Cumulative Biomass-Trophic Level Curves

Jason Link, Chris Kelbe, Howard Townsend

NOAA Fisheries

Ways these measures can be used

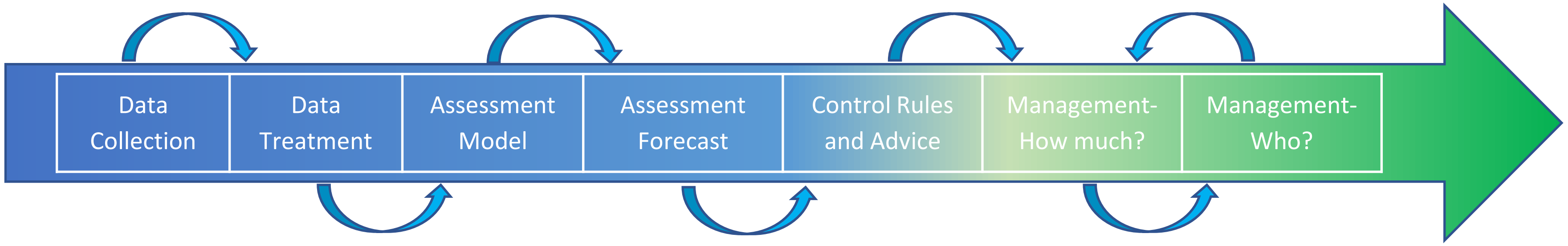
Directly to

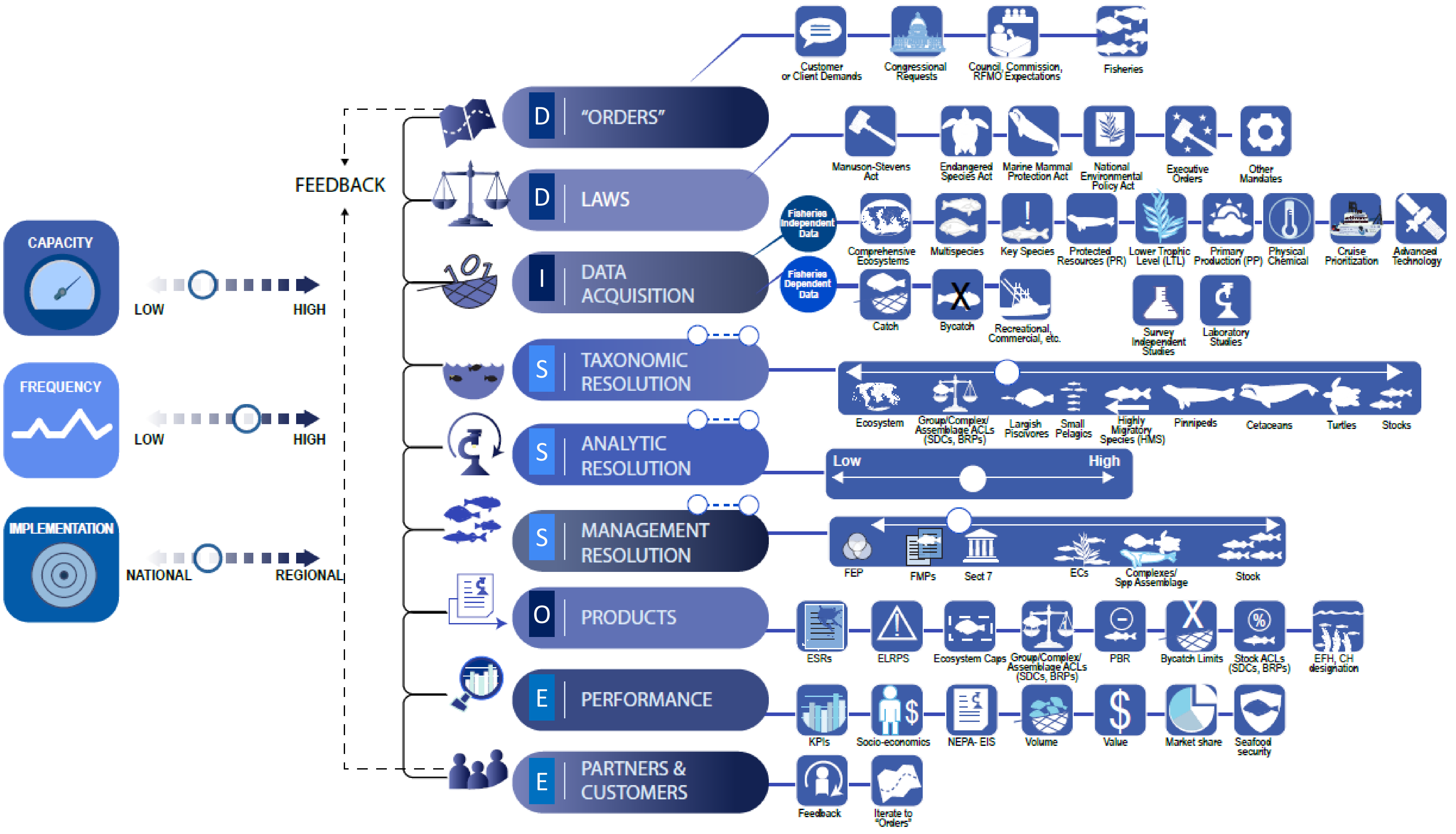
- set OFLs, ACLs, ACTs, SDCs,etc. of the ecosystem, guilds, etc.
- measure EOF
  - serve as comparable “Kobe” plots to delineate EOF when multiple are combined
- inform allocation, effort decisions
- evaluate (overall) fishery performance
- clarify expectations of what Fisheries Removals could be

Indirectly to

- provide context
- provide an ensemble “reality check”
- provide trade space within which systematic degradation is avoided
  - provide backstopping to all fisheries removals
- evaluate the best socio-economic options
- provide insights into system dynamics
- provide early warning signals of system-wide events

Should be viewed as part of a process (or work flow) which combines a set of (different) analytical methods



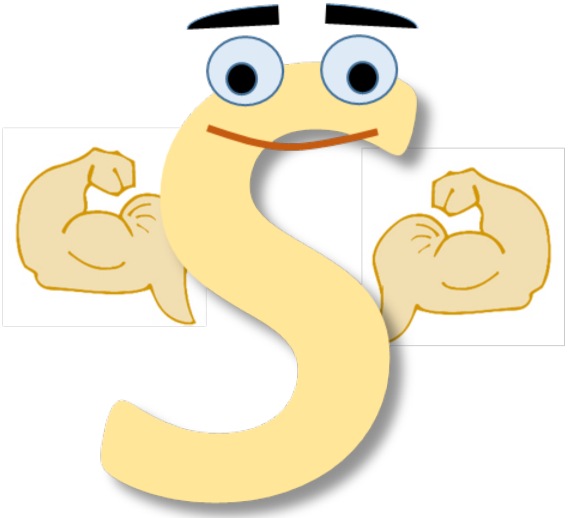


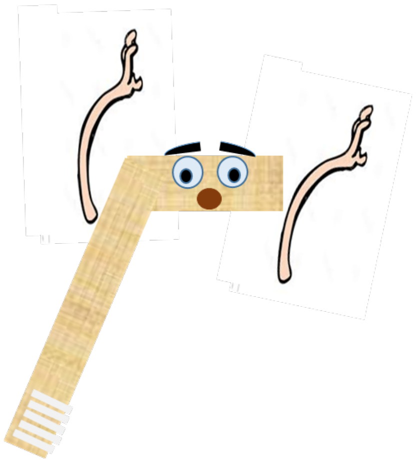
Customer or Client Demands
Congressional Requests
Council, Commission, RFMO Expectations
Fisheries
D
"ORDERS"
D
LAWS
Manuson-Stevens Act
Endangered Species Act
Marine Mammal Protection Act
National Environmental Policy Act
Executive Orders
Other Mandates
FEEDBACK
CAPACITY
LOW
HIGH
I
DATA ACQUISITION
Fisheries Independent Data
Comprehensive Ecosystems
Multispecies
Key Species
Protected Resources (PR)
Lower Trophic Level (LTL)
Primary Production (PP)
Physical Chemical
Cruise Prioritization
Advanced Technology
Fisheries Dependent Data
Catch
Bycatch
Recreational, Commercial, etc.
Survey Independent Studies
Laboratory Studies
S
TAXONOMIC RESOLUTION
Ecosystem
Group/Complex/ Assemblage ACLs (SDCs, BRPs)
Largish Piscivores
Small Pelagics
Highly Migratory Species (HMS)
Pinnipeds
Cetaceans
Turtles
Stocks
FREQUENCY
LOW
HIGH
S
ANALYTIC RESOLUTION
Low
High
IMPLEMENTATION
NATIONAL
REGIONAL
S
MANAGEMENT RESOLUTION
FEP
FMPs
Sect 7
ECs
Complexes/ Spp Assemblage
Stock
O
PRODUCTS
ESRs
ELRPS
Ecosystem Caps
Group/Complex/ Assemblage ACLs (SDCs, BRPs)
PBR
Bycatch Limits
Stock ACLs (SDCs, BRPs)
EFH, CH designation
E
PERFORMANCE
KPIs
Socio-economics
NEPA- EIS
Volume
Value
Market share
Seafood security
E
PARTNERS & CUSTOMERS
Feedback
Iterate to "Orders"

