The dids, dos, don'ts and developments of data-limited catch limits

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NOAA
FISHERIES
SEFSC

QUEST
Quantitative Ecology and Socioeconomics
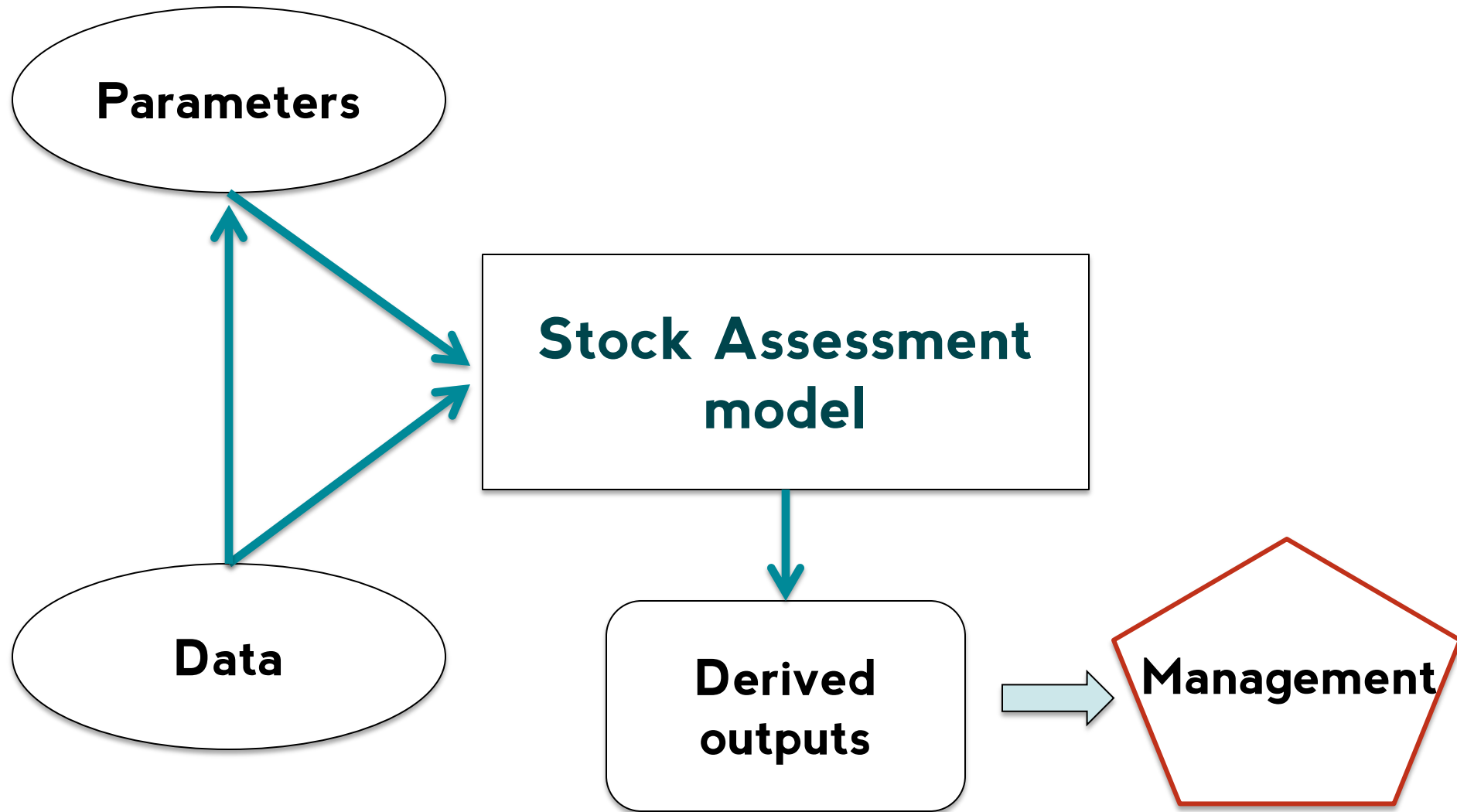**Training Program**

Outline

- **Background**
- **Definitions: What is data-limited?**
- **Innovations of data-limited methods**
- **Post-innovation stages**
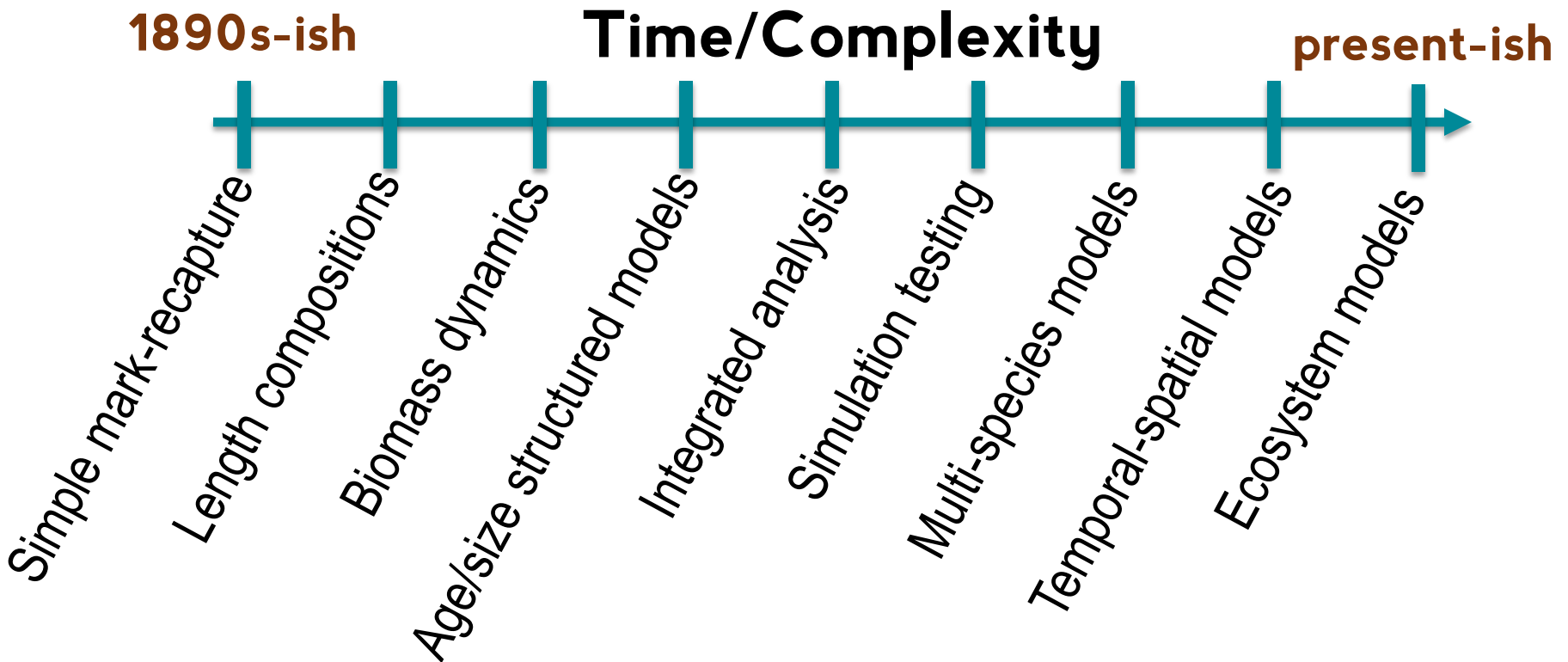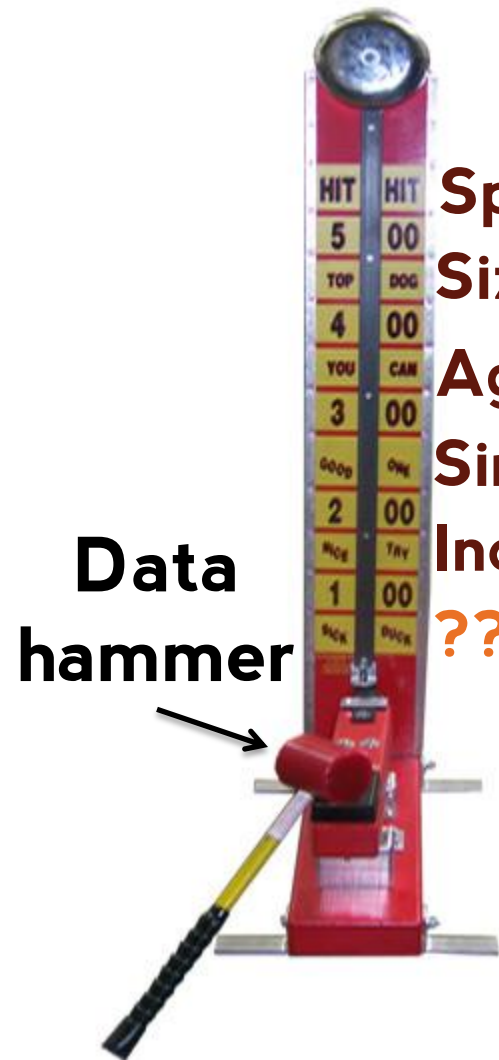- **Summarize the dids, dos, don'ts and developments**

Background

Applied stock assessment

Assessing fisheries stocks through time

Assessing stocks through time

Data hammer

Space/Seasons/Ecosystem included

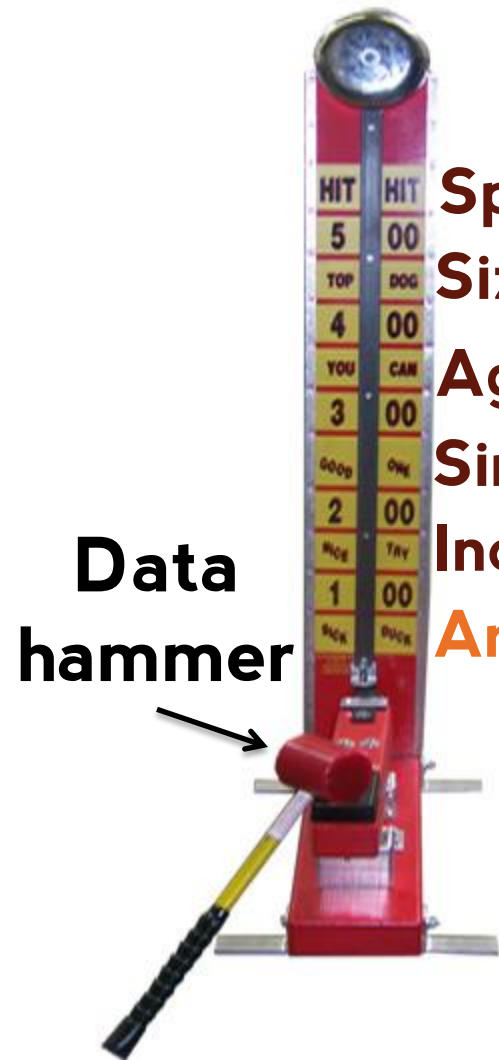Size/age/stage-structured models

Aggregated production models

Simple life history equilibrium models

Index only

????

