Quantifying temporal beta diversity across marine assemblages experiencing variable trajectories of community change

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Marine assemblages are dynamic systems

- Valuable social ecological systems, economic resources, and biodiversity
- Shifting oceanic conditions and stressors are affecting all organizational scales
- Assemblage-level patterns may better characterize ecosystem-level processes
  - Reorganization of community composition and ecosystem function across shelf systems

Image: NOAA Fisheries/Paula Ayotte

Image: Ricardo Rodolfo Metalpa (IRD)

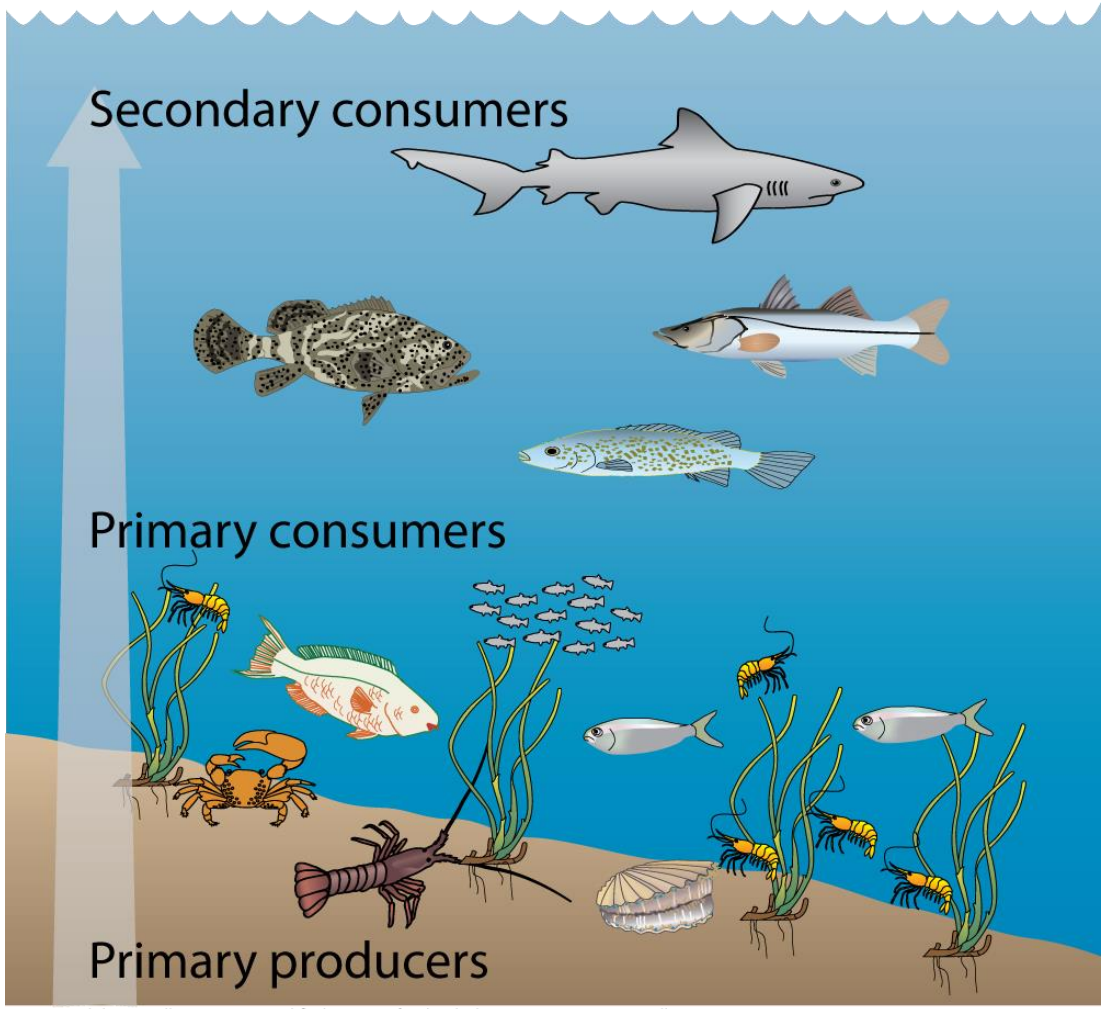
Image: Jeremy Ryan

Shifts in composition can signal ecological change

Temporal beta diversity: shifts in community composition over time in a repeatedly observed area

Valuable indicator because community composition affects:

- Food web dynamics
- Productivity
- Biogeochemical cycling
- Emergent properties of system



Conceptual diagram illustrating a simplified seagrass food web showing some commercially imporant components.
Diagram courtesy of the Integration and Application Network (ian.umces.edu), University of Maryland Center for Environmental Science. Source: Kruczynski, W.L., and P.J. Fletcher (eds.). 2012. Tropical Connections: South Florida's marine environment. IAN Press, University of Maryland Center for Environmental Science, Cambridge, Maryland. 492 pp.

Stability is a critical property of ecological systems

Ecological stability: the ability of a system to retain its structure and function with perturbation or changing conditions

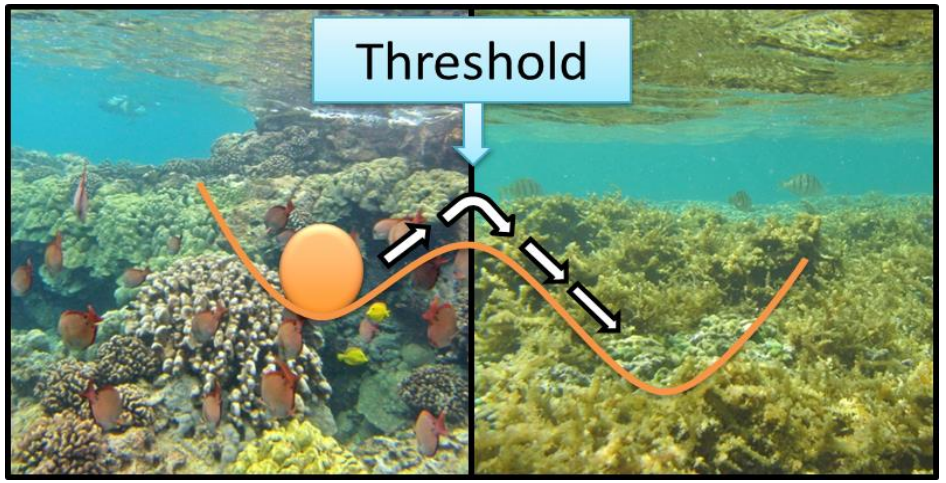


Image: Oceantippingpoints.org

Stability is affected by:

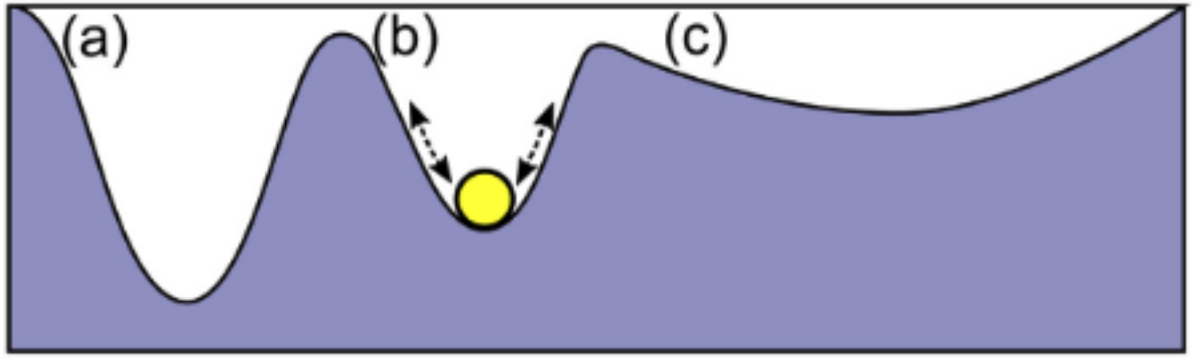
- Strength + mode of species interactions
- Food web connections
- Species environmental responses

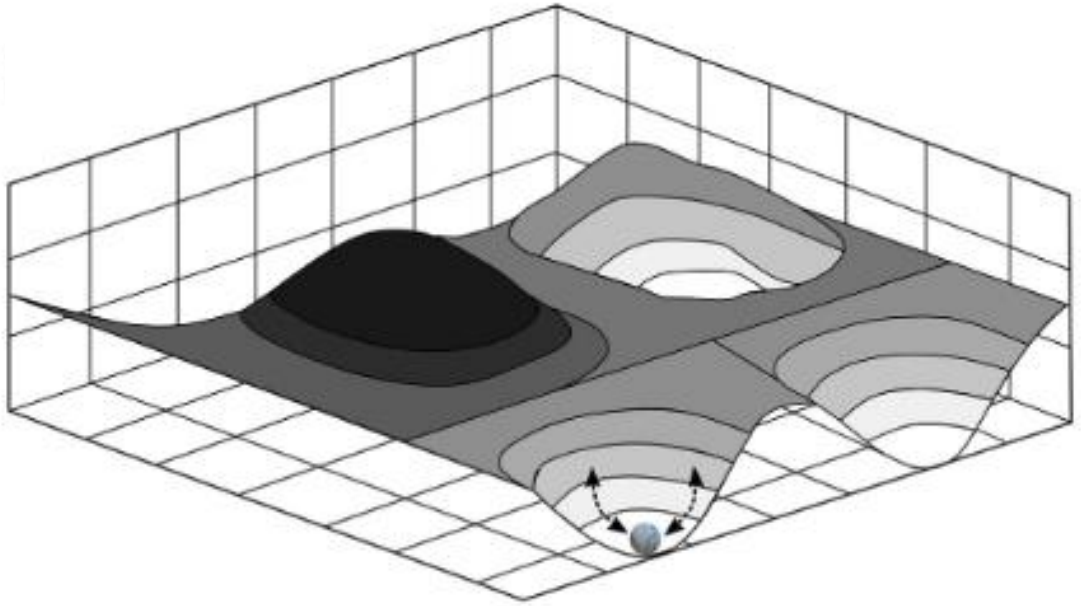
Van Meerbeek et al. 2021

Ecological stability is dynamic

Dynamic stability: ecosystems fluctuating around an attractor with "relatively small", non-directional changes in composition

Stability landscapes





Ball = current ecosystem state

Cup = stability basin

Sánchez – Pinillos et al al. 2024 and Figures edited from Lamothe et al. 2019

It is your 1st day on a new job, and the conditions are very different.

