Ecological Indicators: Lessons Learned from the NEUS

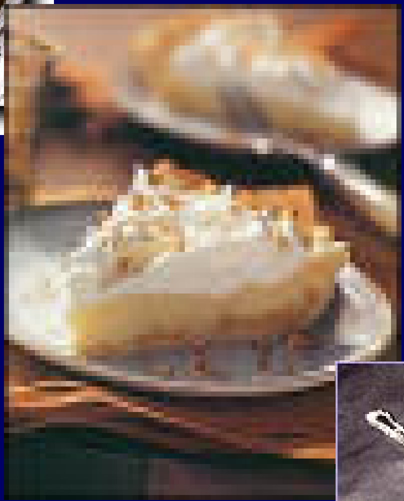
Jason Link

NOAA NMFS NEFSC

Woods Hole, USA

EBFM is as easy as pie








General Indicator Features

What is the issue?

- Is Fishing impacting other Ecosystem Components & Properties?
  - Impacts to other Fishing Sectors
  - Impacts Across broader Ocean-use sectors
  - Impacts to other, legally considered spp.
- Are other Ecosystem Considerations impacting the fishery (i.e. fish stocks)?
- Normally invoked in a broader, EBFM/EBM context

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 an EAF/EAM process

Indicators- Which ones and how many?

- At least initially, Status Indicators should be as inclusive as possible
- Indicators must span full range of appropriate biological, physio-chemical & socio-economic factors
- Global examples of modeling efforts have matched empirically derived indicator lists and thresholds
- Yet, the global experience is that a long “laundry list” of indicators is not immediately helpful for EBFM

Vetting Indicators

- Desirable Properties of Indicators:
- Directional
- Sensitive to change
- Range spans natural variability
- Precision and variance estimable & reasonable
- Unambiguous
- Not duplicative nor repetitious
- 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 EBFM
  - 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

- Socio-economic
- Management Performance - Response

Sources of Indicator Information for EBFM

- FI, FD
- Other Disciplines (e.g., Satelitte imagery, Coastal Zone Mgt, etc.)

- The point is, routine & typical fisheries & environmental monitoring can produce much more information if re-examined from a new perspective
  - Ergo, mine extant data from a new perspective

Presenting Indicators

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

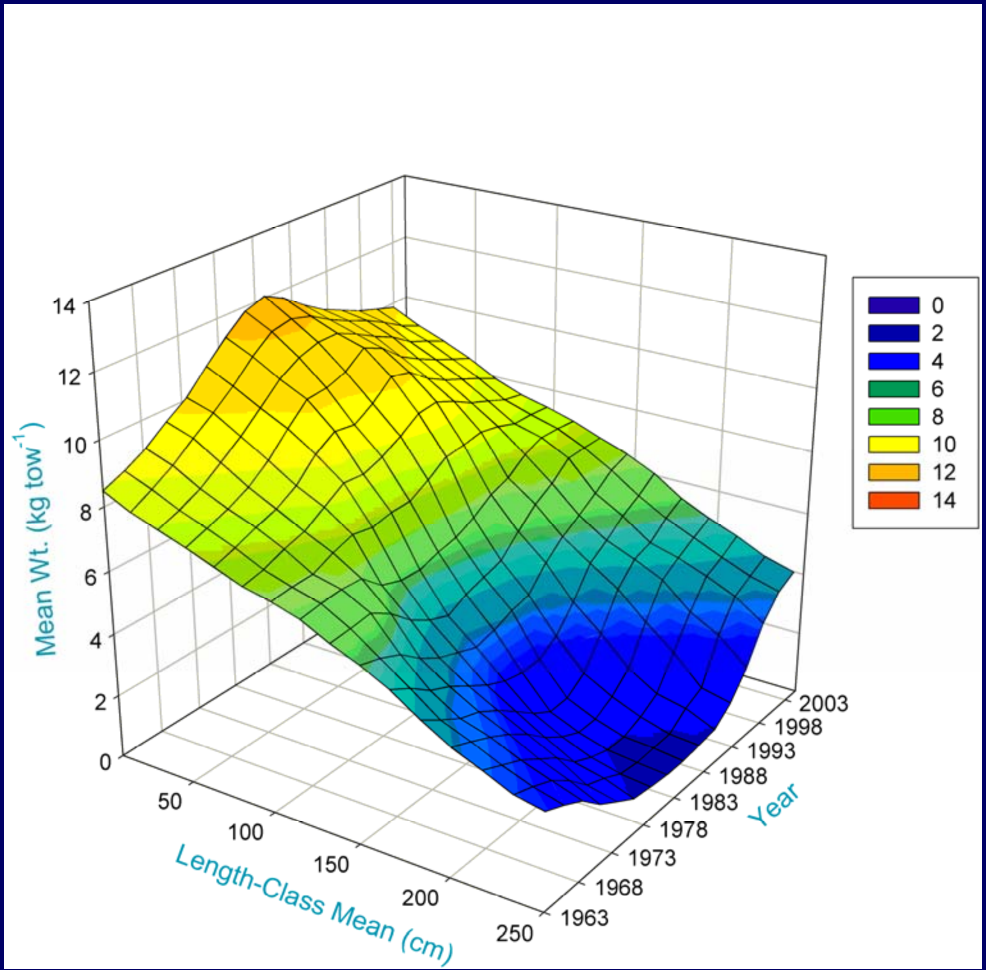
Metric	Value in 2000	Average 1995-99	Average 1990-94	Average 1985-89	Average 1980-84	Average 1975-79	Average 1970-74	Average 1965-69
Domestic Groundfish Landings								
Domestic Elasmobranch Landings								
Average Otter Trawl Income								
Number of Otter Trawl Vessels*								

