Stock Synthesis: an Integrated Analysis Model to Enable Sustainable Fisheries

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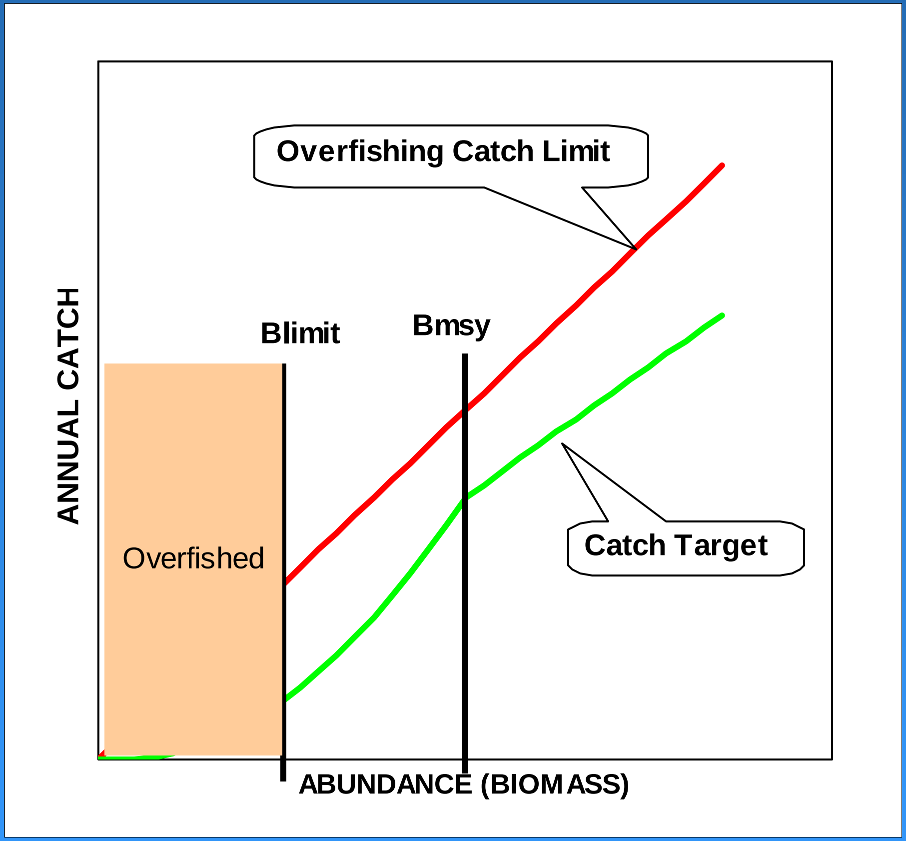
OUTLINE

- Management Needs
- Stock Assessment Role
- Data Requirements
- Stock Synthesis
- Some Technical Advancements
- Getting to Ecosystem

Control Rules, Status Determinations and Operational Models



- Is stock overfished or is overfishing occurring?
- What level of future catch will prevent overfishing, rebuild overfished stocks and achieve optimum yield?

Stock Assessment Defined

Collecting, analyzing, and reporting demographic information to determine the effects of fishing on fish populations

- Simplest System
  - Link control rule to simple data-based indicator of trend in B or F
  - Easy to communicate; assumptions are buried
  - Hard to tell when you've got it wrong
  - Hard to put current level in historical context

- Full Model
  - Estimate level, trend and forecast for abundance and mortality to implement control rules
  - Cross-calibrates data types
  - Complex to review and communicate
  - Bridges to integrated ecosystem assessment

Idealized Assessment System

- Standardized, timely, comprehensive data
- Standardized models at the sweet spot of complexity
- Trusted process thru adequate review of data and models
- Timely updates using trusted process
- Clear communication of results, with uncertainty, to clients

STOCK ASSESSMENT PROCESS

CATCH
RETAINED AND DISCARDED CATCH; AGE/SIZE DATA

ABUNDANCE TREND
RESOURCE SURVEY or FISHERY CPUE, AGE/SIZE DATA

BIOLOGY
NATURAL MORTALITY, GROWTH, REPRODUCTION

POPULATION MODEL:
(Abundance, mortality)

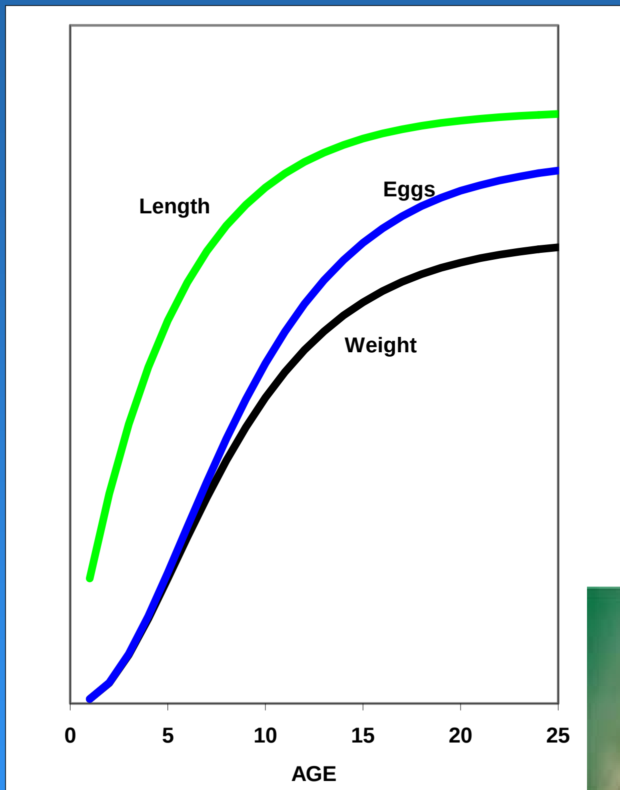
ADVANCED MODELS
- HABITAT
- CLIMATE
- ECOSYSTEM
- MANMADE STRESS

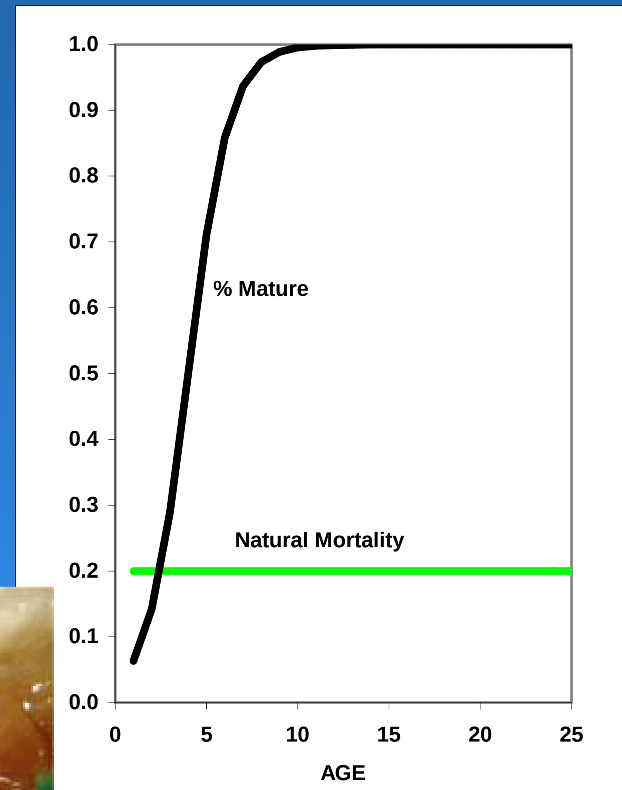
SOCIOECONOMICS

FORECAS

Conceptually like NOAA Weather's data assimilation models, but time scale is month/year, not hour/day

