"Improving models of Pacific salmonids: drawing upon experience from non-salmonid systems"

Randall M. Peterman

School of Resource and
Environmental Management (REM),
Faculty of Environment,
Simon Fraser University,
Burnaby, British Columbia, Canada

NPAFC Symposium, "International Symposium on Pacific Salmon and Steelhead Production in a Changing Climate: Past, Present, and Future",
Kobe, Japan, 17-19 May 2015

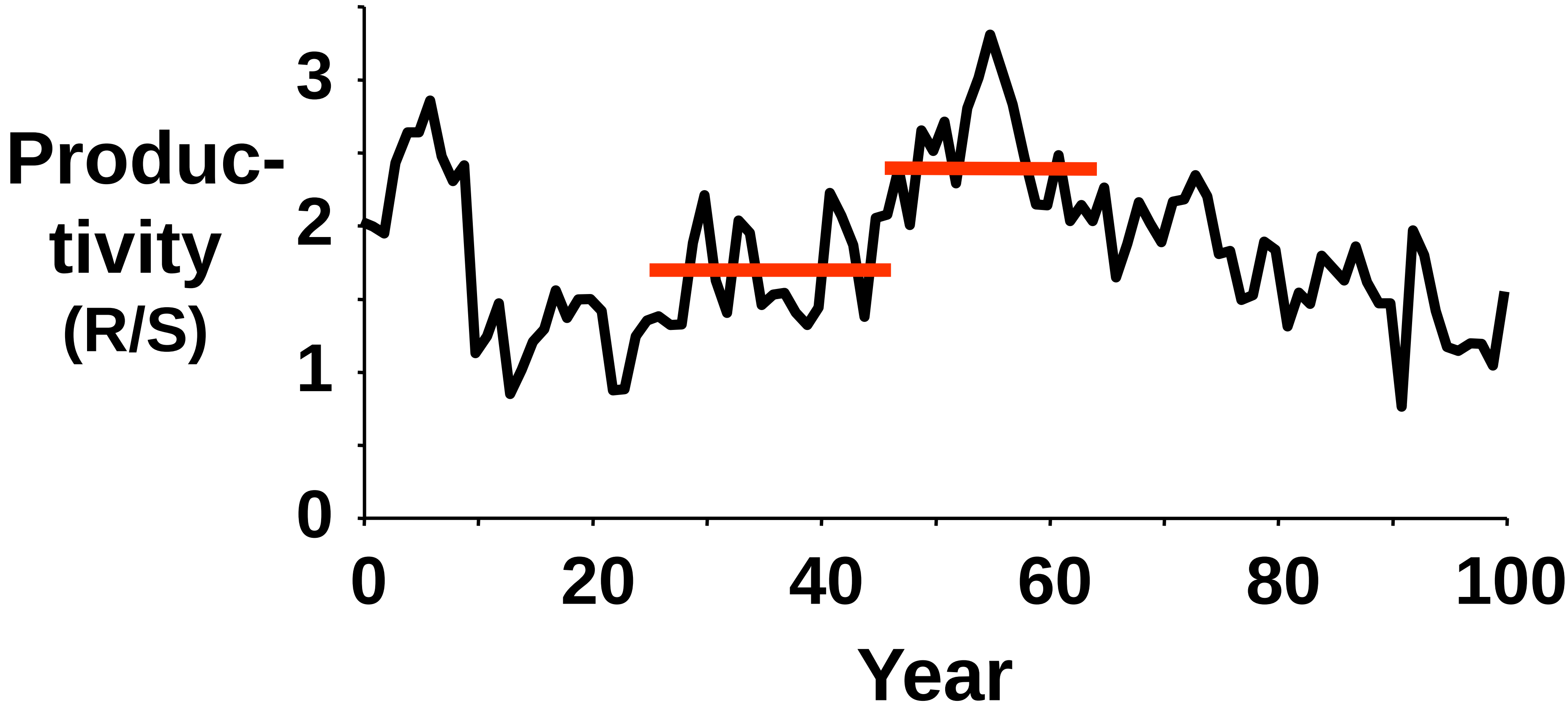
Outline

- **Importance of changing productivity of salmon**

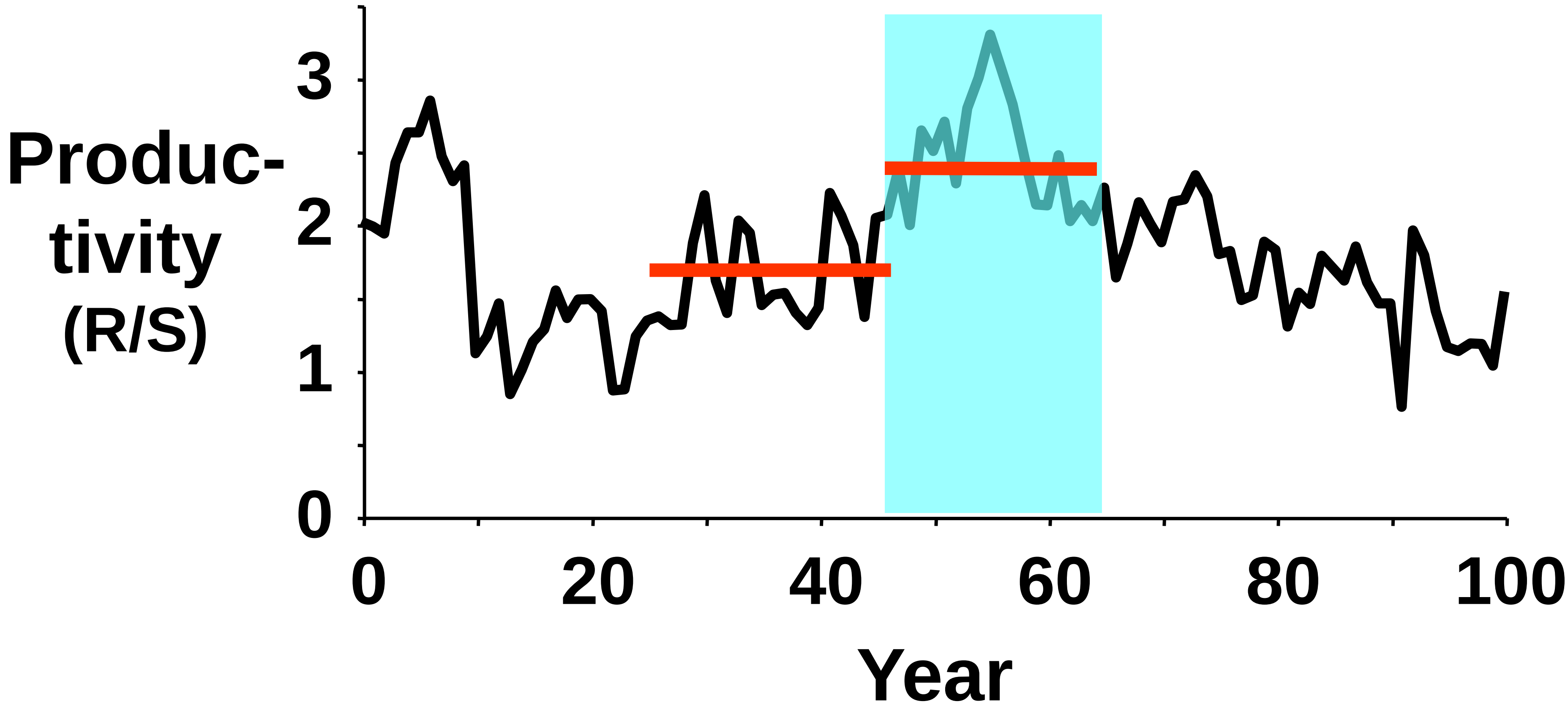
- **How quantitative models can help**

- **Features of advanced models**

Climate-driven non-stationarity



Climate-driven non-stationarity



Given changing productivity, how do we choose

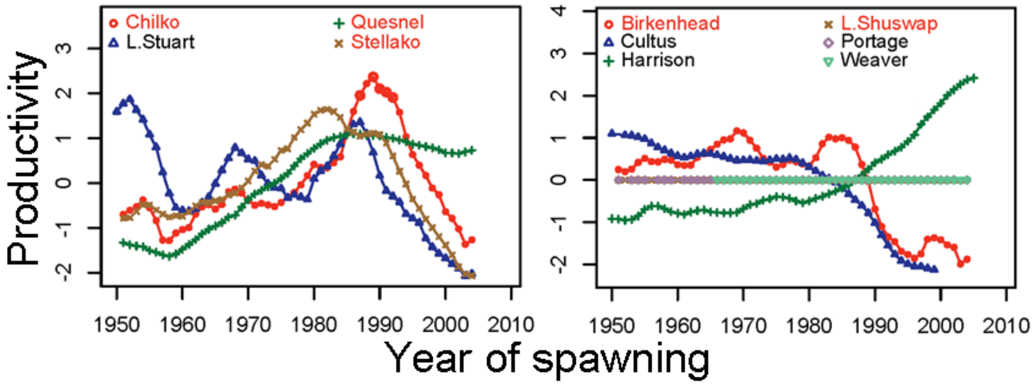
- Fishing regulations?

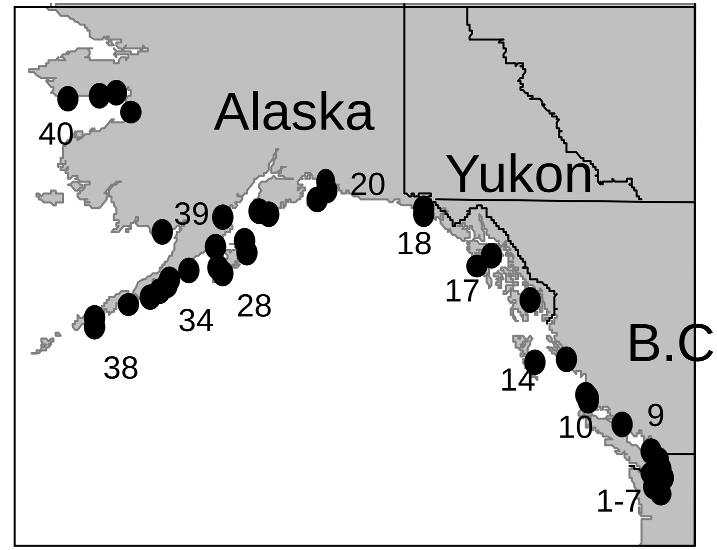
- Hatchery release strategies?

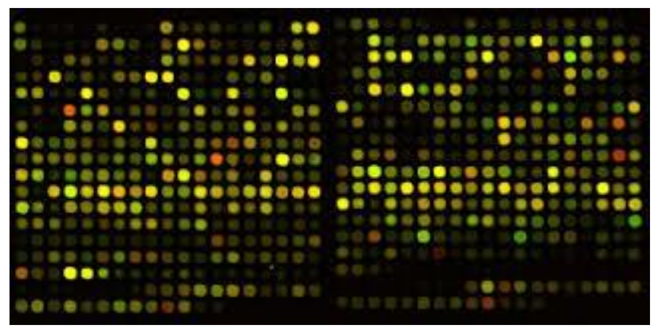
- Habitat protection activities?

