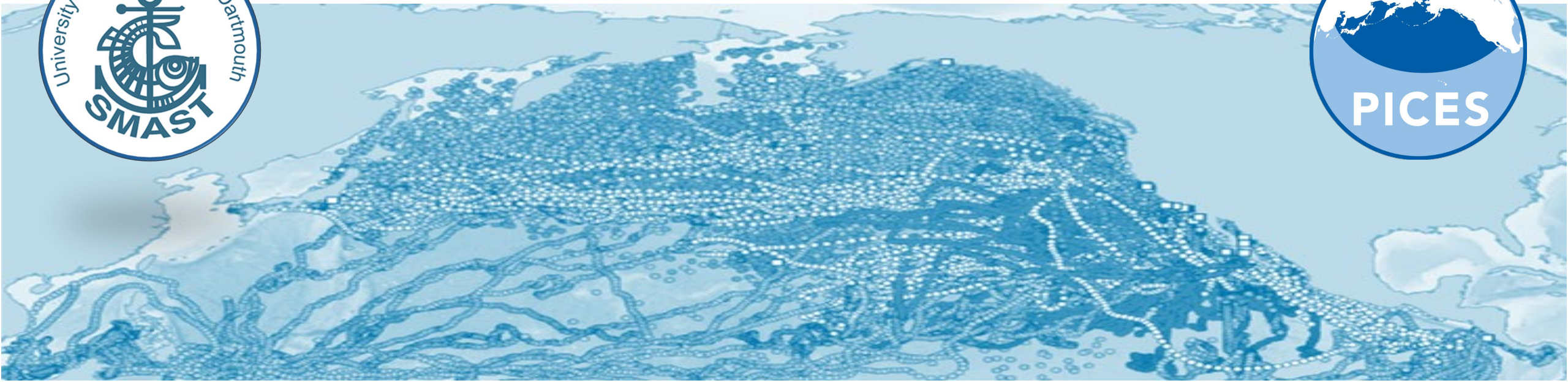
Considering Complex Connectivity in a Changing Ocean for Sustainable Fisheries



Block et al. 2011

Steve Cadrin

University of Massachusetts Dartmouth, School for Marine Science and Technology

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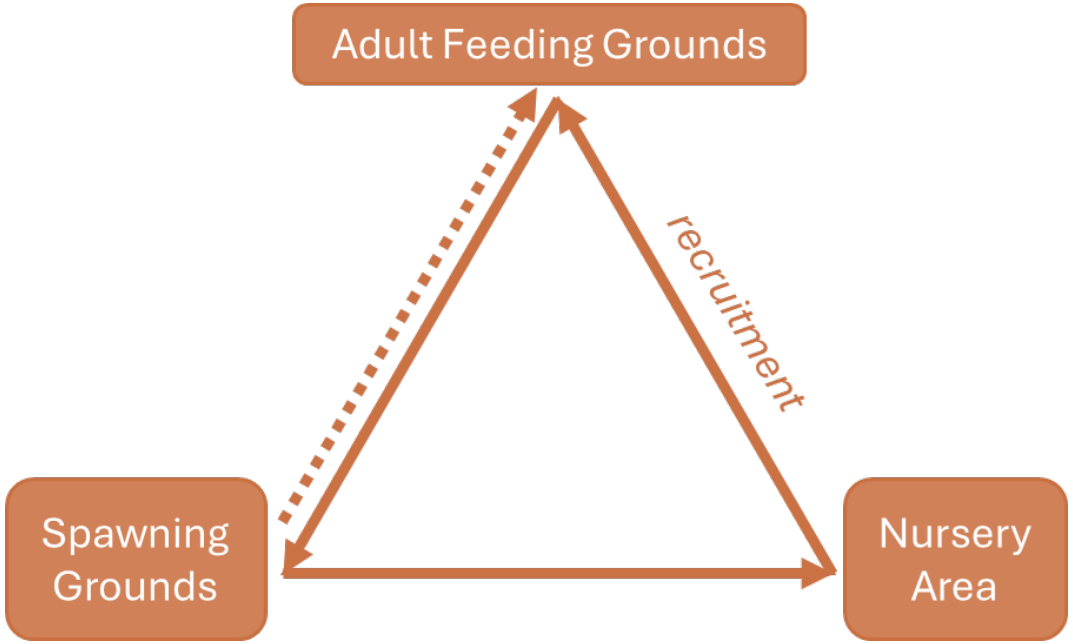
PICES 2026 session 11 “Approaches to Understanding Population Connectivity and Its Impacts”

Introduction

- Professor at the University of Massachusetts School for Marine Science & Technology, New Bedford, Massachusetts USA
  - Stock assessment
  - Scientific advice for fisheries management
  - Stock identification and spatial population modeling



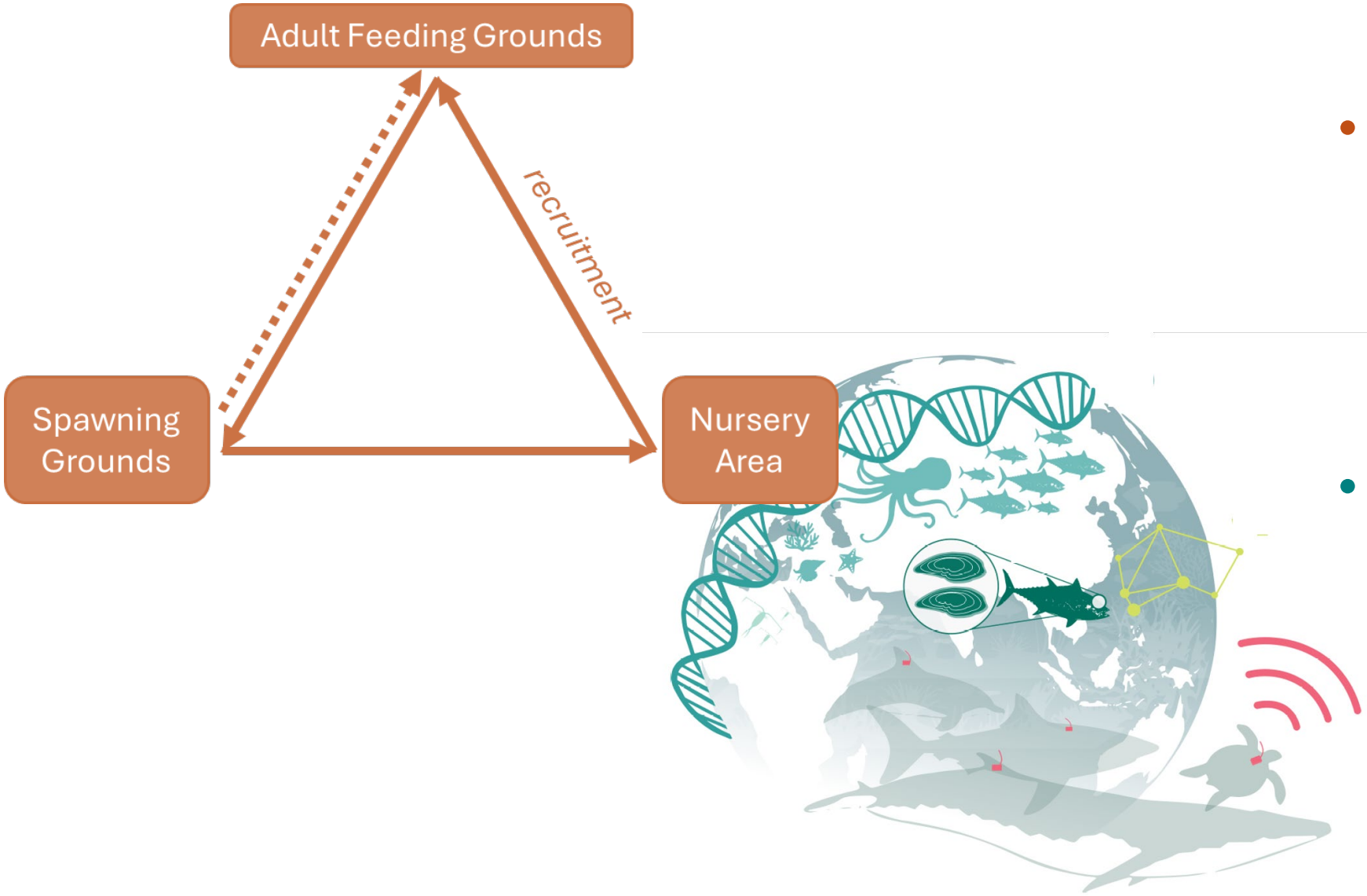
Considering Complex Connectivity



Harden Jones 1968

- Traditional fishery science identified unit stocks and simple migration circuits for transgenerational connectivity.

