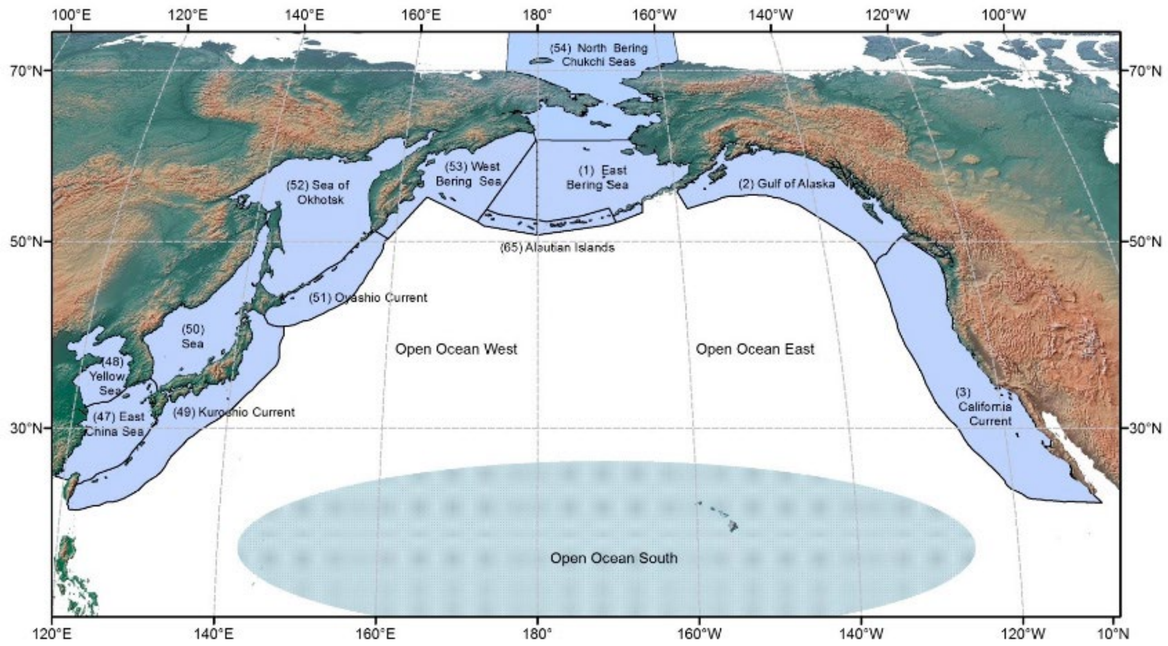
Evidence for Ecosystem Overfishing in North Pacific Ecosystems



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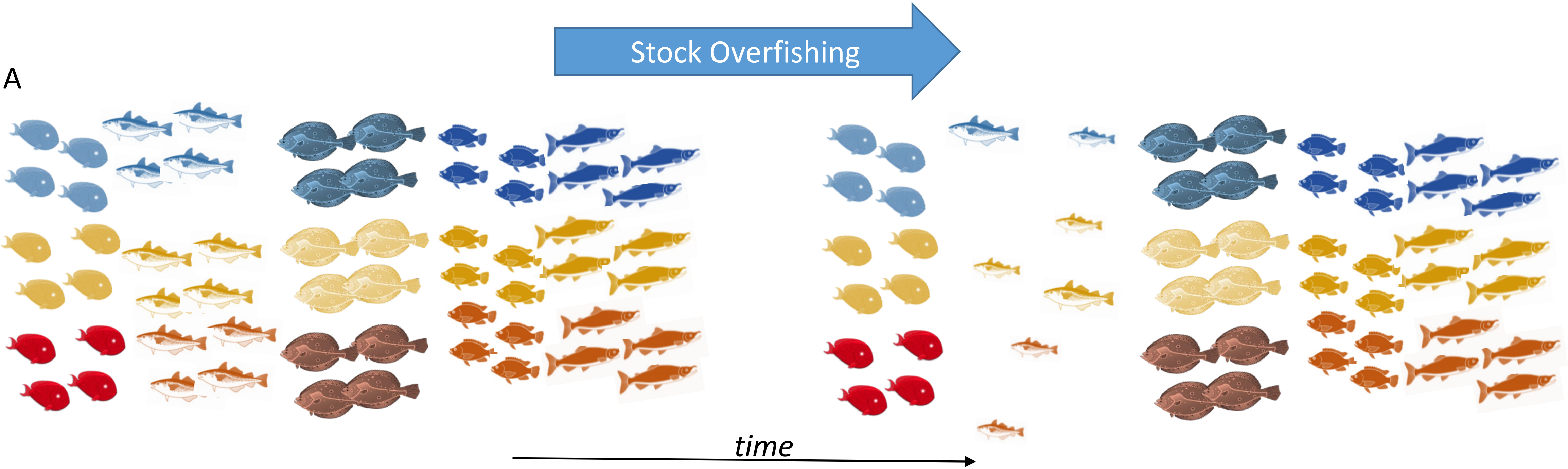
Basic tenet of renewable natural resource mgt

$$R_{removal} \leq R_{renewal}$$

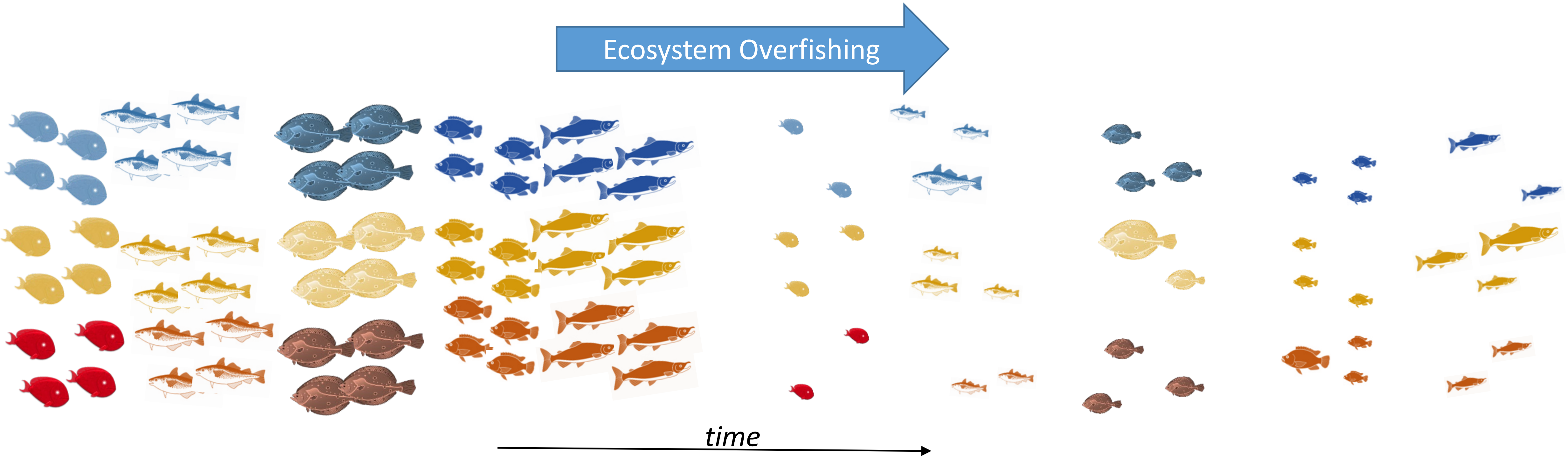
Everybody get the concept?