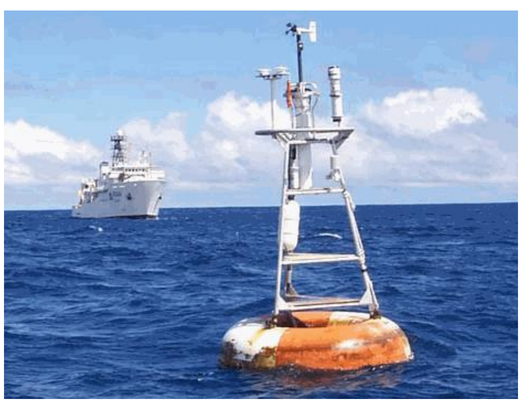
Answers: from data and models

Salmon and related data

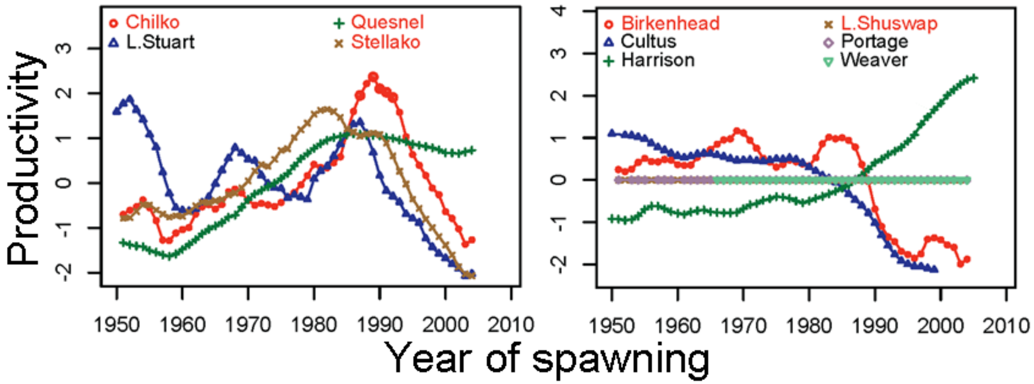


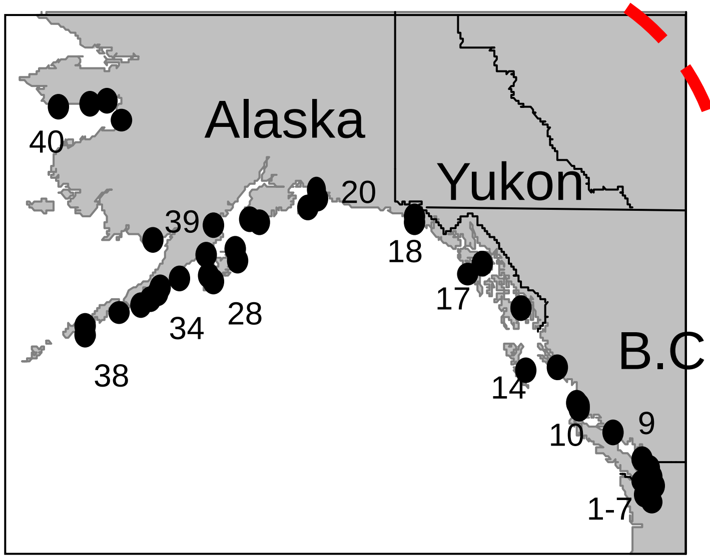


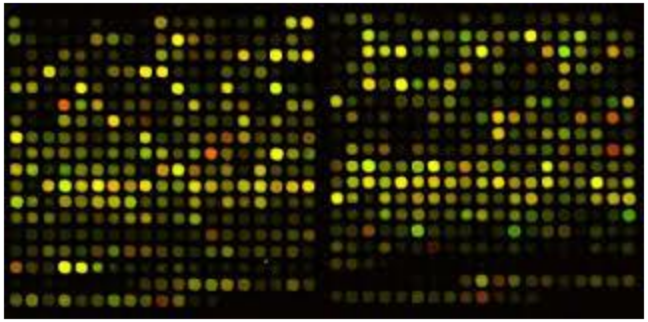


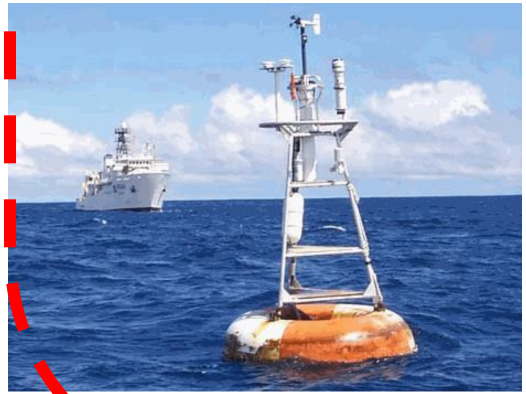


Salmon and related data

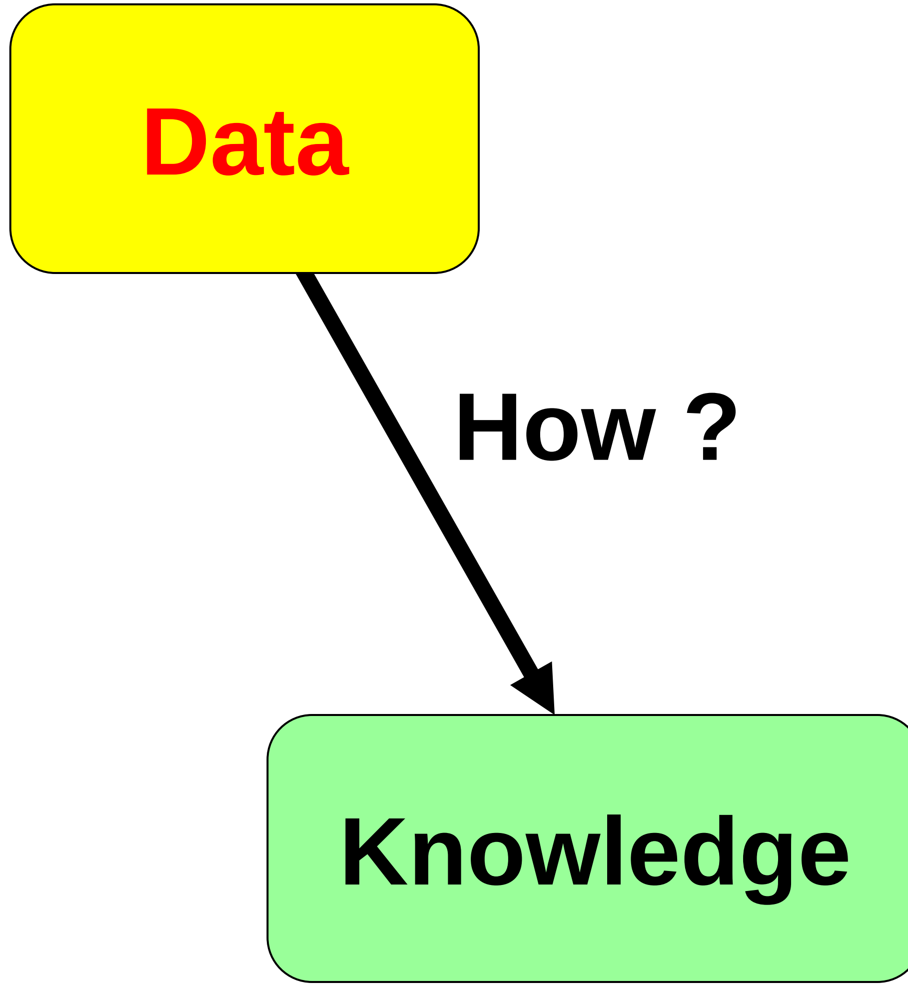


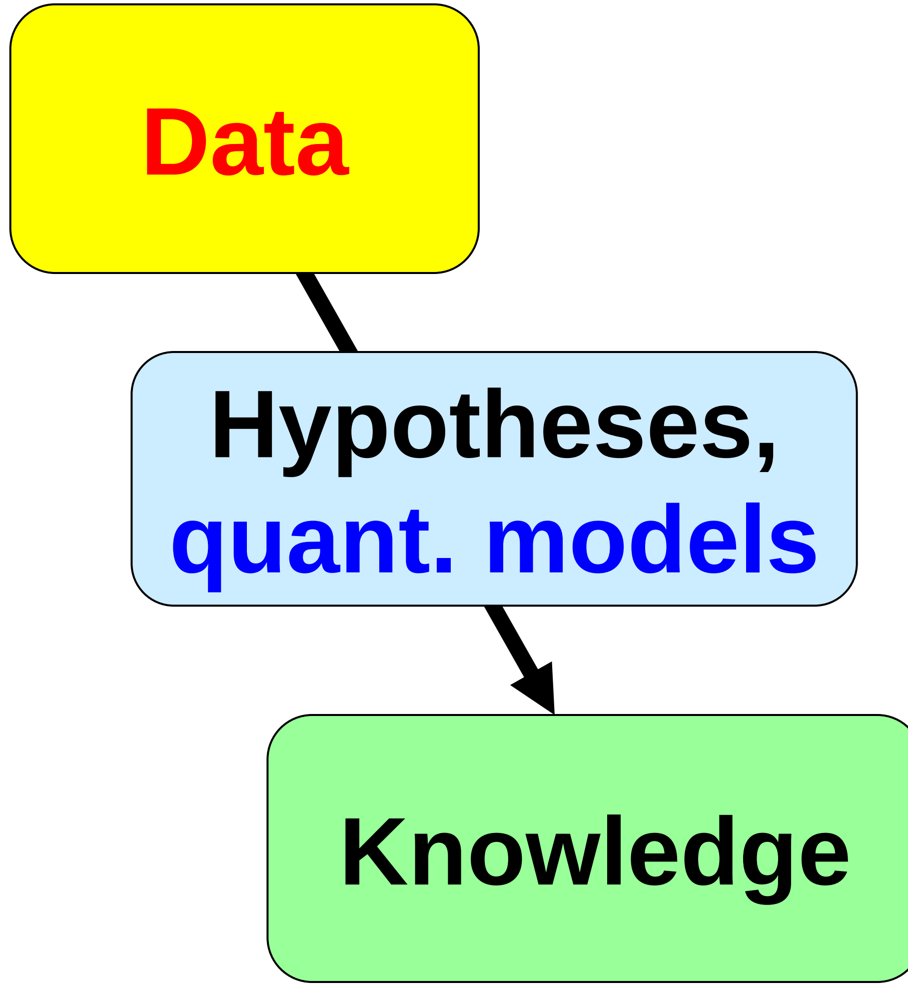






Data

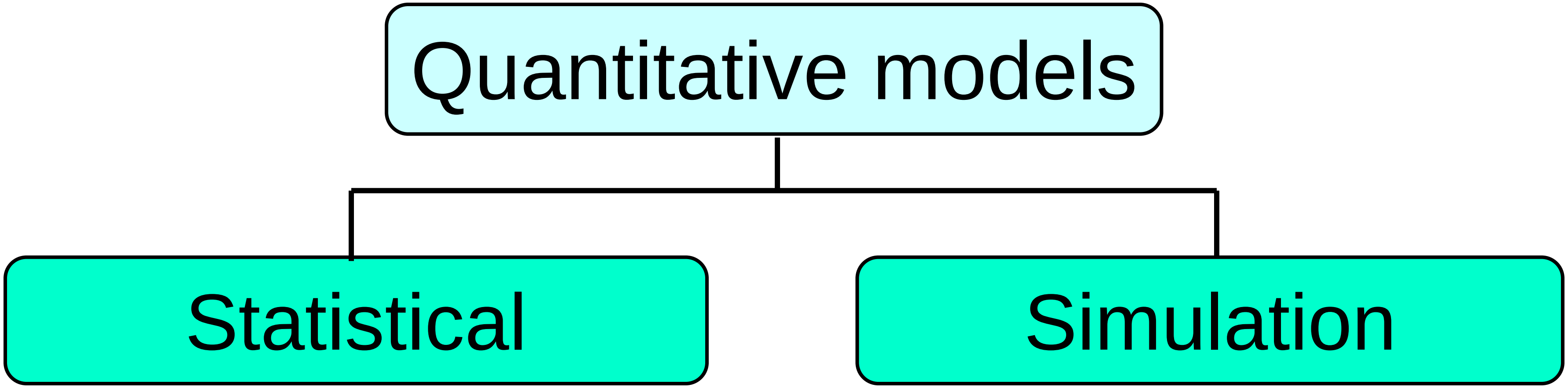

Data
How ?
Knowledge

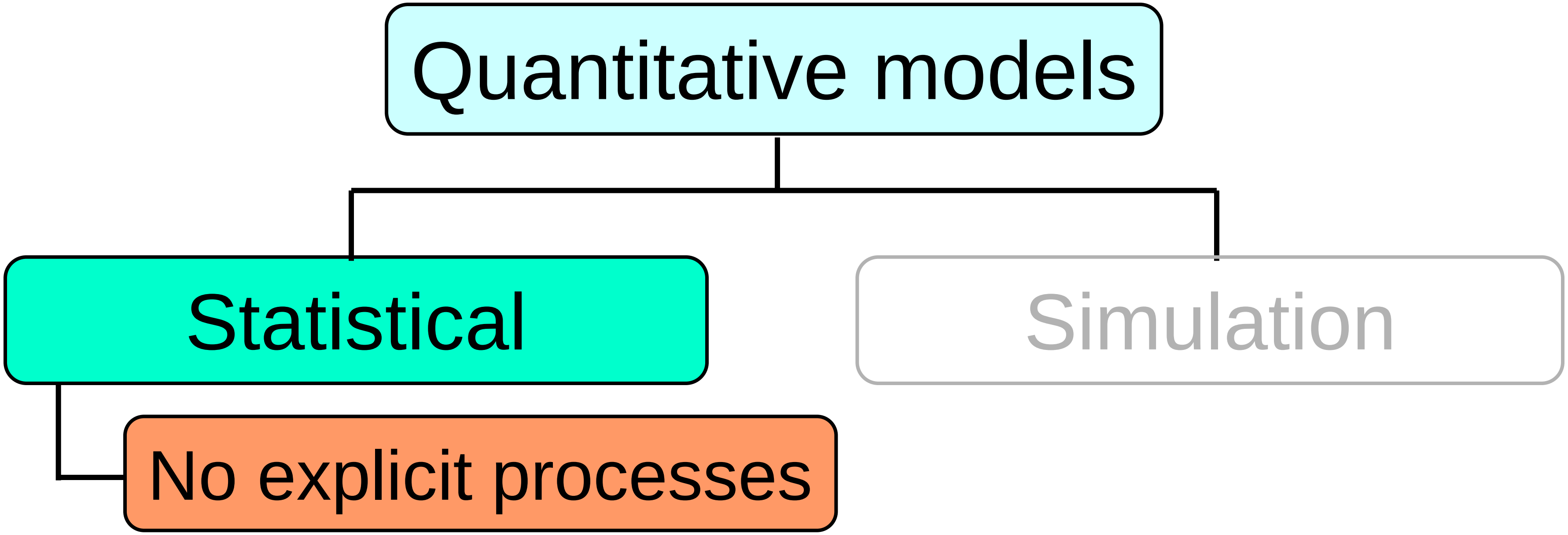

Data
Hypotheses,
quant. models
Knowledge

How can quantitative salmon models help in presence of climate change?