*Order of quintiles is reversed

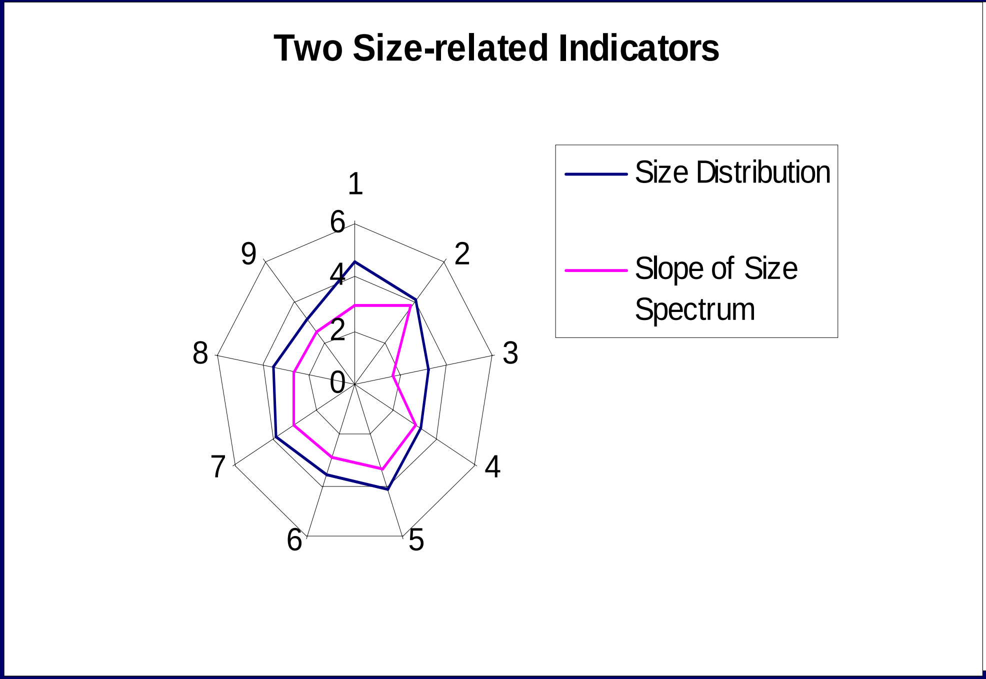
Summary: Traffic Light Approach

- No one buys a toaster or automobile that has consistent and multiple orange or red ratings
- Similarly, fisheries managers and stakeholders would like a greener overall system status relative to the history of the system
  - In redder conditions, caution is heightened
- One could then choose situations to make the overall status of the system greener (Fuzzy logic models)
- Usually empirical, but can also have model-based output
- 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