Summary Up Front

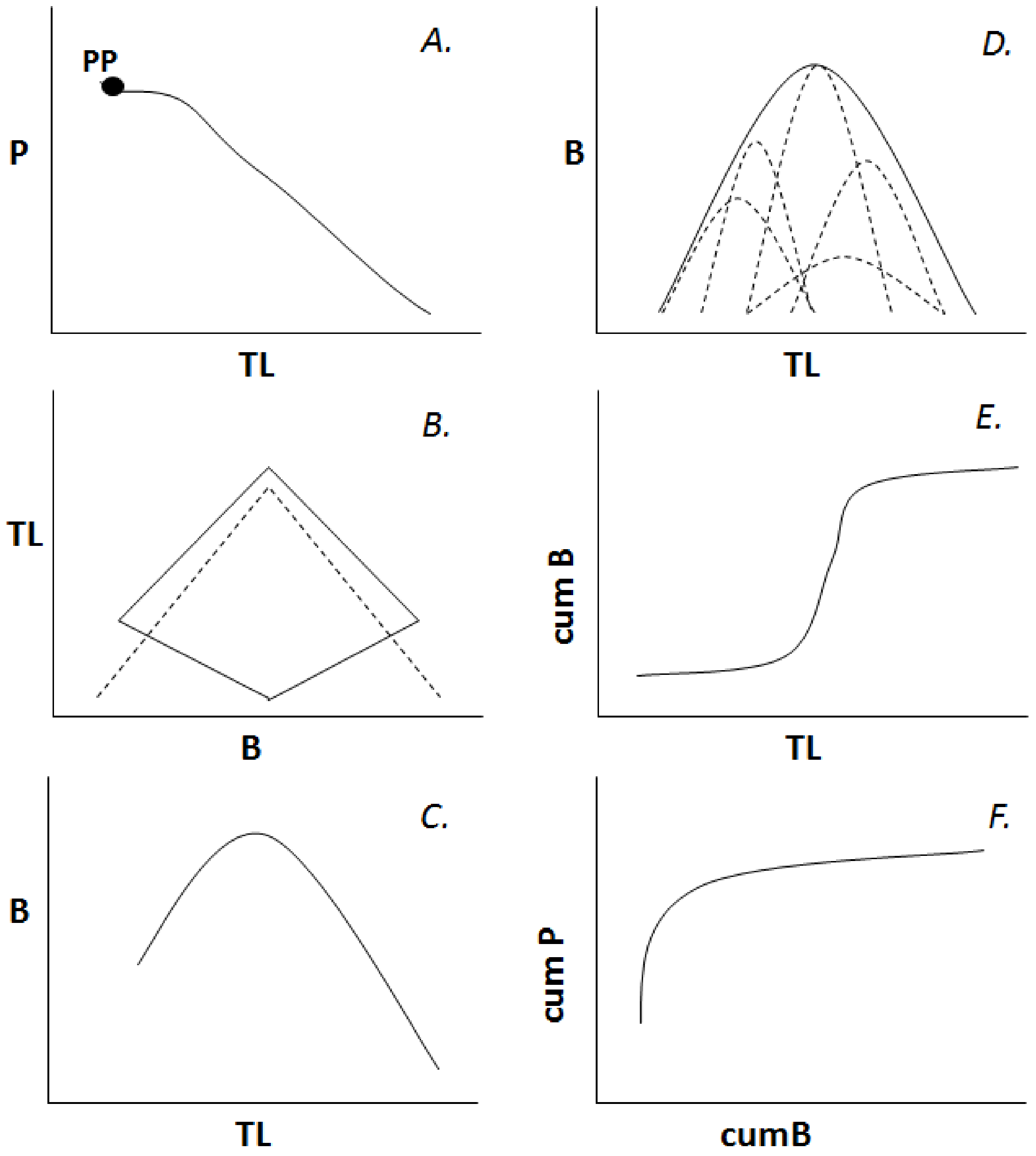
- Method description: Cumulative Biomass-TL curves
- Data inputs (especially critical data and their viability now and in the future): either, Food Web model outputs, *or* Biomass *or* Landings data and TL of all/most species
- Analysis/data output summary: CumB-TL, CumB-CumP curves, with curve properties servings are RPs
- How this method can inform management: Potential Indicator of EOF
- Caveats for this method: Inflection levels depend on inclusion of PP or not; FW model output caveats, veracity/robustness of landings data; does not need copious information as might be implied; TL assignments robust based on sensitivity analyses/simulations; behavior very predictable
- Previous applications of this method: multiple, see list
- Any graphs or diagrams to show for this method: see more info

Cumulative Trophic Theory and useful curves therefrom: Or, the story of big "S" and shrinking hockey sticks





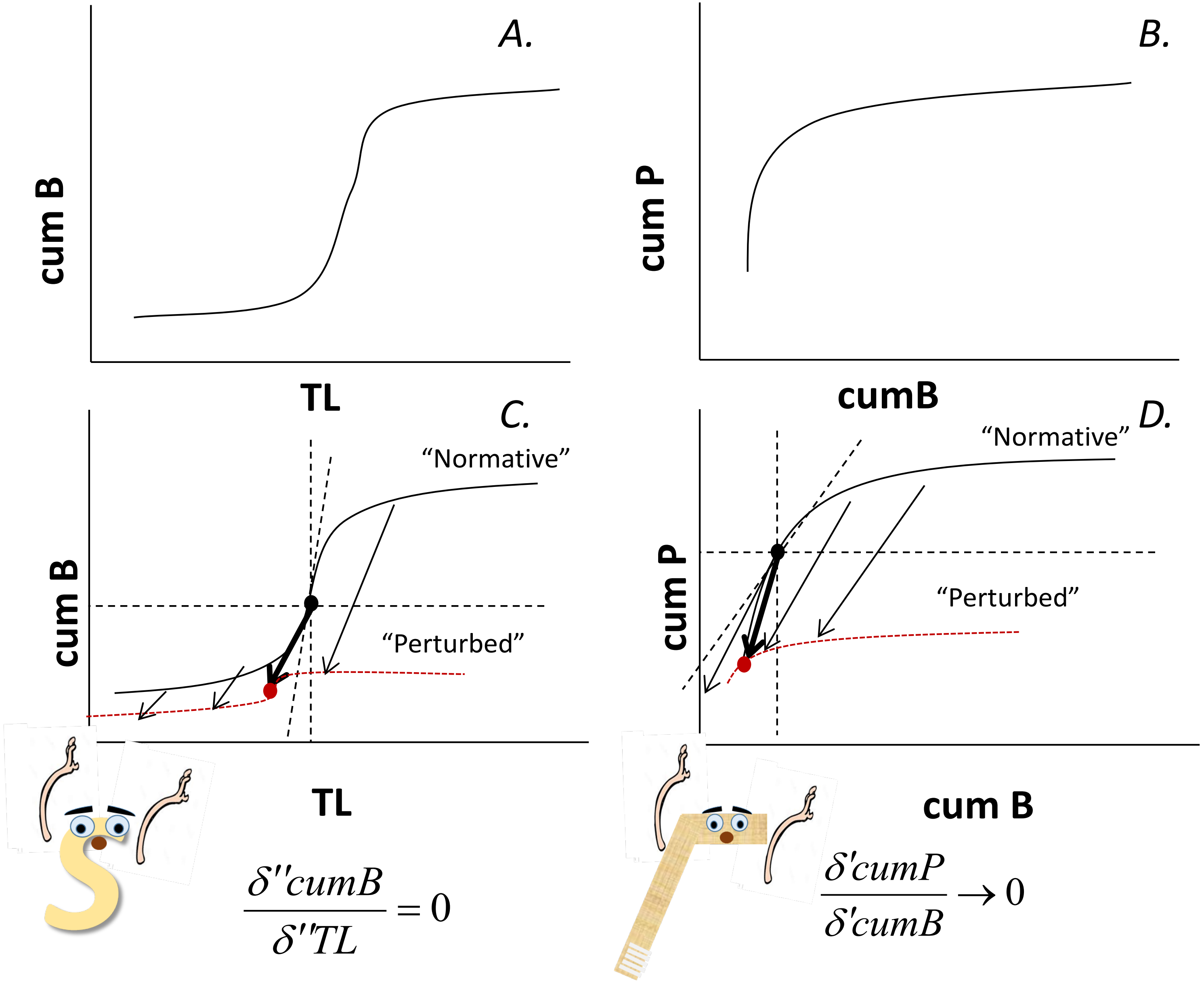
Why these patterns? Cumulative Trophic Theory



A. Thermodynamic constraints, Lindeman TL concept
B. Eltonian pyramid and ME rhomboid modifier
C. System Biomass distribution
D. Trophic spectra of component spp biomass
E. Resultant sigmoidal curve
F. Resultant hockey stick

Link et al., 2015

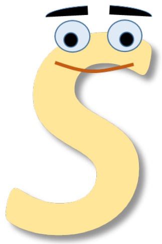
SENSITIVITY TO PERTURBATIONS (OR RECOVERY)