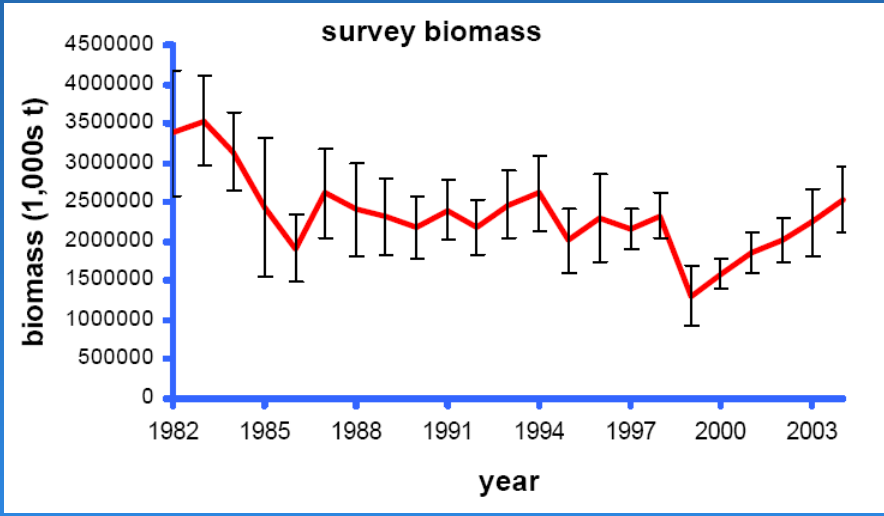
Fish Biology and Life History

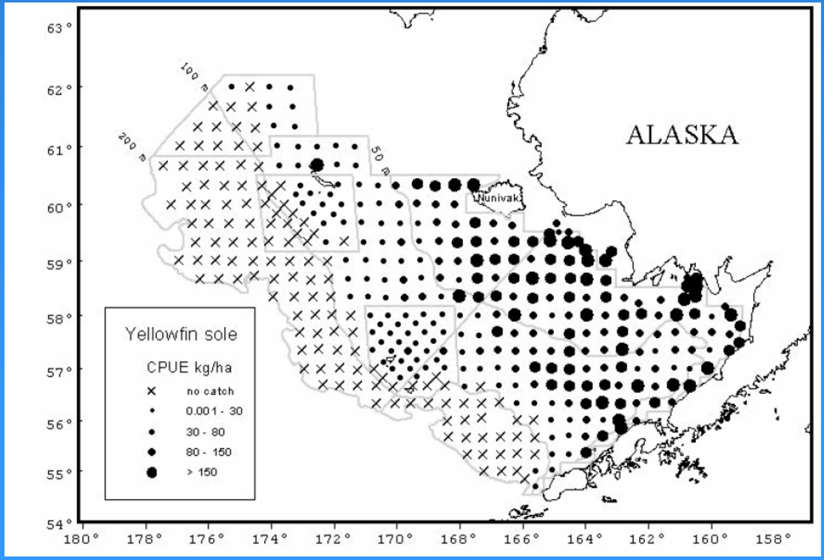




Ease: Length & Weight >> Age > Eggs & Maturity >>> Mortality

Abundance Index
Fishery-Independent Surveys





Source of Abundance Indexes

		Primary Survey (one per asmt)						
		FSV	CHARTER	Comm-CPUE	Recr-CPUE	NON-NMFS	Co-op	unid
Ecosystem	Alaska	2	27					
	Cal. Current	4	16	2	8			
	Caribbean					3		
	Gulf of Mexico	8		3		1		1
	International - Atl	1		7				
	International - Pac			11				
	Northeast	21		1		1		
	Pacific Islands			3				
	Southeast	10		1	1	9		1
	ALL	46	43	28	9	14	0	2

Each survey may support multiple assessments
Each assessment may use data from multiple surveys

Catch: What's Been Removed

- Must account for all fishing mortality
  - Commercial and recreational
  - Retained and discarded
  - Discard survival fraction
- Model finds F that matches observed catch given estimated population abundance
  - Because catch is nearly always the most complete and most precise of any other data in the model
  - But also possible to treat catch as a quantity that is imprecise and then to estimate F as a parameter taking into account the fit to all types of data

Catch Components

- Commercial retained catch
  - fish ticket census
- Commercial discard
  - observer program
- Recreational kept catch
  - catch/angler trip x N angler trips
- Recreational releases
  - Interview x N angler trips

Catch per Unit Effort

- To estimate total catch:
  - Catch = CPUE x Total Effort
  - So CPUE must be effort weighted
- As an index of population abundance
  - Relative biomass index = CPUE x stock area
  - So CPUE must be stratified by area so heavily fished sites are not overly weighted

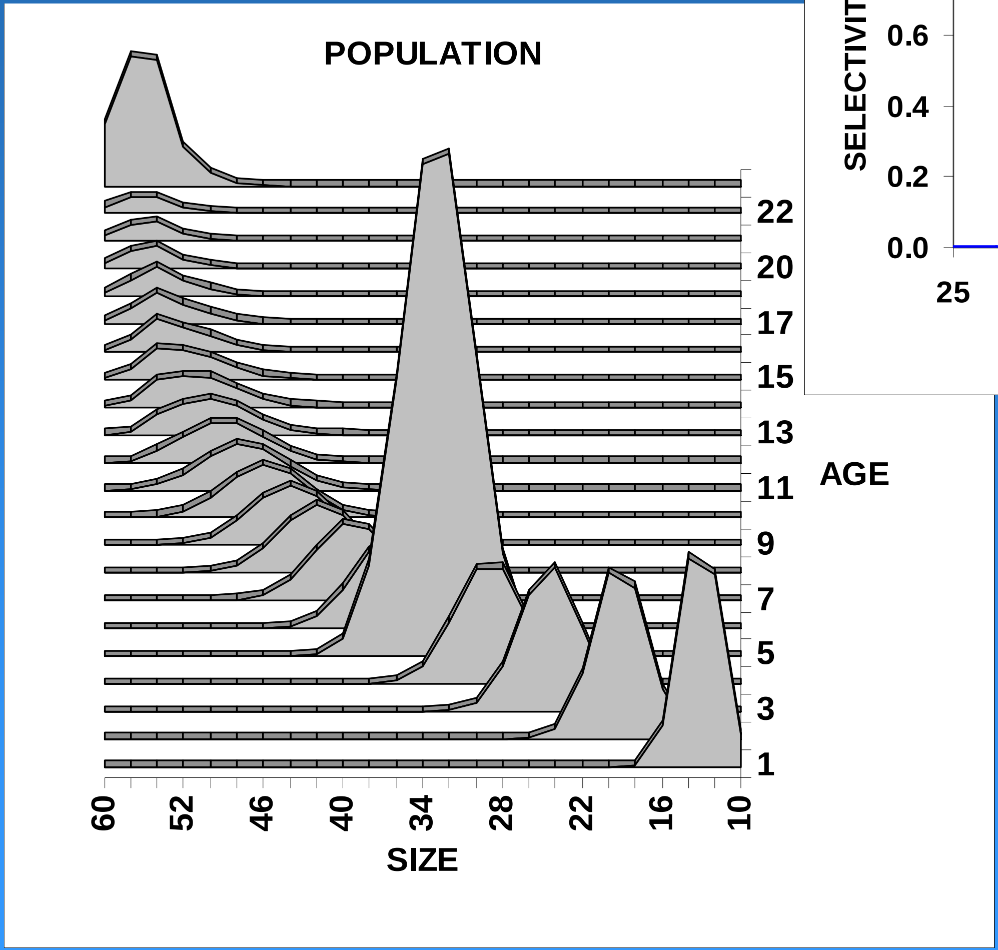
Integrated Analysis Models

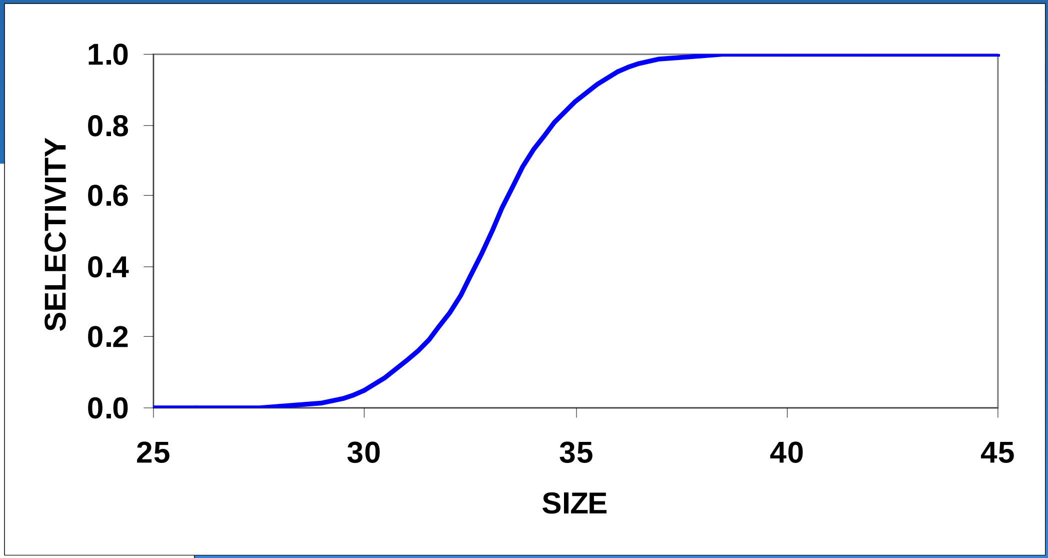
- Population Model – the core
  - Recruitment, mortality, growth
- Observation Model – first layer
  - Derive Expected Values for Data
- Likelihood-based Statistical Model – second layer
  - Quantify Goodness-of-Fit
- Algorithm to Search for Parameter Set that Maximizes the Likelihood
- Cast results in terms of management quantities
- Propagate uncertainty in fit onto confidence for management quantities

Stock Synthesis History

- Anchovy synthesis (~1985)
- Generalized model for west coast groundfish (1988)
- Complete re-code in ADMB as SS2 (2003)
- Add Graphical Interface (2005)
- SS_V3 adds tag-recapture and other features (2009)