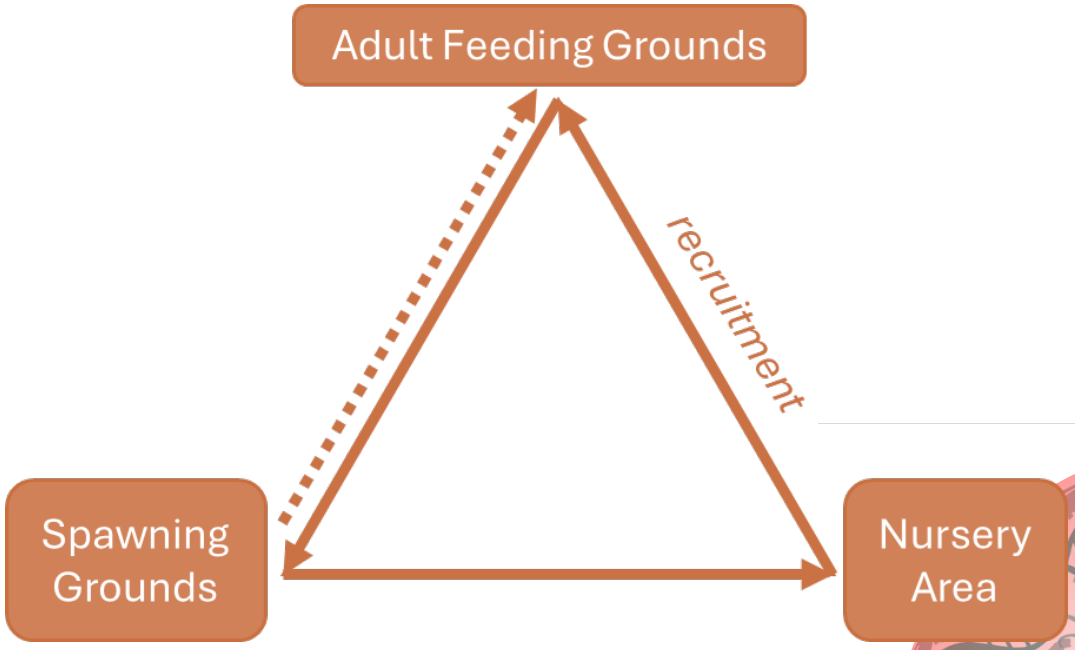
Considering Complex Connectivity

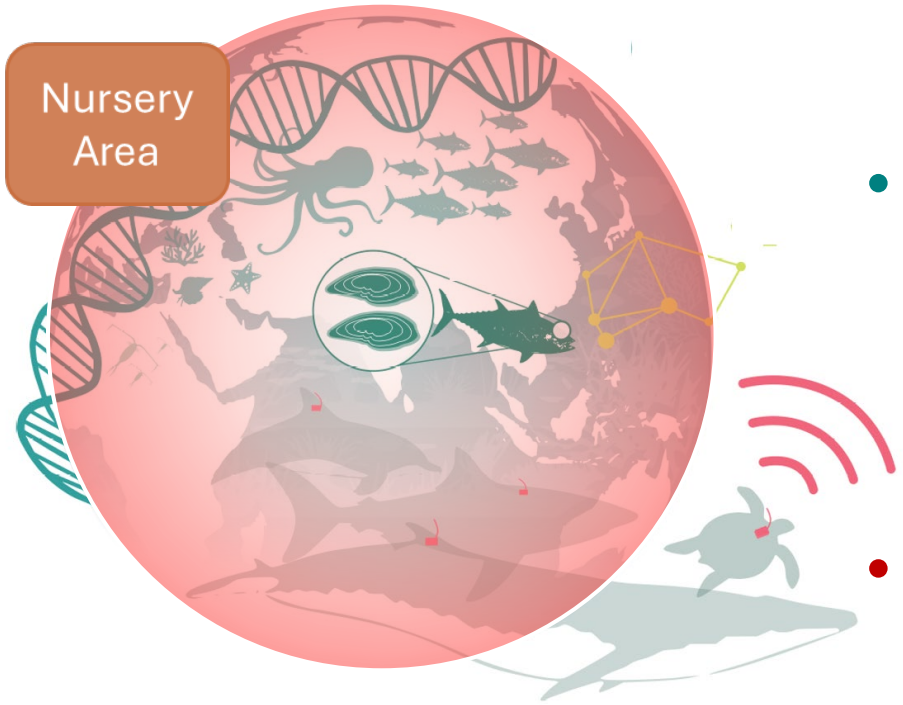


- Traditional fishery science identified unit stocks and simple migration circuits for transgenerational connectivity.
- Technological advancements reveal much more complex patterns of connectivity in space and time.

Sturrock et al. 2026. Methods to estimate marine functional connectivity

Considering Complex Connectivity



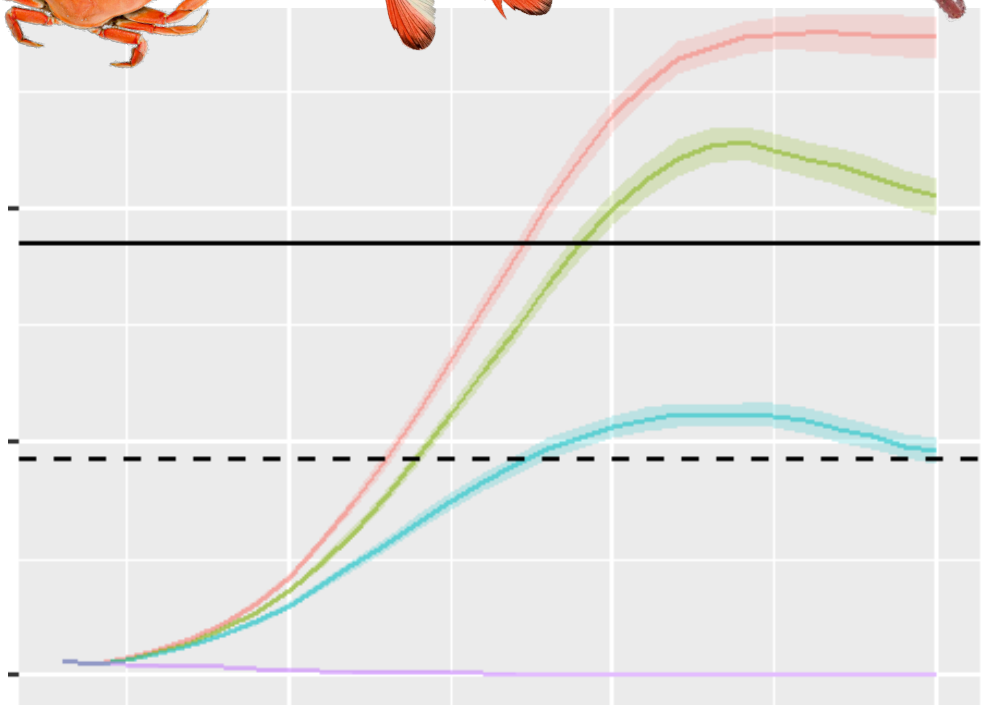


- Traditional fishery science identified unit stocks and simple migration circuits for transgenerational connectivity.
- Technological advancements reveal much more complex patterns of connectivity in space and time.
- … and climate change is altering migration patterns

Considering Complex Connectivity

- Several fishery management failures have been attributed to ignoring complex connectivity (Cadrin 2020).
- Simulation studies show that stock assessments are more accurate and fishery management is more effective when connectivity is appropriately considered.
- Conventional stock assessment and fishery management models continue to assume unit stocks, so stock identification and delineation of stock boundaries should encompass connectivity patterns – *if possible*.