A



C↓, E↑, CPUE ↓, repeat…
(Graham’s Law of Overfishing)

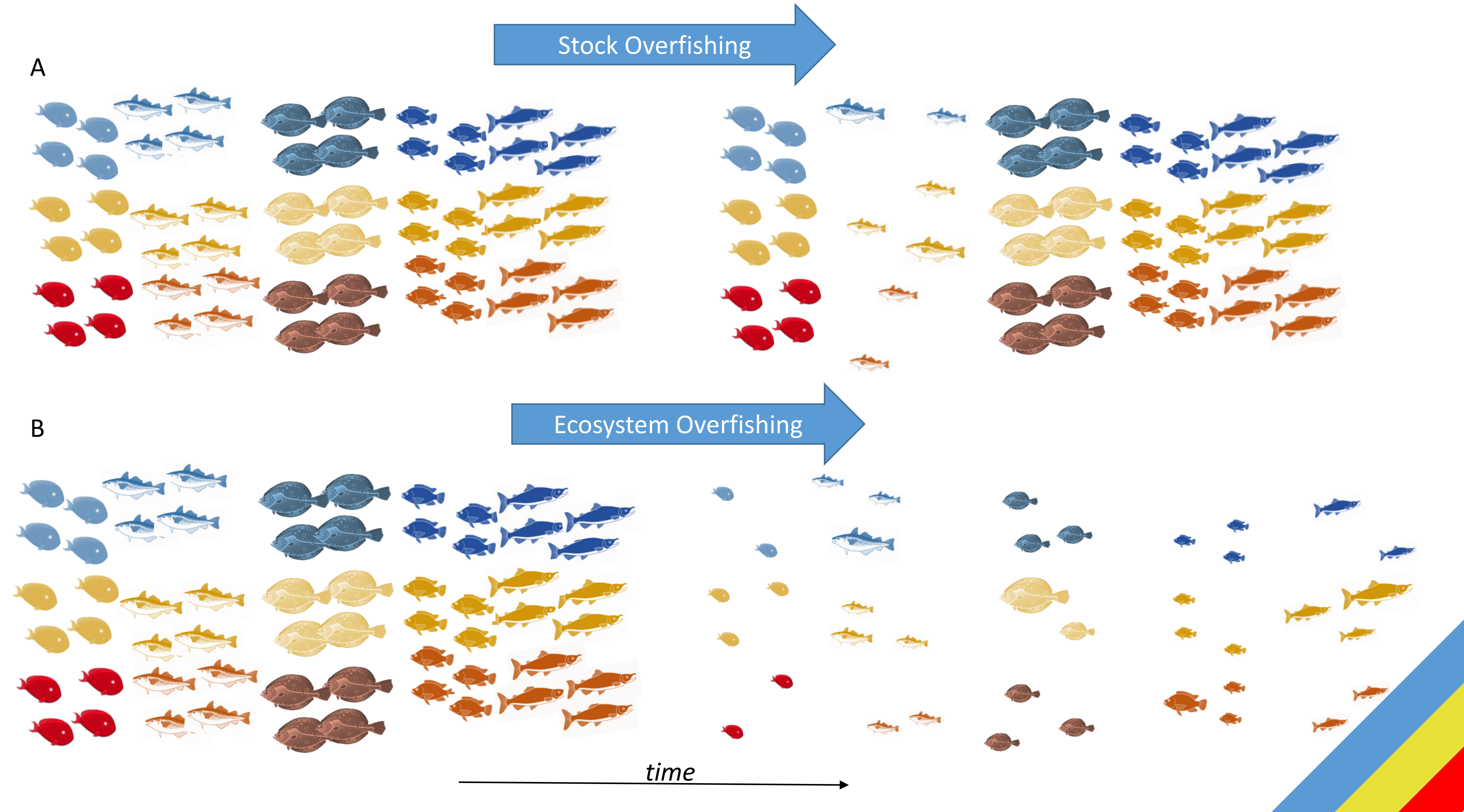
$$F_{\rightarrow max} \xrightarrow{yields} \downarrow \begin{cases} N, B, Y, B/B_{MSY} \\ r, size_{mat}, age_{mat} \\ wt_a, len, g \end{cases}, \uparrow \begin{cases} E \\ Area_{fished} \\ F/F_{MSY} \end{cases}$$



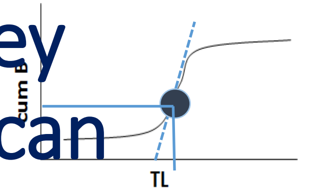
$C_1\downarrow, E_1\uparrow, \ldots \text{CPUE}_1\rightarrow \text{min}; \rightarrow E_2\uparrow, C_2\uparrow, \text{CPUE}_2\uparrow, C_2\downarrow, E_2\downarrow, \ldots \text{CPUE}_2\rightarrow \text{min}; \rightarrow$

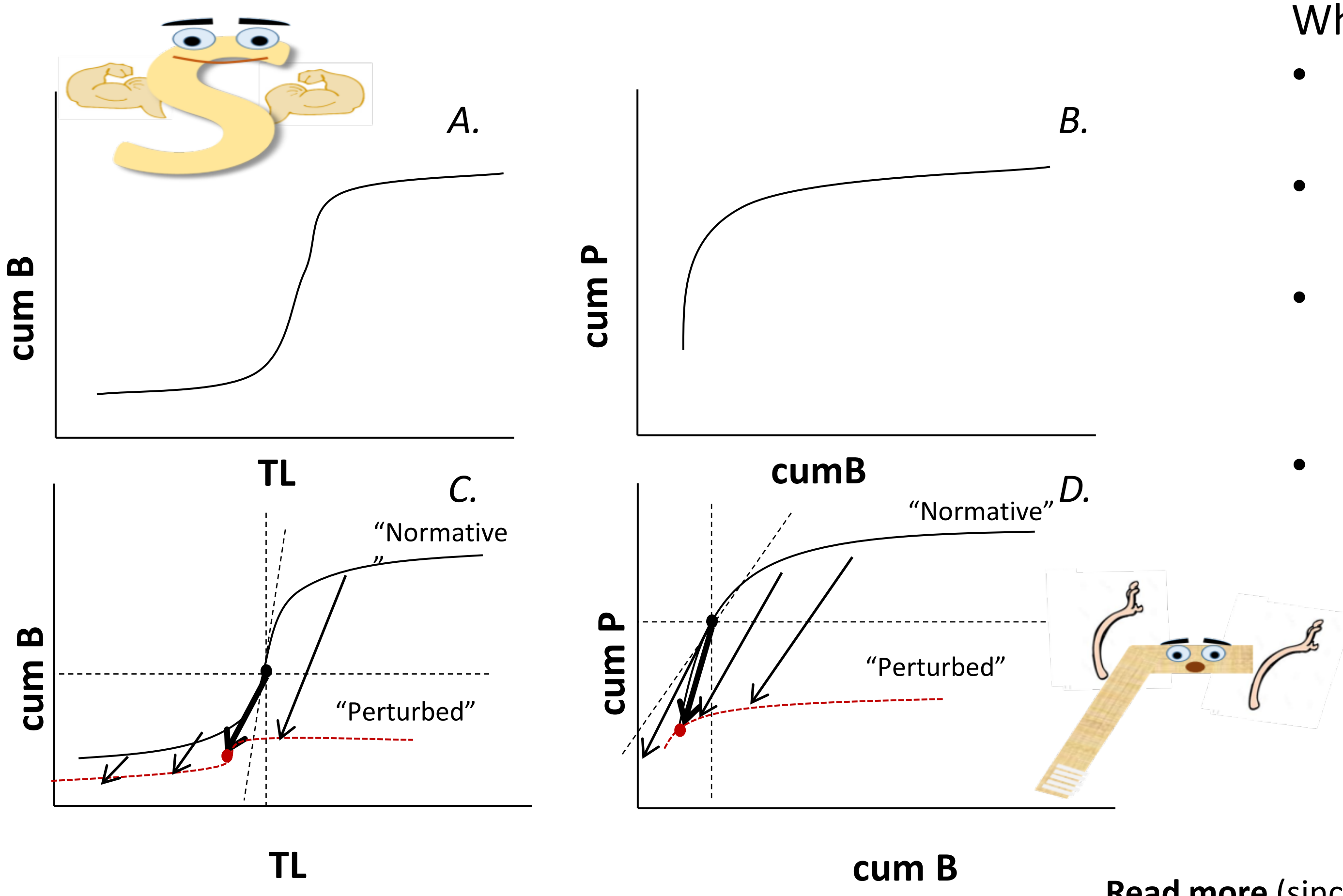
(Law of Sequential Depletion)

$$F_{system\ \rightarrow max} \xrightarrow{yields} \downarrow \begin{cases} \sum N, \sum B, \sum Y, B_{apex} \\ \bar{l}, cumB_{infl}, cumP \\ L_{index}, TST, A, R, TL_{\mu} \end{cases}, \uparrow \begin{cases} E, \beta \\ Area_{fished} \\ F_{system} / F_{System\ \ MSY} \end{cases}$$