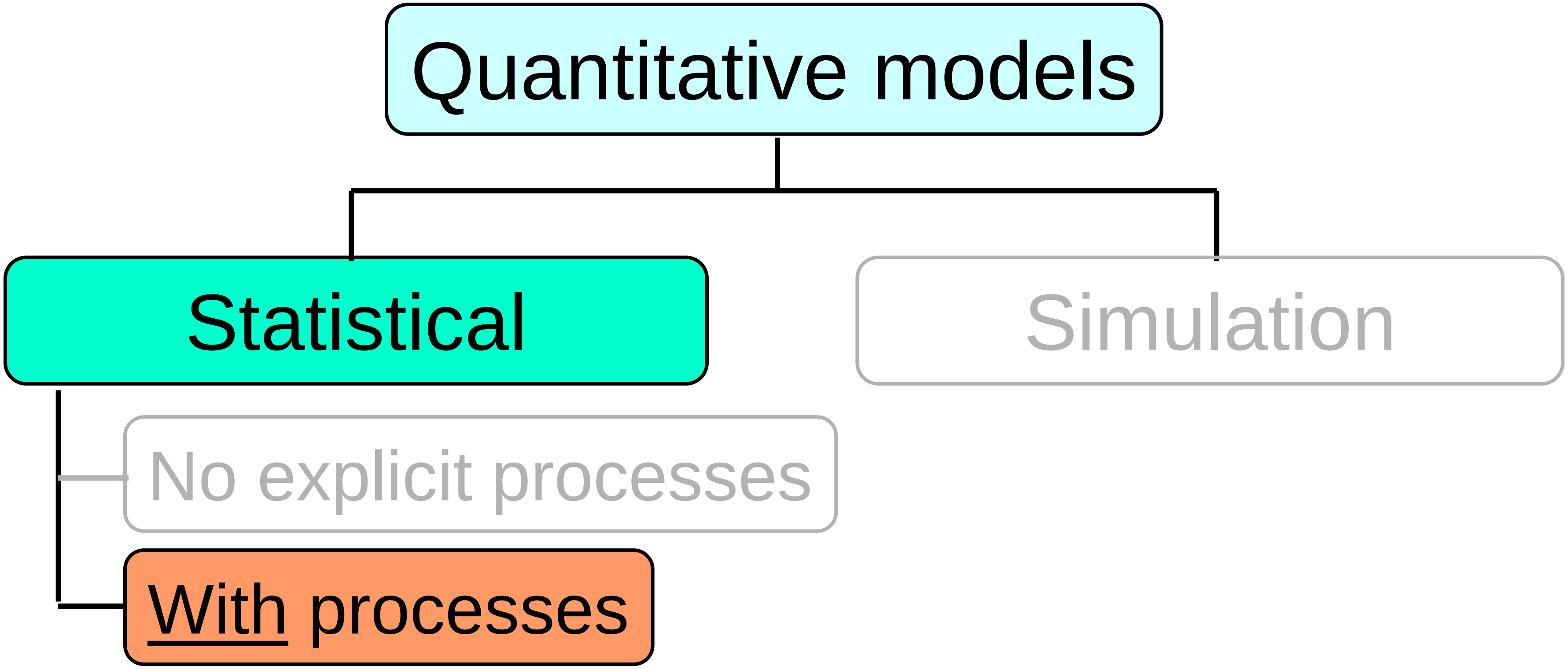
- Improve understanding
- Forecast abundance
- Rank alternative management options

Emerging new modeling methods ...


Quantitative models
Statistical
Simulation



1. Formal time series models
   (auto-regressive AR1, ARIMA, ...)

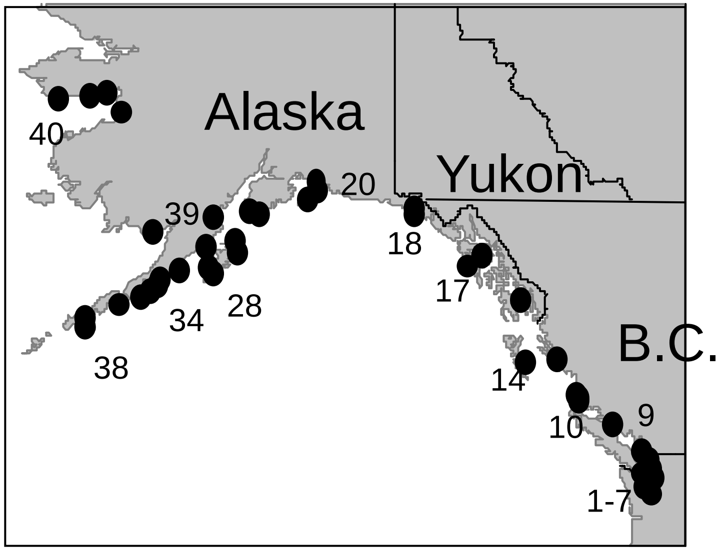


1. Ricker models with environmental covariates
2. Hierarchical models for data across many populs.
3. State-space models (e.g., Kalman filter)
4. Dynamic Factor Analysis (DFA)

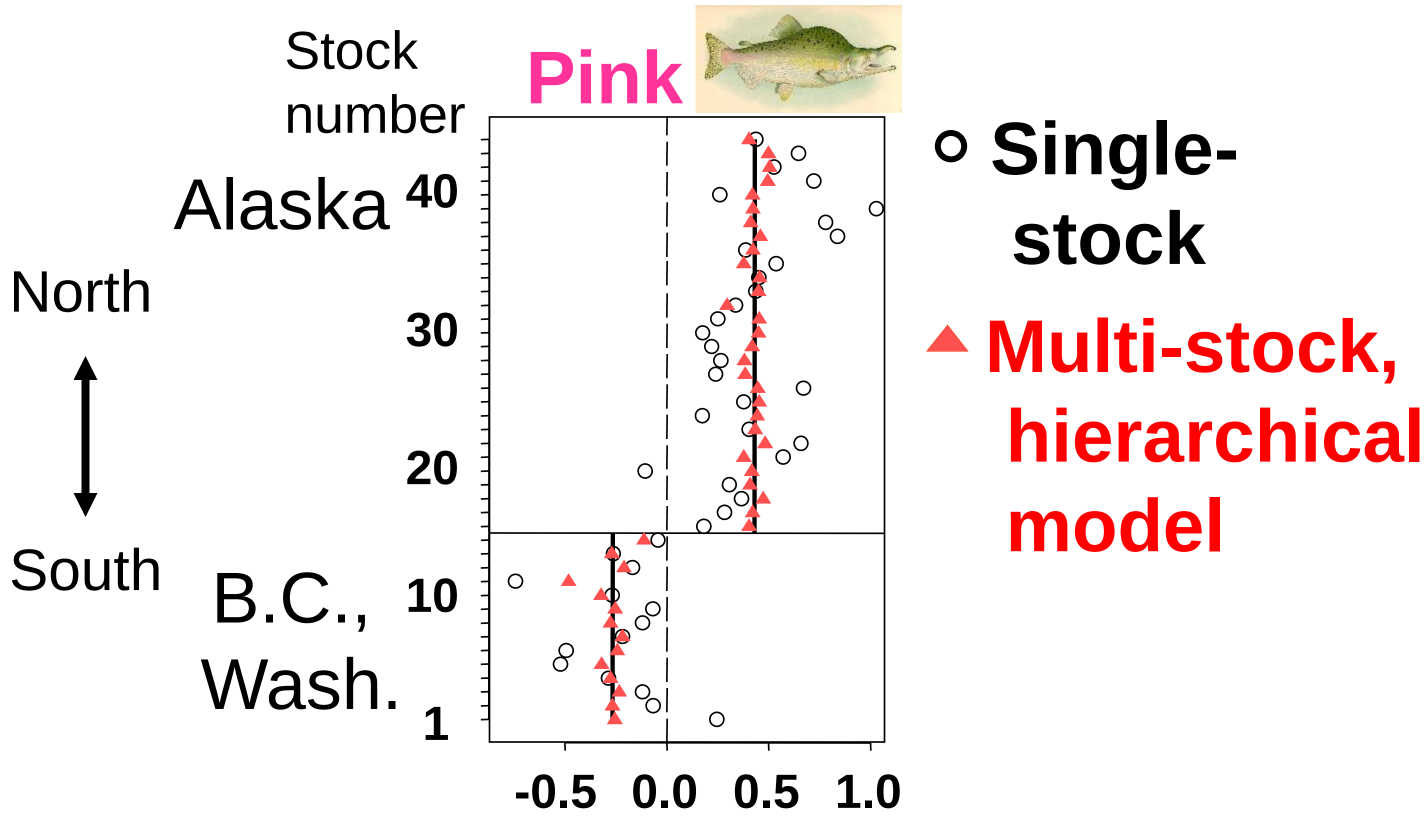
2. Hierarchical models

- Use data from multiple salmon stocks ("replicates")

