Ecological Indicators: Lessons Learned from the NEUS Fisheries Experience

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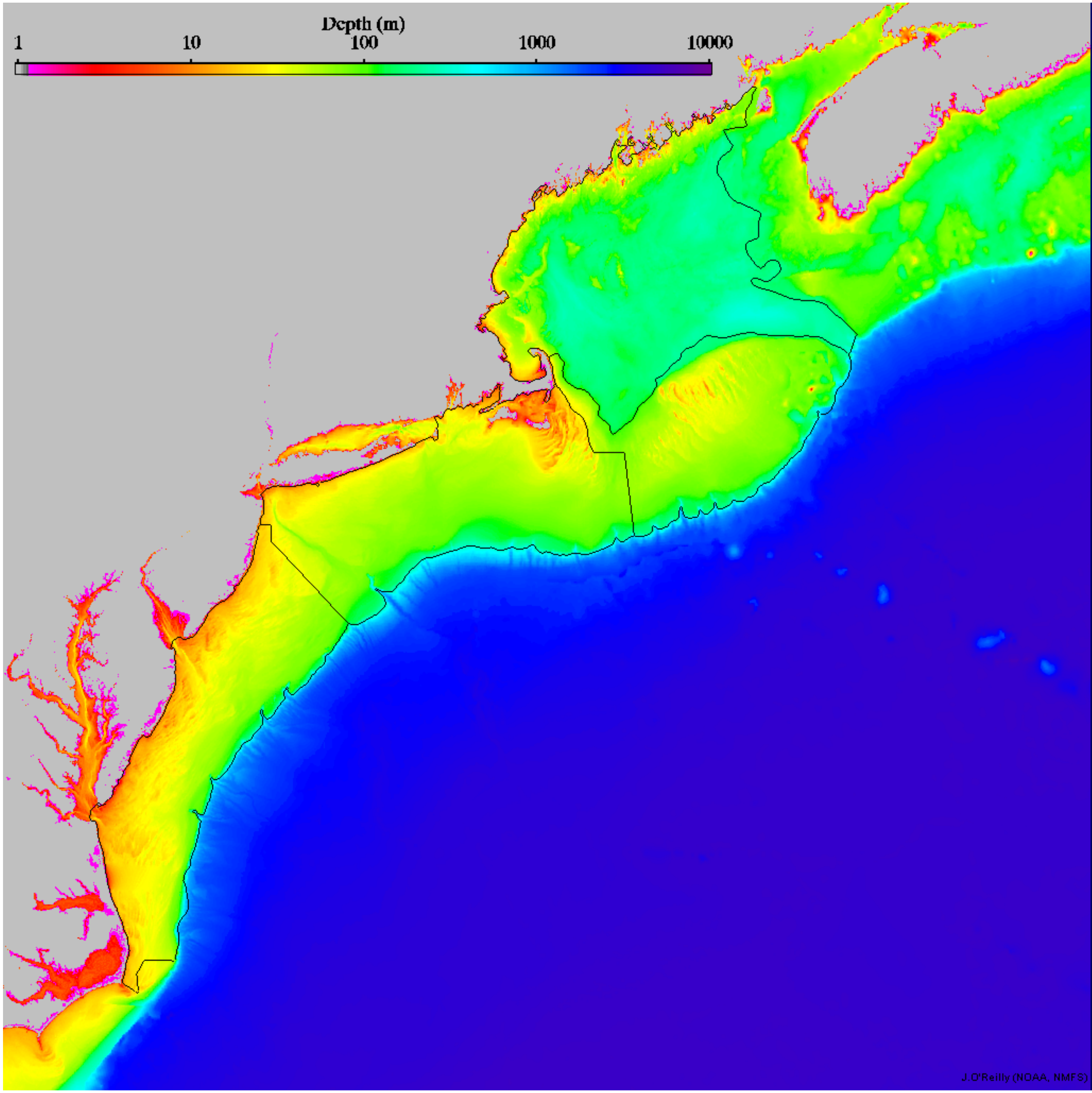
Woods Hole

Indicators- Overview

- Indicators/metrics are an active area of applied and theoretical marine research
- To do EBFM/EAF/EAM, indicators by necessity must represent a multidisciplinary perspective
- Translating indicators into Decision Criteria for EM is THE next big challenge



