Biological Models Used to Evaluate Medium-Term Impacts

9-January-2004

Stock Assessment

- Objectives of an assessment:
  - Stock status
  - Uncertainties
  - Projections

Assessment Input Data

- Basic Biology:
  - lifespan
  - growth
  - movements
- Fishery Information:
  - maturity rate
  - historical development (areas, gears)
  - past and current regulations (size limits, gear restriction
  - catch (landings, discards, age/size distribution)
  - effort (catch rates)

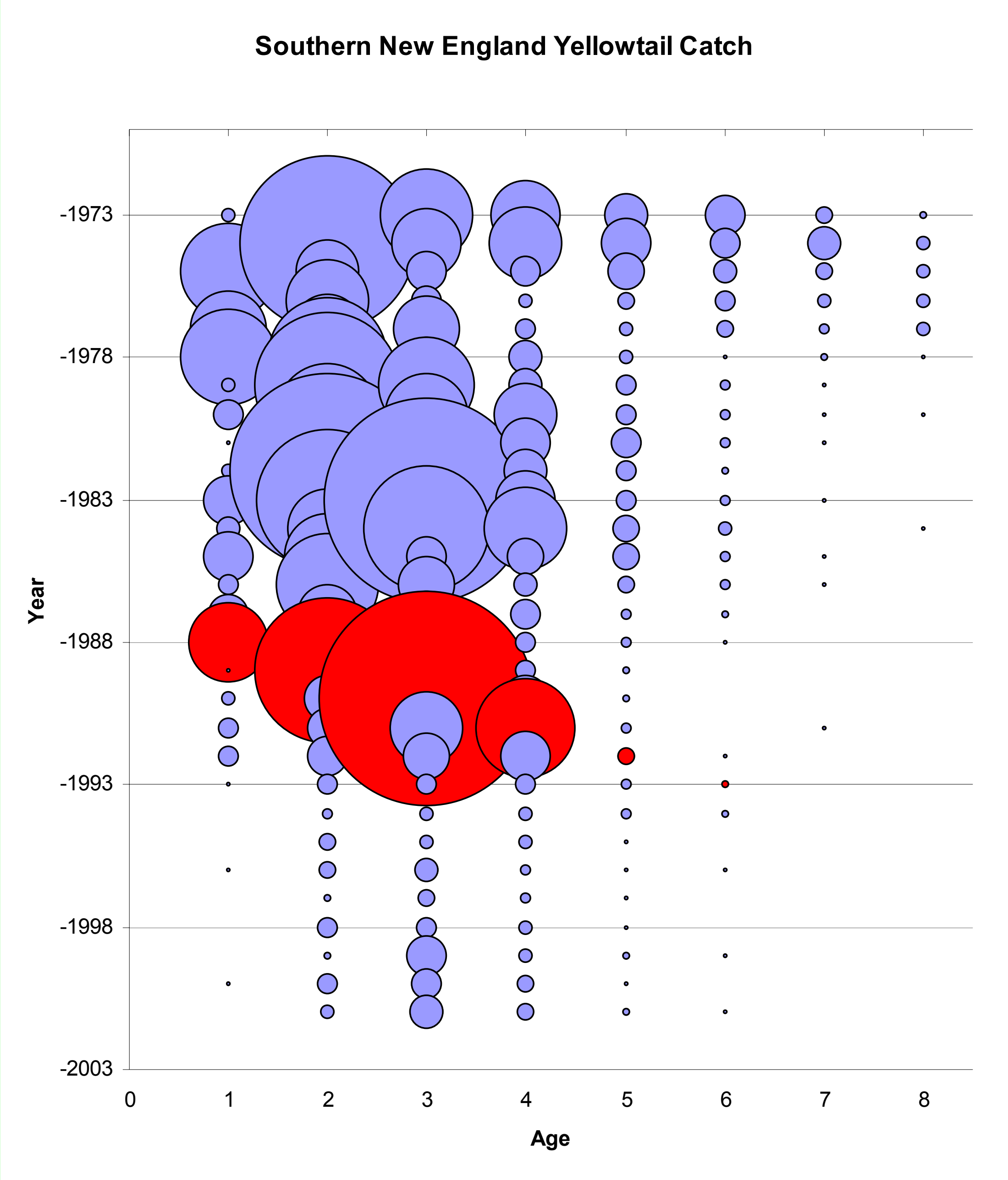
- Surveys
  - distribution
  - relative abundance and biomass over time
  - age/size structure
  - life history (growth, maturity)

Types of Assessments

- A *nonlinear* progression from "data-poor" to "data-rich" situations.
  - Index Methods (n = 7):
    - Descriptive assessment of catch and survey data.
  - Biomass Dynamics Methods (n = 1):
    - Combined analysis of catch and survey data with a simple biomass-based population model.
  - Age-Structured Methods (n = 11, 8 of 11 include discards):
    - Virtual Population Analysis: Back-calculate stock numbers at age using age distribution of the catch, calibrated with survey indices to minimize measurement error.
    - Statistical Catch-at-Age Analysis: Forward-projection of stock numbers at age using age distribution of the catch, calibrated with survey indices or other auxiliary information in a likelihood-based framework.

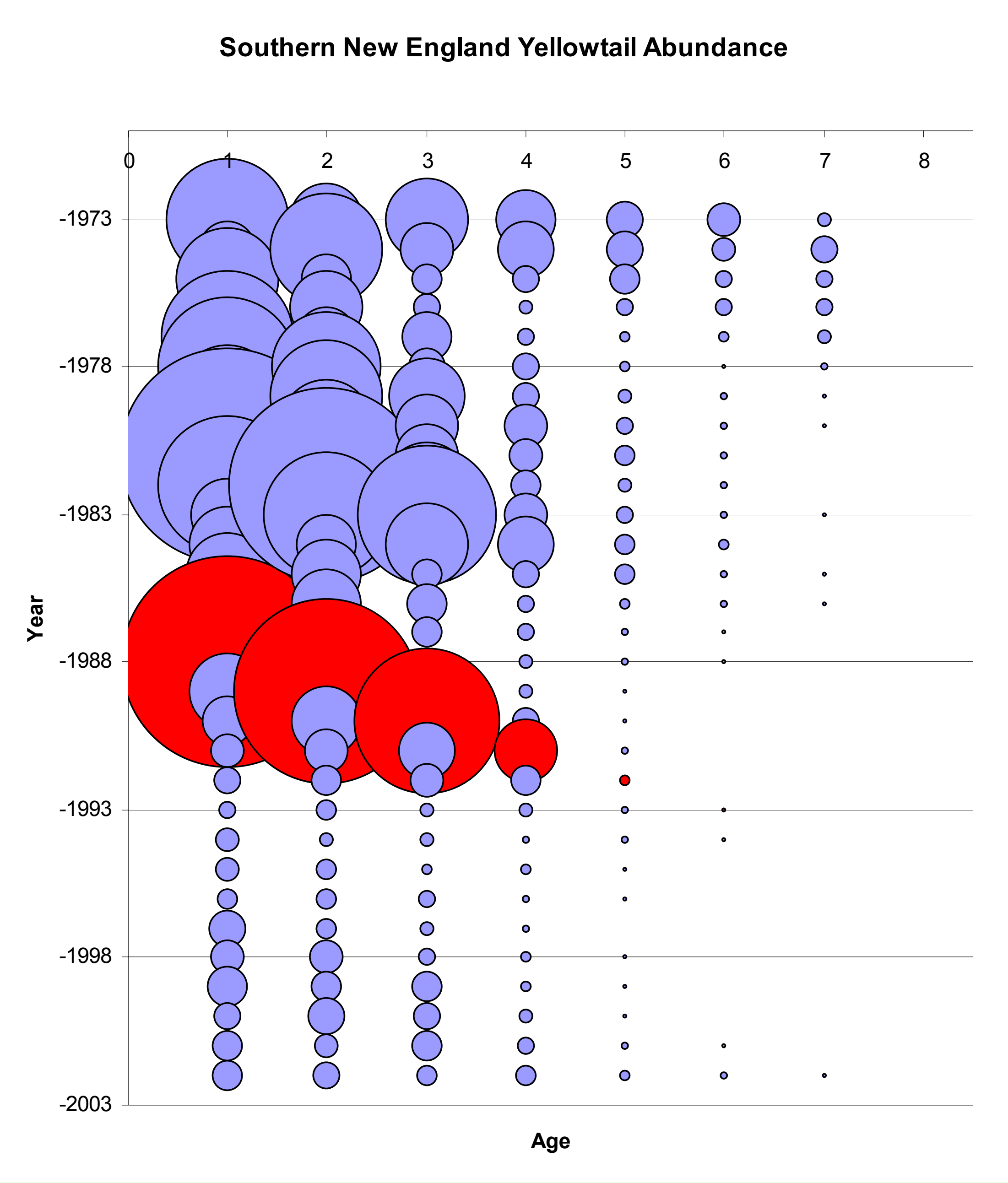
Age-Based Methods

- Age distribution of the catch.
  - From census of total catch biomass and port samples.
  - SNE yellowtail example:
    - 1987 yearclass dominated the catch in the late 80s early 90s.



VPA

- Reconstruction of all yearclasses gives a total population estimate.
- Input Data:
  - catch at age
  - estimate of natural mortality
  - *initial guess* about abundance of survivors at the oldest age.