A
Stock Overfishing
B
Ecosystem Overfishing
time

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





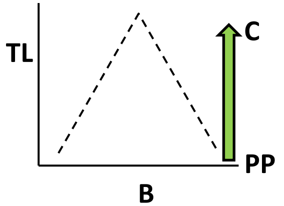
What's the Point:

- Every marine ecosystem exhibits these emergent patterns (>120 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
  - Steep~0.5

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. in press, *Glob. Change Biol*.- decadal patterns for all LMEs

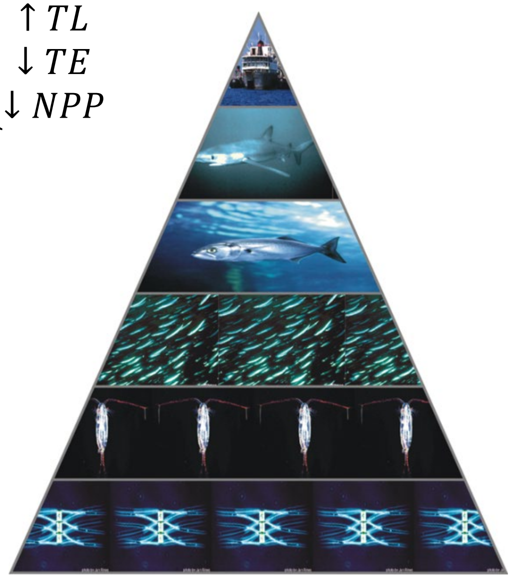
Bottom Line: There are real limits to how much fish any ecosystem can produce, can be caught, and there are associated thresholds that can delineate EOF



What's the Point:

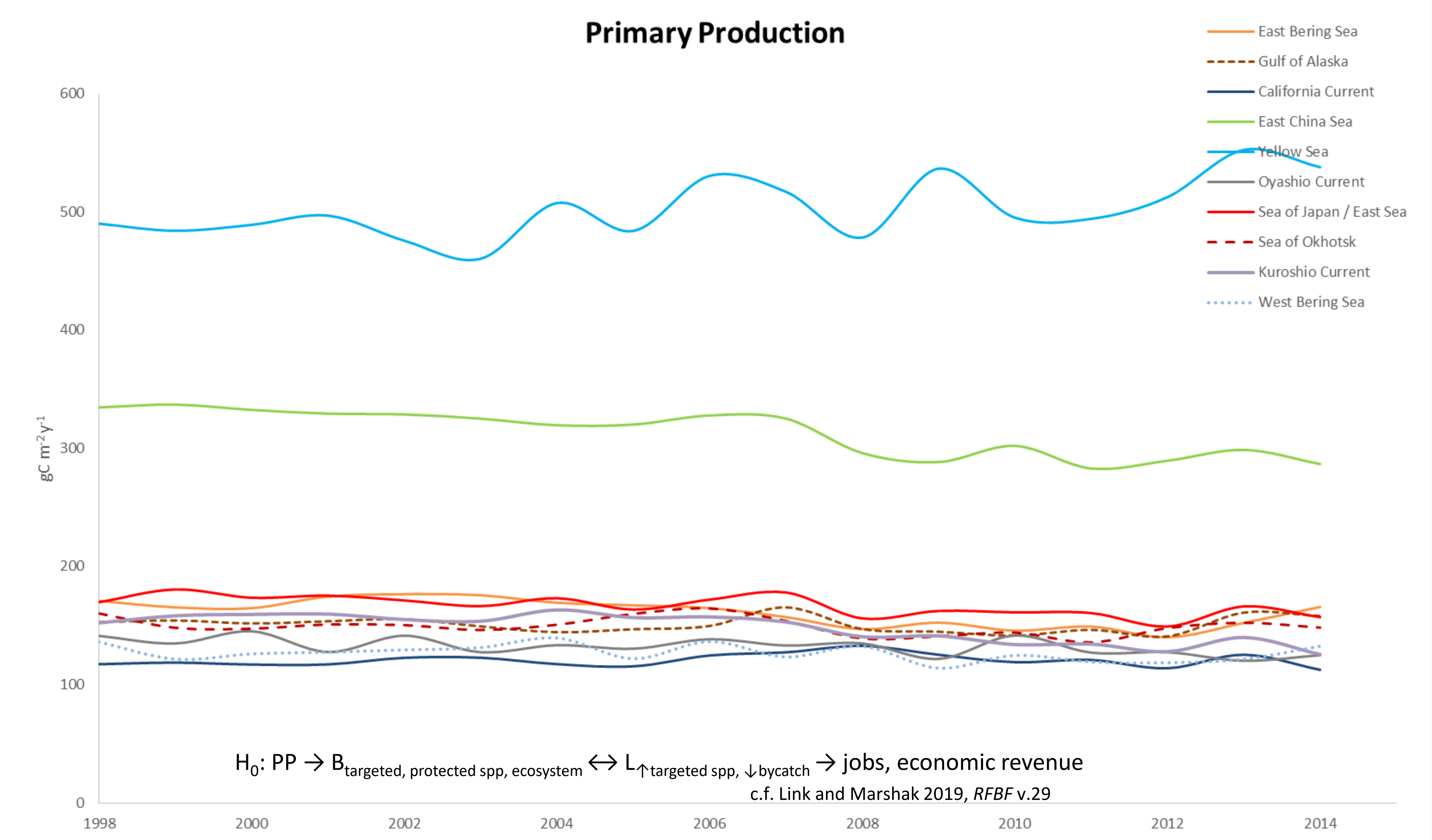
- Trophic transfer calculations, modeling, and global observations, show limits to fisheries production, as set by PP
- Total Oceanic Primary Production is on the order of 40-50 G ton C yr^{-1}
- Total Marine Capture Fishery Yield is on the order of 0.1 G ton yr^{-1} and has been for 30+ years
- From these, we can calculate thresholds used to delineate Ecosystem Overfishing (EOF)
  - Ryther index ~ 1 (to a high of 3) t km^{-2} yr^{-1}
  - Fogarty index ~ 1‰
  - Friedland index ~1
- These thresholds suggest that ~50% of the worlds LMEs are experiencing EOF

$$\downarrow \text{Catch} \begin{cases} \uparrow TL \\ \downarrow TE \\ \downarrow NPP \end{cases}$$