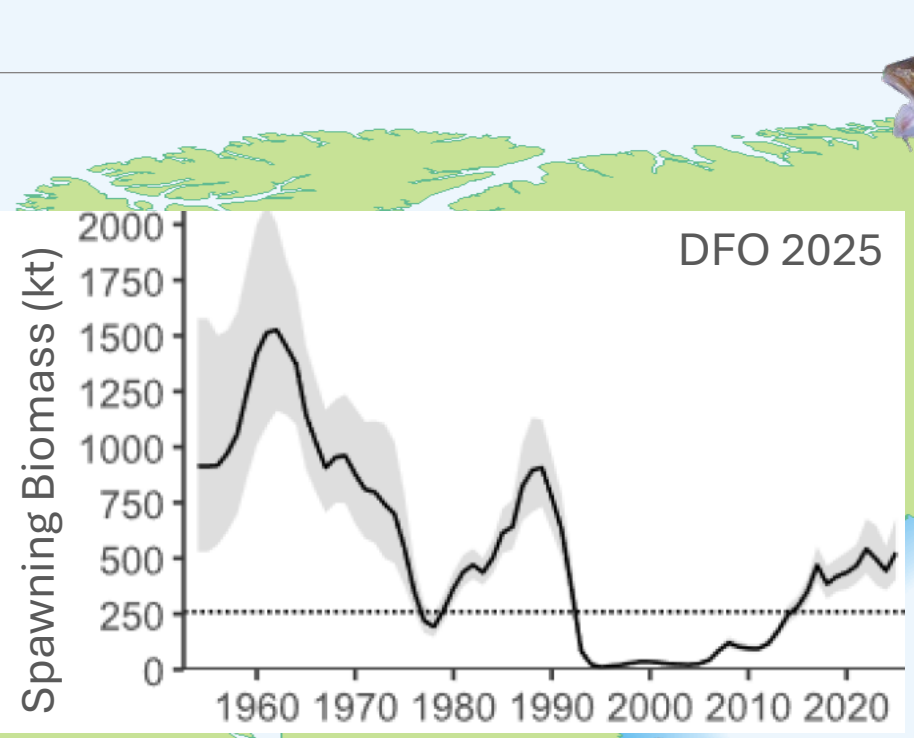
Three Case Studies of Complex Connectivity

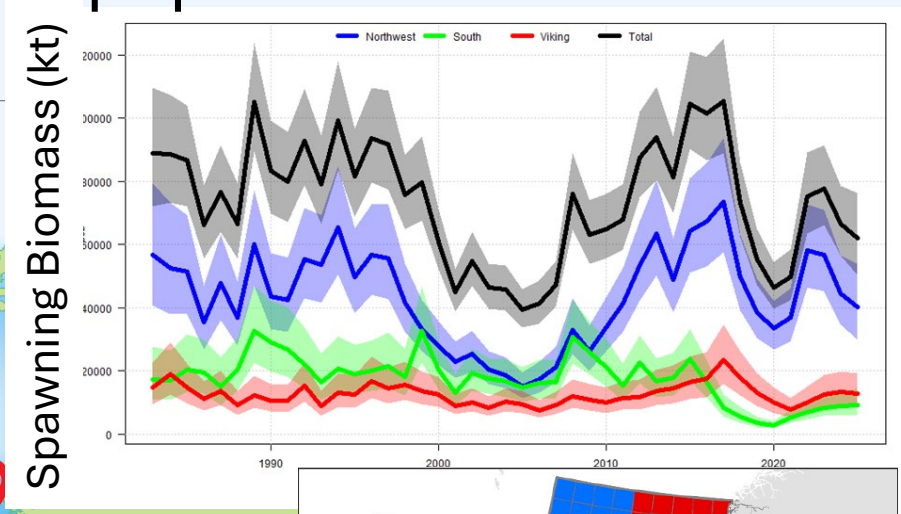
- Atlantic Cod – complex population structure
- Atlantic Bluefin Tuna – ‘back to basics’
- Northeast Atlantic Mackerel – climate-induced shifts

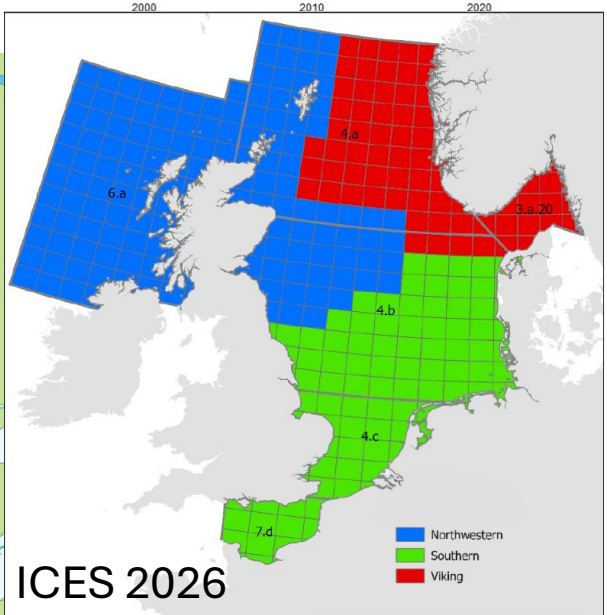


Atlantic Cod Populations

- Seasonal movement patterns with high spawning site fidelity reproductively isolate local spawning groups as genetically distinct populations.



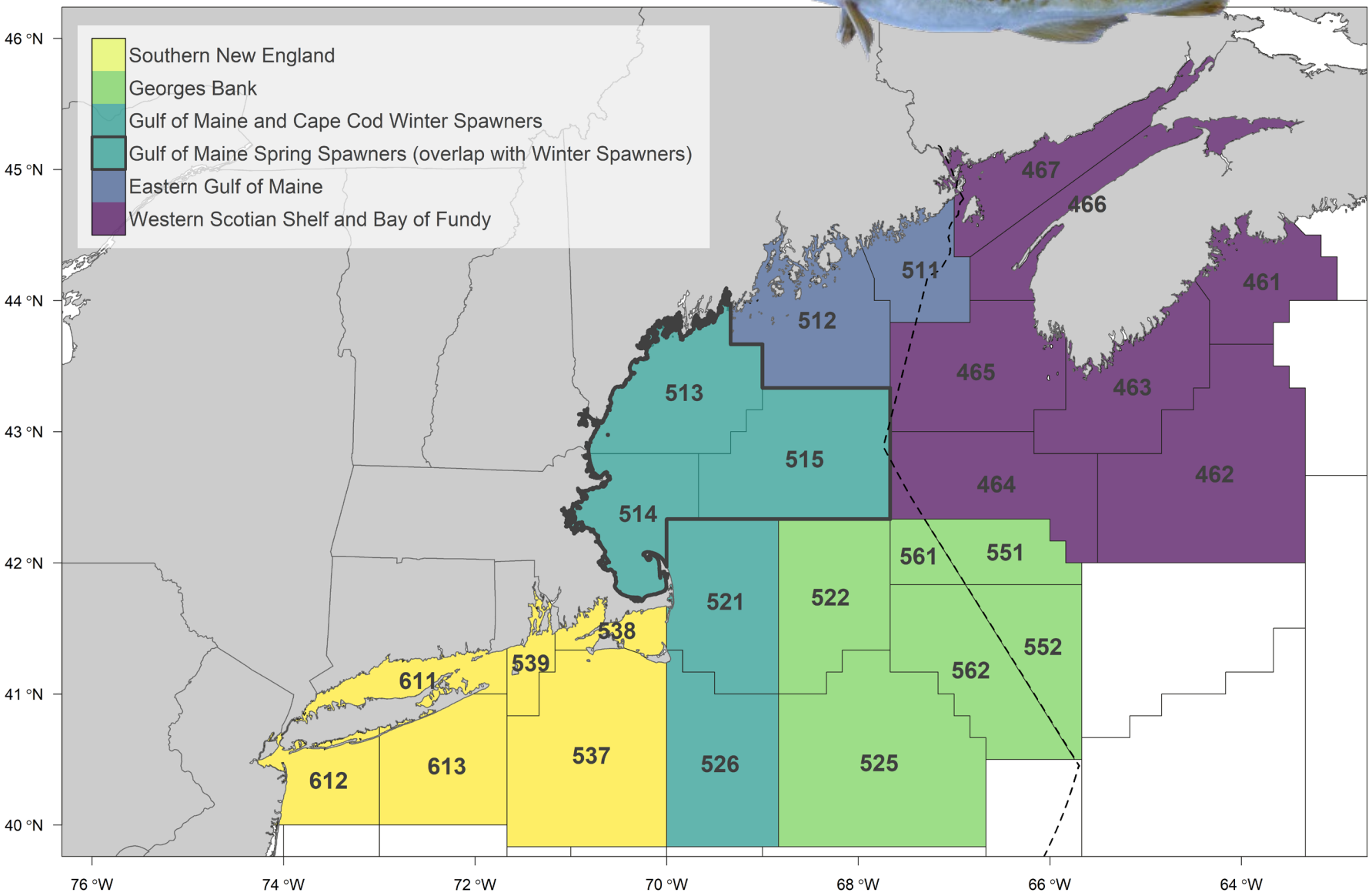




New England Cod Populations



- Previously assessed as 2 stocks (Georges Bank and Gulf of Maine)
- Interdisciplinary analysis of genetics, tagging, larval dispersal, and life history traits identified 5 US cod populations
- Four new separate assessments (NEFSC 2023)
  - Assuming 4 units stocks (no movement)
  - Western Gulf of Maine includes sympatric winter and spring spawners.