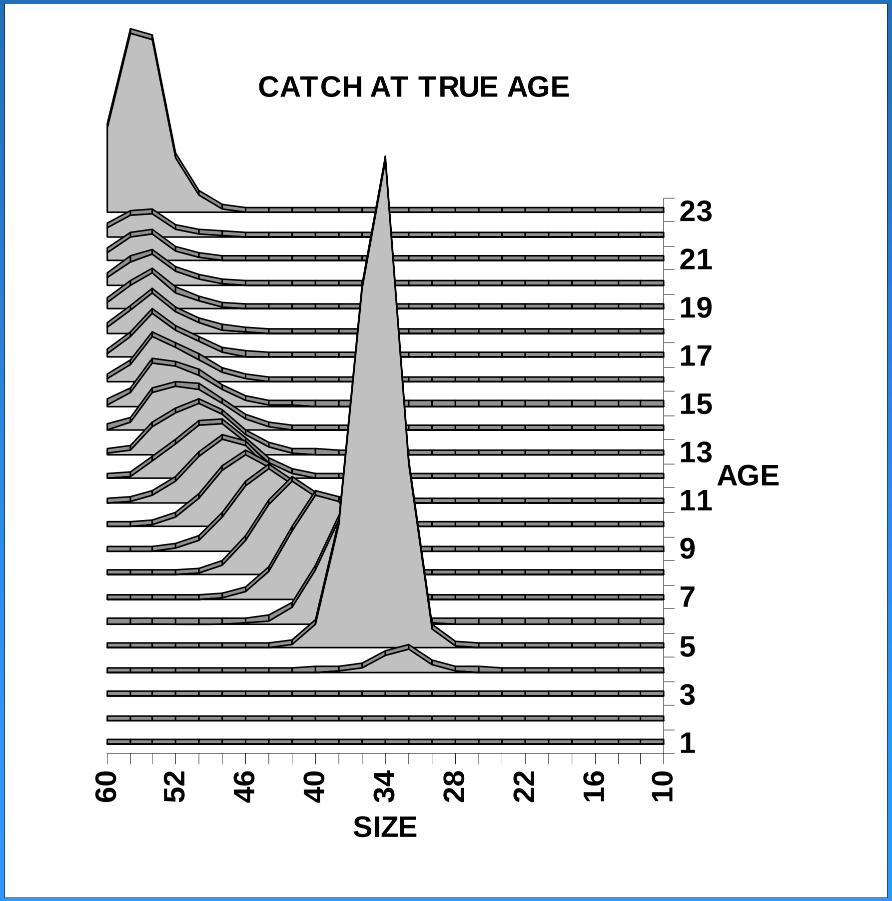
Age-Length Structured Population



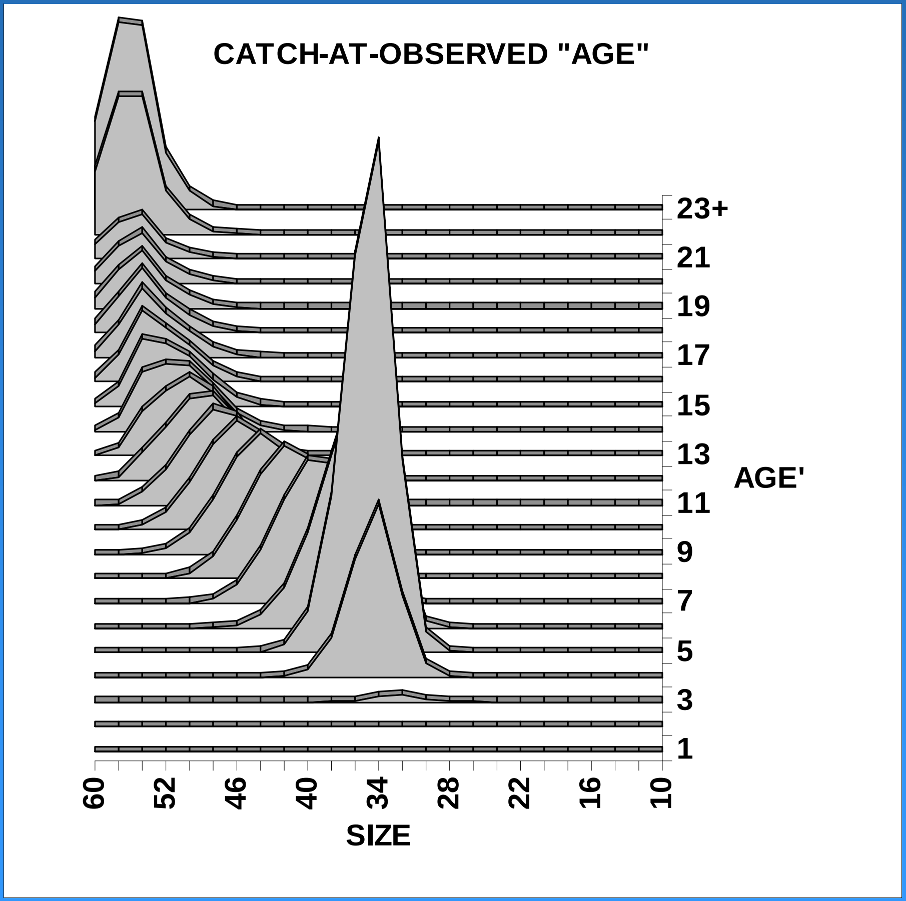


Sampling & Observation Processes

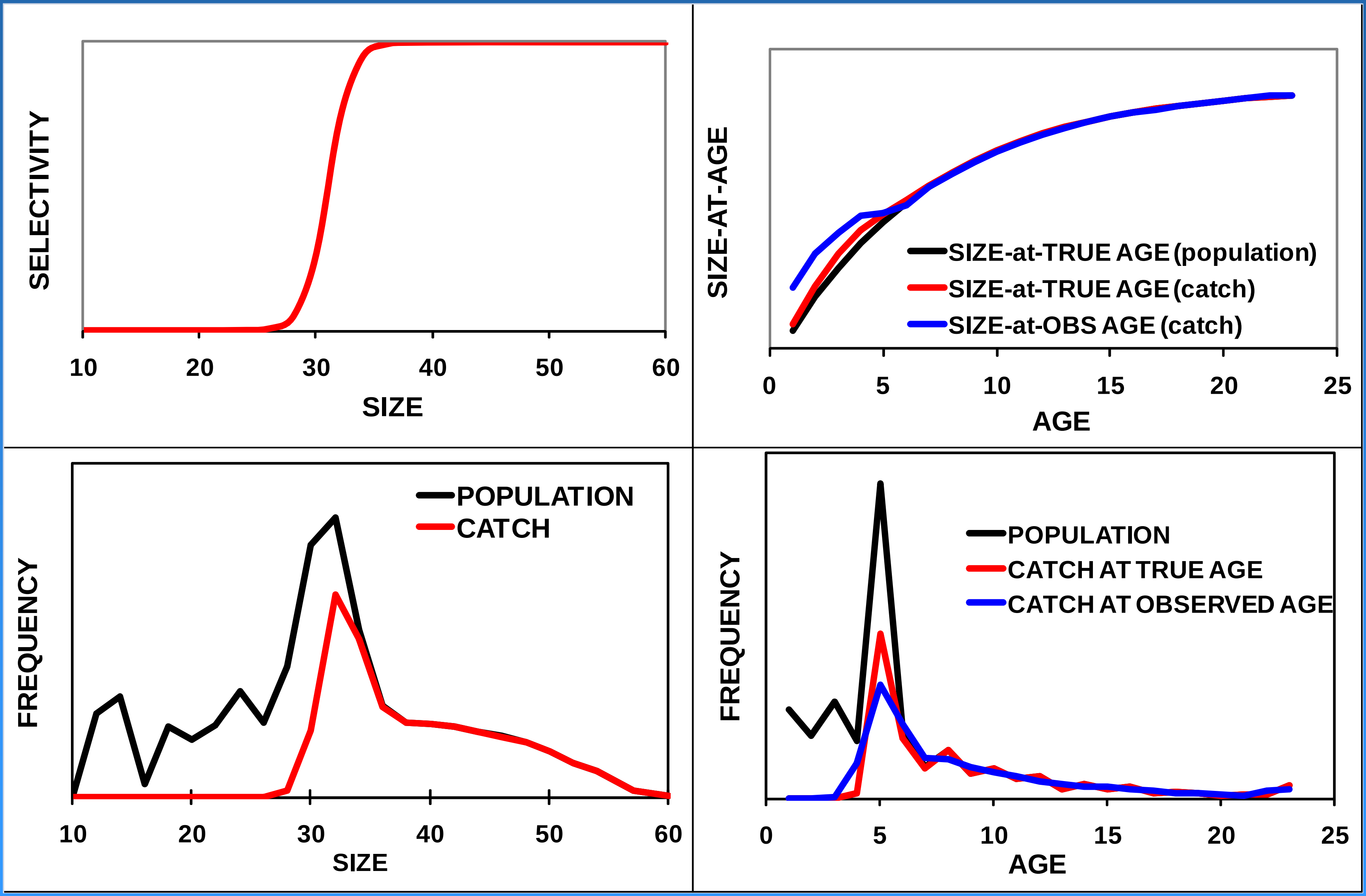
With size-selectivity



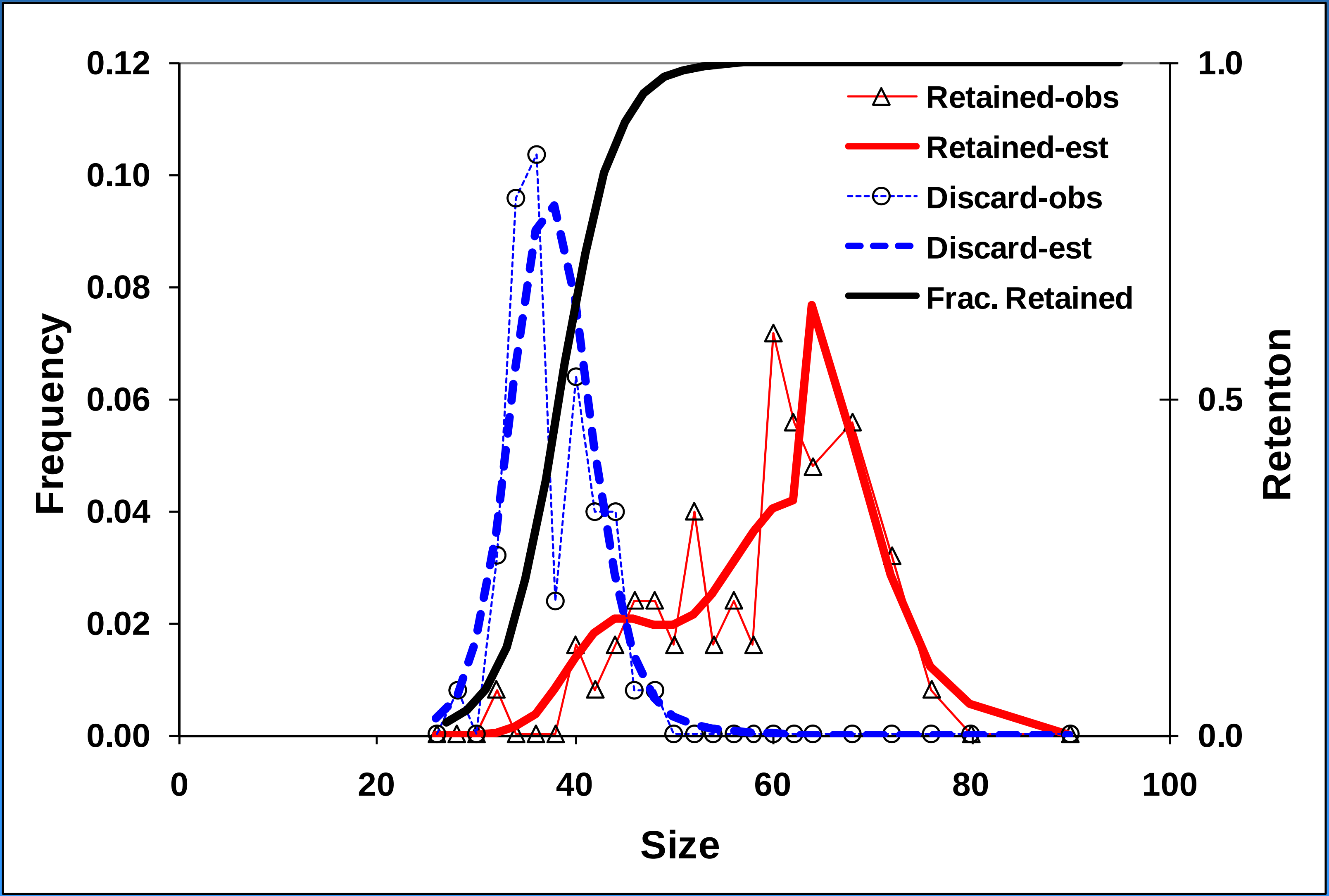
And ageing imprecision



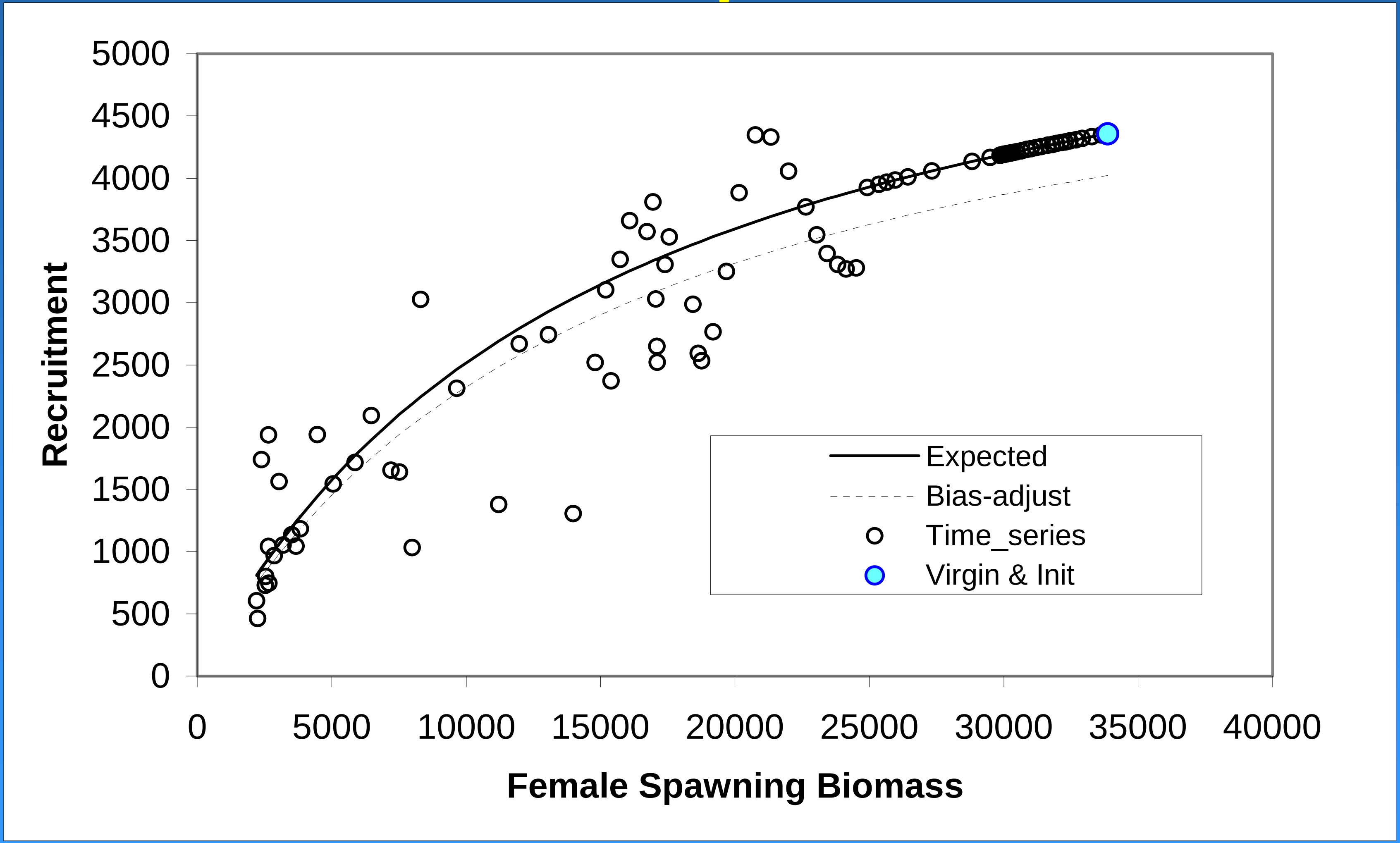
Expected Values for Observations



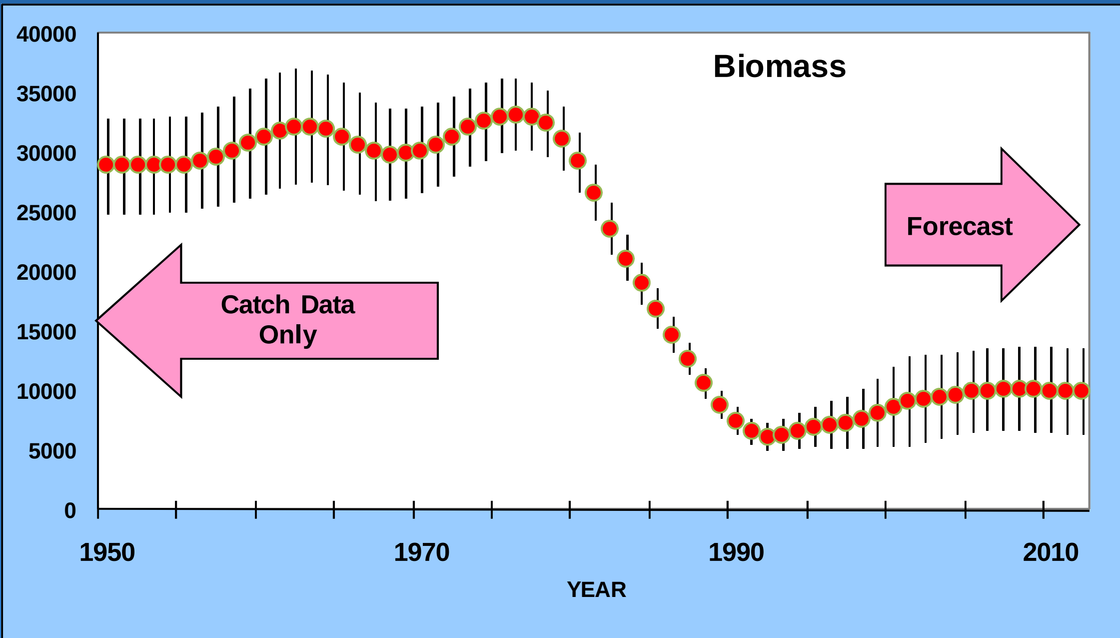
Discard & Retention

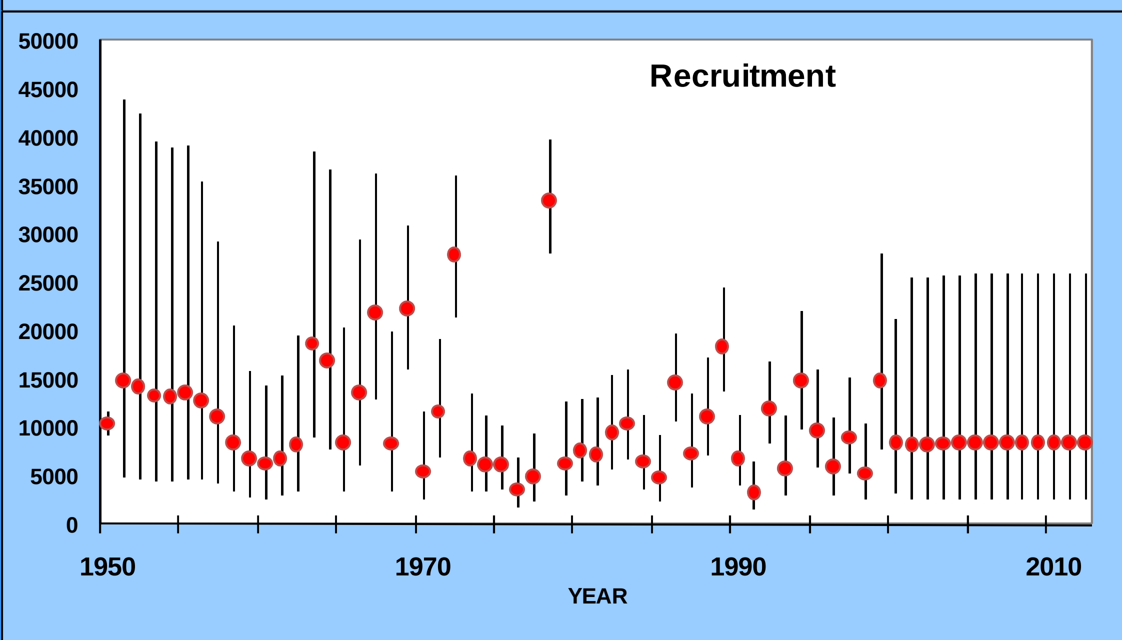


Integrates Time Series Estimation with Productivity Inference



Integrated Analysis





- Produces comprehensive estimates of model uncertainty
- Smoothly transitions from pre-data era, to data-rich era, to forecast
- Stabilizing factor:
  - Continuous population dynamics process

Stock Synthesis Structure

NUMBERS-AT-AGE

Cohorts: gender, birth season, growth pattern;

"Morphs" can be nested within cohorts to achieve size-survivorship;