How do you handle demands to continue providing services?

Dynamic community change can be a mechanism for recovery and resilience

Compensating for the dynamic change

- Busy
- Multi-tasking
- Finding new ways to get the same job done
- Making it work!

Dynamic community change can be a mechanism for recovery and resilience

Compensating for the dynamic change

- Busy
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Overwhelmed by the dynamic change

- Overwhelmed
- Can’t figure out how to measure up in new environment
- Lacking ability to adapt to new demands

Dynamic community change can be a mechanism for recovery and resilience

Compensating for the dynamic change

<u>Prolonged high variability</u> in changing conditions

- The community is stressed but reorganizing to ensure system can still function

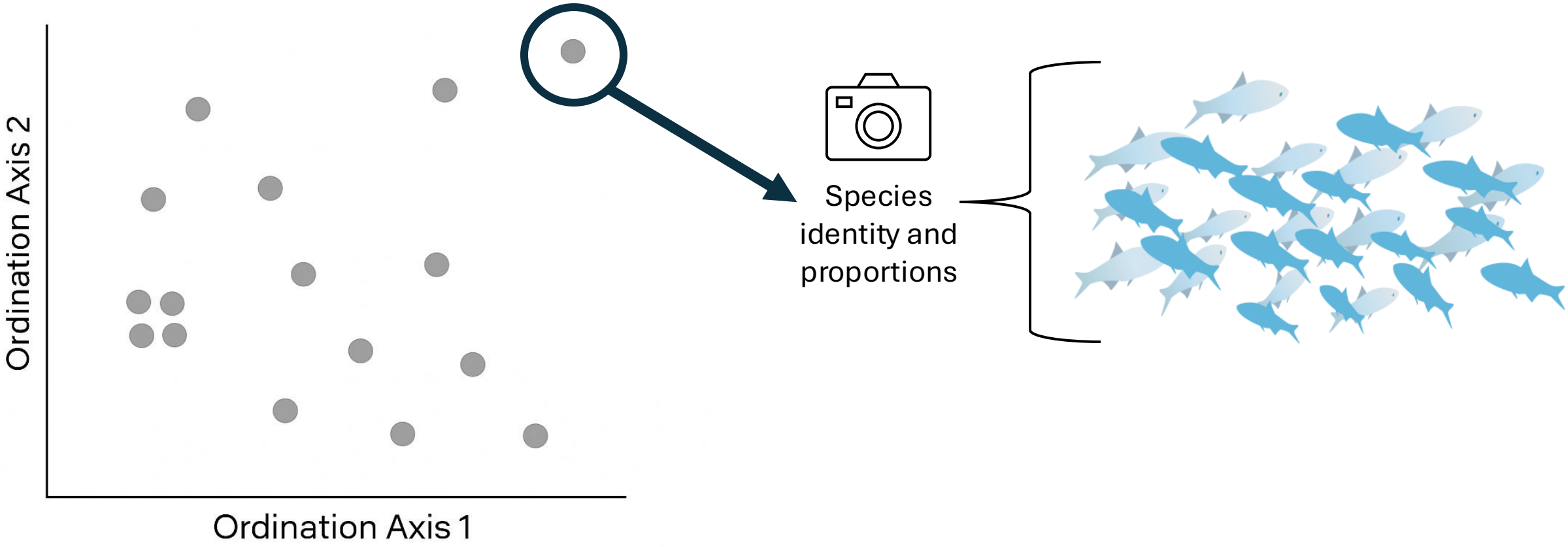
Overwhelmed by the dynamic change

<u>Low variability and return rates</u> in changing conditions

Levin & Mollman 2015, Fath, Cabezas & Pawlowski 2003, Mantua 2004, Peterson et al. 2008, Scheffer & Carpenter 2003

Ordinations visualize ecosystem change

Community at a specific point in time



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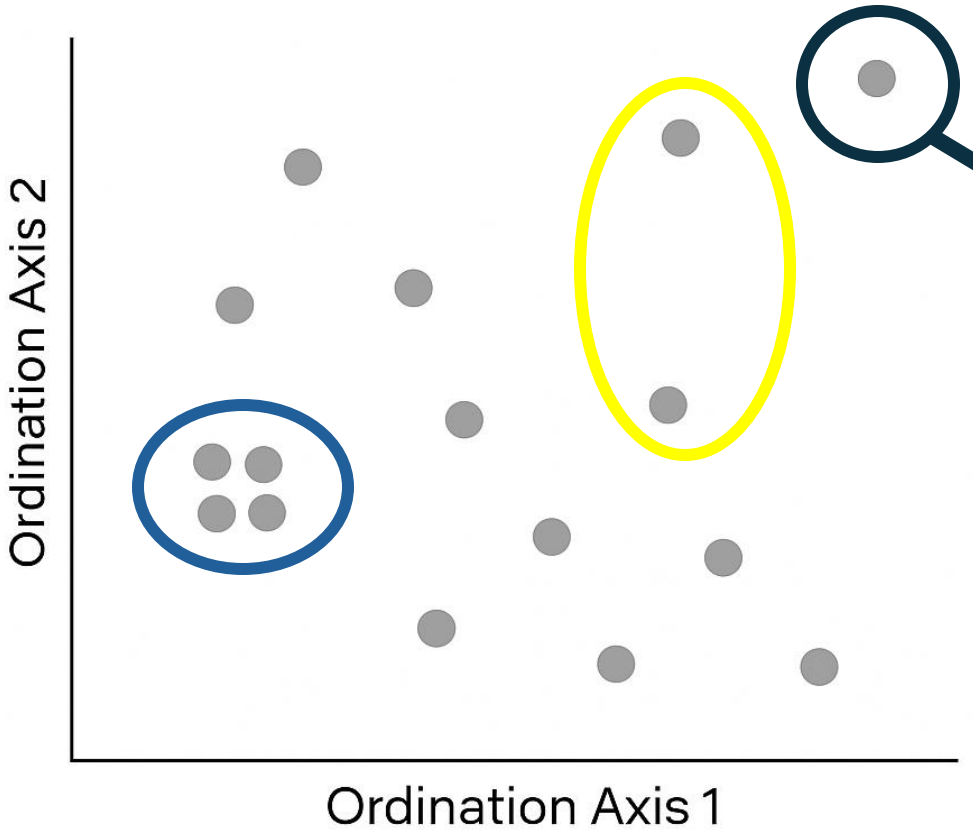

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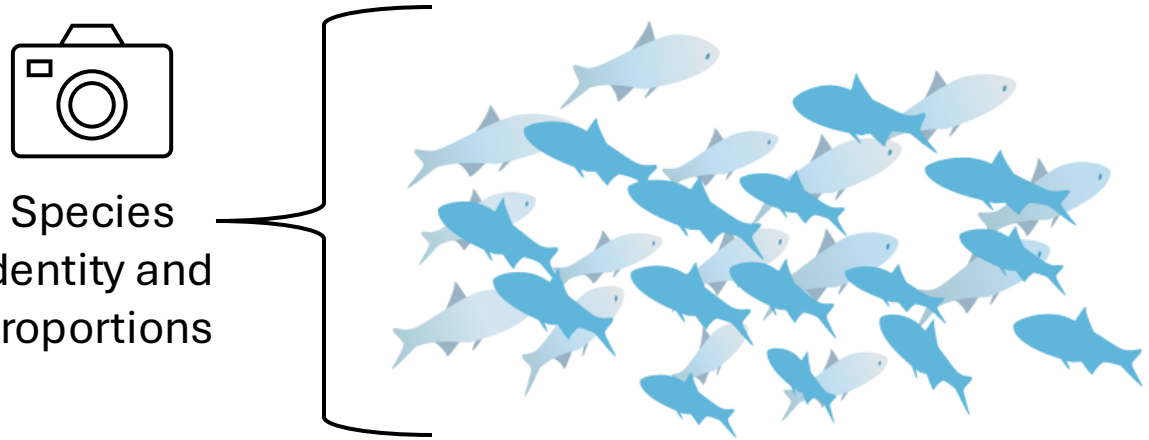


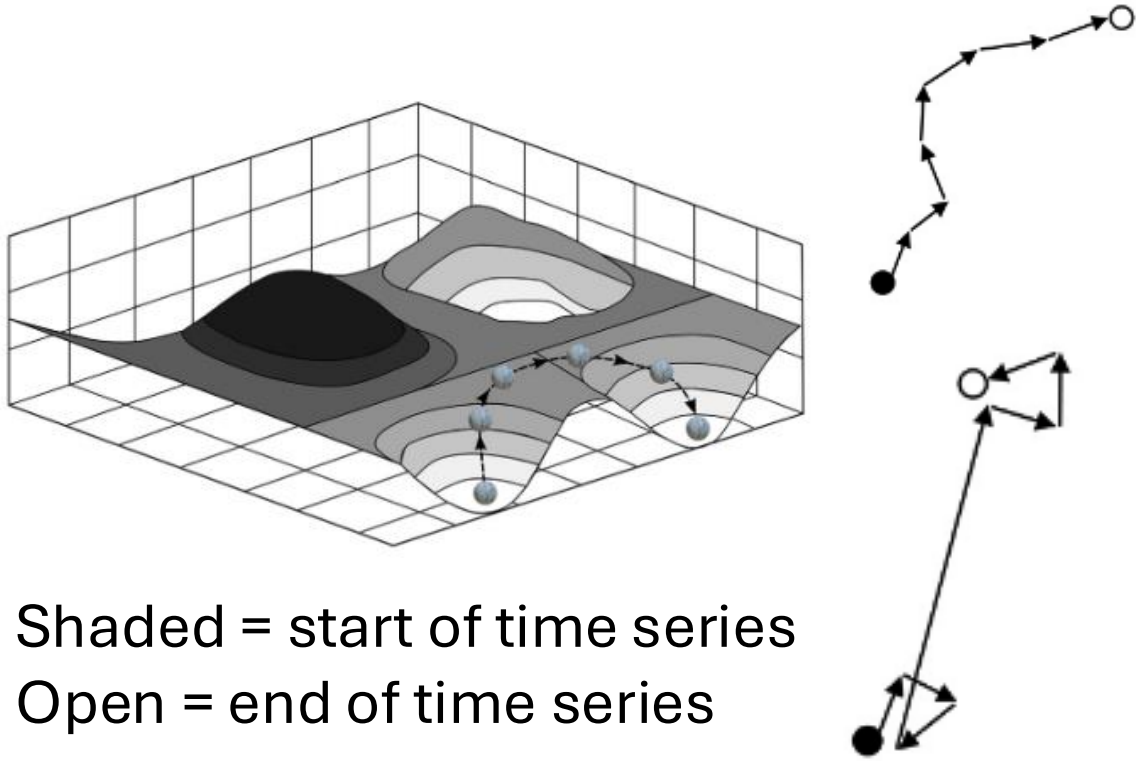
Snapshots of community from year to year