Evaluating Management Procedures

- Management Strategy Evaluation with discrete populations, mixed-stock fisheries, and precautionary harvest control rules suggests that Georges Bank and Western Gulf of Maine stocks can rebuild in all four scenarios.
- Eastern Gulf of Maine stock - rebuilds faster in 2-unit scenarios.
- Southern New England stock
  - rebuilds in 4-management-unit scenarios
  - doesn't rebuild in 2-unit scenarios
- … now 4 management units (NEFMC 2026)



Brothers et al. 2025

Atlantic Bluefin Tuna

- Major spawning grounds and migrations have been identified for millennia (Mediterranean) or centuries (Gulf of Mexico) from targeted fisheries.
- Satellite telemetry, otolith chemistry and genetics refined understanding of seasonal migrations.
- Separate assessment and fishery management of eastern vs. western stocks.
- Management procedures for mixed-population fisheries were tested with alternative operating models of movement and mixing (ICCAT 2022).







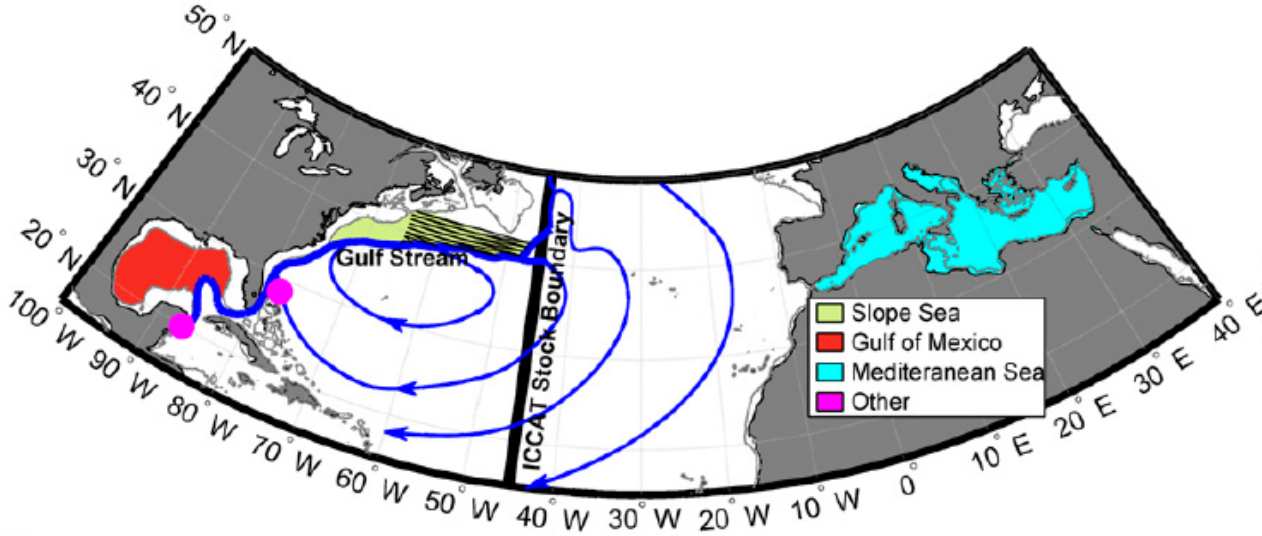
Discovery of a spawning ground reveals diverse migration strategies in Atlantic bluefin tuna (*Thunnus thynnus*)

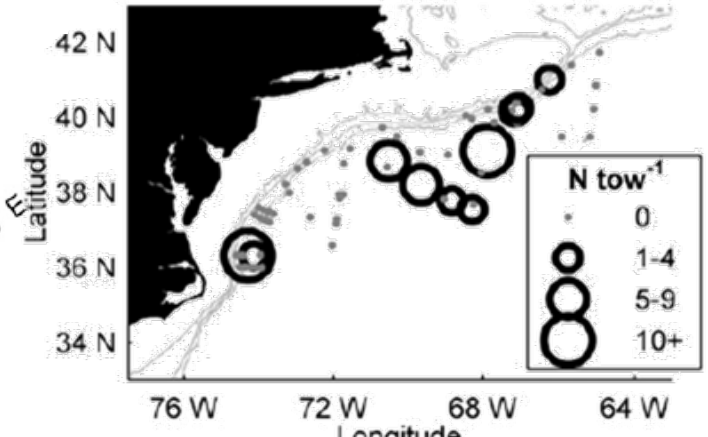


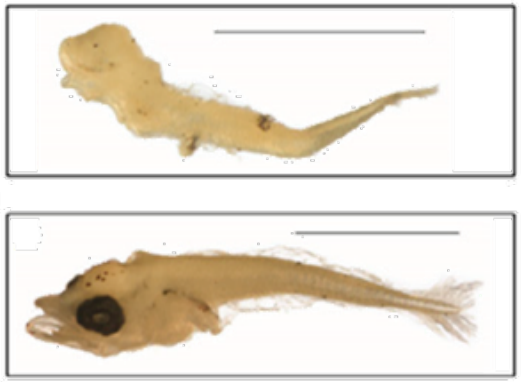
David E. Richardson[a,1], Katrin E. Marancik[b], Jeffrey R. Guyon[c], Molly E. Lutcavage[d], Benjamin Galuardi[e,f], Chi Hin Lam[d], Harvey J. Walsh[a], Sharon Wildes[c], Douglas A. Yates[c], and Jonathan A. Hare[a]

[a]Northeast Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Narragansett, RI 02882; [b]Integrated Statistics, Contractor for Northeast Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Narragansett, RI 02882; [c]Alaska Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Juneau, AK 99801; [d]Large Pelagics Research Center, School for the Environment, University of Massachusetts Boston, Gloucester, MA 01931; [e]School of Marine Science and Technology, University of Massachusetts Dartmouth, Fairhaven, MA 02719; and [f]Greater Atlantic Regional Fisheries Office, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Gloucester, MA 01930

- Larval surveys identified spawning in the Slope Sea (Richardson et al. 2016)







Re-Evaluation of Spawning Areas

Sampling Effort

Plankton tows		Reproductive studies	
	3000+		5+
	500-1000		2-4
	20-500		1
⊗	0-20	⊗	0

