CAPAM Workshop: Development of Spatial Stock Assessment Models

Defining Spatial Structure of Fisheries

Steve Cadrin

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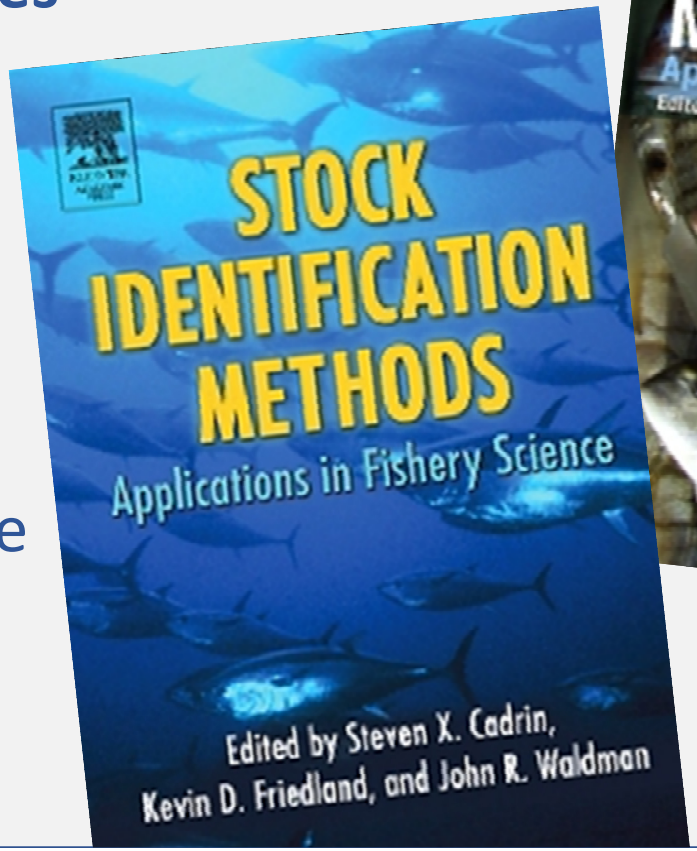
Background

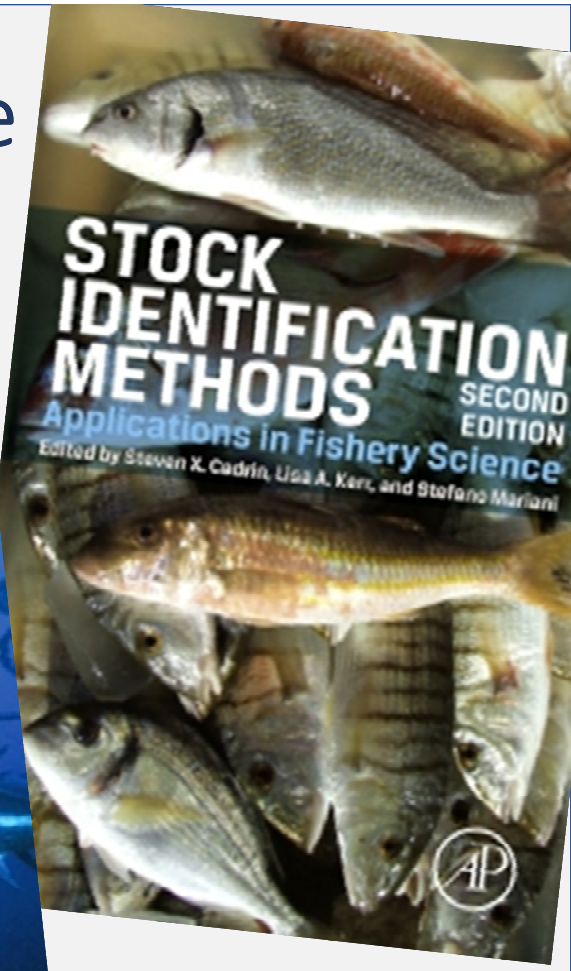

NAFO
Northwest Atlantic
Fisheries Organization
ICES
CIEM
SOUTHEAST
S E
Data, Assessment & Review
ICCAT CICTA CICAA


Tagging Program
Tagging Program

Defining Spatial Structure

- Typical stock assessments
- **Stock Identification Approaches**
  - **Geographic Distribution**
  - **Dispersal Patterns**
  - **Geographic Variation**
    - **Reproductive isolation**
    - **Demographic independence**
  - **Inter-Disciplinary Analyses**
- Approaches to spatial structure





Unit Stock Assumption

- Population dynamics are internally determined
  - Recruitment from spawners in the stock
  - All removals are from fishing or natural mortality in the stock area

Dynamic Pool Assumption

- Homogeneous vital rates

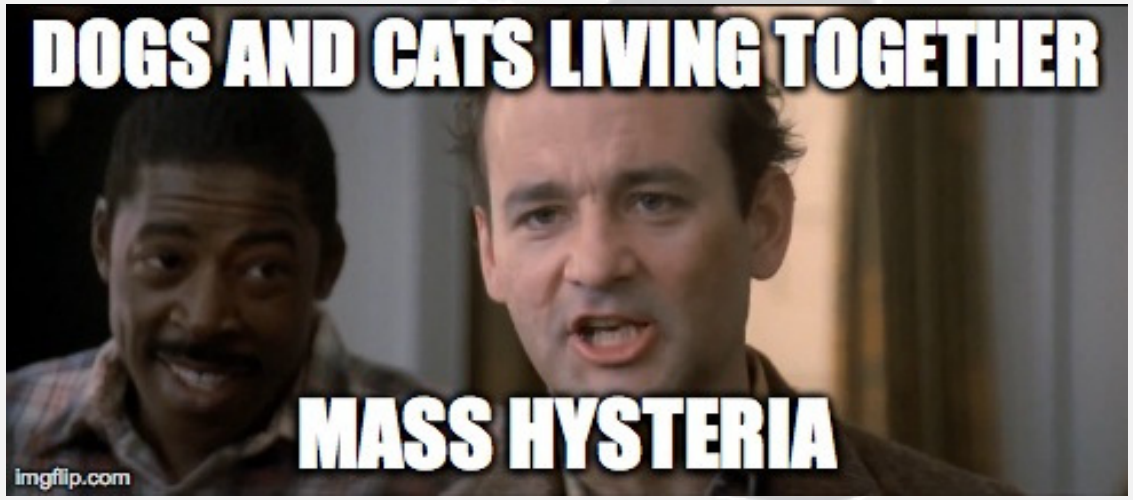
The Ideal

- The unit stock assumption is most suited to a management unit that is reproductively isolated from other populations.

- The dynamic pool assumption implies no spatial heterogeneity and random mating.

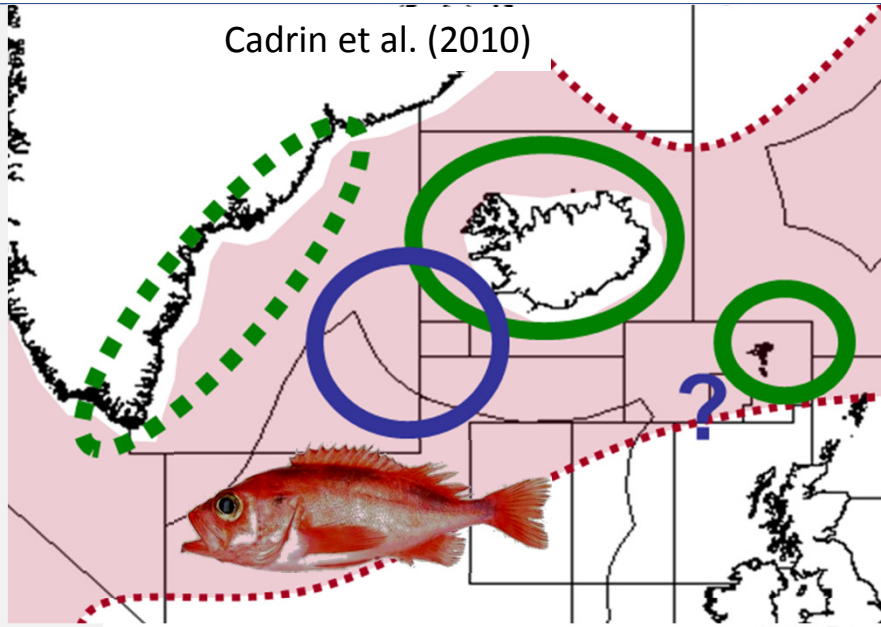
Reality

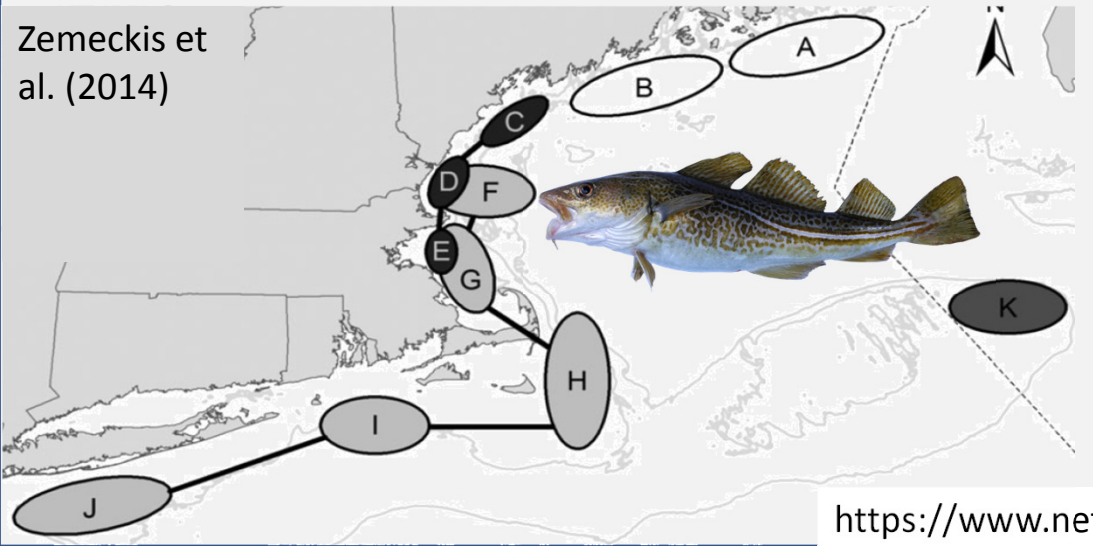
- All populations and all fisheries have some spatial structure.
  - Most species are managed as several separate units, based on distinct populations, jurisdictions or fishing grounds.
  - Some populations contribute to multiple management units.
  - Some subpopulations have considerable connectivity.
  - Some management units are heterogeneous, and may include multiple populations (even multiple species!)

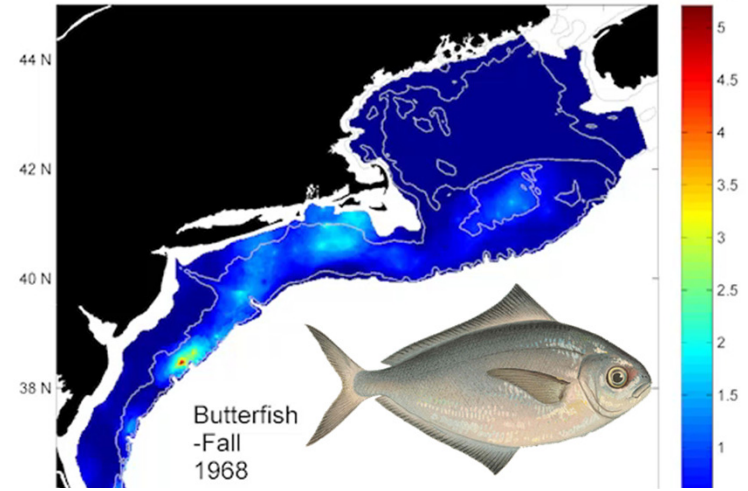


Further Complications

- Stocks are often defined as a self-sustaining group within an area, but many stocks overlap spatially.
- Some stocks are defined by geographic features, but others are more defined by 3-dimensional habitat or temperature.







