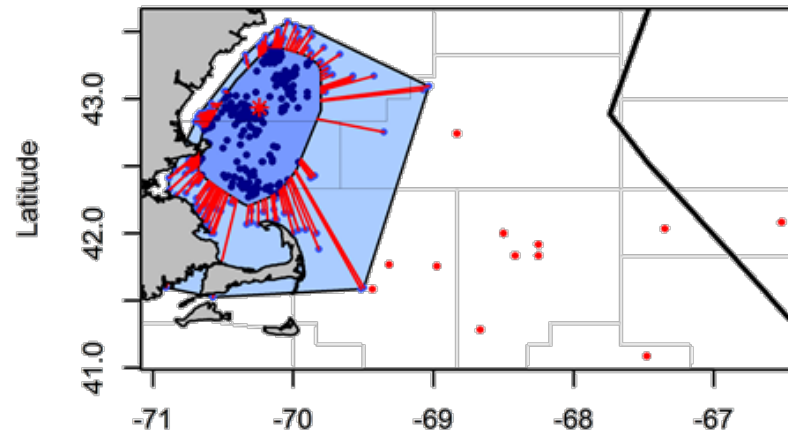


# Dispersal of Cod Spawning Groups – Conventional Tags

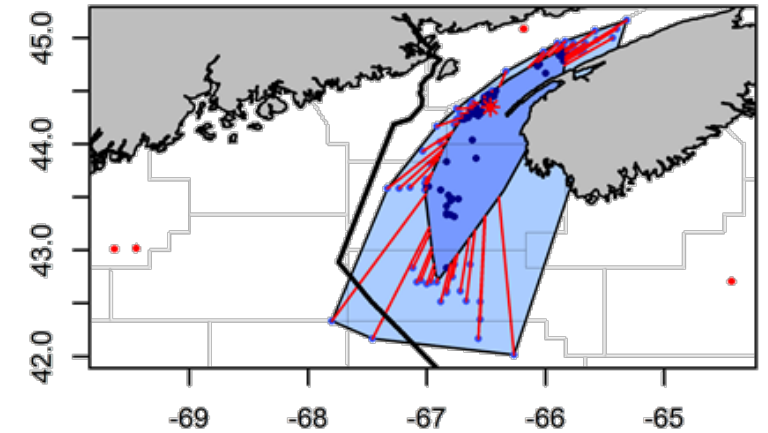
**WGoM Winter Spawners - (Oct.-Jan.)**



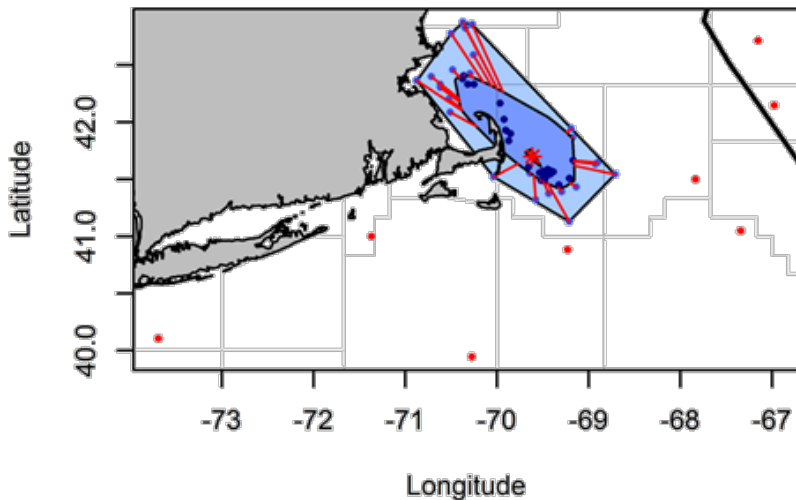
**WGoM Spring Spawners (April-July)**



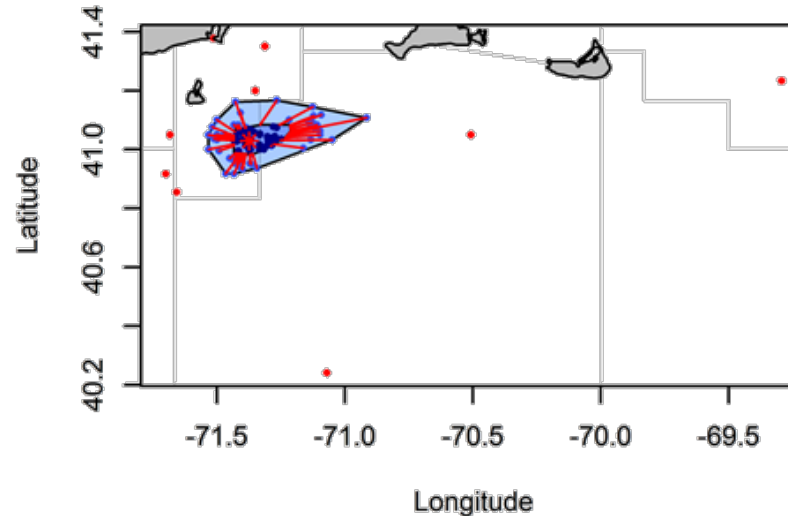
**W Scotian Shelf and BoF Spawners (Jan. - May)**



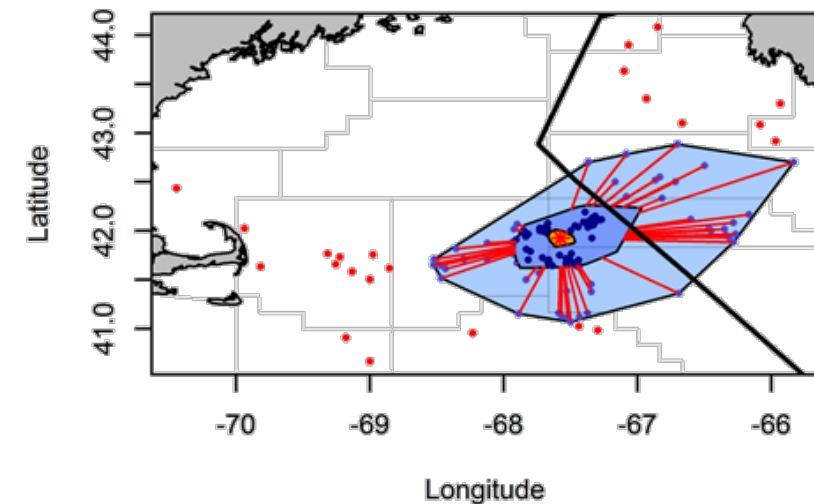
**Cape Cod Spawners (Nov. - Jan.)**



**Southern New England Spawners (Nov. - Mar.)**



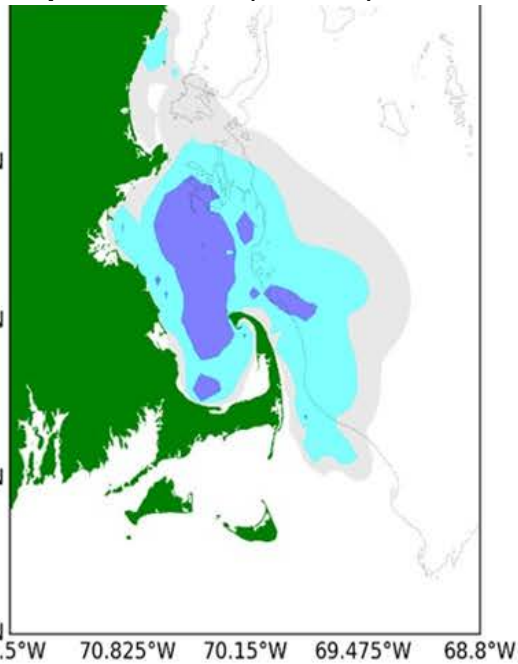
**Eastern Georges Bank Spawners (Dec-May)**



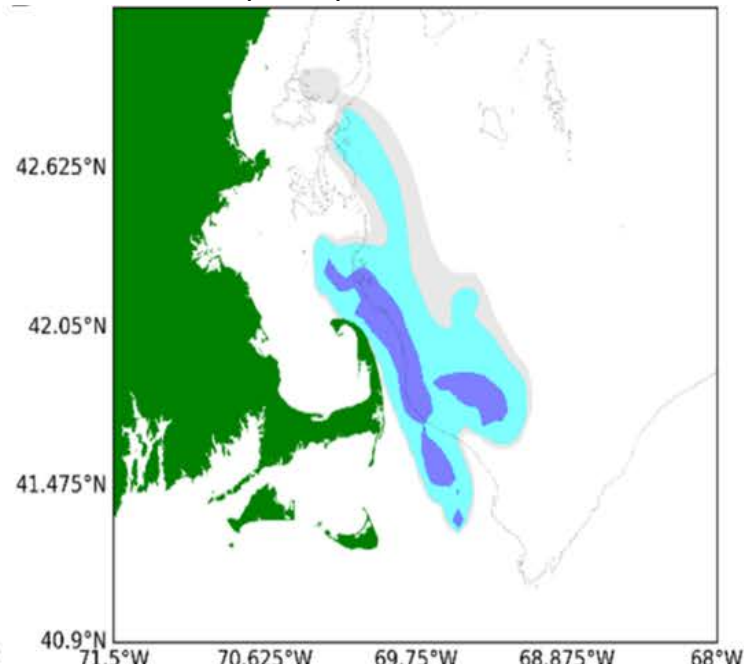
# Dispersal of Cod Spawning Groups – Archival Tags