Loop Current; Florida Current; Gulf Stream

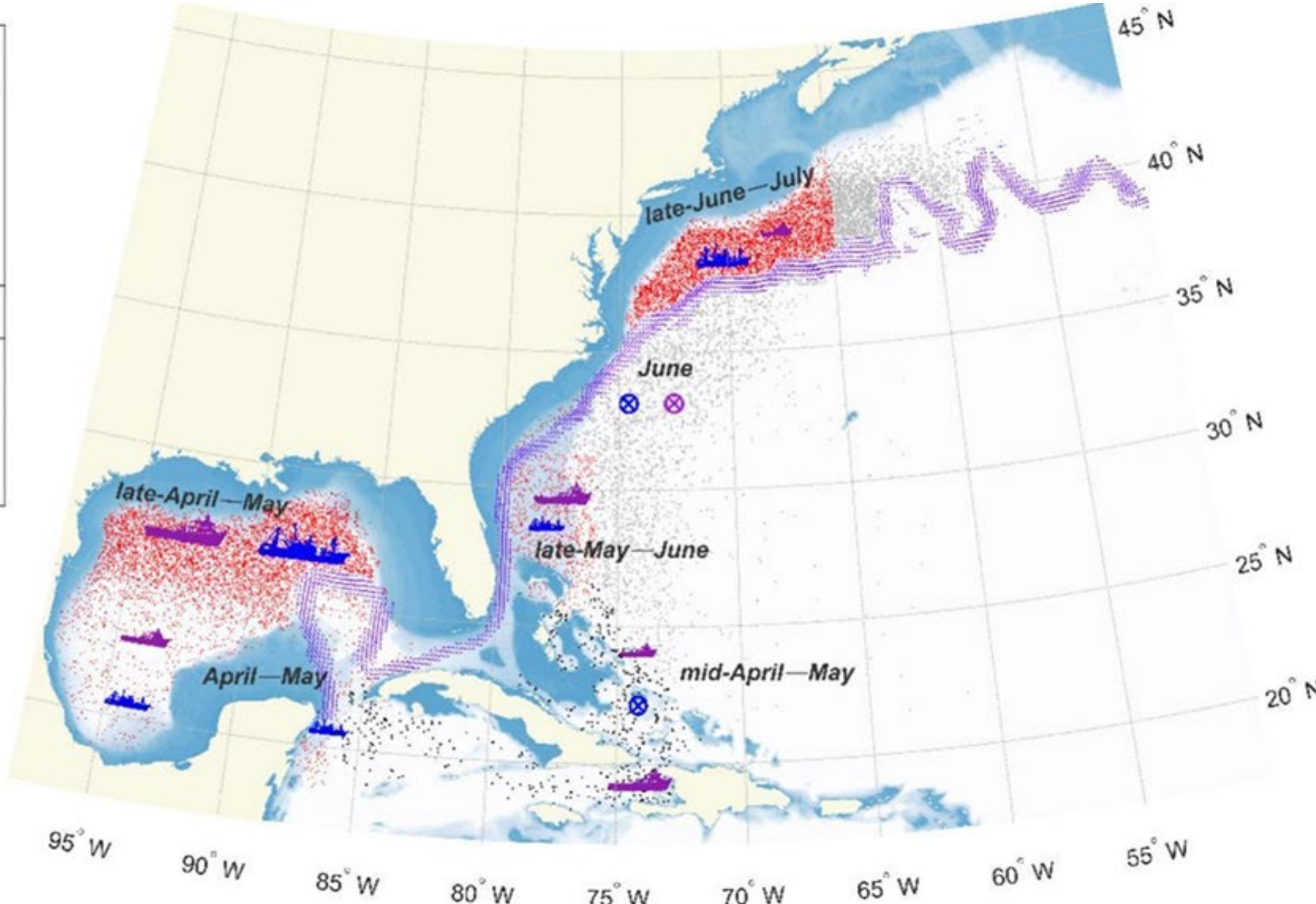
Spawning Intensity Low High

Based on larval and reproductive studies

Based on 1955-61 reproductive studies

Hypothesized based on indirect data

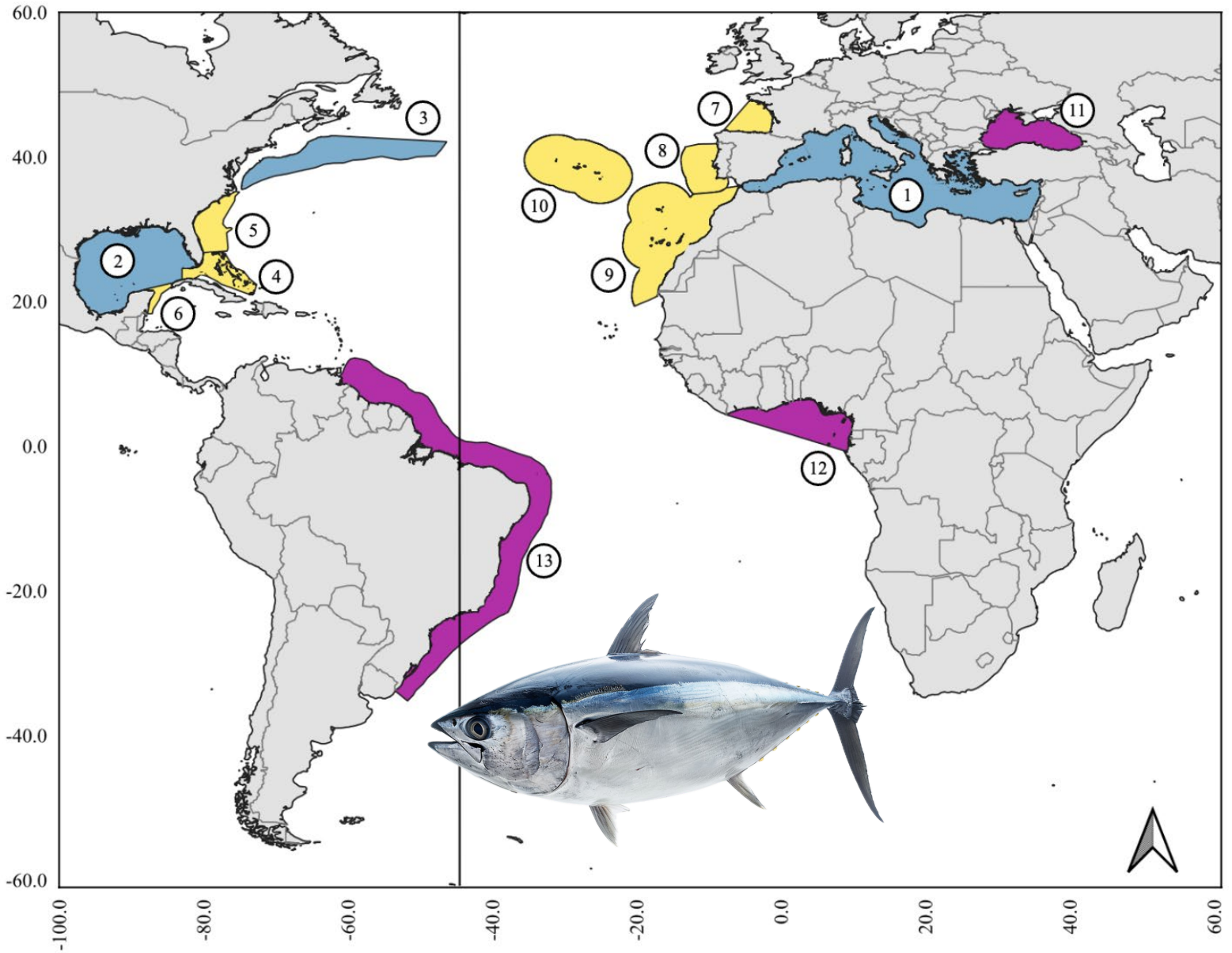




Richardson et al. 2026

Atlantic Bluefin Tuna – Back to Basic Life History

- Confirmed, plausible, and presumed collapsed spawning sites inferred from presence of larvae, adults in spawning condition, young-of-year juveniles, tagging, genetics, microchemistry, and oceanographic conditions (Mnich et al. 2026).
- Interdisciplinary stock identification may need to adopt more complex seascape ecology (Wilcox et al. 2023, Rieder et al. 2025).