https://www.nefsc.noaa.gov/ecosys/spatial-analyses/mp4/butterfish-fall.mp4

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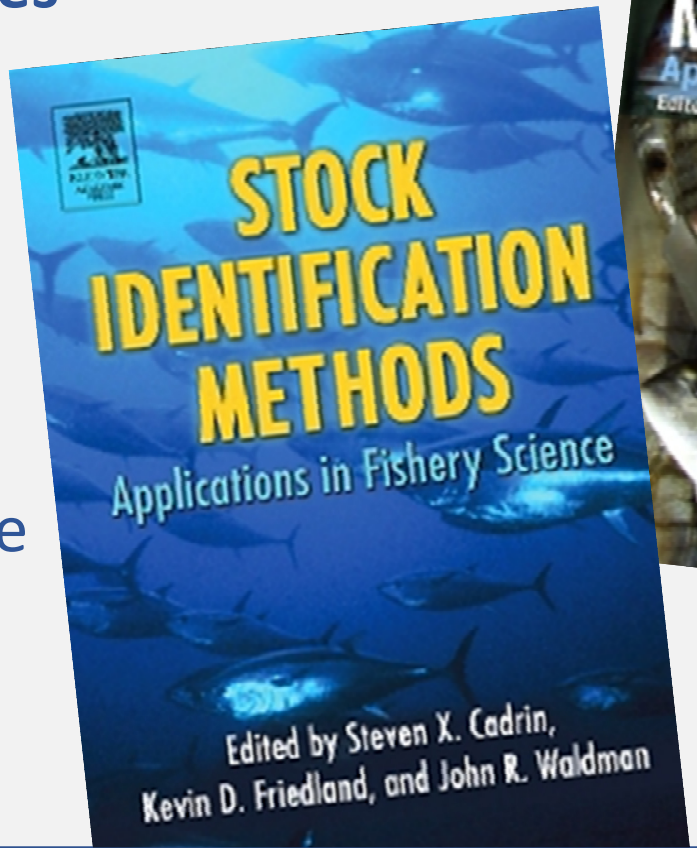
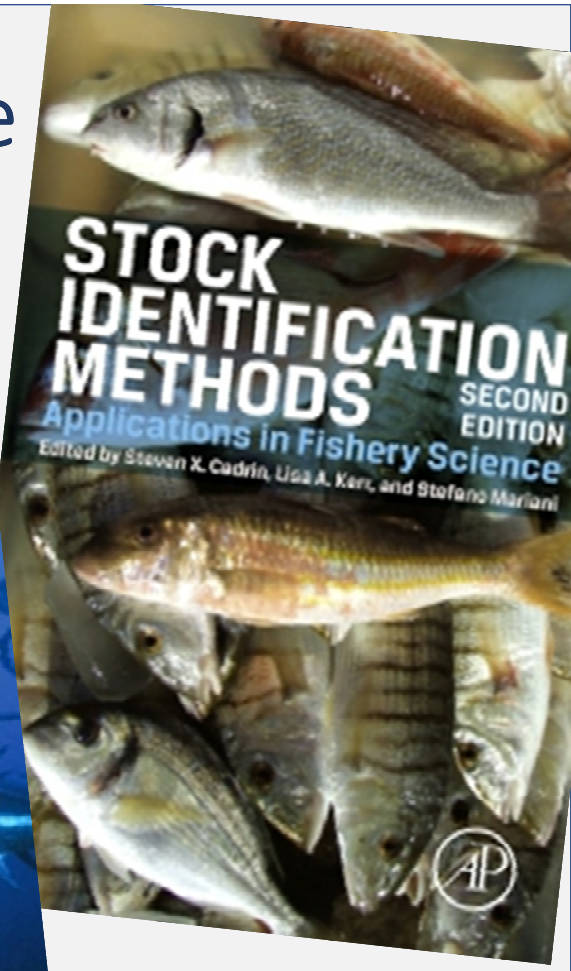
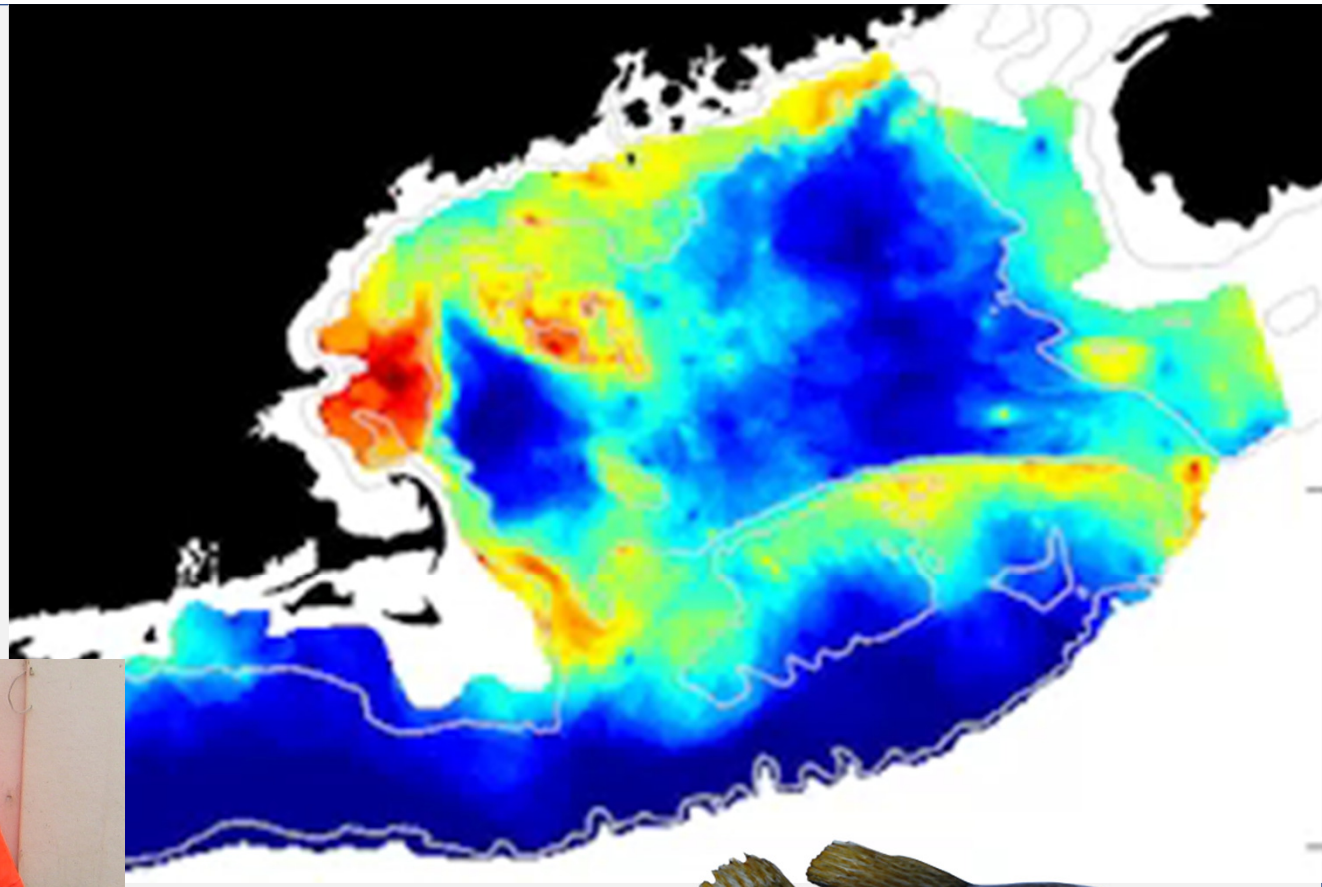




Spatial Distribution

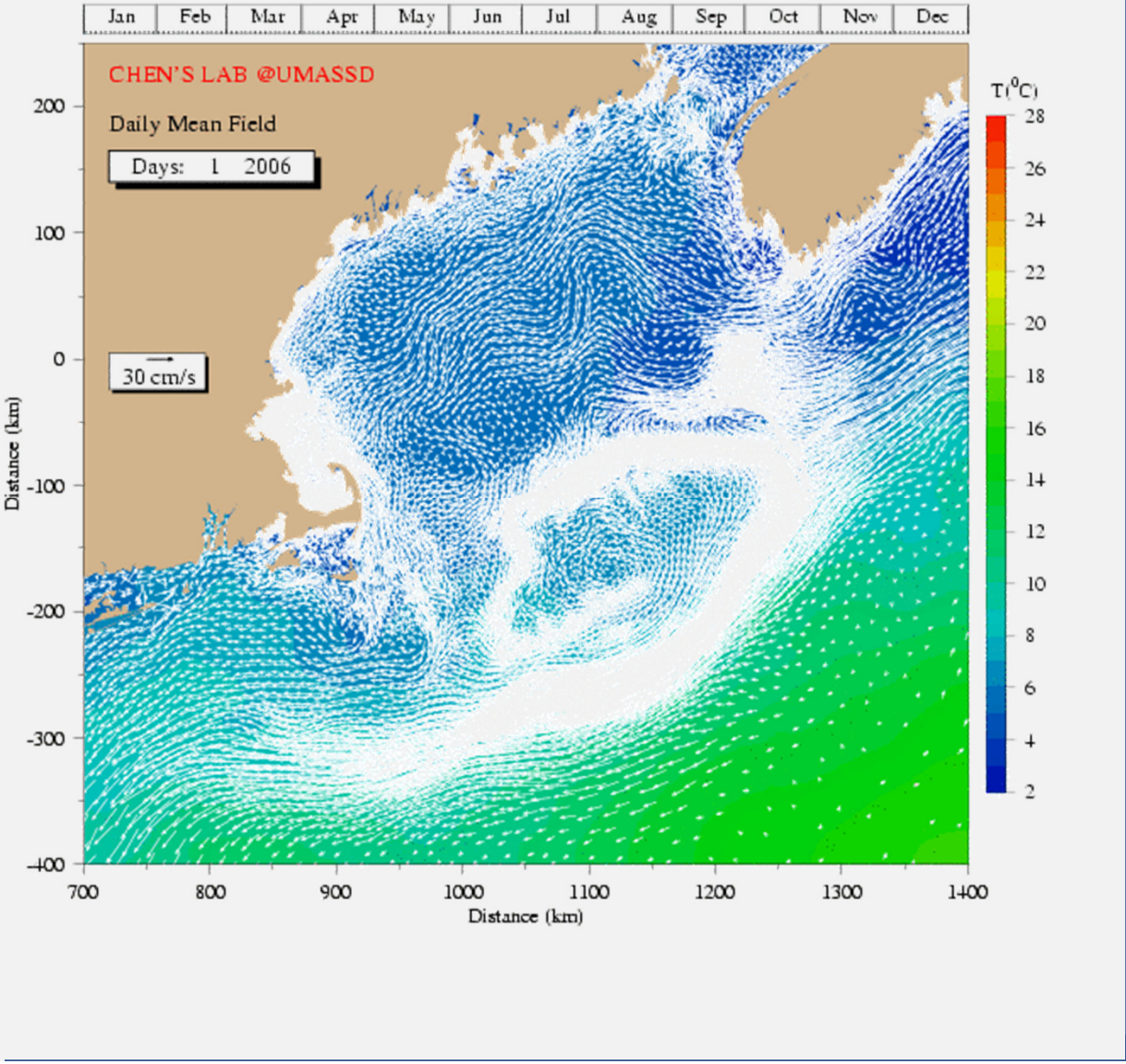
- Geographic Range
- Distribution patterns
- Fishing grounds
- Temporal Stability



https://www.nefsc.noaa.gov/ecosys/spatial-analyses/gadoid/atlantic-cod.html

Dispersal Patterns

- Early life history (eggs larvae)
  - advection-diffusion patterns (Harden Jones 1968)
  - retention mechanisms (Sinclair 1988)
  - effective dispersal (Hare & Richardson 2015)



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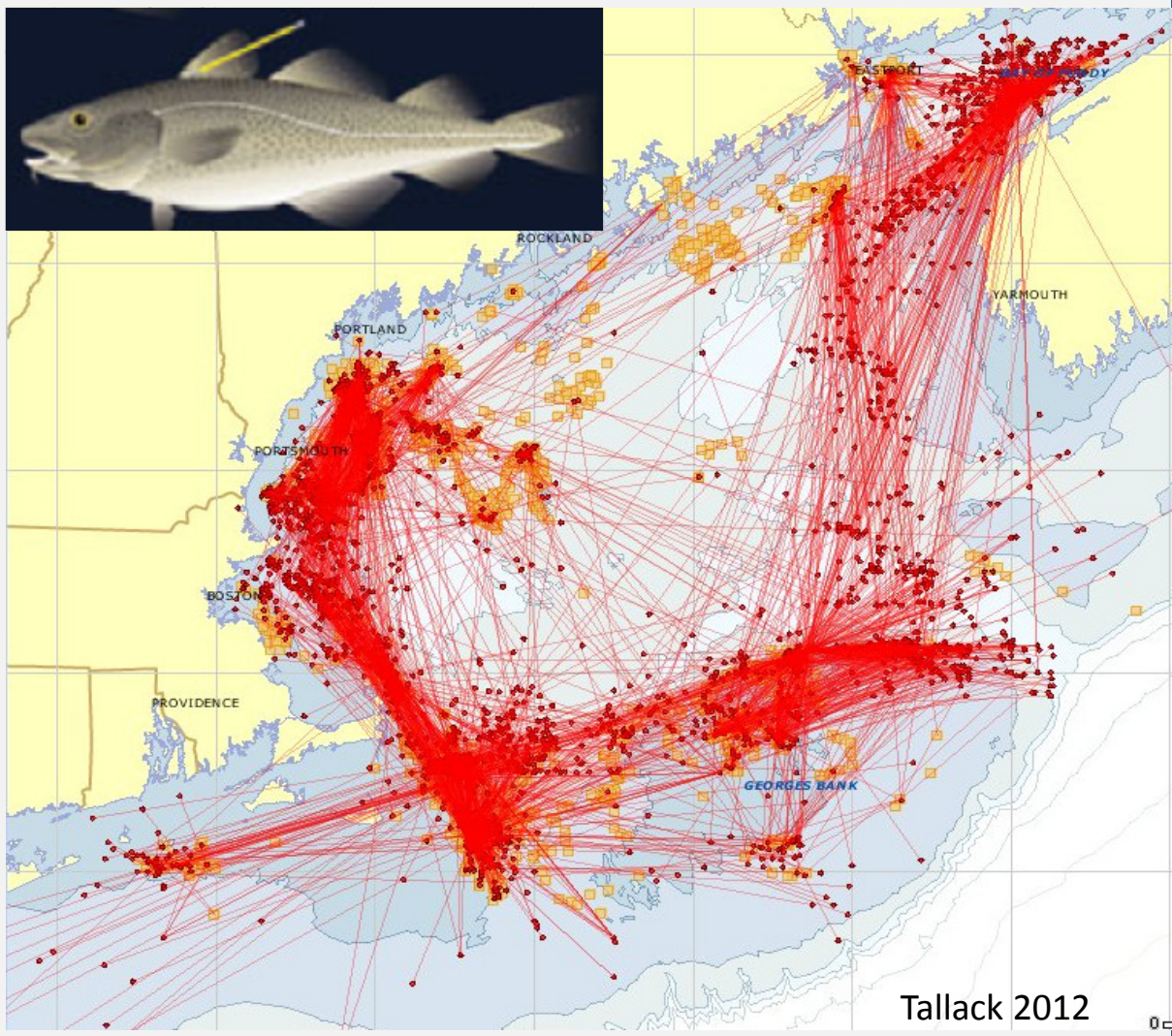
- Later life history
  - Conventional tags