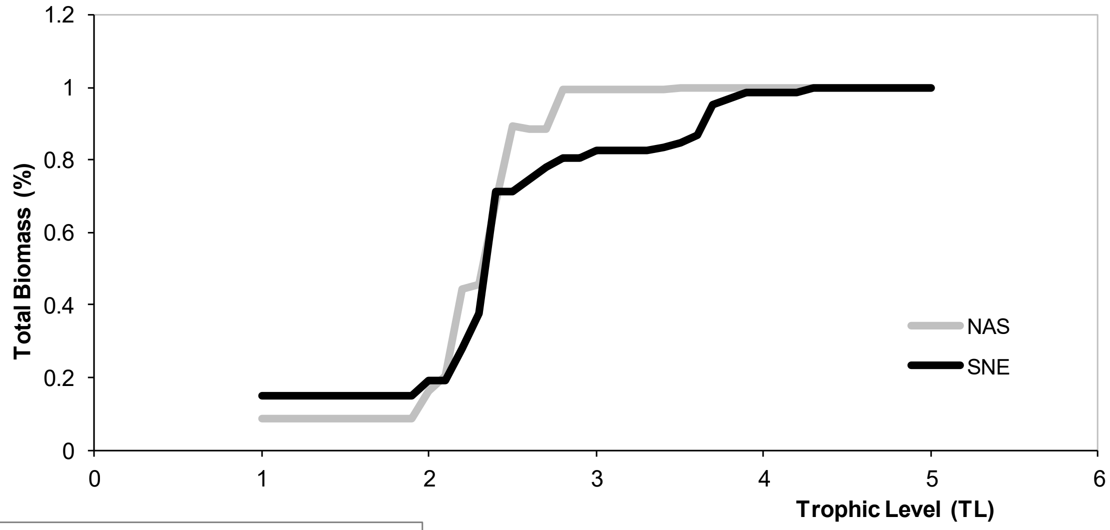


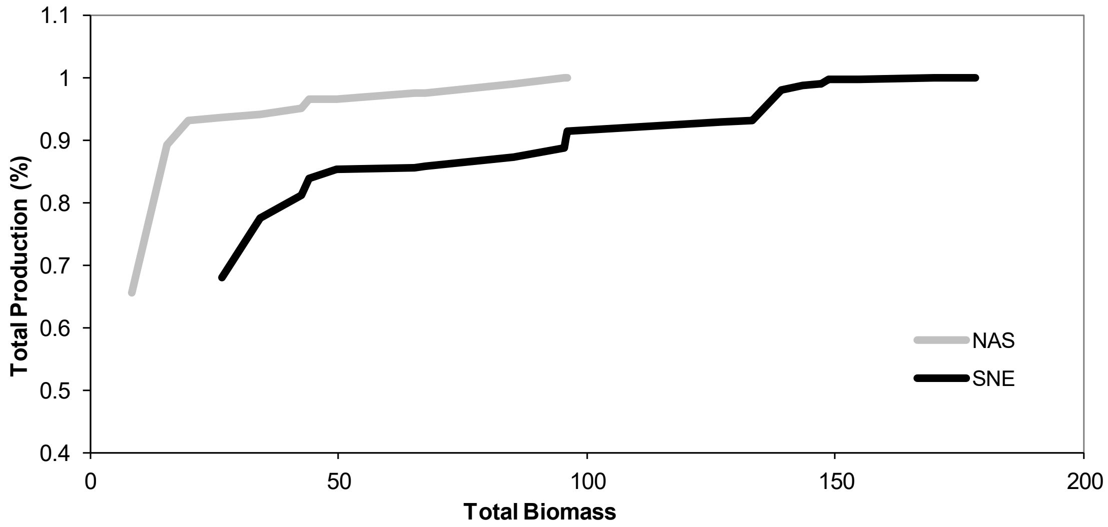
$$\frac{\delta'' cumB}{\delta'' TL} = 0$$

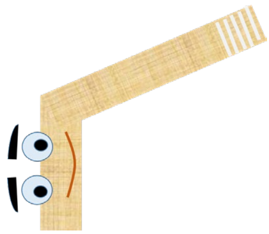
$$\frac{\delta' cumP}{\delta' cumB} \to 0$$