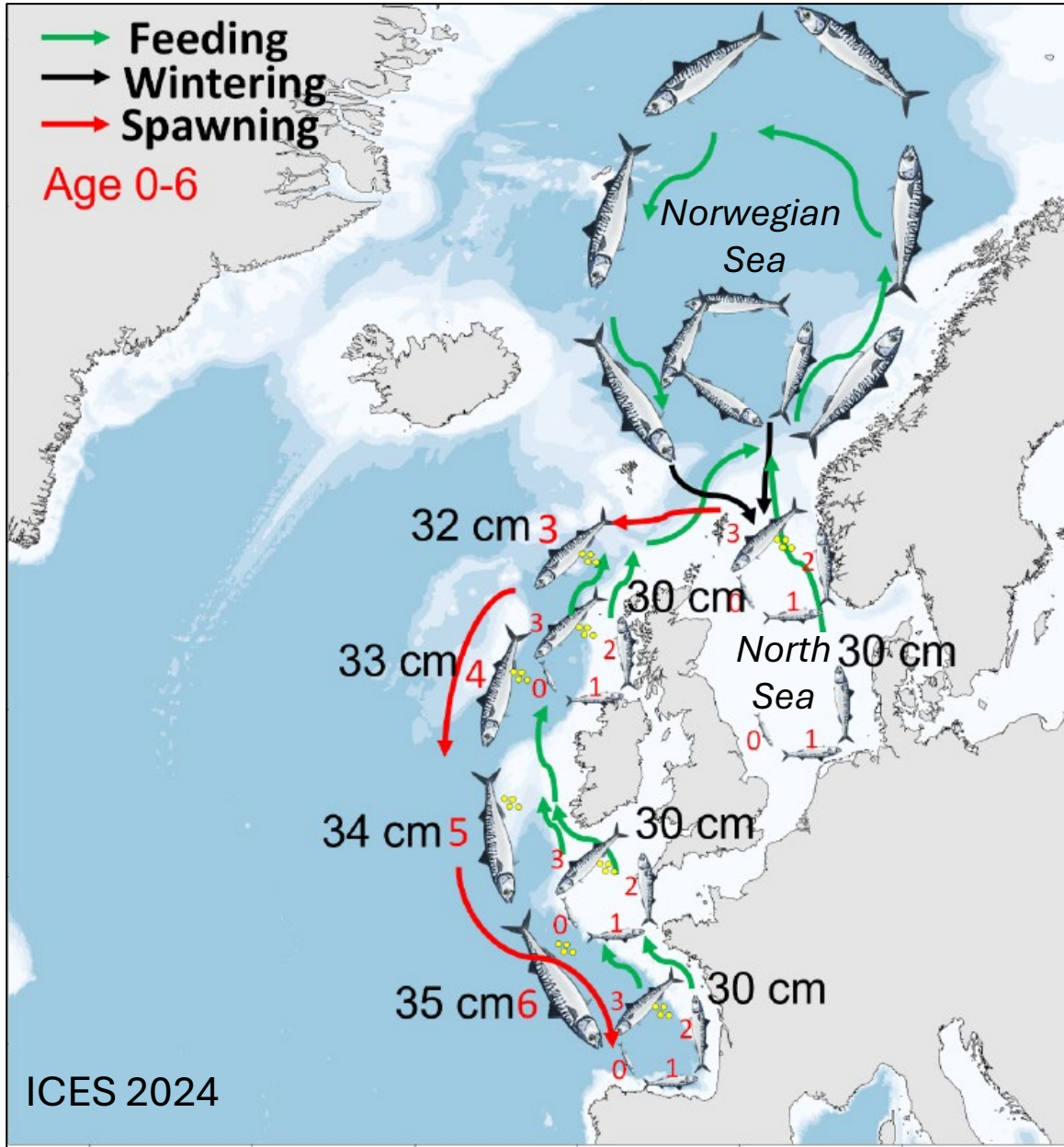



AND NOW FOR
SOMETHING
COMPLETELY
DIFFERENT

Northeast Atlantic Mackerel



- Conventional tagging, surveys and fishery data suggest state-dependent spawning migration:
  - Juveniles leave nursery areas to join adults the main feeding area in the Norwegian Sea at ages 2-3
  - Young mackerel mix with older adults and adopt their triangular migrations, wintering in the North Sea.
  - The largest fish and those in best condition migrate farther south to spawn,
- The European Union, Faroe Islands and Norway have managed mackerel fisheries through a Trilateral Agreement since 1999.

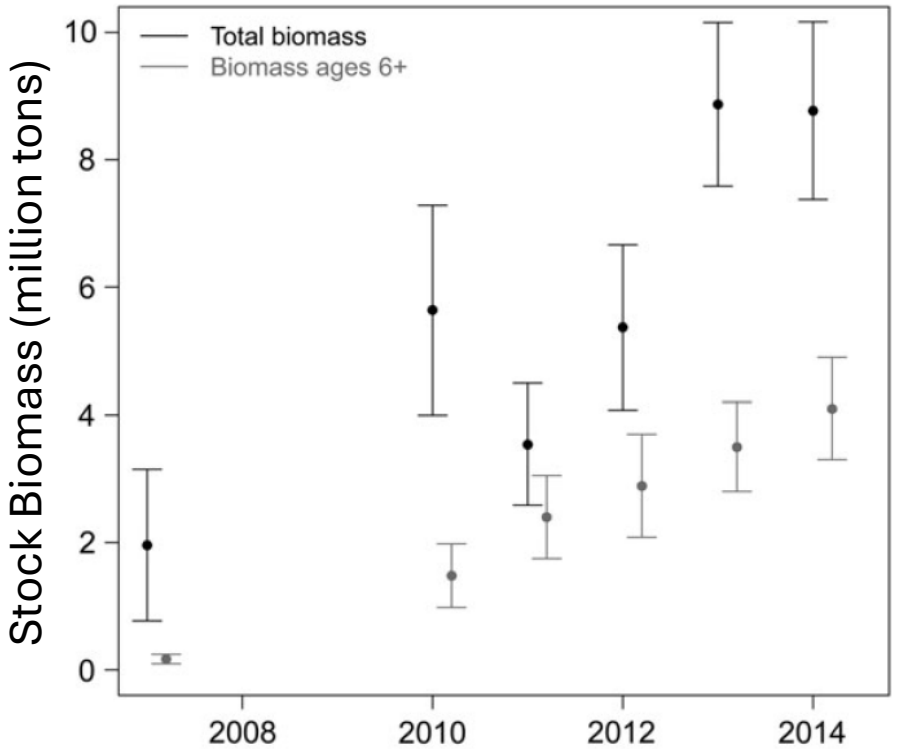


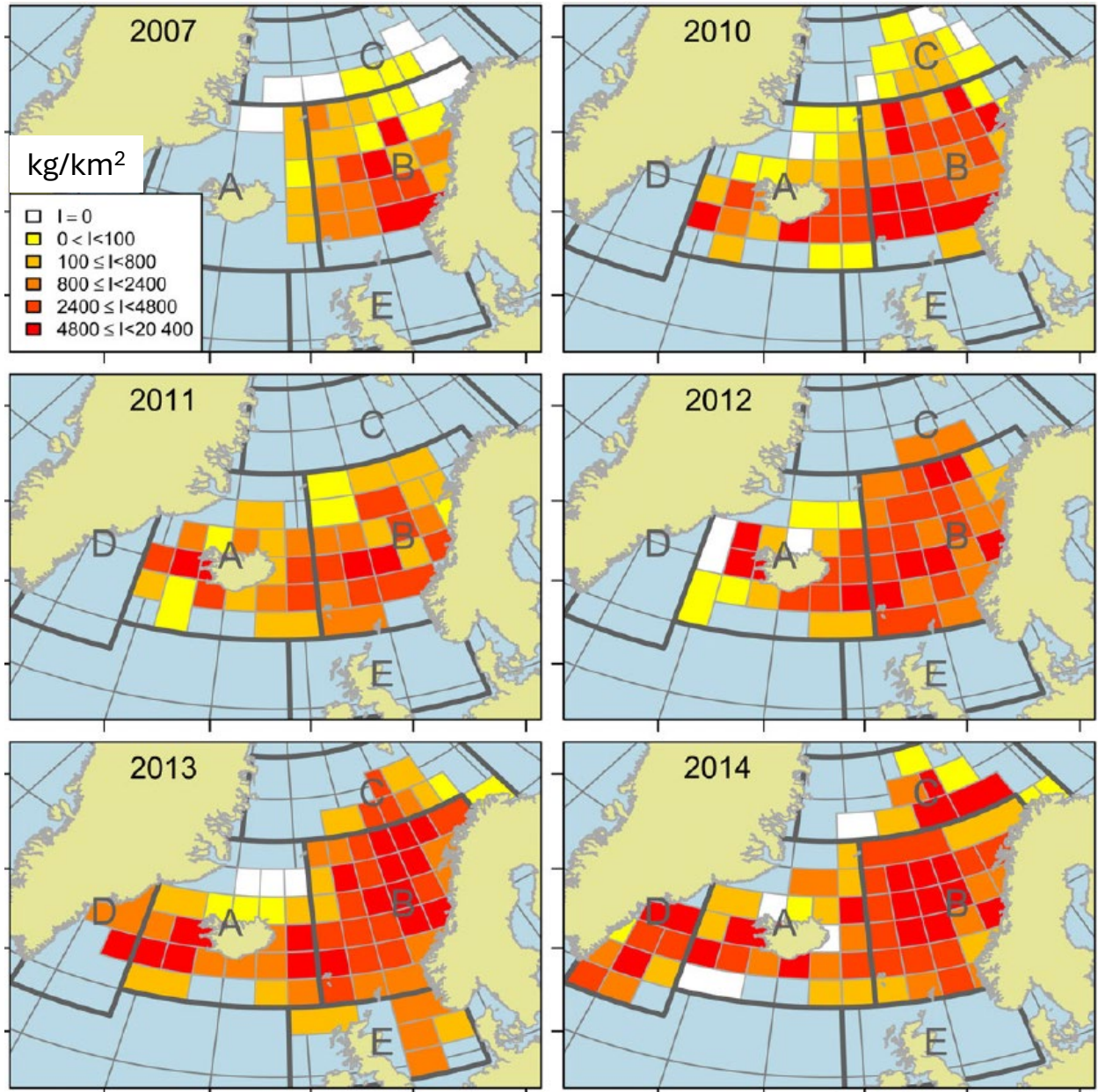
Northeast Atlantic Mackerel



- After strong recruitment and environmental change, geographic range of the stock expanded during the feeding season, into Icelandic waters.