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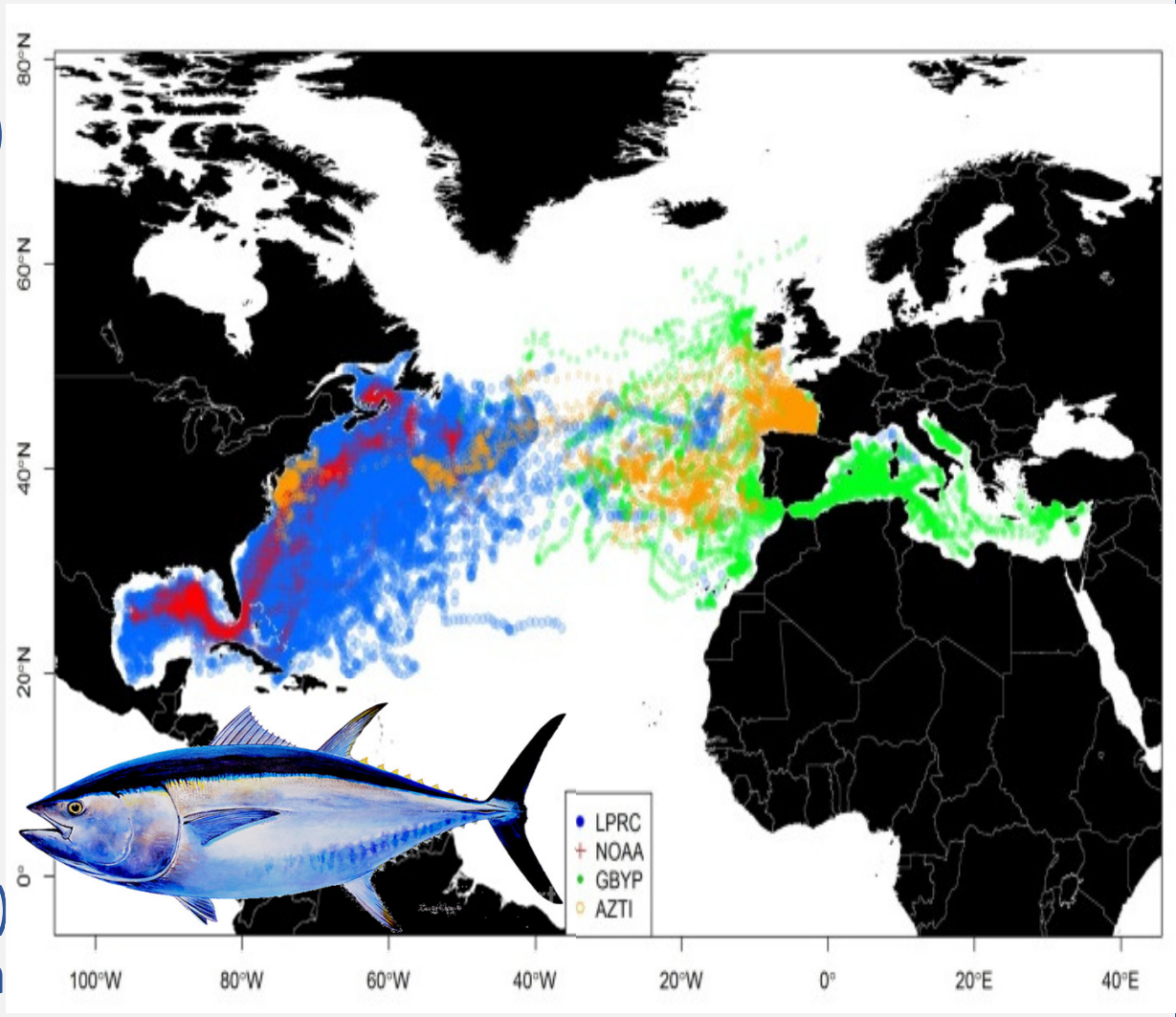
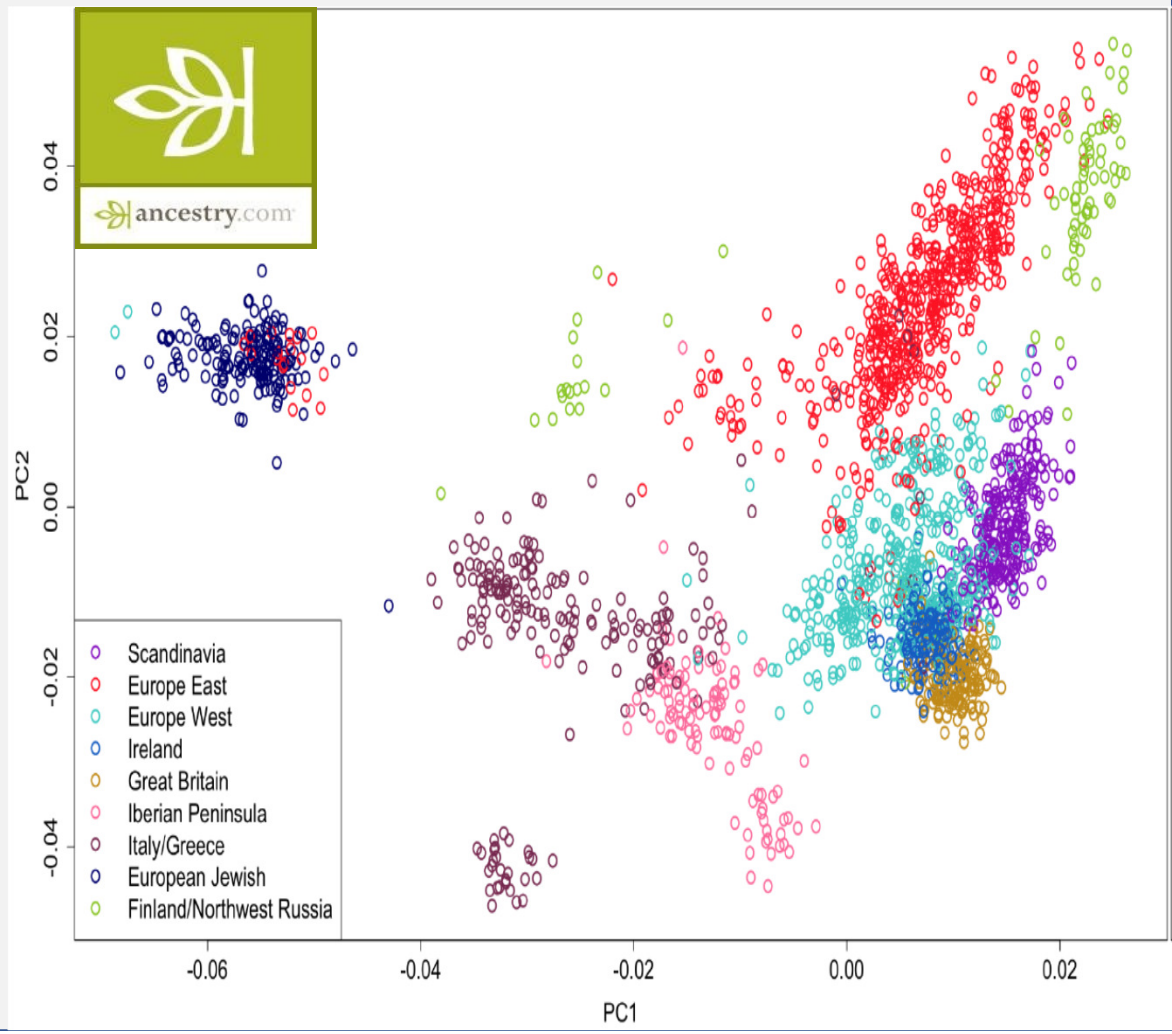
- Later life history
  - Conventional tags
  - Active telemetry or geolocation
  - Passive telemetry (spawning site fidelity, residence time, …)
  - Natural tags (parasites, otolith chemistry)



Galuardi et al. 2017

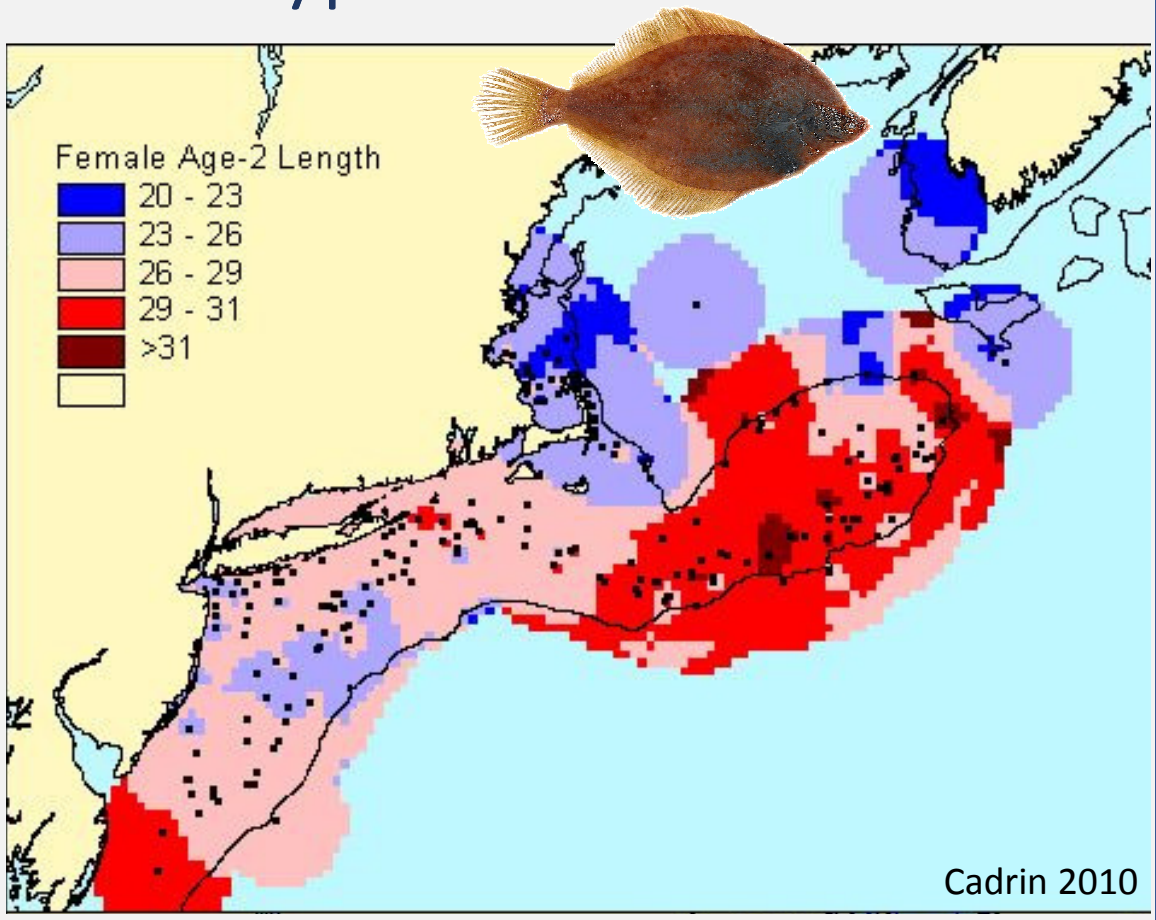
Geographic Variation in Genetic Characters

- Allozymes, mitochondrial DNA loci, nuclear characters (microsatellites, single nucleotide polymorphisms, genomics, …)
  - Functional Characters (subject to selection) – differences indicate adaptation to local environments
  - Neutral Characters (not subject to selection) – differences indicate reproductive isolation



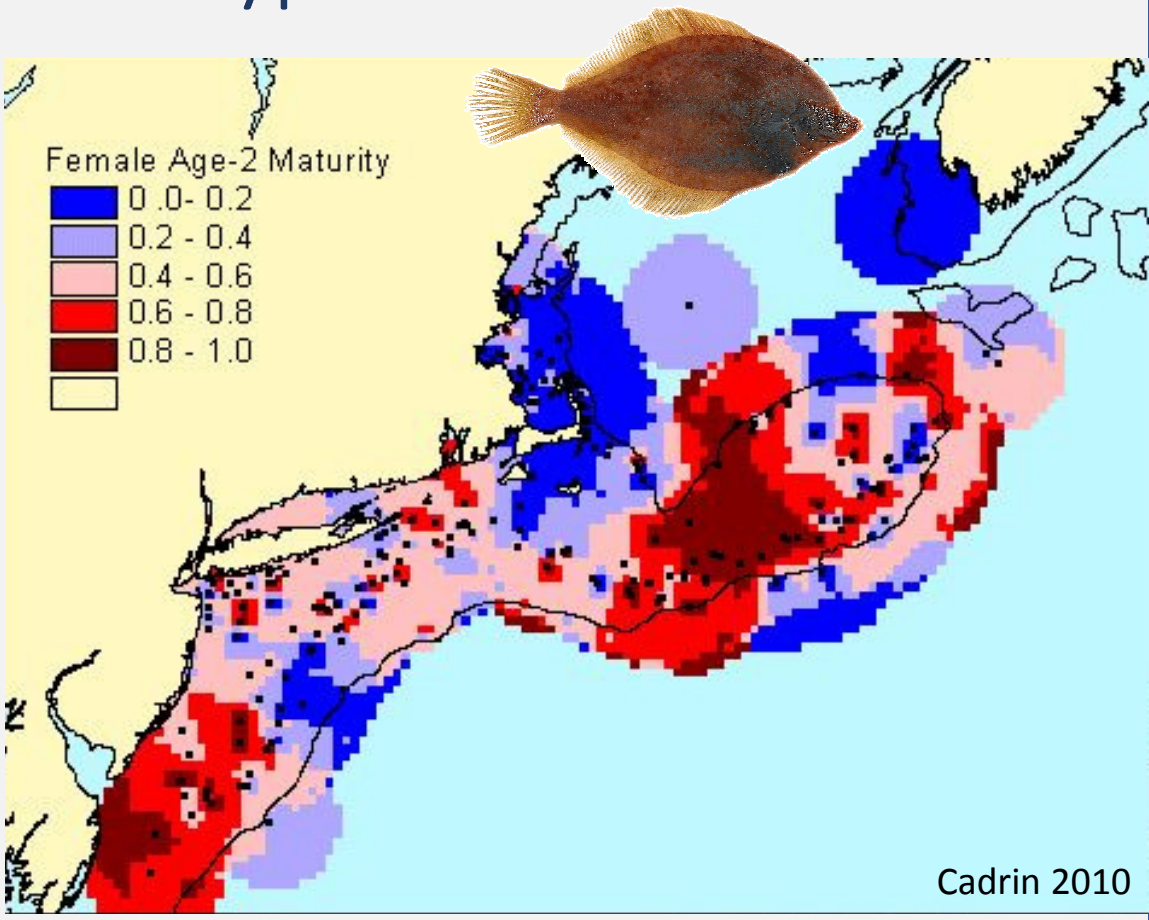
Geographic Variation in Phenotypic Characters