- Estimate variation shared among salmon stocks



Time series for 43 pink salmon stocks



Change in salmon productivity, $\log_e(R/S)$, per ^oC increase in stock-specific summer SST

Mueter et al. (2002, CJFAS)

- **Similar results for chum and sockeye**

- **Northern populations of North American salmon may benefit as SST increases, but southern ones may lose.**

Compared to <u>single-stock</u> analyses,
<u>multi-stock hierarchical models:</u>

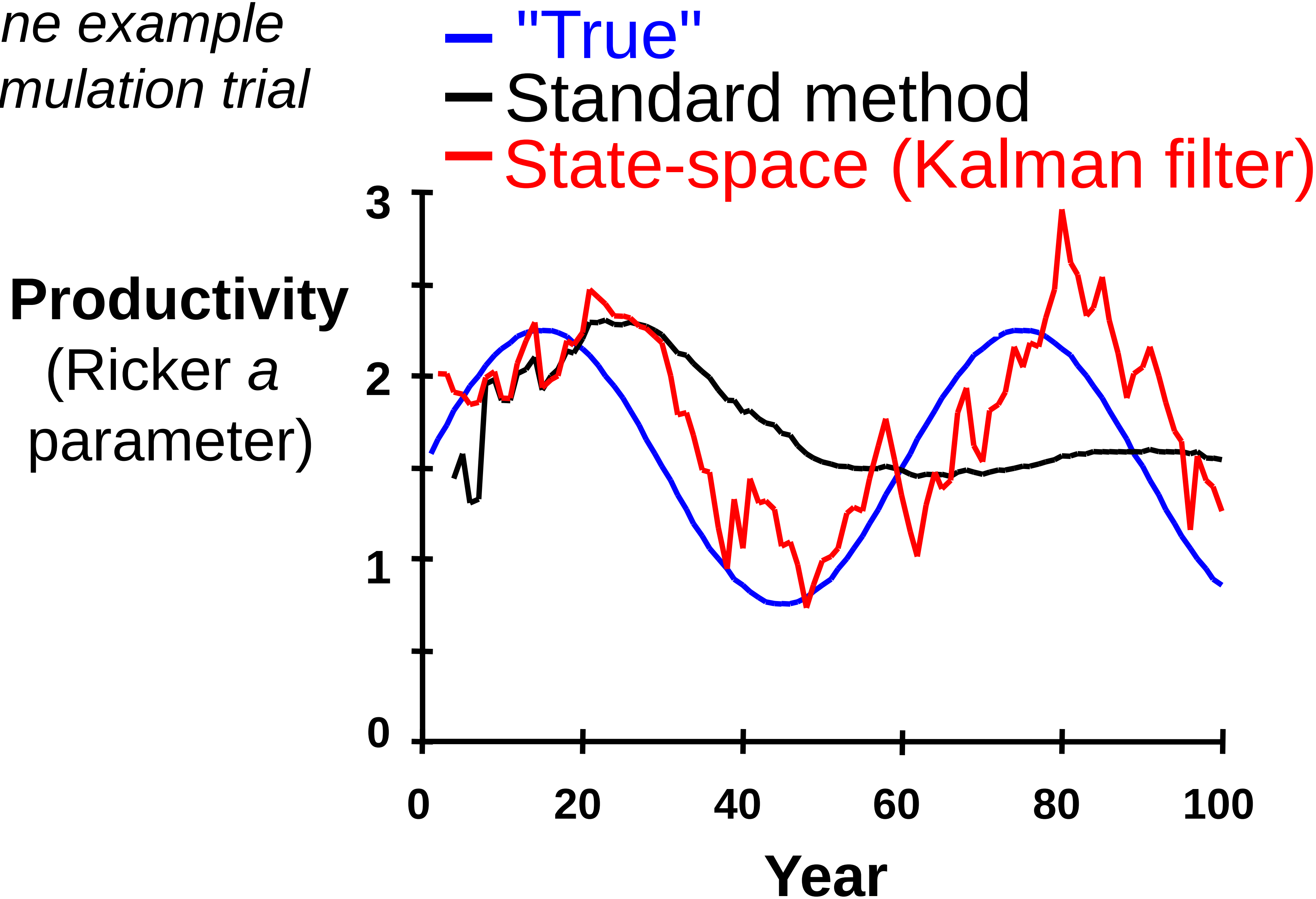
- Improve understanding of environmental effects (like SST) shared across salmon populations

- But stock-specific estimates will be biased (shrinkage)

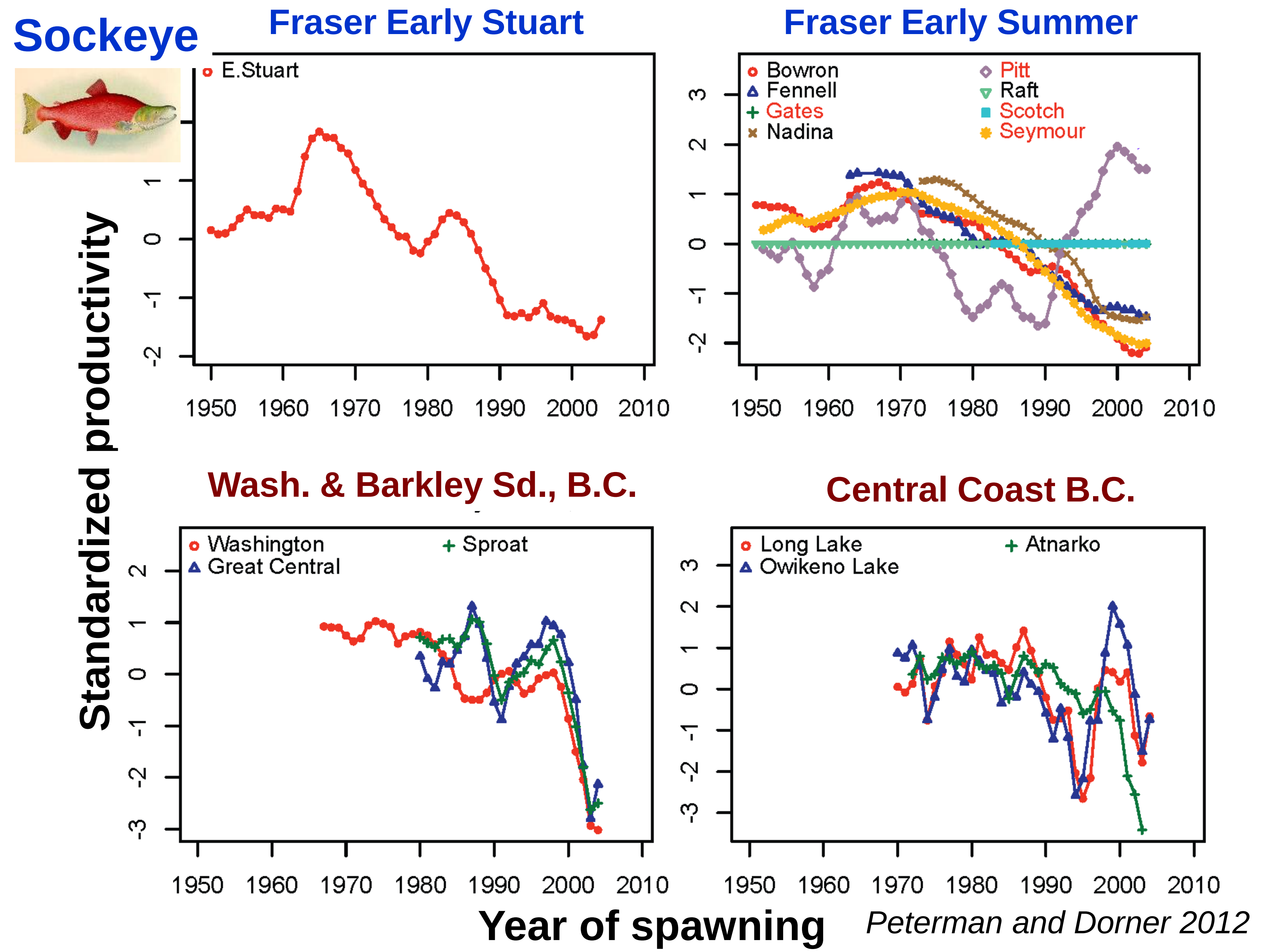
3. State-space models

- Estimate time-varying parameters (e.g. productivity)
- Take into account **natural variability and observation error**
  - Used for several **non**-salmonid species, both pelagic and demersal

One example simulation trial



Peterman et al. (2000)


Sockeye
Fraser Early Stuart
E.Stuart
Fraser Early Summer
Bowron
Fennell
Gates
Nadina
Pitt
Raft
Scotch
Seymour
Wash. & Barkley Sd., B.C.
Washington
Great Central
Sproat
Central Coast B.C.
Long Lake
Owikeno Lake
Atnarko
Standardized productivity
Year of spawning
1950 1960 1970 1980 1990 2000 2010
Peterman and Dorner 2012

4. Dynamic Factor Analysis (DFA)

- Zuur et al. 2003, CJFAS
- Stachura et al. 2014, CJFAS

Many stocks share temporal patterns of variation

Dynamic Factor Analysis:

Quantifies those shared temporal patterns in productivity (finds "signal" amid "noise").

Dynamic Factor Analysis (DFA):

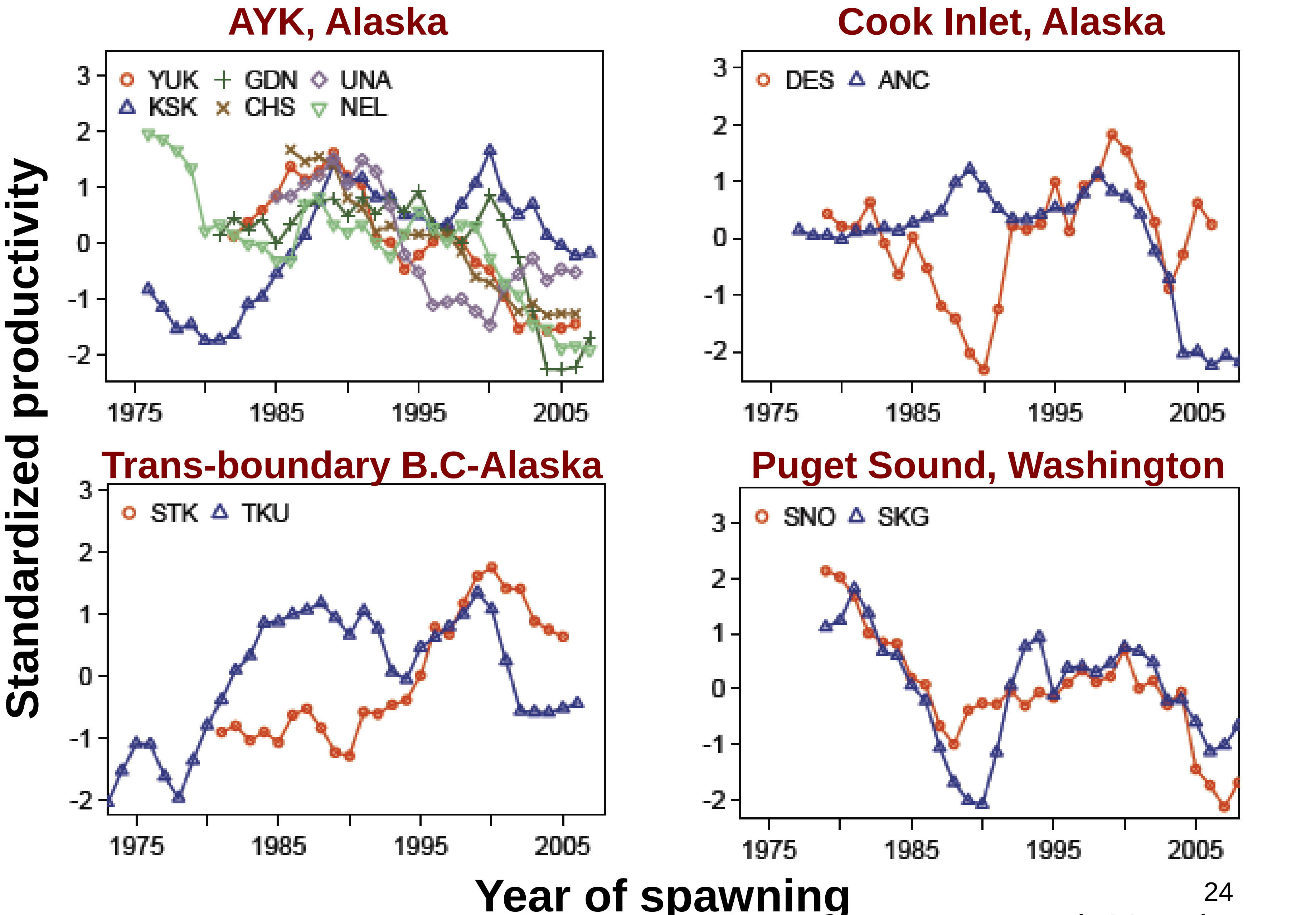
1. Is a factor analysis for time series data