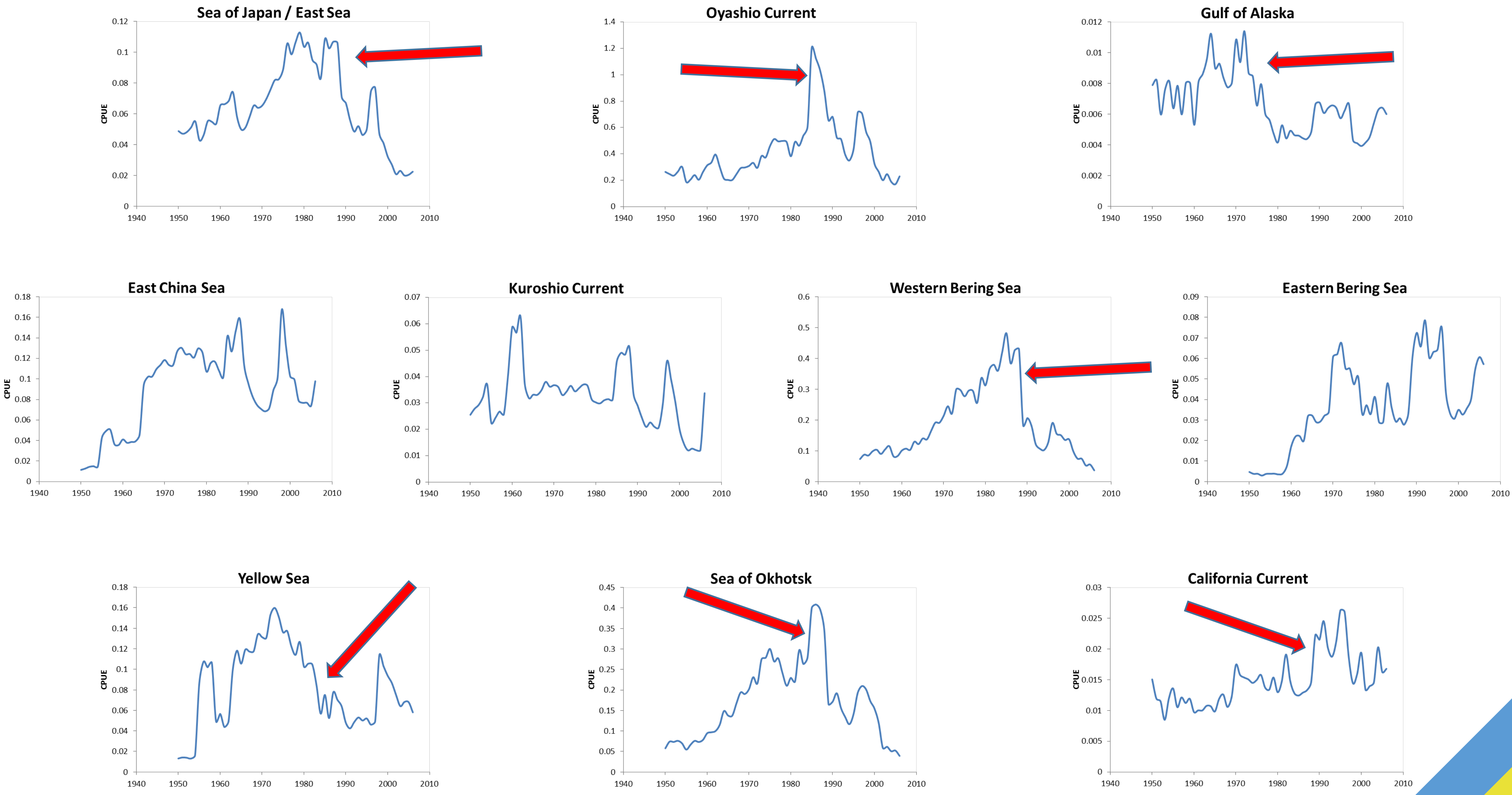
$$C_{tot} = \alpha \sum_{1=1}^{TL} PP \cdot TE_i^{TL-1}$$

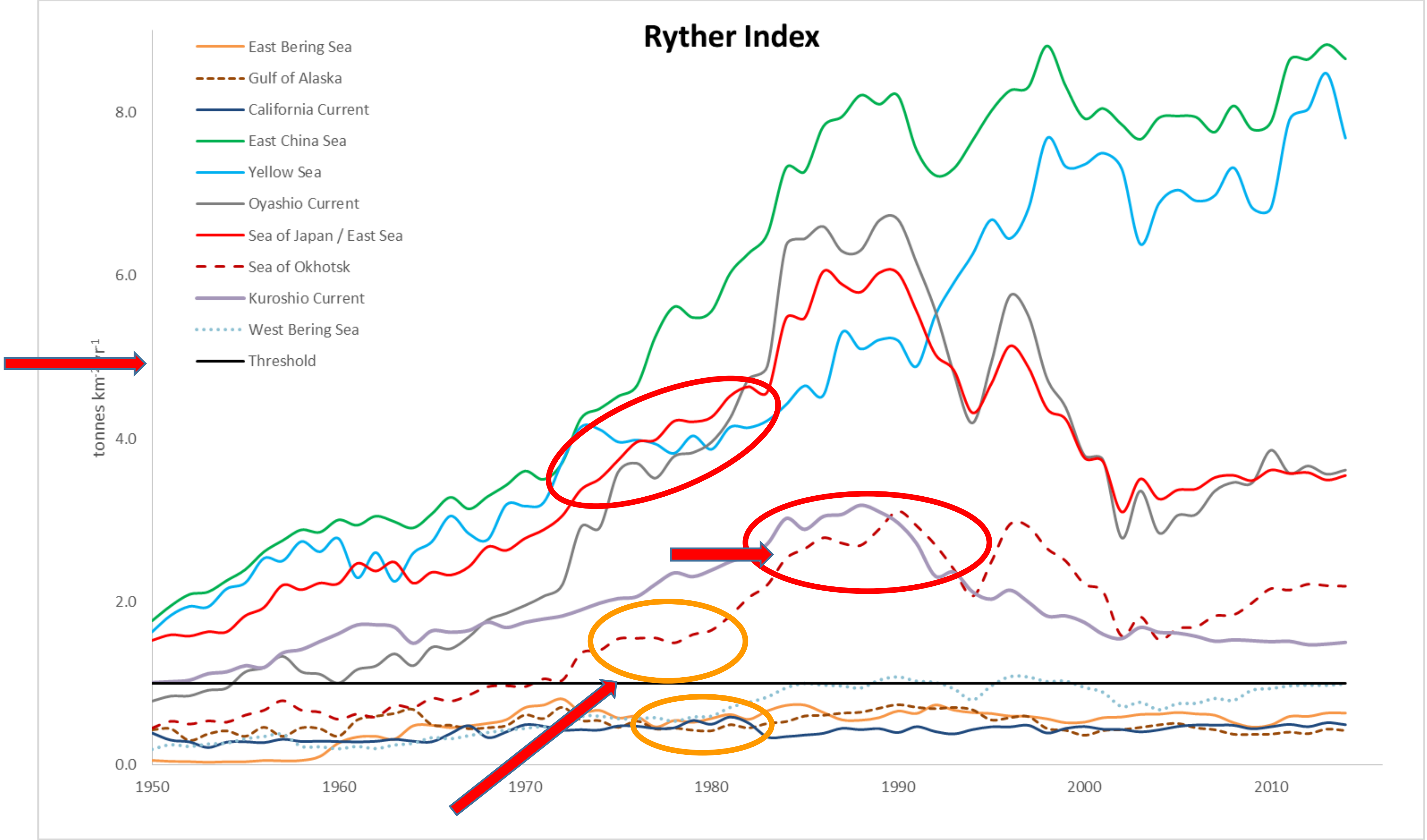
Read more (since we don't have lots of time now):
Link and Watson, *Science Adv.* v.5- main description
Stock et al. 2017, *PNAS* v. 114- relating PP to fish production
Fogarty et al. 2016, *Environ. Dev.* v. 17- fishery production potential
Friedland et al. 2012, *PLoS One* v. 7- relating PP and chl *a* to fish production