- Life History
  - Growth



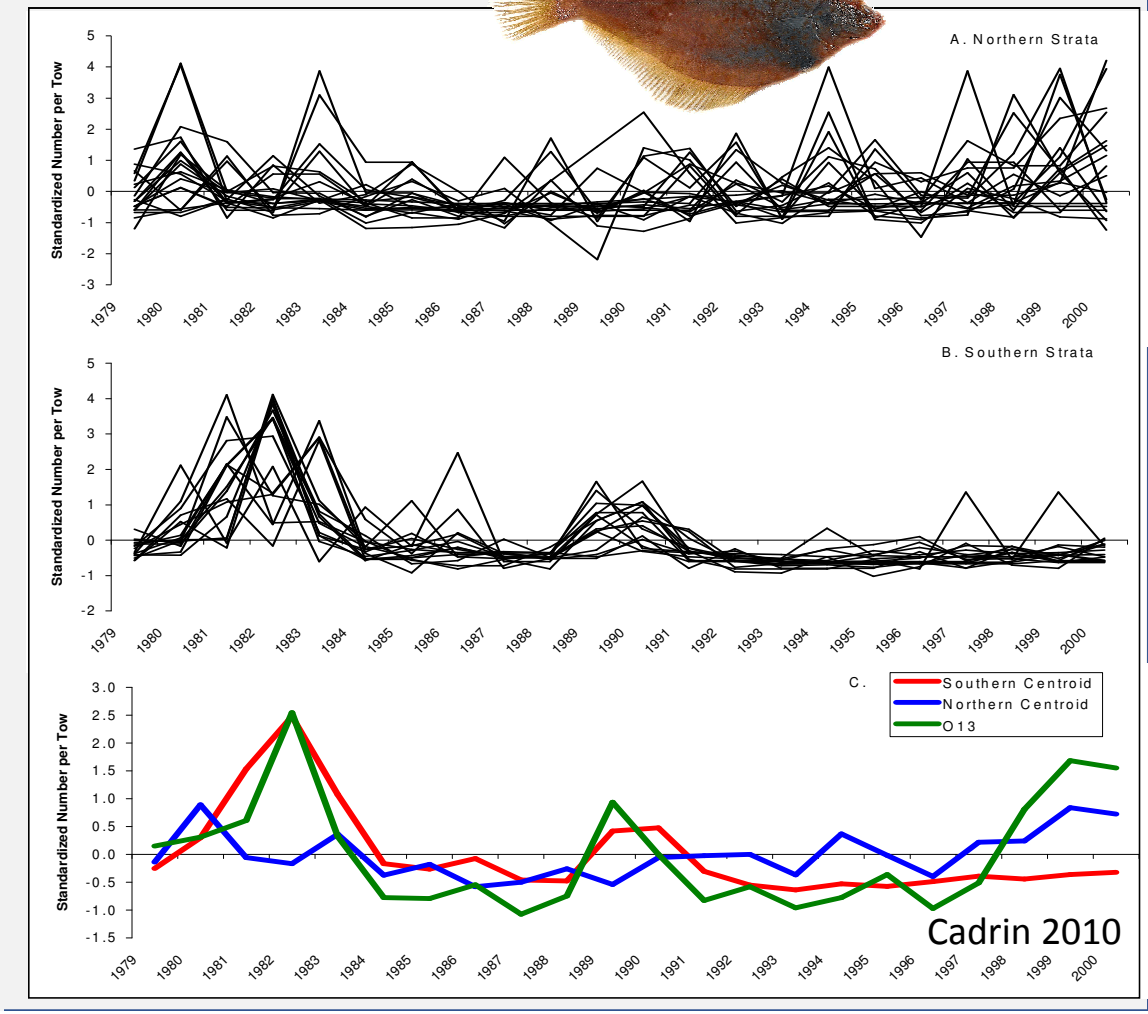
Geographic Variation - Phenotypic

- Life History
  - Growth
  - Reproduction



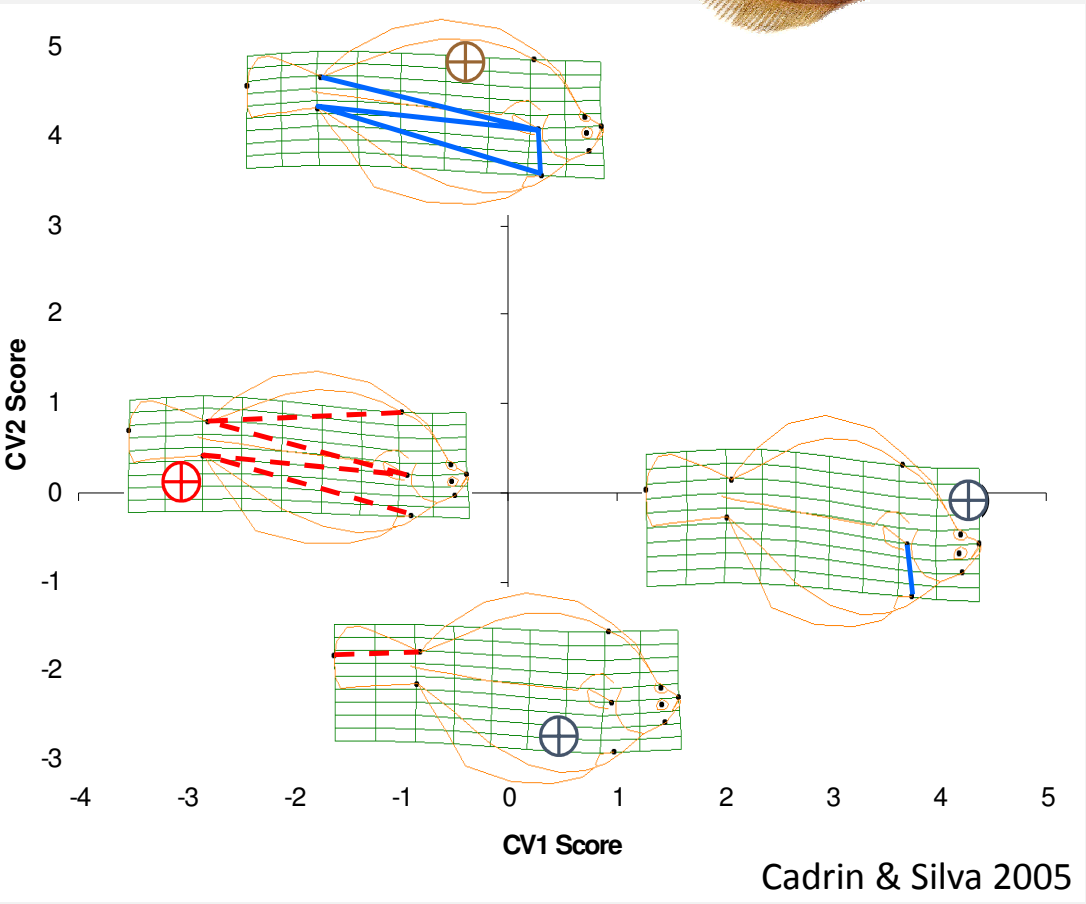
Geographic Variation - Phenotypic

- Life History
  - Growth
  - Reproduction
  - Spatial recruitment synchrony



Geographic Variation - Phenotypic

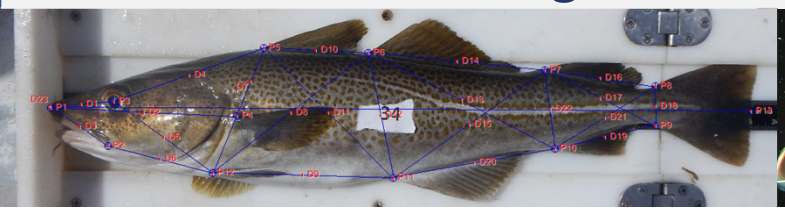
- Life History
  - Growth
  - Reproduction
  - Spatial recruitment synchrony
  - Eco-types
- Life history indicators
  - Morphometrics
  - Meristics

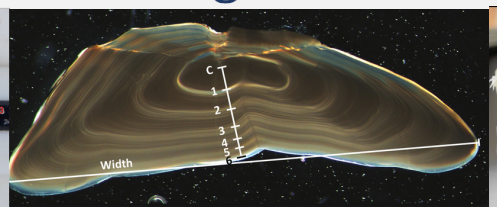


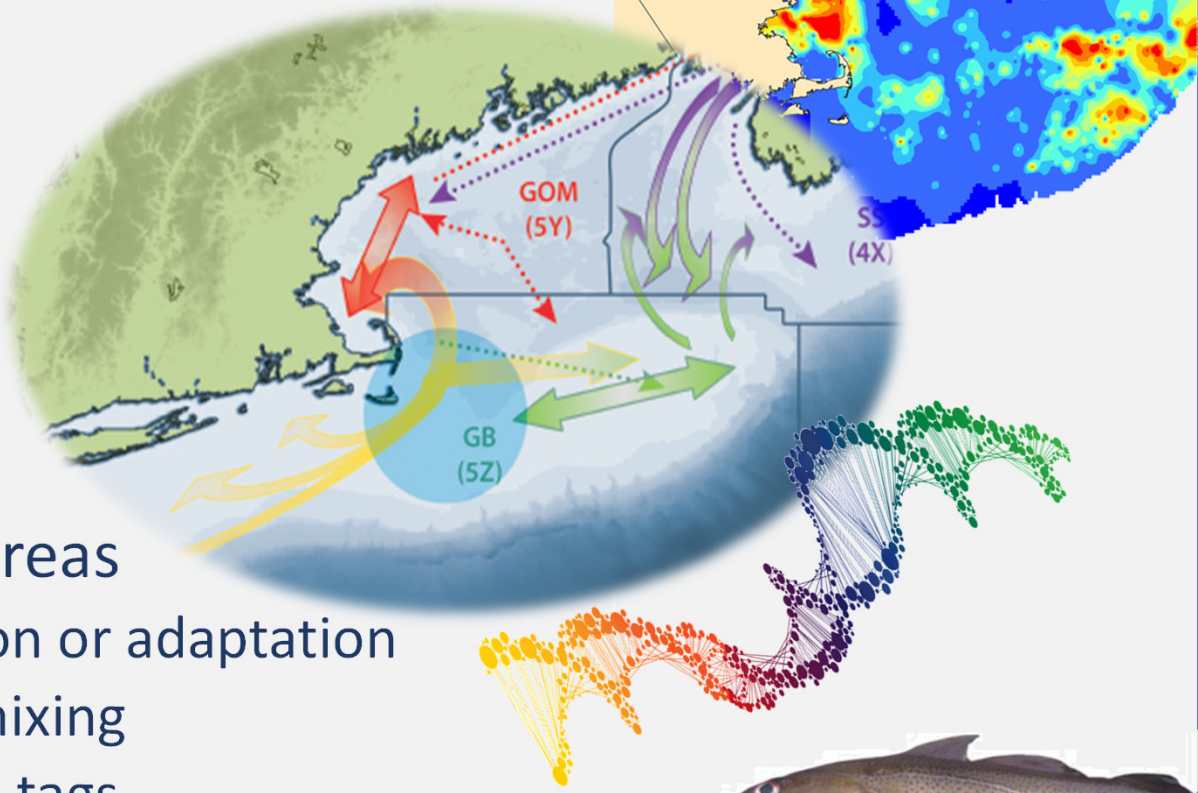
Cadrin & Silva 2005

Interdisciplinary Stock Identification

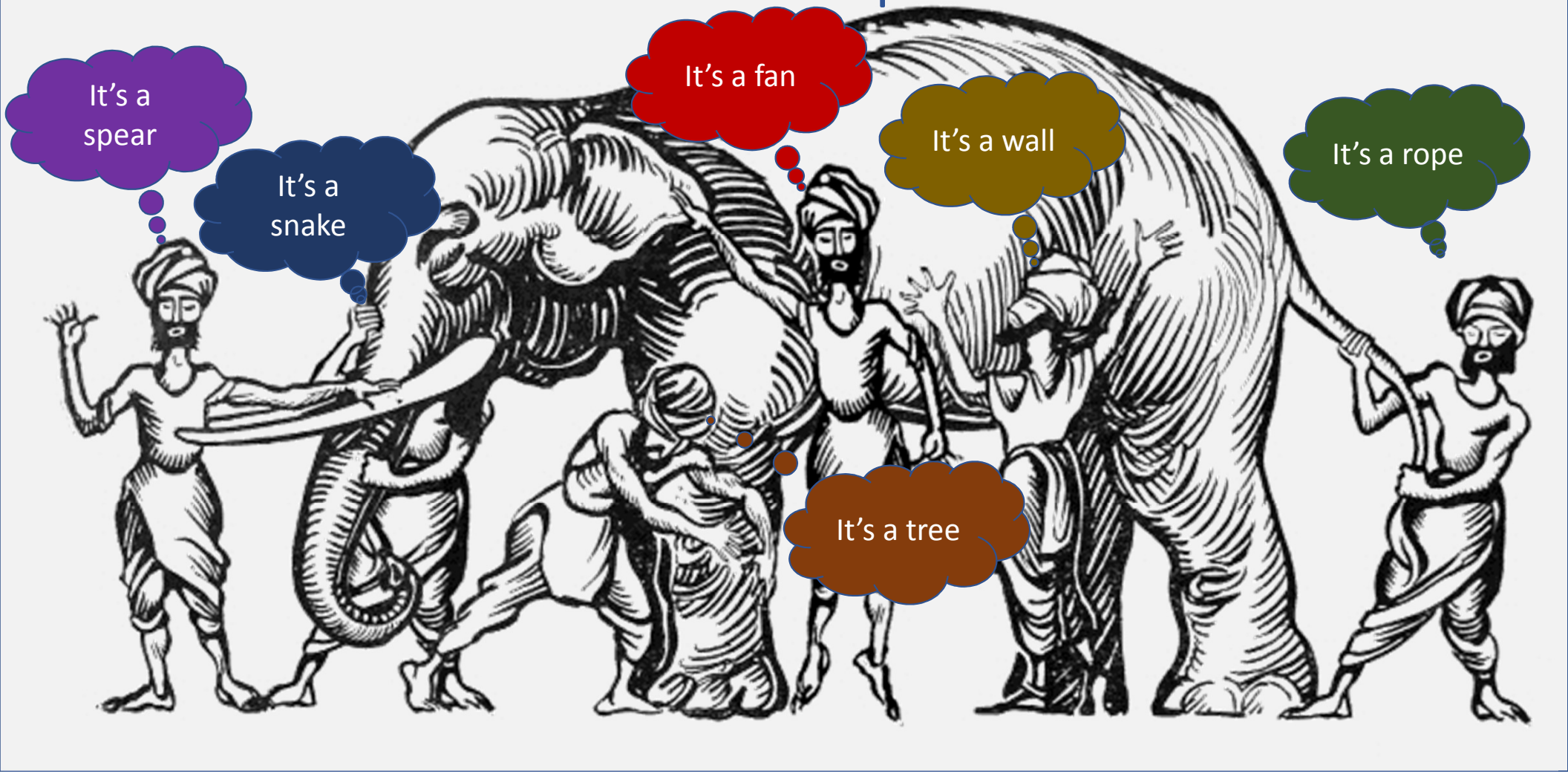
- Geographic distribution
  - Fishing grounds
  - Surveys of all life stages
- Movement among areas
  - Tagging
  - Egg & larval dispersal
- Geographic variation among areas
  - Genetics – reproductive isolation or adaptation
  - Phenotypic patterns – lack of mixing
  - Environmental signals – natural tags