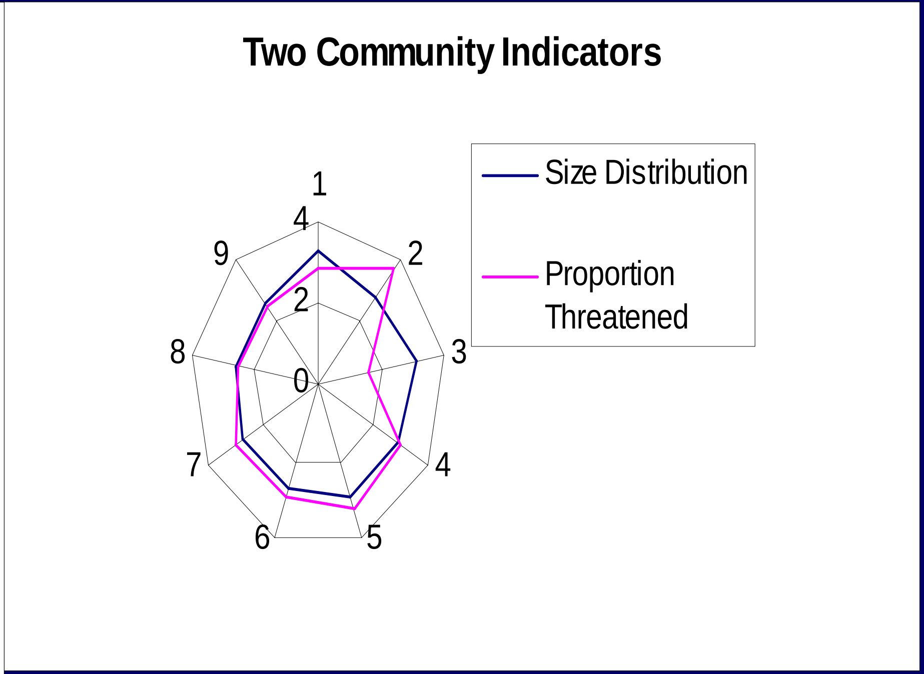
Reference Surfaces



AMOEBAS



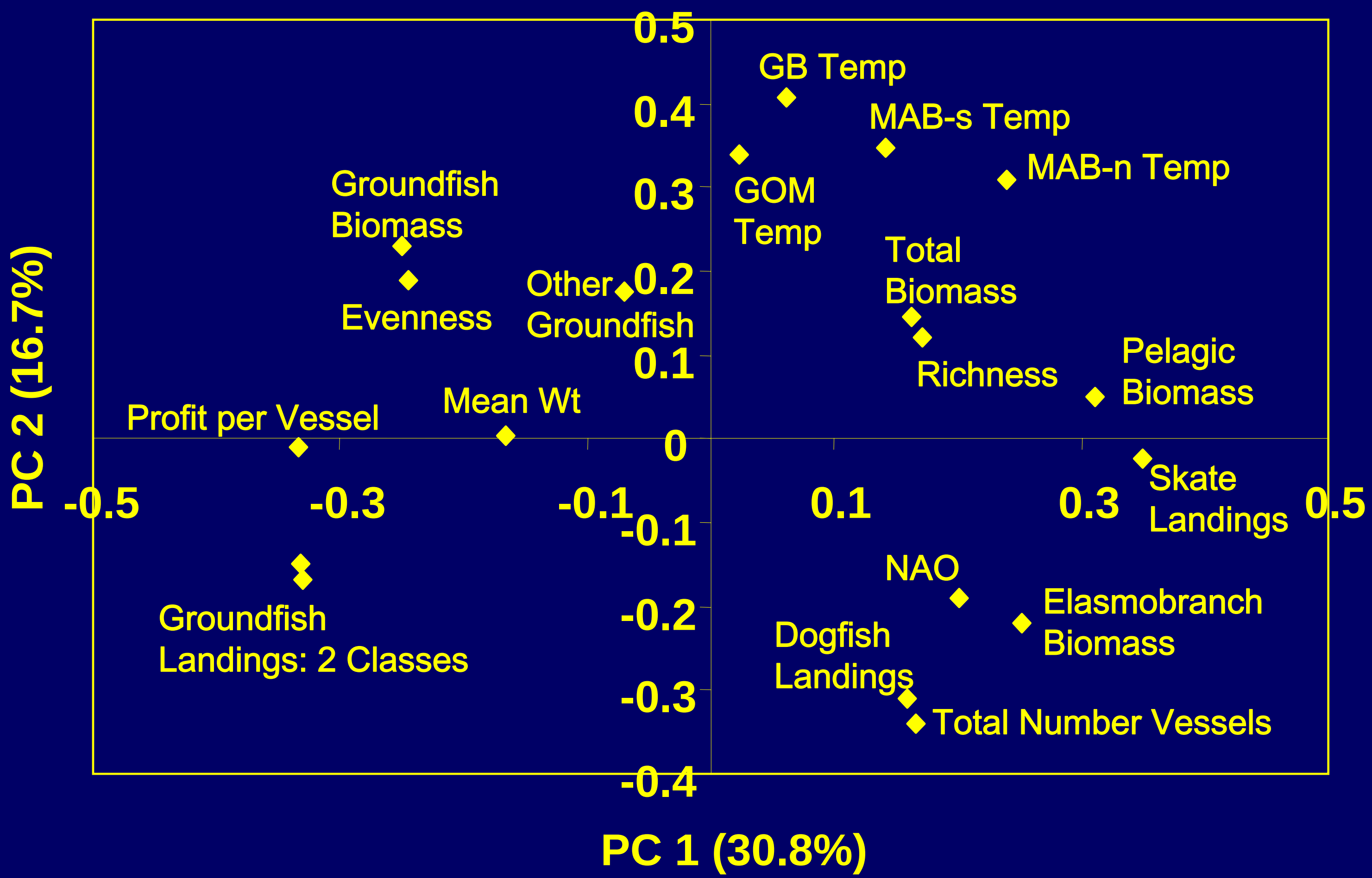
Two Size-related Indicators
1
2
3
4
5
6
7
8
9
0
2
4
6
Size Distribution
Slope of Size Spectrum