2. Is a regression where independent variables (factors) are temporal patterns

3. Allows missing data, unlike PCA

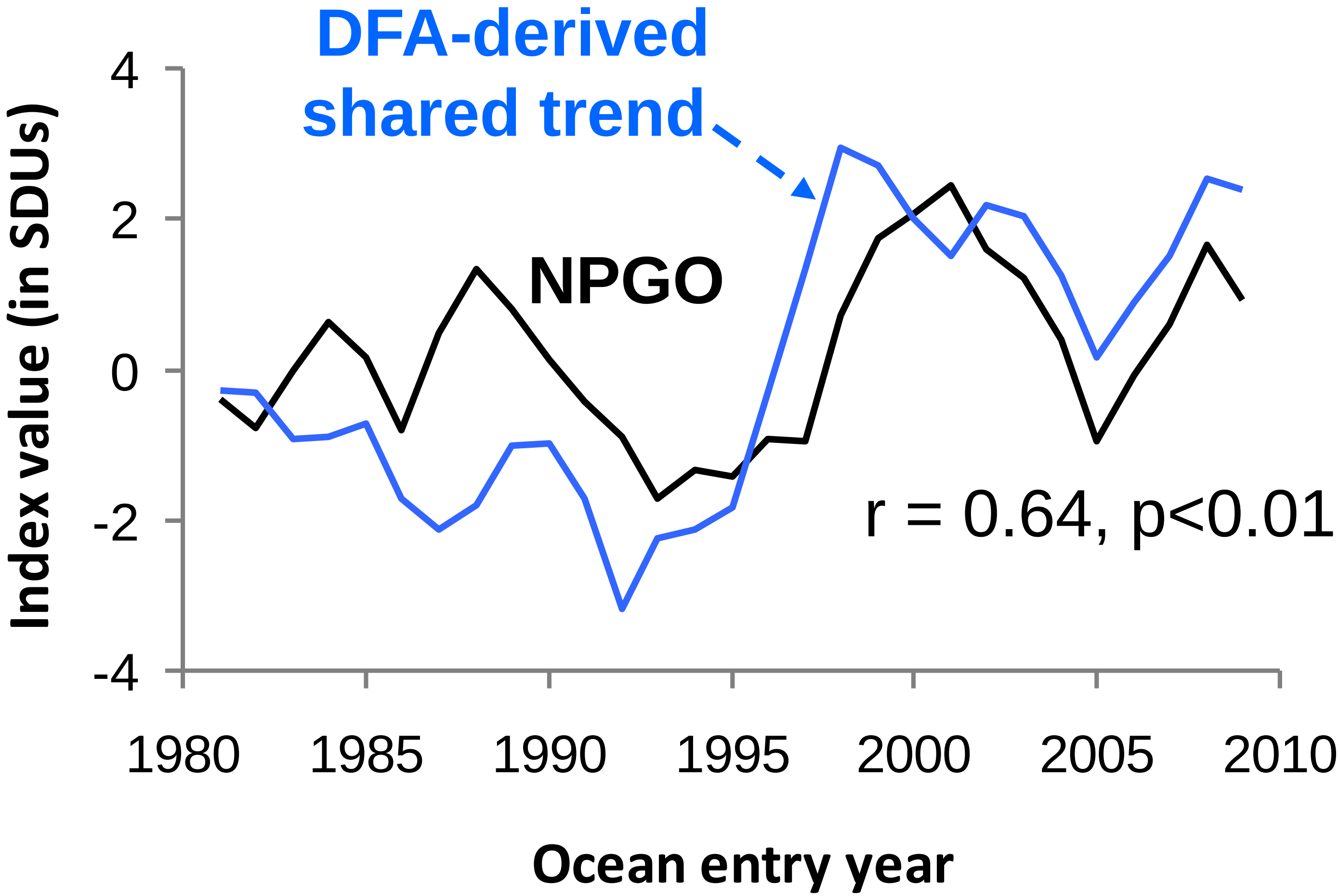
4. Can evaluate importance of independent variables

Chinook (24 wild populs., Oregon through Alaska)



Dorner et al. 2015, in prep.

Chinook salmon (24 wild populs., Oregon thru Alaska)



Dorner et al. 2015, *in prep.*

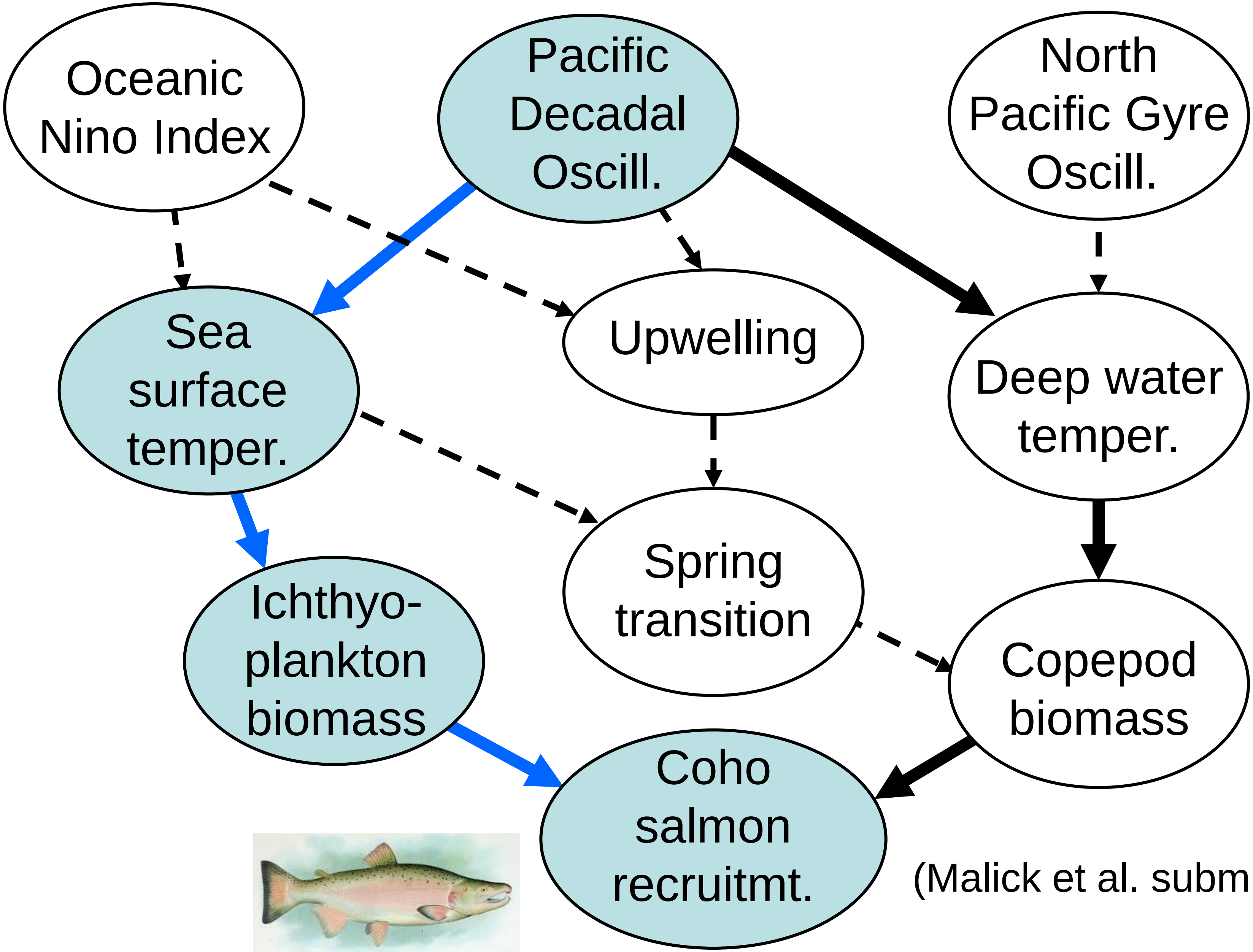
Quantitative models

- Statistical
  - No explicit processes
  - With processes
  - Bayesian (i.e., probabilistic) networks
- Simulation

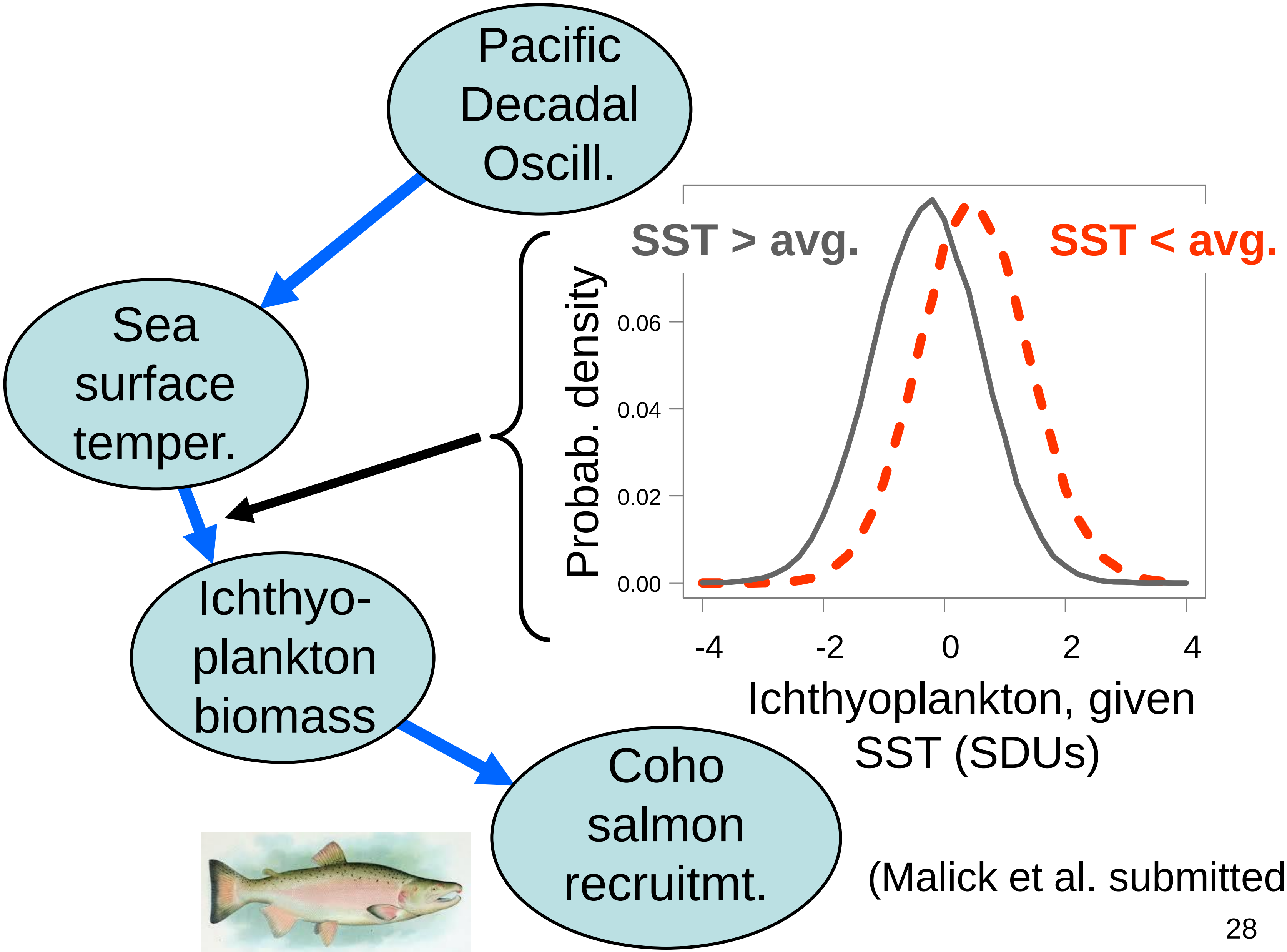
- Data-derived distrib. of probabilities of events