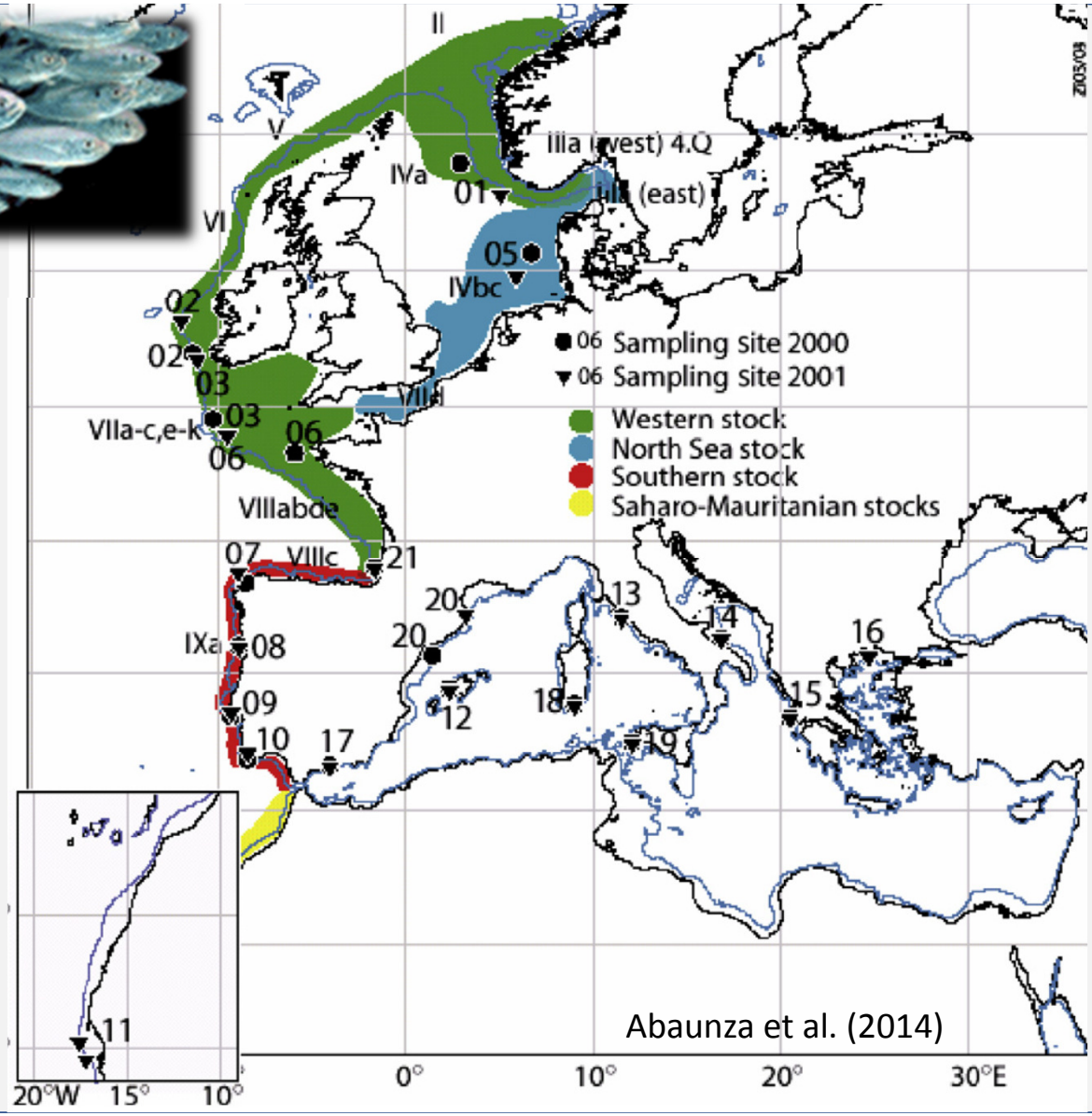


The Six Blind Men and the Elephant

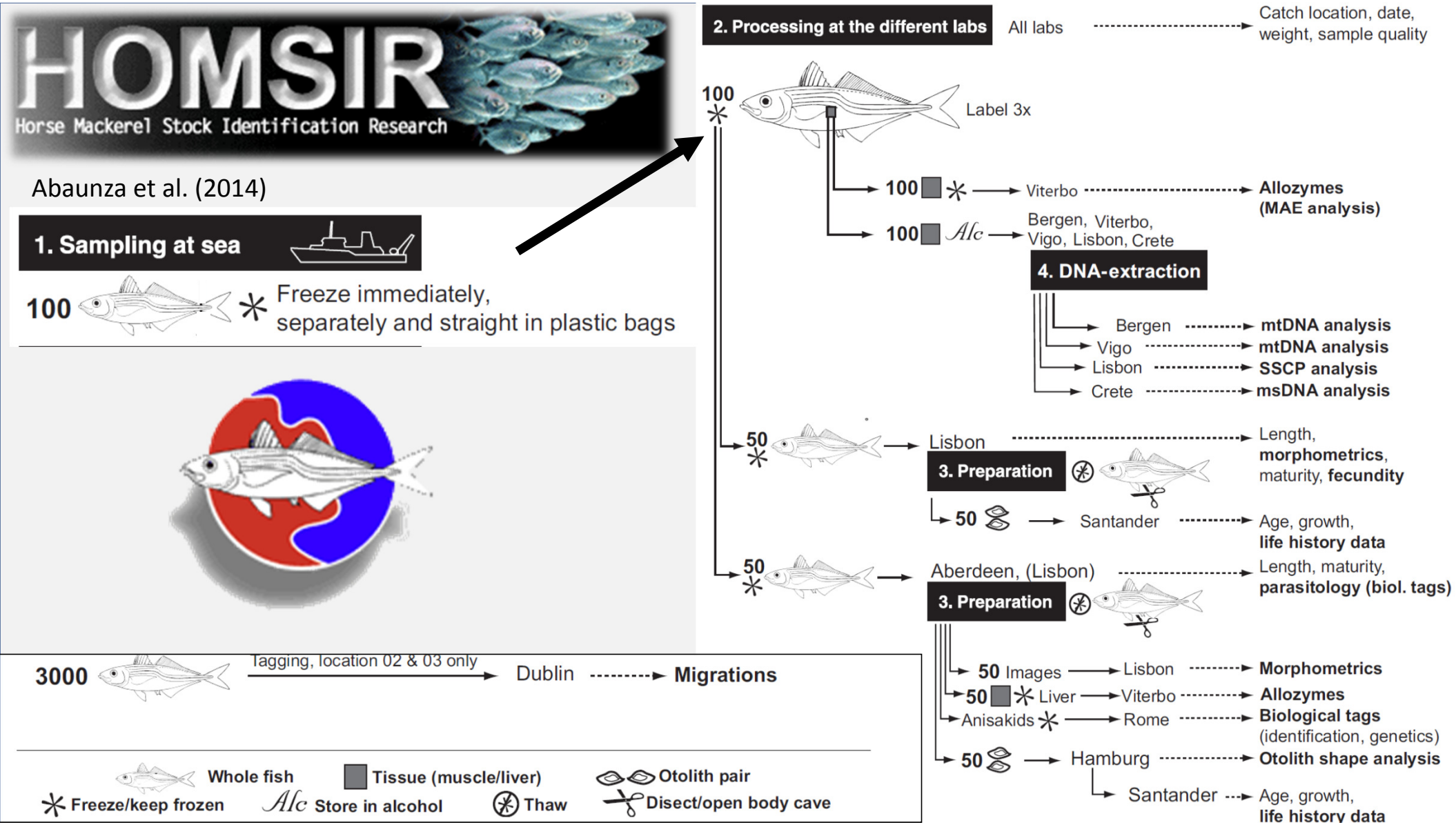


HOMSIR

Horse Mackerel Stock Identification Research

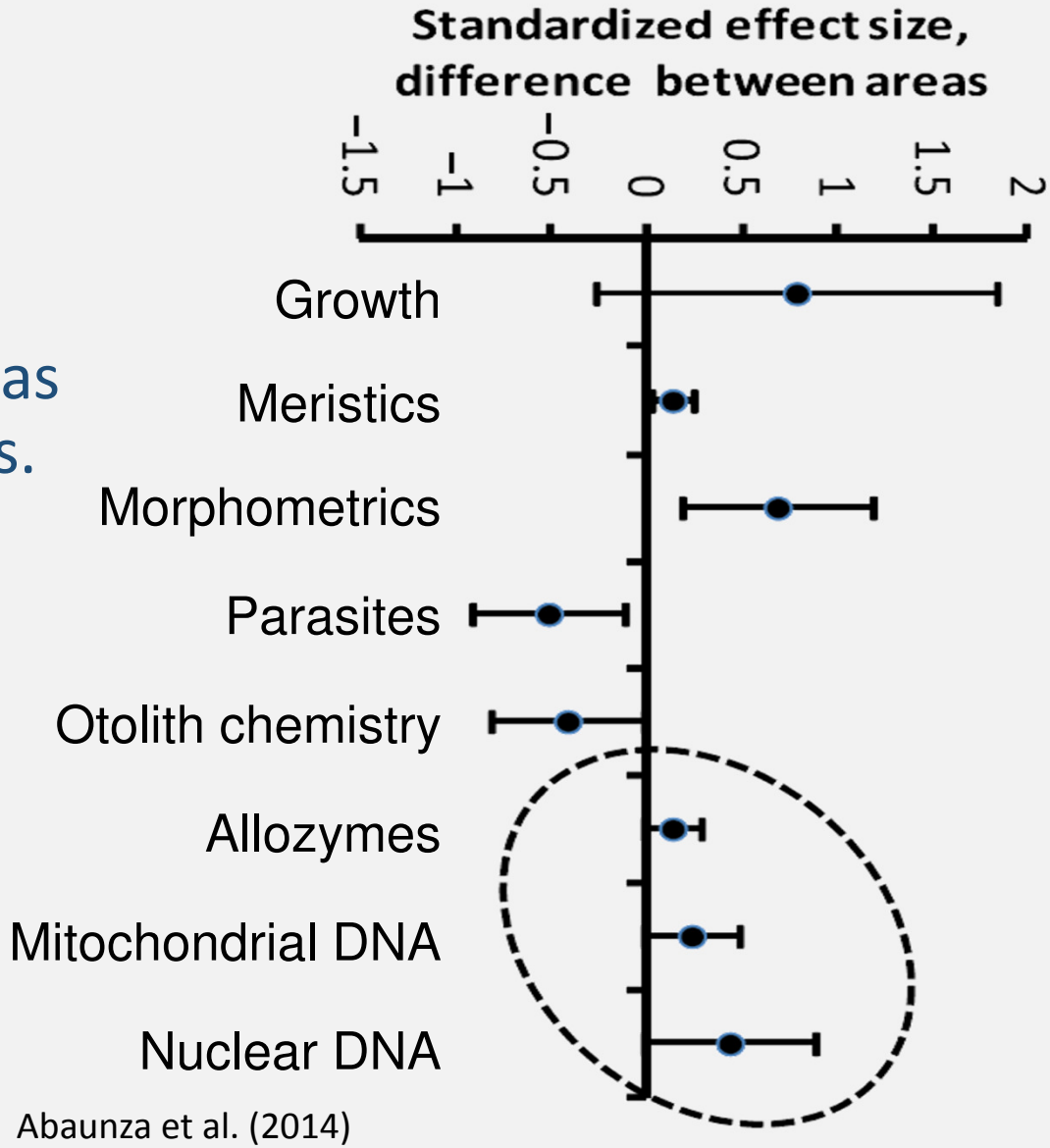


Abaunza et al. (2014)


HOMSIR
Horse Mackerel Stock Identification Research
Abaunza et al. (2014)
1. Sampling at sea
100
Freeze immediately, separately and straight in plastic bags
2. Processing at the different labs
All labs
Catch location, date, weight, sample quality
100
Label 3x
100
Viterbo
Allozymes (MAE analysis)
100
Alc
Bergen, Viterbo, Vigo, Lisbon, Crete
4. DNA-extraction
Bergen
mtDNA analysis
Vigo
mtDNA analysis
Lisbon
SSCP analysis
Crete
msDNA analysis
50
Lisbon
3. Preparation
Length, morphometrics, maturity, fecundity
50
Santander
Age, growth, life history data
50
Aberdeen, (Lisbon)
3. Preparation
Length, maturity, parasitology (biol. tags)
50 Images
Lisbon
Morphometrics
50
Liver
Viterbo
Allozymes
Anisakids
Rome
Biological tags (identification, genetics)
50
Hamburg
Otolith shape analysis
Santander
Age, growth, life history data
3000
Tagging, location 02 & 03 only
Dublin
Migrations
Whole fish
Tissue (muscle/liver)
Otolith pair
Freeze/keep frozen
Alc
Store in alcohol
Thaw
Disect/open body cave

Effect Size

- Multi-disciplinary investigation of geographic variation involves estimating differences among areas and the significance of differences.



Abaunza et al. (2014)

Stages of Stock Identification

Stage	Objective	Sample design	Analytic method
Exploratory stock identification	identify **putative groups**	all areas and seasons (multiple years)	ordination and cluster analysis of many variables
Stock discrimination	develop and test classification function	**known-group** (spawning) samples in each putative group, with sufficient replication (regularly updated)	discriminant analysis of baseline samples (and cross-validation) to identify discriminating variables and functions
Stock delineation	define stock boundaries	boundary areas (all seasons, multiple years)	classification analysis of **selected variables from mixed-group samples** for geographic analysis of scores
Stock composition	**estimate mixture**	all mixed-stock areas and seasons (each year)	mixture analysis of selected variables from mixed-group samples

Interdisciplinary Analysis

- New information from advanced methods can be reconciled with traditional information.
- Exploratory stock identification develops a population structure hypothesis based on all information
  - Geographic Distribution
  - Dispersal Patterns
  - Geographic Variation
    - Reproductive isolation
    - Demographic independence

- Stock discrimination, delineation and mixture analysis are based on the most discriminating features.