Cluster = similar composition

Distance = dissimilarity rel. to distance

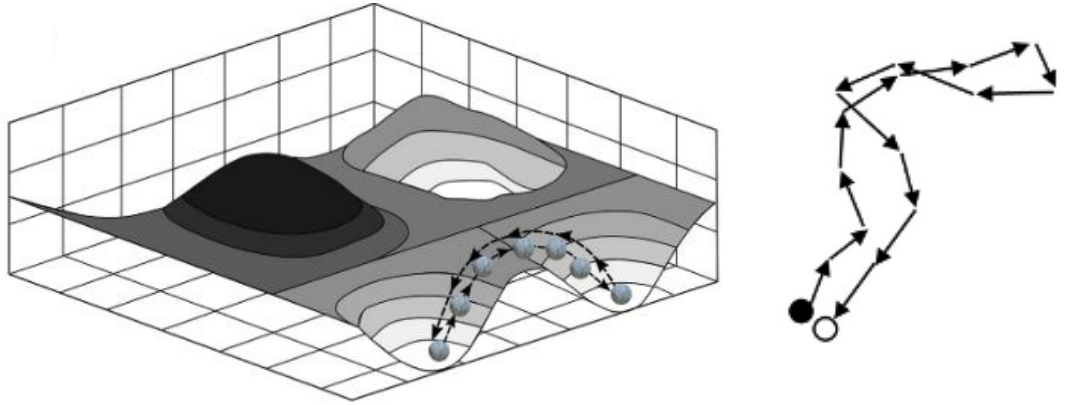
Ordinations can inform stability and resilience

Significant shifts in community state

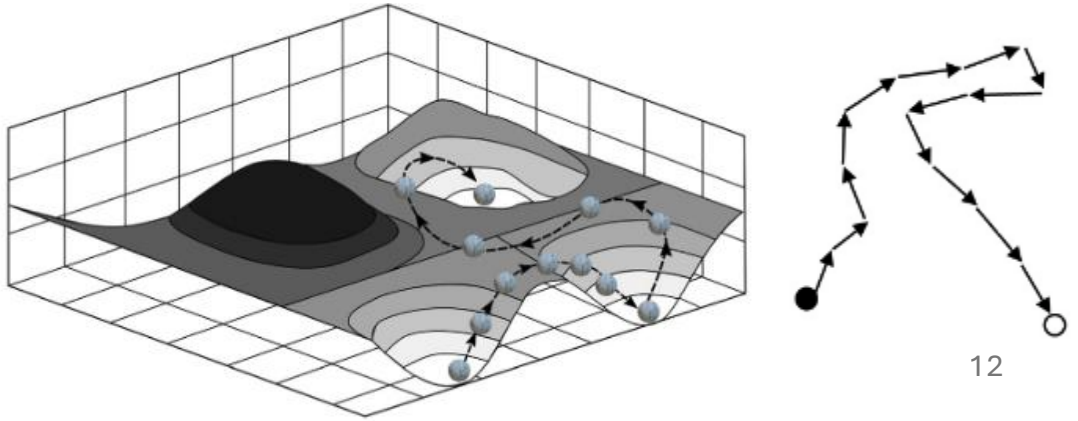


Shaded = start of time series
Open = end of time series

Recovery from directional change

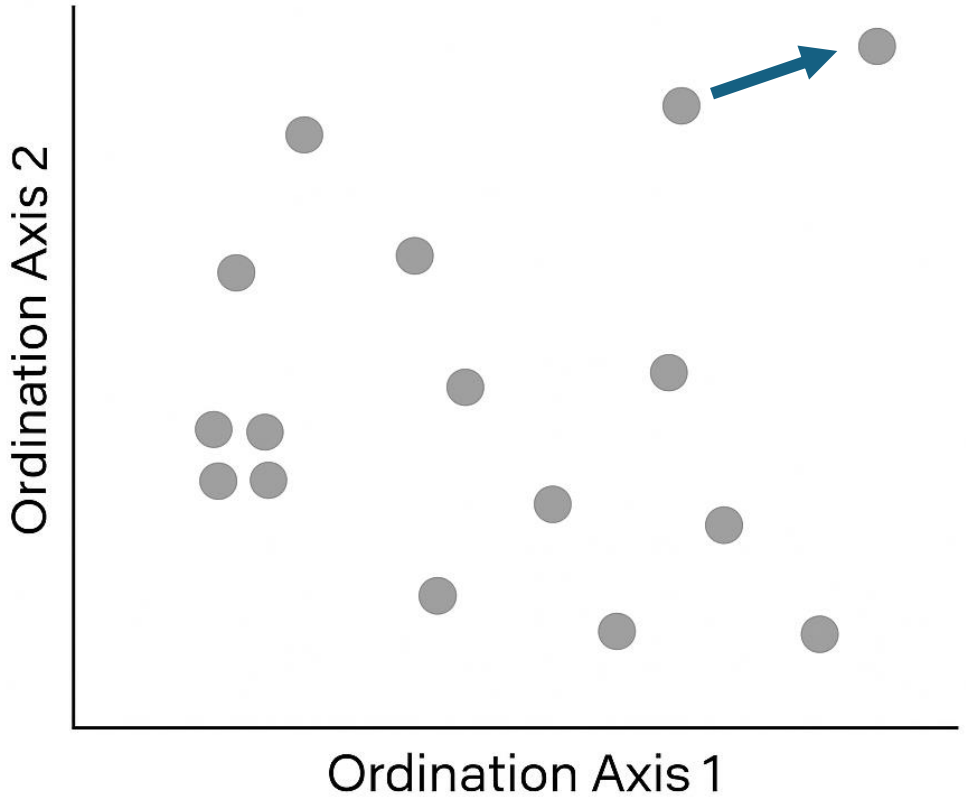


No recovery to historic composition



Figures edited from Lamothe et al. 2019

The Community Trajectory Analysis connects and quantifies trajectories over time



Quantifies:

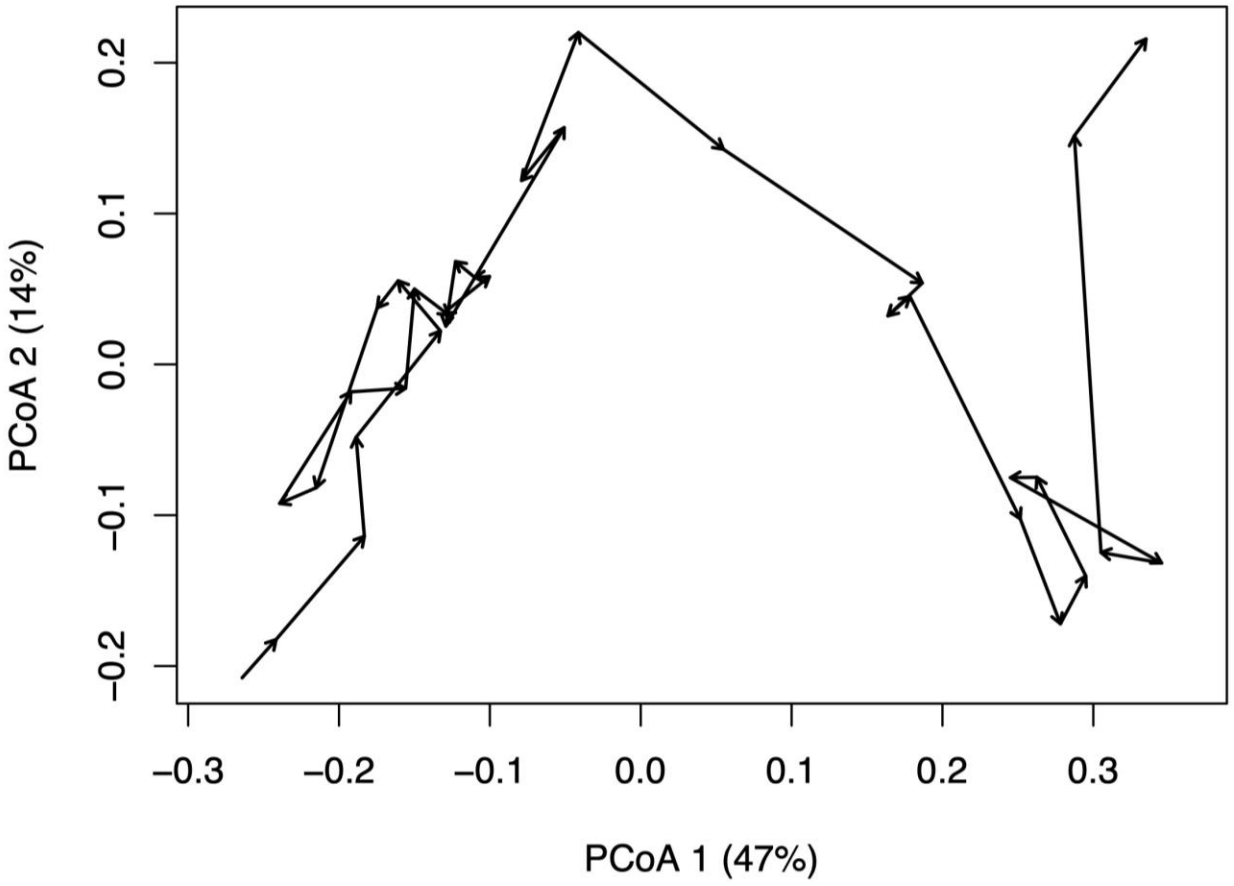
- Magnitude
- Speed
- Directionality

of community change

De Cáceres et al. 2019, Sturbois et al. 2021, Fenwick et al. 2024

The Community Trajectory Analysis connects and quantifies trajectories over time

Gulf of Mexico 1987 to 2020



- **Trajectory segment length**: dissimilarity in composition between consecutive observations
  - Magnitude and speed of change
- **Overall directionality:** the extent to which a community is consistently moving in a given direction
  - 0 = completely non-directional
  - 1 = directional trajectory
- **Distance from reference year:** distance from the initial community state to each year in time series
  - Distance of 1982 to 1985, 1982 to 1990