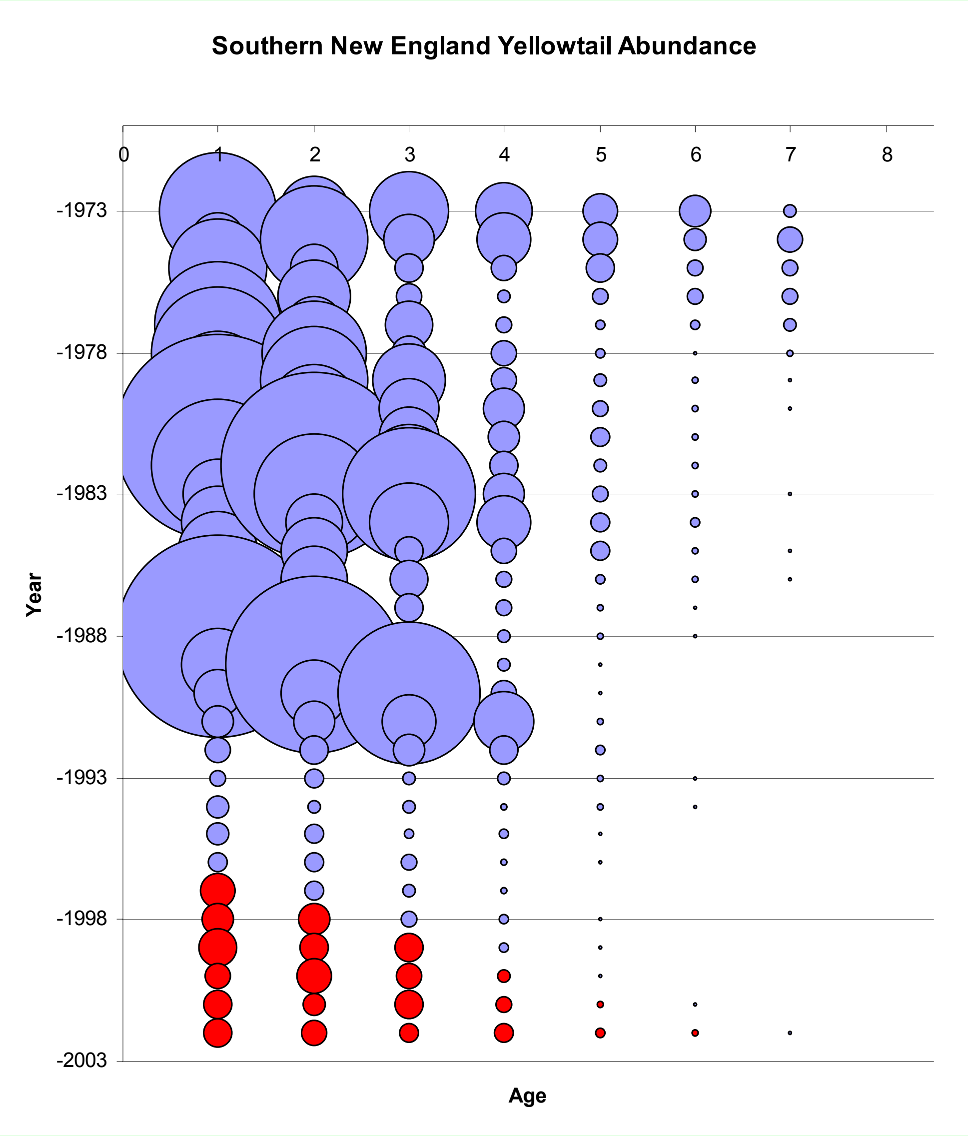


VPA Calibration

- Initial guesses are replaced with <u>estimates</u>:
  - oldest age of historical yearclasses estimated by assuming that age-7 fish have the same vulnerability to the fishery as ages 4-6:

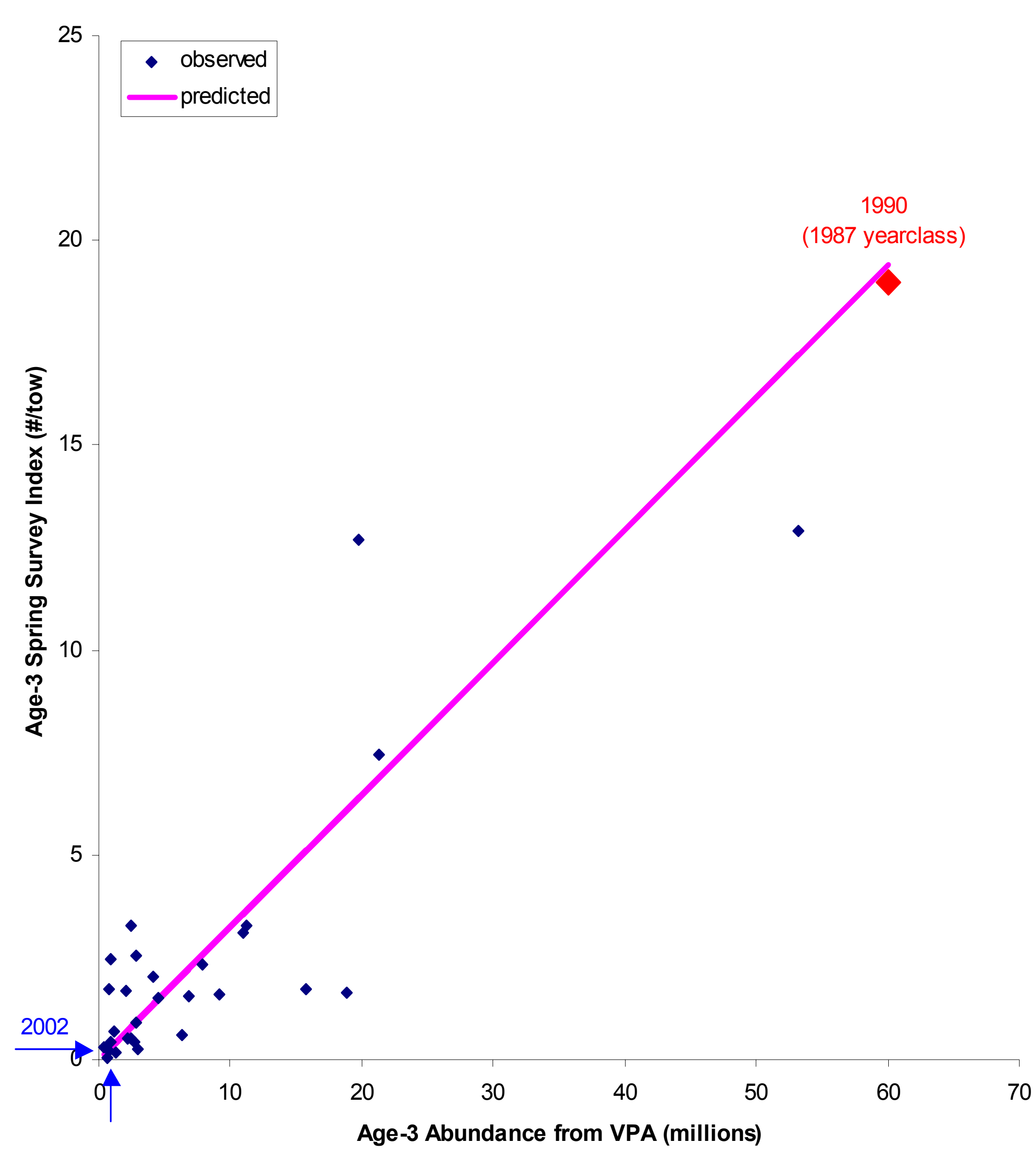
$$N_t = \frac{C_t Z_t}{F_t\left(1 - e^{-Z_t}\right)}$$

  - yearclasses that are alive now require more information.
    - need an independent index of relative abundance over time.



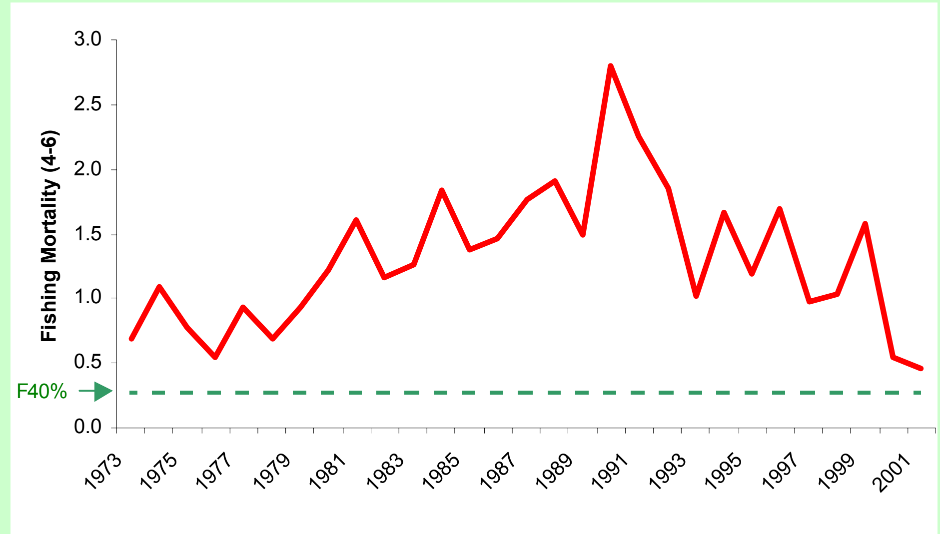
VPA Calibration

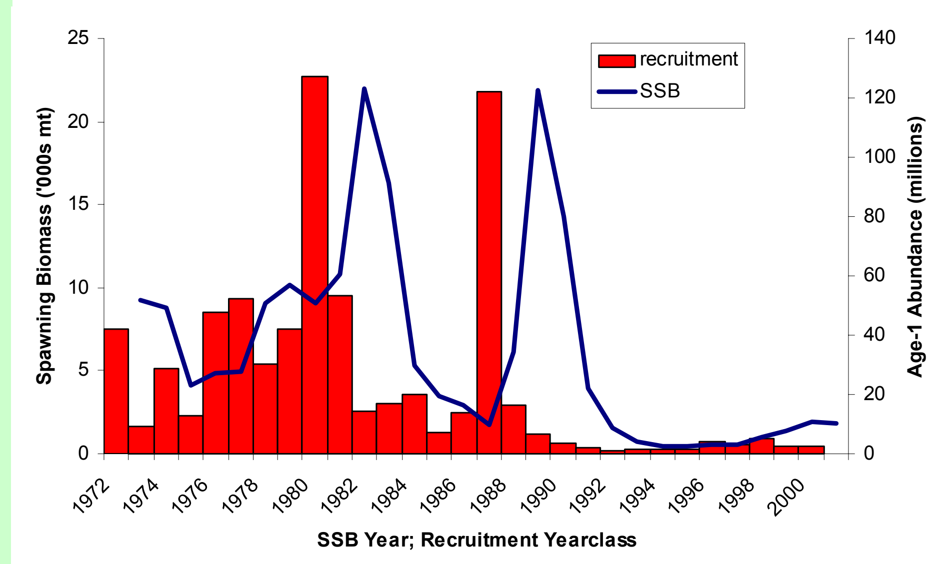
- Abundance of living yearclasses in 2002 are estimated using a predictive relationship between historical VPA abundance and survey indices.