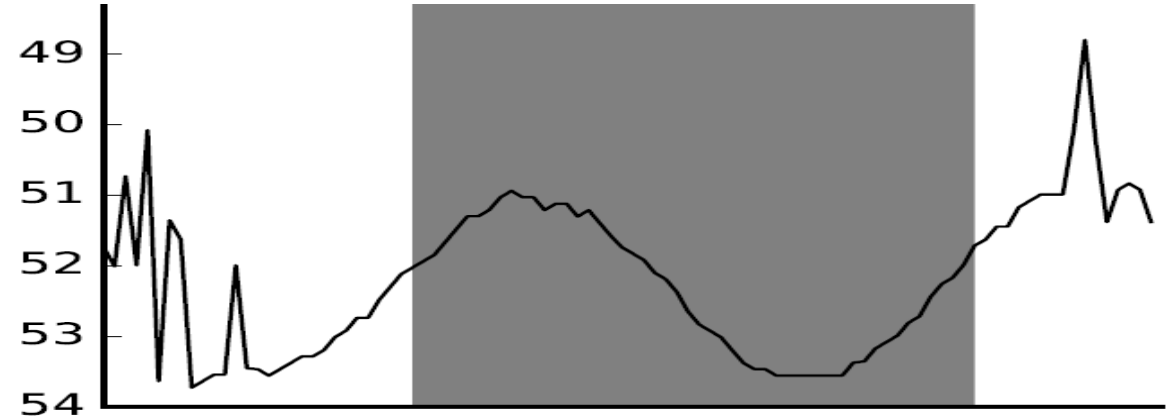
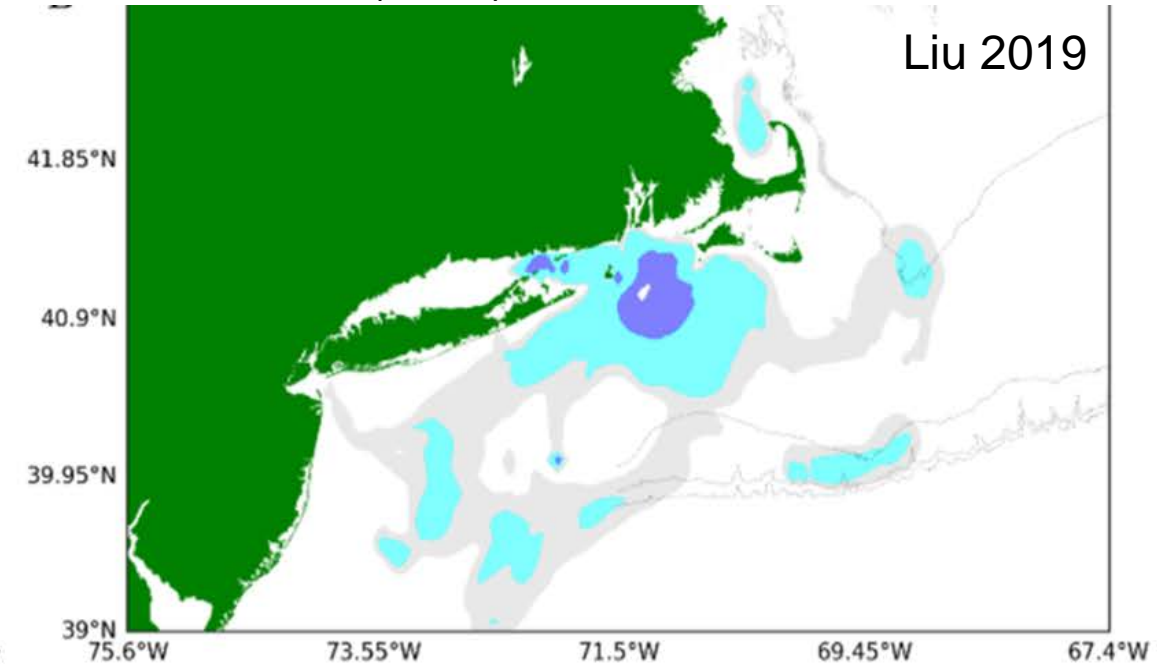
Western Gulf of Maine Spawners (n=19)



Cape Cod Spawners (n=5)

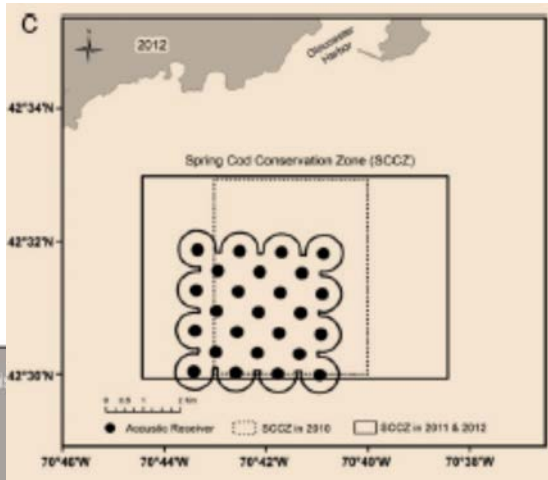


Southern New England Spawners (n=64)

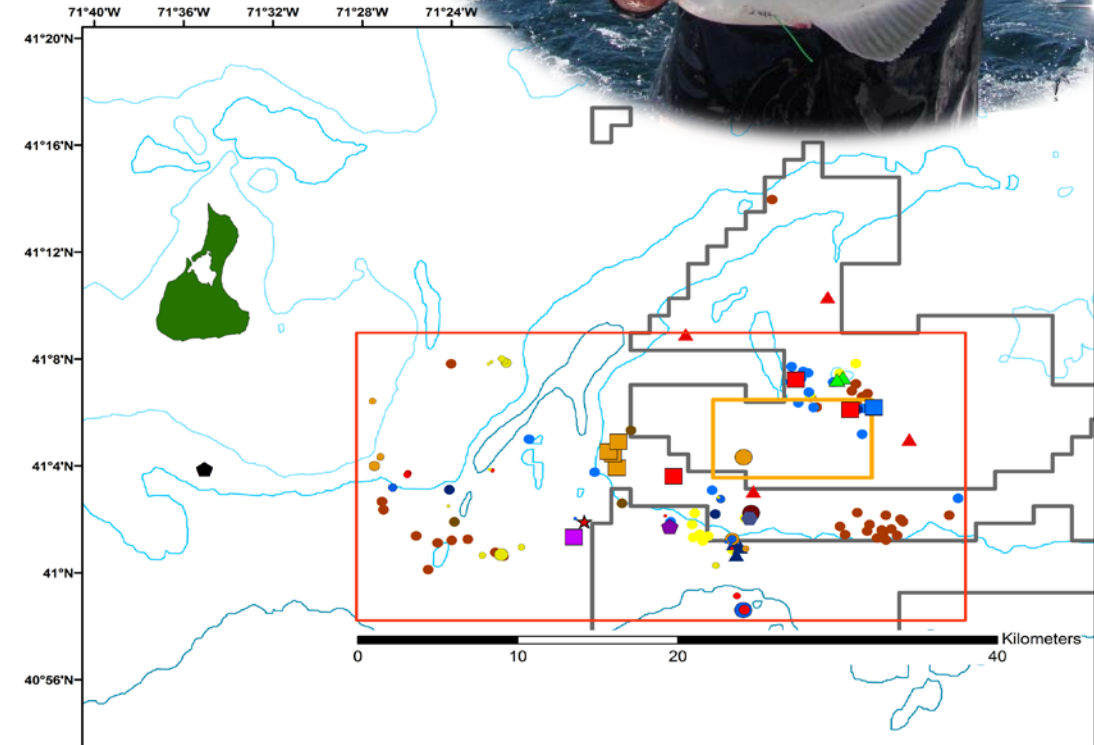
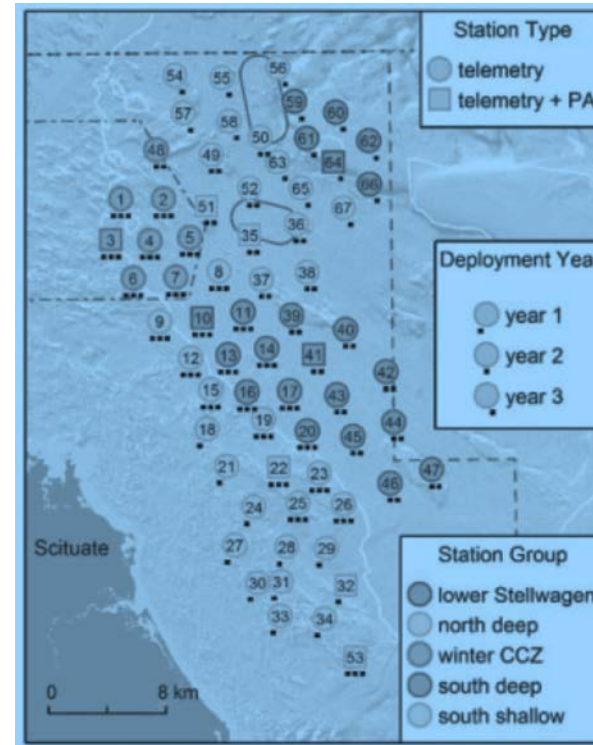