Nøttestad et al. 2017

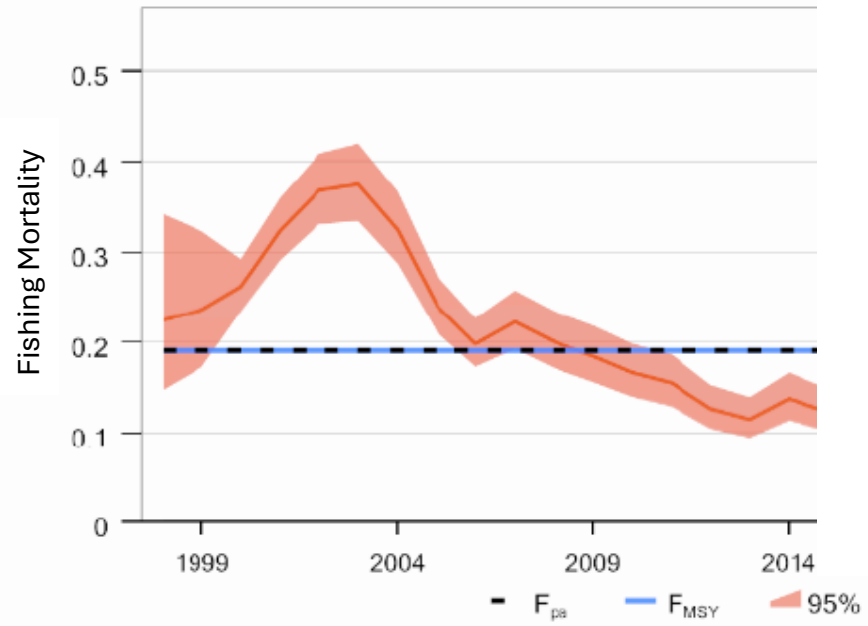


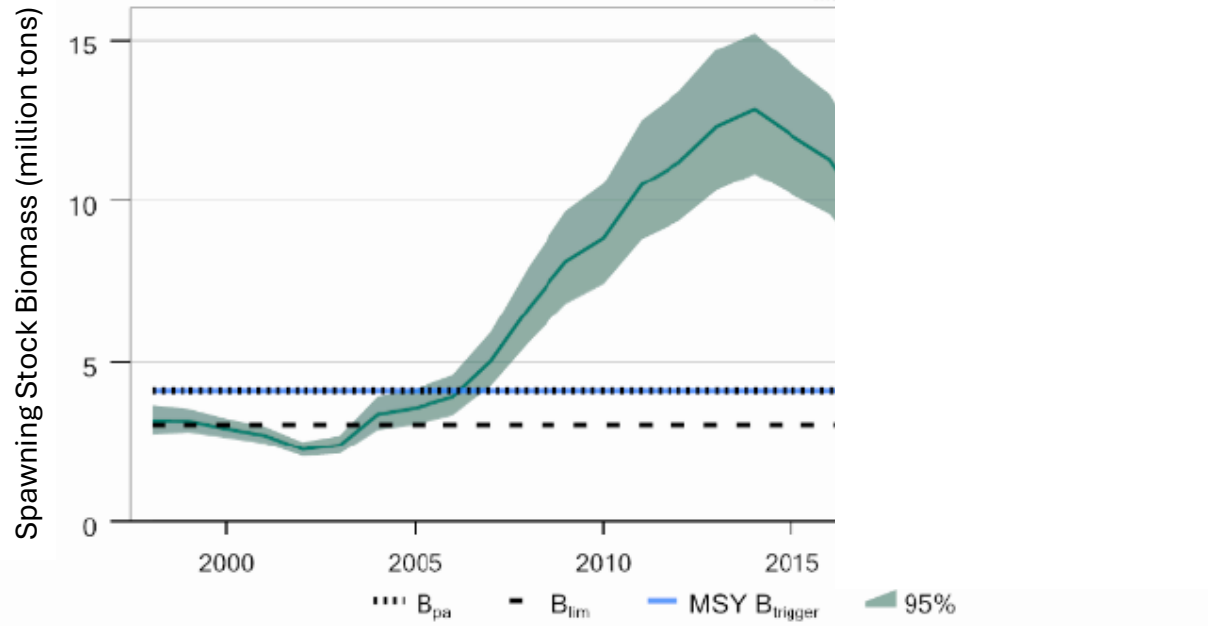


Northeast Atlantic Mackerel



- The trilateral management plan had ended overfishing and rebuilt the stock.
- Coastal States failed to reach a management agreement for the expanded fishing area (Orebech 2013, Østhagen et al. 2020, Akkus 2026).
- Catches have been ~40% greater than advised catch since 2010.