De Cáceres et al. 2019, Sturbois et al. 2021, Fenwick et al. 2024

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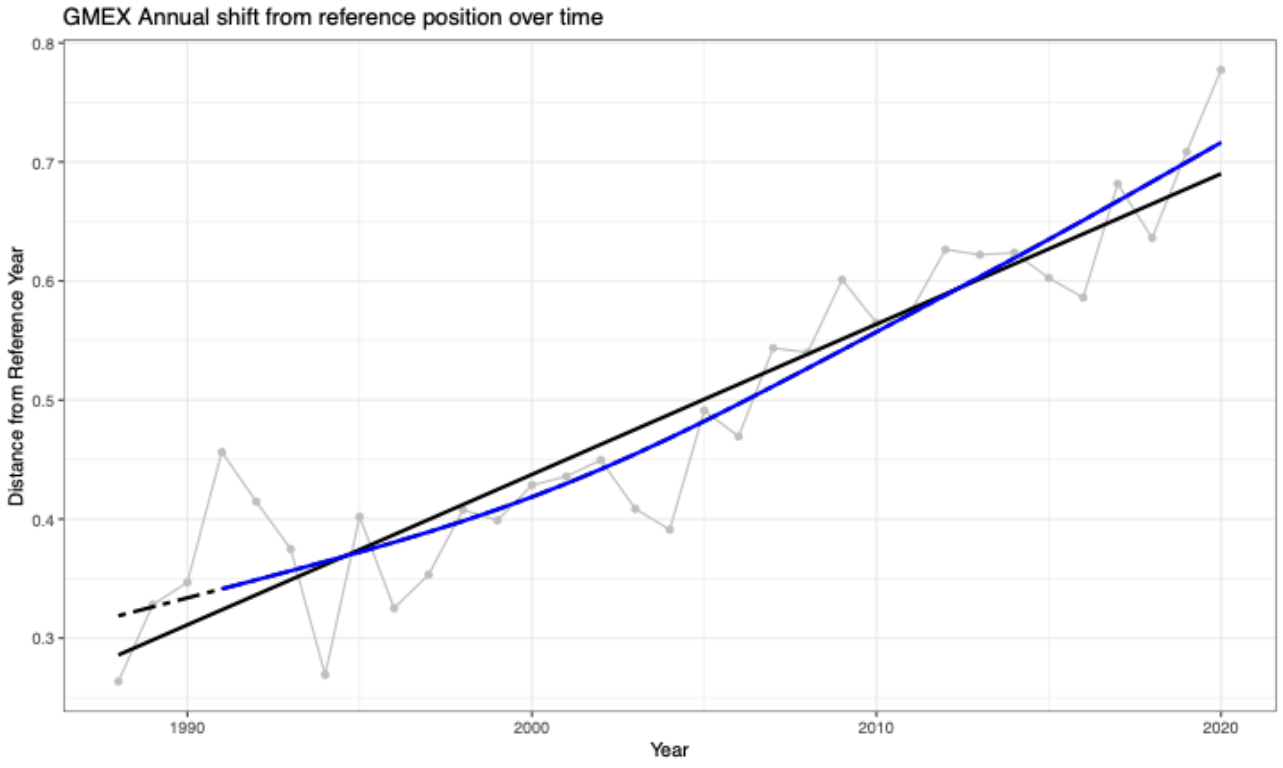

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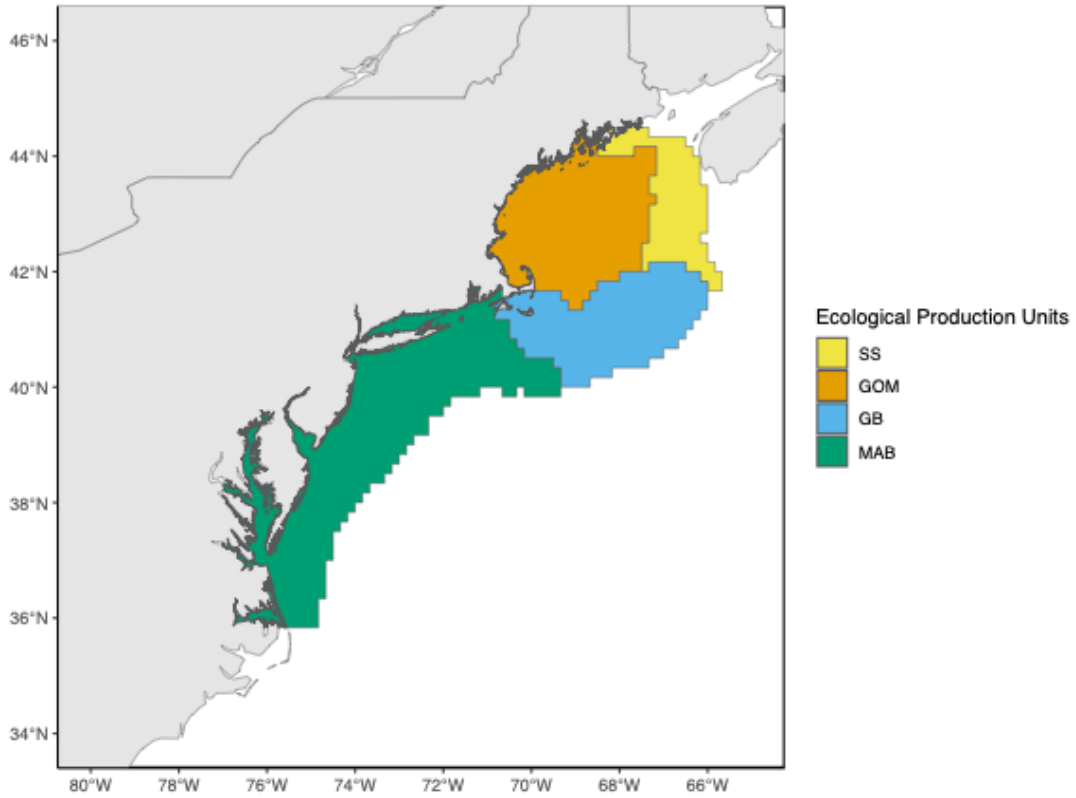
De Cáceres et al. 2019, Sturbois et al. 2021, Fenwick et al. 2024

The CTA can inform community response to disturbances

How do pulse and press disturbances impact assemblage change and reorganization?

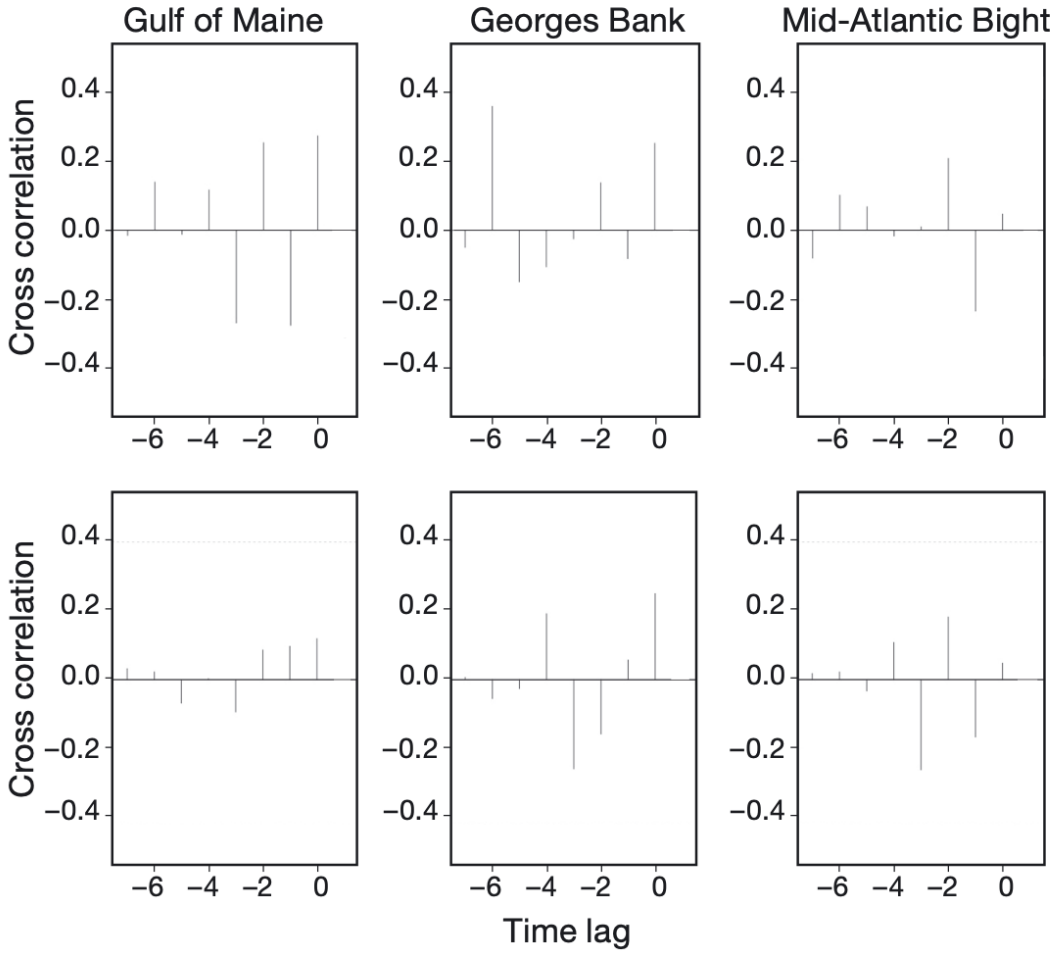
- Northeast US large marine ecosystem
- Expected high magnitude shifts after marine heatwave events
- Evaluated community change metrics with:
  - Gulf Stream index position
  - Ecosystem overfishing
  - Bottom temperature anomalies
  - Small to large zooplankton ratio
  - MHW cumulative intensity