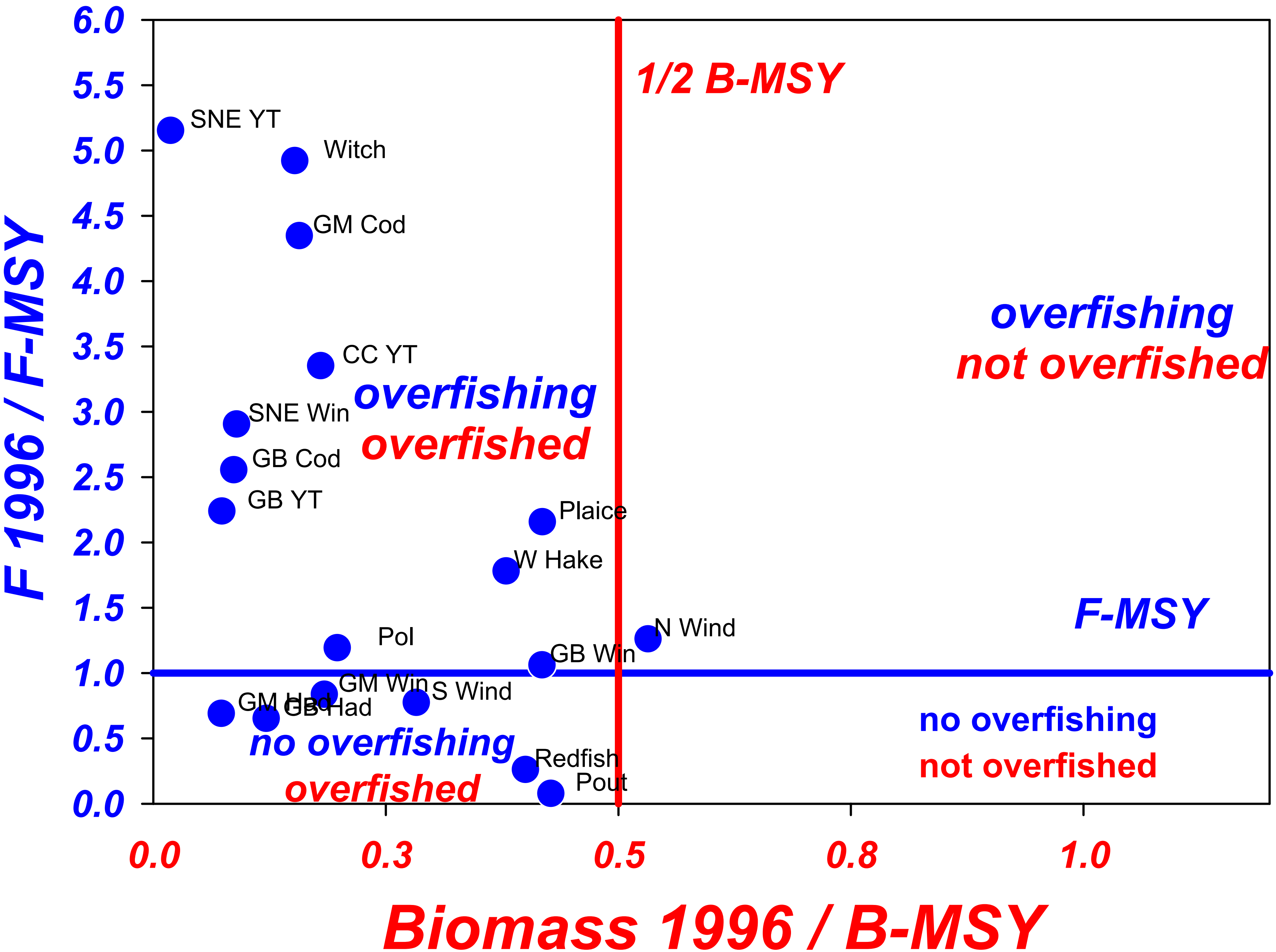
VPA Estimates

- <u>Informative Assessment</u>:
  - Example: SNE yellowtail
  - Estimates of stock size and F,
  - But also age distribution, recruitment, mature biomass, etc.