Initial Observations

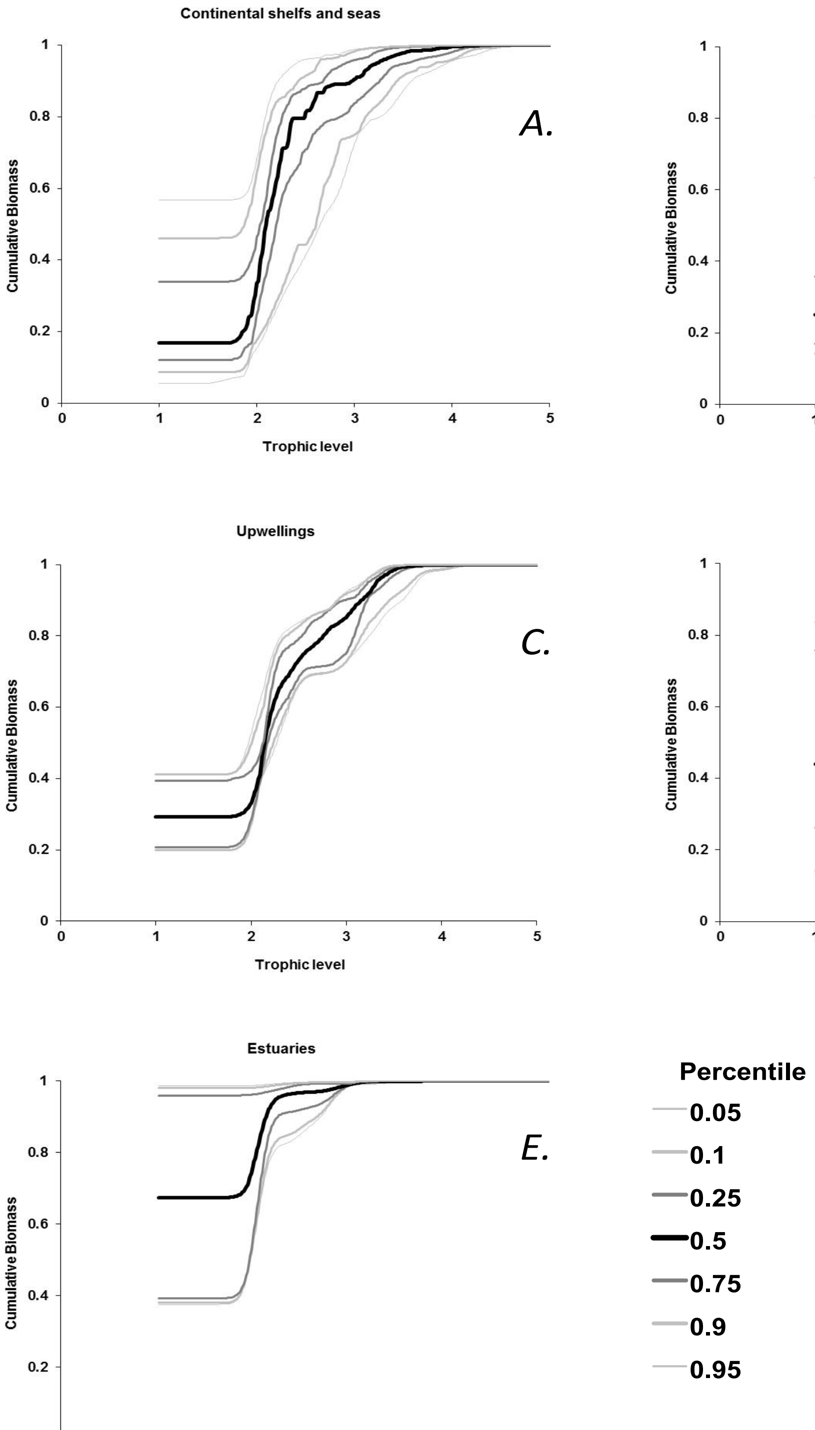




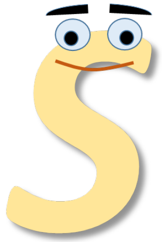




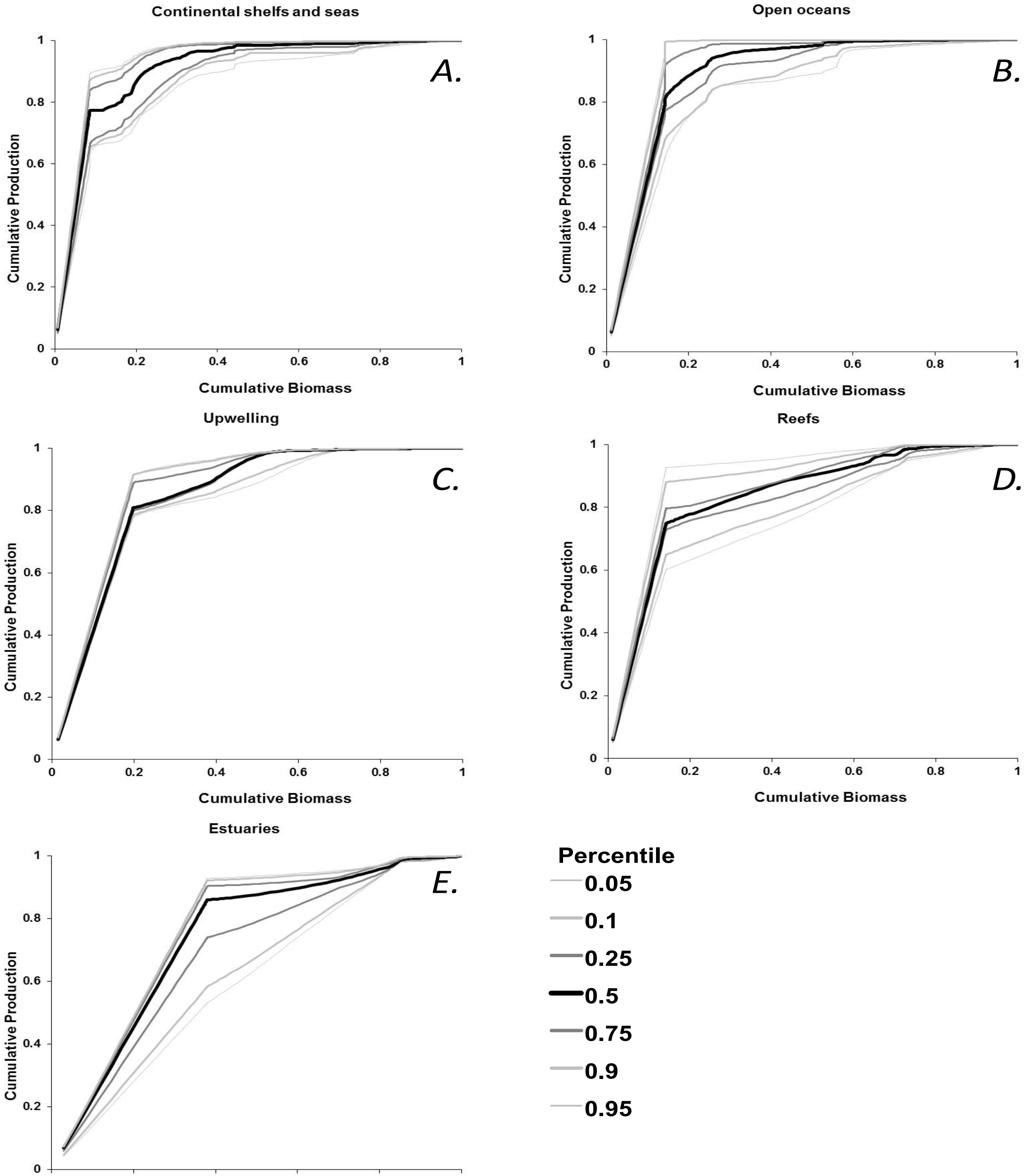
Pranovi and Link 2009 PiO



Patterns held in >120+ marine ecosystems from around the world



Link et al., 2015



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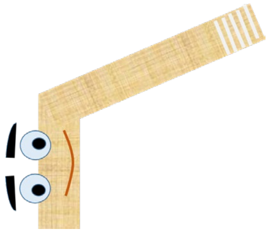
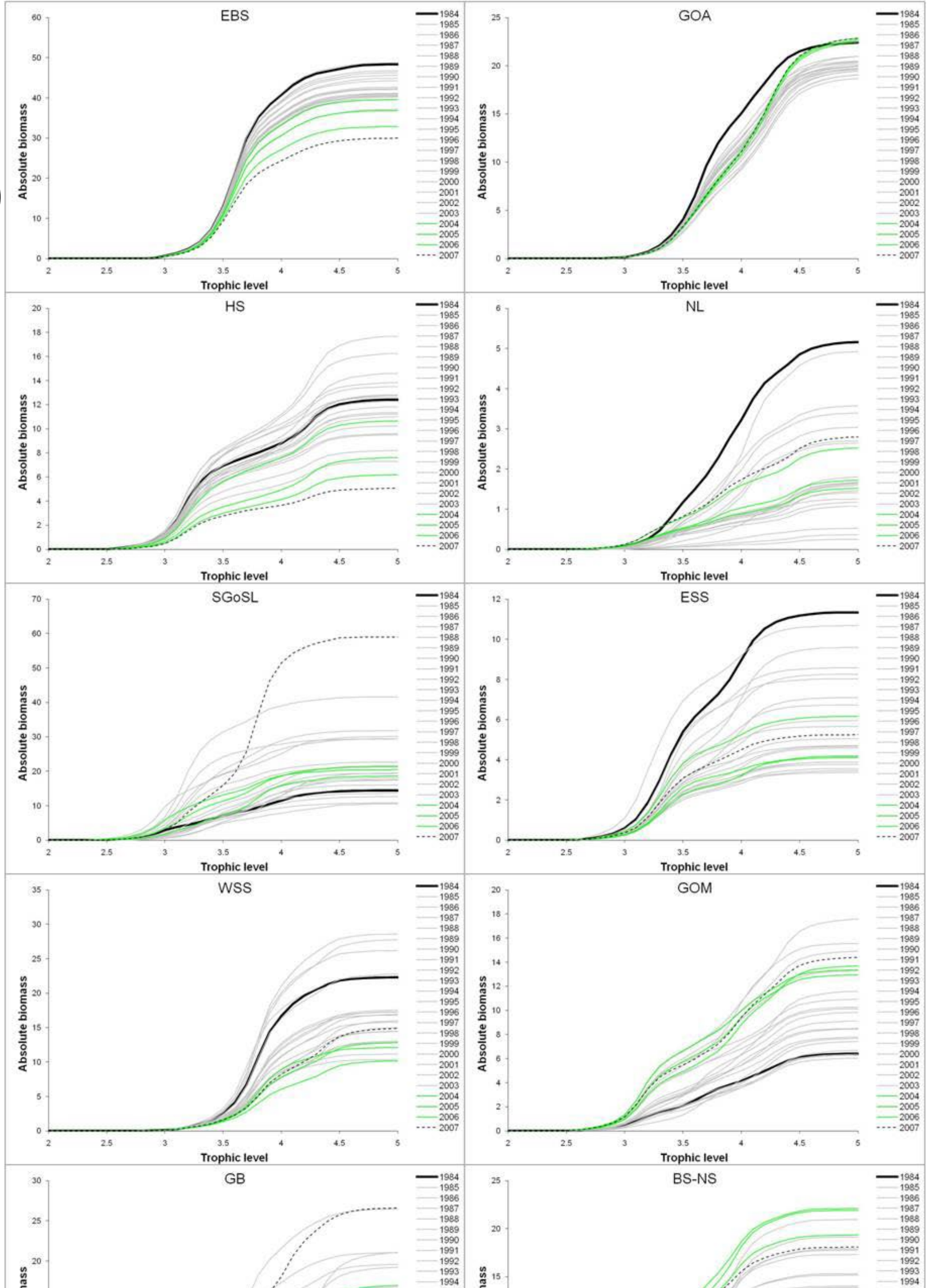


Link et al., 2015

Further Empirical Sup

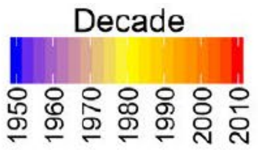
- From >20 survey databases with time series
- Able to statistically link changes in these patterns to known environmental factors