MHW events did not instigate assemblage level change

Long term press disturbances drove community structure over the study

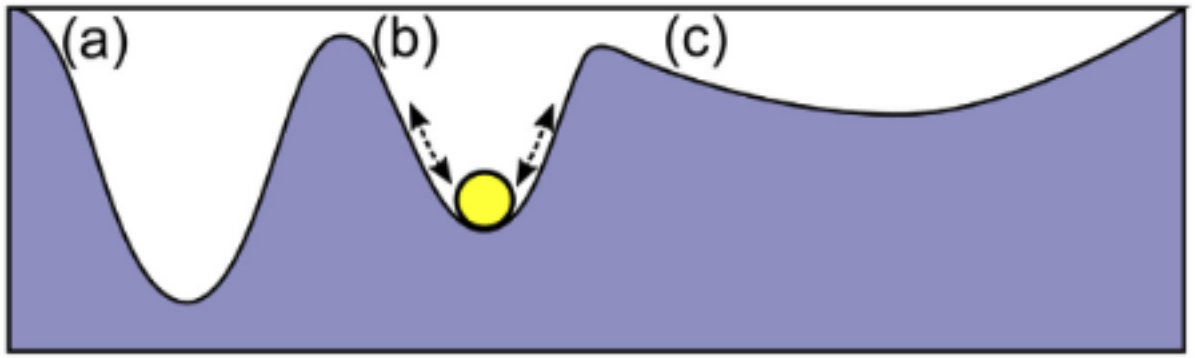
- Ecosystem overfishing and temperature shifts
- Species responses may not scale to assemblage level
- Pulse disturbances did not lead significant shifts in assemblage change
- CTA can relate to environmental parameters & detects abrupt change



Fenwick et al. 2024

Examining theory supports real ecological systems

Stability landscapes



Ball = current ecosystem state

Cup = stability basin

Ball-and-cup model

[conceptual model of stability]

+

Ordination trajectories

[empirical evidence of change)

=

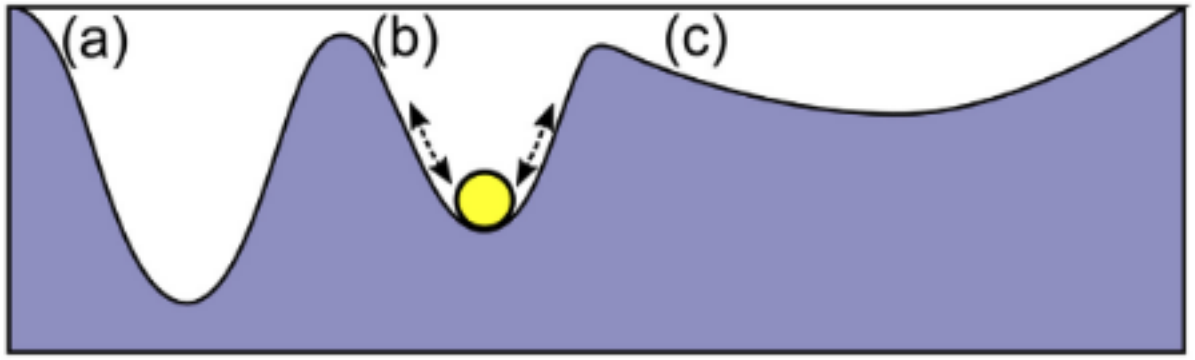
Connecting community change with theoretical stability frameworks

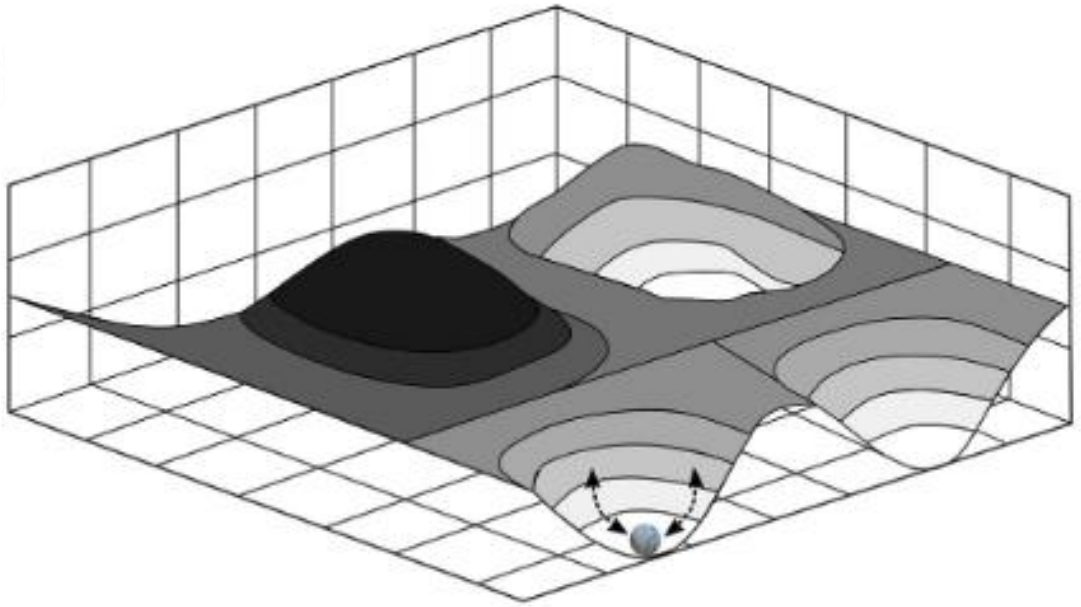
Figure edited from Lamothe et al. 2019

Ecological stability is dynamic

Dynamic stability: ecosystems fluctuating around an attractor with **“relatively small”, non-directional** changes in composition

Stability landscapes





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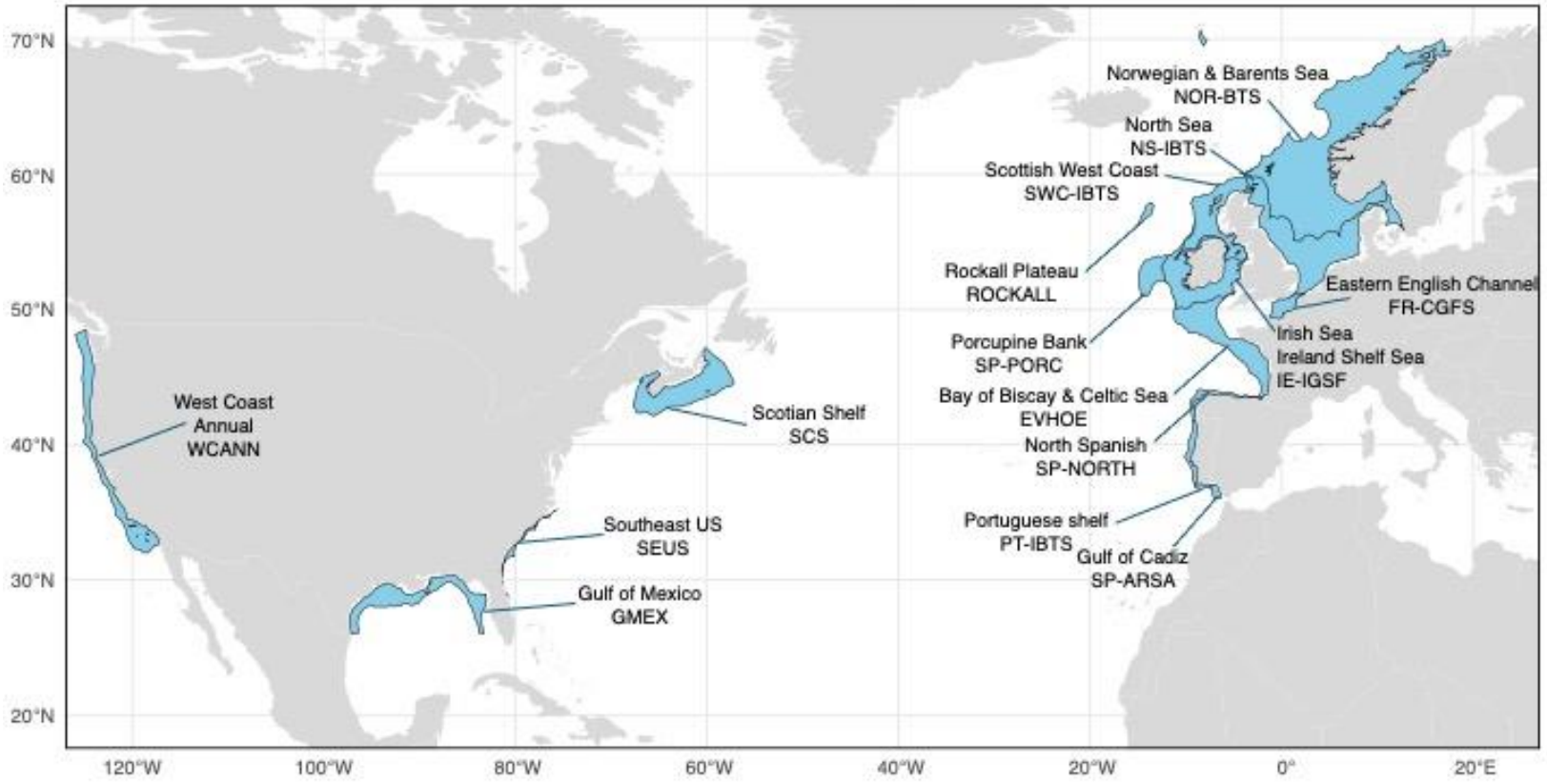
Sánchez – Pinillos et al al. 2024 and Figures edited from Lamothe et al. 2019

Evaluating assemblage stability in demersal marine fish assemblages



- 15 study areas from long term scientific bottom trawl surveys
  - FISH GLOB open access repo
- Valuable grounds for global fisheries
- Marine food webs are an ideal system to test stability theory

Maureaud et al. 2021, Maureaud et al. 2024

Materials and Methods

- Time series ranged from 14-50 years, average 24 years
- Fisheries independent survey data
  - FISH GLOB data disclaimer and processing steps
  - Rare or predominantly absent sp removed
  - Mean stratified catch per unit area
- Hellinger distance coefficient for dissimilarity in observations
- Visualized change with a principal coordinates analysis (PCoA) + extracted CTA metrics

Maureaud et al. 2021, Maureaud et al. 2024

How do patterns of temporal beta diversity inform assemblage stability?