Distributed among areas

RECRUITMENT

Expected recruitment is a function of total female spawning biomass;

Optional environmental input;

apportioned among cohorts and morphs;

Forecast recruitments are estimated, so get variance

AREA

Age-specific movement between areas

FLEET / SURVEY

Length-, age-, gender selectivity

CATCH

F to match observed catch;

Catch partitioned into retained and discarded, with discard mortality

PARAMETERS

Can have prior/penalty;

Time-vary as time blocks, random annual deviations, or a function of input environmental data

Stock Synthesis Data

- Retained catch
- CPUE and survey abundance

- % Discard
- Mean body weight
- Tag-recapture
- Stock composition

- Age composition
  - Within length range
- Size composition
  - By biomass or numbers
  - Within gender and discard/retained
  - Weight bins or length bins
- Mean length-at-age

Variance Estimation

- Inverse Hessian (parametric quadratic approximation)
- Likelihood profiles
- MCMC (brute force, non-parametric)
- Parametric bootstrap

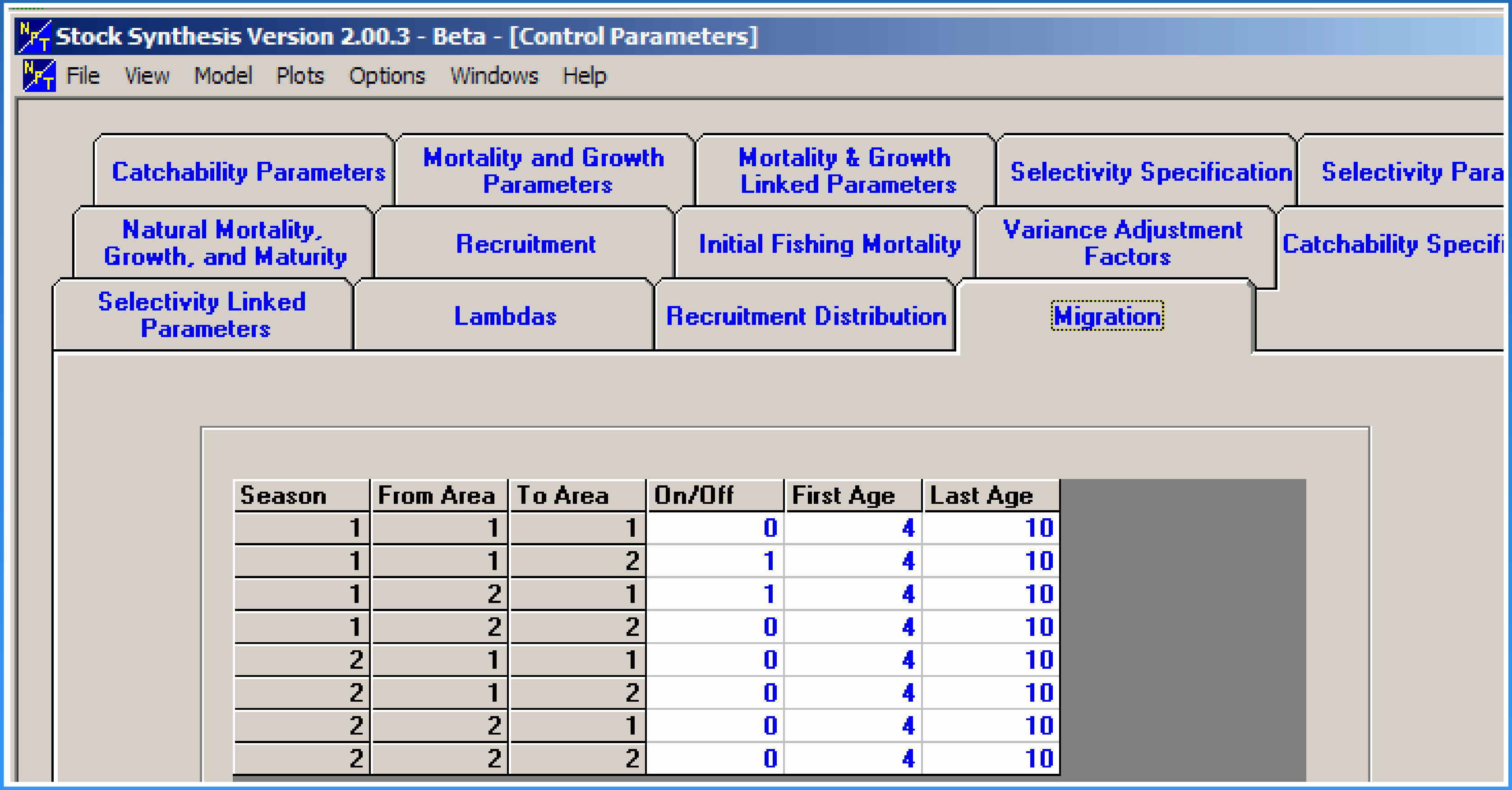
Risk Assessment

- Calculate future benefits and probability of overfishing and stock depletion as a function of harvest policy for each future year
- Accounting for:
  - Uncertainty in current stock abundance
  - Variability in future recruitment
  - Uncertain estimate of benchmarks
  - Incomplete control of fishery catch
  - Time lag between data acquisition and mgmt revision
  - Model scenarios
  - retrospective biases
  - Pr(ecosystem or climate shift)
  - Impacts on other ecosystem components

ADMB

- Auto-Differentiation Model Builder
- C++ overlay developed by Dave Fournier in 1980s
- Co-evolved with advancement of fishery models
- Recently purchased by Univ Cal (NCEAS) using a private grant
- Now available publically and will become open source software