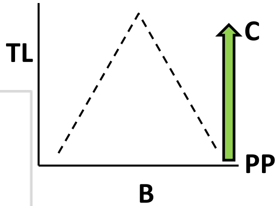


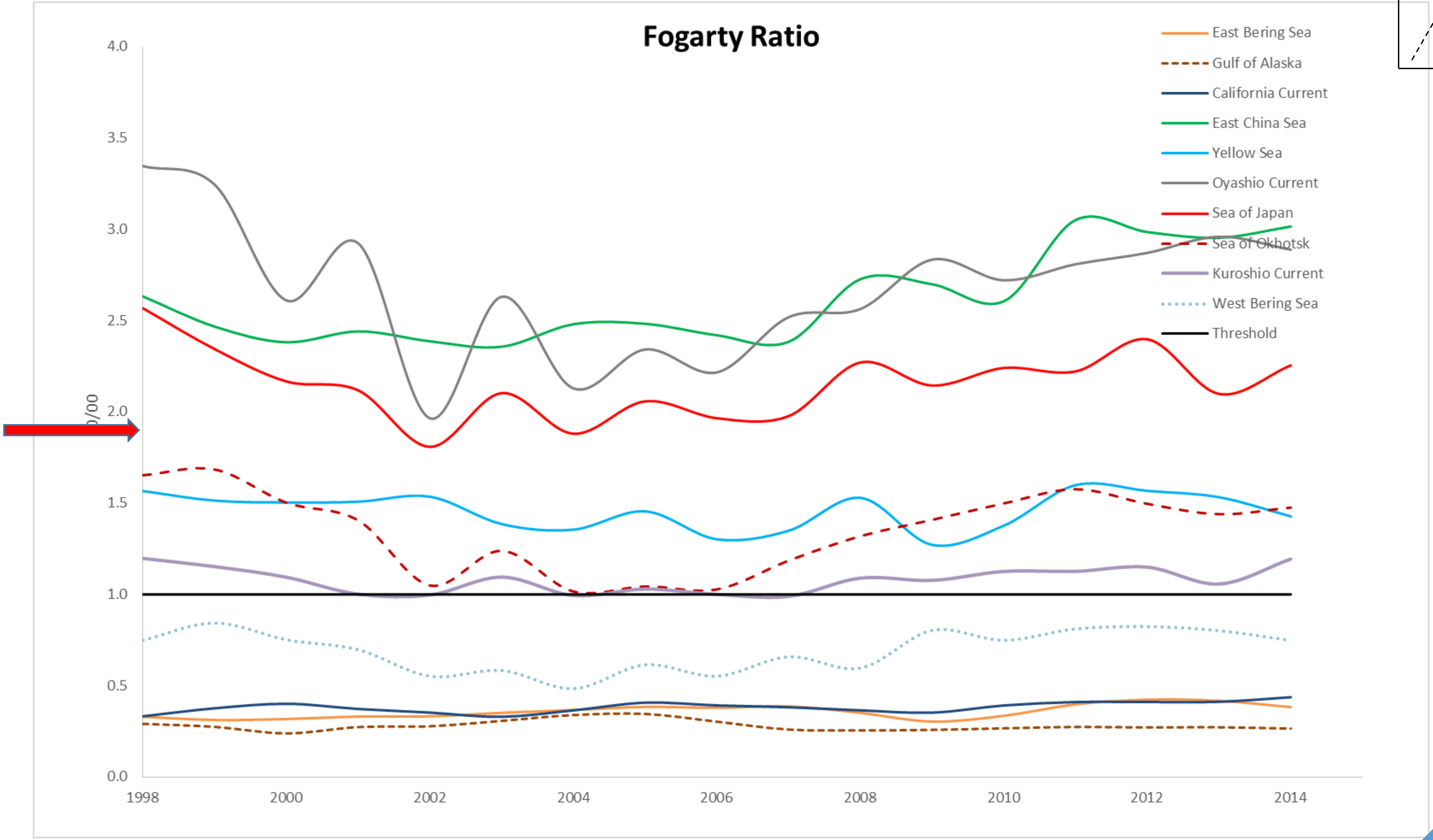
H_0: PP → $B_{\text{targeted, protected spp, ecosystem}}$ ↔ $L_{\uparrow\text{targeted spp, }\downarrow\text{bycatch}}$ → jobs, economic revenue

c.f. Link and Marshak 2019, *RFBF* v.29

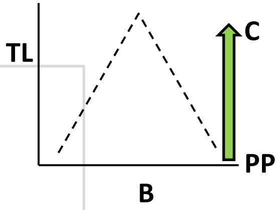

Sea of Japan / East Sea
CPUE
0 0.02 0.04 0.06 0.08 0.1 0.12
1940 1950 1960 1970 1980 1990 2000 2010
Oyashio Current
CPUE
0 0.2 0.4 0.6 0.8 1 1.2 1.4
1940 1950 1960 1970 1980 1990 2000 2010
Gulf of Alaska
CPUE
0 0.002 0.004 0.006 0.008 0.01 0.012
1940 1950 1960 1970 1980 1990 2000 2010
East China Sea
CPUE
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18
1940 1950 1960 1970 1980 1990 2000 2010
Kuroshio Current
CPUE
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07
1940 1950 1960 1970 1980 1990 2000 2010
Western Bering Sea
CPUE
0 0.1 0.2 0.3 0.4 0.5 0.6
1940 1950 1960 1970 1980 1990 2000 2010
Eastern Bering Sea
CPUE
0 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09
1940 1950 1960 1970 1980 1990 2000 2010
Yellow Sea
CPUE
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18
1940 1950 1960 1970 1980 1990 2000 2010
Sea of Okhotsk
CPUE
0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45
1940 1950 1960 1970 1980 1990 2000 2010
California Current
CPUE
0 0.005 0.01 0.015 0.02 0.025 0.03
1940 1950 1960 1970 1980 1990 2000 2010


Rythter Index
East Bering Sea
Gulf of Alaska
California Current
East China Sea
Yellow Sea
Oyashio Current
Sea of Japan / East Sea
Sea of Okhotsk
Kuroshio Current
West Bering Sea
Threshold
tonnes km⁻² yr⁻¹
0.0
2.0
4.0
6.0
8.0
1950
1960
1970
1980
1990
2000
2010