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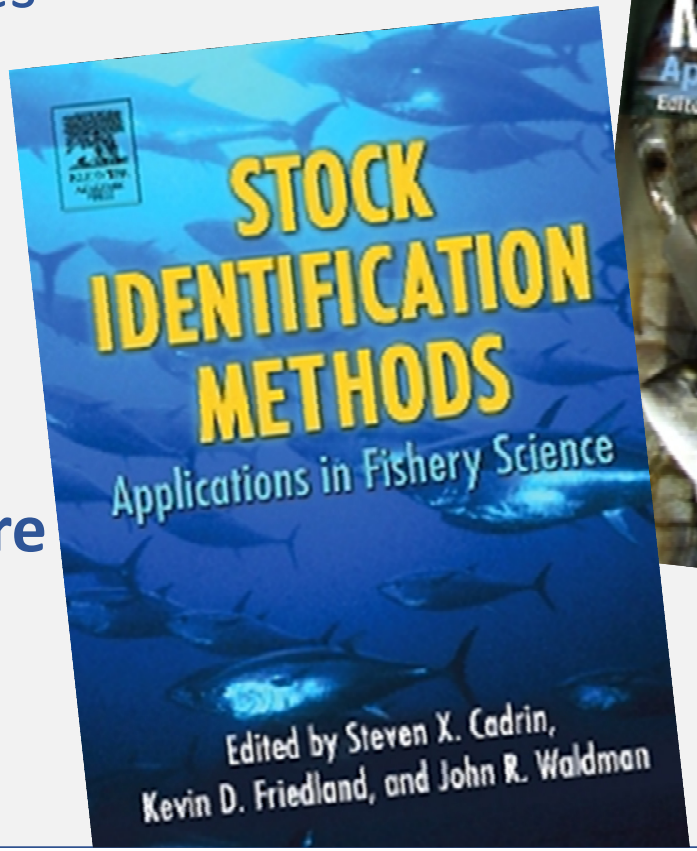
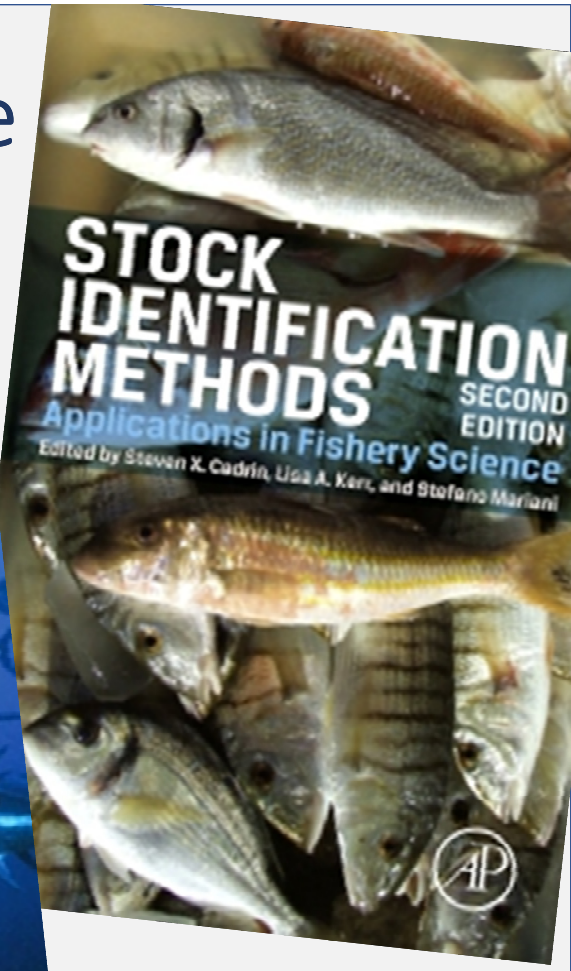
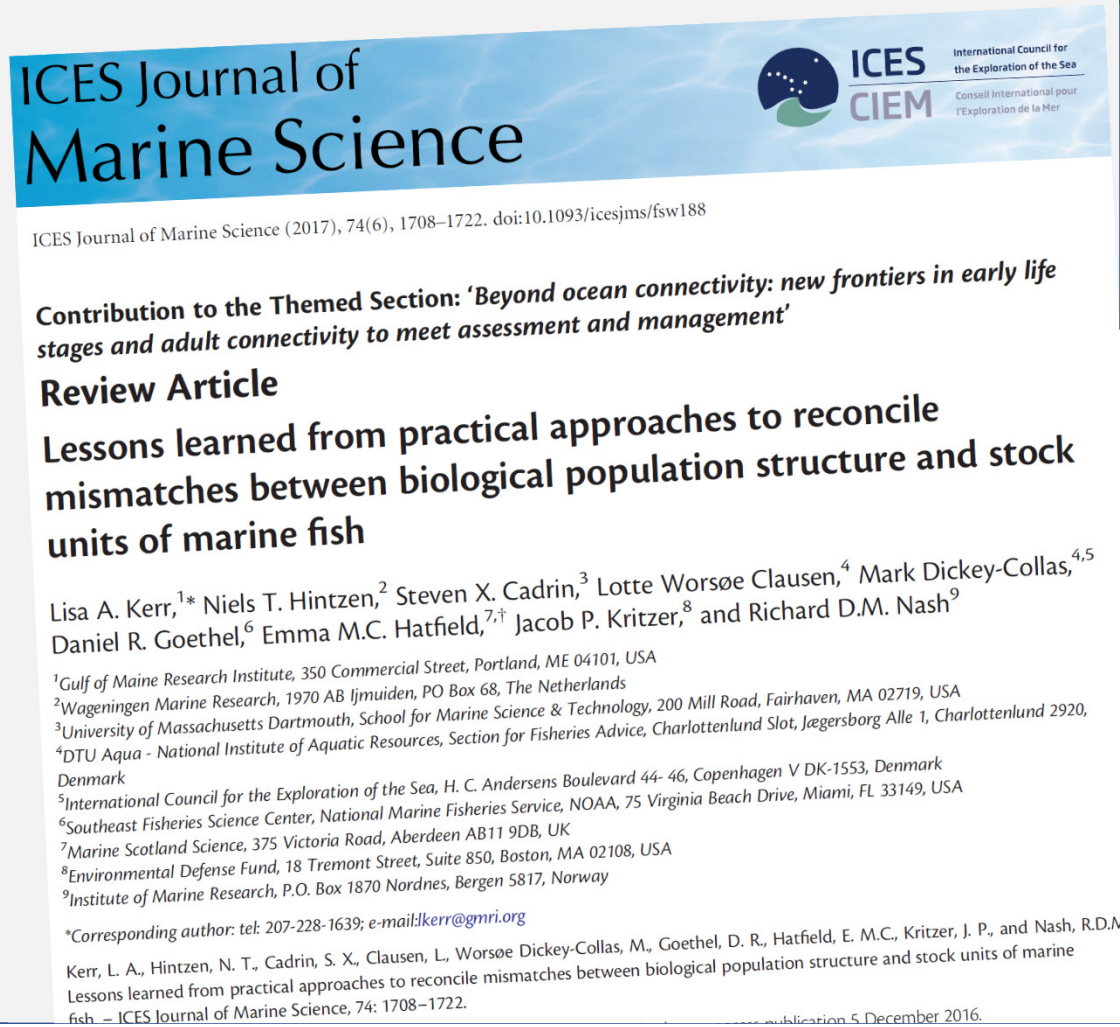




Considering Biological Population Structure in Stock Assessment

1. Holistic review of information
2. Identification of alternative options to reflect biological structure
3. Consideration of the practical limitations
4. Evaluate outcomes of alternative options relative to objectives through simulation.



ICES Journal of Marine Science

ICES International Council for the Exploration of the Sea
CIEM Conseil International pour l'Exploration de la Mer

ICES Journal of Marine Science (2017), 74(6), 1708–1722. doi:10.1093/icesjms/fsw188

Contribution to the Themed Section: *'Beyond ocean connectivity: new frontiers in early life stages and adult connectivity to meet assessment and management'*

Review Article

Lessons learned from practical approaches to reconcile mismatches between biological population structure and stock units of marine fish

Lisa A. Kerr,[1]* Niels T. Hintzen,[2] Steven X. Cadrin,[3] Lotte Worsøe Clausen,[4] Mark Dickey-Collas,[4,5] Daniel R. Goethel,[6] Emma M.C. Hatfield,[7,†] Jacob P. Kritzer,[8] and Richard D.M. Nash[9]

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[4]*DTU Aqua - National Institute of Aquatic Resources, Section for Fisheries Advice, Charlottenlund Slot, Jægersborg Alle 1, Charlottenlund 2920, Denmark*
[5]*International Council for the Exploration of the Sea, H. C. Andersens Boulevard 44- 46, Copenhagen V DK-1553, Denmark*
[6]*Southeast Fisheries Science Center, National Marine Fisheries Service, NOAA, 75 Virginia Beach Drive, Miami, FL 33149, USA*
[7]*Marine Scotland Science, 375 Victoria Road, Aberdeen AB11 9DB, UK*
[8]*Environmental Defense Fund, 18 Tremont Street, Suite 850, Boston, MA 02108, USA*
[9]*Institute of Marine Research, P.O. Box 1870 Nordnes, Bergen 5817, Norway*

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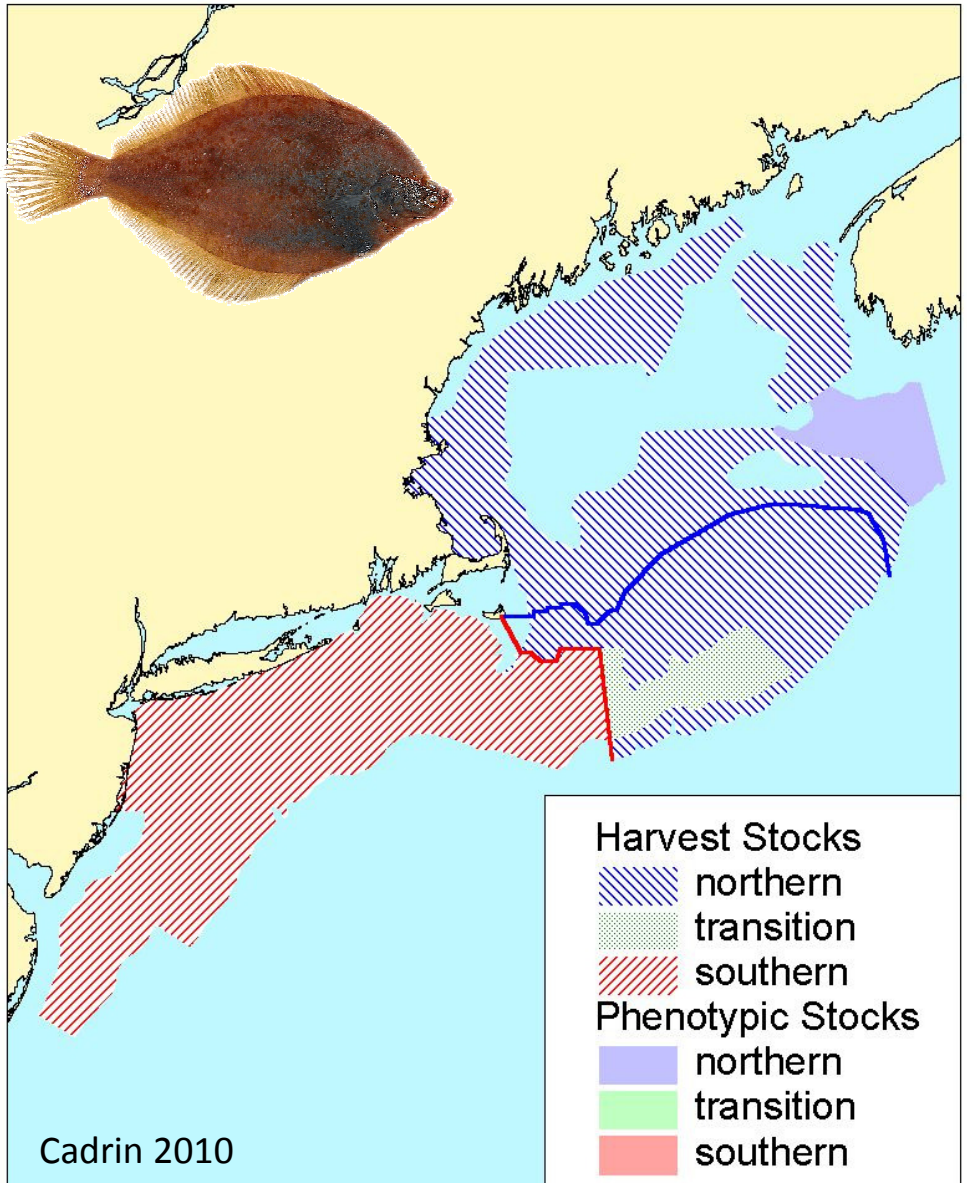
Kerr, L. A., Hintzen, N. T., Cadrin, S. X., Clausen, L., Worsøe Dickey-Collas, M., Goethel, D. R., Hatfield, E. M.C., Kritzer, J. P., and Nash, R.D.M. Lessons learned from practical approaches to reconcile mismatches between biological population structure and stock units of marine fish. – ICES Journal of Marine Science, 74: 1708–1722.

publication 5 December 2016.