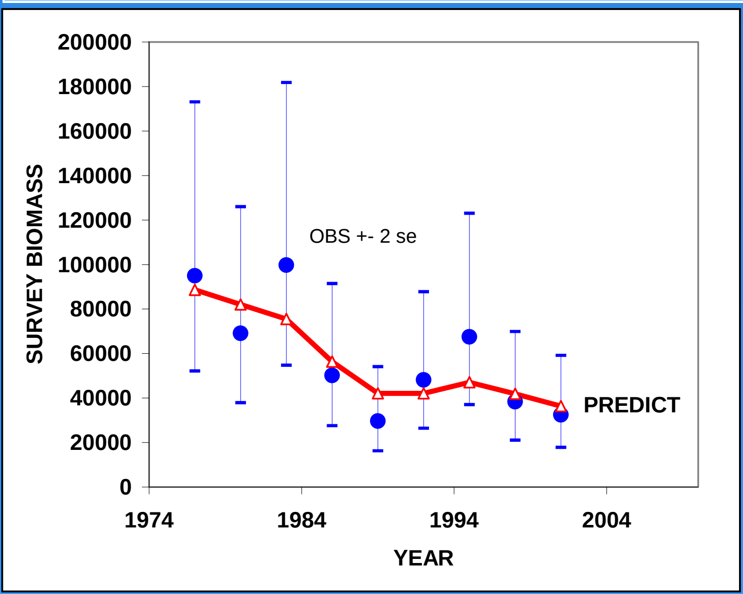
Graphical Interface: Toolbox

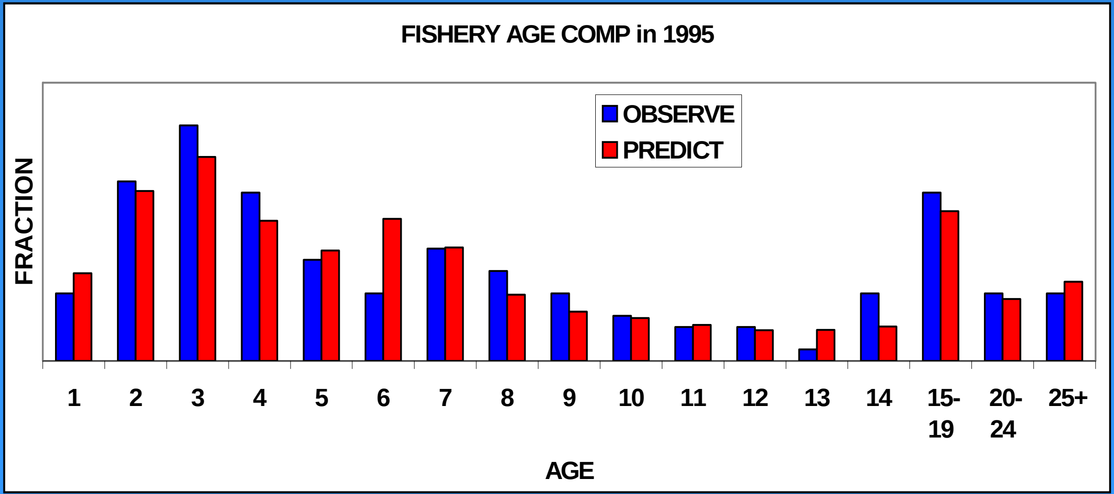


Season	From Area	To Area	On/Off	First Age	Last Age
1	1	1	0	4	10
1	1	2	1	4	10
1	2	1	1	4	10
1	2	2	0	4	10
2	1	1	0	4	10
2	1	2	0	4	10
2	2	1	0	4	10
2	2	2	0	4	10

Stock Synthesis Overview

- Age-structured simulation model of population
  - Recruitment, natural and fishing mortality, growth
- Observation sub-model derives expected values for observed data of various kinds and is robust to missing observations
  - Survey abundance, catch, proportions-at-age or length
- Can work with limited data when flexible options set to mimic simplifying assumptions of simple models
- Can include environmental covariates affecting population and observation processes





An Example

- Simple vs. complex model structure
- Time-varying model parameter
- First, motivation for an advanced approach to catchability

Calibrating Abundance Index

- The observed annual abundance index, O_t, is basically density (CPUE) averaged over the spatial extent of the stock
- Call model's estimate of abundance, A_t
- In model: $E(O_t) = q \times A_t + e$
- Where q is an estimated model parameter
- Concept of q remains the same across a range of data scenarios:

Calibrating Abundance Index

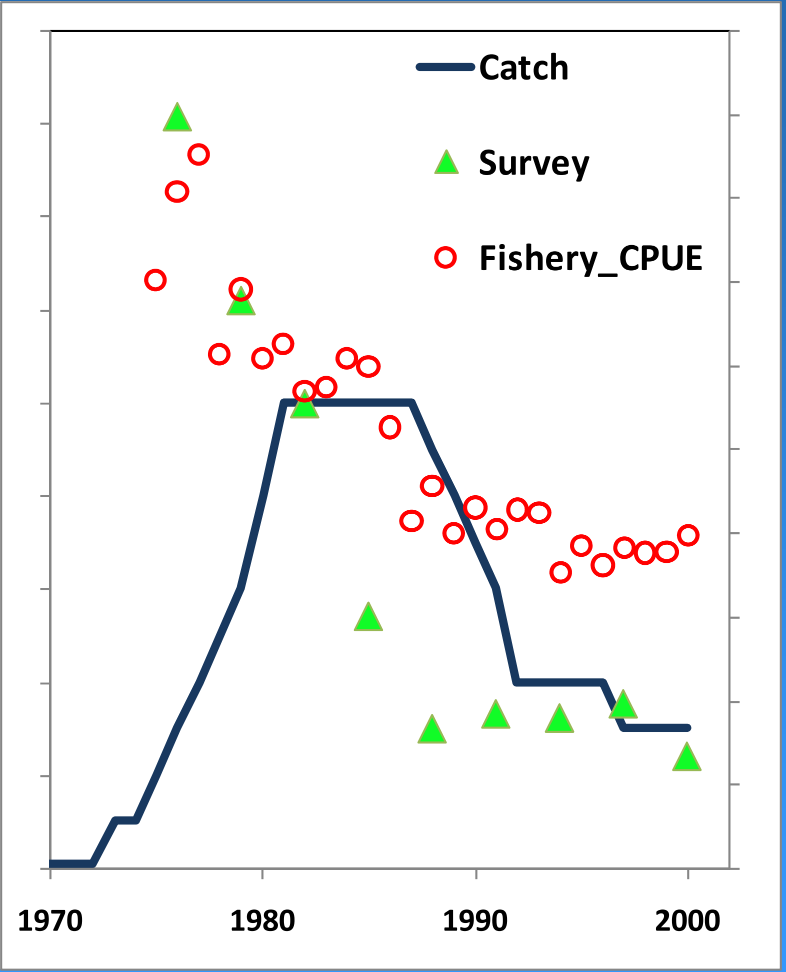
- If O time series comes from a single Fisheries Survey Vessel
- If survey vessel A replaces survey B and a calibration experiment is done
- If O come from four chartered fishing vessels each covering the entire area
- If O come from hundreds of fishing vessels using statistical model to adjust for spatial and seasonal effort concentration

Abundance Index Time Series

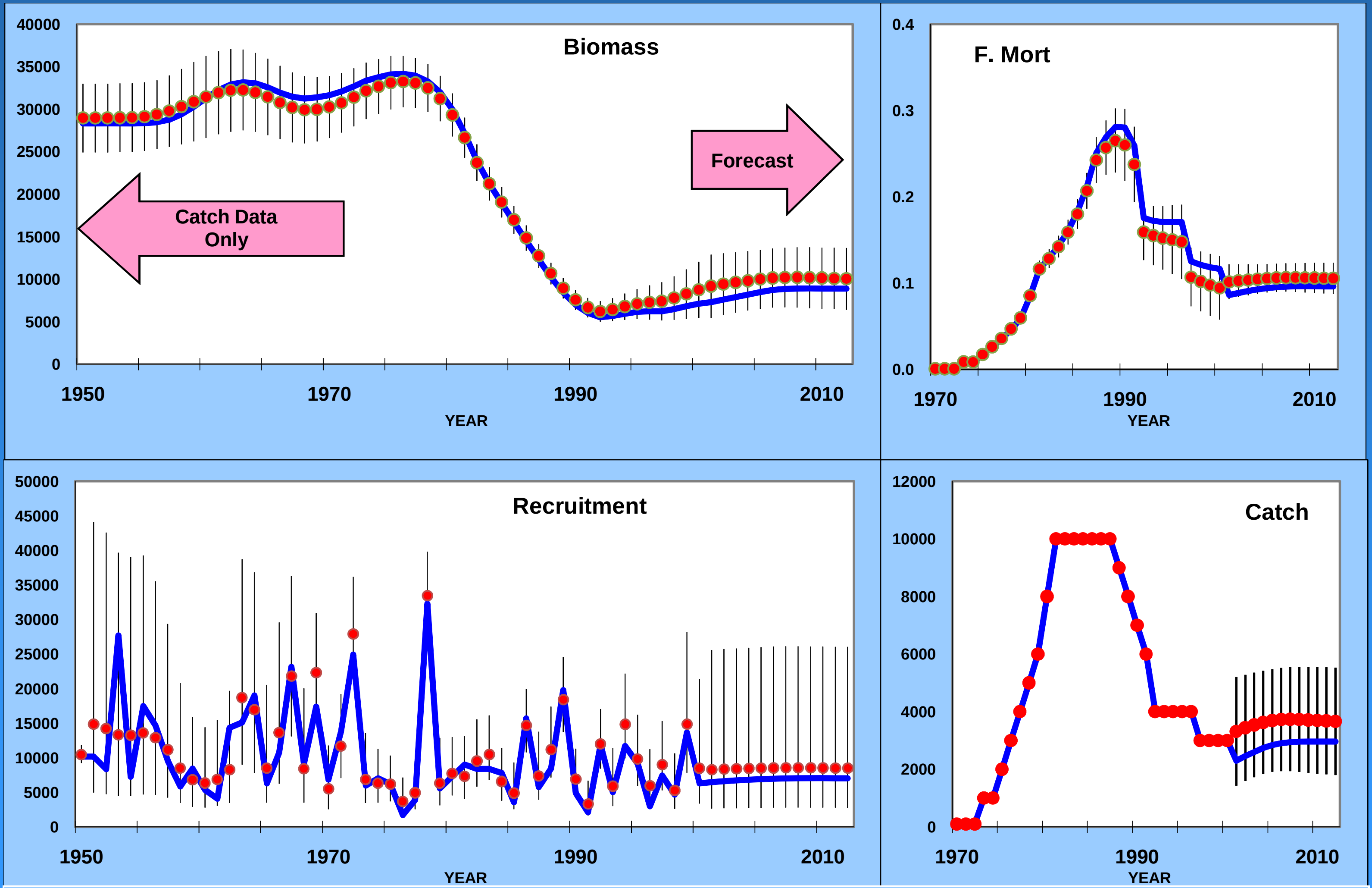
- Each set-up is correct, but what's wrong with the big picture?
- q is not perfectly constant for any method!
- Some methods standardize q better than others
- Building models that admit the inherent variability in q_t and constrain q variability through information about standardization and calibration can:
  - achieve a scalable approach across methods;
  - incorporate q uncertainty in overall C.I.;
  - Show value of calibration and standardization