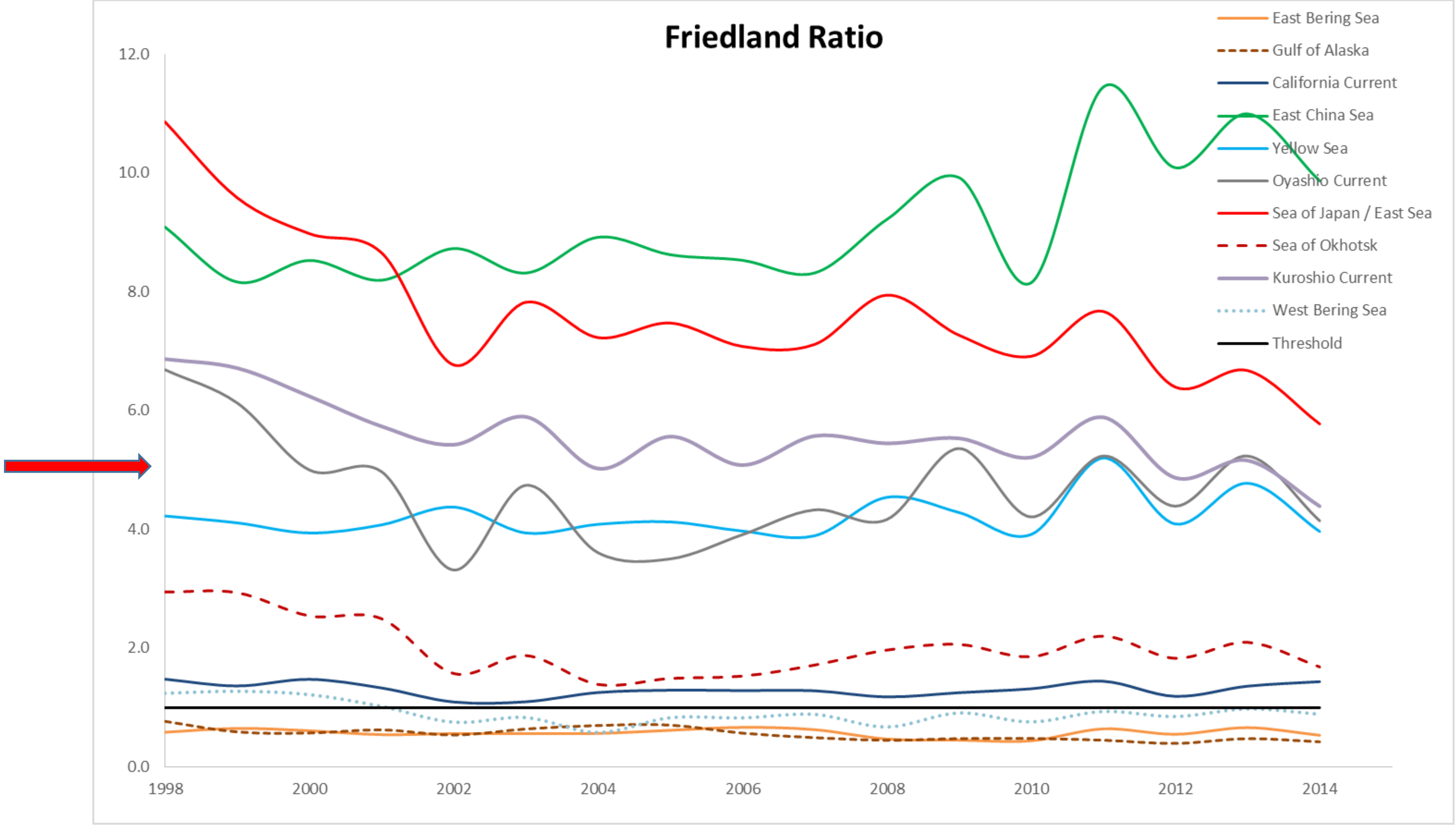

TL
C
PP
B

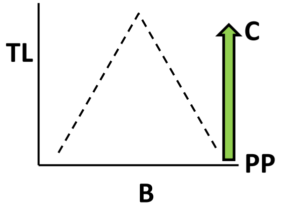


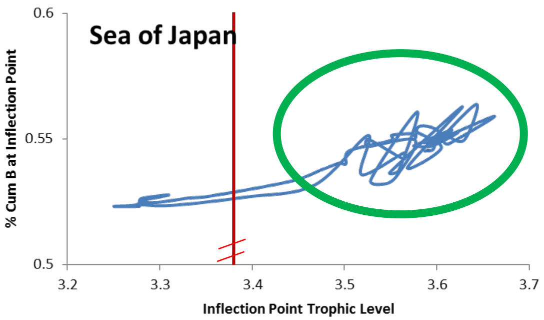
Fogarty Ratio
0/00
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1998
2000
2002
2004
2006
2008
2010
2012
2014
East Bering Sea
Gulf of Alaska
California Current
East China Sea
Yellow Sea
Oyashio Current
Sea of Japan
Sea of Okhotsk
Kuroshio Current
West Bering Sea
Threshold

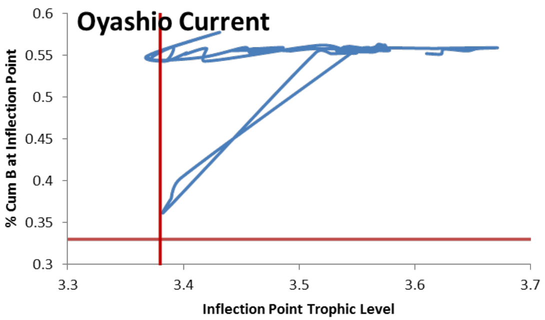


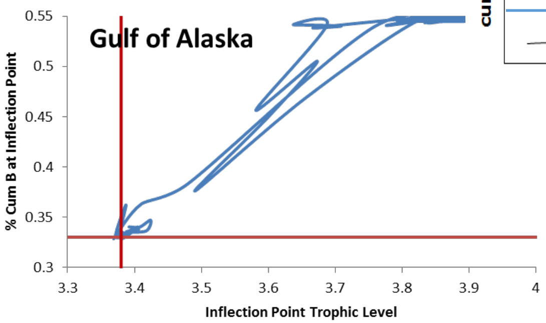
TL
C
PP
B

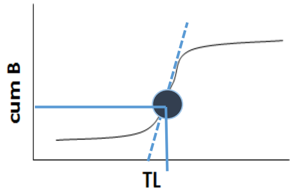

Friedland Ratio
12.0
10.0
8.0
6.0
4.0
2.0
0.0
1998
2000
2002
2004
2006
2008
2010
2012
2014
East Bering Sea
Gulf of Alaska
California Current
East China Sea
Yellow Sea
Oyashio Current
Sea of Japan / East Sea
Sea of Okhotsk
Kuroshio Current
West Bering Sea
Threshold