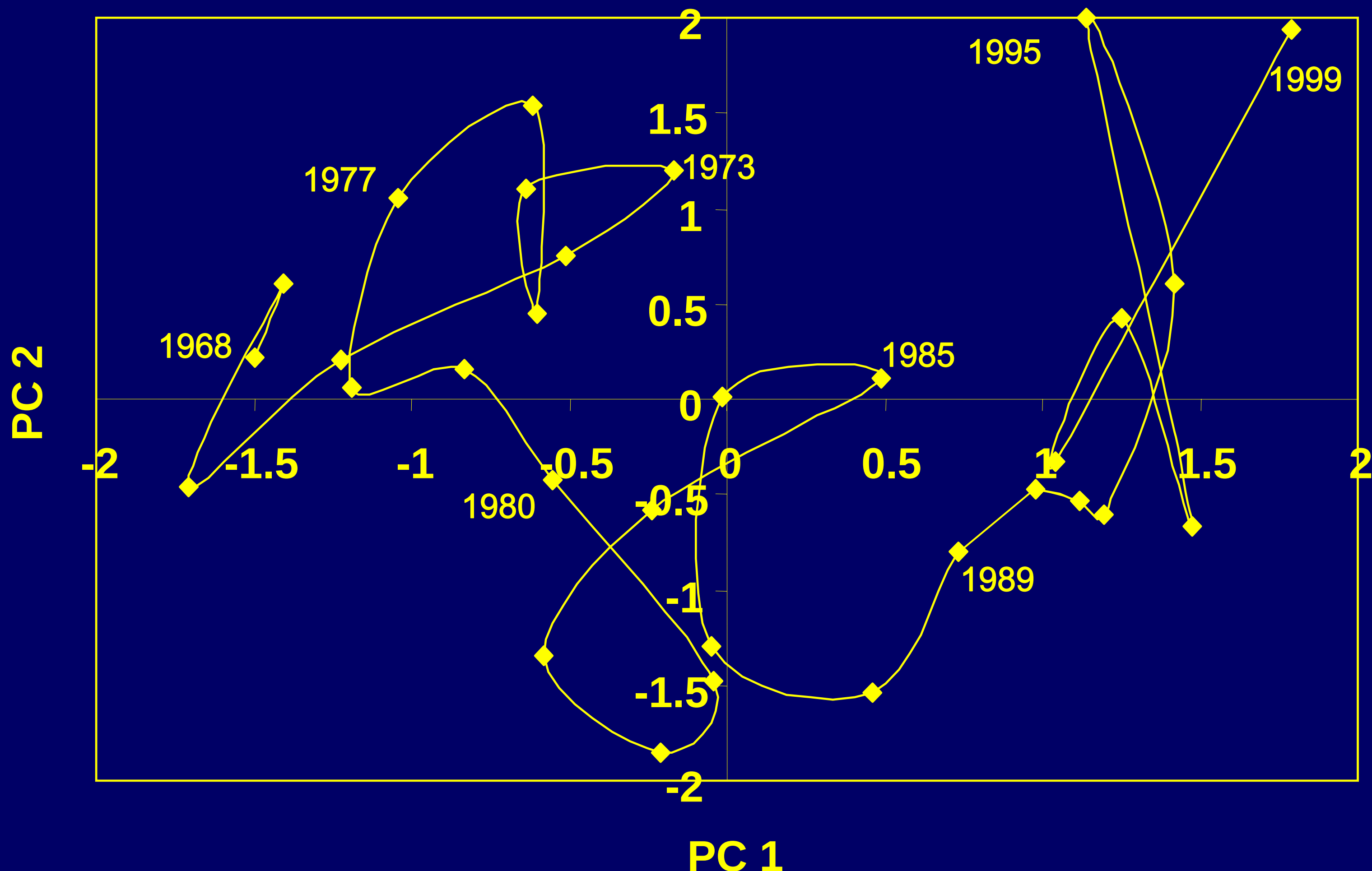
Two Community Indicators
1
2
3
4
5
6
7
8
9
0
2
4
Size Distribution
Proportion Threatened

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).
- 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.