Example

- Fishery catch
- CPUE, CV=0.1, density-dependent q
- Triennial fishery-independent survey, CV=0.3
- Age and size composition, sample size = 125 fish

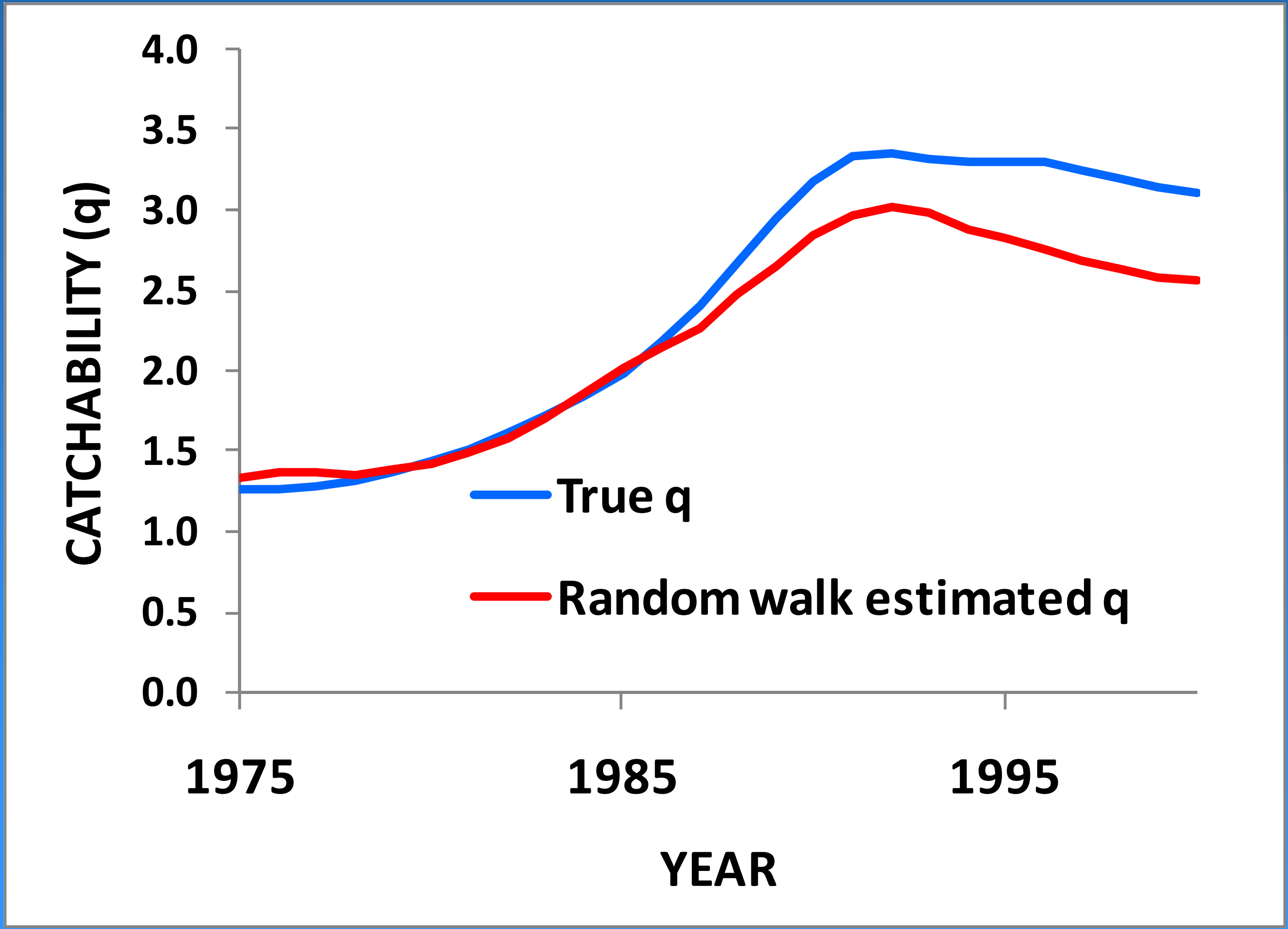


Results:
all data, all parms, random walk q



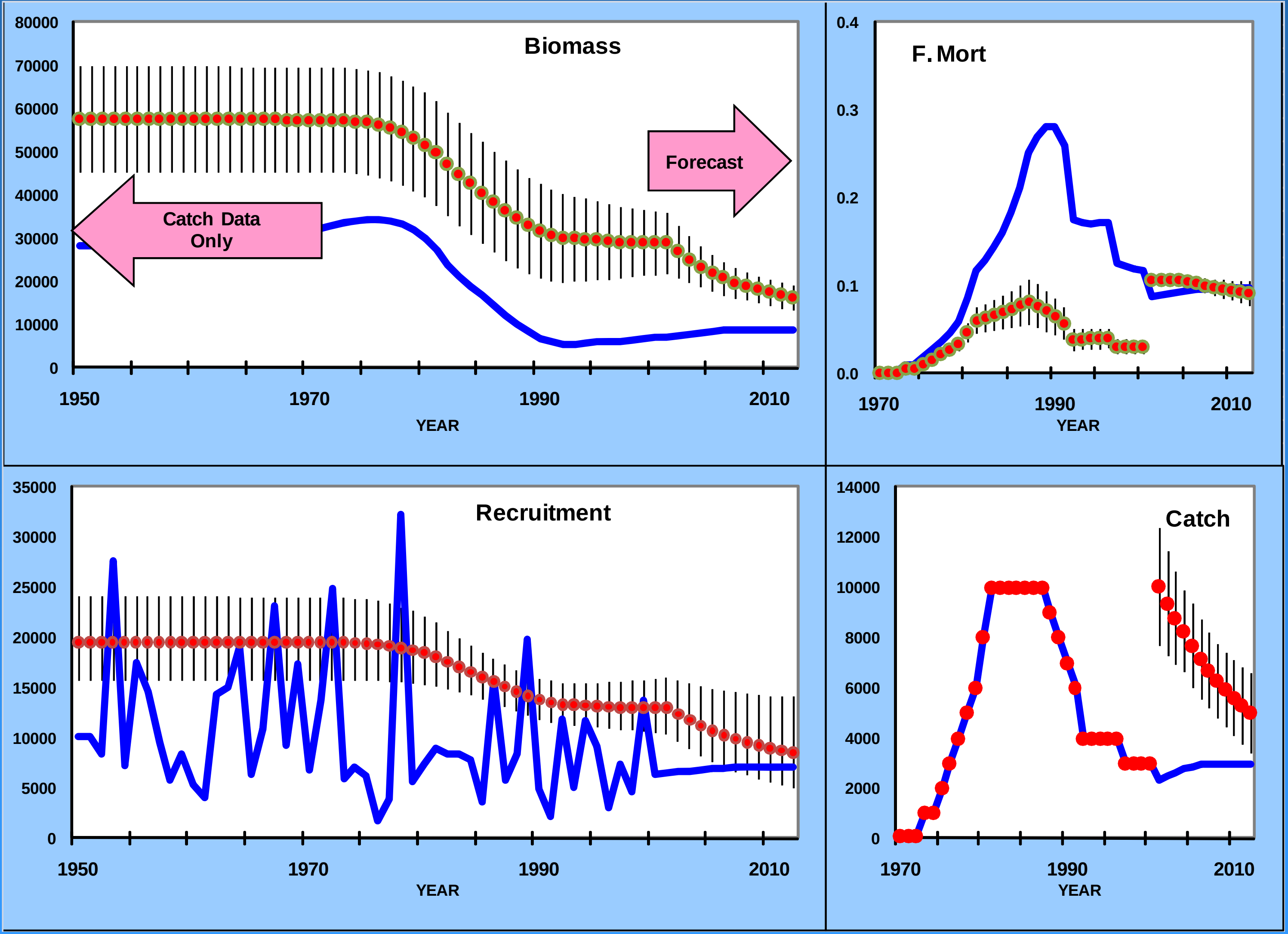
Blue line = true values; red dot = estimate with 95% CI