U.S. National Assessment Levels (SAIP 2001)

Assessing stocks through time

Data hammer

Space/Seasons/Ecosystem included

Size/age/stage-structured models

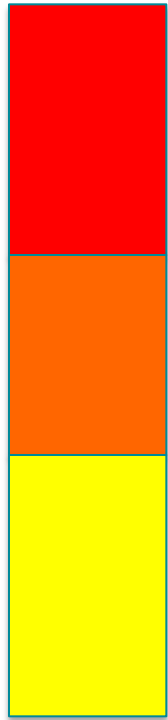Aggregated production models

Simple life history equilibrium models

Index only

Are these stocks "sick ducks"?

U.S. National Assessment Levels (SAIP 2001)

2007: Magnuson-Stevens Reauthorization

Overfishing Limit

Maximum amount that can be caught in a year _without resulting in overfishing_.

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Maximum amount that can be caught in a year without resulting in overfishing.

Acceptable Biological Catch

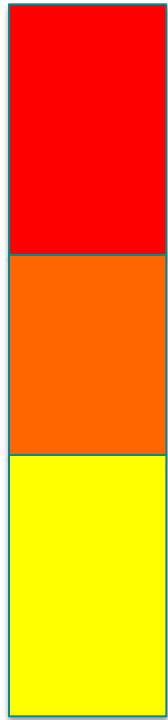**Incorporates scientific uncertainty. _Determined by scientists_ on regional technical committees.**

2007: Magnuson-Stevens Reauthorization

Overfishing Limit

Maximum amount that can be caught in a year without resulting in overfishing.

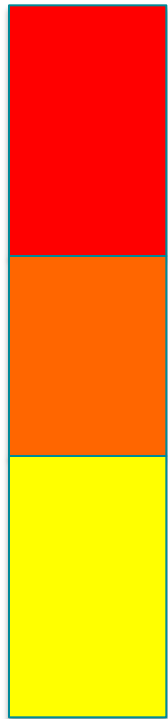**Acceptable Biological Catch**

Incorporates scientific uncertainty. Determined by scientists on regional technical committees.

Annual Catch Limit

The amount that can be caught in a given year, set by policymakers.
Can't exceed the ABC.

2007: Magnuson-Stevens Reauthorization

All stocks needed annual catch limits (ACLs)

- **Few exceptions**

- **ACLs required for stocks subject to overfishing by 2010.**

- **For stocks "in the fishery" by 2011.**

Stock assessments through time

Example: PFMC Groundfish FMP
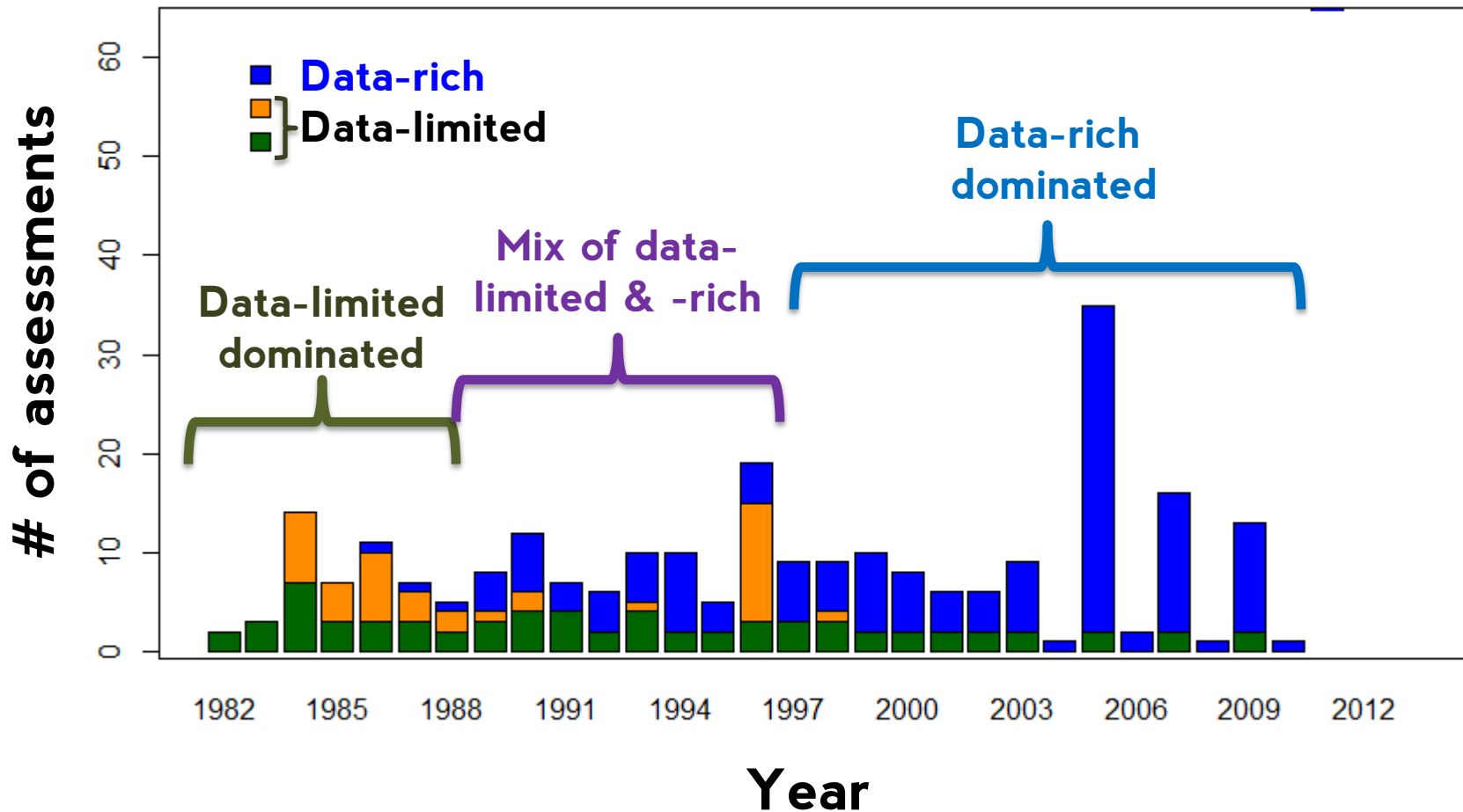
Stock assessments through time

Example: PFMC Groundfish FMP
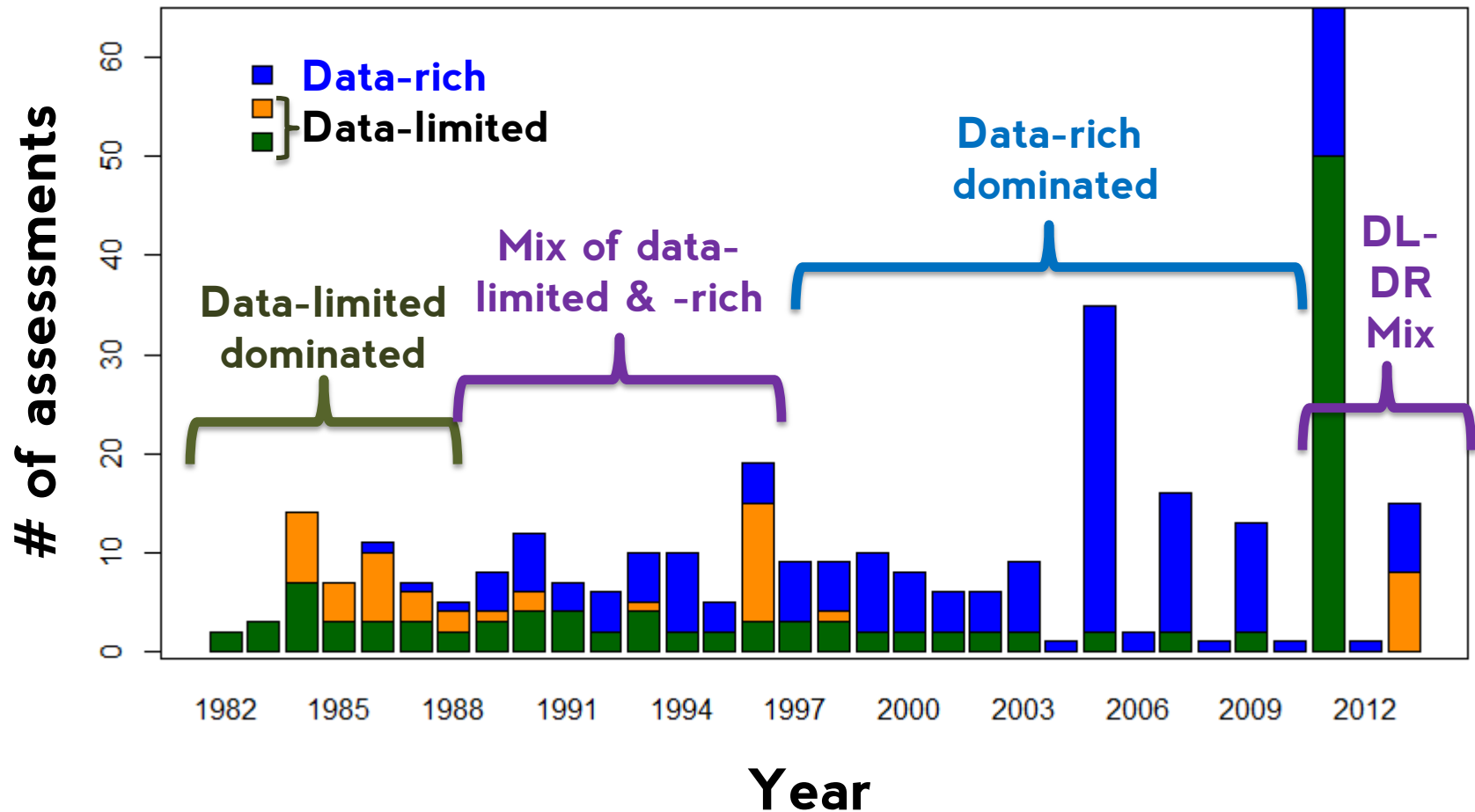
Why weren't these stocks previously assessed?