SRTM30_PLUS:
SRTM30, COASTAL & RIDGE MULTIBEAM, ESTIMATED TOPOGRAPHY

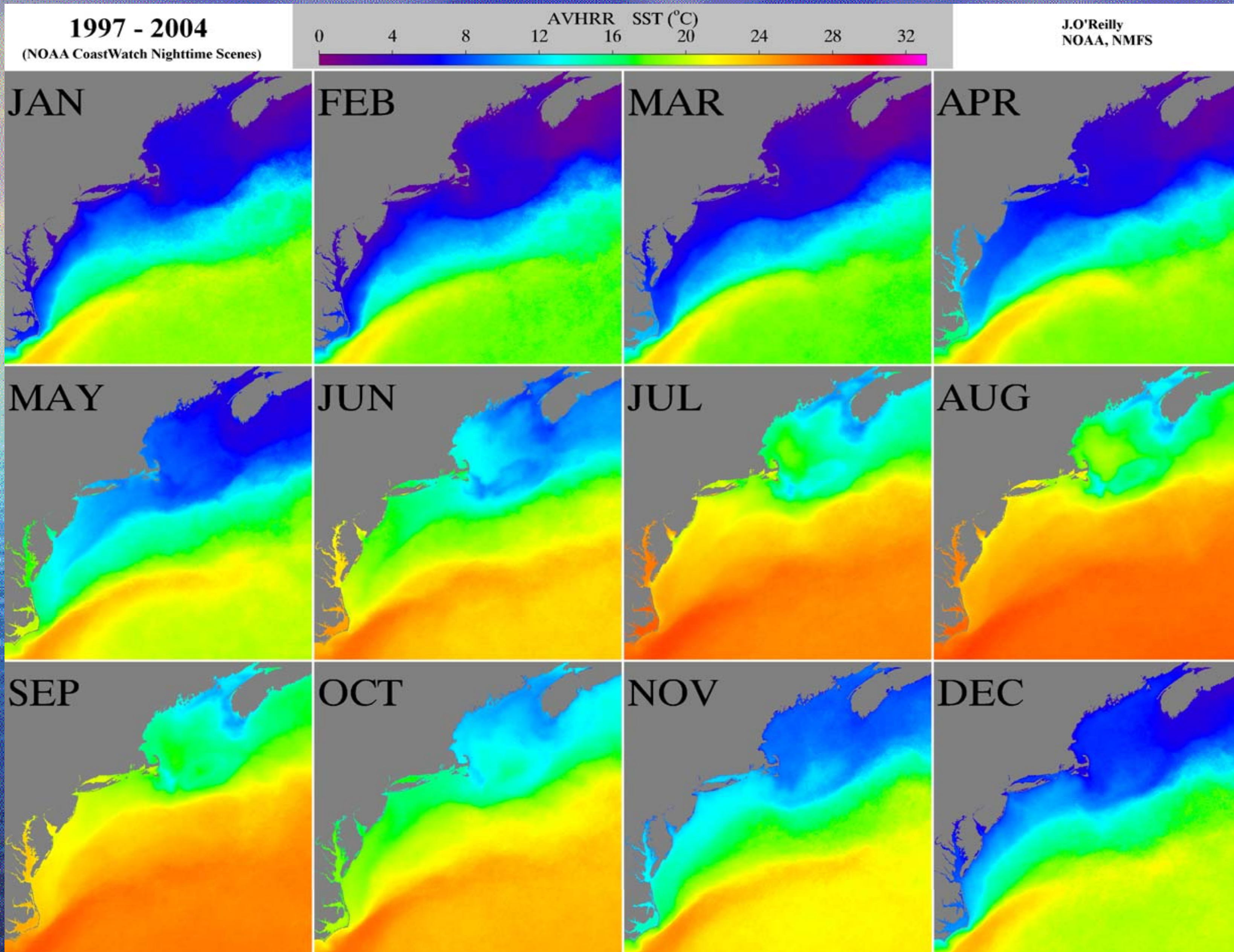
Joseph J. Becker & David T. Sandwell

30 second grid resolution = 0.9 km

This map = 1.25km/pixel

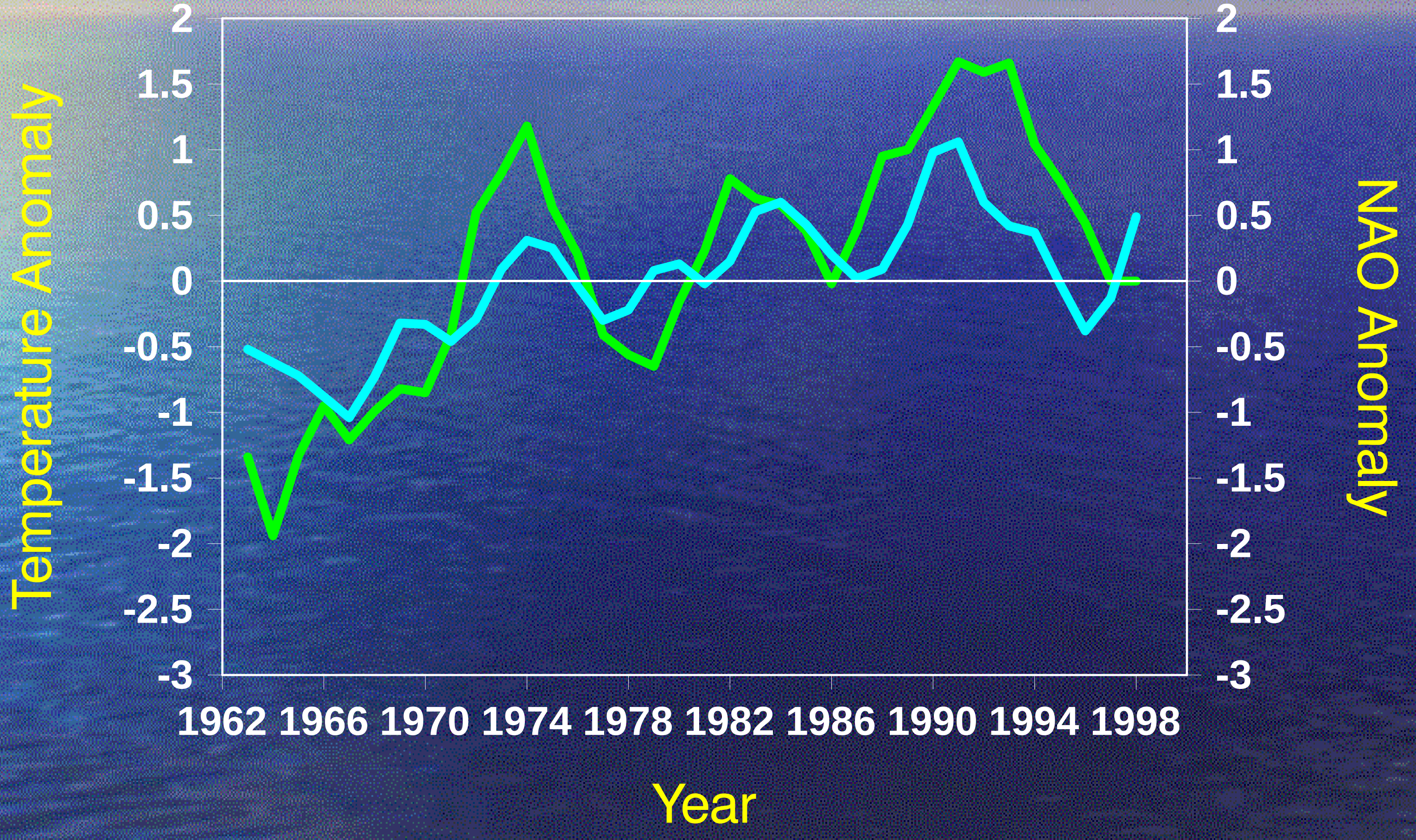
Shelf Region	Median Depth (m)
Middle Atlantic Bight	34
Southern New England	58
Georges Bank	70
Gulf of Maine	176

Satellite Sea Surface Temperature



Courtesy Jay O’Reilly

Woods Hole Temperature - NAO



Courtesy D. Mountain

Both series smoothed

Indicator Taxonomies

- Indicators have had several “taxonomies”, e.g:
  - Pressure (Dose, Stressor)-State-Response
  - Heuristic-Strategic-Tactical
  - Conceptual-Strategic-Operational Objectives
  - System-Response-Performance
- But loosely group into:
  - Status indicators
  - Management indicators
- They key point being that they are used at all steps in a EM process

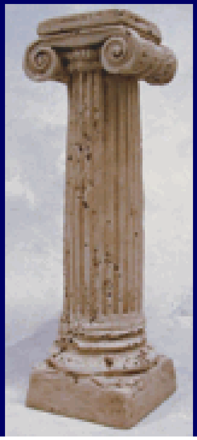
Pillars of Any Management System

1. Goal Setting (Priorities & Allocation of Biomass)

2. Assessing Ecosystem Status (MV Metrics)

Indicators are used at all steps in the process

3. Achieving Ecosystem Goals (Management Tools)



Ecosystem Indicators: Status

- Assess historical ecosystem trends and influences
  - -TS, PS, NTS, & Systemic indicators
  - -what is the recent history?

- Determine status of present ecosystem state
  - -where are we relative to where we want to be ?

- Provide forecasts for future ecosystem attributes
  - -in short-, medium- and long-term
  - -what are the effects of trends/variations in abiotic factors?
  - -what are the effects on other biota
  - -what are the effects of alternative policy choices?
    (also called management strategy evaluation)

Ecosystem Indicators: Management

- Set thresholds and limits
  -what do we know is precautionary?
  -if not able to pick what ecosystem state is desirable,
  at least what states do we want to avoid?

- Evaluate performance of past management actions
  -where are we relative to where we want to be ?
  -what did we do to get here?

- Invoke control rules
  -what actions need to be taken to achieve objectives?
  -what are the effects of alternative policy choices?
  (also called management scenario analysis)

Indicators- Which ones and how many?

- At least initially, Status Indicators should be as inclusive as possible (in terms of germane processes)
- Indicators must span full range of appropriate biological, physio-chemical & socio-economic factors
- Yet, the global experience is that a long “laundry list” of indicators is not immediately helpful for EM

Vetting Indicators

Desirable Properties of Indicators:

- Directional
- Sensitive to change
- Range spans natural variability
- Precision and variance estimable & reasonable
- Unambiguous
- Not duplicative nor repititious
- Expressive/representative of key processes

Culling Indicators

- Indicators need to map to major/key processes and phenomena in ecosystems
- Indicators need to map to stated (or unstated but legislatively mandated) objectives and criteria
- Broad stakeholder involvement in selecting and identifying indicators assists their use/acceptance later on in the management process
- General protocols exist for the selection of desirable indicators for EAF/EBFM/EM
  – Most examples of selected indicators for EBFM fall into 5-7 main categories

Usual Categories/Classes of EBFM Indicators

- Size
- Production
- Diversity
- “Canary” species
- Energy Flow - Trophodynamics
- Habitat
- Physio-chemical Regime

- Management Performance - Response

Packaging Indicator Information

- General protocols exist for the grouping, combining, and integrated examination of multiple indicators
- Traffic Lights
- Amoebas, Surfaces
- MV Analyses
  - Dimensionality
  - Causality