- Explicitly represent uncertainties in all processes

Bayesian network linking climate to Oregon coho salmon



(Malick et al. submitted)



(Malick et al. submitted)

Advantages of Bayesian networks

1. Complexity is represented simply

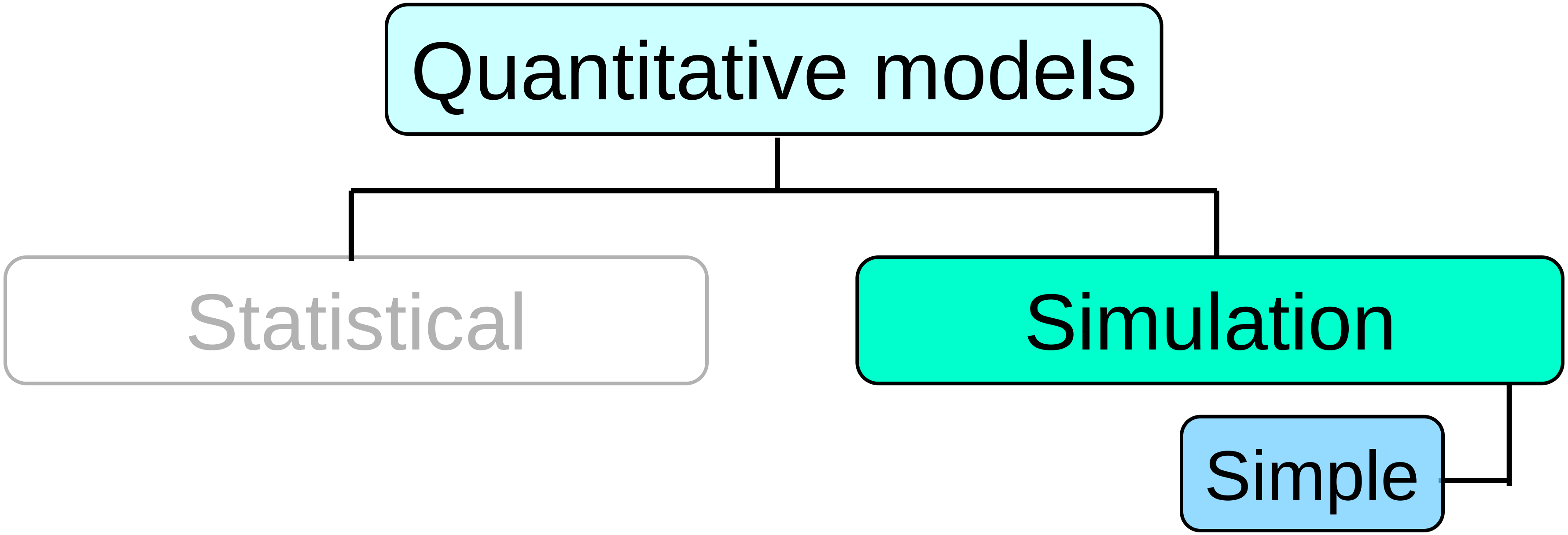
2. Can do extensive sensitivity analyses

Quantitative models

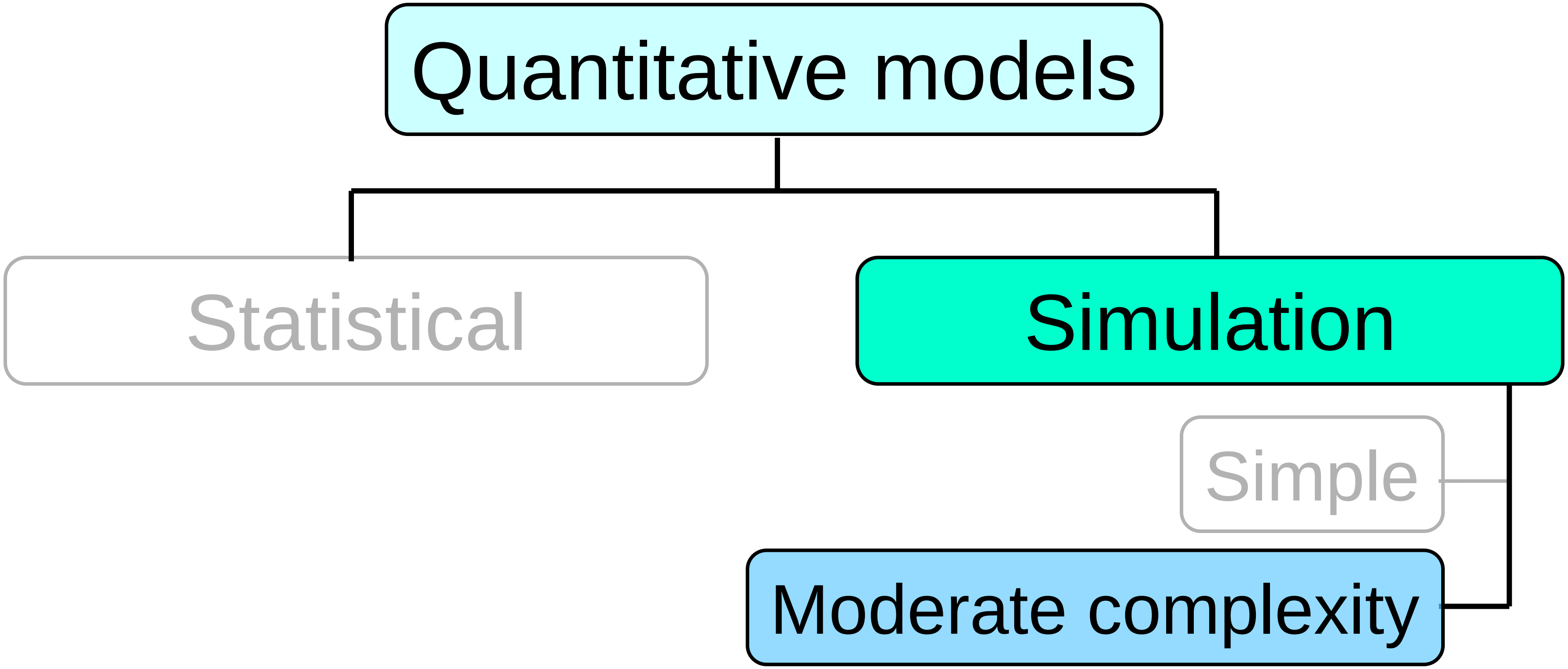
Statistical

Simulation

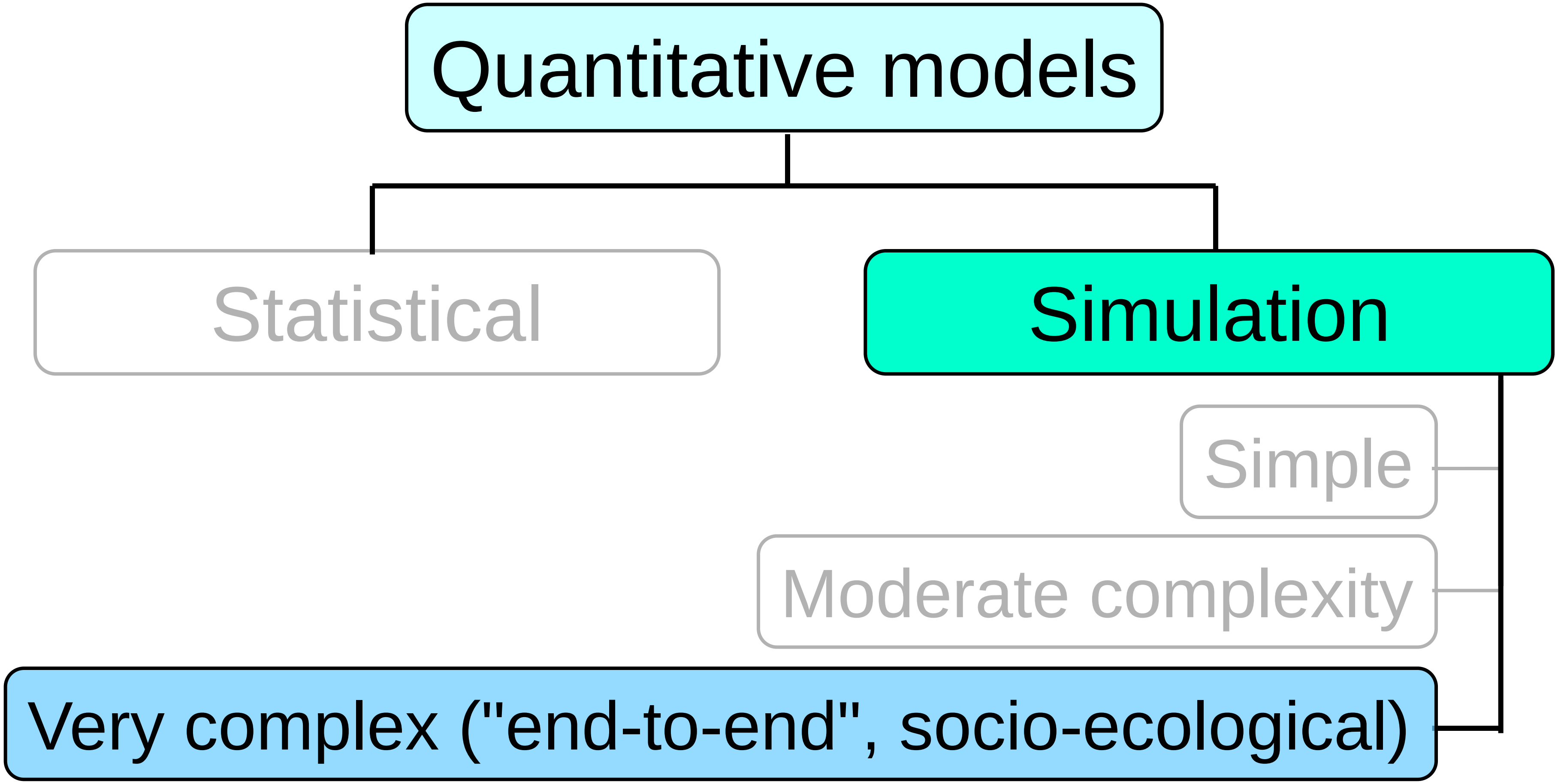
- Mechanistic
- Include physical and biological processes
    -- Salmon prey, predators, competitors
- Range from simple to complex