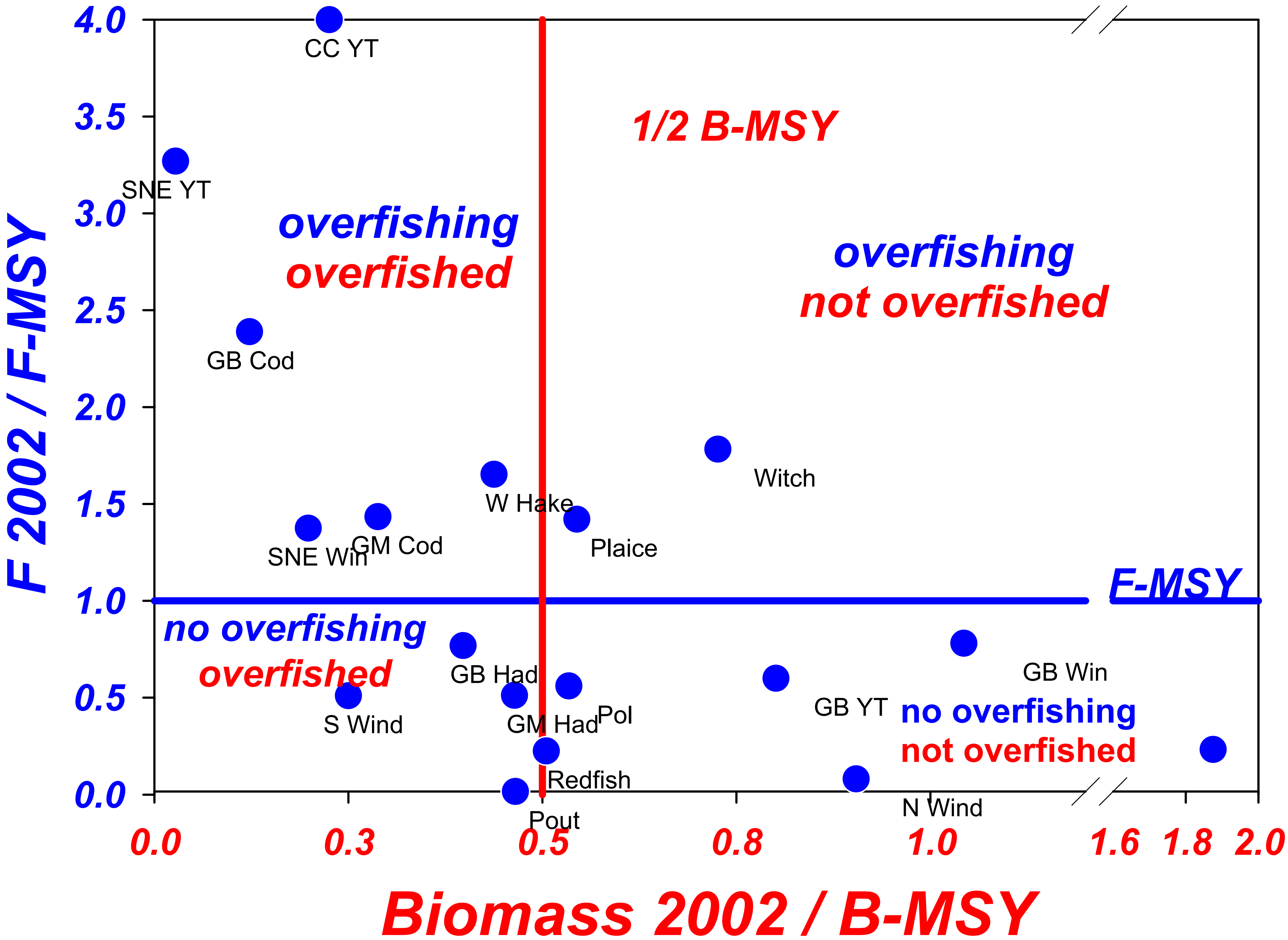




Groundfish Stock Status - 1996

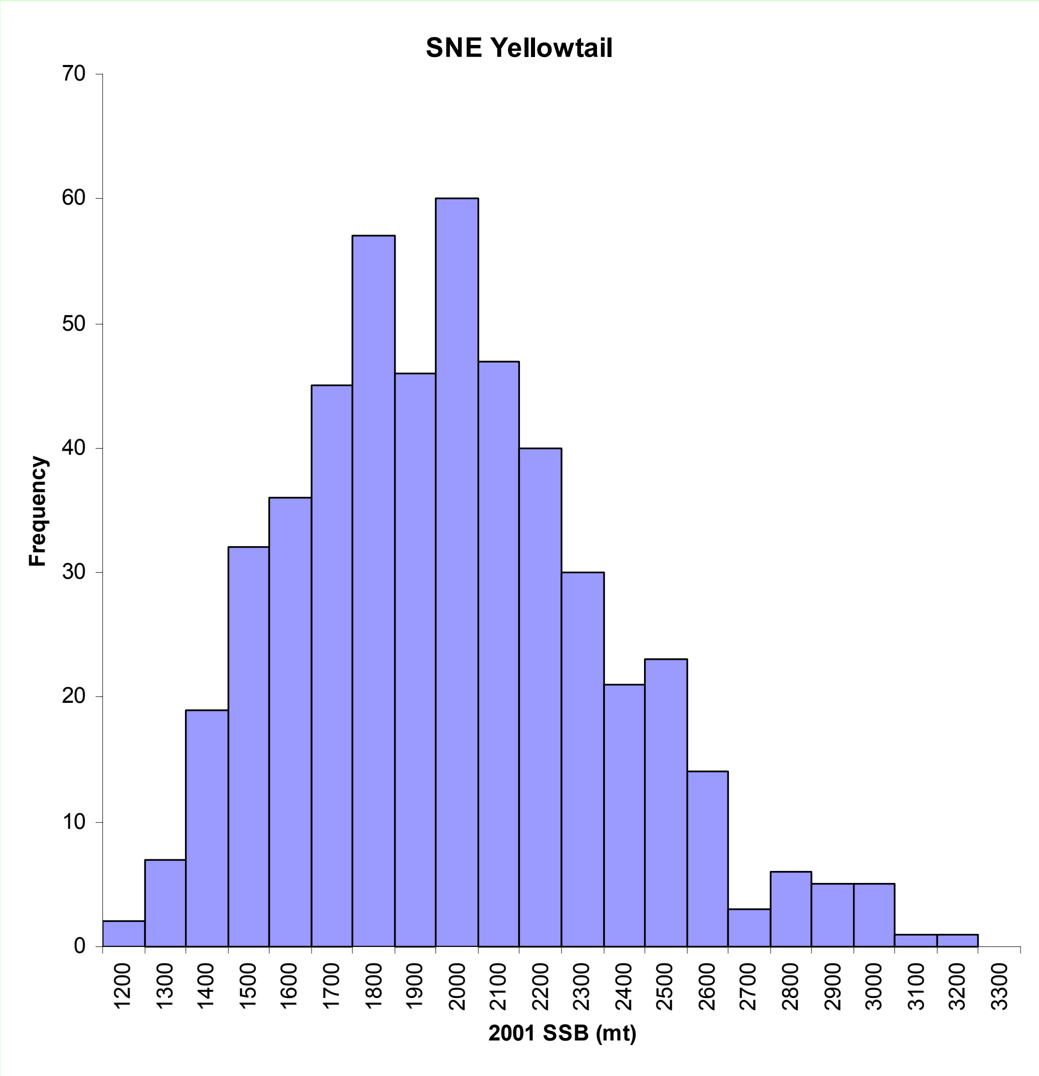


Groundfish Stock Status - 2002



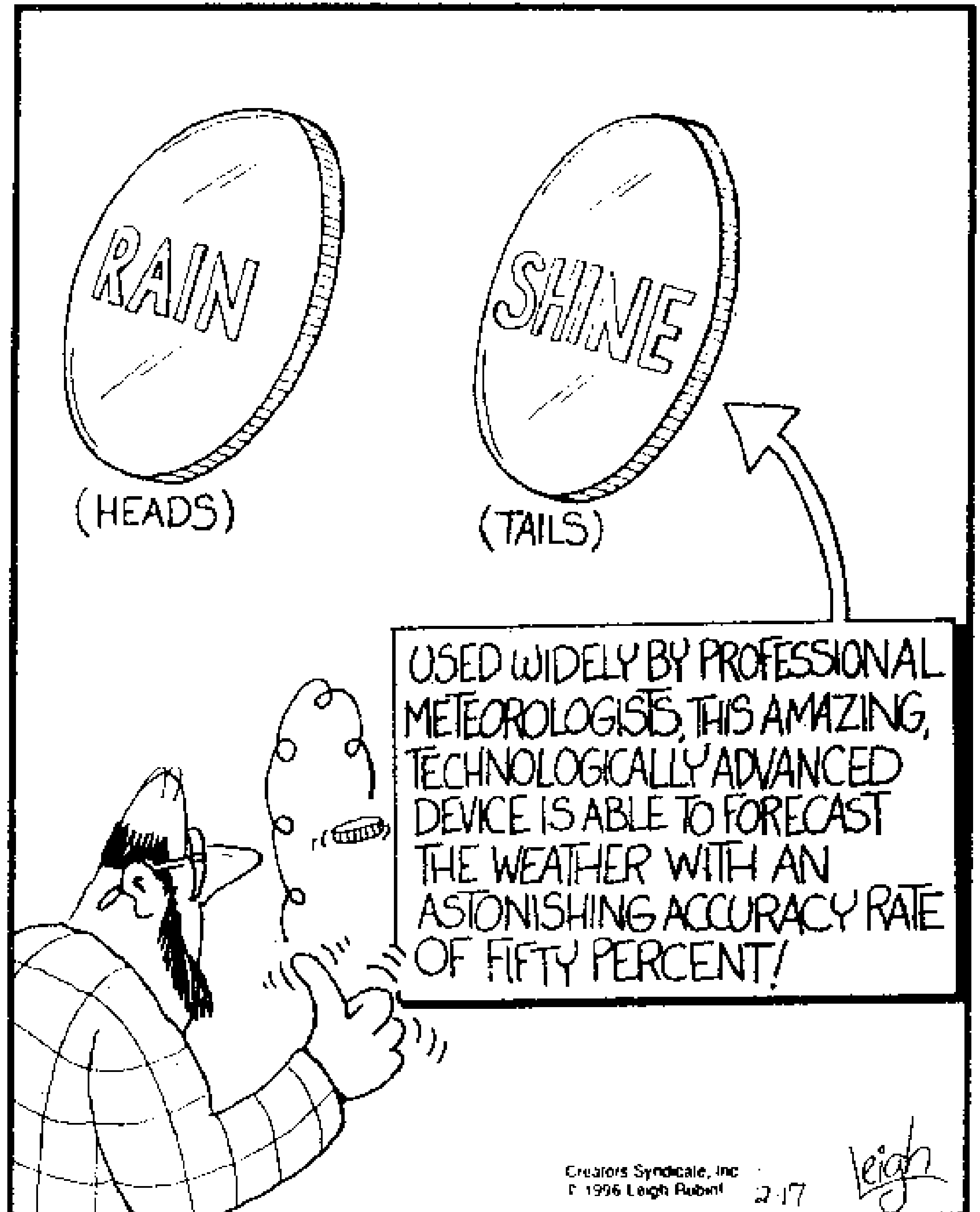
VPA Uncertainty

- Similar to production model: survey measurement errors are reshuffled many times to estimate precision. (“bootstrapping”).
- The estimate of 2001 SSB is 1850mt, with a 80% confidence limit of 1500 to 2500mt.



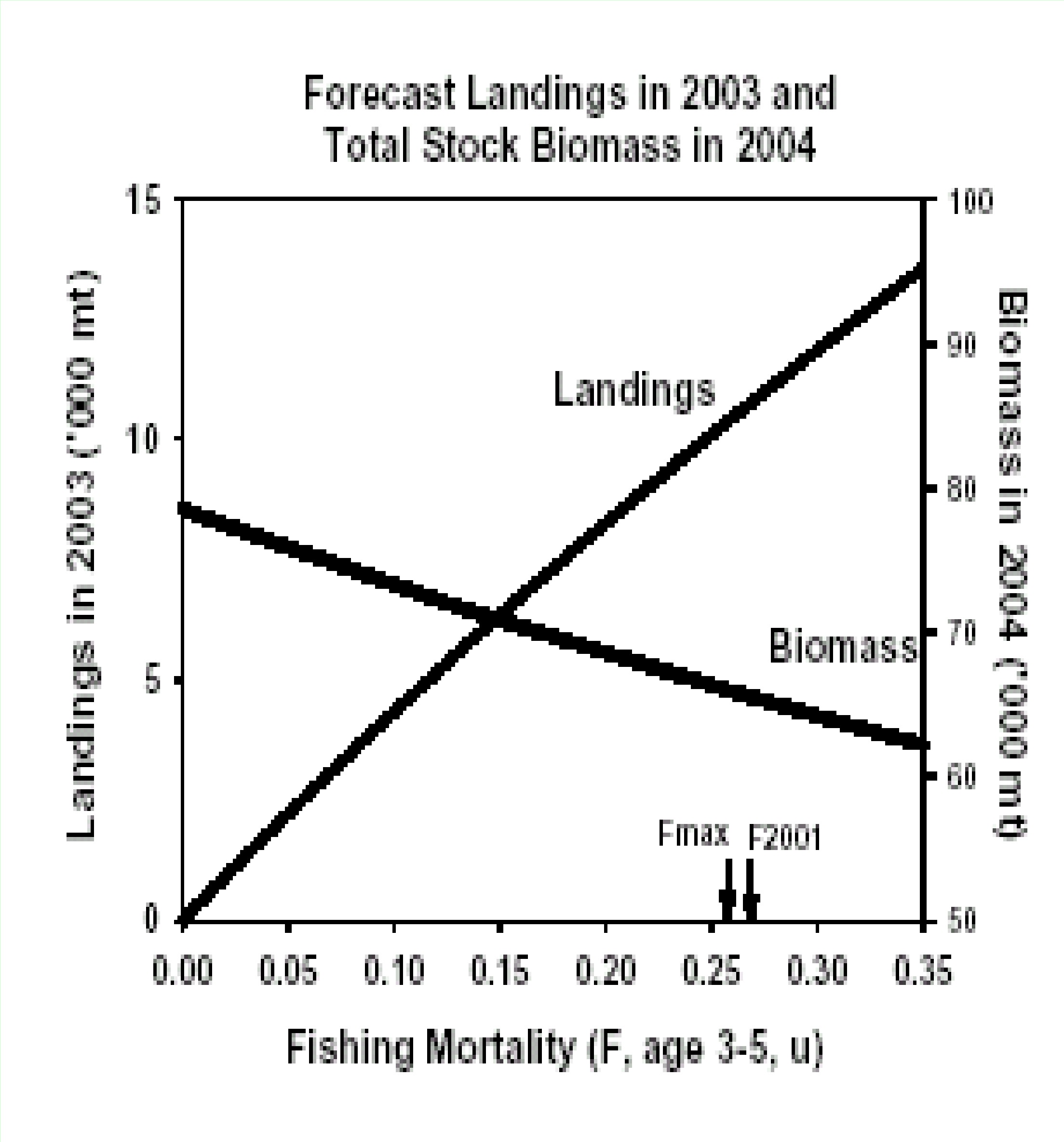
Projections

"It is far better to foresee even without certainty than not to foresee at all" Poincare, *The Foundations of Science*