Traffic light-consumer report approaches

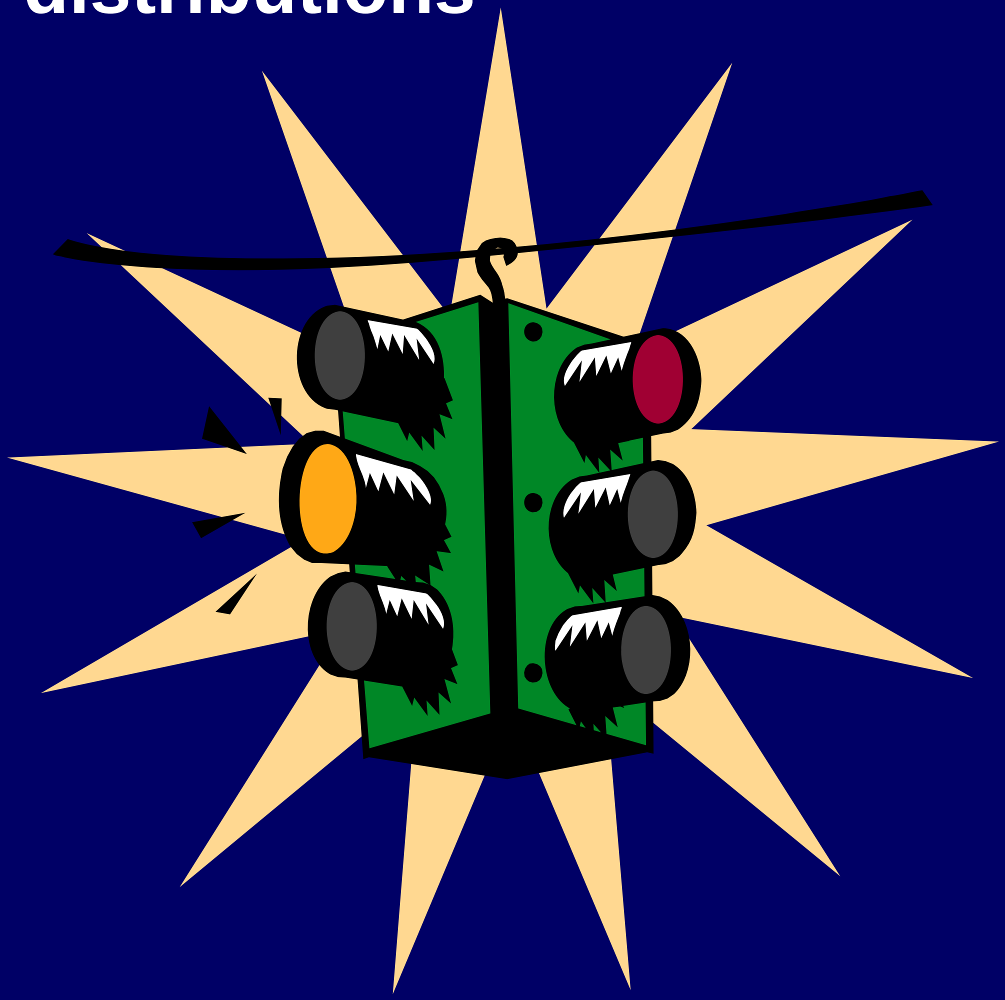
Based upon empirical distributions

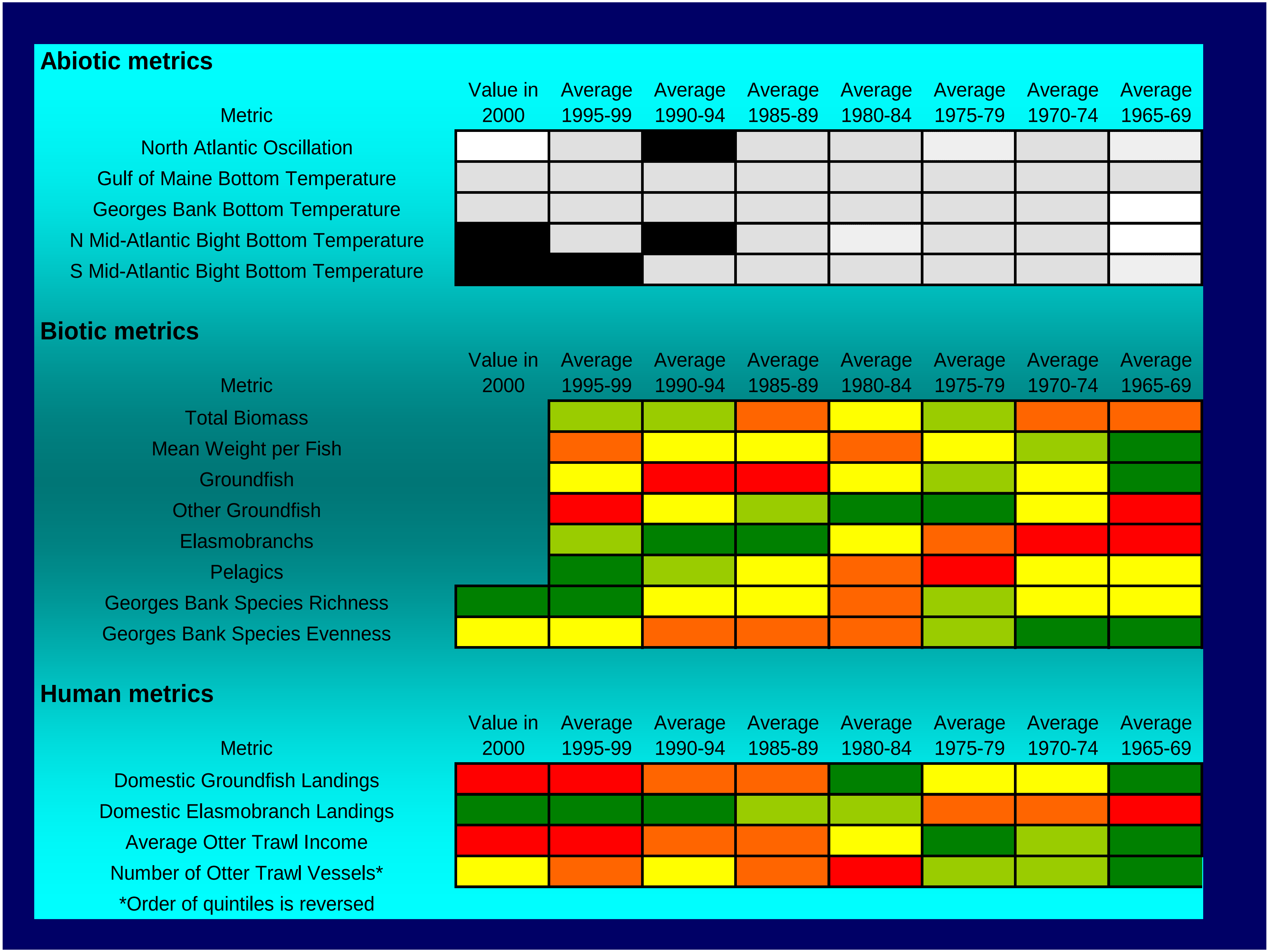
Metric 1

Metric 2

Metric 3

Etc.




Abiotic metrics
Metric
Value in 2000
Average 1995-99
Average 1990-94
Average 1985-89
Average 1980-84
Average 1975-79
Average 1970-74
Average 1965-69
North Atlantic Oscillation
Gulf of Maine Bottom Temperature
Georges Bank Bottom Temperature
N Mid-Atlantic Bight Bottom Temperature
S Mid-Atlantic Bight Bottom Temperature
Biotic metrics
Metric
Value in 2000
Average 1995-99
Average 1990-94
Average 1985-89
Average 1980-84
Average 1975-79
Average 1970-74
Average 1965-69
Total Biomass
Mean Weight per Fish
Groundfish
Other Groundfish
Elasmobranchs
Pelagics
Georges Bank Species Richness
Georges Bank Species Evenness
Human metrics
Metric
Value in 2000
Average 1995-99
Average 1990-94
Average 1985-89
Average 1980-84
Average 1975-79
Average 1970-74
Average 1965-69
Domestic Groundfish Landings
Domestic Elasmobranch Landings
Average Otter Trawl Income
Number of Otter Trawl Vessels*
*Order of quintiles is reversed

Summary of Traffic Light

- “Greenest” period of all metrics was during the 1960s
- Recent time periods generally more “orange” for all metrics
- Pelagic biomass, elasmobranch biomass, temperatures “greener” in more recent years
- Analogous to consumer reports
  - Qualitative application for management

Using the Traffic Light Approach

1. No one buys a toaster or automobile that has consistent and multiple orange or red ratings
2. Similarly, fisheries managers and stakeholders would like a greener overall system status relative to the history of the system
3. In redder conditions, caution is heightened
4. One could then choose situations to make the overall status of the system greener (Fuzzy logic models)

- Assumes mechanisms and specific processes to obtain green conditions are known and manipulatible
  - Although qualitative, feasible for most agencies to at least use in assessing system-level status

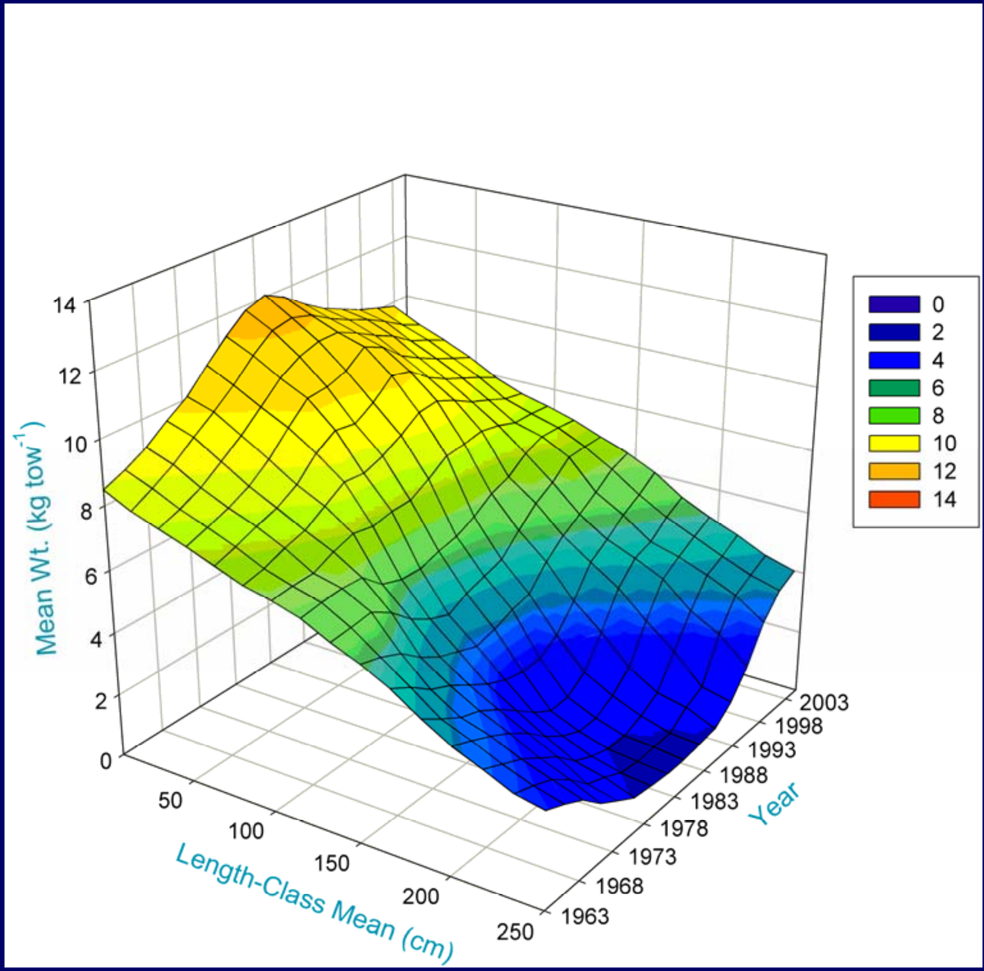
Reference Surfaces & AMOEBAS

- Surface plots allow the simultaneous evaluation of 3 to 4 dimensions. Often used to show concurrent minima or maxima.