- Not valuable in a socioeconomic, human-centric way.

- No data or little data
  - Not target of fisheries or surveys
  - Not enough catch

- Not enough resources
  - Stock assessment scientists
  - Not enough time and money

- Ecological value slowly being incorporated

Definitions: What is "data-limited"?

Defining assessment approaches

Data hammer

Data-rich methods
- **Age/size structured**
- **Catch, biological compositions. Indices, etc.**

Data-moderate methods
- **Catch; Index or limited biological compositions**

Data-poor methods
- **Catch only; length comps; no catch; no length comps**

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One person's trash is another person's less smelly trash

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Fisheries in space: A Bayesian assessment of a commercially exploited fish stock on the Jupiter moon Europa.

Gavin Fay, Jason Cope ,Doug Kinzey ,Teresa A'mar and Melissa Haltuch

Marine Population Assessment & Management Group
School of Aquatic and Fishery Sciences
University of Washington

SUMMARY

The use of Bayesian statistical methods in quantitative fisheries stock assessment have become increasingly common in recent years. Such methods can provide a statistically rigorous means for including and accounting for uncertainty in the estimation of the status and size of fish populations (Punt & Hilborn, 1997). Recent findings indicating the presence of substantially sized oceans under the surface ice of Europa, one of the moons of the planet Jupiter, has led many scientists to suggest the possibility that extra-terrestrial aquatic life may exist. Given the biological knowledge and status of such aquatic populations is very low, it will be difficult for resource managers to assess the impact of fishing activities directed at the harvesting of these populations.

Using a Bayesian estimation approach to accommodate the significant uncertainties associated with extra-terrestrial fish populations, the impact of a trawl fishery on the population dynamics of a Europan fish stock are investigated. Informative prior distributions for key biological parameters are developed by integrating knowledge from Earthly fish populations with information on Europan year length; these are used to determine a posterior distribution for the maximum sustainable exploitation rate of this alien fish stock. Given a constant fishing mortality control rule, the length of exploitation resulting in overfishing of the stock is also assessed.

Keywords: Space, Fisheries Stock Assessment, Uncertainty, Data-Absent.

METHODS

A Bayesian estimation procedure was applied to the available data on the Europan fish stock, in order to obtain a posterior probability distribution for the Maximum Sustainable Fishing Mortality rate F_{MSY}, defined as:

$$F_{MSY} = \frac{MSY}{B_{MSY}} \qquad (1.1)$$

where MSY is the maximum sustainable yield, and B_{MSY} is the biomass at MSY.

For the Schaefer type surplus production model:

$$MSY = \frac{rK}{4} \quad \& \quad B_{MSY} = \frac{K}{2} \qquad (1.2)$$

giving:

$$F_{MSY} = \frac{r}{2} \qquad (1.3)$$

Where r is the intrinsic rate of population growth, and K is the pre-exploitation carrying capacity.

Bayesian methods require that prior probability distributions be placed on all the parameters of the model (Goodman (1984), and Myers et al. (1997) relate the intrinsic rate of population growth, r, to two parameters: α, the age at maturity, α, and the adult survival rate, p_s. Given these three parameters, the value for r can be evaluated by finding the solution to the equation:

$$(e^r)^\alpha - p_s (e^r)^{\alpha-1} - \alpha = 0 \qquad (1.4)$$

A distribution for r was evaluated using equation (1.4) by selecting appropriate values for the three demographic parameters. Prior probability distributions for these parameters were obtained by incorporating information from Earthly fish stocks.

Prior distributions

Myers et al. (1999) show that the maximum reproductive rate, that is the number of replacement spawners per spawner per year is relatively constant among Earthly fish species, with values ranging from between 1 and 7. The distribution of these rates is approximately uniform in log-space over this range.

$$1 \text{ Europan year} = 1220.25 \text{ Europan days} \qquad (1.5)$$

However,

$$1 \text{ Earth year} = 365.25 \text{ Earth days} \qquad (1.6)$$

Europan fish then have

$$\frac{1220.24}{365.25} = 3.34 \qquad (1.7)$$

times the number of days of growing time available to them during a year compared to Earthly fish populations.

So, for highly reproductive Europan fish:

$$\alpha = 3.34 \times 7 = 23.39 \qquad (1.8)$$

Therefore, the prior probability distribution used for the maximum reproductive rate of alien fish stock is

$$\alpha \sim \text{Uniform}[0, \ln(23.39)] \qquad (1.9)$$

Age at maturity for commercially exploited earthly fish species varies widely, from about 1 - 2 years (DeMartini, 1969) to about 85 years for some species of shark (Saunders & McFarlane, 1993). These bounds were used to develop a prior for age at maturity of Europan fish:

$$\alpha_{max} = 85 \text{ Earth years} = 350.34 = 1048 \text{ Europan years} \qquad (1.10)$$

Therefore

$$\alpha \sim \text{Uniform}[0, 11]$$

Annual survival rates of adult Europan fish are unknown. Earthly species exhibit wide-ranging values for this parameter which can depend on a large number of factors. However, the fractional nature of this parameter enables a simple uniform prior distribution to encompass all possible values.

$$p_s \sim \text{Uniform}[0, 1] \qquad (1.11)$$

Parameter Estimation

Bayes theorem states:

$$\pi(\theta)d\theta = \frac{L(D \mid \theta) p(\theta) d\theta}{\int L(D \mid \theta) p(\theta) d\theta} \qquad (1.12)$$

where $\pi(\theta)$ is the posterior probability of the vector θ given the data,
$L(D \mid \theta)$ is the likelihood of the data given vector θ, and
$p(\theta)$ is the prior probability of the vector θ.

The SIR (sampling-importance-resampling) algorithm (Gelman et al. 1995 ,Punt and Hilborn, 1997), was used to numerically approximate the posterior distribution of F_{MSY} by drawing a large number (100000) of vectors of parameter values from the priors, evaluating the likelihood of the available data given each parameter vector, and then re-sampling with replacement (n=1000) from these parameter vectors with probability proportional to likelihood, and equal to the importance weight for that vector.

Given the current data for the Europan fish stock,

$$L(D \mid \theta_j) = L(D \mid \theta_j) \text{ for all } \theta_j \text{ and } \theta_j \qquad (1.13)$$

Therefore, the importance weight w_j for a given parameter vector θ_j is defined so be:

$$w_j = w_j \text{ for all } i \text{ and } j \qquad (1.14)$$

Evaluation of time to over-fishing

US fishery resources are declared to be overfished if the stock is assessed o be below 25% of its pre-exploitation biomass (PFMC, 2003). Given the distribution for the intrinsic rate of population growth described above, a constant fishing mortality rate control rule was evaluated in terms of the probability distribution of the time required to deplete the Europan fish stock to 25% of the carrying capacity.

The population dynamics of the Europan fish stock were modelled using the discrete form of the Schaefer model:

$$\left(\frac{N}{K}\right)_{t+1} = \left(\frac{N}{K}\right)_t \left\{ 1 + r \left[1 - \left(\frac{N}{K}\right)_t \right] - F \right\} \qquad (1.15)$$

where $\left(\frac{N}{K}\right)_t$ is the population depletion with respect to carrying capacity at time t, and F is the exploitation rate.

Assuming no previous alien exploitation of the resource,

$$\left(\frac{N}{K}\right)_{t=1} = 1 \qquad (1.16)$$

Values for the intrinsic rate of population growth rate r were sampled from the distribution constructed previously using equation (1.4). Values for the exploitation rate F were sampled according to the distribution:
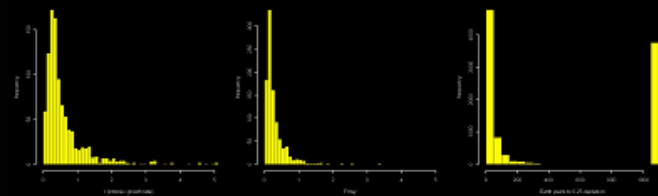
$$F \sim \text{Uniform}[0, 1] \qquad (1.17)$$

Given these values for r and F, the model 4 equation (1.15) was run until the depletion was less than 0.25, and the time t taken to reach this depletion level recorded.

DISCUSSION OF RESULTS

Panels a) and b) of Figure 1 show the posterior distributions for the intrinsic rate of population growth r and F_{MSY}. The median value for r was 0.387 ,with the central 95% probability interval ranging from 0.060 to 4.74. While the majority of the posterior probability density for r centres values comparable to those for exploited Earthly species, there exists a small probability that the intrinsic growth rate of the Europan fish population is very high. Similarly ,the median for F_{MSY} was 0.19 .However, this is the exploitation rate over a Europan year, meaning that the required exploitation rate per Earth year would be much lower.

Panel c) of Figure 1 shows the distribution of time (in Earth years) to the depletion of the resource to 25% of its current level, given a constant exploitation rate. The median time to this level of depletion was 5 Europan years ,or 39 Earth years. Given the uncertainty associated with the estimation of F_{MSY}, there exists almost equal probabilities that the Europan stock will either be considered "overfished" shortly following the onset of the fishery, or that the population cannot ever be depleted to this level.

Posterior distributions for (a) Intrinsic rate of growth (r), (b) maximum sustainable exploitation rate (F_MSY) and (c) time to depletion to 25% of current biomass (bar on far right indicates simulations not depleted to 0.25 in 1000 earth years).
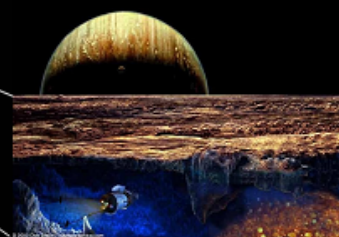
Biprobot trawl fishery under Europan ice sheet (Artist's rendition)

REFERENCES

DeMartini, E.E. ,1969 .A correlative study of the ecology and comparative feeding mechanism morphology of the Embiotocidae (surf-fishes) as evidence of the family's adaptive radiation into available ecological niches. The Washington Journal of Biology 27(2):177-247.