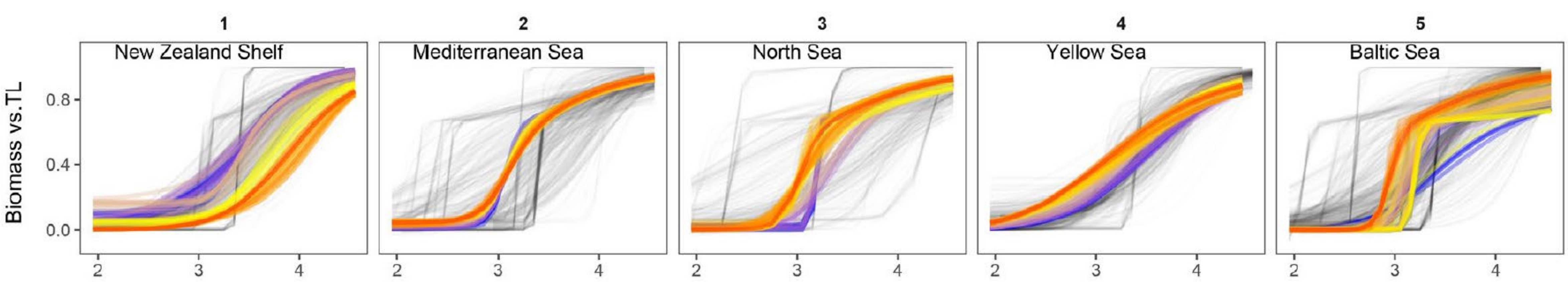


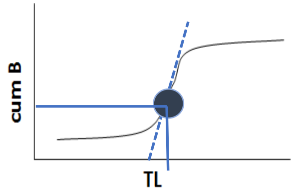
Pranovi et al. 2012 MEPS; 2014 MEPS

TEMPORAL DYNAMICS, >70 YRS

$$\frac{\delta' cumB}{\delta' TL} = ??$$

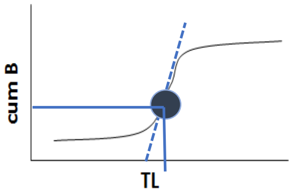


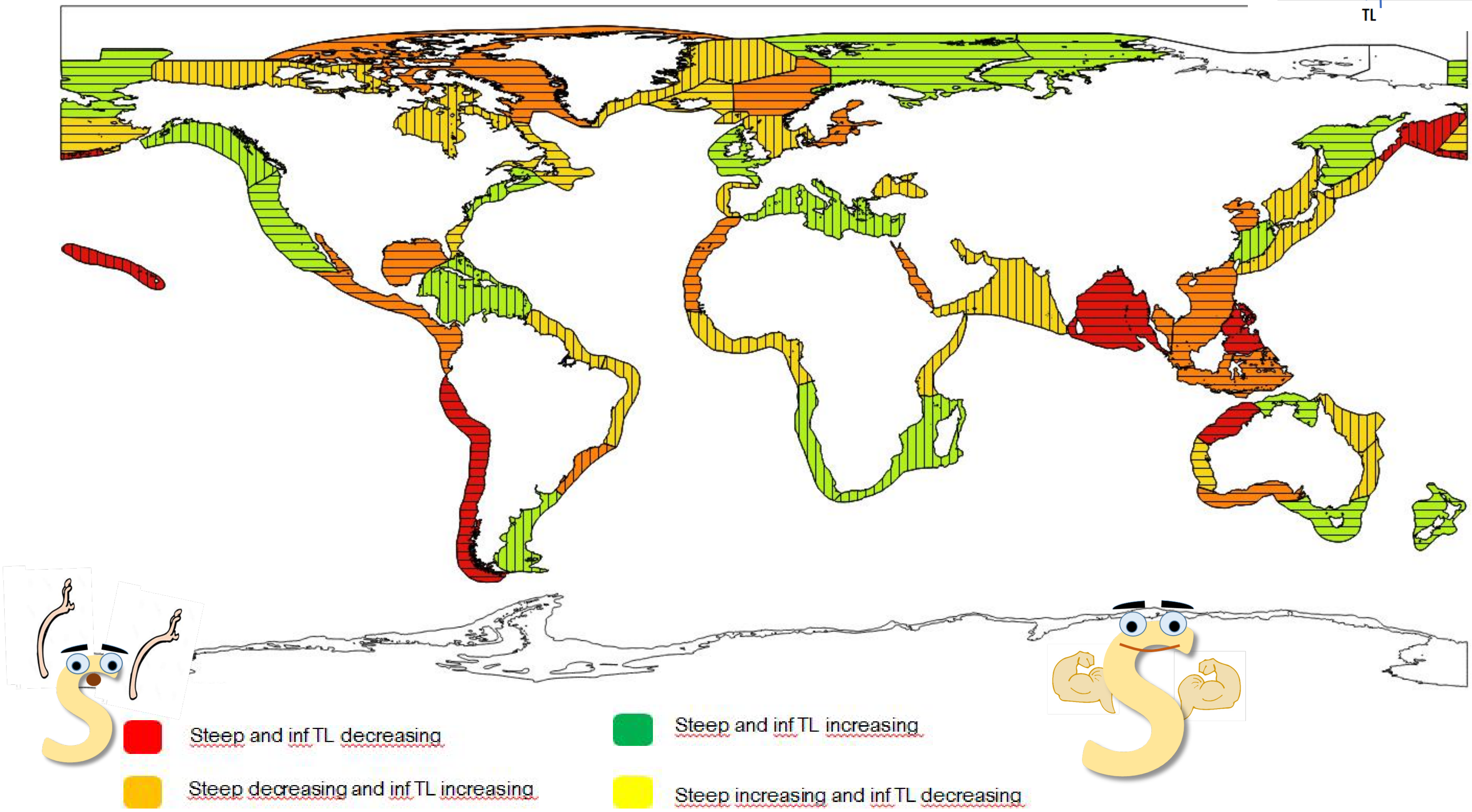




Link et al., 2015, Pranovi et al. 2020

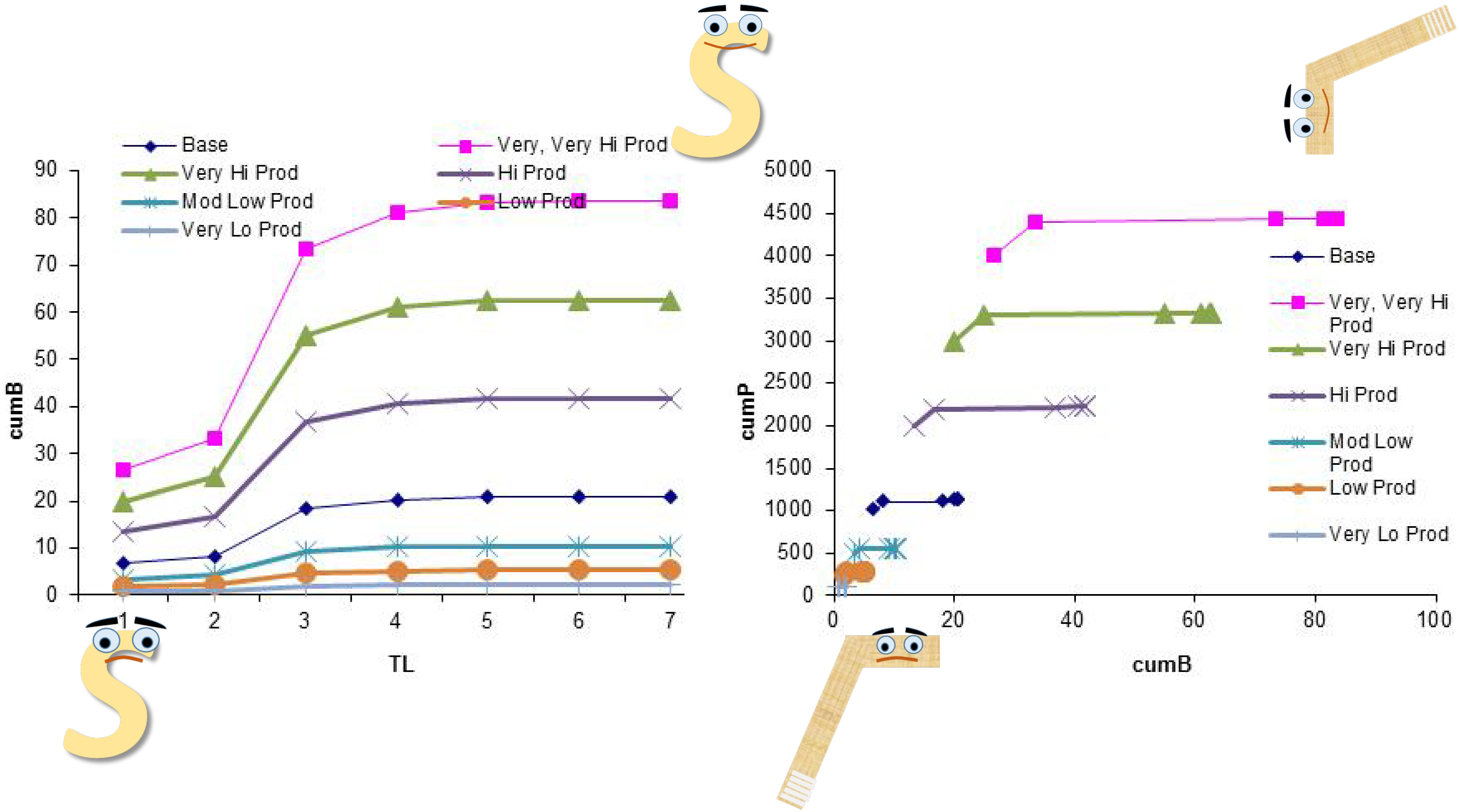
'00s with reference to '90s





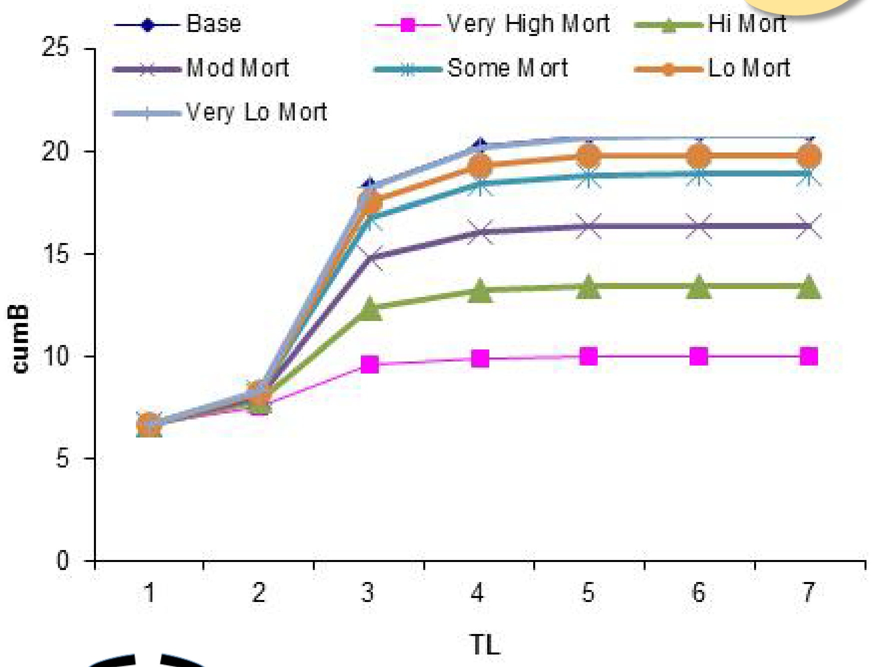
Pranovi et al., 2020

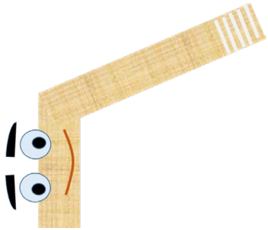
Simulation testing

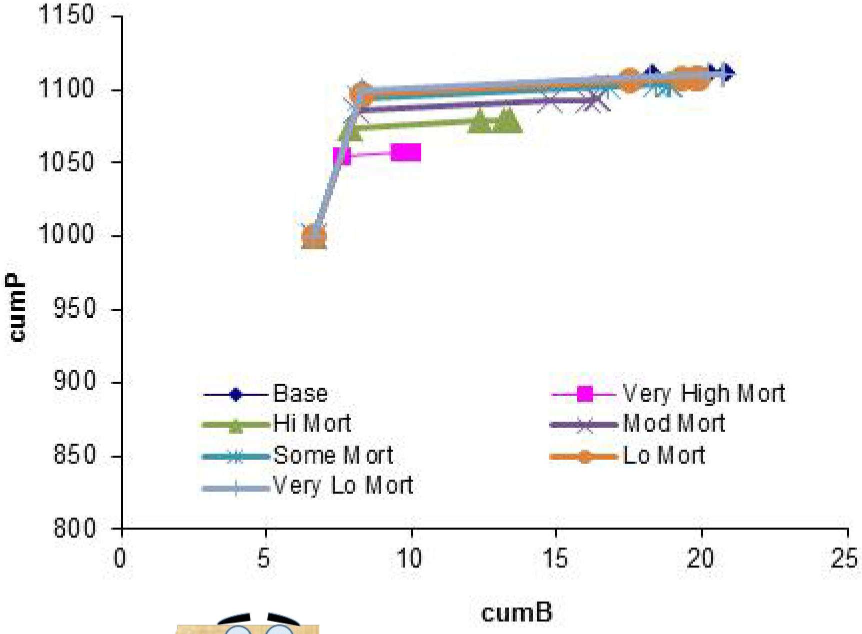


Link et al., 2022, unpubl. data

Simulation testing

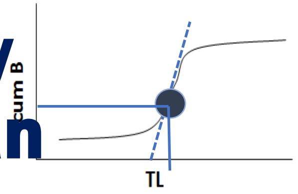


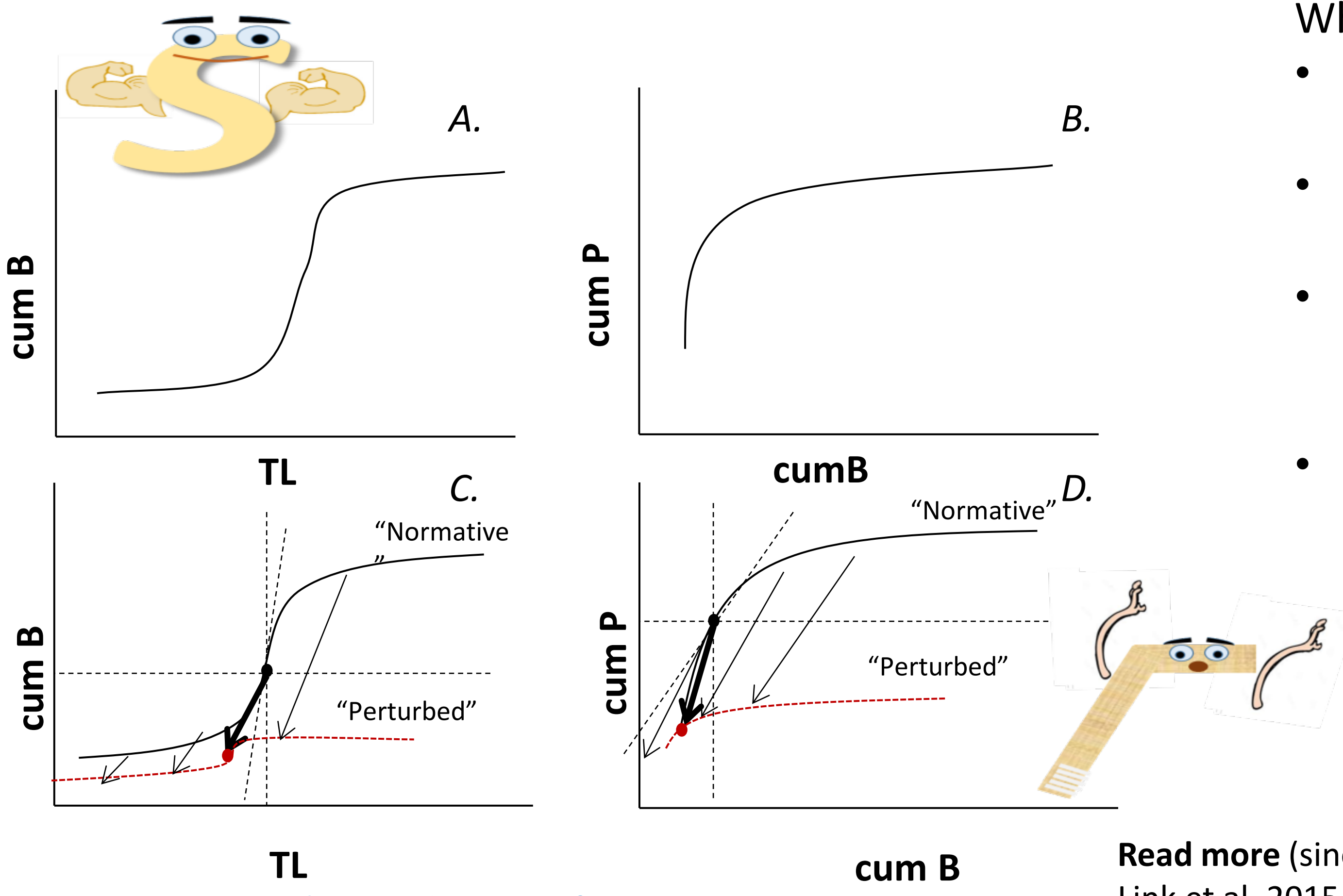




Link et al., 2022, unpubl. data

Bottom Line: cumulative trophic curve big “S” and shrinking hockey sticks are everywhere, respond consistently to perturbation, and can inform marine ecosystem overfishing





What’s the Point:

- Every marine ecosystem exhibits these emergent patterns (>200 cases) of cumB-TL, cumB-cumP
- The “S” and hockey stick curves always stretch, shrink and move toward origin under perturbation
- Tracking curve parameters follows dynamics of an ecosystem and indicates degree of recovery/ perturbation
- Globally, empirical and modeled thresholds emerge when tracking perturbation wrt 1st & 2nd derivative (i.e. slope & inflection point) on “S” curve
    - $cumB_{infl\ pt}$ ~33%
    - $TL_{infl\ pt}$T~3.38
    - Slope~0.5

Most recently used to verify recovery in N. GoMex after DWH
Previously used to ascertain reef status in trophic Pacific Island reefs

Read more (since we don’t have lots of time now):

Link et al. 2015, *TREE* v.30- main description
Pranovi et al. 2012, 2014, *MEPS* v.459, 512- empirical cases
Libralato et al. 2019, *Ecol. Ind.* v. 103- thresholds
Pranovi et al. 2020, *Glob. Change Biol*. 26- decadal patterns for all LMEs
Link et al. 2022, *Ecol. Model.* 463- simulations

Management implications

- Potential Indicator of EOF