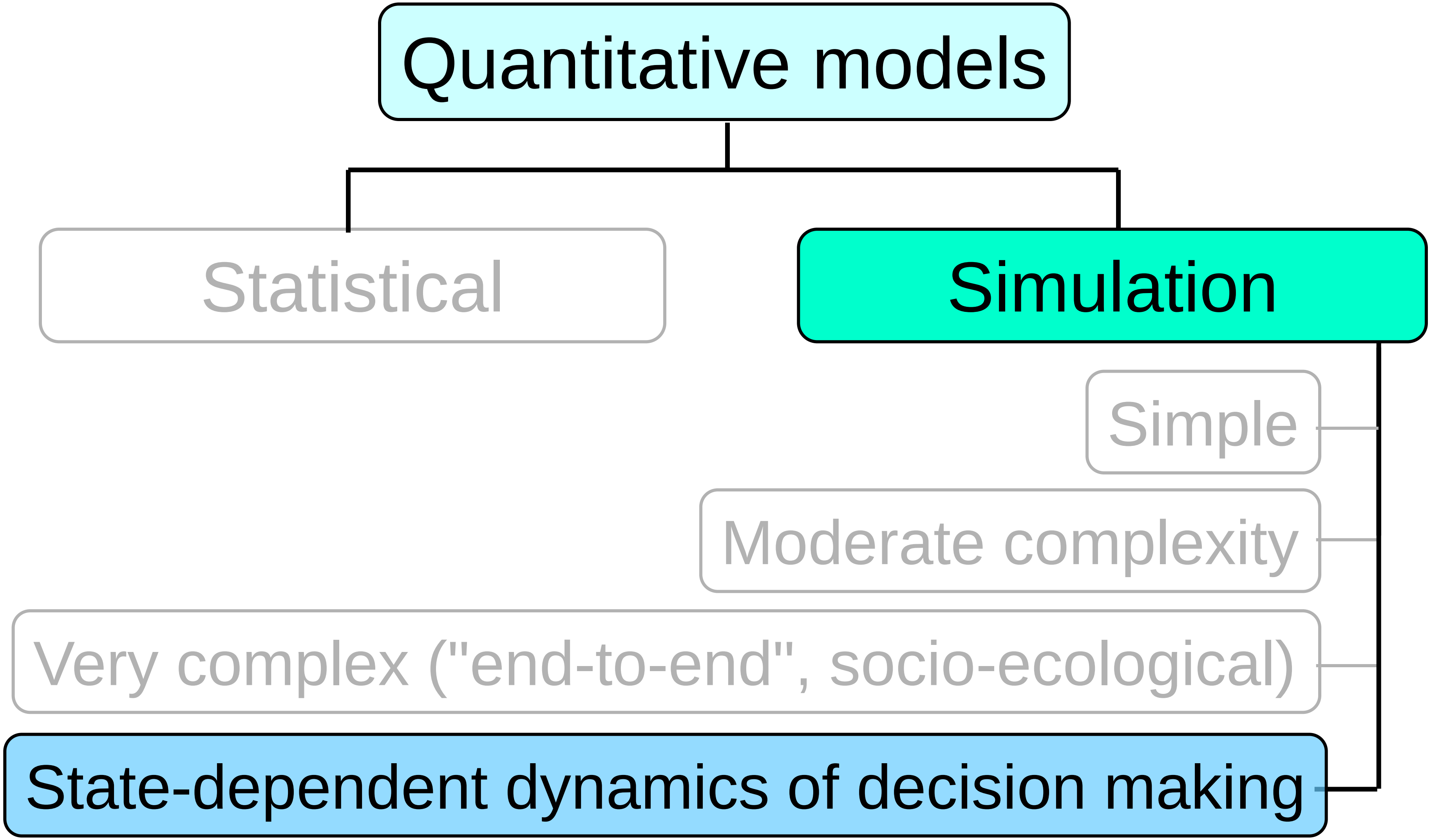
- Single-population, Ricker model with SST or ...



- NEMURO.FISH
- **M**odels of **I**ntermediate **C**omplexity (**MIC** or **MICE**) for **non-salmonids** (Hannah et al. 2010 Prog. Oceanog.; Plaganyi et al. 2014 Fish and Fisheries)
- Multi-popul., climate-driven changes (Dorner et al. 2009)



- Bering Sea Ecosystem (BSIERP)
- ATLANTIS for California Current system



- In-season management models (Bristol Bay, ...)

- **Management Strategy Evaluation (MSE) models**

Management Strategy Evaluation (MSE) models

Take into account uncertainties

- Include multiple alternative models (structural uncert.)

- Change focus away from finding the best model to **finding management procedures that are the most robust to uncertainties**

Management Strategy Evaluation (MSE) models

Take into account uncertainties

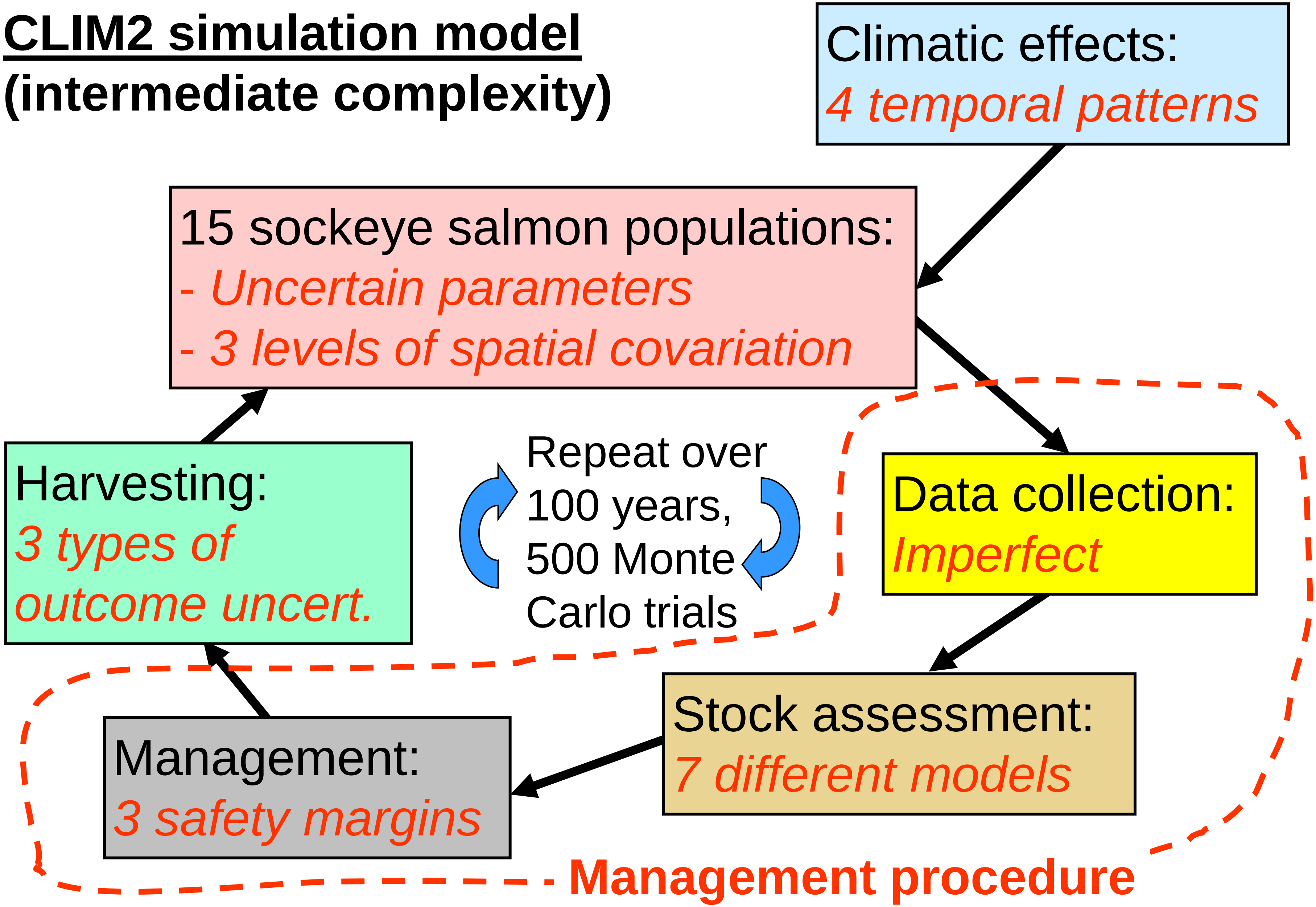
- Include multiple alternative models (structural uncert.)

- Change focus away from finding the best model to **finding management procedures that are the most robust to uncertainties**

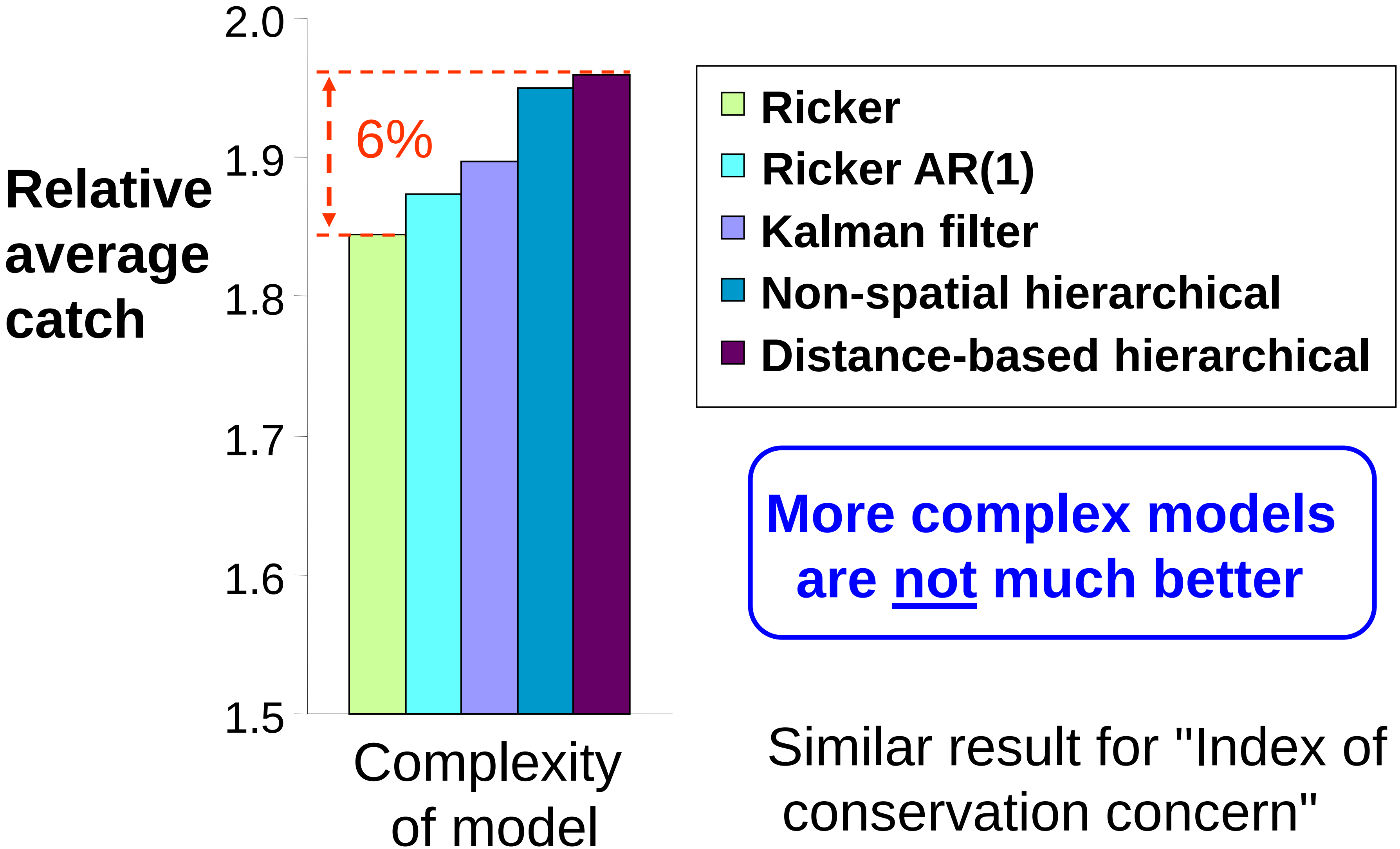
Management procedures

1. Data collection
2. Analysis of data
3. Decision rules based on data on state of system

CLIM2 simulation model
(intermediate complexity)



Dorner et al. (2009, CJFAS)



More complex models are not much better

Similar result for "Index of conservation concern"

Dorner et al. (2009, CJFAS)

FAO's 2008 "Best practices" for evaluating models of aquatic ecosystems

- Multiple models
- Management Strategy Evaluation is best approach

Features of advanced models ...