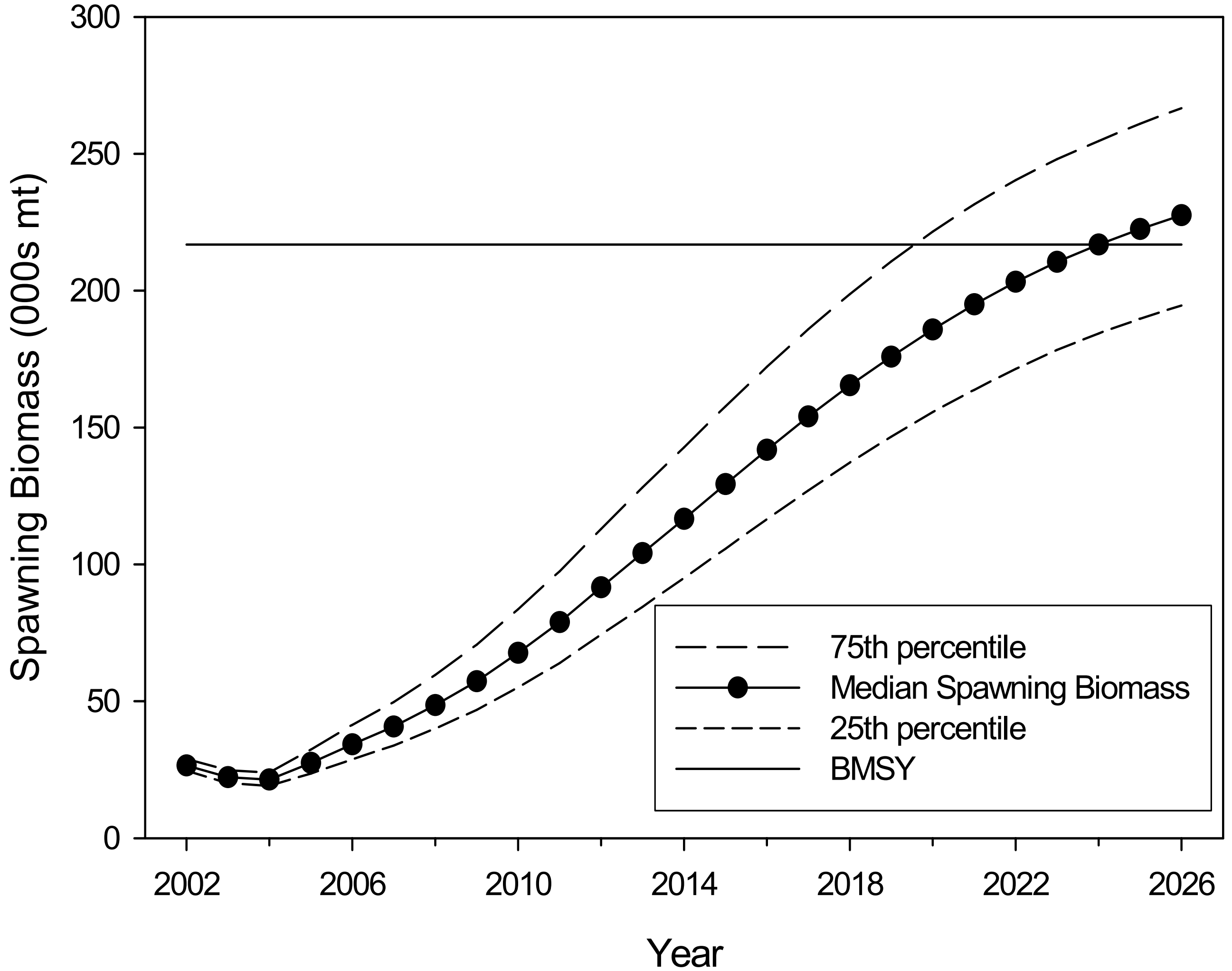
Short-Term Projection

- <u>Fluke (SAW35):</u>
  – Landings in 2003 would need to be 10,580 mt (23.3 million lbs) to meet the target F rate of Fmax = 0.26 with 50% probability.



Long-Term Projection

- Georges Bank Cod
  - the stock is expected to have approximately a 50% chance of rebuilding to SSB_{MSY} by 2026 if fished at an F of 0.18.



Age-Structured Model

- Population Numbers, Survival, Spawning Biomass
- Catch, Landings, and Discards
- Population Harvest

Population Numbers at Age

$$\underline{N}(t) = \begin{bmatrix} N_R(t) \\ N_{R+1}(t) \\ N_{R+2}(t) \\ \vdots \\ N_A(t) \end{bmatrix}$$

Survival by Age Class

$$N_a(t) = N_{a-1}(t) \cdot e^{-M(t-1) - F_{a-1}(t-1)}$$

$$for\ a = R + 1\ to\ A - 1$$

Survival of Plus Group

$$N_A(t) = N_A(t-1)\cdot e^{-M(t-1)-F_A(t-1)}$$
$$+ N_{A-1}(t-1)\cdot e^{-M(t-1)-F_{A-1}(t-1)}$$

Spawning Biomass

$$SSB(t) = \sum_{a=R}^{A} W_{S,a} \cdot FM_a \cdot N_a(t) \cdot e^{-Z_{PROJ}(t)\cdot\left[M(t)+F_a(t)\right]}$$

Catch Numbers at Age

$$C_a(t) = \frac{F_a(t)}{M(t) + F_a(t)}\left[1 - e^{-M(t) - F_a(t)}\right] \cdot N_a(t)$$

Landings

$$L(t) = \sum_{a=1}^{A} C_a(t) \cdot \left[1 - DF_a(t)\right] \cdot W_{L,a}$$

Discards

$$D(t) = \sum_{a=1}^{A} C_a(t) \cdot DF_a(t) \cdot W_{D,a}$$

Population Harvest

- Input fully-recruited fishing mortality F(t)
- Input partial recruitment vector PR(t) and $Z_{PROJ}(t)$
- Input discard fraction at age vector DF(t) if applicable

- Input landings quota Q(t)
- Input partial recruitment vector PR(t) and $Z_{PROJ}(t)$
- Input discard fraction at age vector DF(t) if applicable
- Solve for F(t)

Fishing Mortality at Age

$$F_a(t) = F(t) \cdot PR_a(t)$$

Catch Numbers at Age as a Function of Fishing Mortality

$$C_a(F) = \frac{PR_a(t)\cdot F}{M(t) + PR_a(t)\cdot F}\left[1 - e^{-M(t) - PR_a(t)\cdot F}\right]\cdot N_a(t)$$

Landings as a Function of F

$$L(F) = \sum_{a=1}^{A} C_a(F) \cdot \left[1 - DF_a(t)\right] \cdot W_{L,a}$$

Solve for Fishing Mortality to Harvest Landings Quota

$$Q - L(F) = 0$$

Age-Structured Model

- Stock-Recruitment Relationship
- Initial Population Abundance
- Abundance and Fishing Mortality Thresholds

Stock-Recruitment Relationship

- Deterministic component

- Stochastic component

$$N_R(t) = f\left(SSB(t-R), \underline{\theta}\right) \cdot \varepsilon\left(t, \underline{\varpi}\right)$$

Recruitment Models

- Dependent on spawning biomass (n = 10)
- Independent of spawning biomass (n = 5)
- Uncorrelated stochastic component (n = 10)
- Correlated stochastic component (n = 5)

Beverton-Holt Curve Lognormal Error

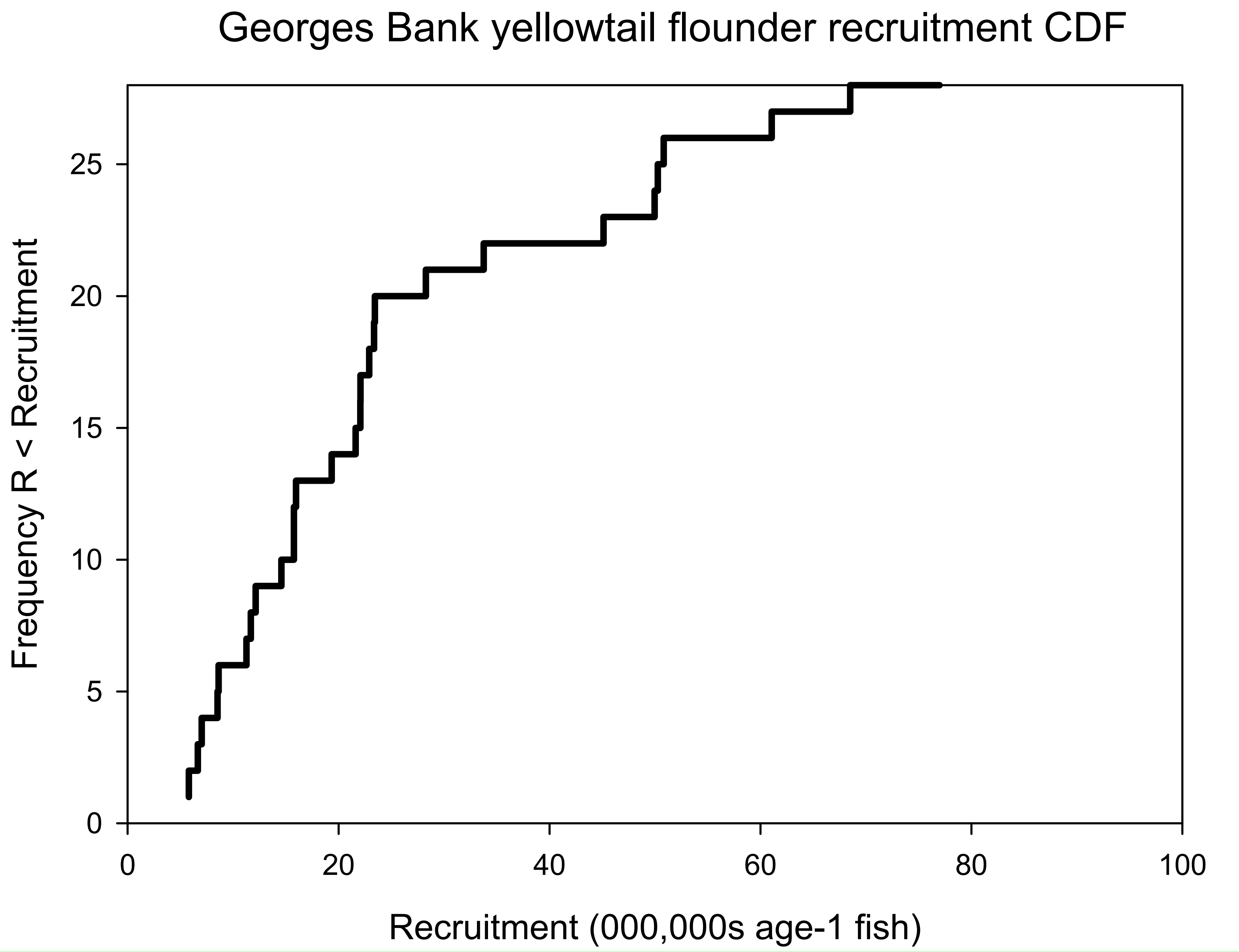
$$n_R(t) = \frac{a \cdot ssb(t-R)}{b + ssb(t-R)} \cdot e^{w}$$