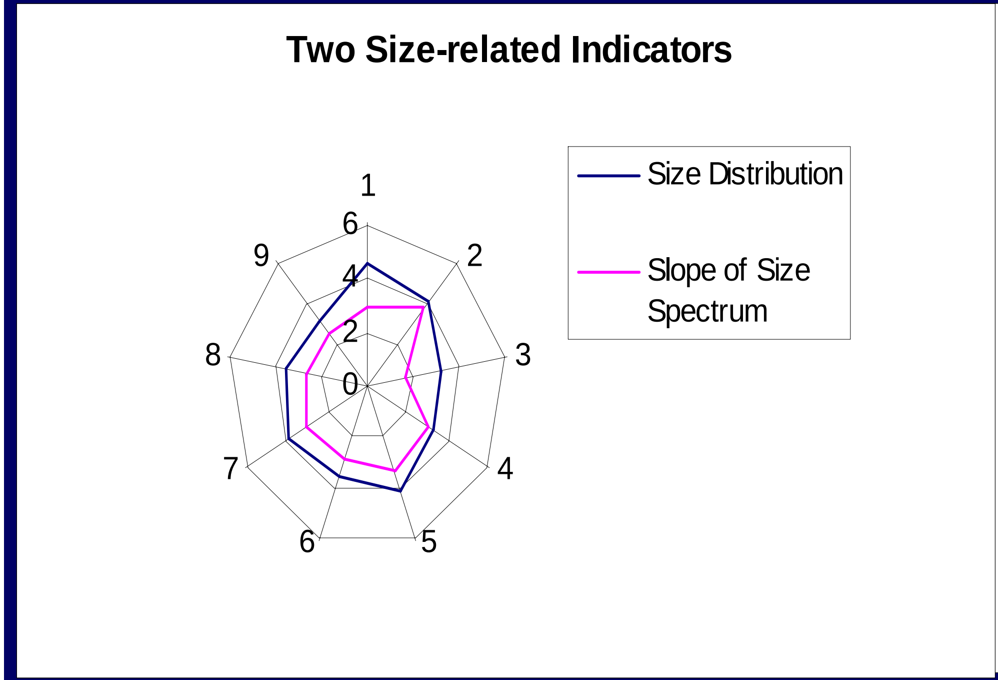
- Polar plots (compass plots) allow the simultaneous evaluation of multiple indicators. Often used to examine Biological LRP concurrently.

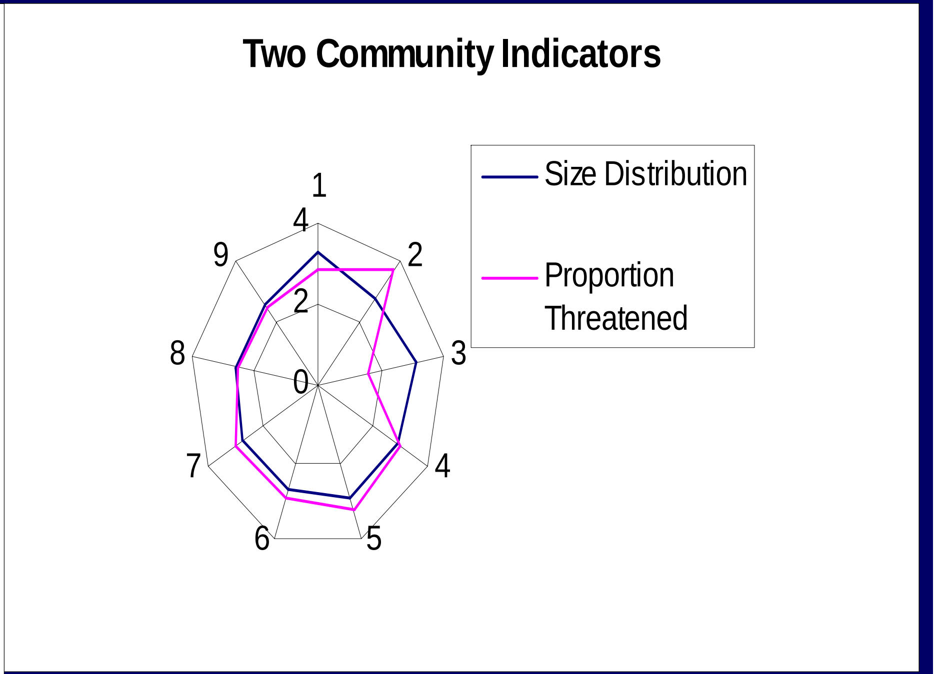
- Both can be either model or empirically based.
- Pro- evaluation of multiple indicators simultaneously
- Con- limited to a select set (subset) of indicators, not necessarily integrative.

Reference Surfaces



AMOEBAS


Two Size-related Indicators
1
2
3
4
5
6
7
8
9
0
2
4
6
Size Distribution
Slope of Size Spectrum


Two Community Indicators
1
2
3
4
5
6
7
8
9
0
2
4
Size Distribution
Proportion Threatened

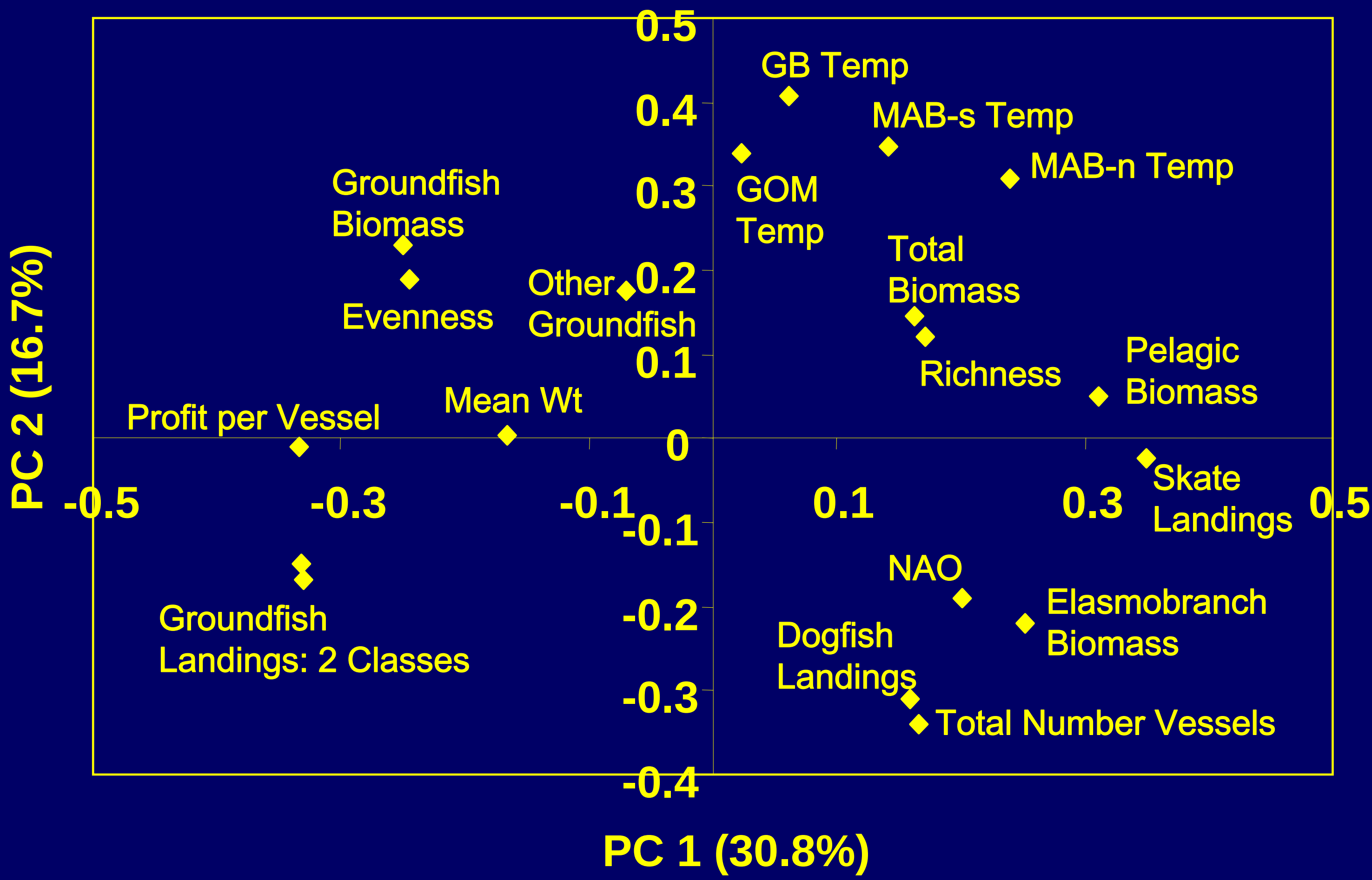
Summary: Surfaces & AMOEBAS

- Both can be used to set regions of desirability (e.g. aiming for local maxima, avoiding a global minima, bounded within a universal circumference, etc.) in a reference point (surface) sense.
- Are particularly useful in evaluating a family of related indicators (e.g. Biological Limit Reference Points).