Gelman, A., Carlin, B.P. Stern, H.S. and Rubin, D.B. 1995. Bayesian Data Analysis. Chapman and Hall:London.

Goodman, D.1984. Statistics of reproductive rate estimates, and their applications for population projection. Rep.Int. Whaling Comm. Spec. Issue 6:161-173.

Myers, R.A., K.G.Rowan, and N.J.Barrowman .1999 .Maximum reproductive rate of fish at low population sizes. Can. J.Fish. Aquat. Sci. 56:2404-2419.

Myers, R.A., G. Mertz, and P.S. Fowlow .1997. Maximum population growth rates and recovery times for Atlantic cod, Gadus morhua. Fishery Bulletin 95:762-772.

Pacific Fishery Management Council. Pacific Coast Groundfish Fishery Management Plan for the California, Oregon, and Washington Groundfish Fishery as Amended Through Amendment 16, October2003, 115pp.

Punt, A.E. and Hilborn, R. ,1997. Fisheries stock assessment and decision analysis: the Bayesian approach. Reviews in Fish Biology and Fisheries 7:35-63.

Saunders, M.W., and G.A. McFarlane 1993. Age and length at maturity of the female spiny dogfish, Squalus acanthias, in the Strait of Georgia, British Columbia, Canada. Environmental Biology of Fishes 38:49-57,1993.

Defining assessment approaches

Data hammer

Data-rich methods
- **Age/size structured**
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Data-moderate methods
- **Catch; Index and/or limited biological compositions**

Data-poor methods
- **Catch only; length comps; no catch; no length comps**

Data-limited methods
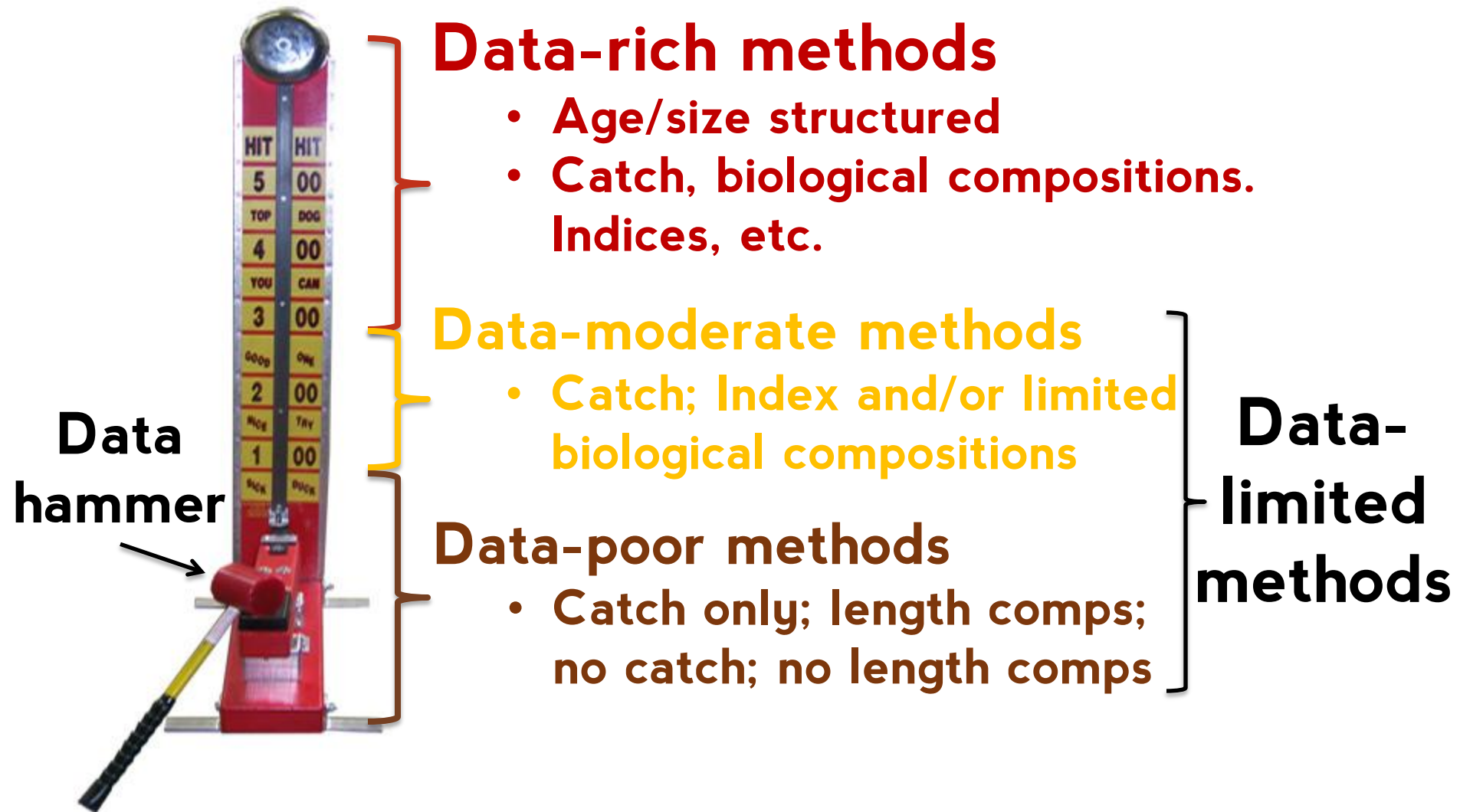
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More Definitions: Stock complex

Image: David Malan

- **A species grouping for management purposes**
  - **May or may not be based on ecological or fisheries interactions**
- **Managed as a conglomerate "stock"**
- **Stock complex catch levels calculated**
  - **Over all stocks combined**
  - **Additive over individual stocks**

Nationally: 504 catch limits

Method	Number of catch limits based on method	Percentage of catch limits based on method
Data-rich	150	30%
Data-moderate	59	11%
Data-poor	295	59%

from Newman, Berkson, and Suatoni. 2014. Fisheries Research. *In Press.*

Method distribution varies greatly by region

	NEFMC	MAFMC	SAFMC	GMFMC	CFMC	HMS	PFMC	NPFMC	WPFMC
Data-Rich	28	8	14	9	0	3	46	38	4
Data-Mod	1	1	0	0	0	0	8	48	1
Data-poor	2	1	47	25	23	37	106	13	41

from Newman, Berkson, and Suatoni. 2014. Fisheries Research. *In Press.*

Innovations of data-limited methods

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Started with:

Data-poor control rule
- Restrepo et al. (1998)

Windfall ratios
- Alverson and Pereyra (1969)
- Gulland (1970)

Stock reduction analysis
- Kimura and Tagart (1982)
- Walters et al. (2006)

Started with:

Data-poor control rule
- **Restrepo et al. (1998)**

Windfall ratios
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Turned into:

Scalar approaches
- **Berkson et al. (2011)**

DCAC
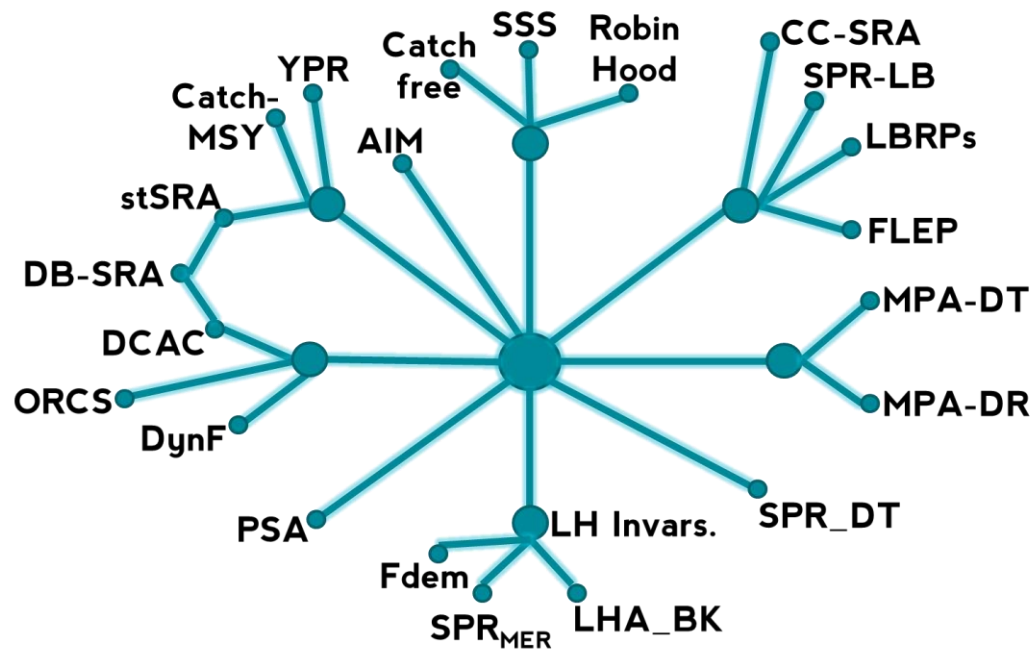- **MacCall (2009)**

DB-SRA
- **Dick and MacCall (2011)**

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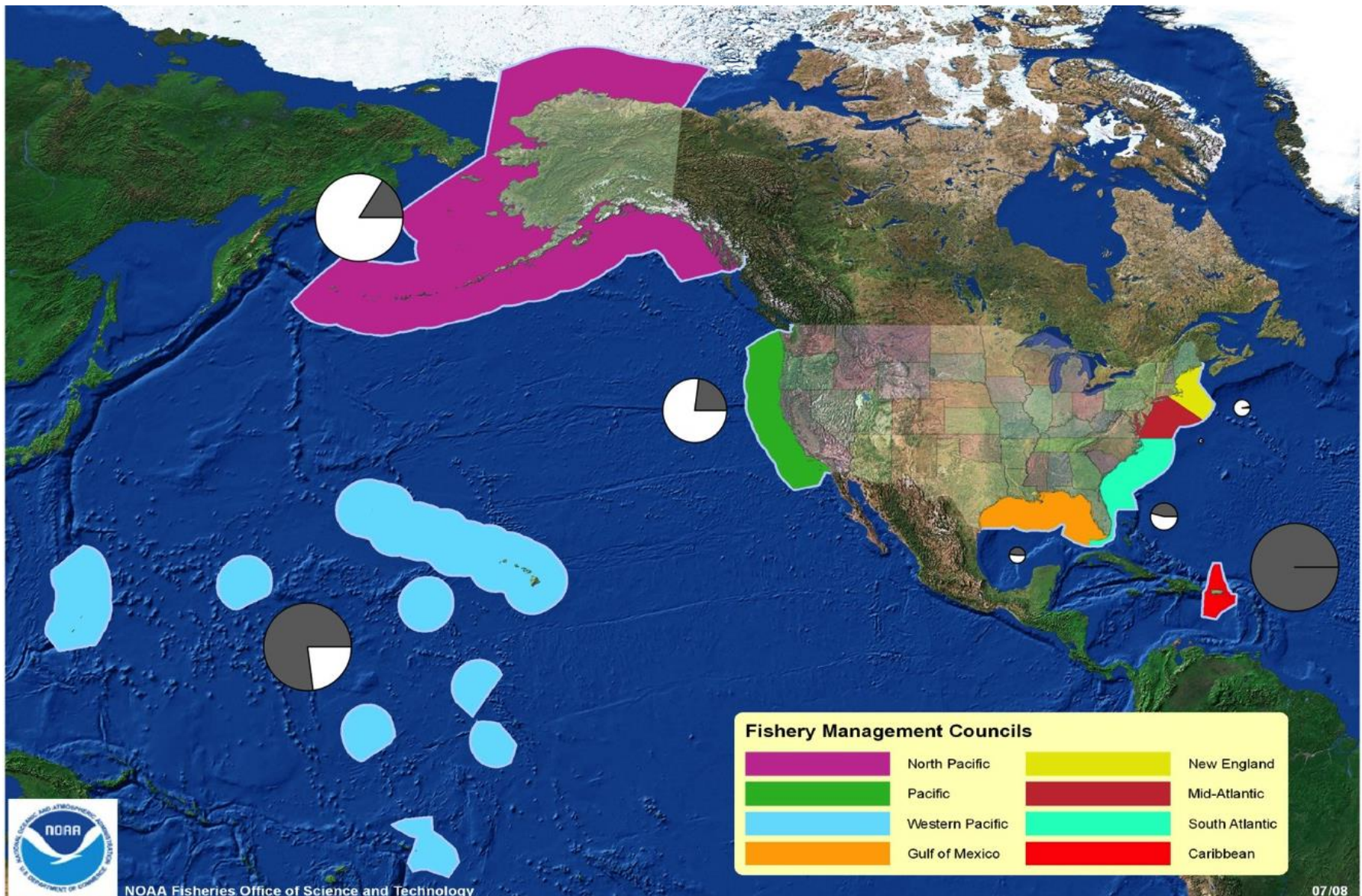
from Berkson and Thorson. 2014. ICES Journal of Marine Science

Innovation of data-limited approaches
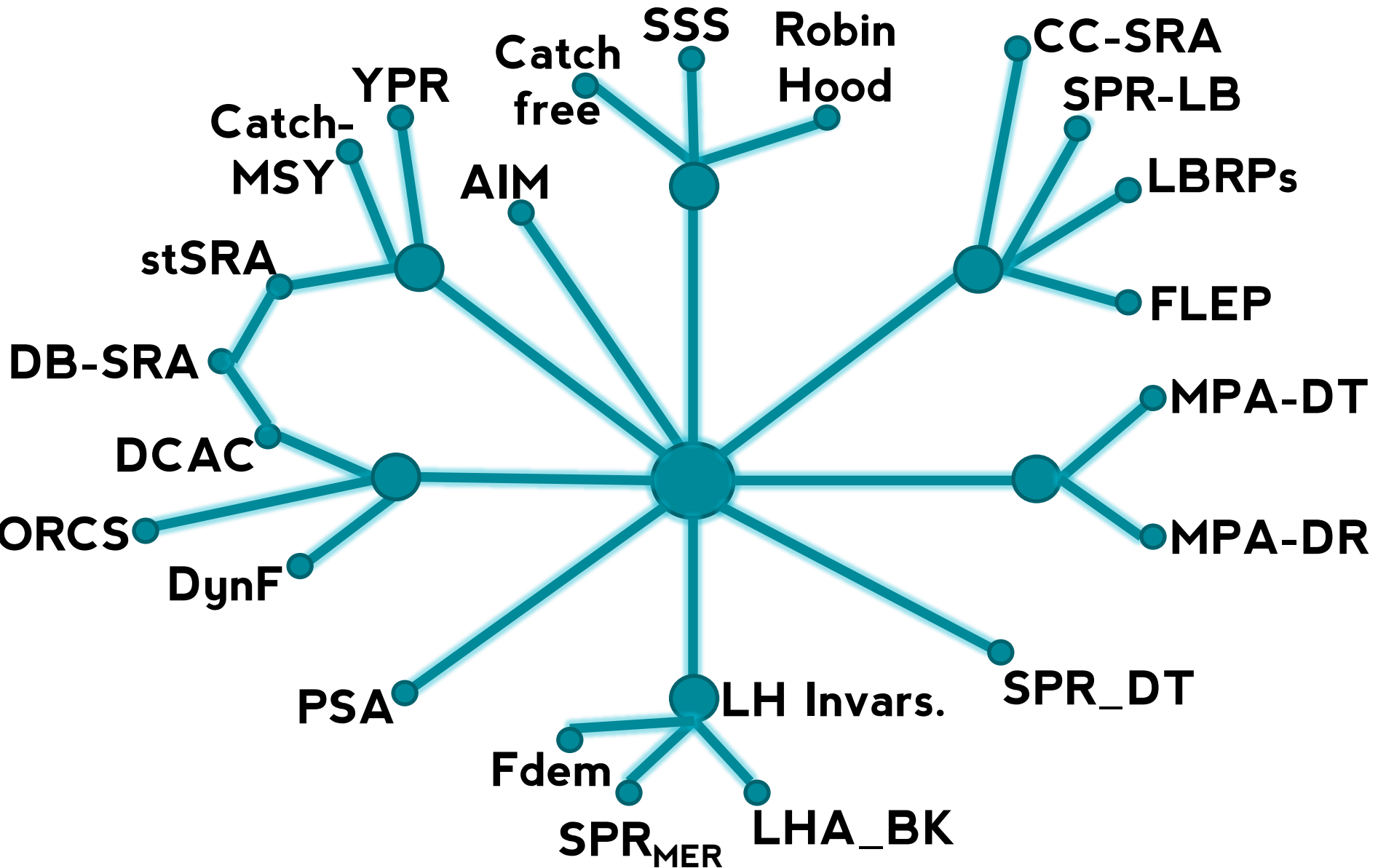
Grouping data-limited approaches

- Input/Data types

- Static vs dynamic

- Baseline vs non-baseline

- F vs catch (management units)