$$where \;\; w \sim N\left(0, \sigma_w^2\right)$$

Empirical Cumulative Distribution Function

$$N_R(t) = (T-1)\left(R_{S+1} - R_S\right)\left(U - \frac{S-1}{T-1}\right) + R_S$$

$$where \;\; S = \left\lfloor 1 + U \cdot (T-1) \right\rfloor$$



Georges Bank yellowtail flounder recruitment CDF
Frequency R < Recruitment
Recruitment (000,000s age-1 fish)
0
5
10
15
20
25
0
20
40
60
80
100

Population Abundance and Fishing Mortality Thresholds

- Abundance
  - Spawning biomass
  - Mean biomass of USER-selected age range
  - Total biomass
- Fishing mortality
  - Fully-recruited fishing mortality
  - Fishing mortality weighted by biomass

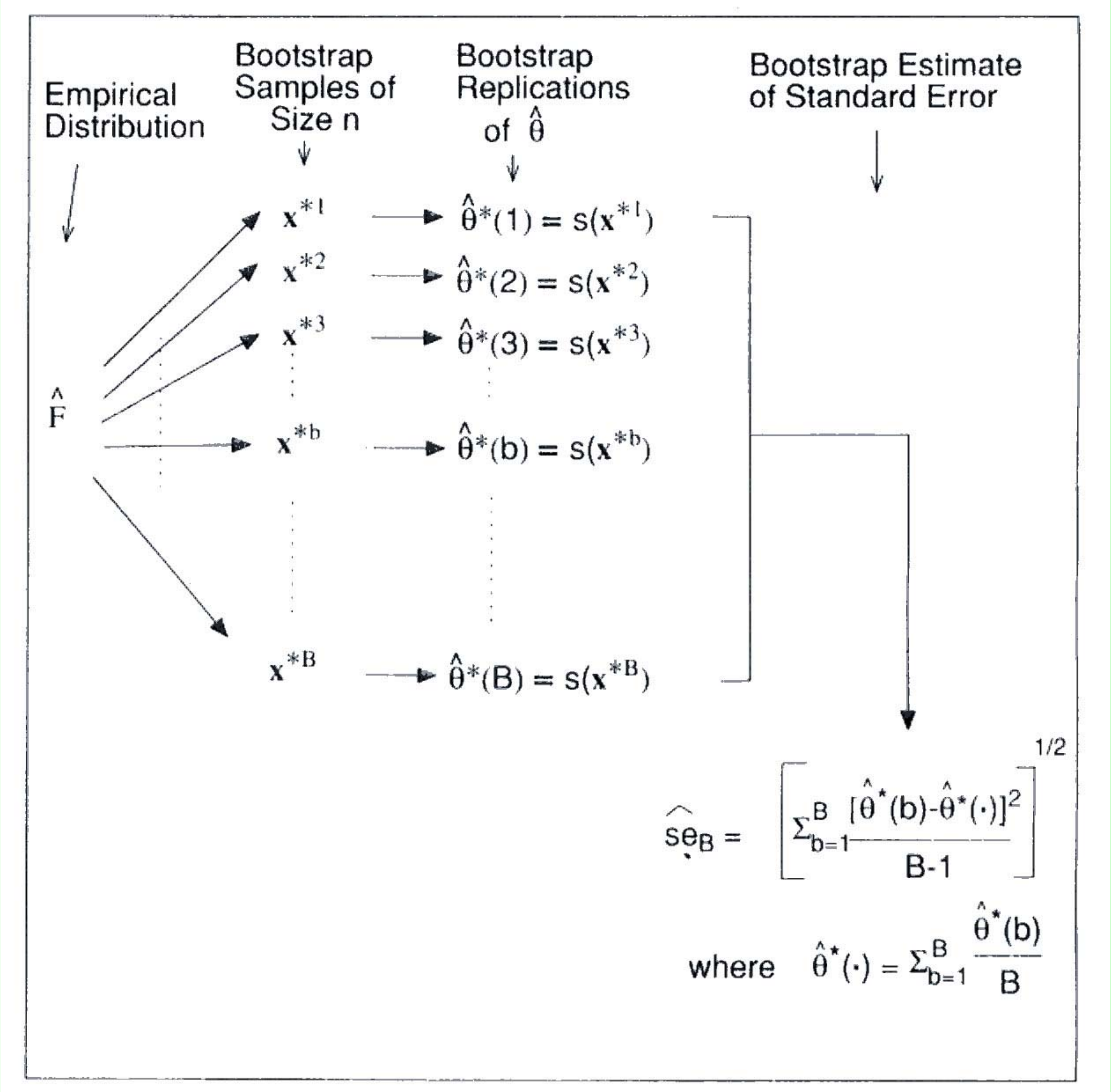
Probability of Achieving Threshold

$$\Pr\left(SSB(t) \geq SSB_{THRESHOLD} \right) = \frac{K_{THRESHOLD}(t)}{K_{TOTAL}(t)}$$

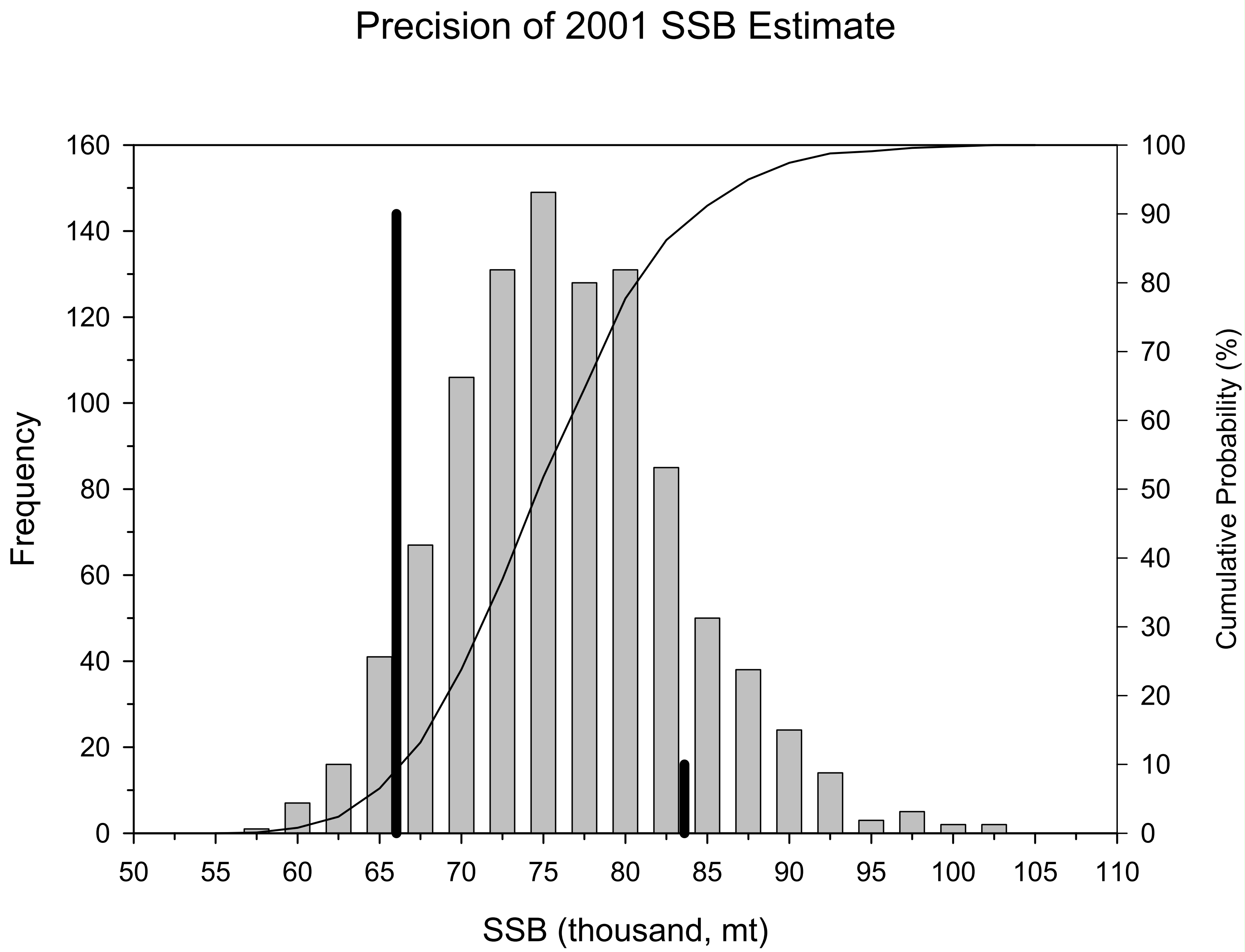
Initial Population Abundance

- No uncertainty for estimate of $\underline{N}(1)$
- Uncertainty for estimate of $\underline{N}(1)$
  - Distribution of bootstrap replicates of $\underline{N}(1)$
    - Nonparametric
    - Parametric
  - Samples from posterior distribution of $\underline{N}(1)$