Expectations

Stable assemblages have low directionality and may have higher variability

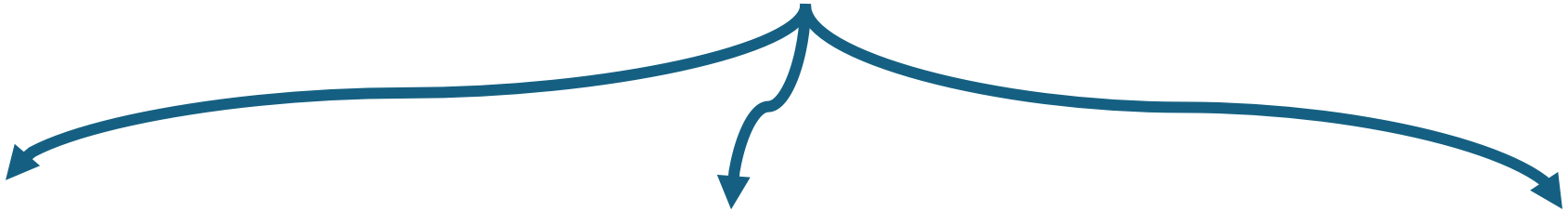
- Fluctuating population dynamics
- Weak interactions can support reorganization
- Functional diversity

Shifting assemblages have high directionality and significant deviation from baseline