- 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)?

Summary: 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.

Using (Management) Indicators

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}

$F_{0.1}$

$B_{90\%\ Surv.}$

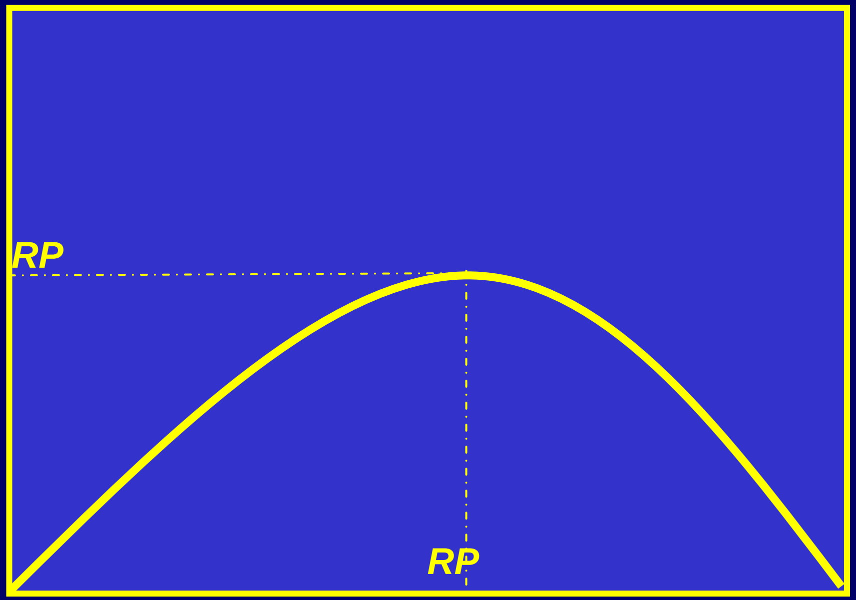
Indicators & Decision Criteria

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

Decision Criteria

Single Species Fisheries-

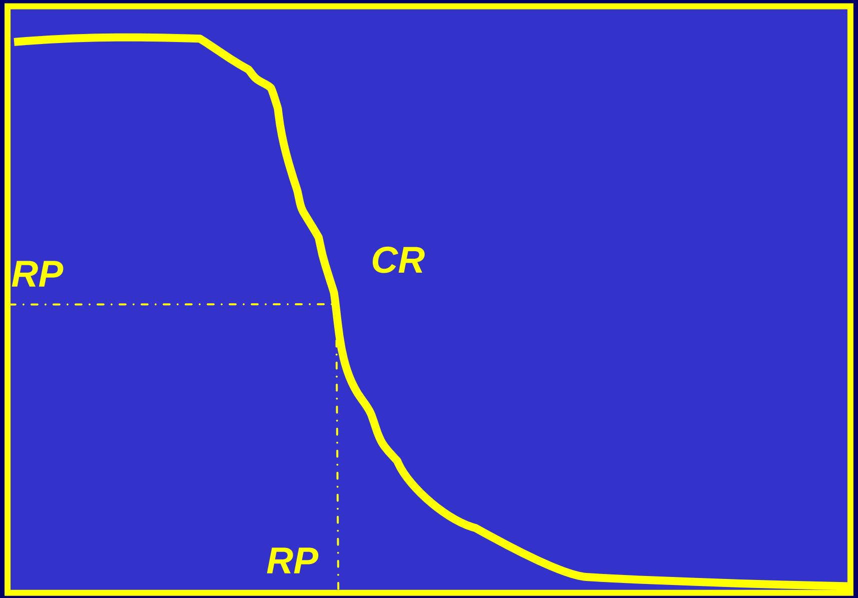
- **Model & empirical-based ref points**
- **Model-based control rules**