- Every marine ecosystem exhibits these emergent patterns (>200 cases) of cumB-TL, cumB-cumP
- The "S" and hockey stick curves always stretch, shrink and move toward origin under perturbation
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  - cumBinfl pt ~33%
  - TLinfl ptT~3.38
  - Slope~0.5

Management Applications

- Has been used to track recovery in Gulf of Mexico/America from DWH impacts (Lewis et al. 2024).
- Has been used to test and inform policy on good environmental status in the EU under their MSFD auspices (ICES 2014, Tam et al. 2017).
- Has been used to identify and verify gradients/levels of human-induced perturbation in remote Pacific tropical reefs (Link et al. 2024).
- Backstopping and testing for EOF, especially with ecosystem-level Kobe plots, in the US (Link 2021).
- Identified EOF for African LMEs and used to inform sustainable development decisions (Link et al. 2020).
- Reported on in various national and regional Ecosystem Status Reports

Responses specific to SEDAR 103 and CFMC

- Are the required data currently available for some number of Caribbean species based on the data reviews provided in the Data Webinars? Yes
- What species or species groups can the method currently be performed on? All
- Does the time step (e.g., day, week, year) required for the method align with currently available data? Typically annual, but can be flexible
- Can the method inform management now? Yes

Recommended Approach to use all this information and address major considerations

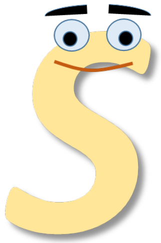
1. Evaluate Ecosystem Caps for each Island
   - Use 1-2 main methods, complement with an ensemble for reality check
2. Estimate ACLs for guilds/aggregate groups
   - Use 1-2 main methods of modeling
3. Estimate ACLS/etc. for top 3-4 individual taxa
   - Use appropriate data ltd Stock Assessment methods
   - Use appropriate prioritization protocols
4. Evaluate economic performance
   - Some form of efficiency frontier
5. Translate to clear mgt decisions
   - Likely to focus on effort (input) controls