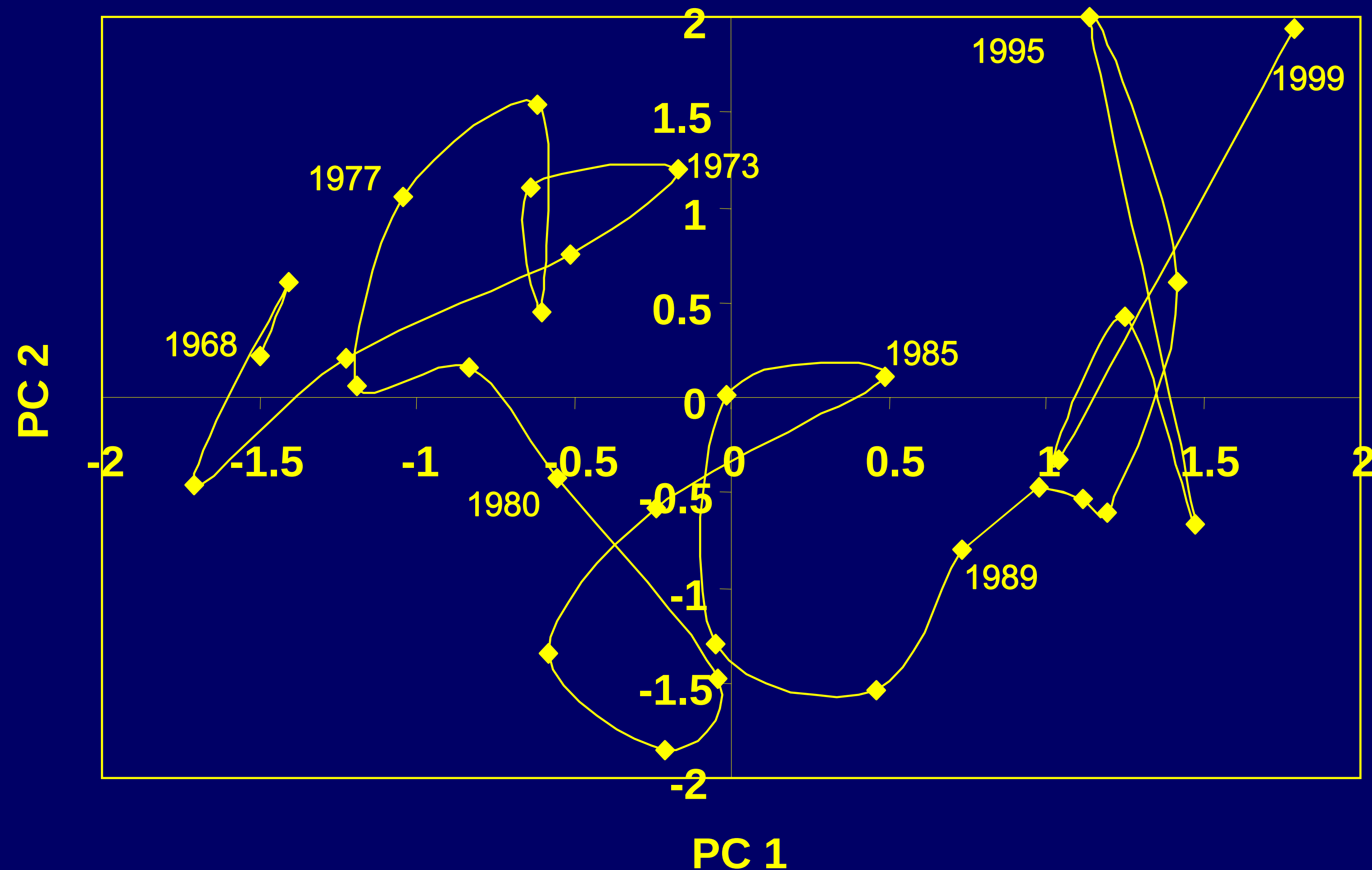
Multivariate Analyses

- PCA, MDS, etc. can help to reduce dimensionality
- Can help to detect major systemic patterns
- Can provide indicator weighting to determine the major processes acting upon the overall system
- Also useful in a culling/vetting exercise

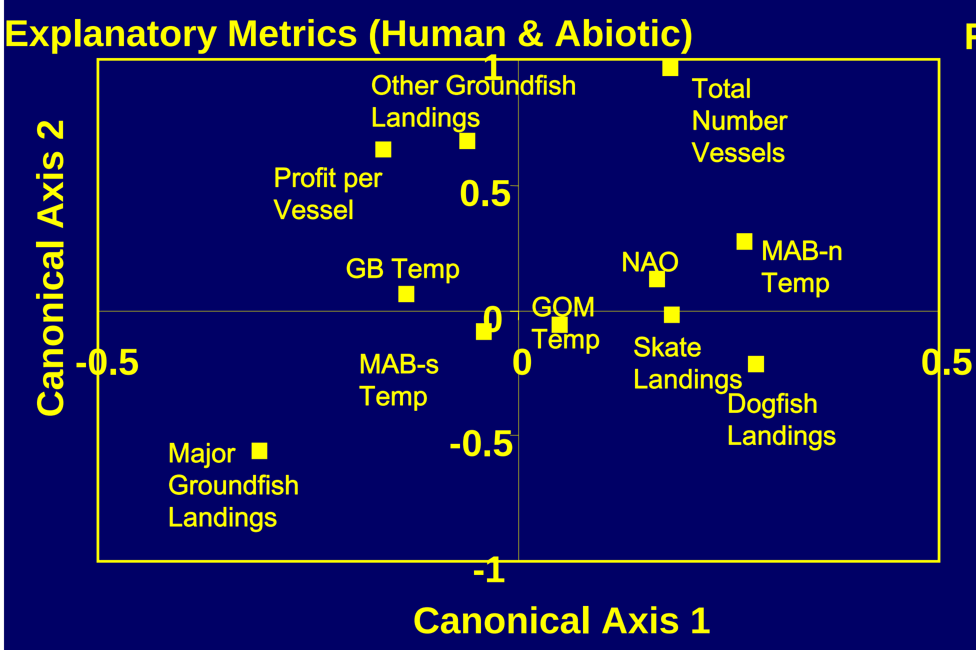
- Canonical Analyses- CanCorr, CCA, RA, DA etc.- can help to elucidate causality between multivariate pressure and response indicators.

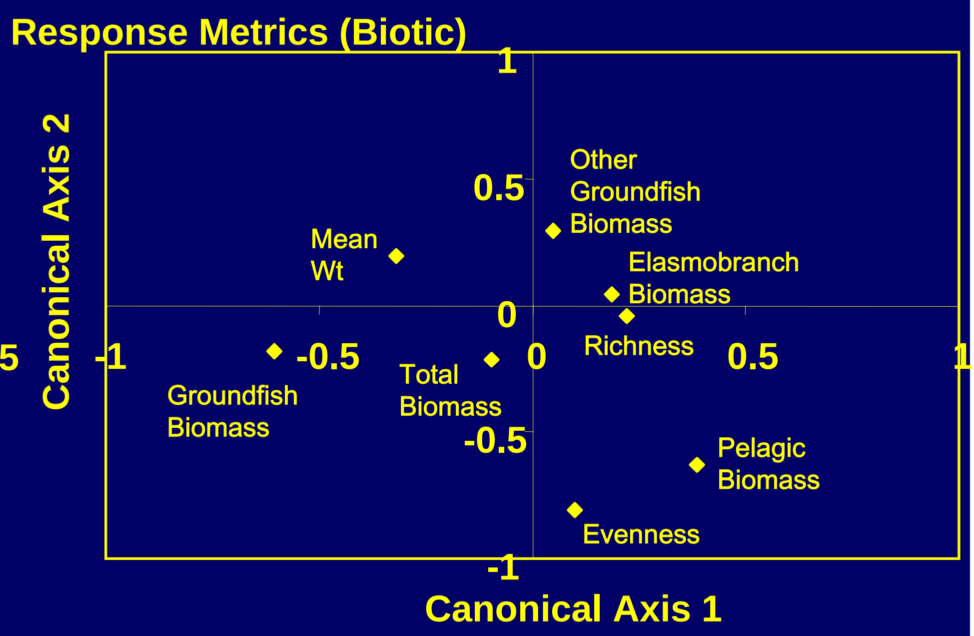


- Axis 1- groundfish (biomass, landings), profit, evenness & fish size vs. elasmobranchs & pelagics
- Axis 2- temperature & groundfish vs. effort (landings, # vessels)
- Various permutations explain 45-60% of total variance with similar results