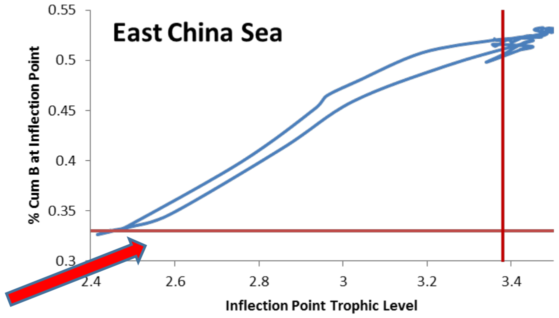

TL
C
PP
B

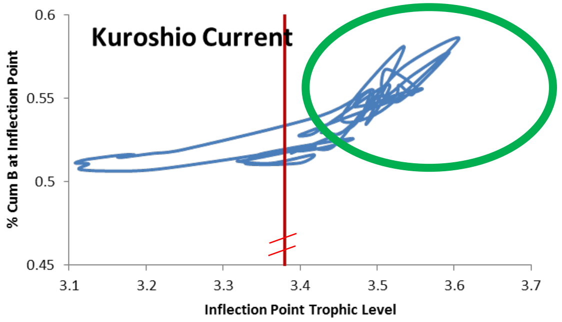

Sea of Japan
% Cum B at Inflection Point
Inflection Point Trophic Level

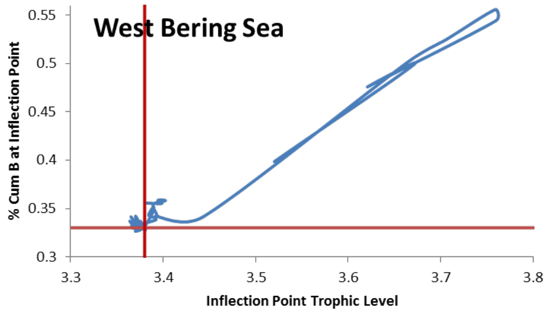

Oyashio Current
% Cum B at Inflection Point
Inflection Point Trophic Level

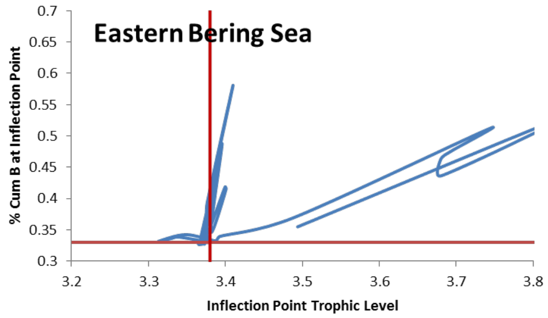

Gulf of Alaska
% Cum B at Inflection Point
Inflection Point Trophic Level

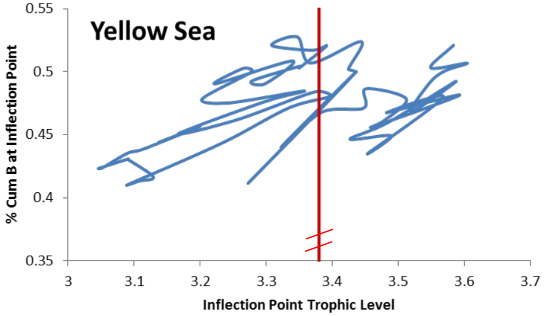

cum B
TL

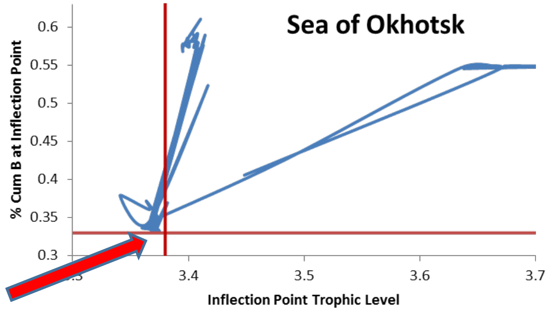

East China Sea
% Cum B at Inflection Point
Inflection Point Trophic Level

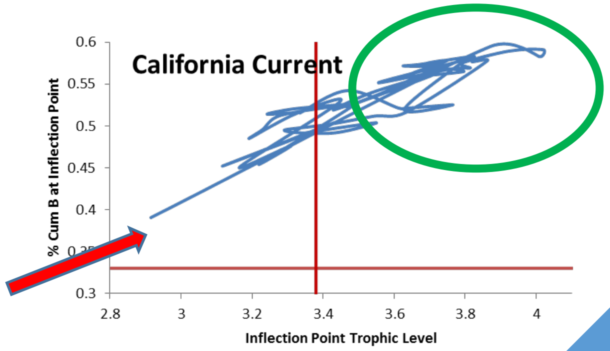

Kuroshio Current
% Cum B at Inflection Point
Inflection Point Trophic Level


West Bering Sea
% Cum B at Inflection Point
Inflection Point Trophic Level

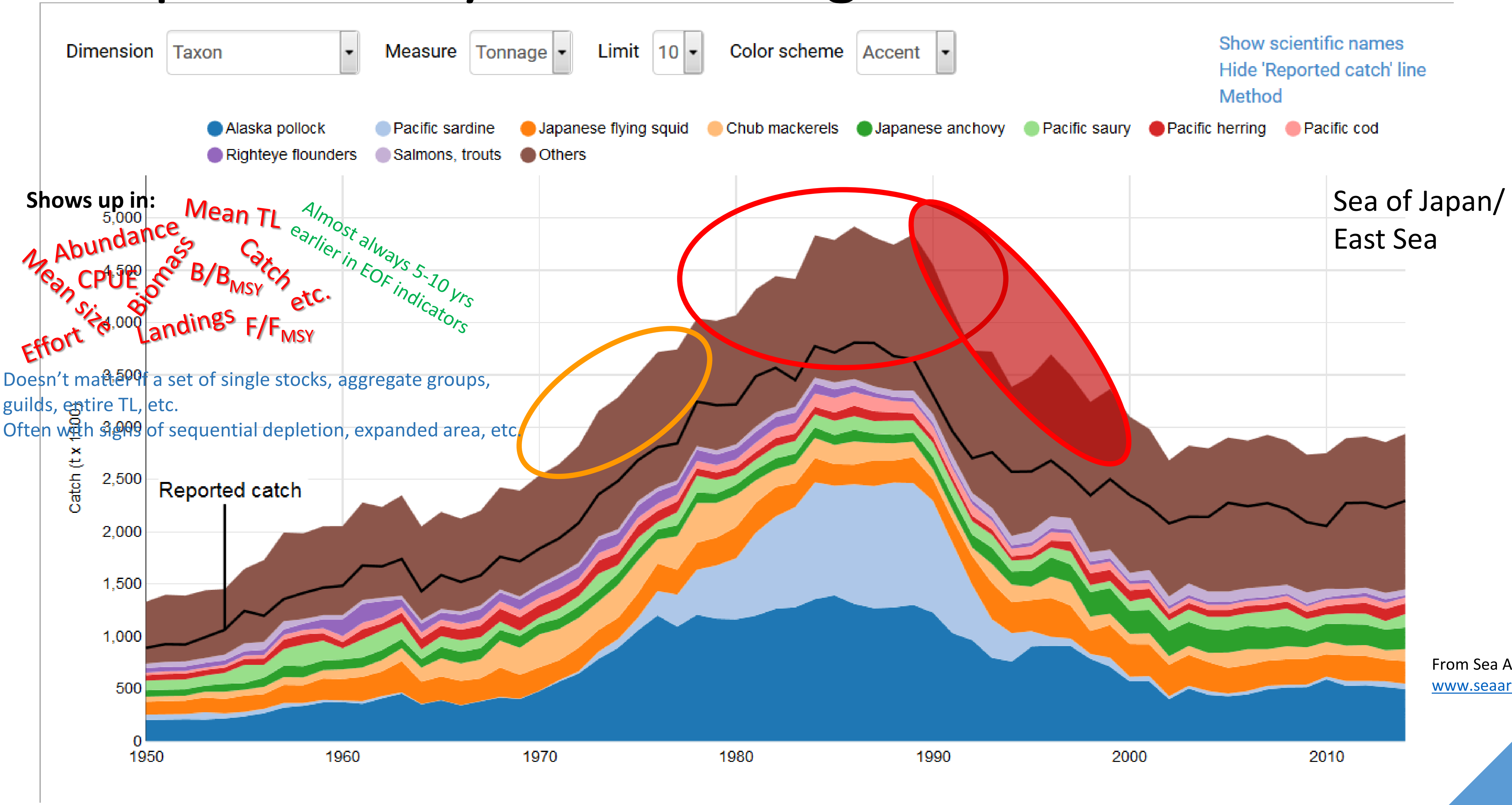

Eastern Bering Sea
% Cum B at Inflection Point
Inflection Point Trophic Level


Yellow Sea
% Cum B at Inflection Point
Inflection Point Trophic Level


Sea of Okhotsk
% Cum B at Inflection Point
Inflection Point Trophic Level

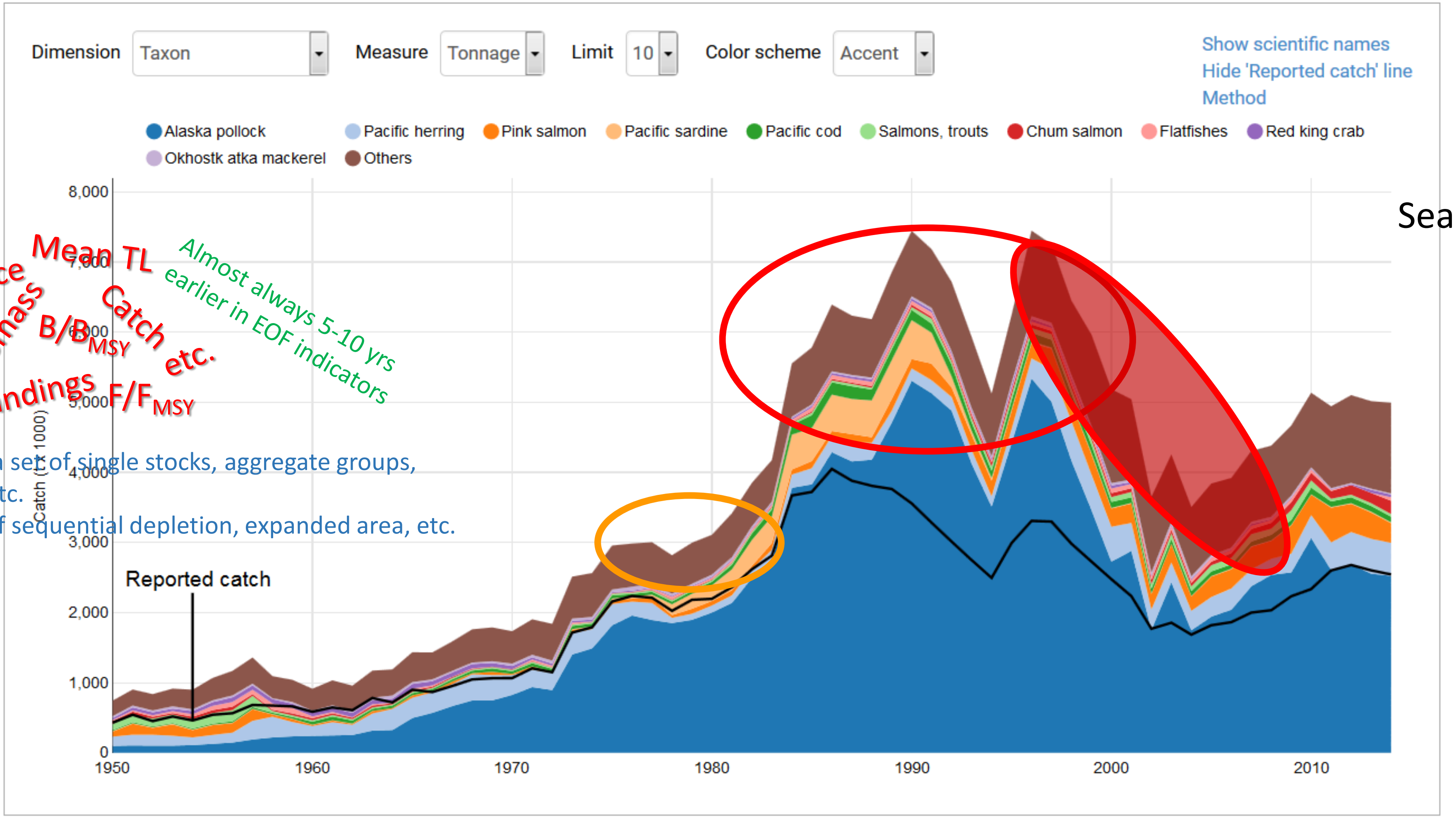

California Current
% Cum B at Inflection Point
Inflection Point Trophic Level

Examples of early detection signal



From Sea Around Us
www.seaaroundus.org

Examples of early detection signal



Shows up in:

Mean TL, Abundance, Mean size, CPUE, Biomass, B/B_{MSY}, Catch, etc., Effort, Landings, F/F_{MSY}

Almost always 5-10 yrs earlier in EOF indicators

Doesn't matter if a set of single stocks, aggregate groups, guilds, entire TL, etc.

Often with signs of sequential depletion, expanded area, etc.

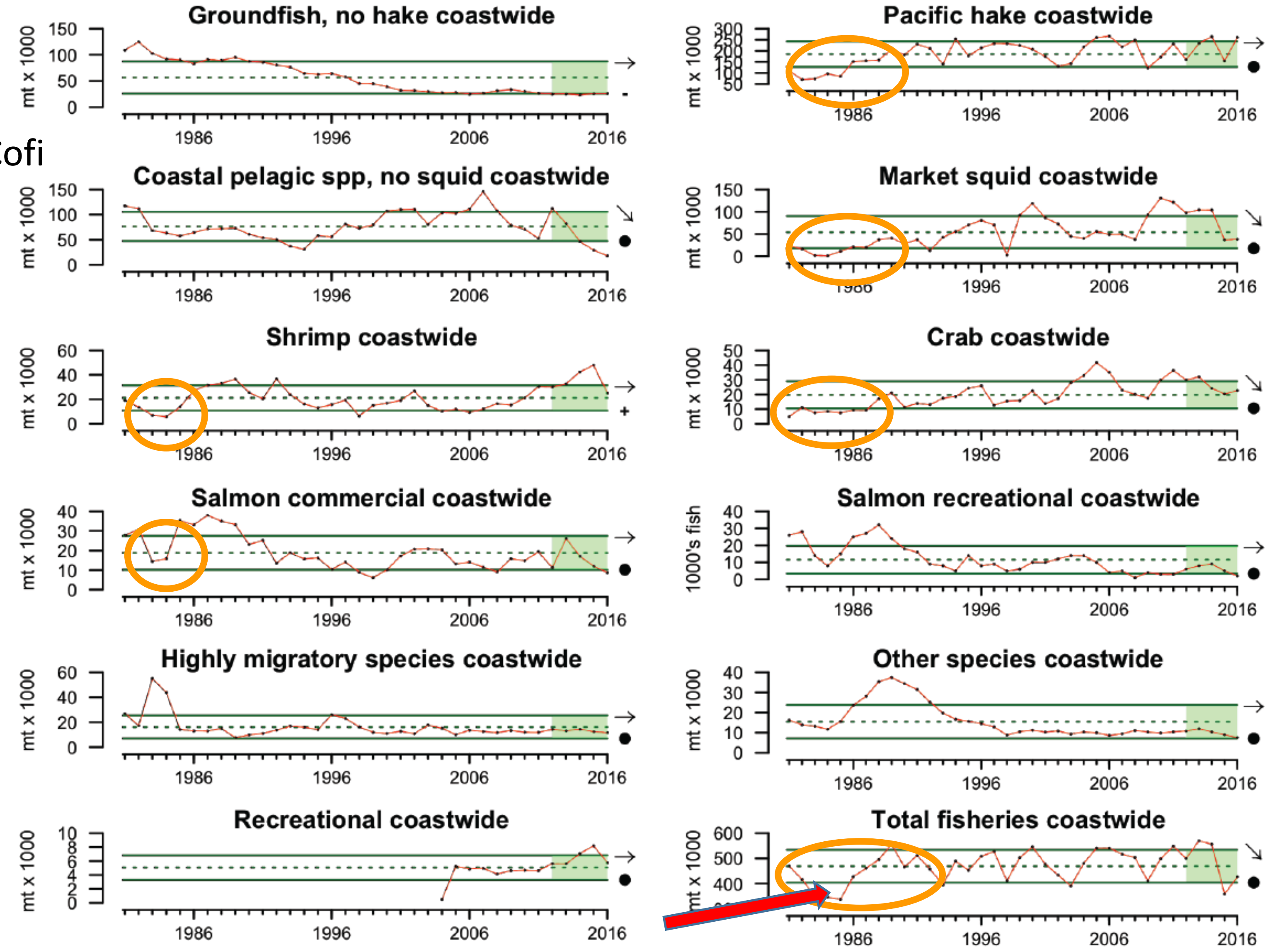
Sea of Okhotsk