Stock Delineation

- Management unit boundaries have been revised based on stock identity
  - Yellowtail flounder (Cadrin 2010)
  - Horse mackerel (Abaunza 2014)
  - Beaked redfish (Cadrin et al. 2011)



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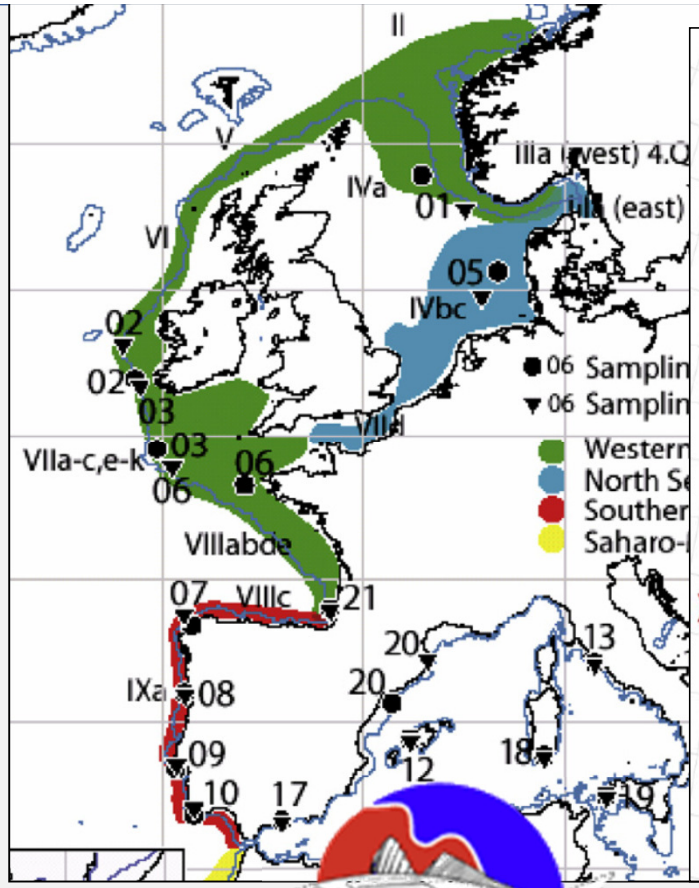

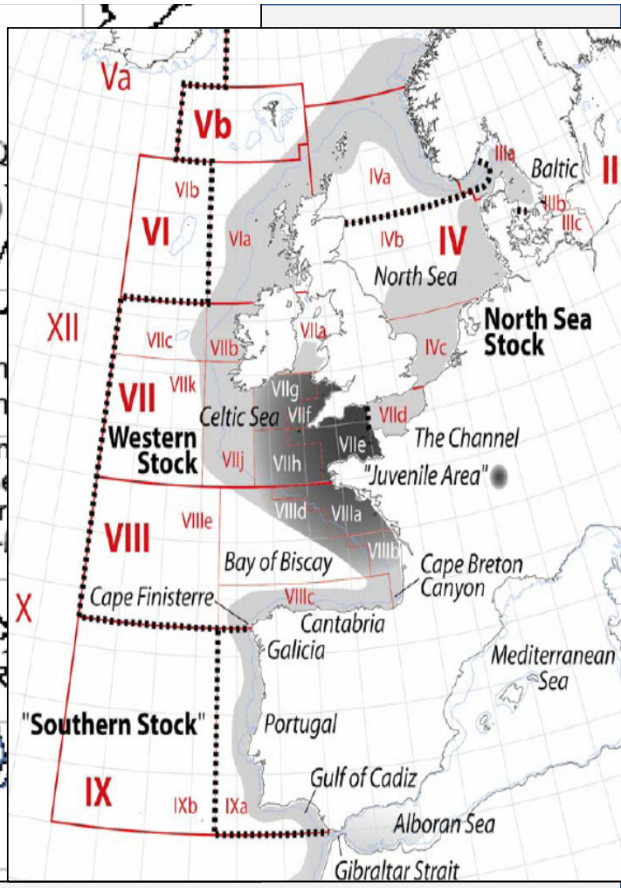

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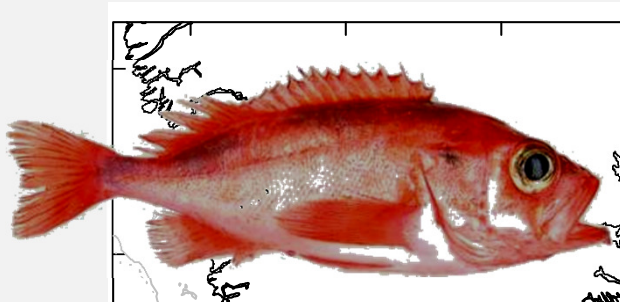
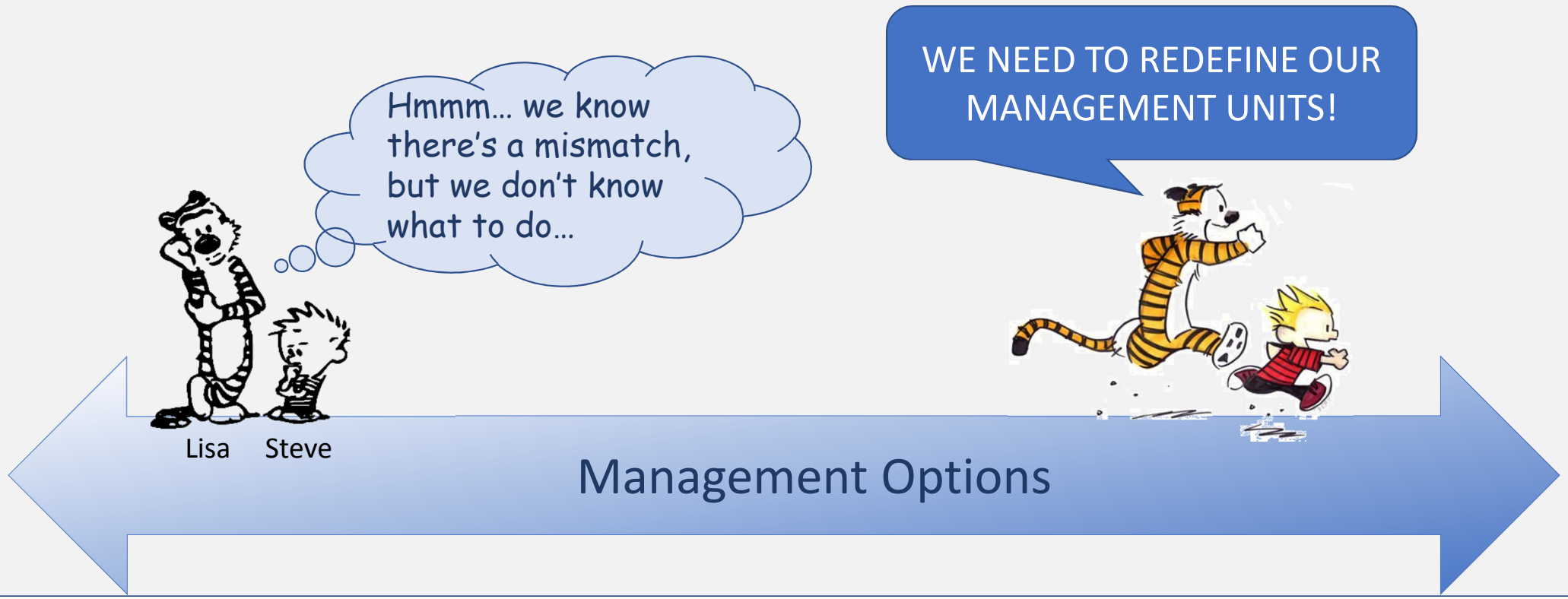


Cadrin et al. (2011)

Alternative Assessment & Management Approaches

- There are several other alternatives for improving assessment and management when there are mismatches between biological units and management units (Kerr et al. 2017).



Options for Spatially Complex Stocks

- Status quo (simple) assessment and management
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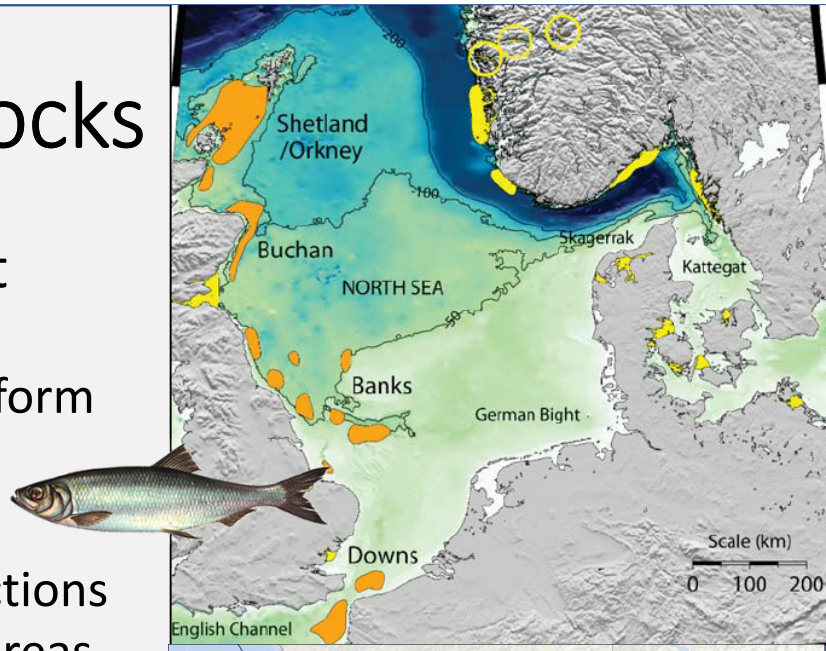
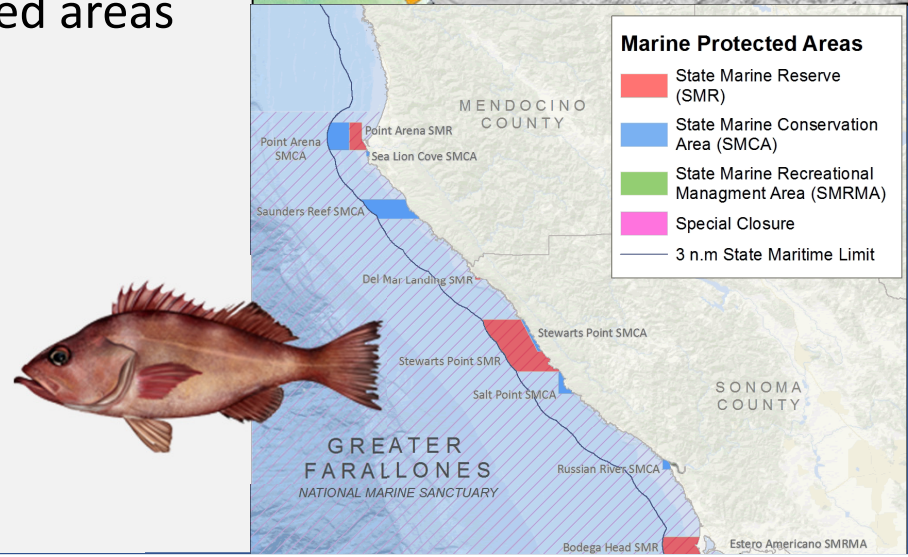
  - Catch allocations based on spatial indices, protected areas based on life history or habitat





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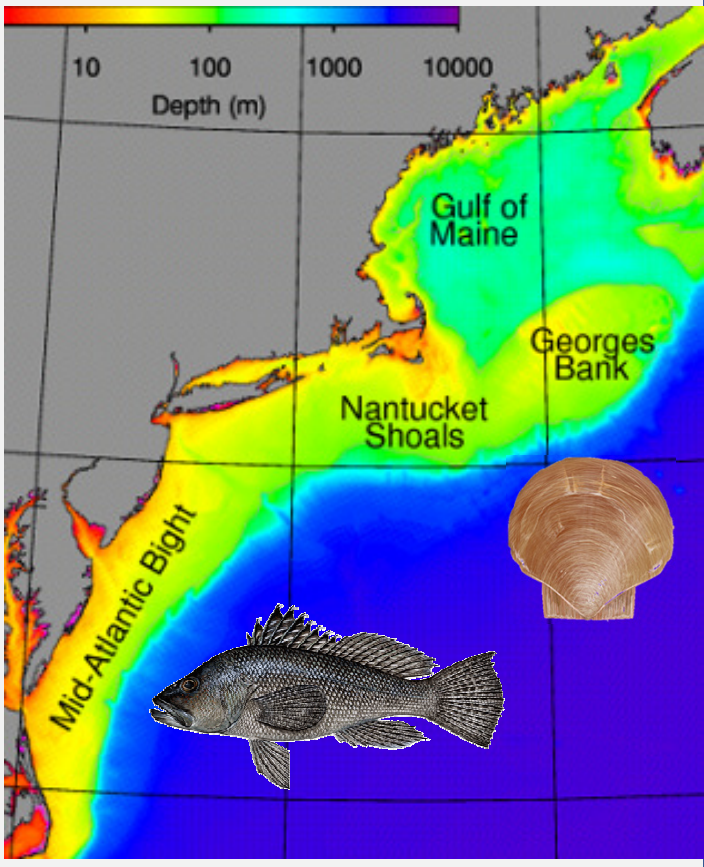
- Complex assessment and simple management
  - Spatially explicit assessment
  - Spatially aggregated management