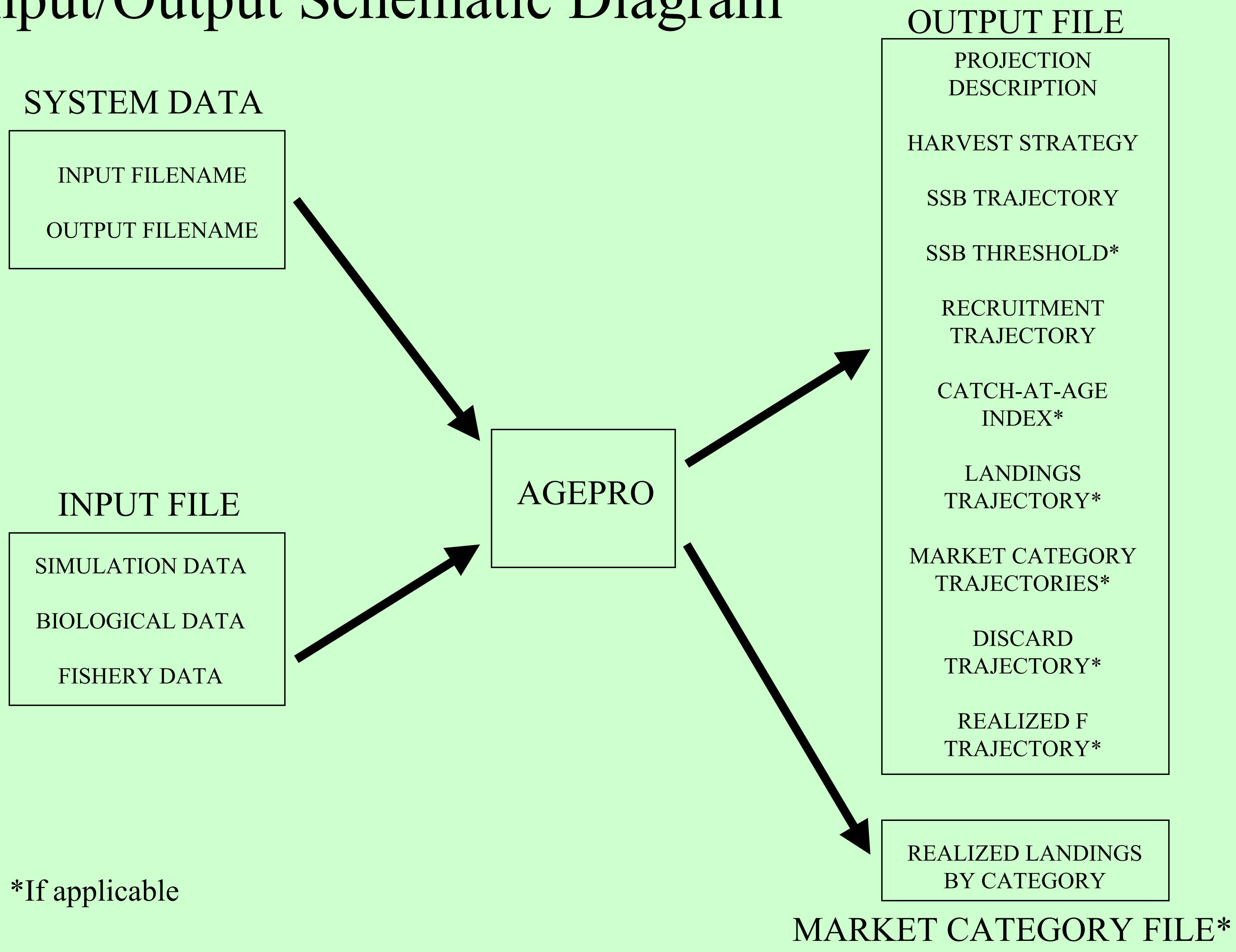
Bootstrap Algorithm



George Bank Haddock
2001 Spawning Biomass Distribution

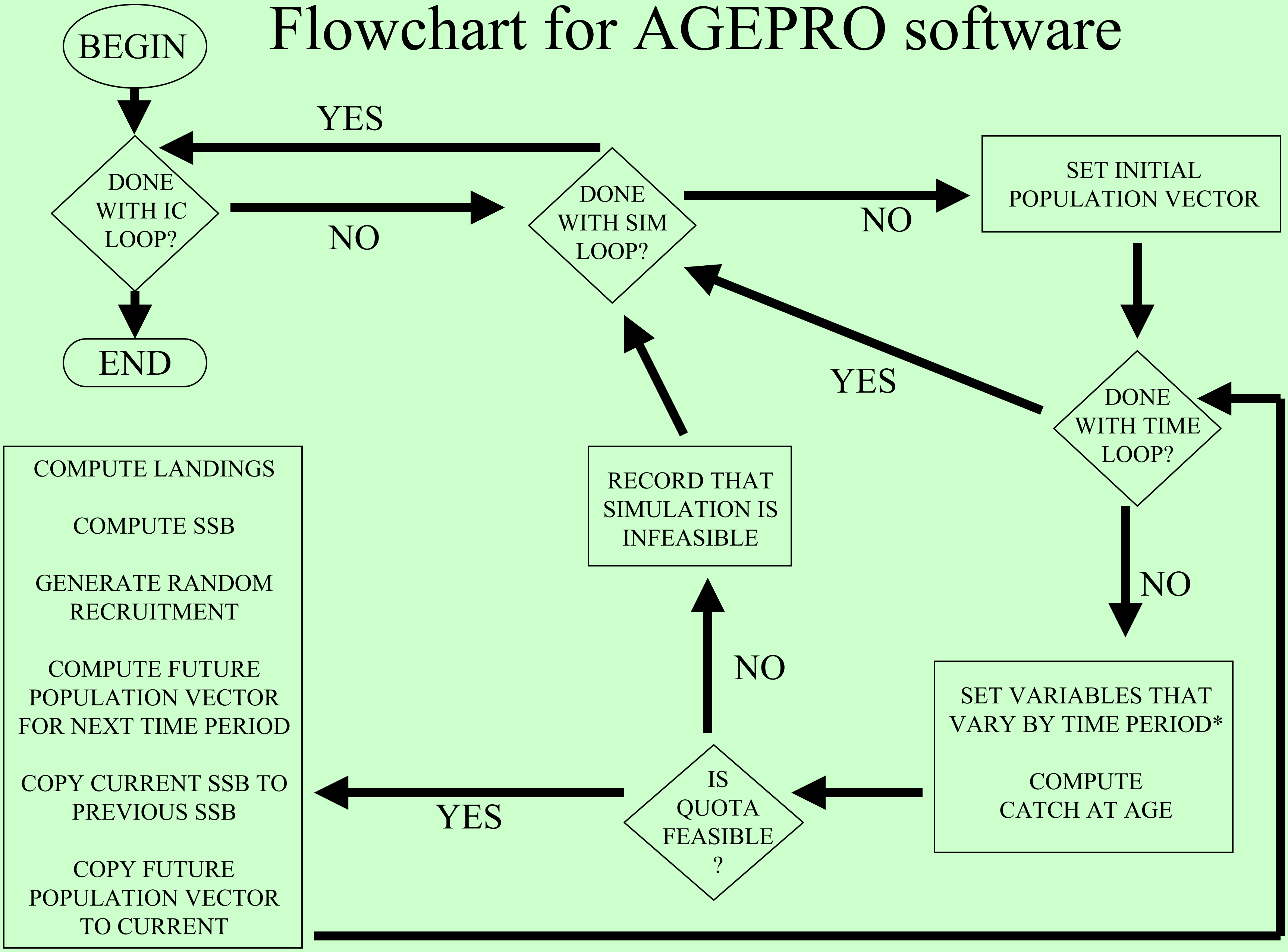


Input/Output Schematic Diagram



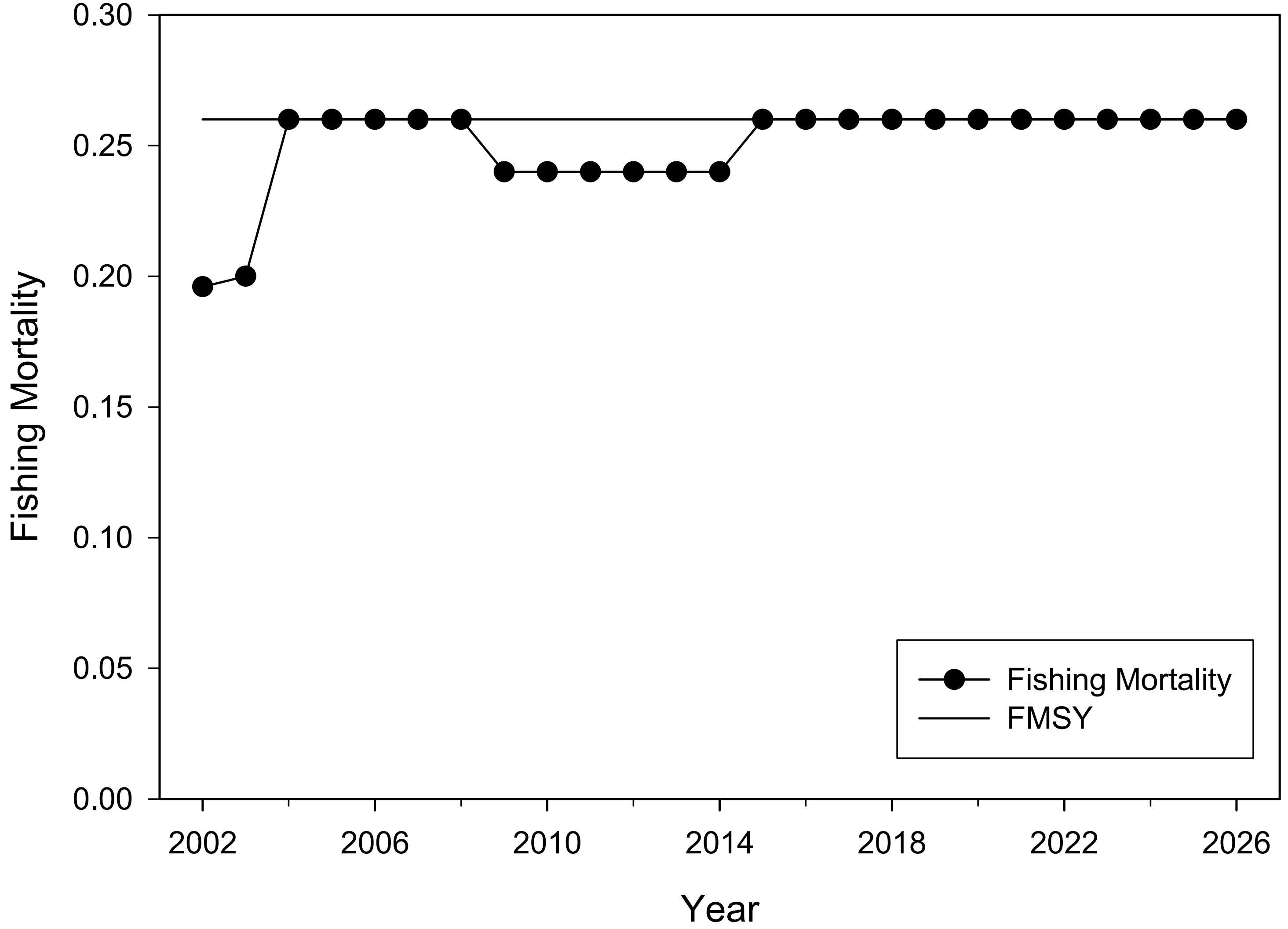
*If applicable

Flowchart for AGEPRO software

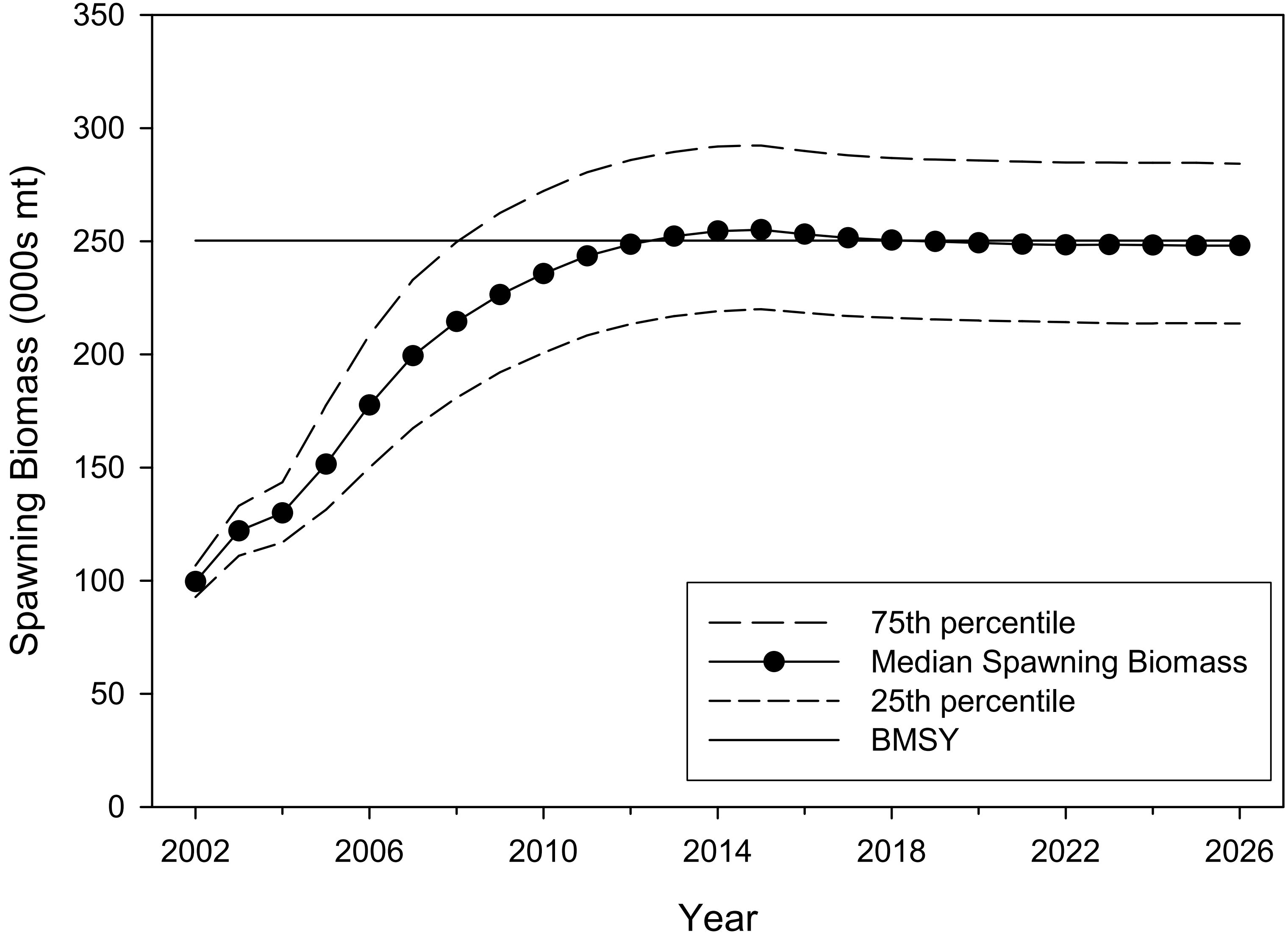