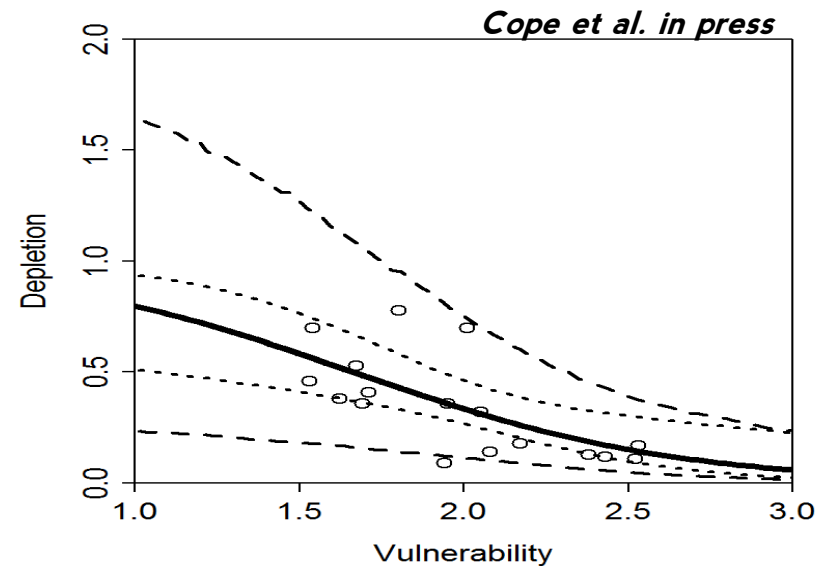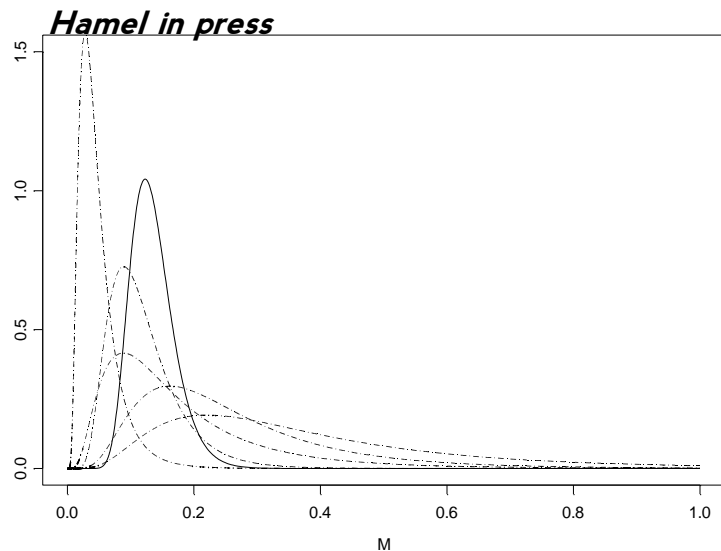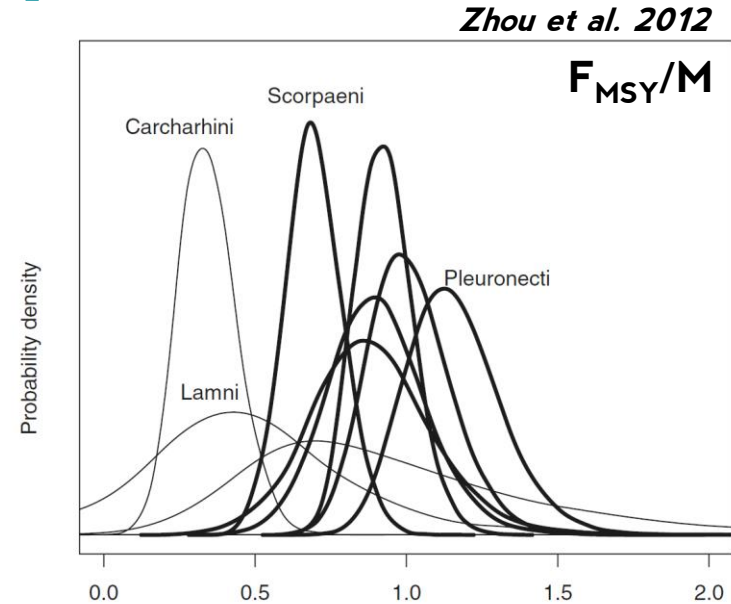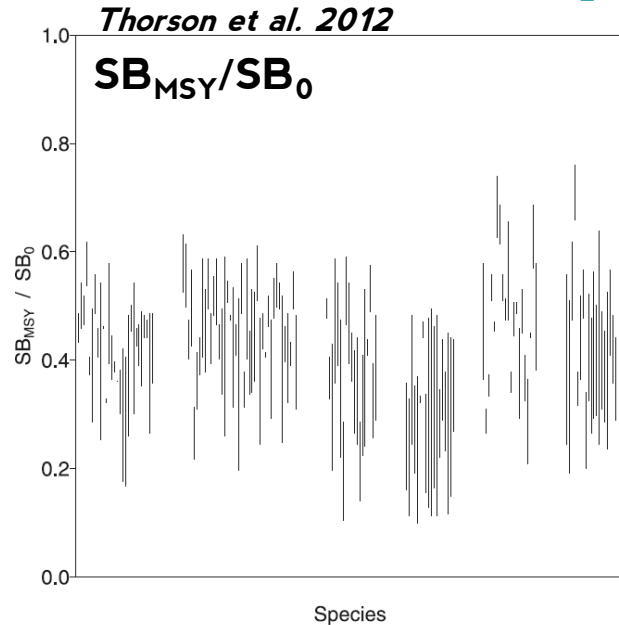Organizing may help the how and why methods are used ("Implementation")
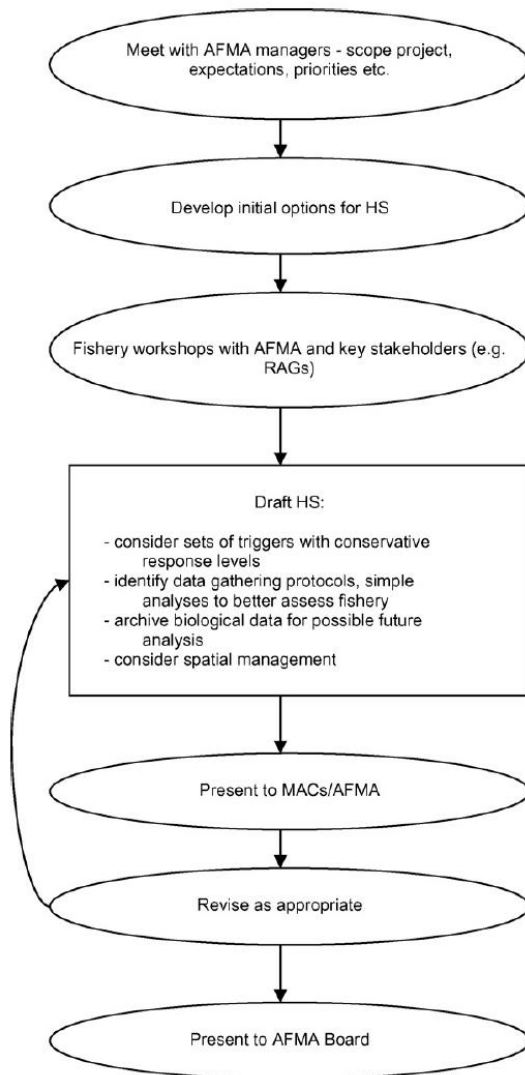
Post-innovation stages

During/after innovation, there is:

- **Improvement**
  - **Input parameters**
  - **Harvest control rules (including uncertainty estimation)**
- **Evaluation**
  - **Simulation testing**
  - **Management Strategy Evaluation**
- **Implementation**
  - **Toolboxes**
  - **Application planning**
- **Standardization**

Improvements: inputs parameters

Thorson et al. 2012

SB_{MSY}/SB_0

Zhou et al. 2012

F_{MSY}/M

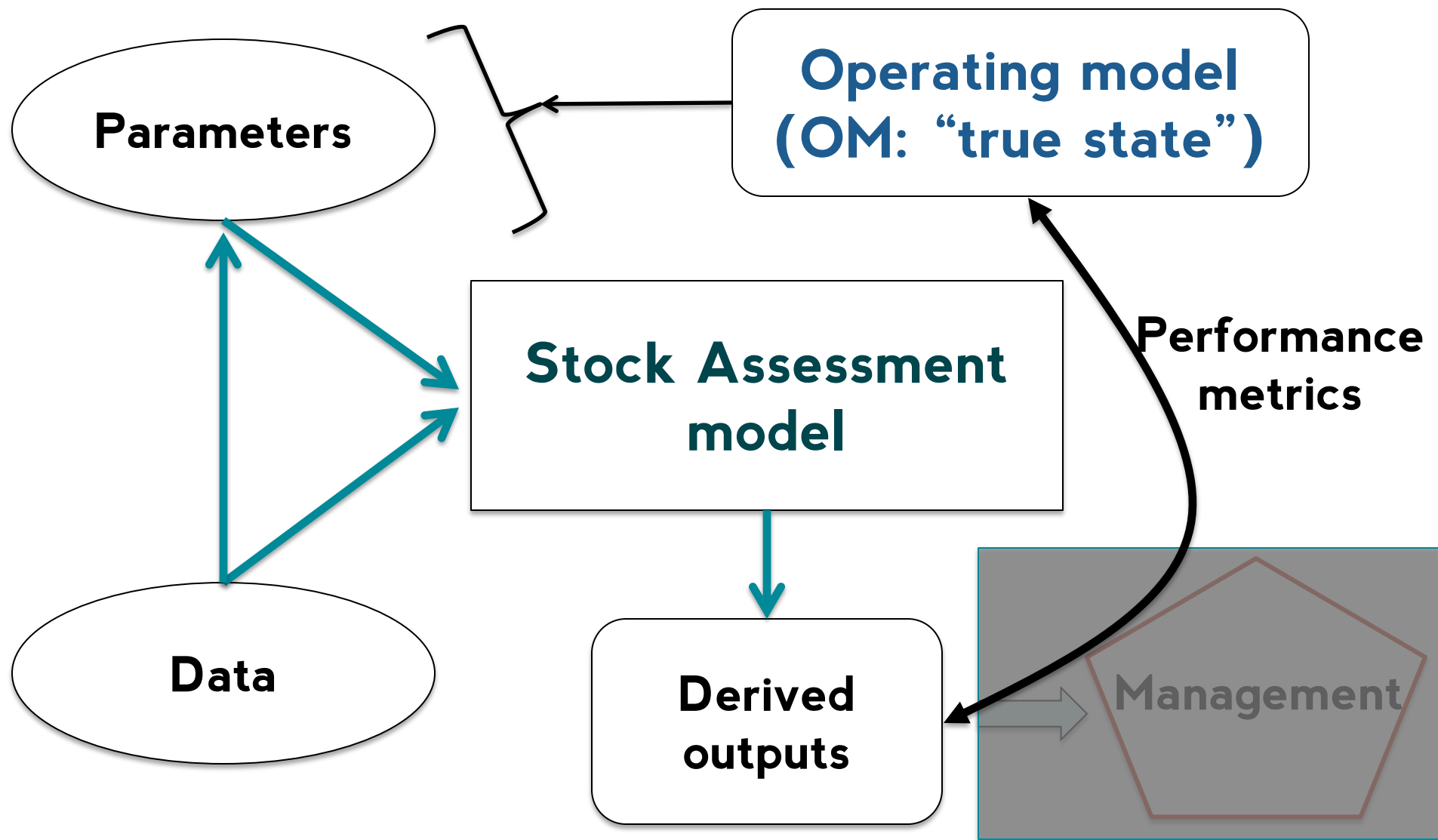*Hamel in press*

Cope et al. in press

Improvements: Harvest control rules (HCRs)
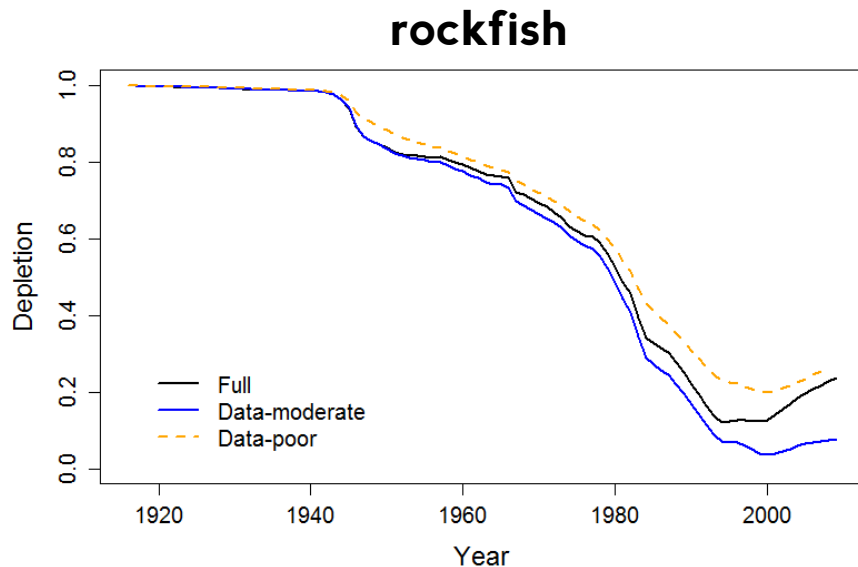