Fishery q

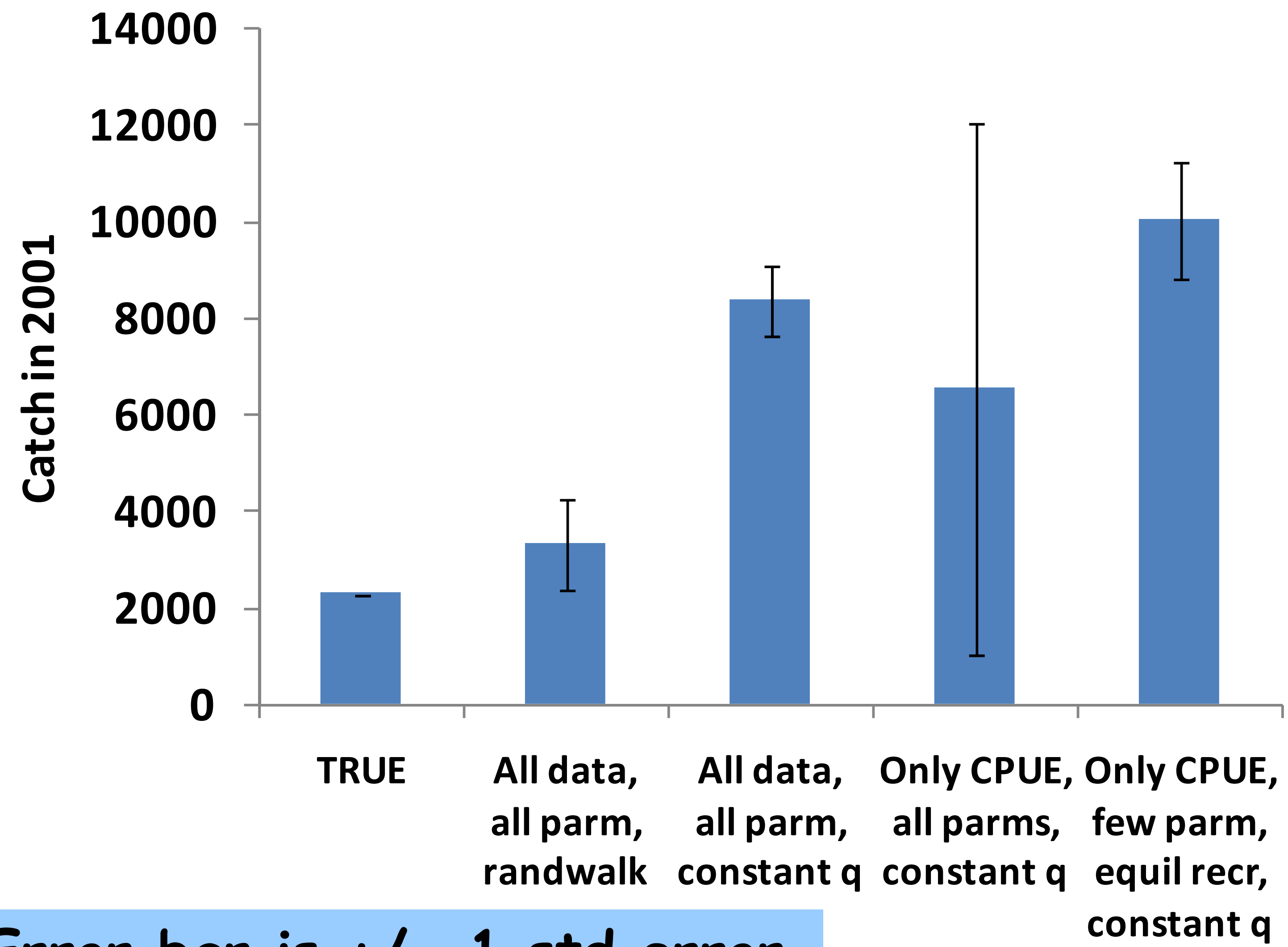


CATCHABILITY (q)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1975
1985
1995
YEAR
True q
Random walk estimated q

CPUE only, Simple Model, constant q



Bias and Precision in Forecast Catch



Error bar is +/- 1 std error

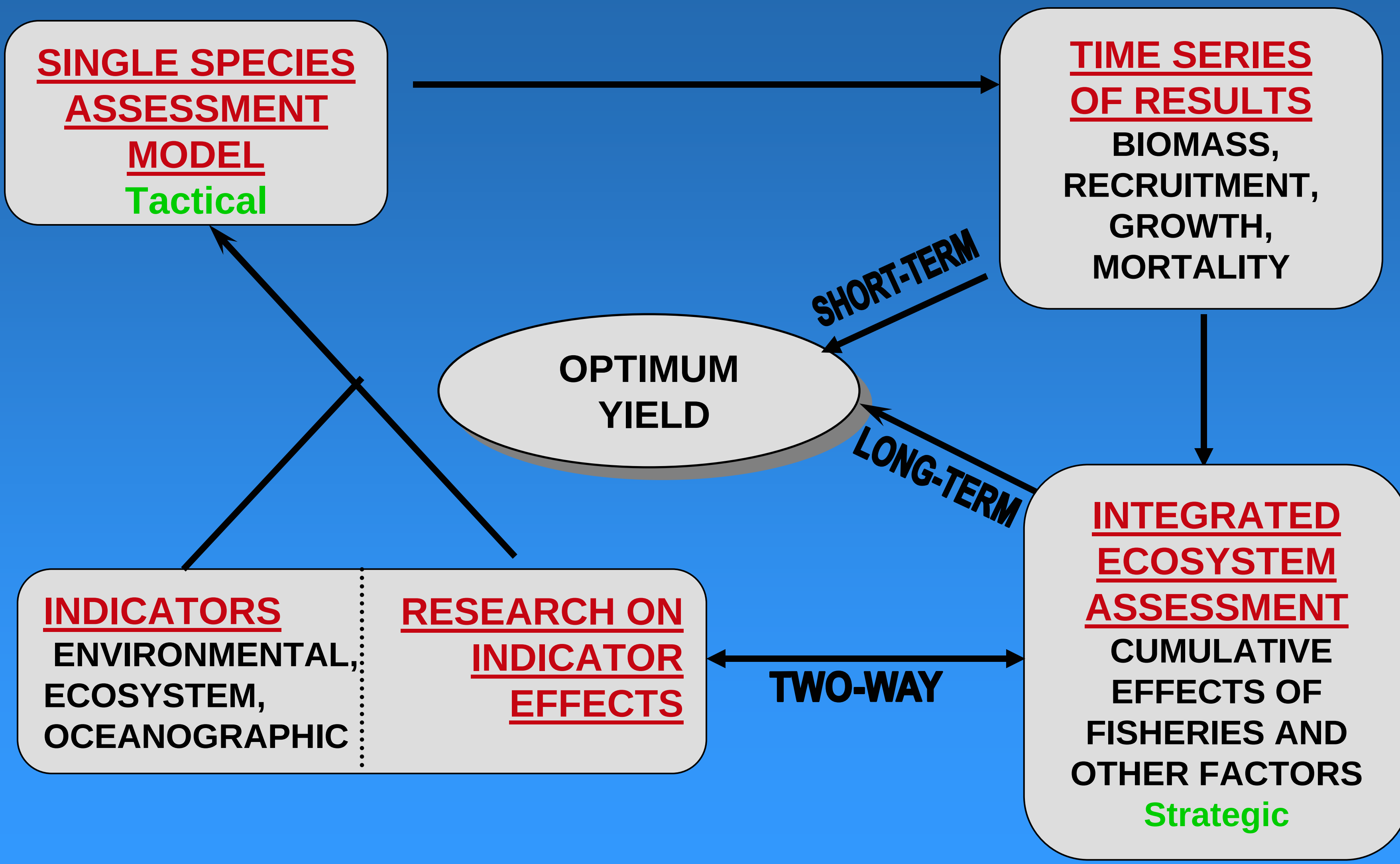
NEXT STEPS

- Tier III Assessments
  - Spatially explicit
  - Linked to ecosystem processes

Space: The Final Frontier

- "Unit Stock" paradigm:
  - Sufficient mixing so that localized recruitment and mortality is diffused throughout range of stock
  - Spatially explicit data is processed to stock-wide averages
- Marine Protected Area paradigm:
  - Little mixing so that protected fish stay protected
- Challenge: Implement spatially explicit assessment structure with movement and without bloating data requirements

Stock Assessment – Ecosystem Connection



Getting to Tier III

Process	Tier II	Tier III
Average Productivity (Spawner-Recruitment)	Empirical over decades of fishing	Predict from Ecosystem Food Web and Climate Regimes
Annual Recruitment	Annual random process with measurable outcome	Predictable from ecosystem and environmental factors
Growth & Reproduction	Measurable, but often held constant	Predictable from ecosystem and environmental factors
Survey Catchability	Usually Constant or random walk	Linked to environmental factors
Natural Mortality	Mean level based on crude relationships and wishful thinking	Feasible?, or just wishful thinking on larger scale?

How Are We Doing?

Assessments of 230 FSSI stocks following SAIP and increased EASA funds

Year	Assessments Done	Stocks with Adeq. Asmt.
2000	37	106
2001	53	111
2002	64	106
2003	60	107
2004	63	108
2005	105	120
2006	68	120
2007	74	128

Summary

Stock Synthesis Integrated Analysis Model

- Flexible to accommodate multiple fisheries and surveys
- Explicitly models pop-dyn and observation processes (movement, ageing imprecision, size and age selectivity, discard, etc.)
- Parameters can be a function of environmental and ecosystem time series
- Estimates precision of results
- Estimates stock productivity, MSY and other management quantities and forecasts