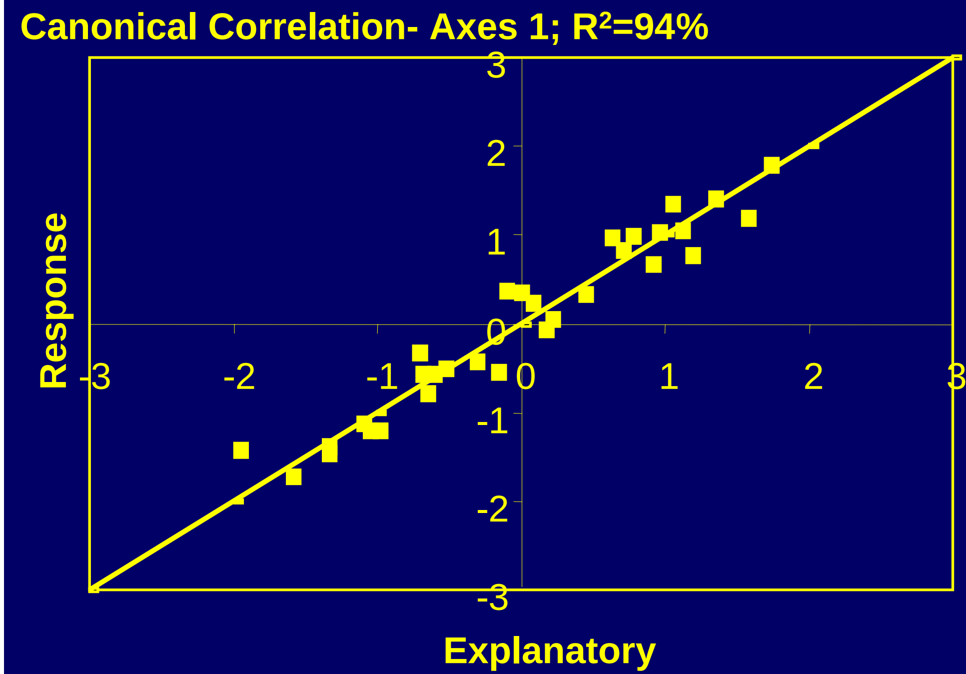


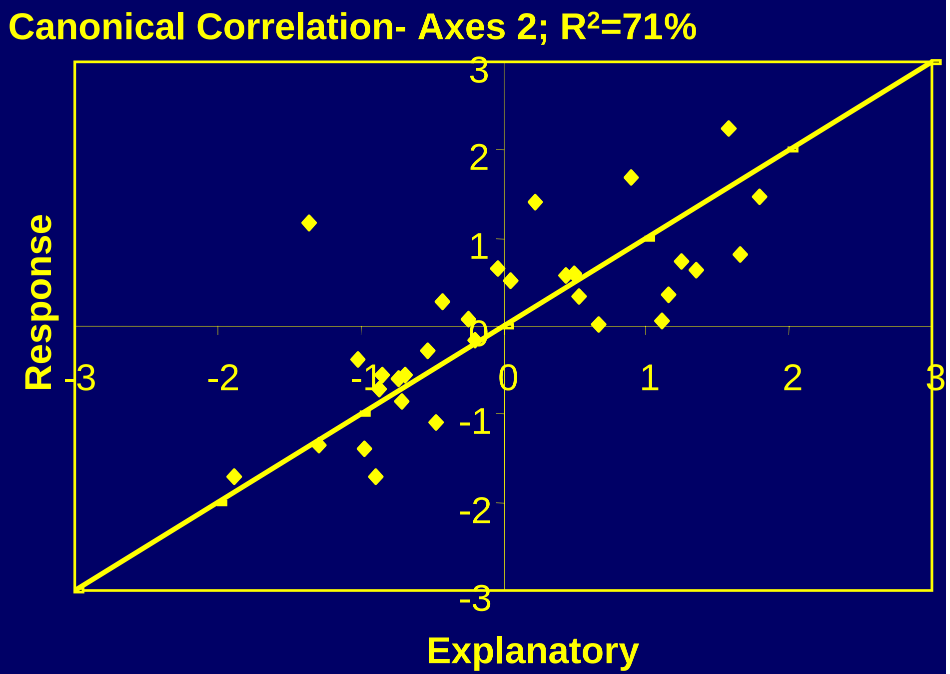
- ❖Multivariate trajectory generally counter-clockwise
- ❖Scores on first axis generally increasing across time
- ❖Scores on second axis lower during 1980s
- ❖Can we get from current position (upper right quadrat) to 1960s or early 1970s conditions (upper left quadrat)?



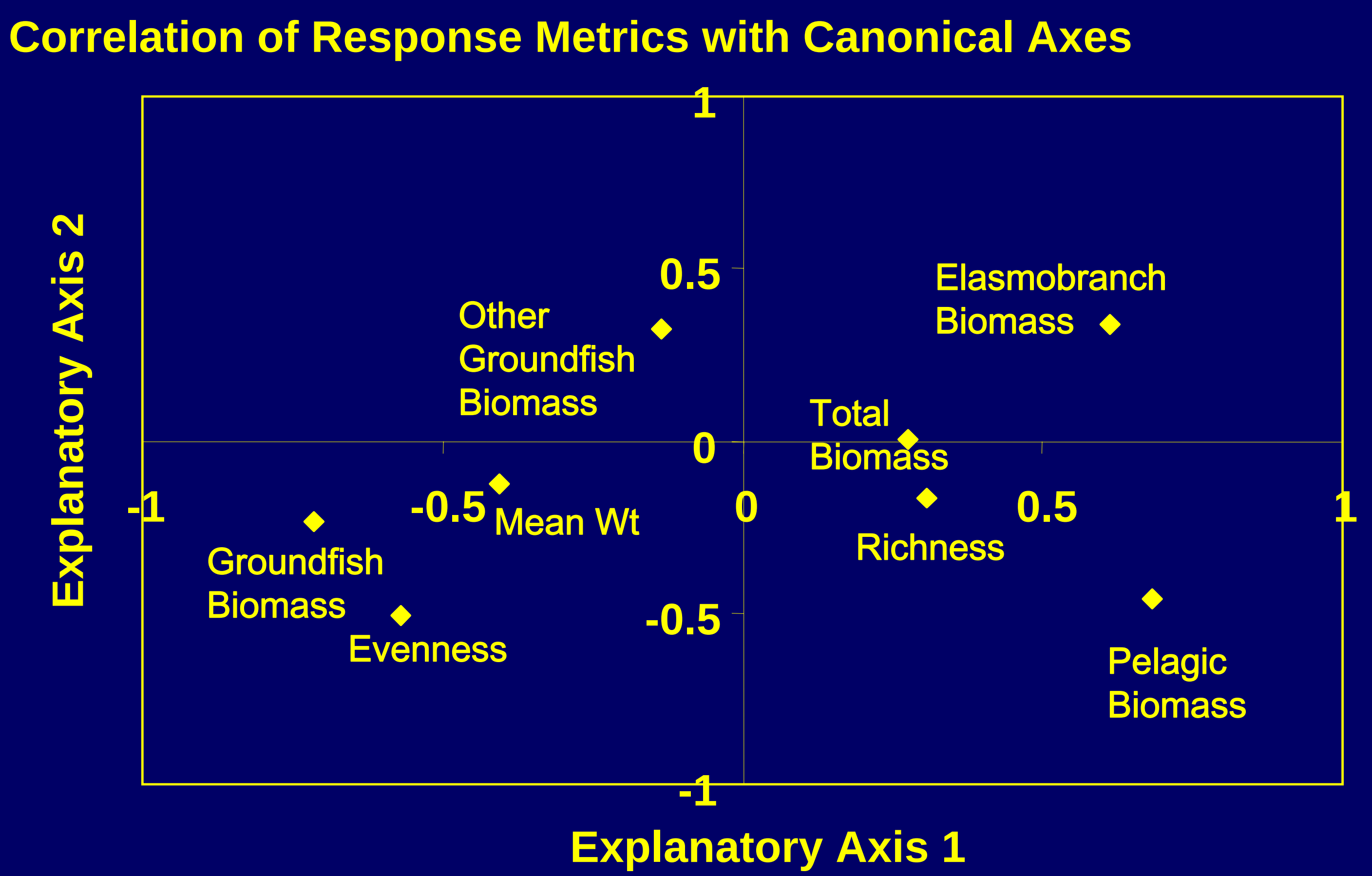


- Canonical Explanatory Axis 1- North MAB temperature, elasmobranchs vs groundfish
- Canonical Explanatory Axis 2- profit, # vessels, other groundfish vs. other species landings
- Canonical Response Axis 1- groundfish vs. pelagics
- Canonical Response Axis 2- evenness vs. other groundfish, fish size
- Results similar to PCA, but split out biotic from other metrics





- First 2 canonical axes explain 81% of the total variance among response variables
- Linear relationships between explanatory and response canonical axes are significant and strong



❖Assuming causality, we interpret the canonical correlation as:

❖1) hi groundfish landings, hi elasmobranch landings, hi # vessels, and hi MAB temperatures produce low groundfish biomass and hi pelagic biomass;

❖2) hi levels of effort and sequential fishing produce smaller-sized fish, low biomass of other groundfish (i.e. demersals), and lower species evenness

Summary of MV Analysis

- In example, PCA explains 50% of total variance among the ecosystem metrics
- MV trajectory confirms and integrates metrics of multiple processes
- Canonical correlation useful:
  - MV relationships established
  - Relative importance of different processes
- MV reference points/directions possible, although empirically based
- Can we get from one quadrat to another?