Compensating for the dynamic change

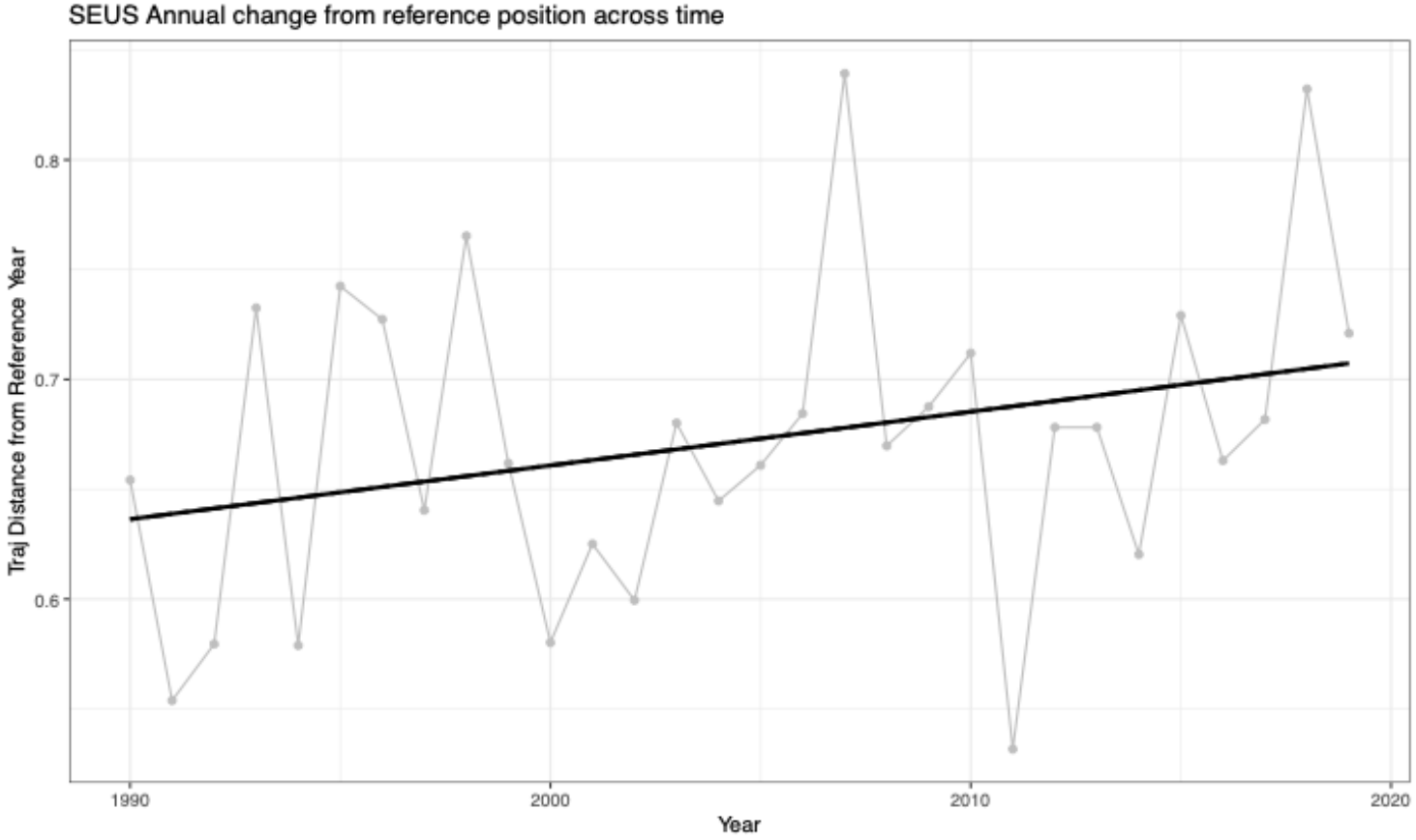
Overwhelmed by the dynamic change

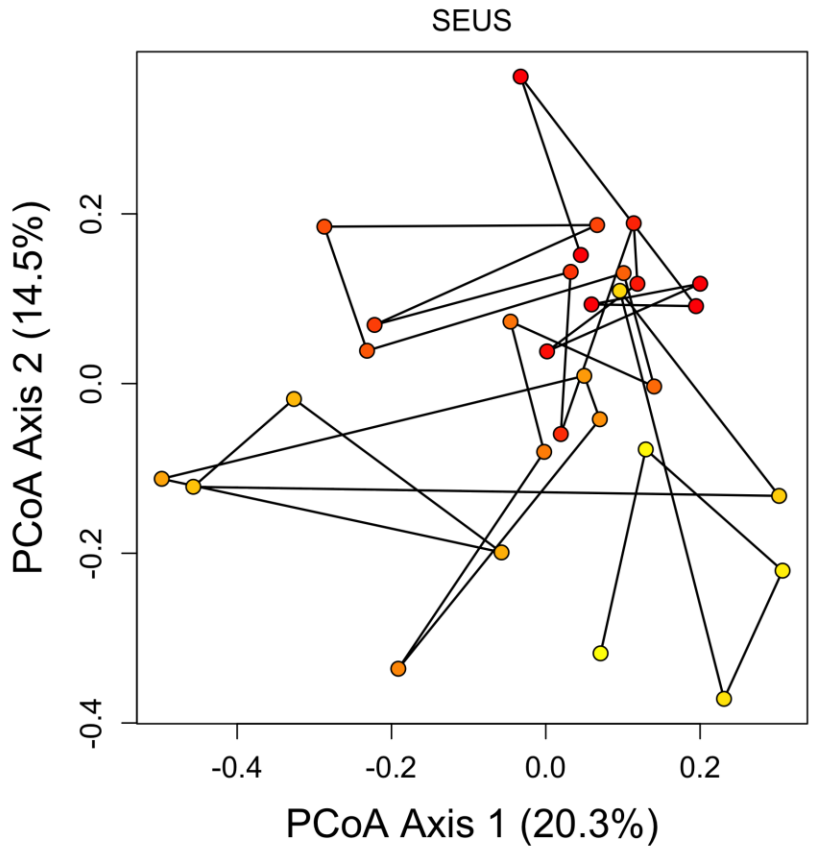
Trends in temporal beta diversity



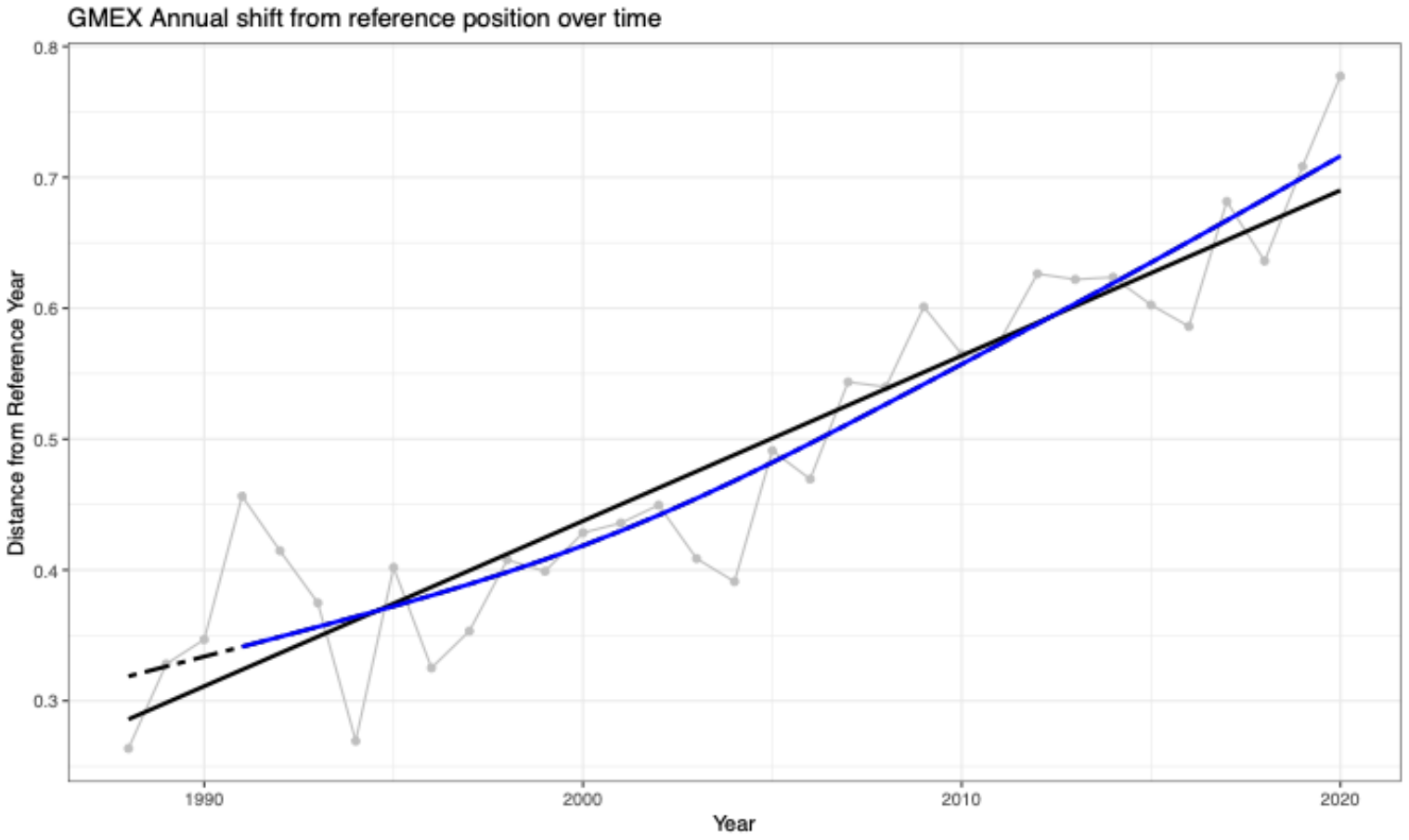
STABLE **UNSTABLE** **RECOVERY**

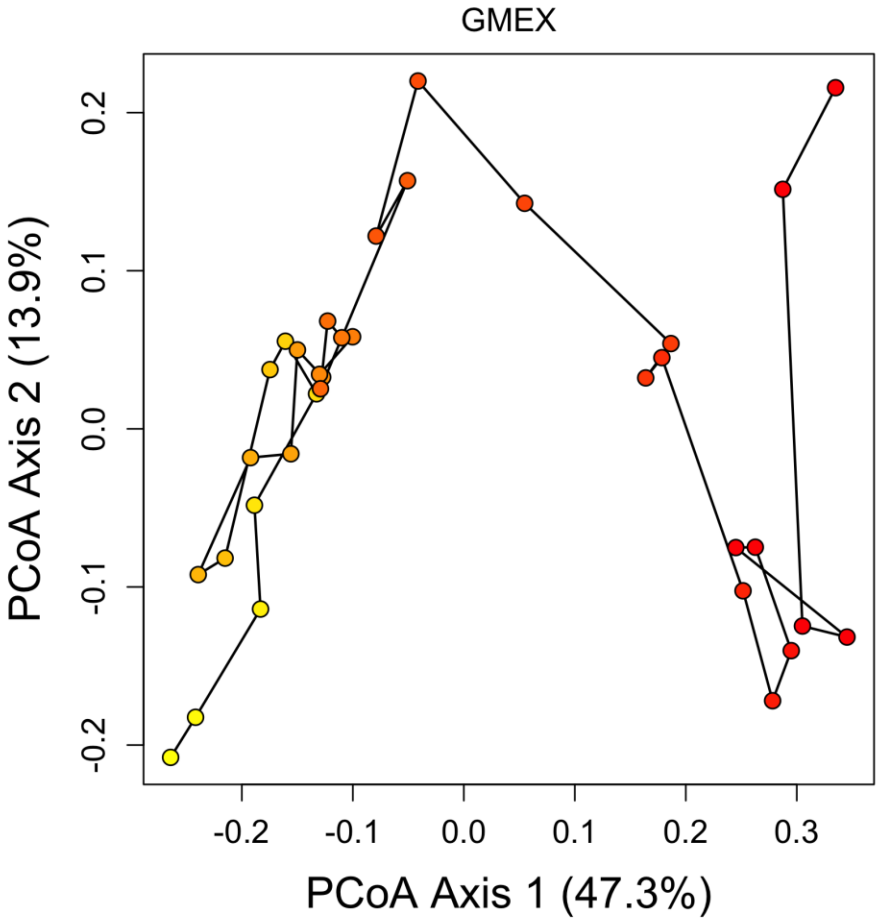
Stable assemblages had higher variability



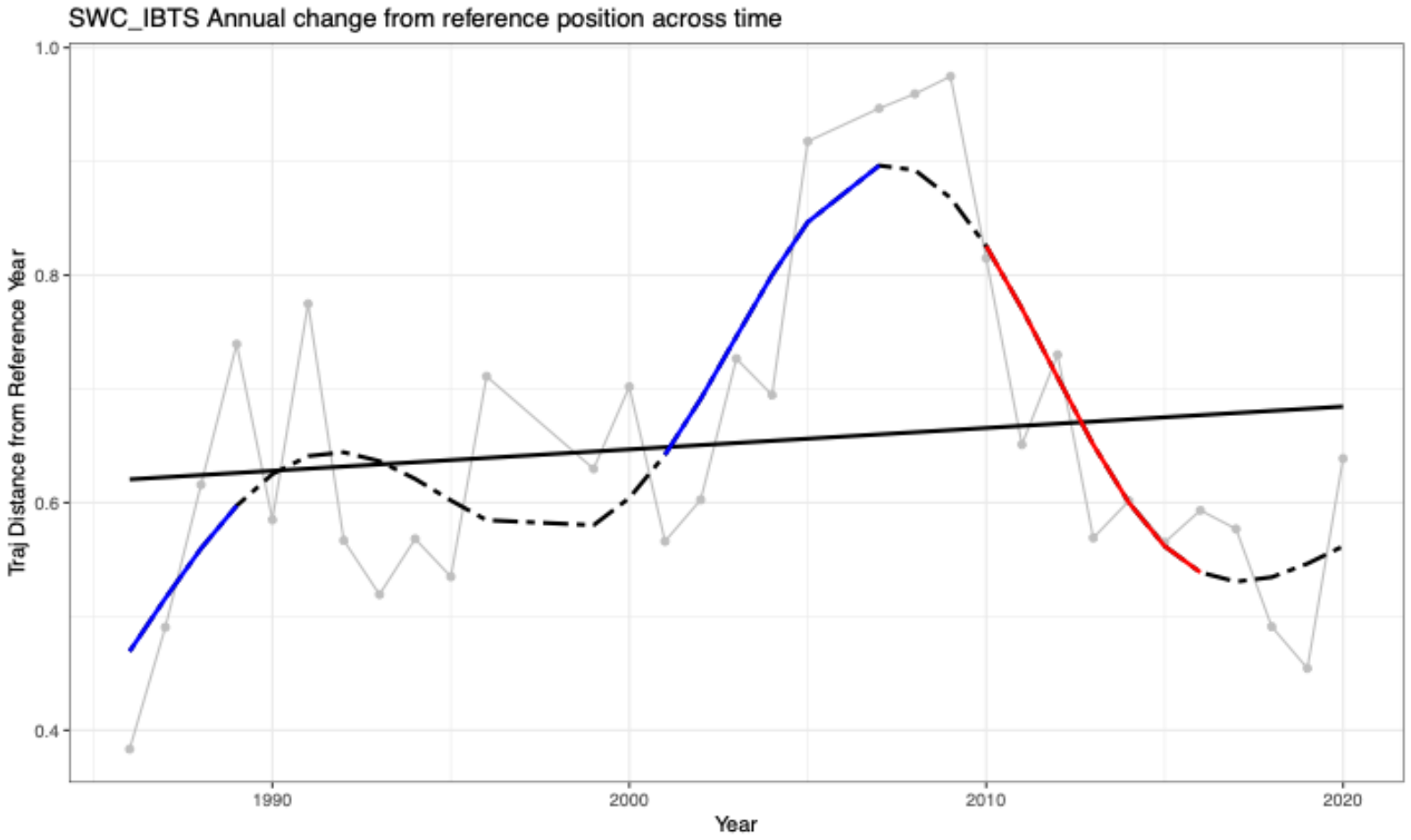


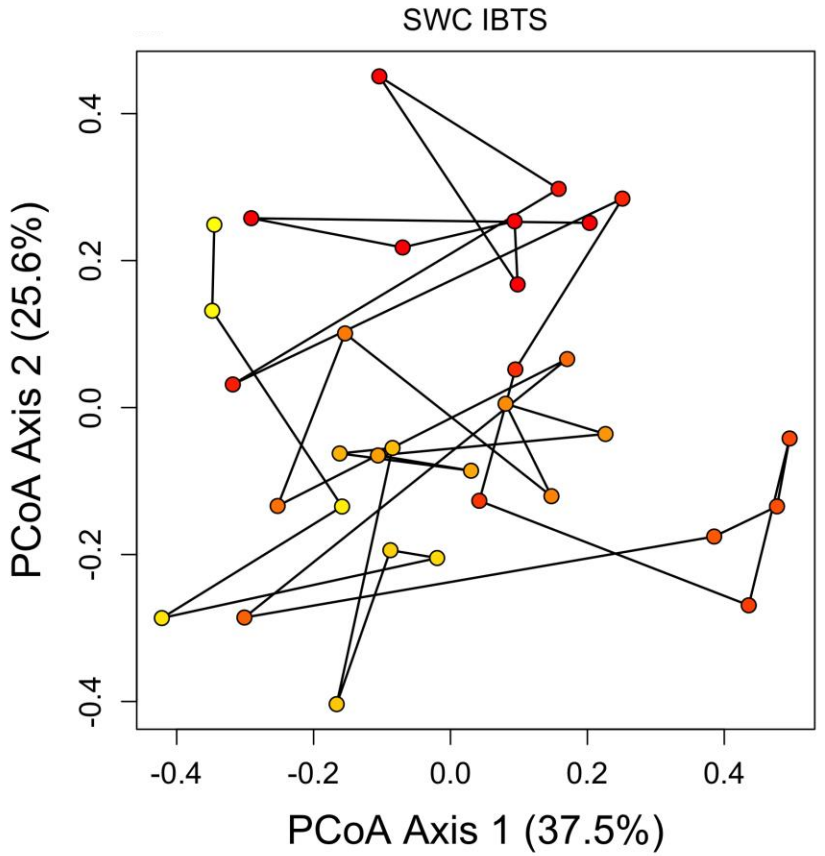
Incremental change resulted in significant divergence in unstable assemblages