# Fidelity of Cod Spawning Groups – Acoustic Tags

Mass Bay Spring Spawners

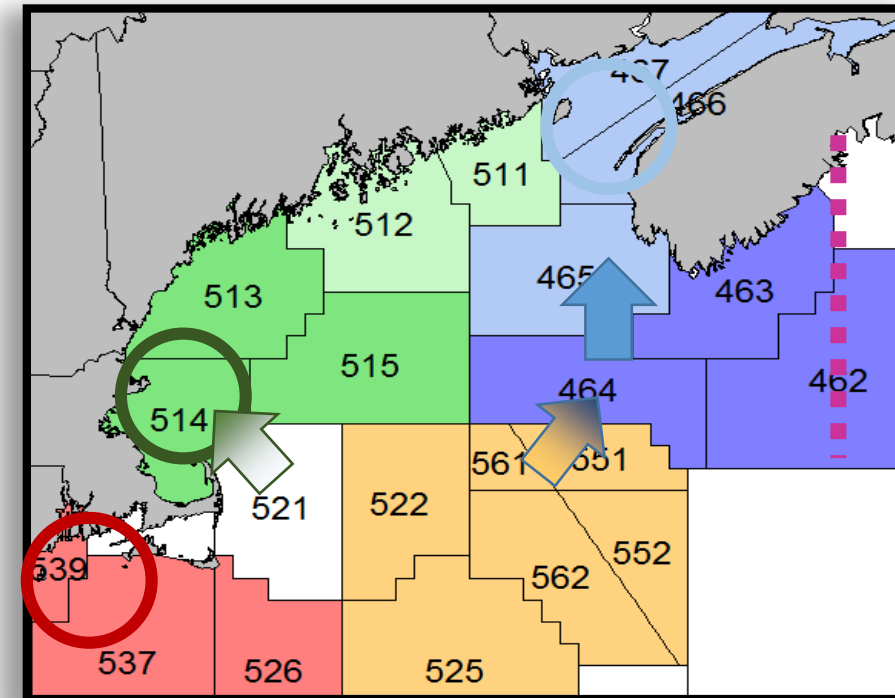
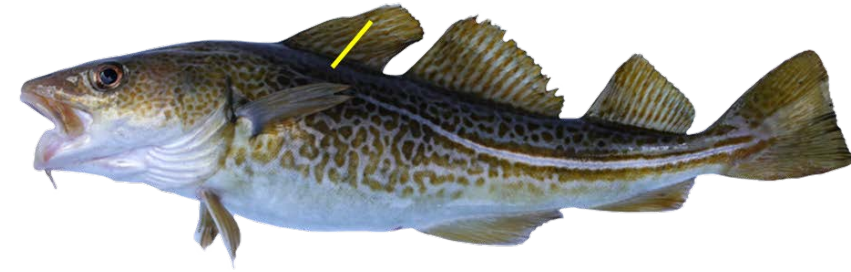


Mass Bay Winter Spawners Cox Ledge Spawners



# Conclusions about Cod Movement

- Little movement between the eastern and western Scotian Shelf
- Relatively sedentary groups within the Bay of Fundy, the western Gulf of Maine, and southern New England
- Substantial movement
  - from eastern Georges Bank to Browns Bank
  - from the Great South Channel to the western Gulf of Maine
  - from Browns Bank to the Bay of Fundy and the western Scotian Shelf
- Fidelity to spawning areas
  - high in the western Gulf of Maine and the Bay of Fundy
  - moderate on eastern Georges Bank
  - low from the 'Cape Cod' spawning grounds.





# Atlantic cod stock structure in US waters: Synthesis

**The Atlantic Cod Stock Structure Working Group (ACSSWG)**

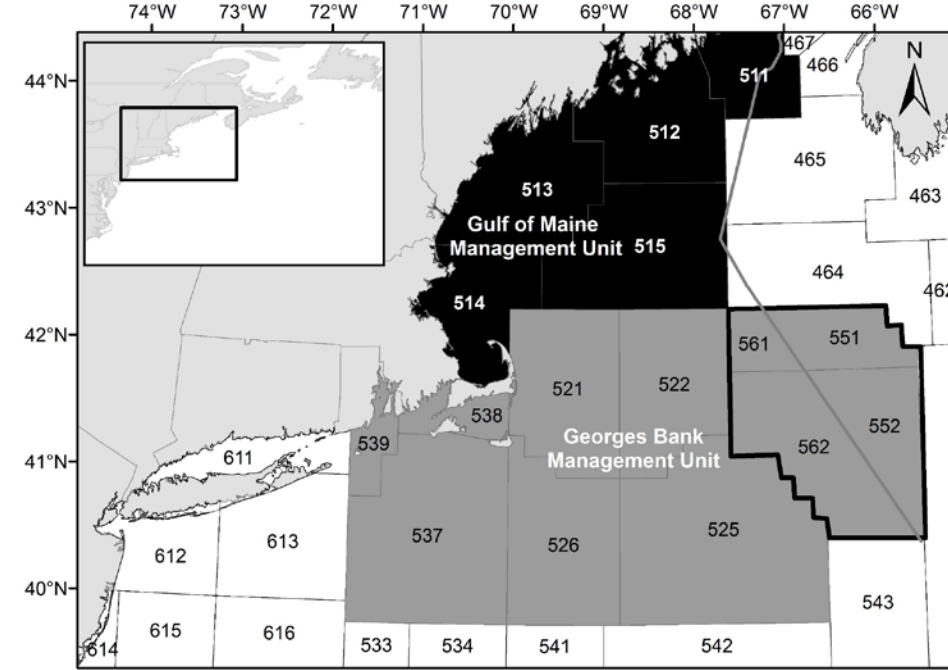
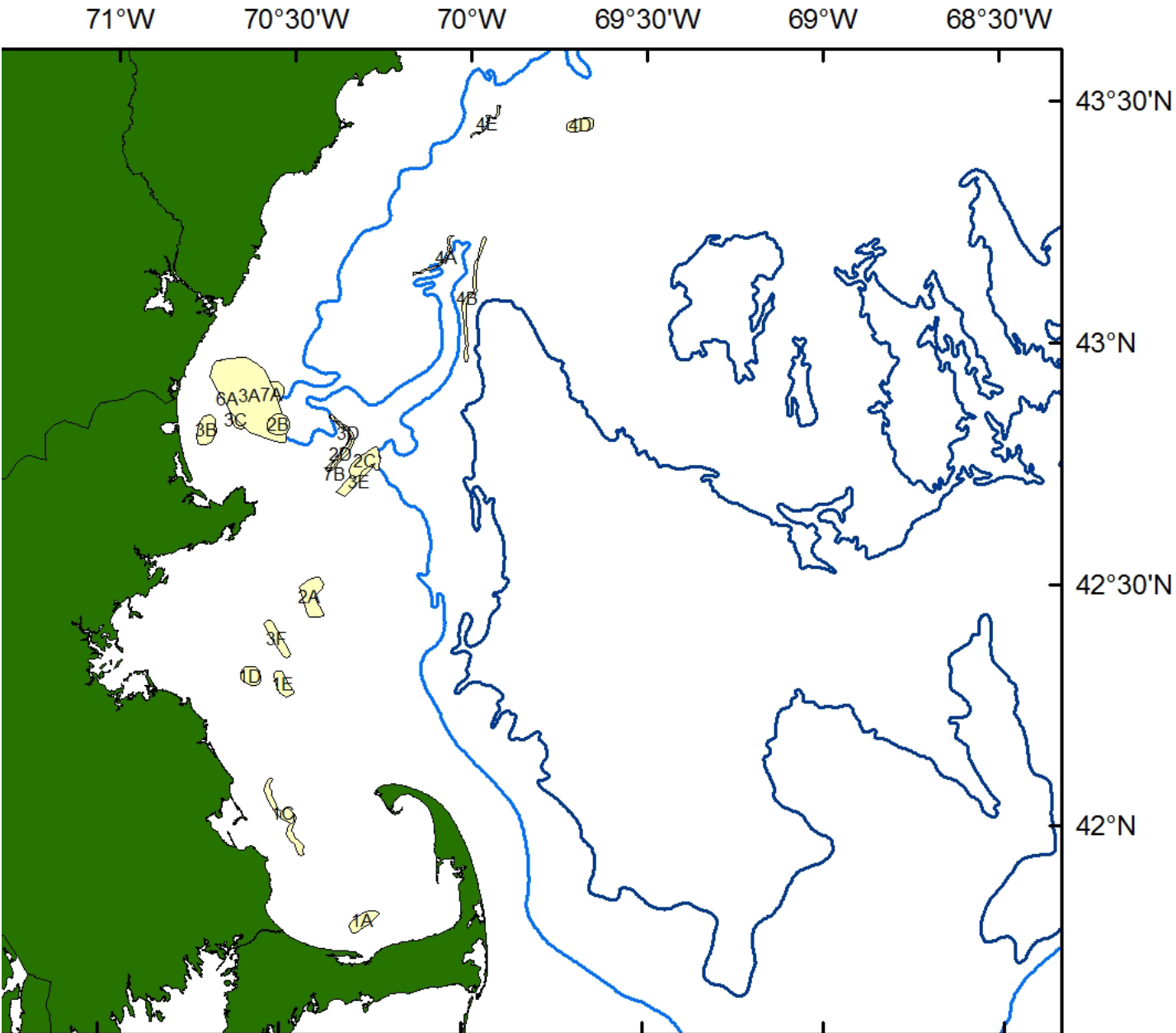
**Presenter: Richard McBride, NOAA Fisheries**