Translation of Ecosystem Indicators into Decision Criteria

Reference points (surfaces, regions, directions, etc.),
Control rules, decision theoretics, etc.

B_{MSY}

$B_{20\%\ B\text{-}virgin}$

$F=M$

$r/2$

$K/2$

B_{MAX}

B_{MSST}

$F_{20\%MSP}$

F_{MSY}

50%YPR

F_{max}

$F_{0.1}$

$B_{90\%\ Surv.}$

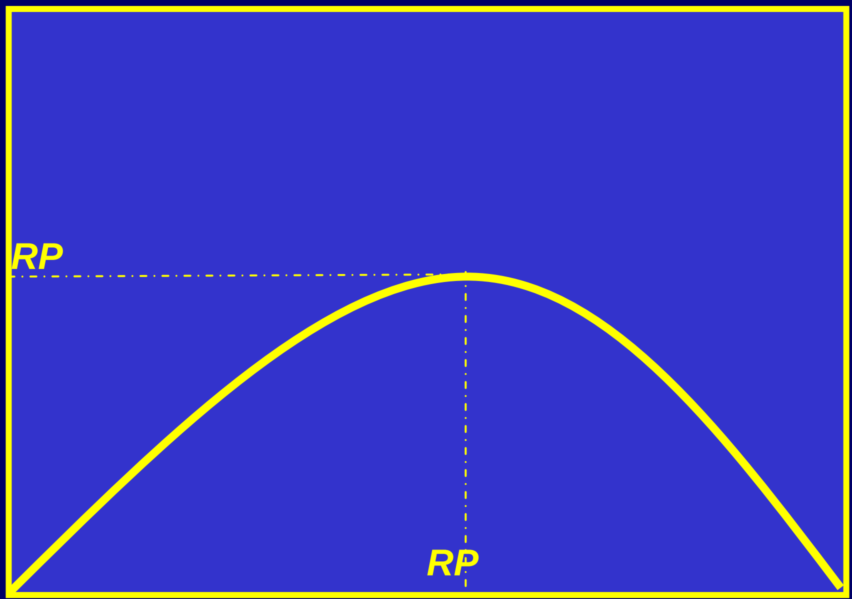
Indicators & Decision Criteria

- Most indicators are not yet usable as reference points
- Empirical use of indicators as a function (or partial function) of a stressor (e.g. F) can help establish specified thresholds or LRPs
- Development of empirically based indicator thresholds needs further work, but can be used ***NOW*** to establish some intermediate decision criteria
- The role of MV Reference Directions, Surfaces, etc. merits further examination and application

Decision Criteria

Single Species Fisheries-

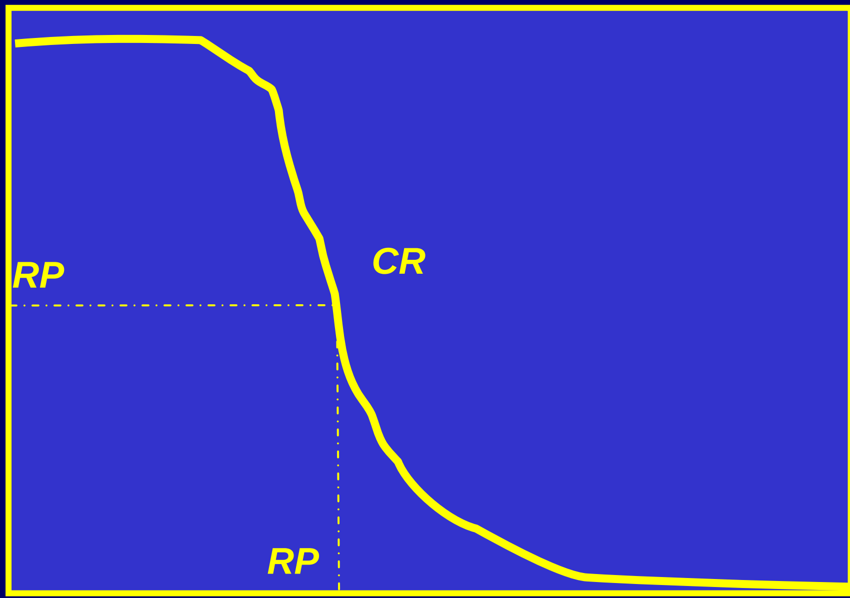
- **Model & empirical-based ref points**
- **Model-based control rules**



Decision Criteria

Toxicity & Ecological Risk Assessment-

- **Model & empirical-based ref points**
- **Model-based control rules**

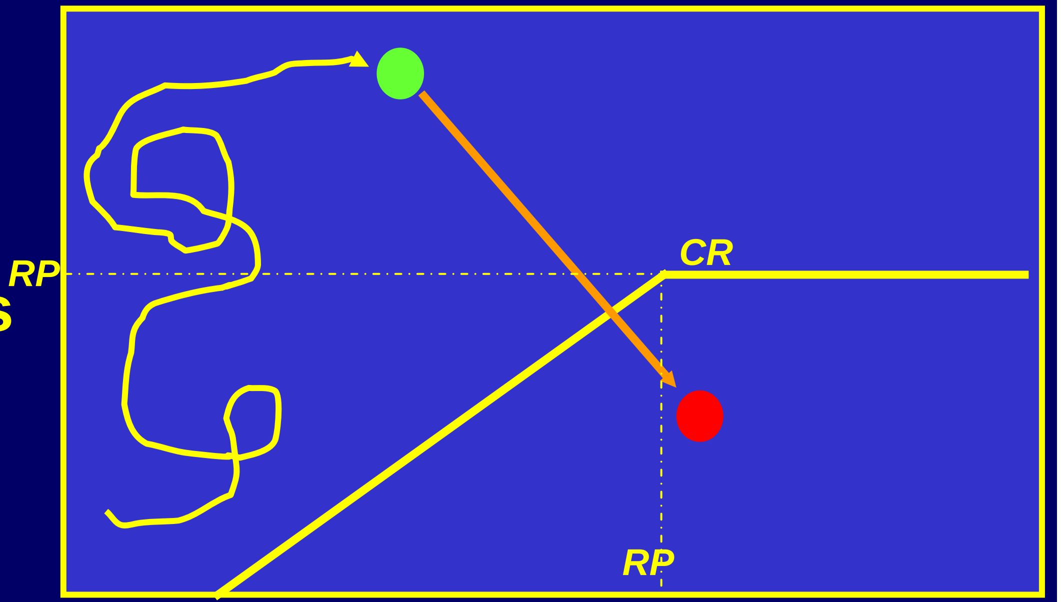


- **Are these arbitrary?**
  - What's special about a set fraction of survivorship or 50% of K or so forth

Decision Criteria

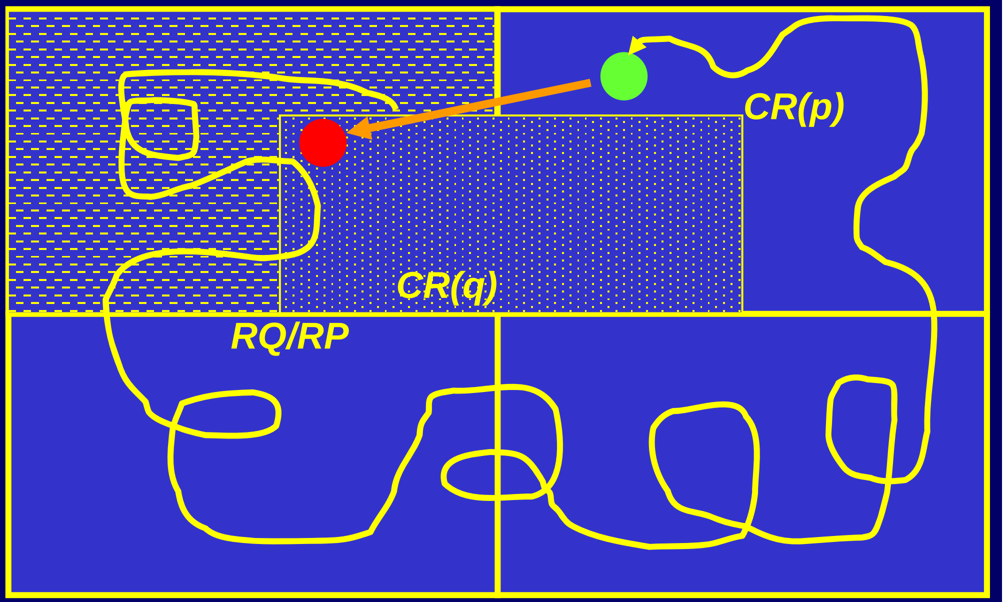
Single Species-

- **Model & empirical-based ref point**
- **Model-based control rules**
- **Action to be taken shows direction and magnitude**



Ecosystem-

- **Empirical-based ref points & directions**
- **Arbitrary/empirical control rules**
- **Action to be taken may only show direction**



Using MV Indicator Derived Reference Directions, Surfaces, Quadrats, AMOEBAS, etc.