Dowling et al. 2008

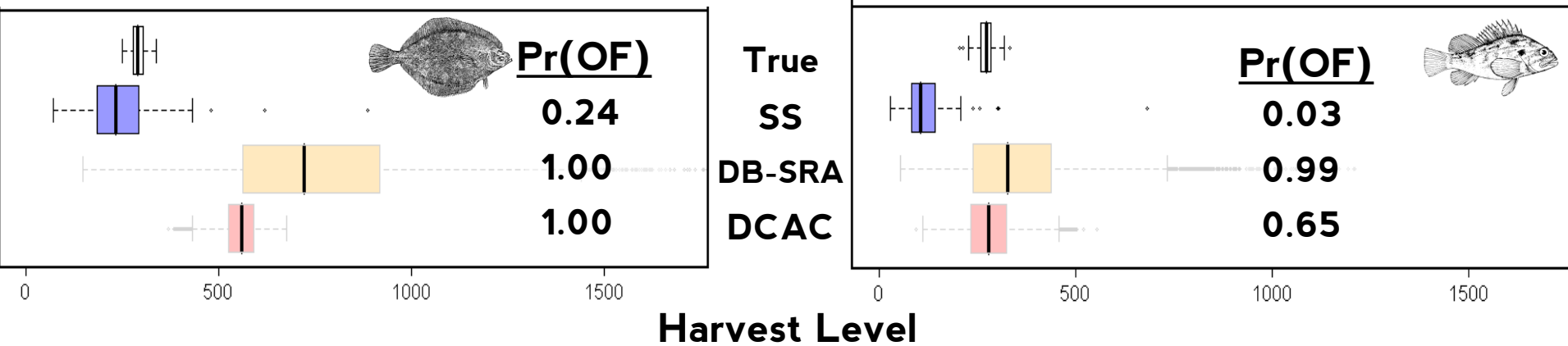- **Decision rule that modifies catch**

- **Uses references points**

- **Incorporates uncertainty**

- **Oft needed connection between D-L method and management**

- **May improve poorly performing D-L method**

Evaluation: Simulation testing

Parameters

Operating model (OM: "true state")

Stock Assessment model

Performance metrics

Data

Derived outputs

Management

Testing methods: Comparison tests

	Pr(OF)		Pr(OF)
True			
SS	0.24		0.03
DB-SRA	1.00		0.99
DCAC	1.00		0.65

Harvest Level

rockfish

- Full
- Data-moderate
- Data-poor

Depletion / Year
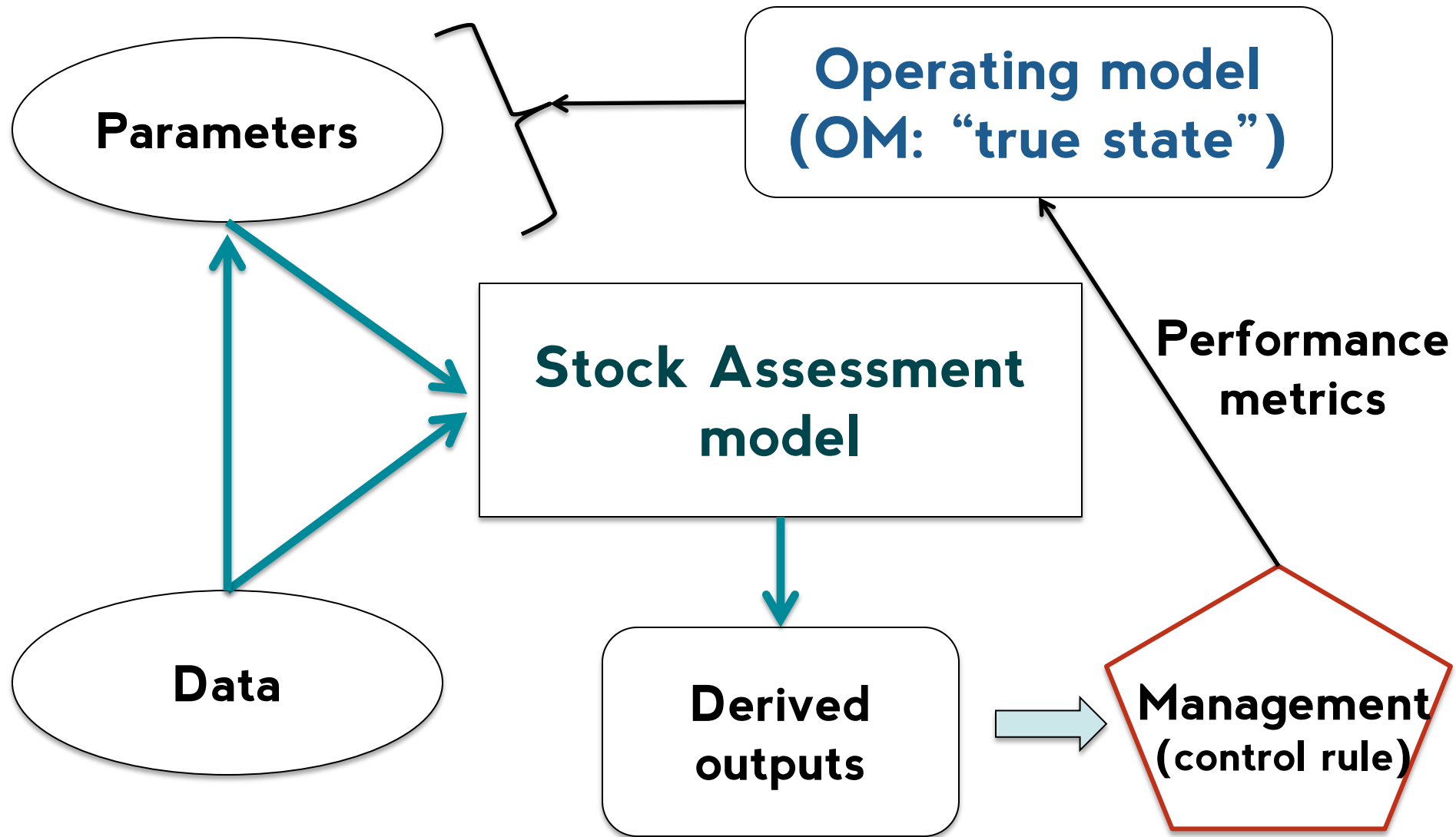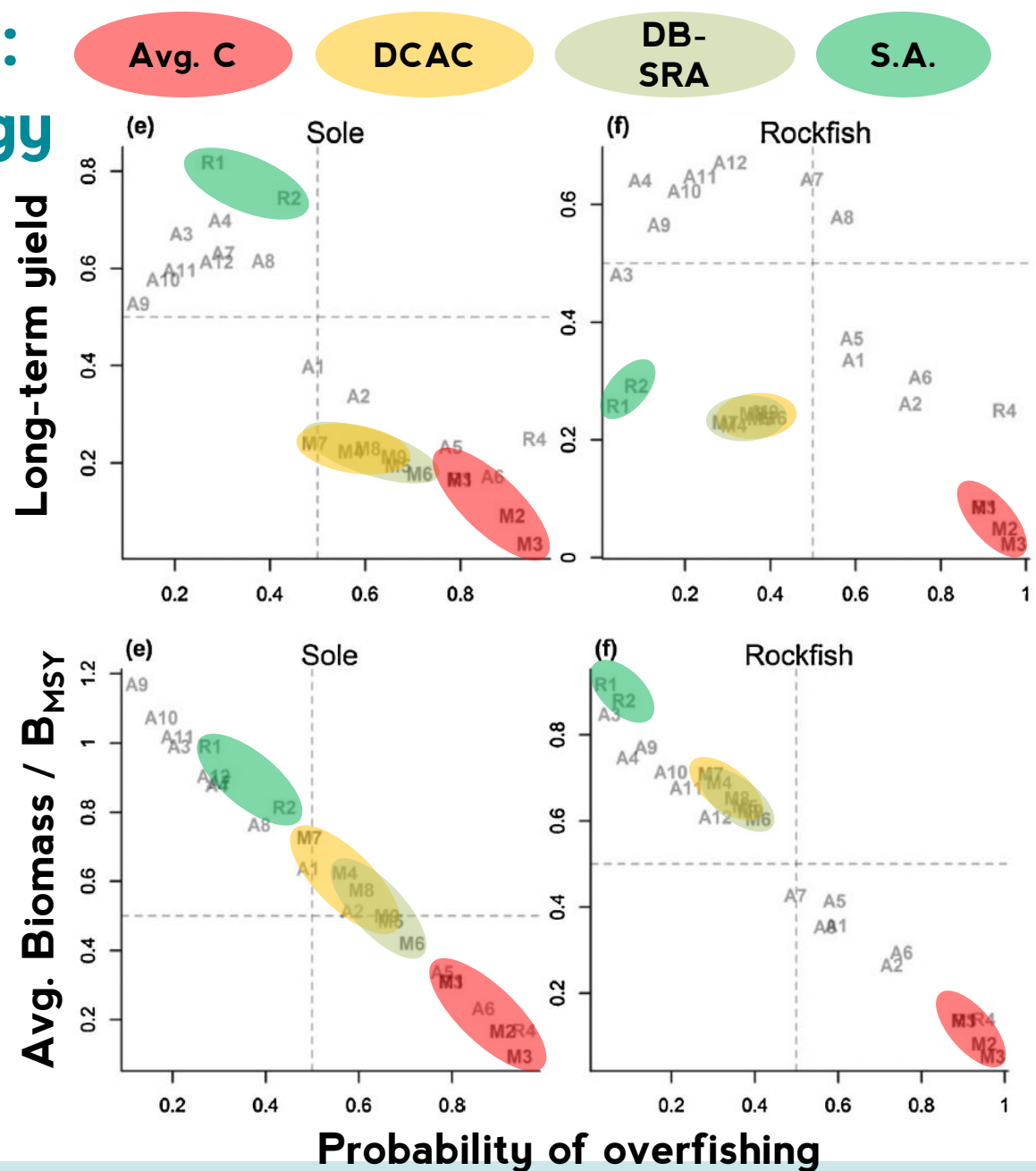
Cope et al. in press

- **Performance relative to OM or benchmark assessment**

- **Focuses on method performance**

Evaluation: Management strategy evaluation

Testing methods:
Management strategy evaluation

- **Performance relative to OM**

- **Focuses on method AND control rule performance**

Implementation

- ## DLMtool (R; T. Carruthers) toolkit
  - http://cran.r-project.org/web/packages/DLMtool/index.html
  - Choose models given data
  - MSE mode
- ## Science for Nature and People (SNAP)
  - D-L group http://www.snap.is/groups/data-limited-fisheries/
  - Application-based
  - Resource evaluation
- ## Using multiple models
- ## Not everyone is an innovator

Standardization?