**New England Fishery Management Council Peer Review**

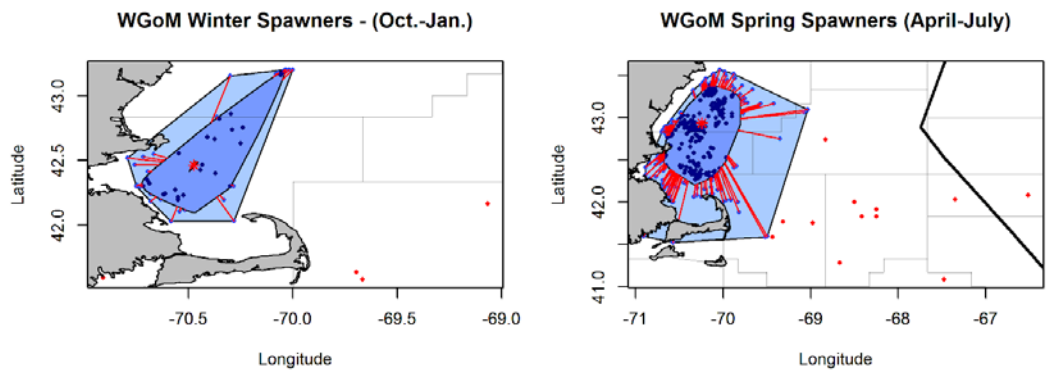
# Interdisciplinary highlights

- 1) Notable phenotypic and genetic variability among statistical areas
  - Cod not well mixed in either US management unit
- 2) Extensive movements by adults
  - exchange between US-US management units
  - as well as between US-Canada management units
- 3) Larval dispersal around Cape Cod
  - one-way connectivity between US-US management units
- 4) Two sympatric, genetically differentiated stocks in SW Gulf of Maine
  - adaptive differences between winter- and spring-spawning cod

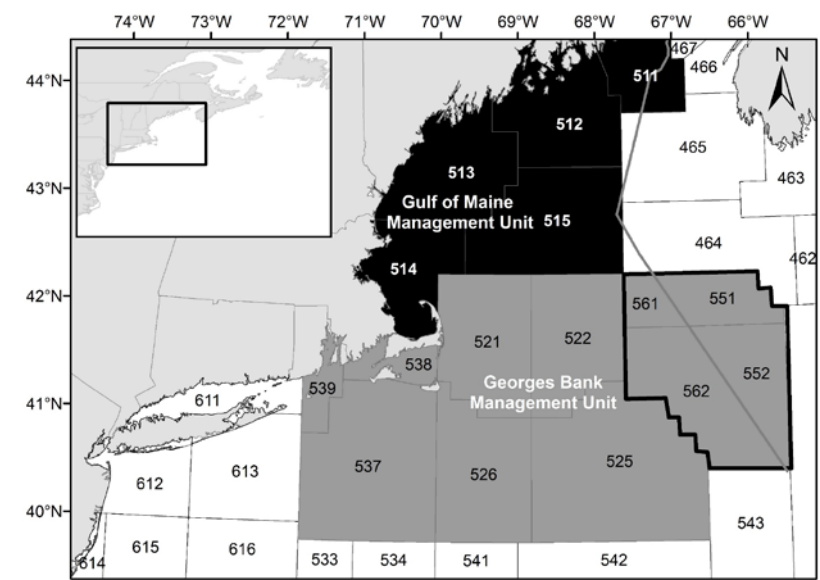
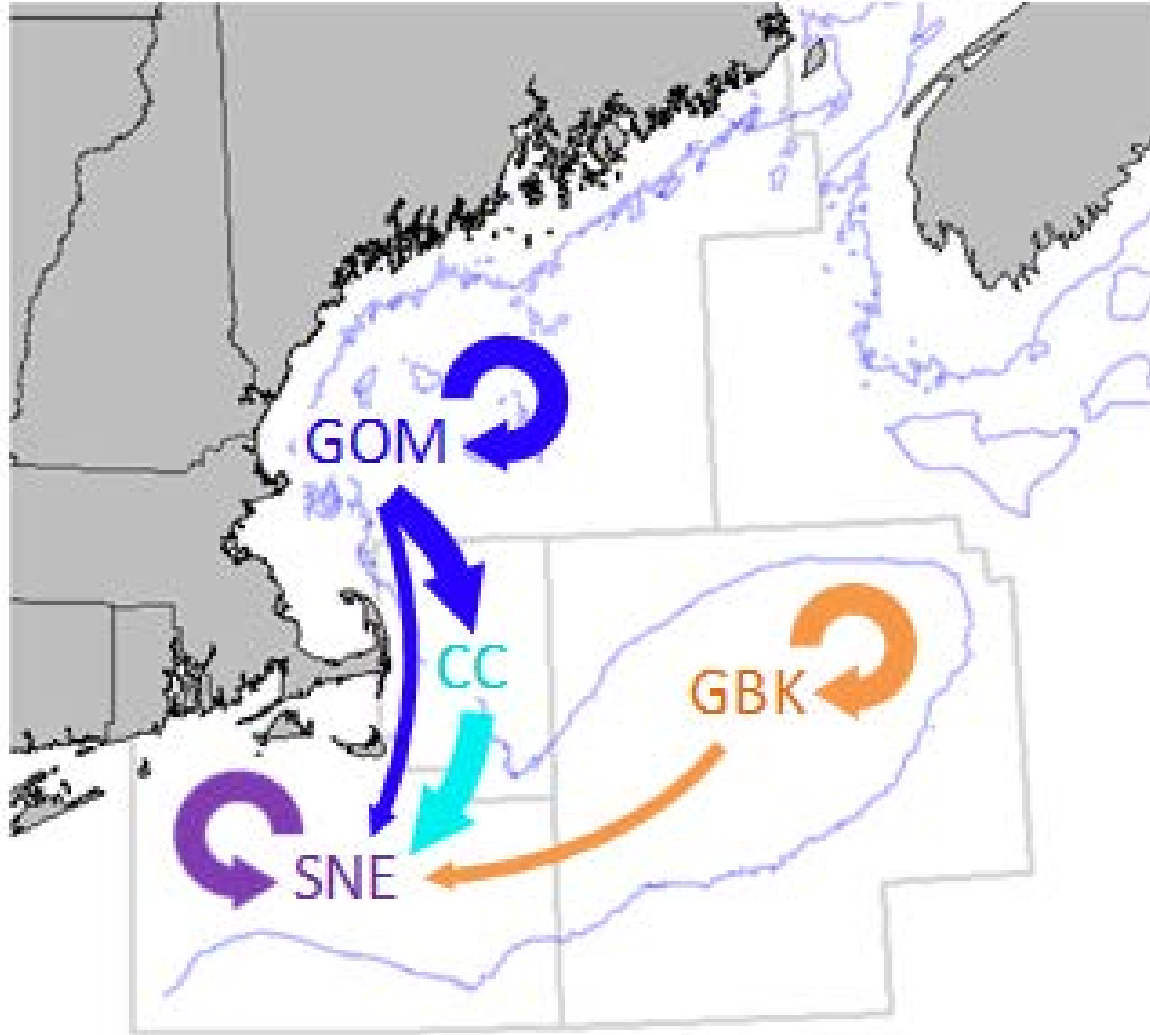
# Ecological knowledge



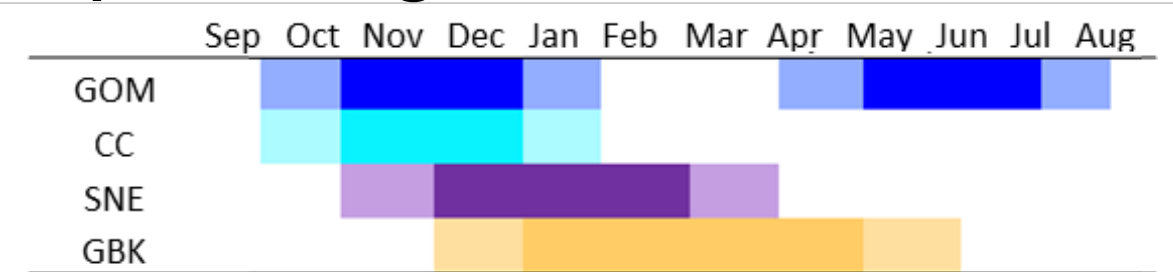
Recaptures of tagged fish show fidelity to spawning grounds