Decision Criteria

Toxicity & Ecological Risk Assessment-

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

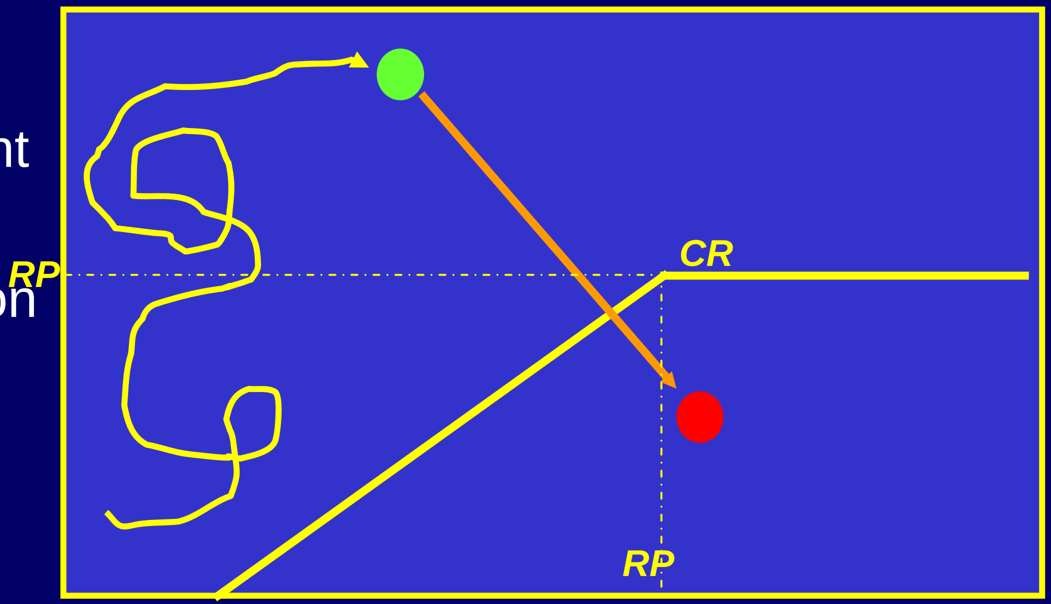


- **Are these arbitrary?**
- What's special about a set fraction of survivorship or 50% of K or so forth