*If Applicable

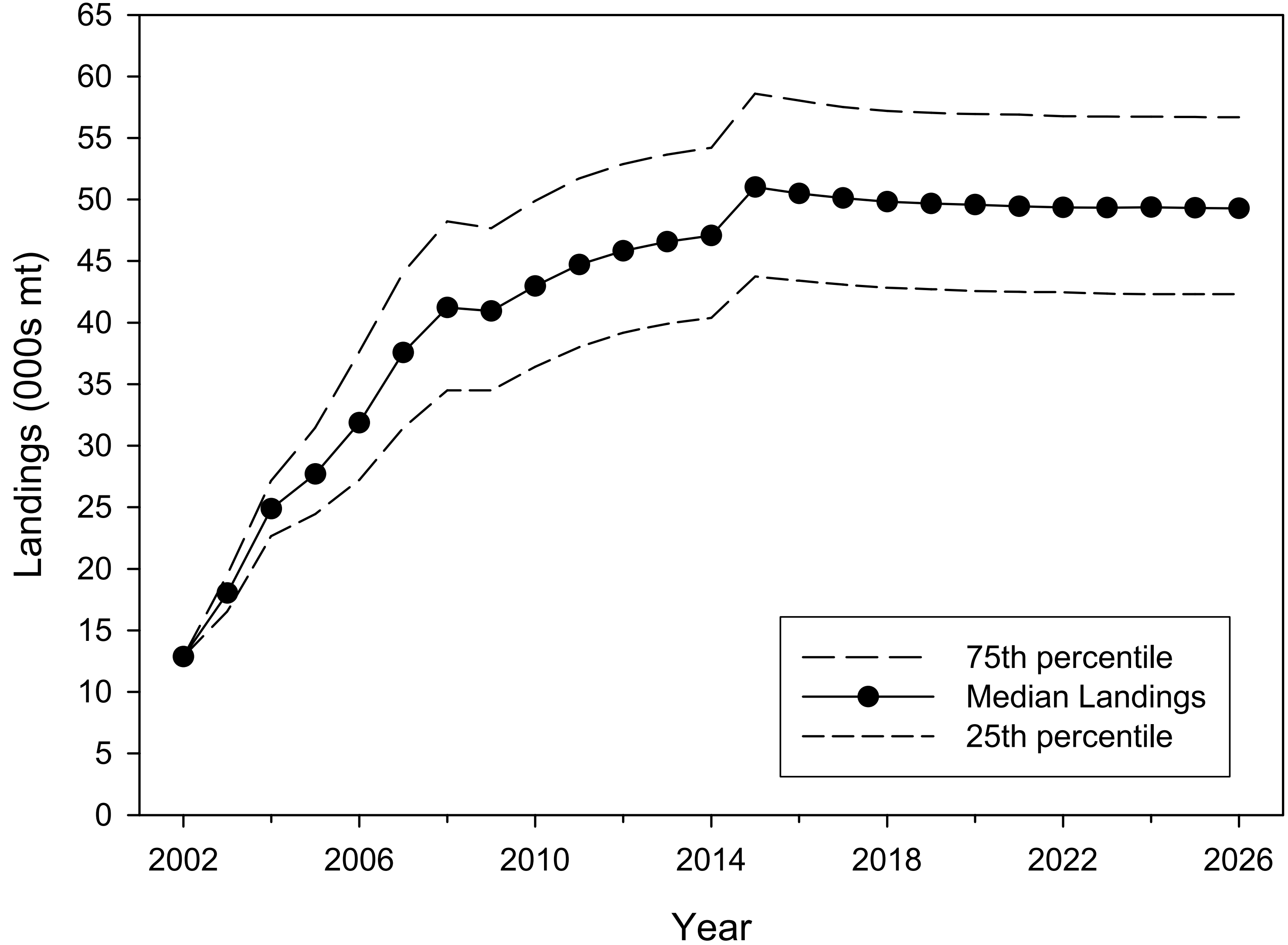
George Bank Haddock $F_{REBUILD}$ for 1999-2009 Time Horizon



George Bank Haddock $F_{REBUILD}$ Spawning Biomass Distribution



George Bank Haddock $F_{REBUILD}$ Landings Distribution




"Prediction is very difficult
…especially about the future"
Niels Bohr