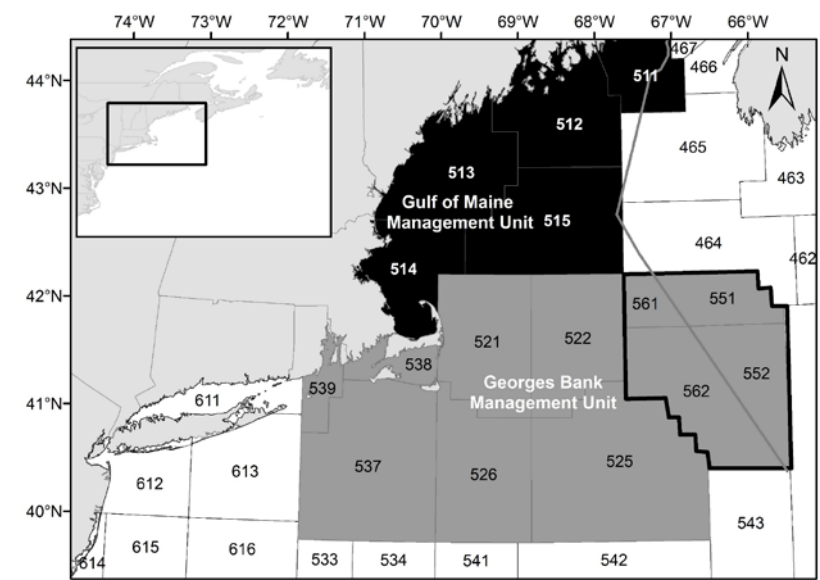
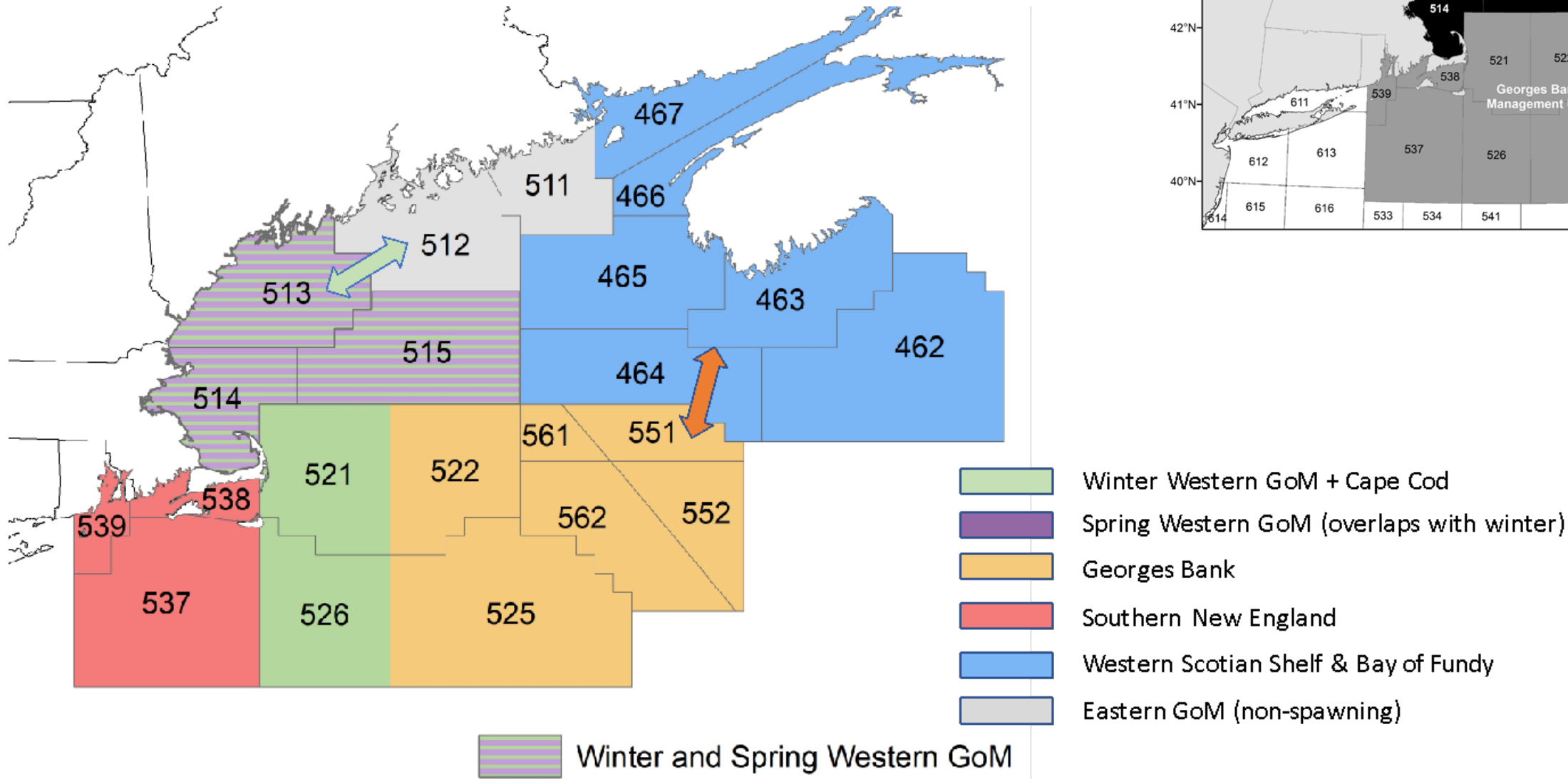
# Early life history



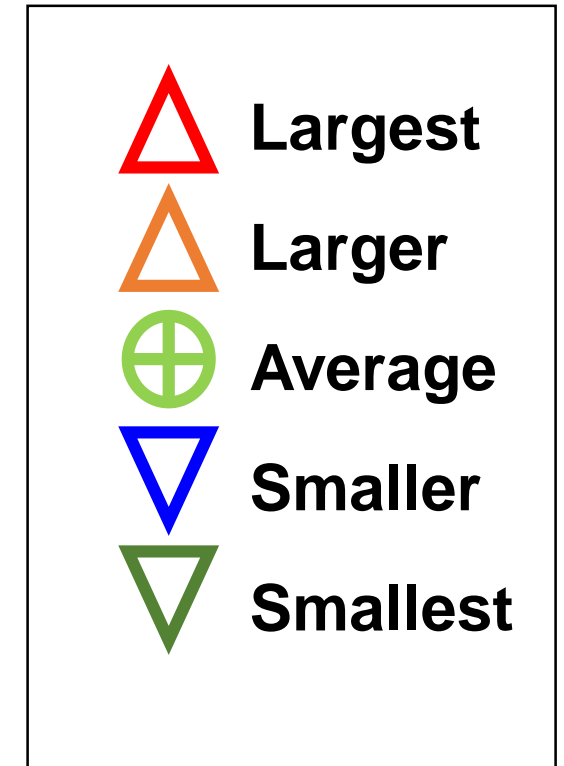
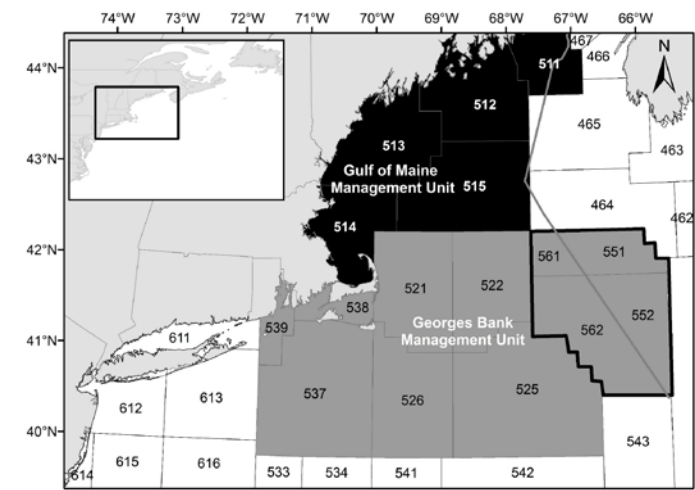
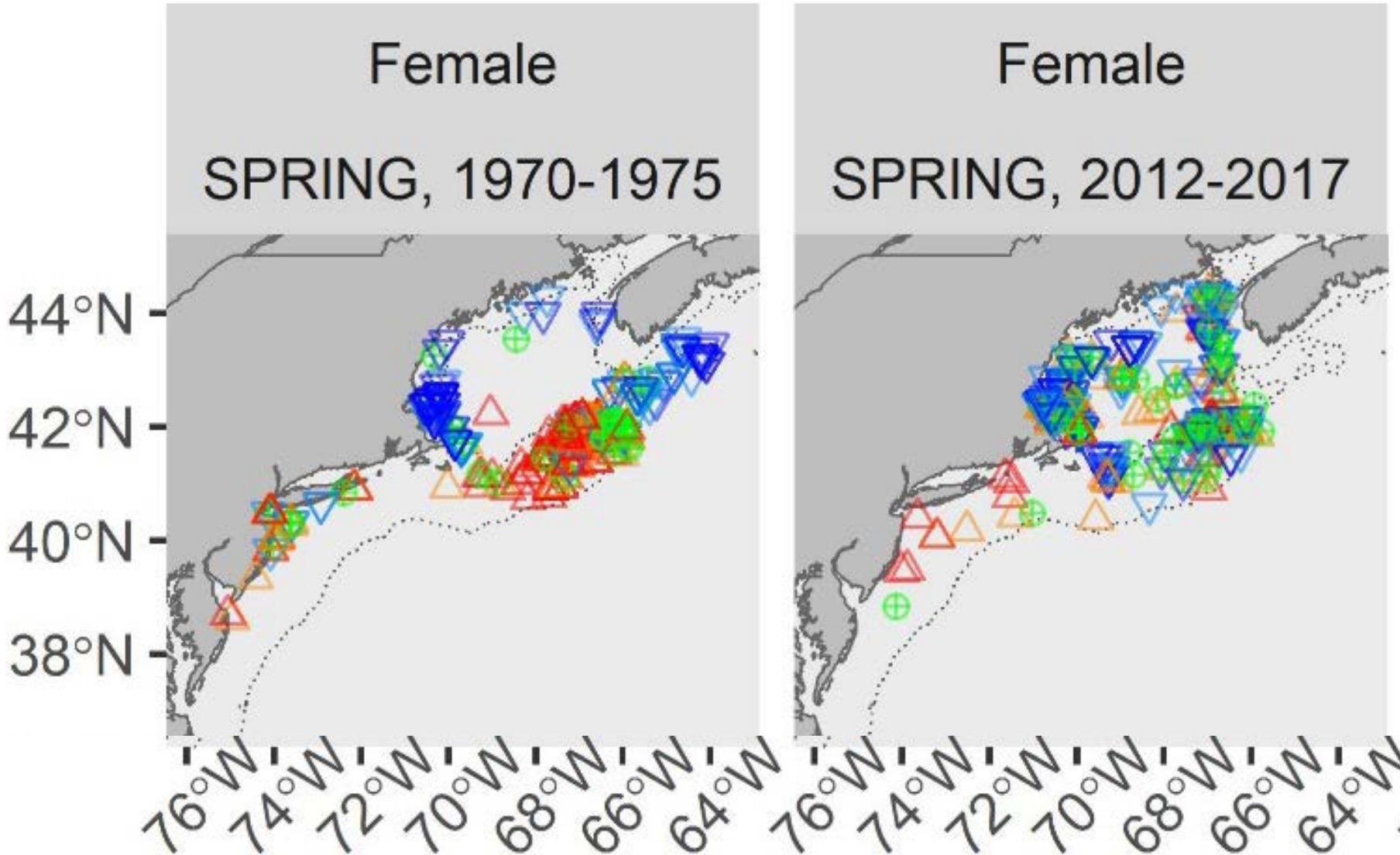
# Spawning Seasons