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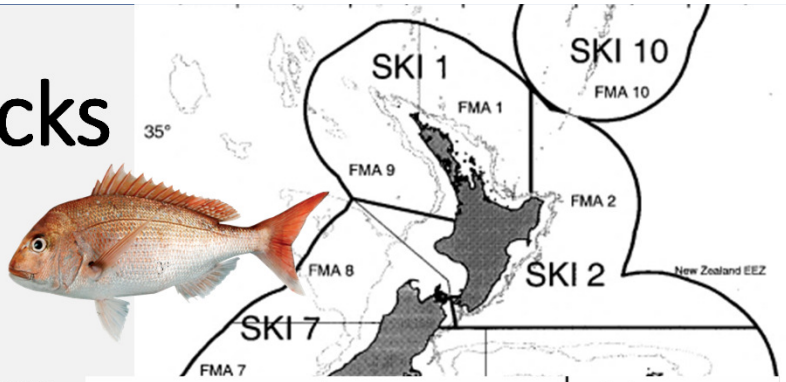
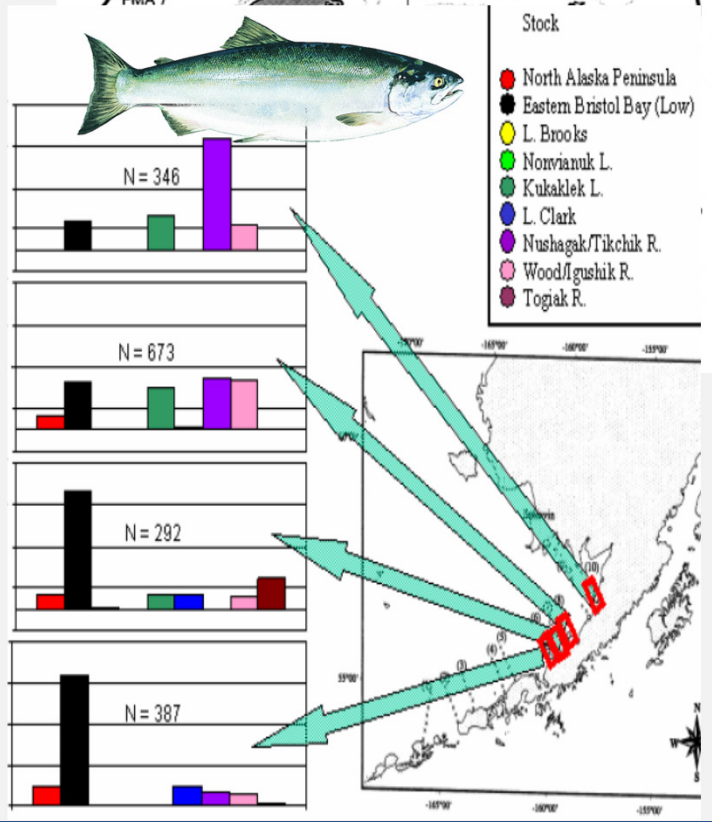
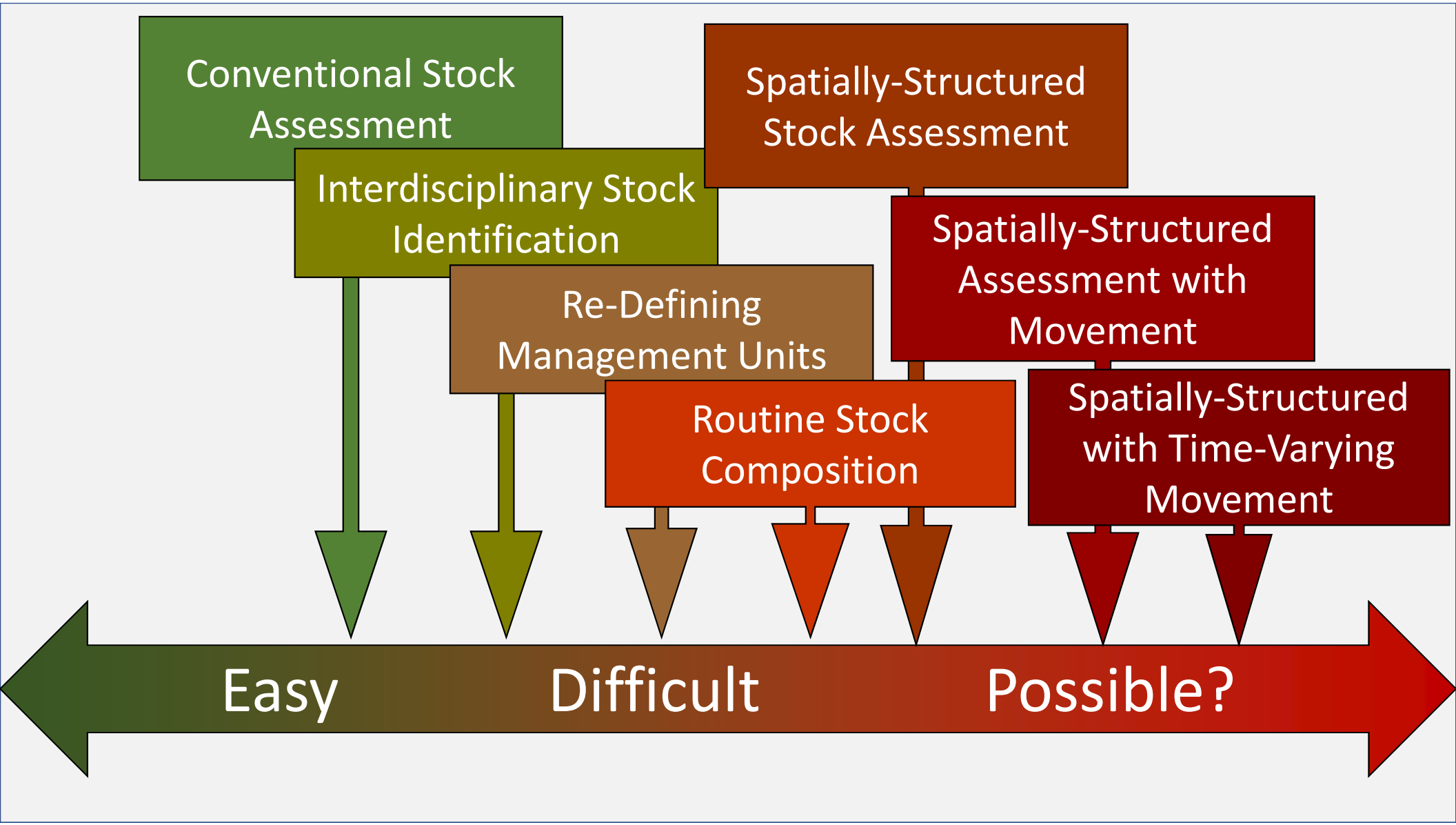
  - Spatially aggregated management
- Spatially complex assessment and management
  - Spatial structure in assessment model
  - Stock composition sampling and estimation





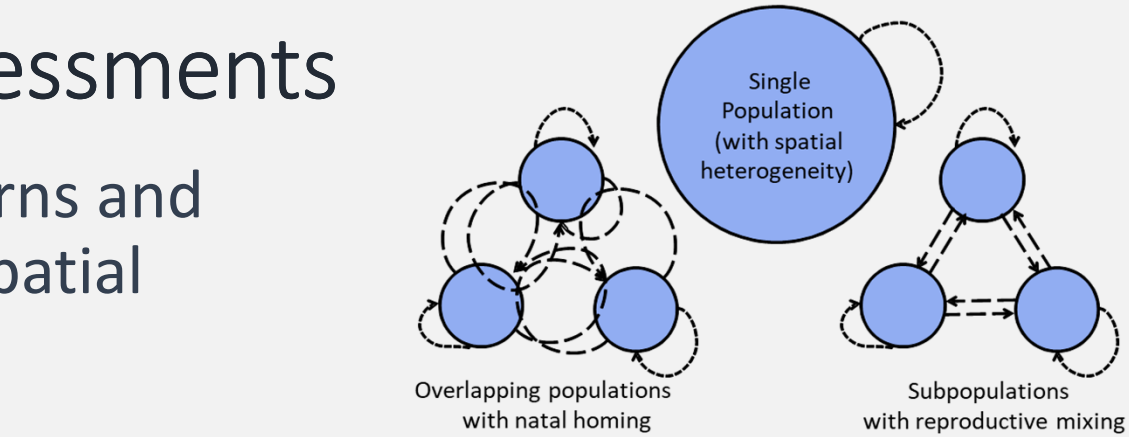

Conventional Stock Assessment
Interdisciplinary Stock Identification
Re-Defining Management Units
Routine Stock Composition
Spatially-Structured Stock Assessment
Spatially-Structured Assessment with Movement
Spatially-Structured with Time-Varying Movement
Easy
Difficult
Possible?

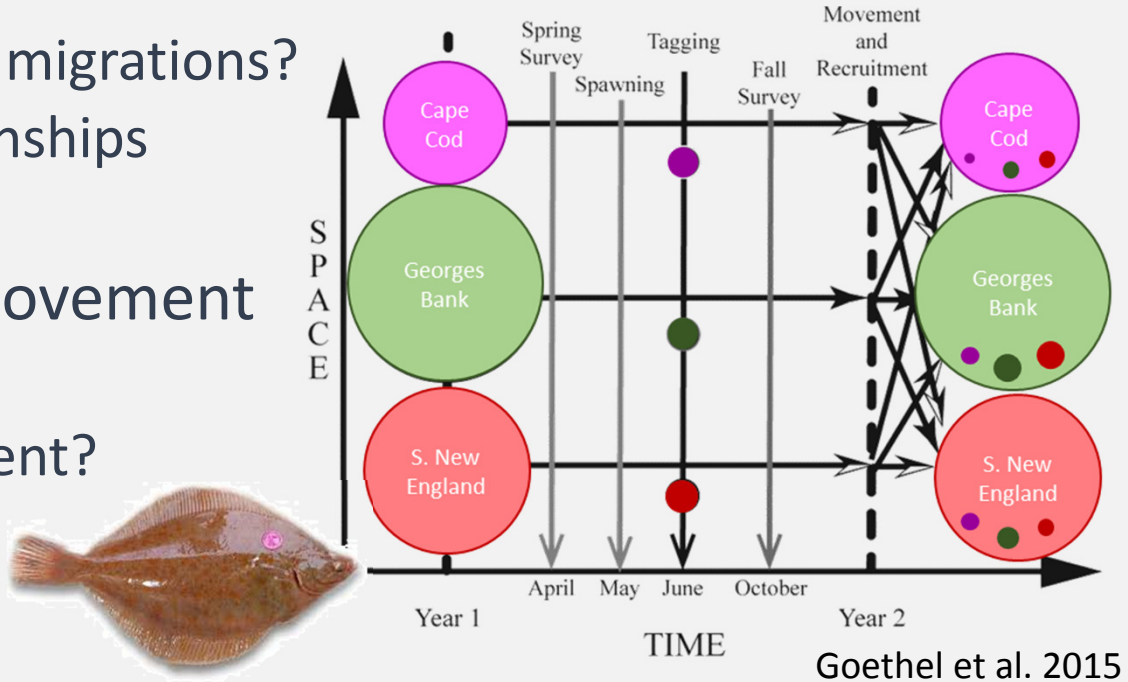
Costs & Benefits of Revised Management Units

- Transition costs
  - Develop new stock assessment
  - Develop new management procedure
- Monitoring costs?
  - Spatially explicit fishery monitoring
  - Routine stock composition sampling
- Benefits
  - More explicit management objectives?
  - More effective fisheries management?

Spatially-Structured Assessments

- Account for spatial fishing patterns and demographically independent spatial components
  - Areas-as-fleets?
  - Seasonal structure to account for migrations?
  - Distinct stock-recruitment relationships reflect reproductive isolation
- Tag-integrated models inform movement rates among areas
  - Constant or time-varying movement?
  - Short-term or long-term tagging?





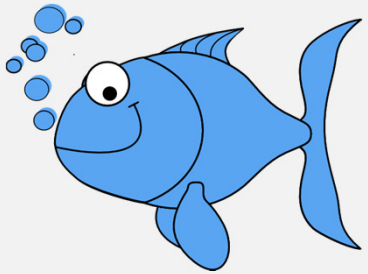
Goethel et al. 2015

Spatially-Structured Assessments

- Methods have been well established.
- "*Limited examples where spatial assessment models are used as the basis for management advice*" (Berger et al. 2017)
  - Spatially-structured models are complex, data-hungry, and difficult to fit and interpret.
  - Spatially-structured models have challenging policy implications (e.g., allocations, reference points).

Spatial Operating Model for Simulation Testing

- Developing a spatially-complex operating model that represents most likely biological population structure and fisheries is a challenge
  - Generic ('fish-like') operating model
    - + Can help to inform best practices
    - - Results may not represent the system of interest



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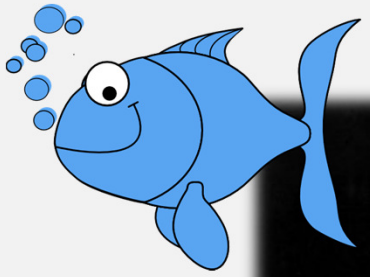

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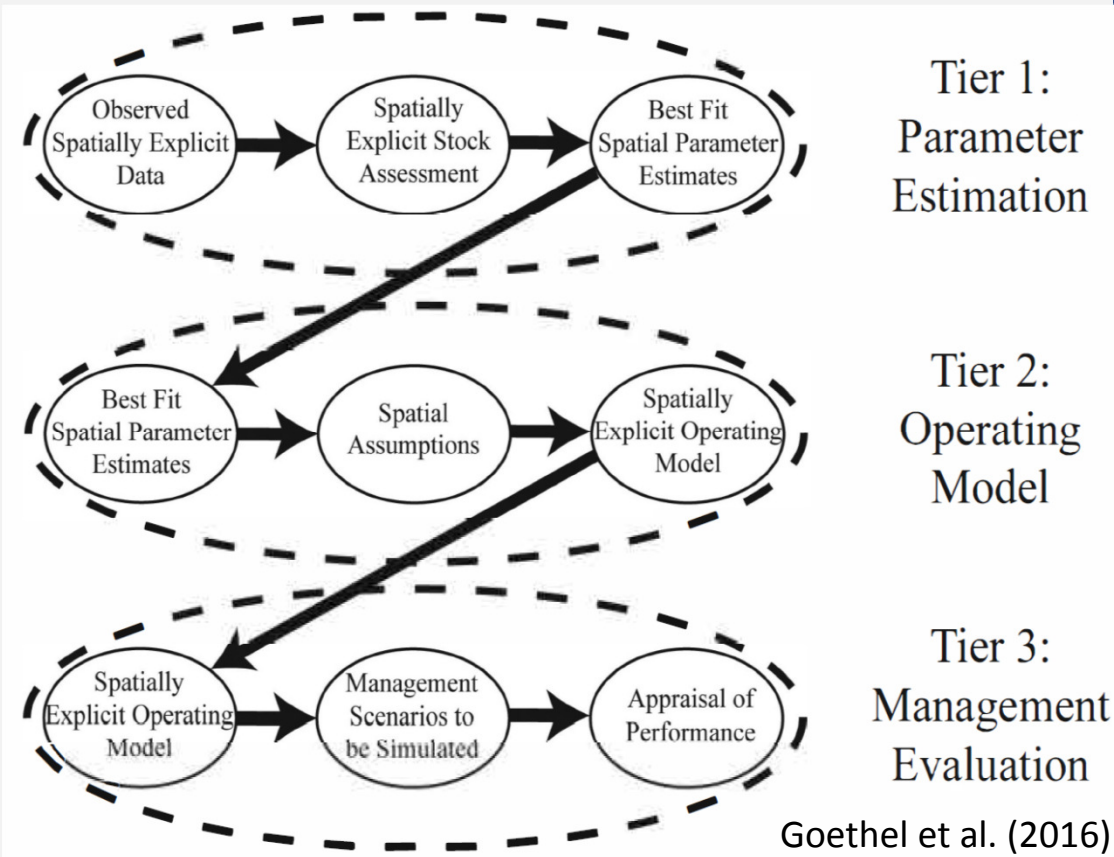
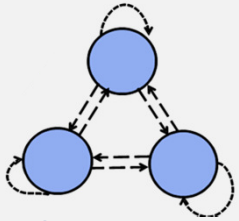
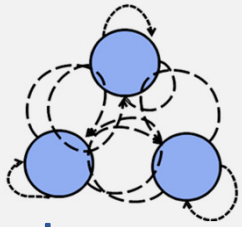
    - - Parameter values may not optimally fit the available data
  - Operating model conditioned on complex estimation model
    - + The parameter values fit available data
    - - Often over-parameterized and unstable



Goethel et al. (2016)



Conclusions



- Interdisciplinary stock identification can determine the most likely spatial structure that is consistent with all information available.
- There are several options for addressing mis-matched population structure, assessment units and management units, with practical considerations.
  - The best alternative should be determined from performance testing.
  - The primary role of spatially complex stock assessment models may be to condition operating models for simulation testing.
- As advances in stock identification methods are applied to more fisheries, detecting spatial complexities is expected, so guidance on best practices in spatially-structured stock assessment models is needed.