NORTH PACIFIC
F_{ratio}
PIGGYBACK ON ASSESSED STOCK
PREDATION MODEL
CATCH SCALAR
ZERO LANDINGS

NEW ENGLAND
CATCH + SURVEY BIOMASS
CATCH SCALAR
PERCENT OF ASSESSED STOCK

MID-ATLANTIC
CATCH + SURVEY BIOMASS
CATCH SCALAR

PACIFIC
F_{ratio}
PIGGYBACK ON ASSESSED STOCK
XDB-SRA
exSSS
CATCH SCALAR
ZERO LANDINGS
DB-SRA
DCAC
ZERO CONTRIBUTION

CONSOLIDATED ATLANTIC HMS
CATCH SCALAR
ZERO LANDINGS
ZERO CONTRIBUTION

WESTERN PACIFIC
BIOMASS-AUGMENTED CATCH MSY
PIGGYBACK ON ASSESSED STOCK
CATCH SCALAR
ZERO LANDINGS
PERCENT OF INDICATOR STOCK HABITAT

GULF OF MEXICO
CATCH SCALAR
ZERO LANDINGS

SOUTH ATLANTIC
CATCH SCALAR
ZERO LANDINGS

CARIBBEAN
CATCH SCALAR
ZERO LANDINGS

DATA-LIMITED METHODS BY REGION:
Blue = Data-Moderate
Red = Data-Poor

Newman et al. 2014

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Why don't we have standardization?

- **Regional Councils have a history of doing things their own way.**

- **The data, stocks, and fisheries are unique by region.**

- **We're still in the innovation stage.**

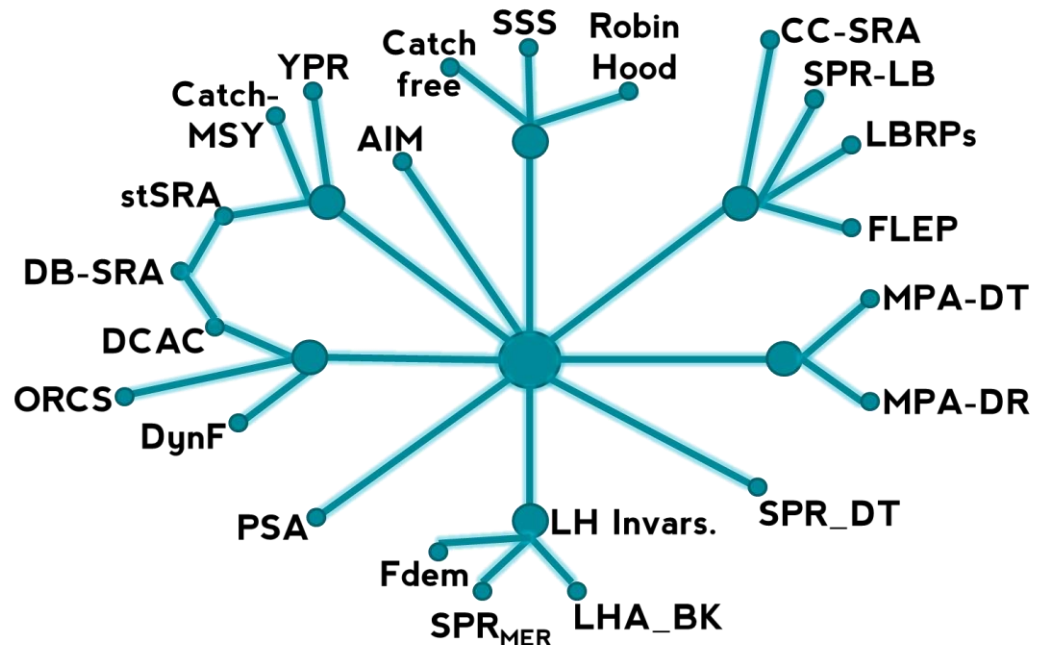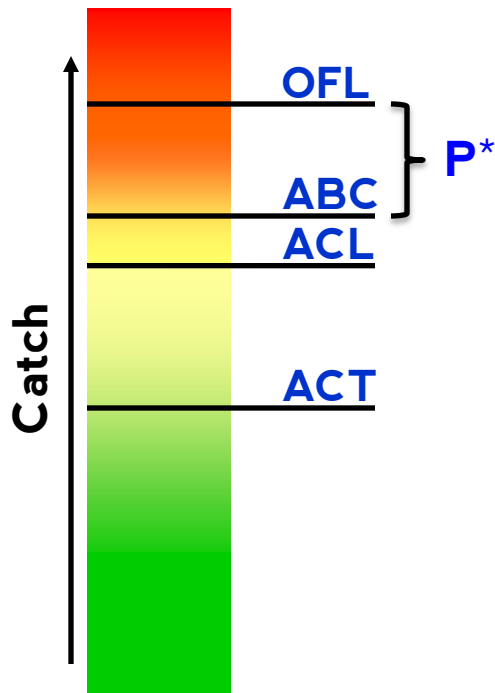# Summary/Considerations: the dids, dos, don'ts, and developments

Summary – Context

- **Era of rigid mandates**
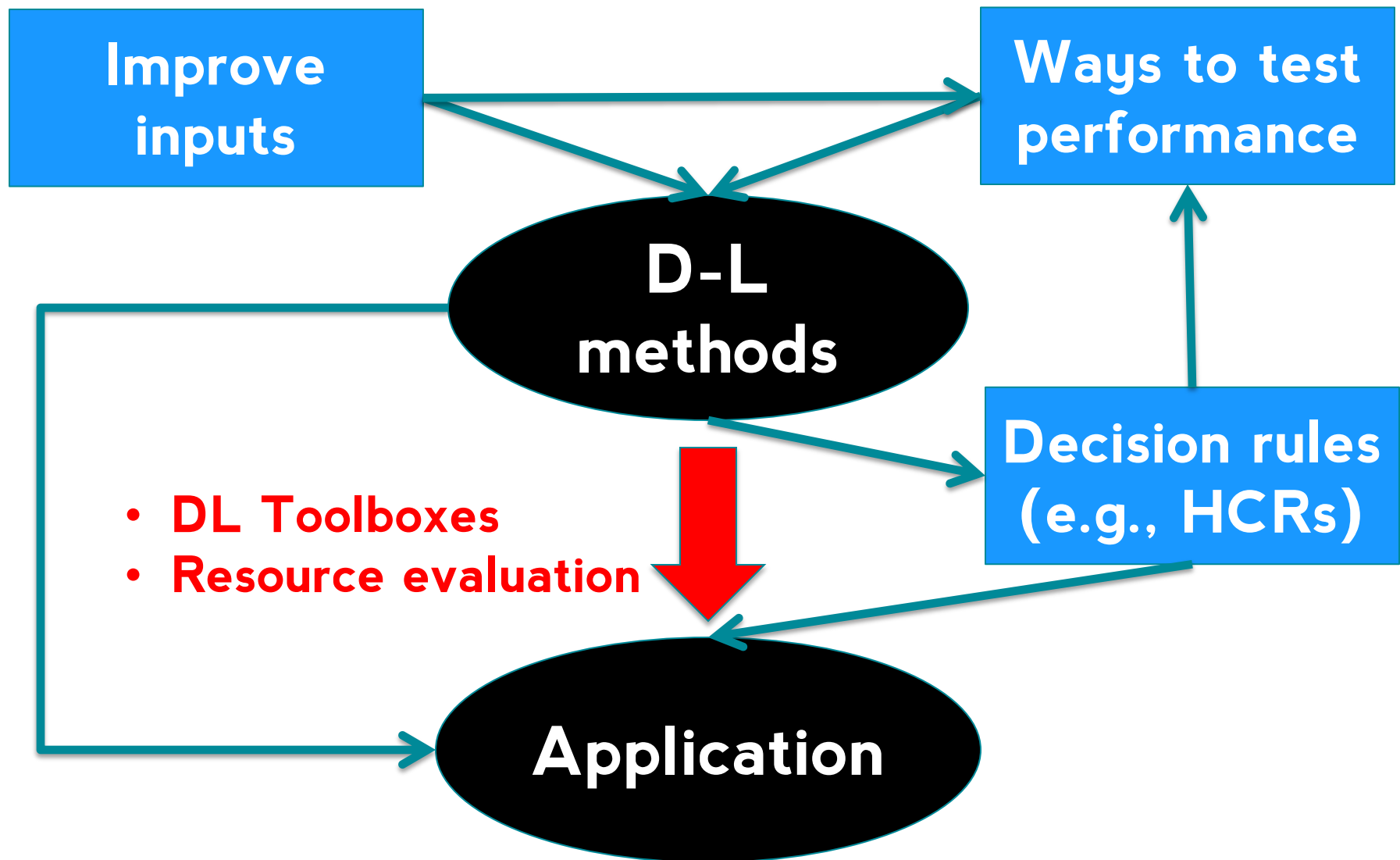
- **Era of limited resources**

What _did_ we do?

- ## Created a lot of acronyms

- ## Held a lot of workshops

Summary: Developments

Improve inputs

Ways to test performance

D-L methods

Decision rules (e.g., HCRs)

- DL Toolboxes
- Resource evaluation

Application

Suggestion

- Do's
    - Consider multiple methods
    - Be creative/continue innovation
    - Simulation/MSE testing
    - Compare to benchmark assessments
    - Seek best practices
    - Common framework approach

- Don'ts
    - Avoid "Shotgun" approach
    - Pseudo-replication
    - Beware stock complexes

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End with two questions

- **Will the need to conduct stock assessments on data-limited stocks go away?**

- **For the students attending: Are you spending 59% of your time in relevant courses learning about these methods?**

Questions