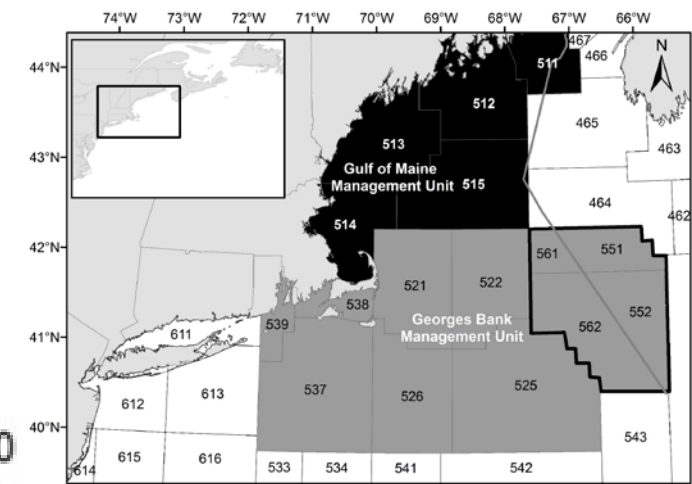
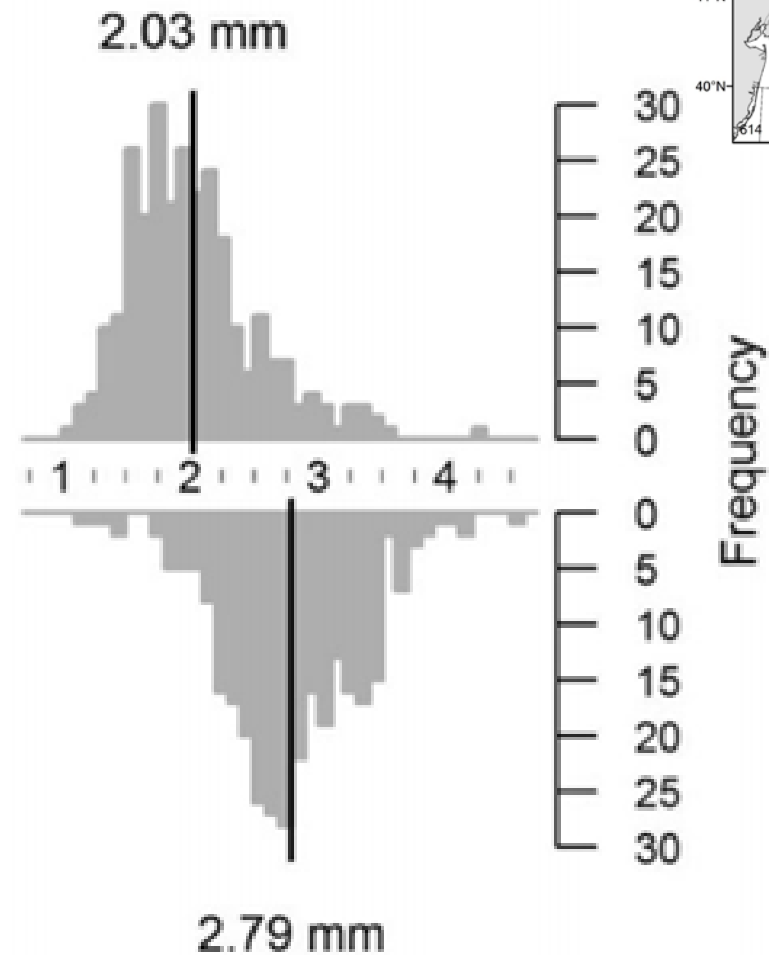
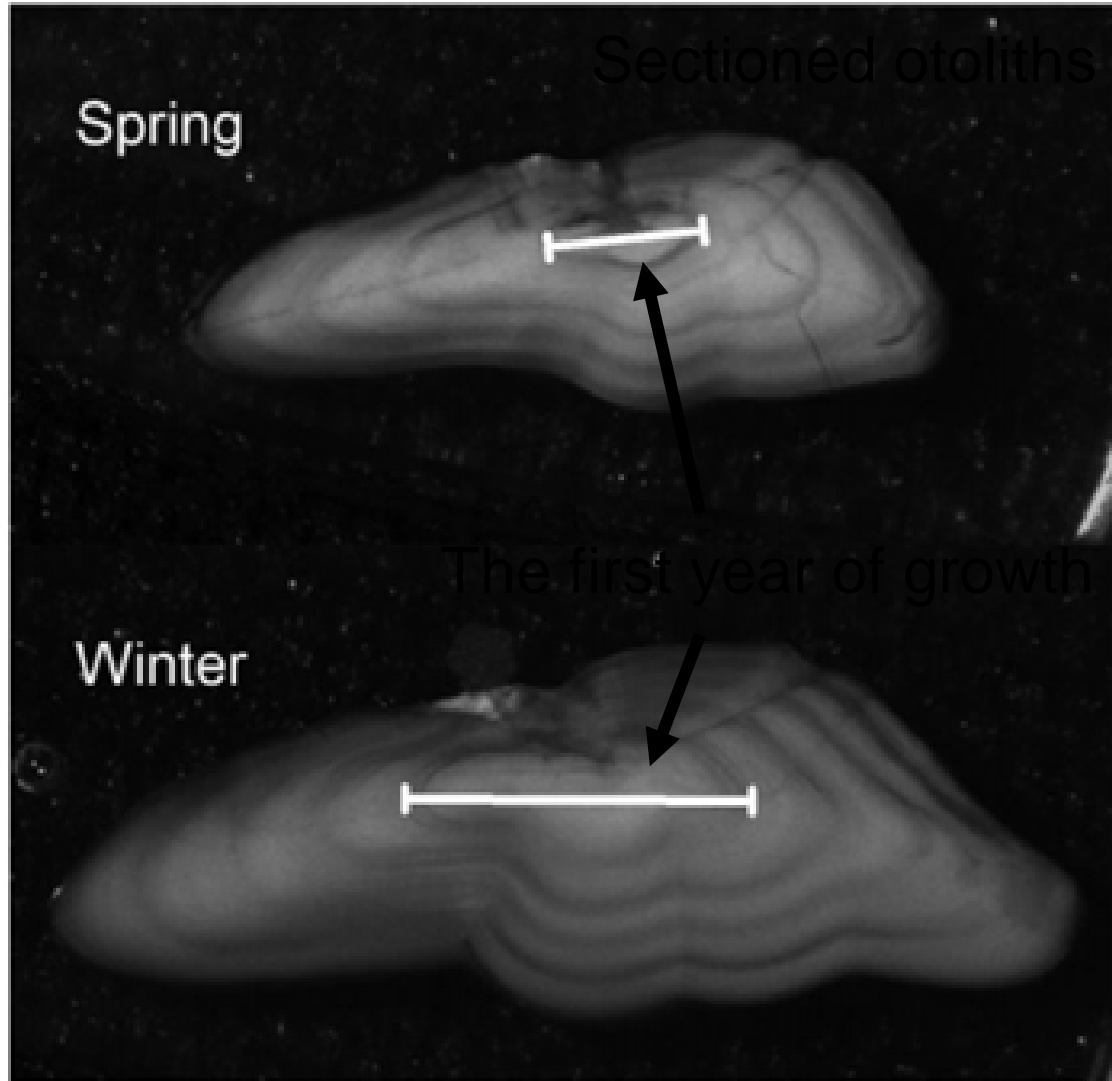
# Genetic structure