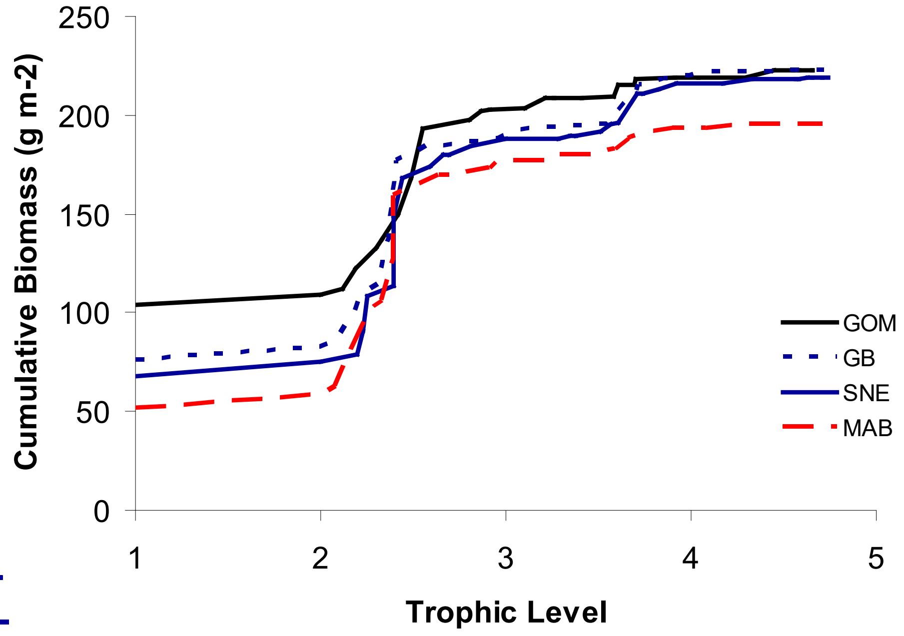
Extra Slides

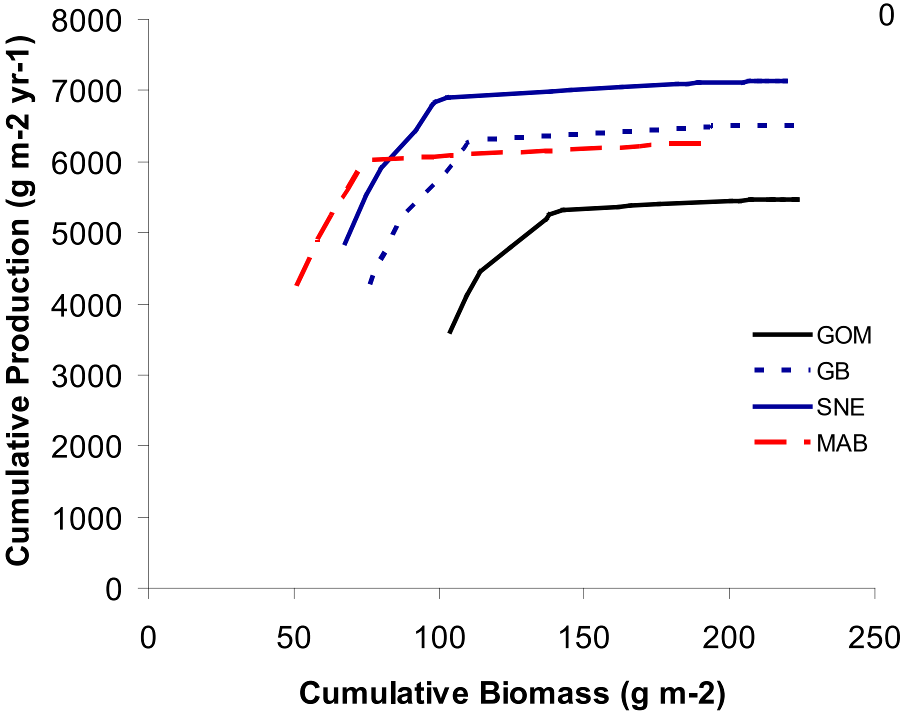
EMERGENT properties

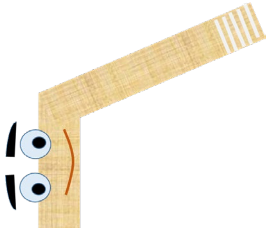
- Emergent properties are properties that manifest themselves as the result of various system components working together, not as a property of any individual component.
- To put that another way, it is a property that a complex system or collection of system parts has, but which individual parts do not possess.
- Since emergent properties are viewable at more macro levels of analysis, only examining individual parts of the system will prevent one from seeing emergent properties.
- i.e., the whole is greater than the sum of the parts…

Initial Observations

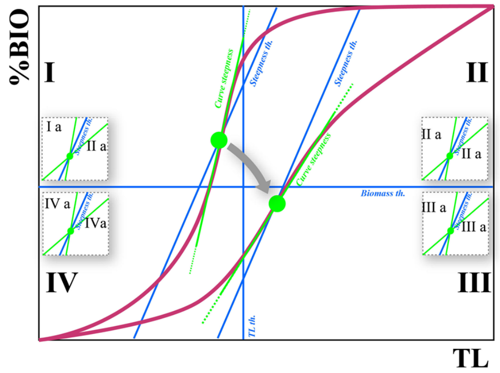








Link et al. 2008 J. Mar. Sys.

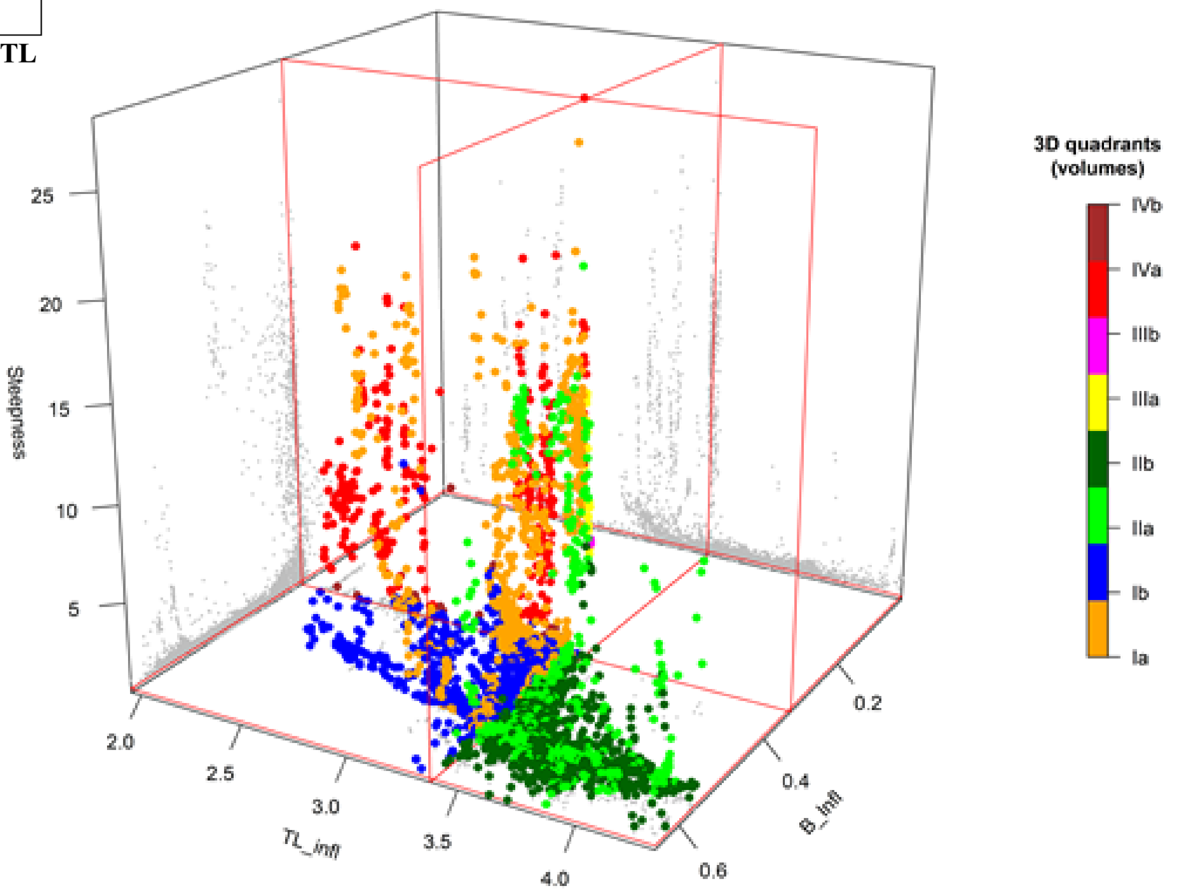


THRESHOLDS

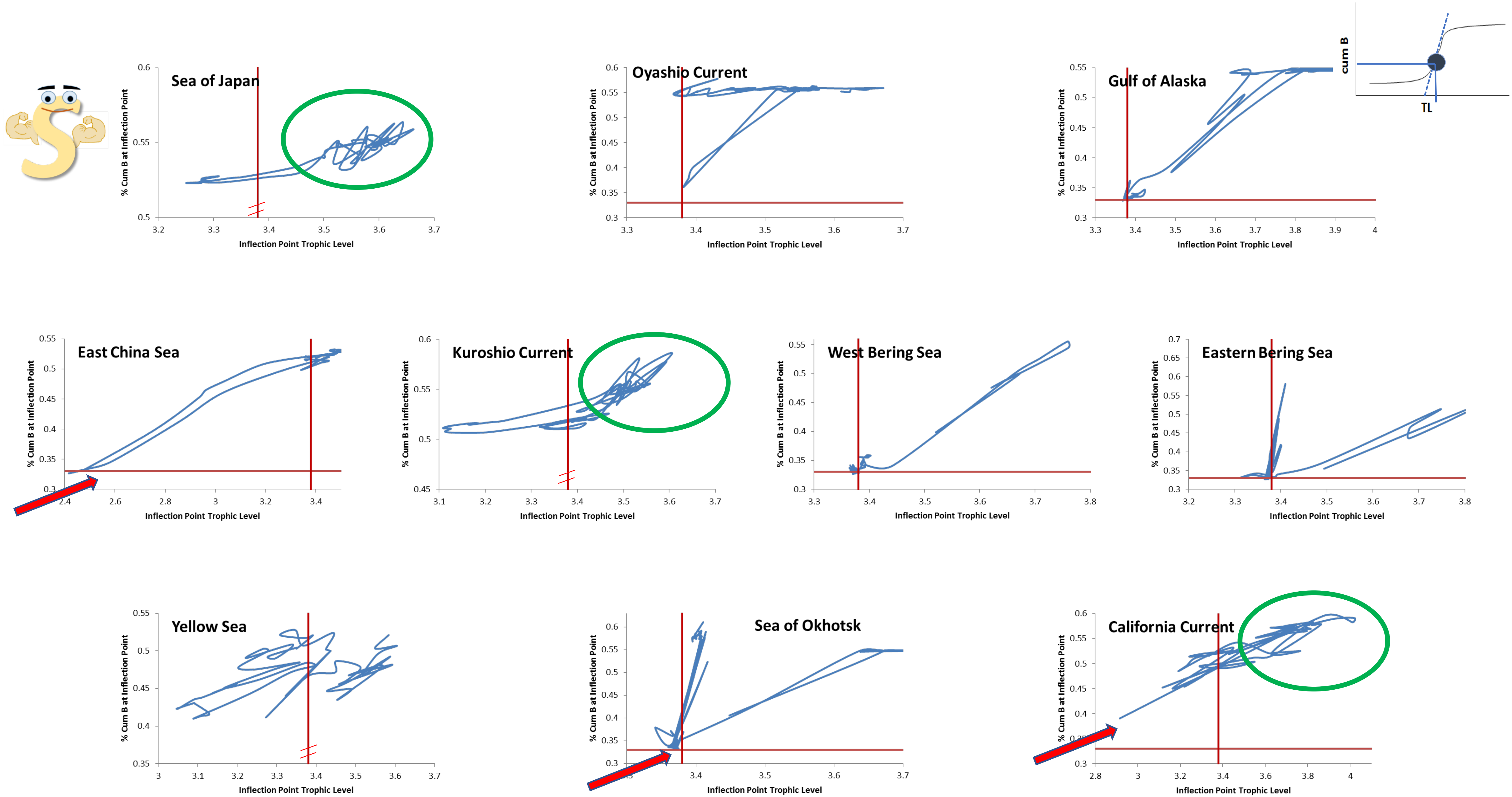
Empirical and modeled thresholds emerge when tracking perturbation on “S” curve.