Note: The data we present ('reconstructed data') combine official reported data and reconstructed estimates of unreported data (including major discards), with reference to individual EEZs. Official reported data are mainly extracted from the Food and Agriculture Organization of the United Nations (FAO) FishStat database. The "Reported catch" line overlaid on the catch graph represent all catches deemed reported (including foreign) and allocated to this spatial entity. **For background information on the reconstruction data, download the .pdf file for the specific EEZ(s) and also examine our methods for data and spatial allocation.**

From Sea Around Us
www.seaaroundus.org

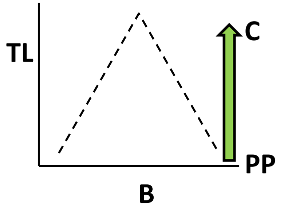
Examples of early detection signal

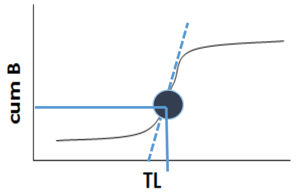
CalCofi



From SWFSC
Harvey et al. 2018

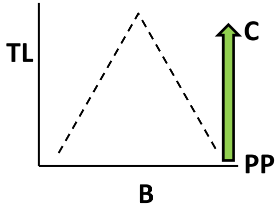
Conclusions

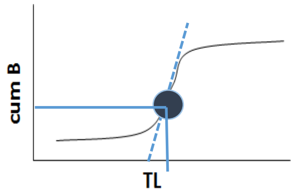




- Many (>6 out of 10) N. Pacific marine ecosystems exhibit signs of Ecosystem-Overfishing (EOF)
- Some N. Pacific marine ecosystems exhibit signs of ecosystem recovery or have experienced minimal Ecosystem-Overfishing (EOF)
- At least 3 N. Pacific marine ecosystems continue to experience significant Ecosystem-Overfishing
- EOF was detectable at least half a decade prior to major stock or stock group collapses in many of these LMEs
- Even if EOF was not detected, EOF indicators provided early warning signals at least half a decade prior to other observable changes in the ecosystem
- Detecting and acting on the ecosystem-level information can prevent both continued EOF and sequential stock OF, as well as save money

What's Next?





- How do we operationalize this in real world fisheries mgt?
- How do we robustly translate EOF into economics & value?
  - Ecosystem Overfishing
  - Ecosystem Underfishing
- Can we use this approach to make predictions/projections, in time & space, of potential ecosystem catch levels?
  - wrt models of changing PP
  - wrt models of changing fish distributions
- Anybody wanna help with this effort?