Decision Criteria

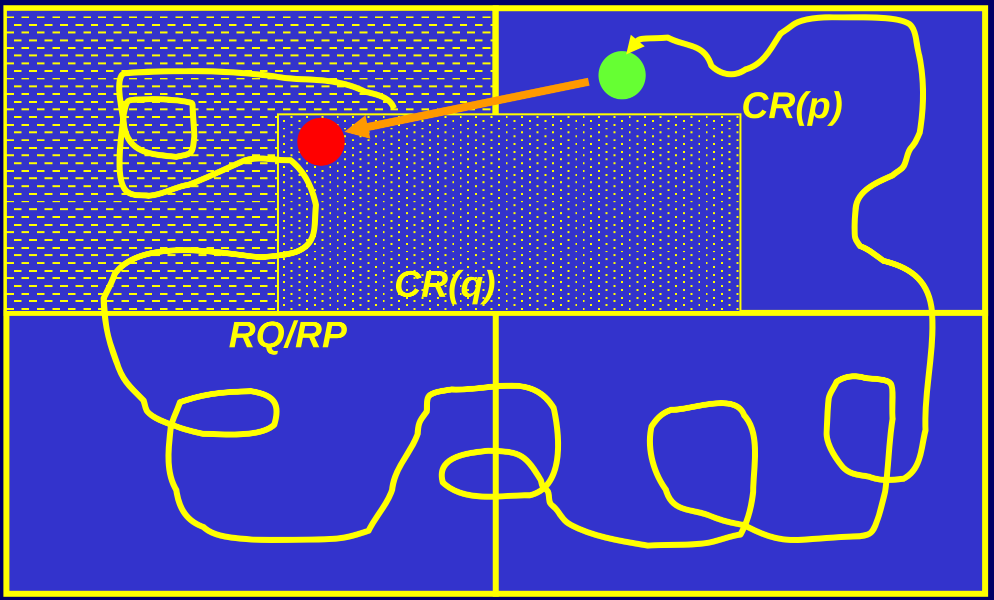
Single Species-

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

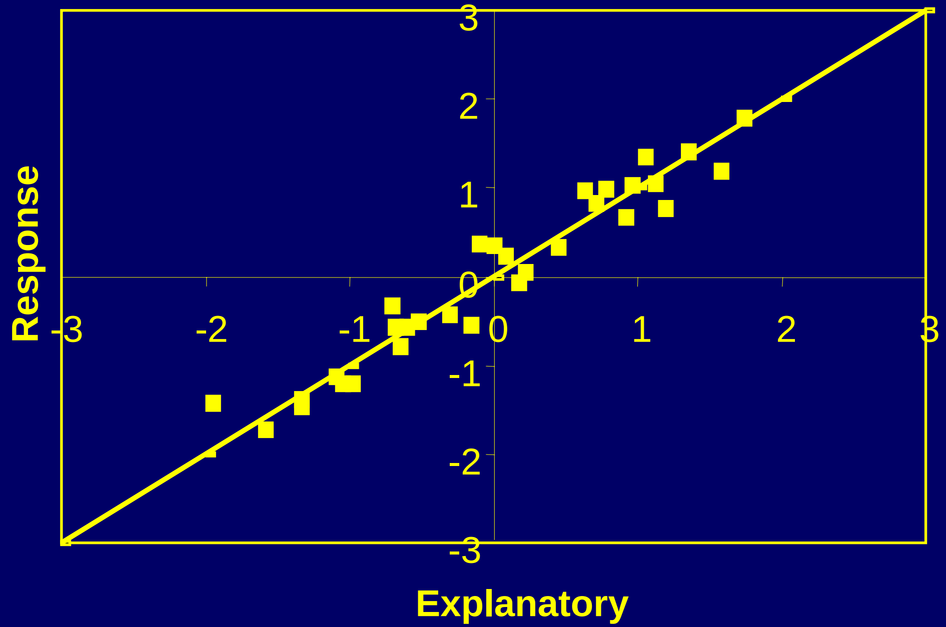


Ecosystem-

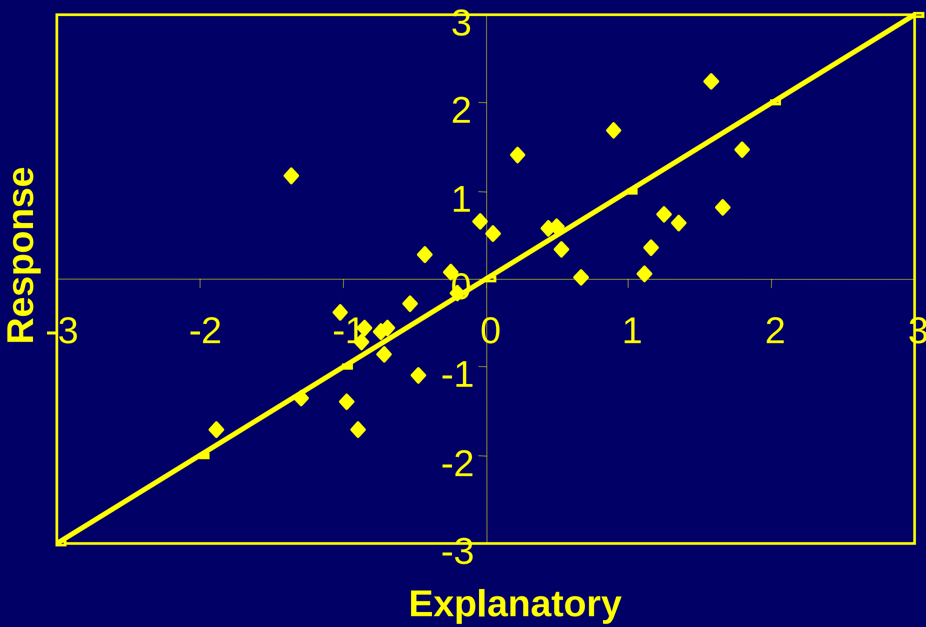
- Empirical-based ref points & directions
- Arbitrary/empirical control rules
- Action to be taken may only show direction
- Emphasizing integrated, systemic view