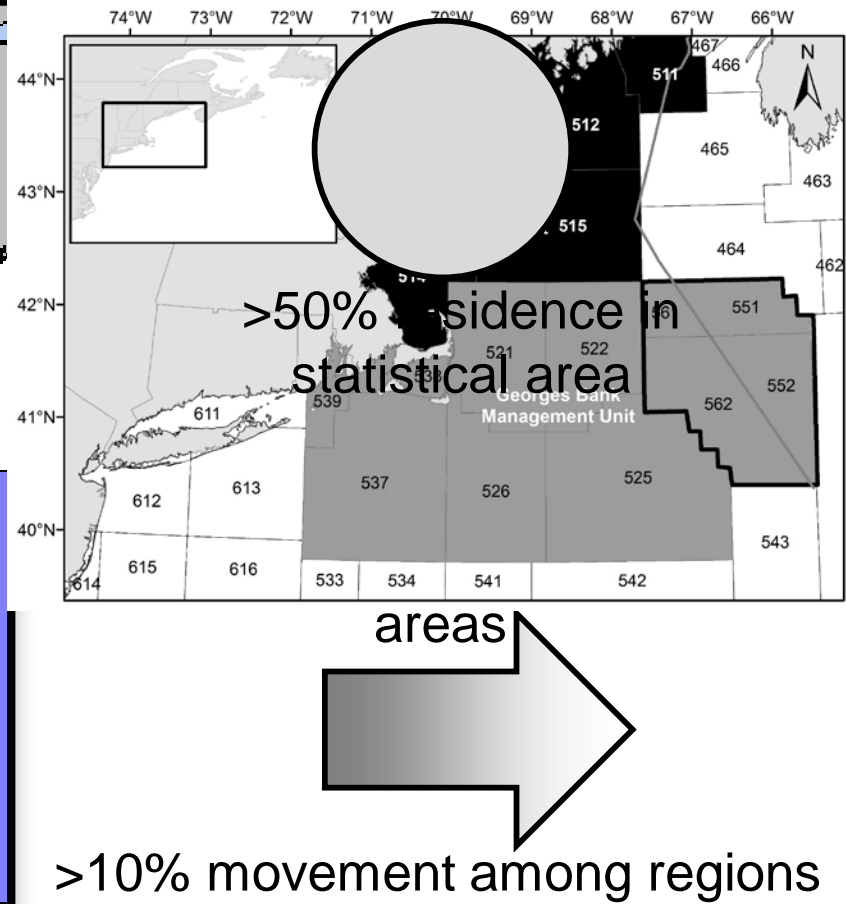
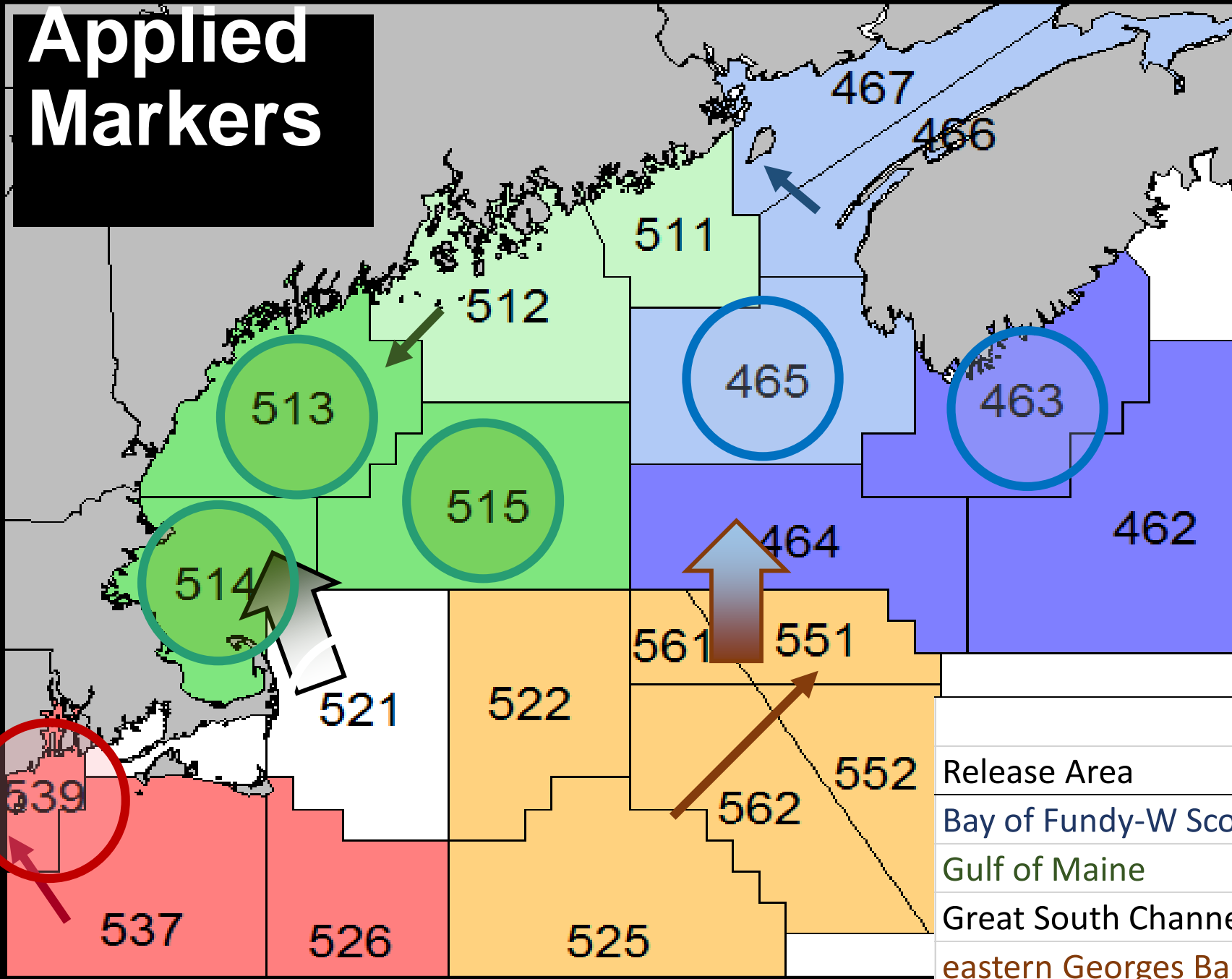
# Life history (size @ age-2)



# Natural Markers

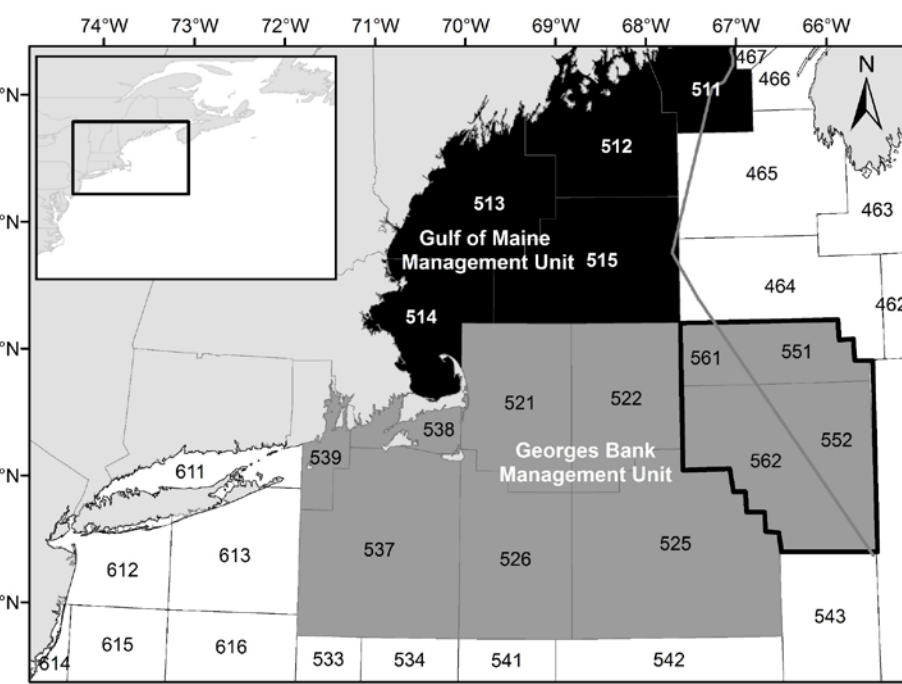
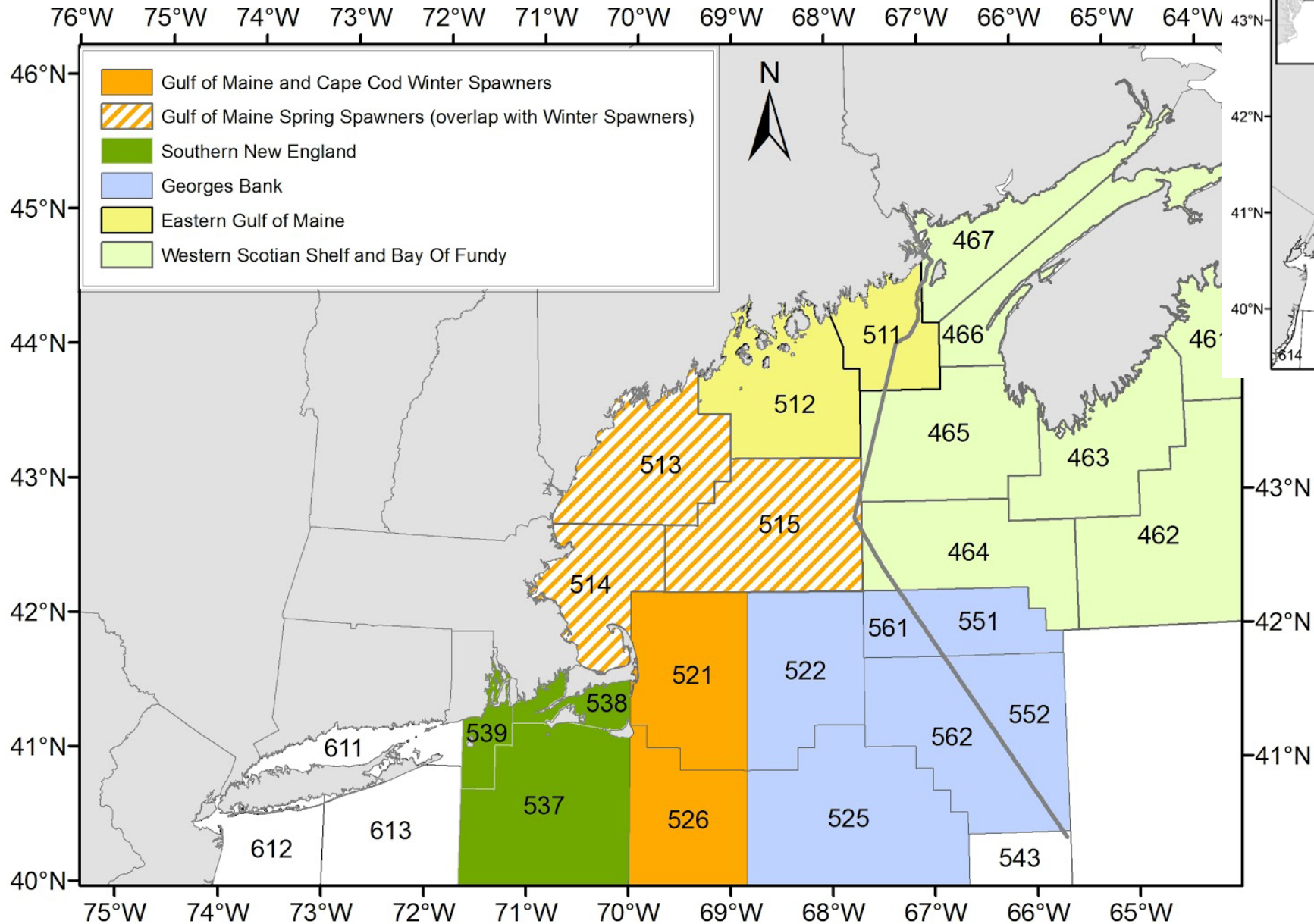