1. What quadrat are we in (e.g., from PCA, or surface, or pole, etc.)?
2. What quadrat do we wish to be in?
3. Irrespective of mechanism, what factors produce the conditions in the desired quadrat (e.g., from CanCorr)?
4. Which of these can we control?
5. Can we then limit effort, landings, etc. for particular aggregate groupings to obtain the desired response? Or do we simply need to wait for a change in environmental conditions?

- Assumes a reversible trajectory and causality among canonical axes

Empirically Derived Indicator-Based Reference Points & Thresholds

- How we established the Thresholds and LRPs
- Determinants of change
  - Empirical observations
  - Linked to major events in US NW Atlantic Ecosystem
  - Inflection points or regions of change
  - Supported by strong literature and theoretical basis

Using Indicator-Based Reference Points & Thresholds

Indicator	Description	Warning Threshold	Limit Reference Point
l	Mean length, all spec.	30%	50%
⁇	Slope size spectrum, all spec.	N/A	10%
$B_{flatfish}$	B of all flatfish spec.	$B_{flatfish}$ >50% $B_{✍}$	$B_{flatfish}$ >75% $B_{✍}$
$B_{pelagic}$	B of all pelagic spec.	$B_{pelagic}$ >75% $B_{✍}$ or $B_{pelagic}$ <20% $B_{✍}$	$B_{pelagic}$ >85% $B_{✍}$ or $B_{pelagic}$ <10% $B_{✍}$
B_{TL4+}	B of all spec. at trophic level 4 and above	B_{TL4+} >25% B_{TL3}	B_{TL4+} >50% B_{TL3}
B_{pisc}	B of all piscivores	N/A	B_{pisc} >B_{benth} + B_{plank}
$L_{✍}$	Landings of target spec.	$L_{✍}$ >5% PP $\overline{L/S}_{max}$	$L_{✍}$ >10% PP
L/S	Mean number of interactions per spec.	10% below	N/A
B_{remov}	Fishery removals of all spec. (landings, bycatch, discards, etc.)	N/A	B_{remov} >$B_{✍Cons}$
S	Species richness (number of spec.)	S <S_{min}, for 3 yrs	S <S_{min}, for 5 yrs
C	Number of cycles	30% below C_{max}	N/A
N_{scav}	Abundance of scavengers	100% above $N_{scav\text{-}med}$	200% above $N_{scav\text{-}med}$
V_{jelly}	Volume of gelatinous zooplankton	100% above $V_{jelly\text{-}med}$	200% above $V_{jelly\text{-}med}$
A_{coral}	Area of live, hard coral	30% below A_{max}	50% below A_{max}

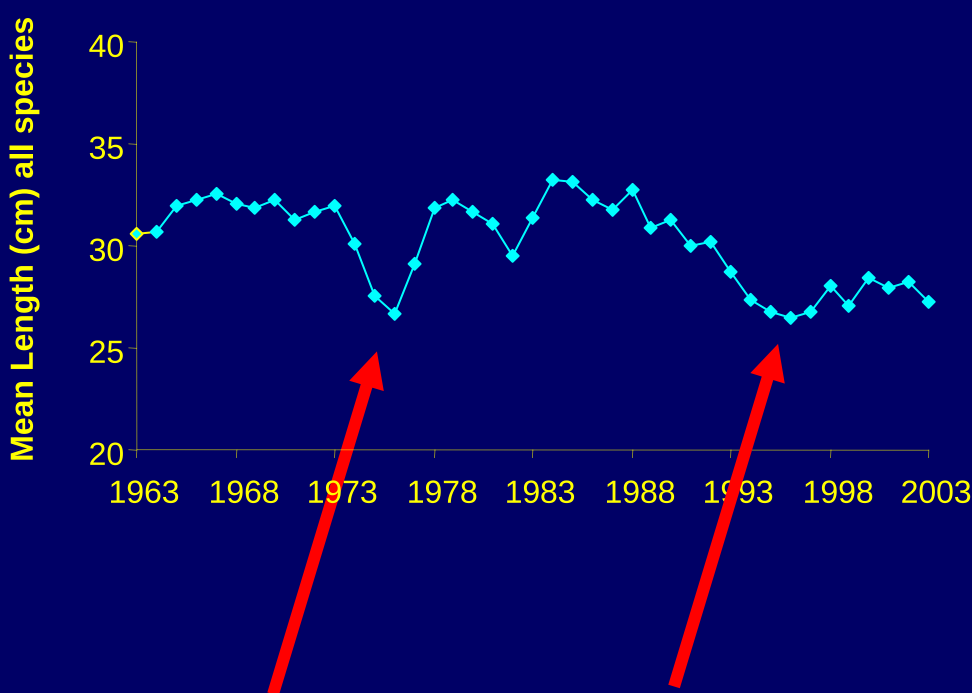
Decision Criteria: Size

$\bar{l}$

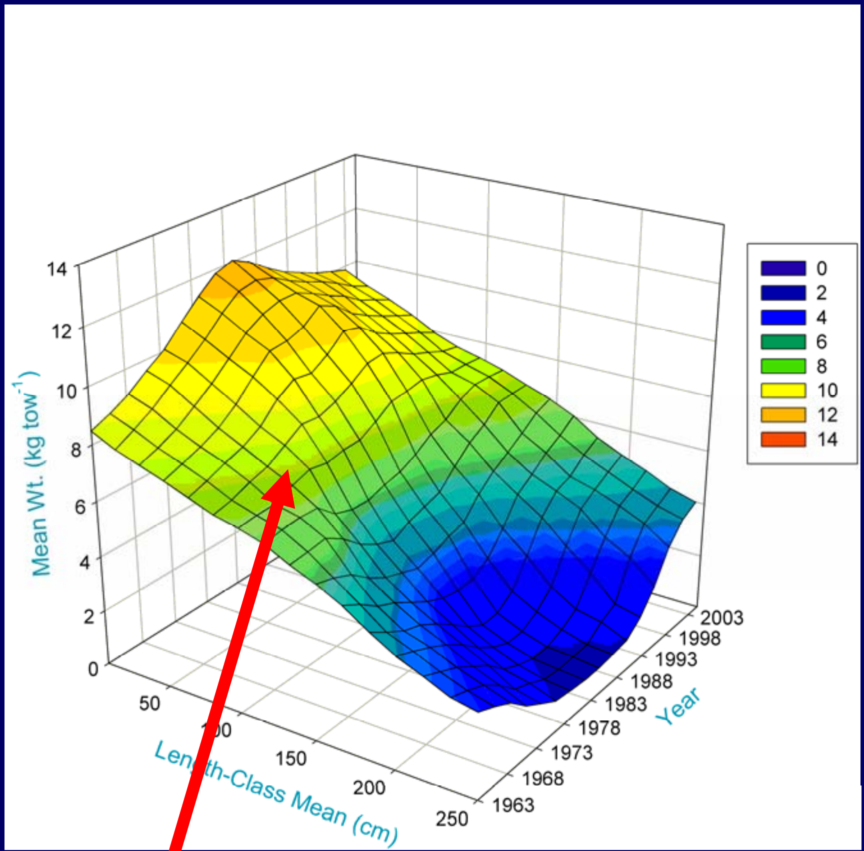
<✆30 OK

✆30+ Threshold

✆50+ Limit



Decision Criteria: Slope of Size Spectrum



<✆10	OK
N/A	Threshold
✆10+	Limit

Decision Criteria: Aggregate Biomass

B_{TL4+}	$< 25\%\ B_{TL3}$	OK
	$> 25\%\ B_{TL3}$	Threshold
	$> 50\%\ B_{TL3}$	Limit

Decision Criteria: Trophodynamics

L ☞ $< 5\% \, PP$ OK

$> 5\% \, PP$ Threshold

$> 10\% \, PP$ Limit

Indicators & Models

- Further development/translation of indicators into Decision Criteria will need a predictive element
- Underlying models linking “dose-response” of selected indicators are required for the broader acceptance of using indicators as Decision Criteria
- Global examples of modeling efforts have matched empirically derived results of indicator thresholds, but further exploration is merited

Summary

- Assessing the status of an ecosystem is not trivial, but is feasible
- Need multiple metrics to assess ecosystem status and develop system reference points
- MV methods exist to establish and synthesize relationships & relative importance among numerous processes in marine ecosystems
- We now know the status of many marine ecosystem- trends, magnitudes, and relationships- in a manner we have never known before

Summary

- Ecosystem Reference Points exist
- Ecosystem level Management Indicators are currently difficult to implement
- Indicators ⑤ Reference Points
- Reference Points ⑤ Control Rules
- Represents a key step towards operationalizing EBFM, EAF, EM
  - Many steps to go

What do we need?

- Further Identification and Vetting of key ecosystem Indicators
- Establish Indicators as a function of F (or other stressors) relative to other potential perturbations
- Commitment to data sources
- Commitment to modeling resources and development
- Novel ways to package, combine, visualize & communicate the multi-attribute, multivariate information
- More formalized decision analysis, MSE, DSS, and similar approaches to better use translated Indicators