Canonical Correlation- Axes 1; R^2=94%

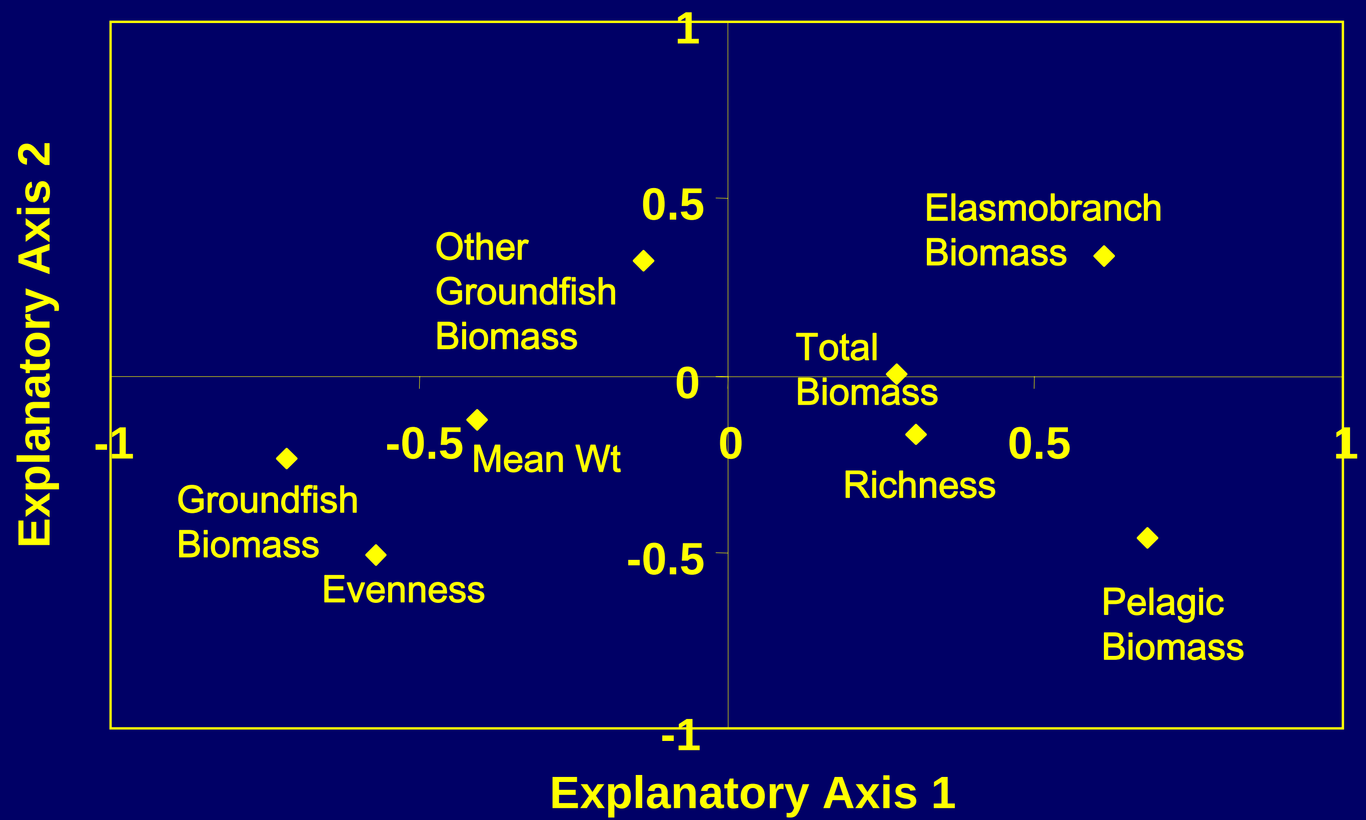


Canonical Correlation- Axes 2; R^2=71%



- 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

Correlation of Response Metrics with Canonical Axes



- 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

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

- What quadrat are we in (e.g., from PCA, or surface, or pole, etc.)?
- What quadrat do we wish to be in?
- Irrespective of mechanism, what factors produce the conditions in the desired quadrat (e.g., from CanCorr)?
- Which of these can we control?
- 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

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

Decision Criteria: Indicator Species

A_{coral}

A_{max}-(<✆30) OK

A_{max}-(✆30+) Threshold

A_{max}-(✆50+) Limit

Empirically Derived Indicator-Based Reference Points & Thresholds- Binding

- Can be used to establish Thresholds and LRPs
- Emphasizing Ecosystem Effects of (Over)Fishing
- Determinants of change
  - Mainly Empirical observations, some model outputs
  - Linked to major events in US NW Atlantic Ecosystem
  - Inflection points or regions of change
  - Supported by strong literature and theoretical basis

Where are we, where are we going?

Where We Are

- Current- System Status Emphasis
  - contextual (heuristic)
- Forthcoming- Aggregate or Systemic Reference “Regions” of Desirability (or non-desirability)
  - bounding (strategic)
- Longer term- Ecosystem or aggregate level reference points
  - binding (tactical)

Current Cautions when Using Indicators

- Ecosystem Reference Points/Regoins 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

Extant & Feasible

- 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

What do we need?

- INFORMATION:
  - Further Identification and Vetting of key ecosystem Indicators
  - Commitment to data sources
- RESEARCH:
  - Establish Indicators as a function of F (or other stressors) relative to other potential perturbations
  - Commitment to modeling resources and development
- PROCESS:
  - More formalized decision analysis, MSE, DSS, and similar approaches to better use translated Indicators