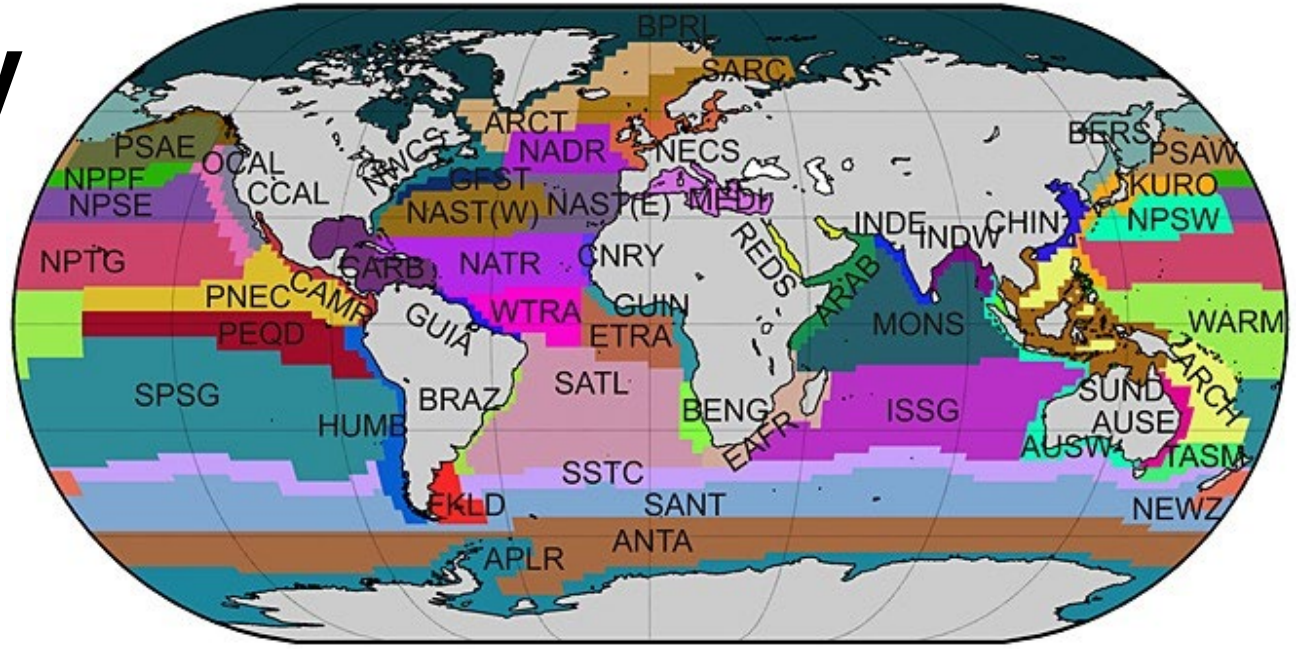


ICES 2025

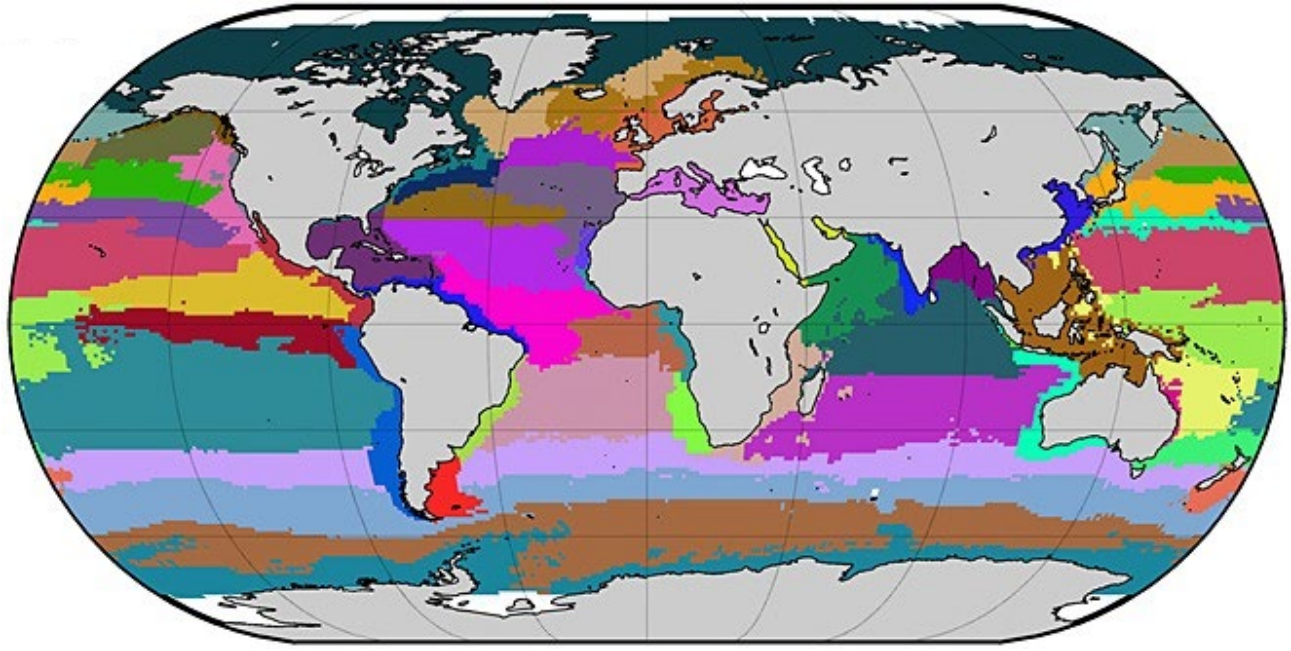
Ecosystem Connectivity

- The Ecosystem-Based Fishery Management initiative has also been ‘place-based.’
- Ecosystem boundaries ignore some connectivity among areas (e.g., major ocean currents, highly migratory species).
- Biogeochemical provinces can be dynamic.

Longhurst (2007) Ecological Geography of the Sea

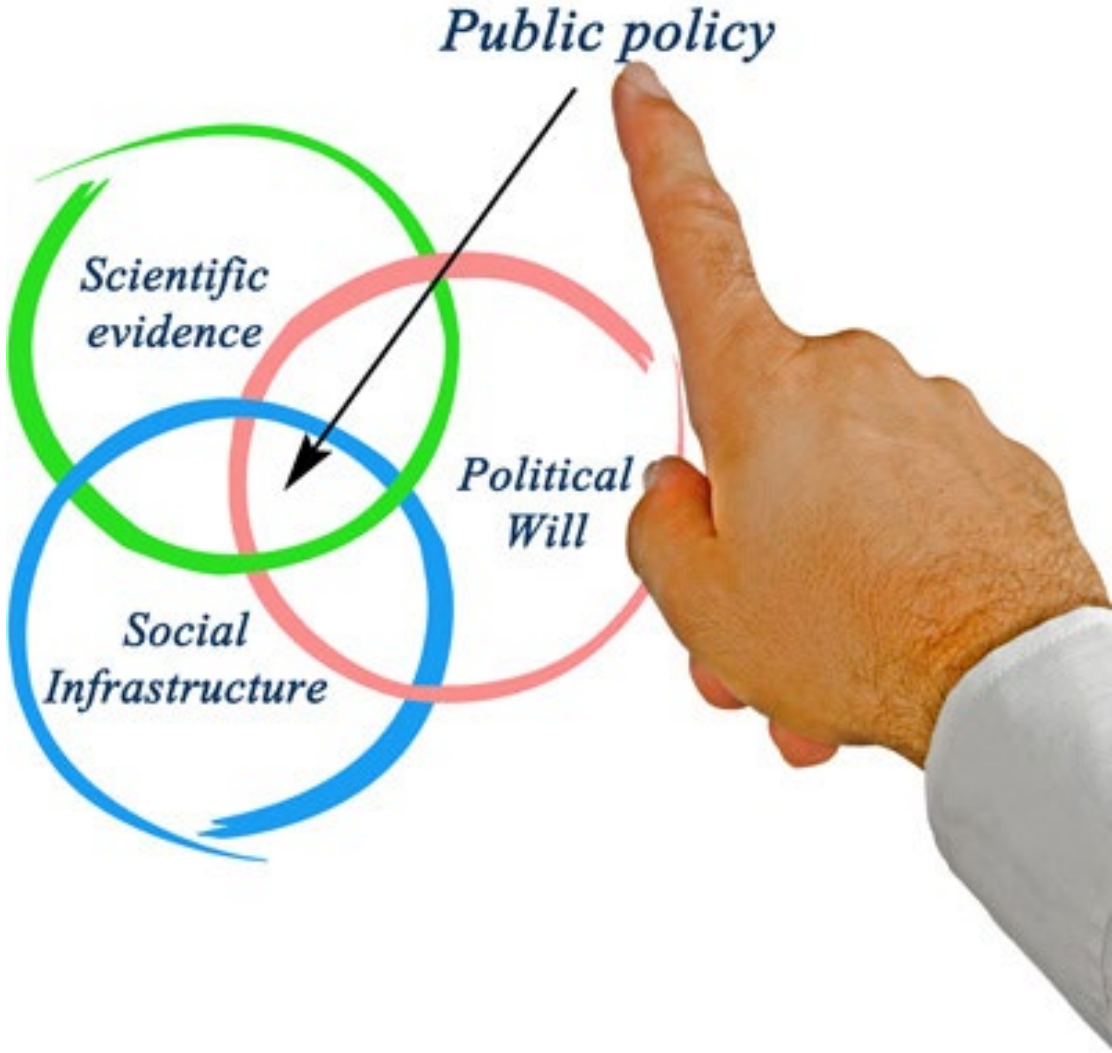


Reygondeau et al. (2013) Dynamic Biogeochemical Provinces



Considering Complex Complexity

- Spatial population structure can be complex and uncertain.
- Special interests that benefit from status quo will use uncertainty and complexity to argue against change or adaptation.
- Marine science can provide compelling evidence of connectivity, spatial population structure, and climate-induced spatial shifts when they exist – ***IF*** we:
  - continue investments in developing and applying advanced technologies;
  - apply good practices in quantifying connectivity; and
  - test life history paradigms with new information.
- Scientific advice should recognize practical constraints and communicate the risks of status quo and alternatives.



Considering Complex Connectivity

- Management strategy evaluation can be conditioned on best available evidence of connectivity (*and associated uncertainties*).
  - Spatial management of fisheries may be robust to complex patterns of connectivity:
    - spawning closures
    - protection of nursery habitat
    - rotational access
    - catch allocation based on resource distribution
  - Complex spatial assessment and management may be needed to sustain fisheries.
- Adapting to spatiotemporal shifts in transboundary stocks will require increased interjurisdictional collaboration in science and fisheries management.