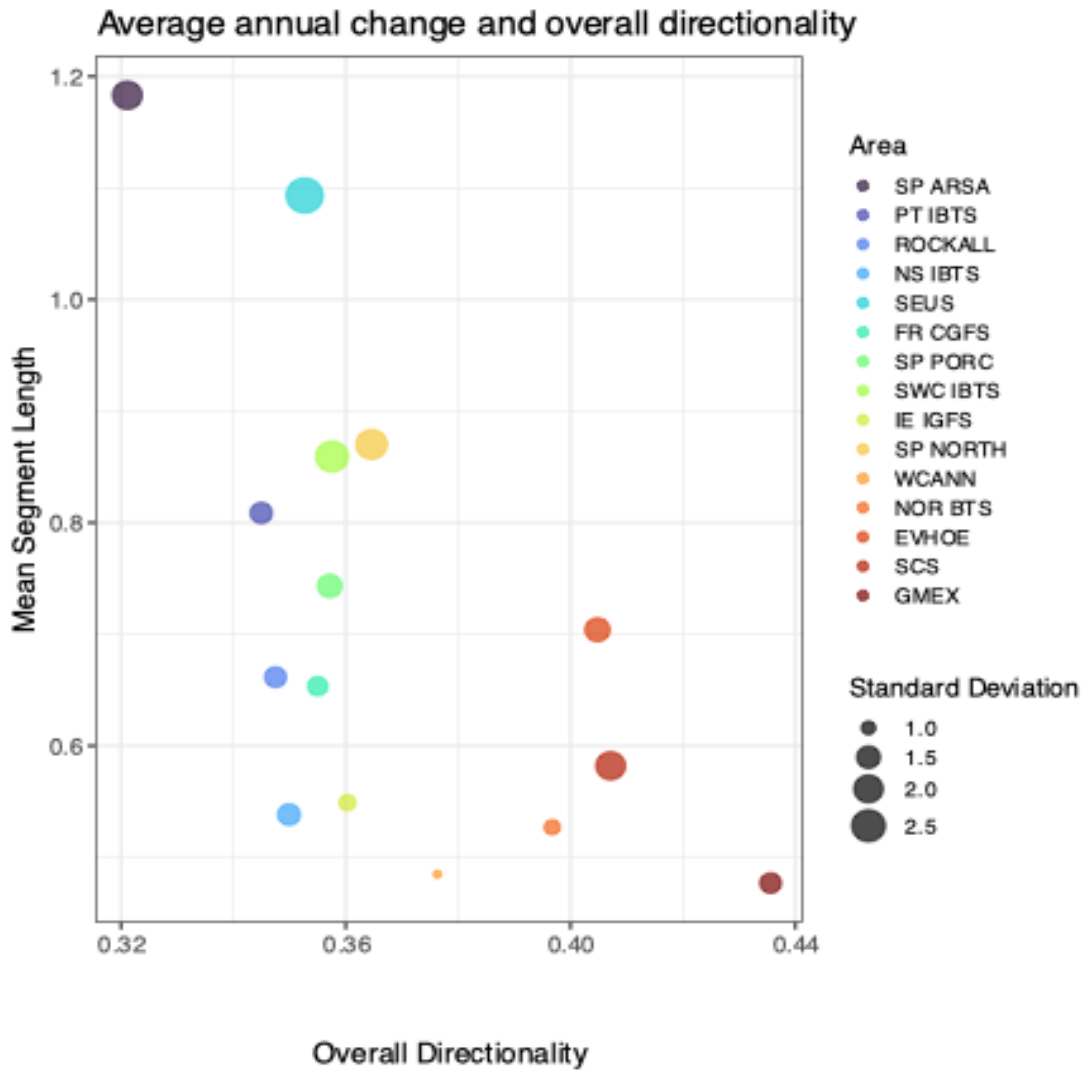


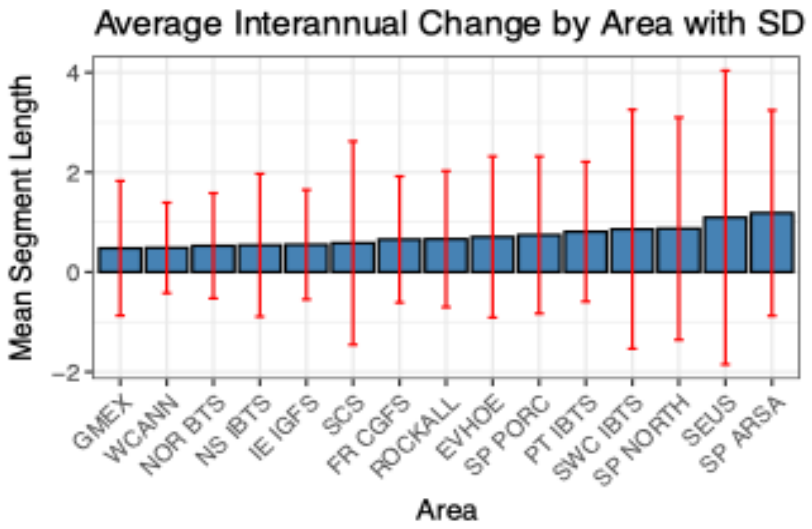
Recovery occurred in less directional, more variable assemblages

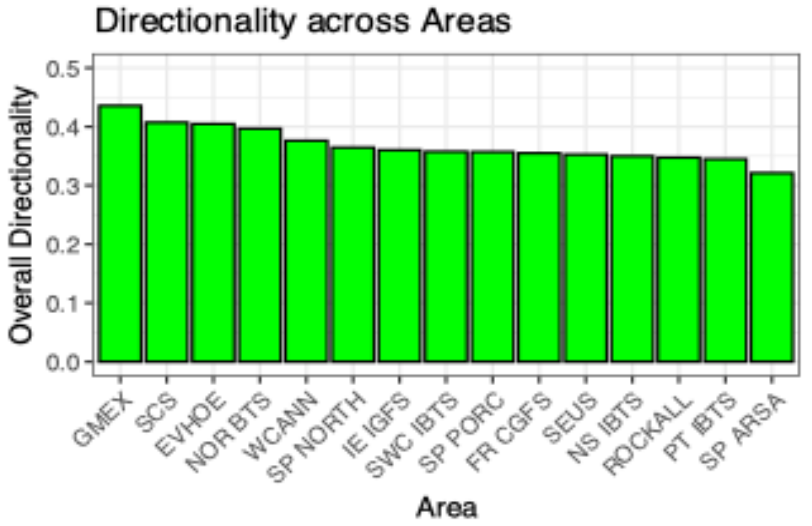




Directionality and variability are negatively coupled



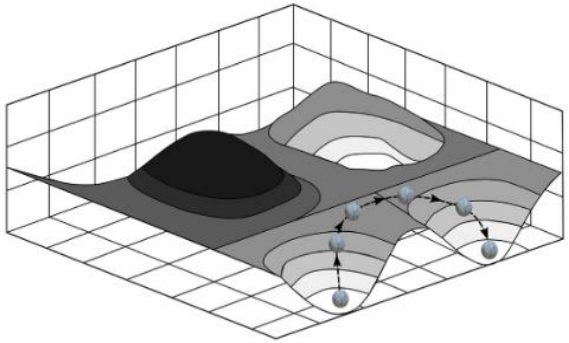




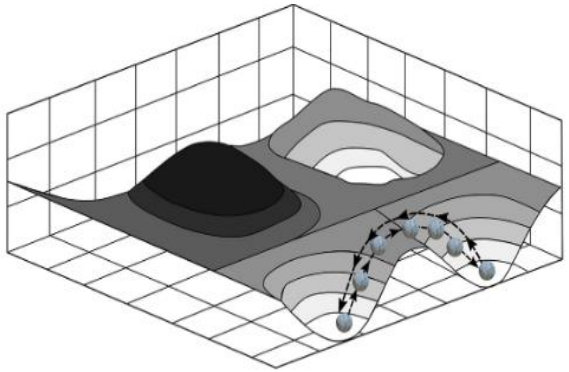
Incremental, directional change is the most concerning

- No acute, abrupt reorganization persisted in any area
- Diverging assemblages had the lowest interannual variability
- Variability is a management challenge but may be a buffer
- Ecological shifts are often lagged and non-linear
  - Integrate temporal beta diversity into management assessments
- Managing for the future

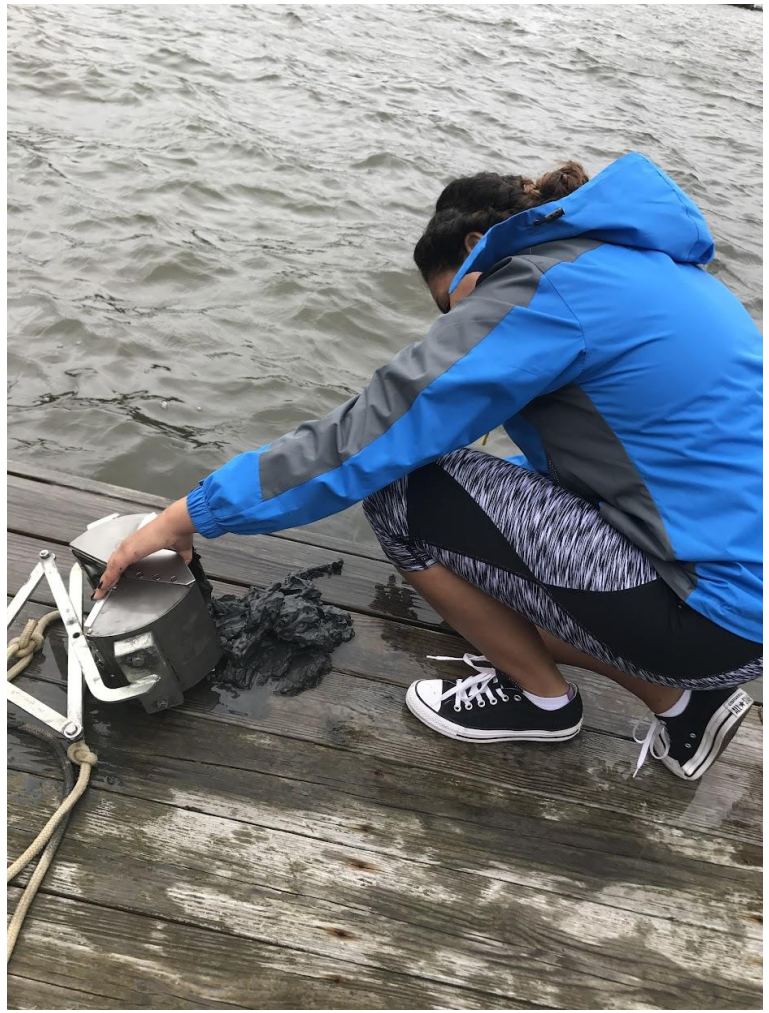
Compensating for the dynamic change



Overwhelmed by the dynamic change



Stability and resilience in ecological systems



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- Sarah Weisberg
- Funding sources

Nye Lab

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Fish Biodiversity facing Global change

BWEEMS
Black Women in Ecology, Evolution, and Marine Science

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Questions?

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MEPS Pulse and Press disturbance paper
Fenwick et al. 2024