Explicitly include uncertainties in ...

- Natural variability
- Observation error
- Model structure
- Parameter values
- Outcome uncertainty (difference between actual outcomes and planned outcomes)

Incorporate knowledge from social as well as natural sciences

- Economics
- Management decision-making processes
- Fishing behaviour (e.g., discarding)

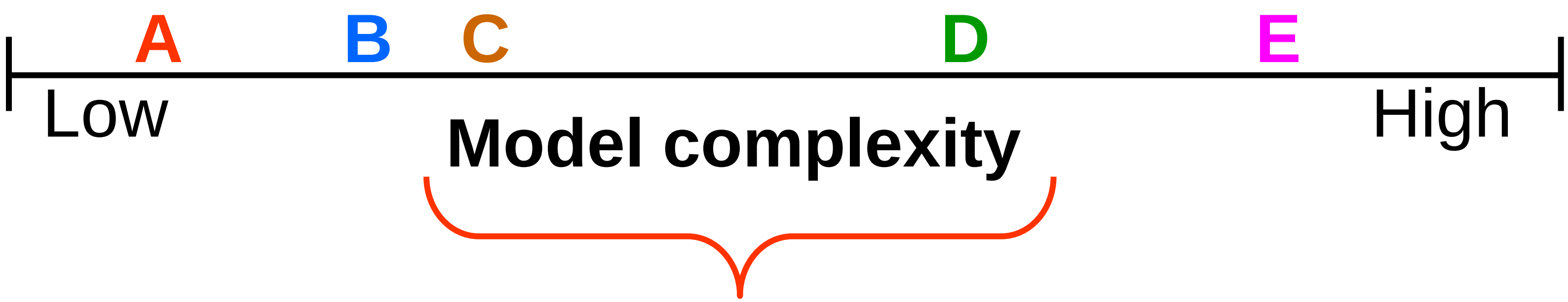
…

Recommendations for climate-salmon modellers

1. Explore multiple models (i.e., multiple hypotheses) instead of aiming to develop THE single "best" model.

   a. Such models that include uncertainties will better reflect uncertainties about climatic effects on salmon.

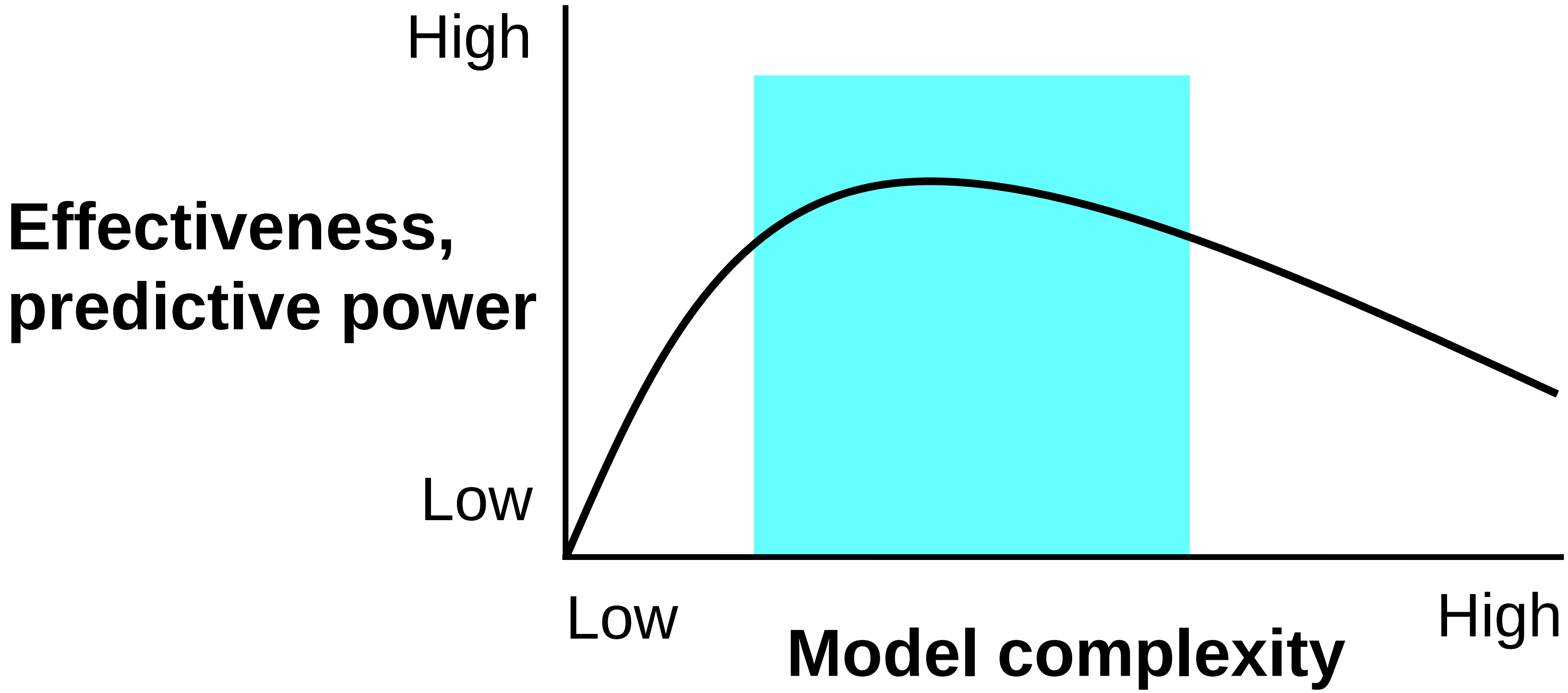
   b. Cover range of complexity:



Models of intermediate complexity (MICE); frequently used in non-salmonid fisheries

Recommendations for climate-salmon modellers ...

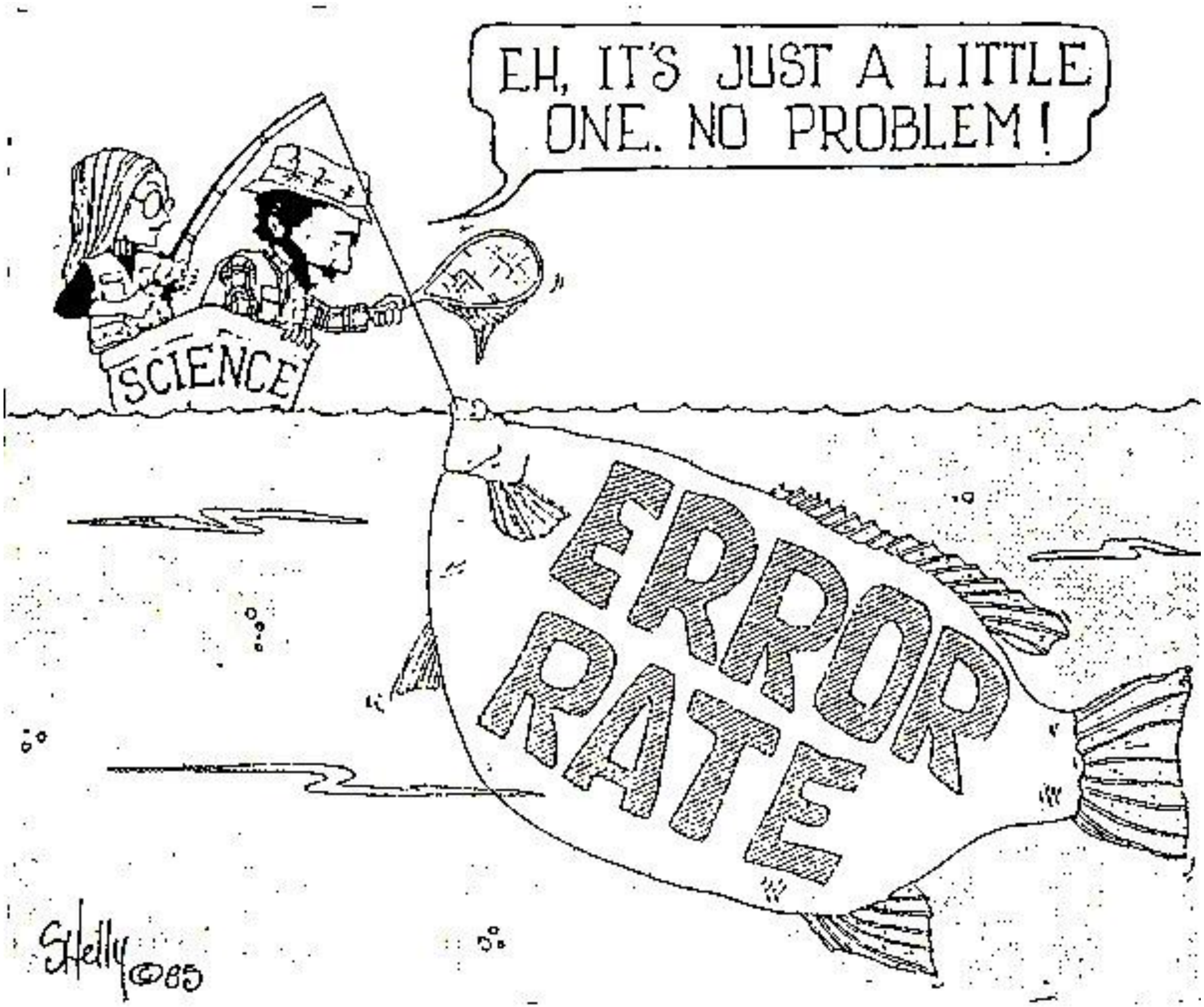
2. Models that are too complex may be unreliable.



Fulton et al. (2003), others

Recommendations for climate-salmon modellers ...

3. Explore newer methods such as:
   - Hierarchical models (for data on multiple locations)
   - State-space models (for time-varying parameters)
   - Dynamic Factor Analysis (for both multiple locations and time-varying parameters)
   - Bayesian networks
   - Management Strategy Evaluation (MSE)


EH, IT'S JUST A LITTLE ONE. NO PROBLEM!
SCIENCE
ERROR RATE
SHelly ©85