# Applied Markers



Release Area	Recapture Area				
	BOF	GOM	GSC	EGB	SNMA
Bay of Fundy-W Scotian Shelf	0.93	0.03	0.00	0.04	0.00
Gulf of Maine	0.02	0.92	0.03	0.02	0.01
Great South Channel	0.00	0.17	0.69	0.08	0.04
eastern Georges Bank	0.19	0.02	0.03	0.76	0.00
S. New England-Mid Atlantic	0.00	0.01	0.08	0.01	0.92

# 5 US cod stocks proposed

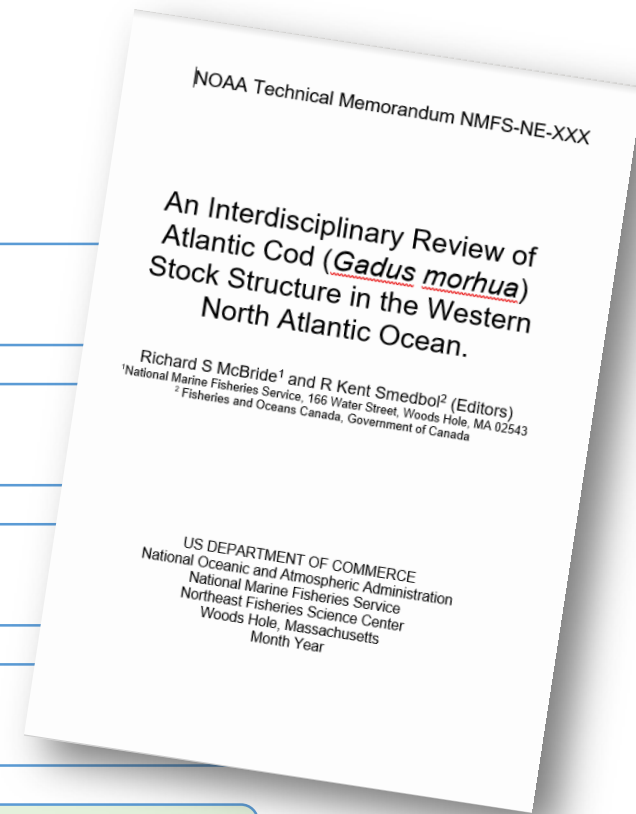
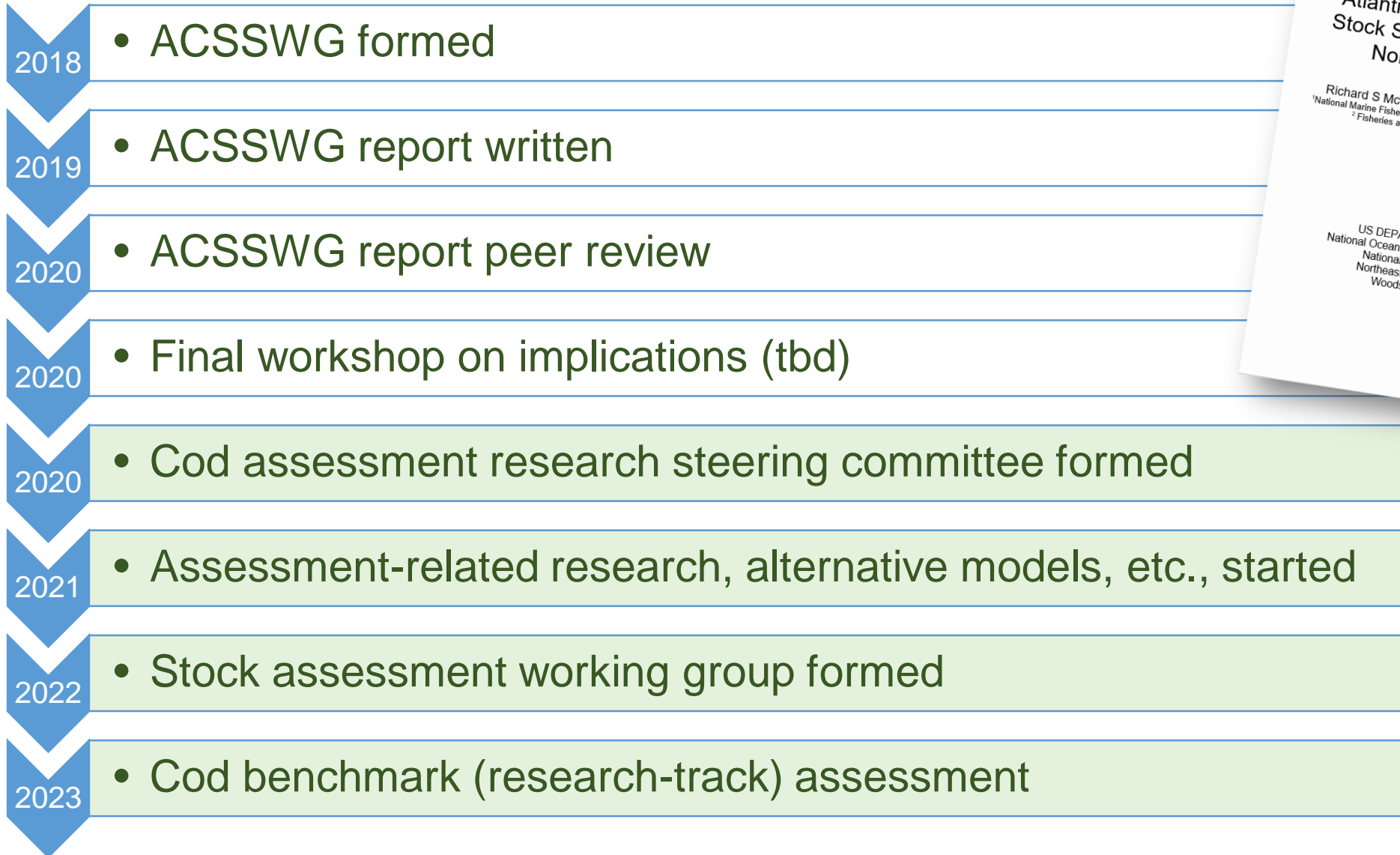


This proposal accounts for:

- Within unit variation
- Between unit connectivity
- Winter/spring sympatry

# The broader timeline?

You  
Are Here →



# Acknowledgements

## The working group

Ames, Ted  
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Massachusetts Division of Marine Fisheries  
Gulf of Maine Research Institute  
University of New Hampshire  
Northeast Fisheries Science Center  
Cornell University  
University of New Brunswick  
Canadian Department of Fisheries & Oceans  
Canadian Department of Fisheries & Oceans  
Rutgers University

New England Fishery Management Council  
NOAA's Northeast Fisheries Science Center  
New Hampshire Sea Grant  
Maine Fishermen's Forum

[https://www.nefsc.noaa.gov/press\\_release/pr2018/other/cod-stock-structure/](https://www.nefsc.noaa.gov/press_release/pr2018/other/cod-stock-structure/)