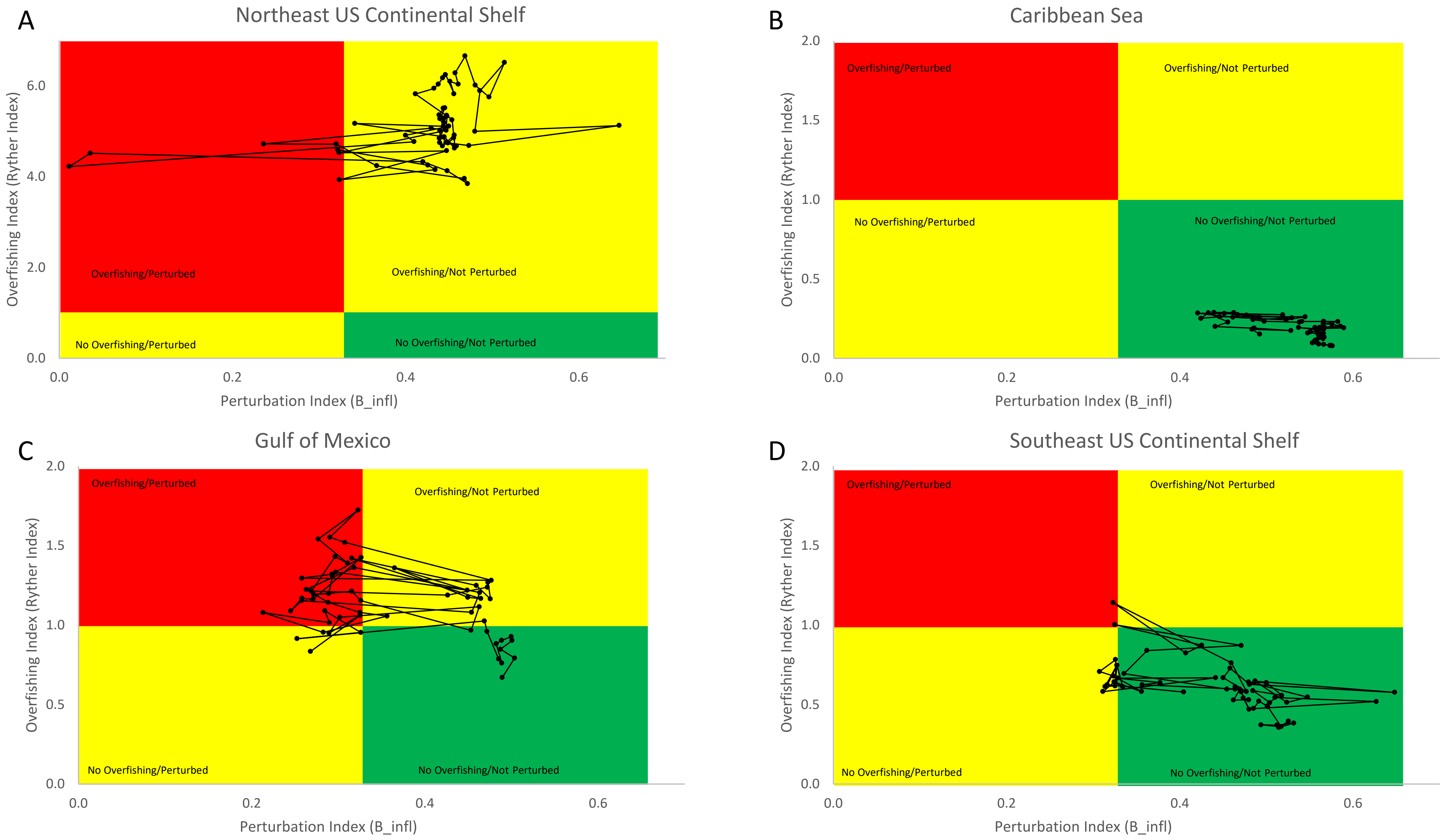
Identified tresholds:

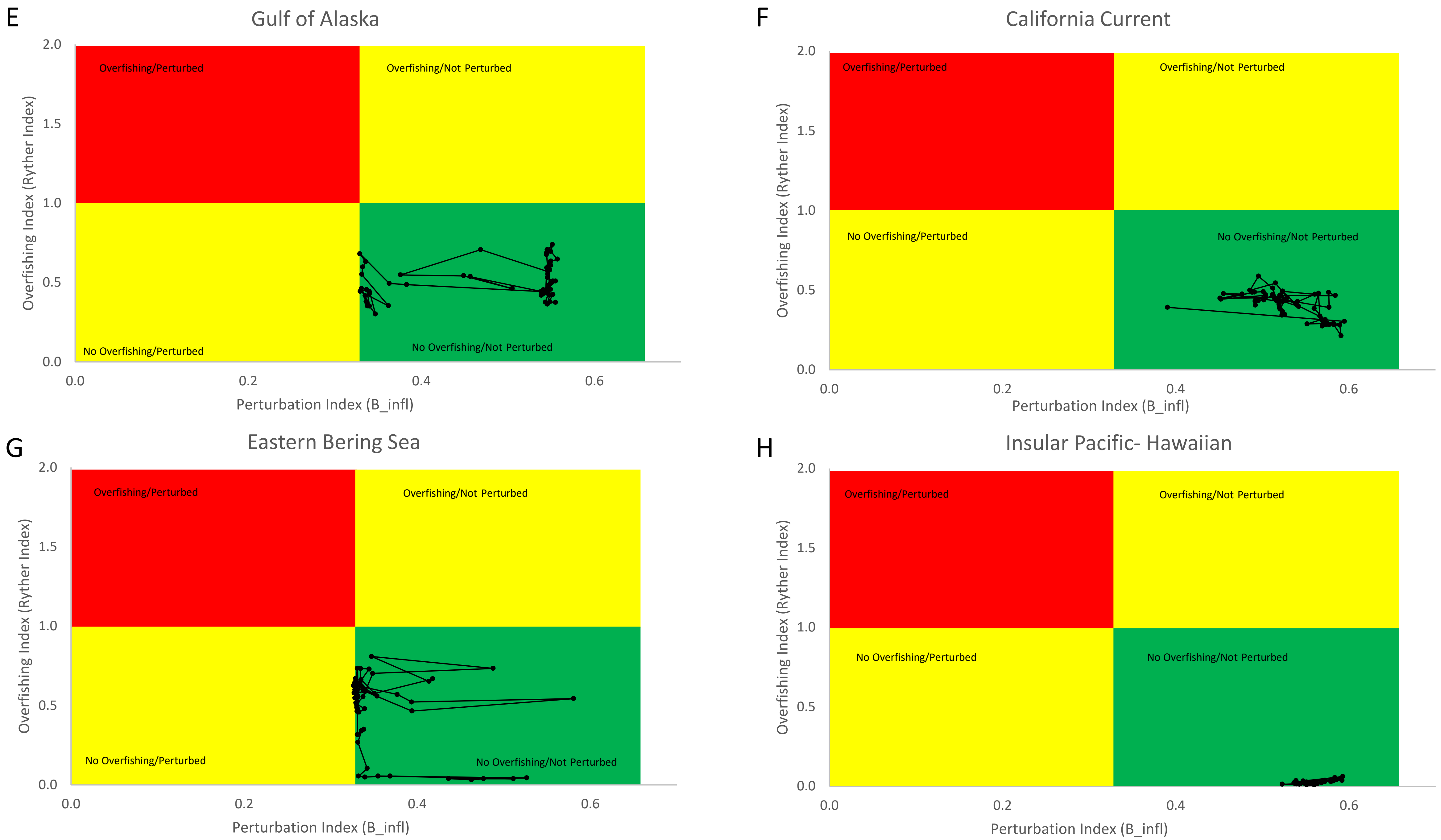
- $cumB_{infl\ pt}$ ~33%
- $TL_{infl\ pt}T$~3.38
- Slope~0.5



Libralato et al., 2019


Sea of Japan
Oyashio Current
Gulf of Alaska
cum B
TL
East China Sea
Kuroshio Current
West Bering Sea
Eastern Bering Sea
Yellow Sea
Sea of Okhotsk
California Current
% Cum B at Inflection Point
Inflection Point Trophic Level


A
Northeast US Continental Shelf
Overfishing Index (Ryther Index)
Perturbation Index (B_infl)
Overfishing/Perturbed
Overfishing/Not Perturbed
No Overfishing/Perturbed
No Overfishing/Not Perturbed
B
Caribbean Sea
C
Gulf of Mexico
D
Southeast US Continental Shelf


E
Gulf of Alaska
F
California Current
G
Eastern Bering Sea
H
Insular Pacific- Hawaiian
Overfishing/Perturbed
Overfishing/Not Perturbed
No Overfishing/Perturbed
No Overfishing/Not Perturbed
Overfishing Index (Ryther Index)
Perturbation Index (B_infl)
0.0
0.5
1.0
1.5
2.0
0.0
0.2
0.4
0.6