# Stock Assessments:
# The Science of Fisheries

"Counting fish is just like counting trees except they are invisible and they keep moving", John Shepherd


Paul Rago

Richard Methot

NOAA Fisheries

Office of Science & Technology

# PRESENTATION OUTLINE

- Mandate for Assessments
- Stock Assessment Goals
- Data Requirements
- Assessment Methods
- Stock Productivity & Fishery Control Rules
- Rebuilding Analyses
- Risk Assessment
- Data-Poor Situations
- Ecosystem Considerations

# Mandate From MSFCMA

- National Standard 1:
  - Conservation and management measures shall *prevent overfishing* while achieving…the *optimum yield* from each fishery...
- Fishery Management Plans must:
  - specify objective and measurable criteria for identifying when a fishery is overfished
    - how the criteria were determined
    - relationship of criteria to reproductive potential
    - Annual catch limits set such that overfishing does not occur
    - Thus, stock assessments!

# Stock Assessment: Why, What, How

# Assessments Support Management

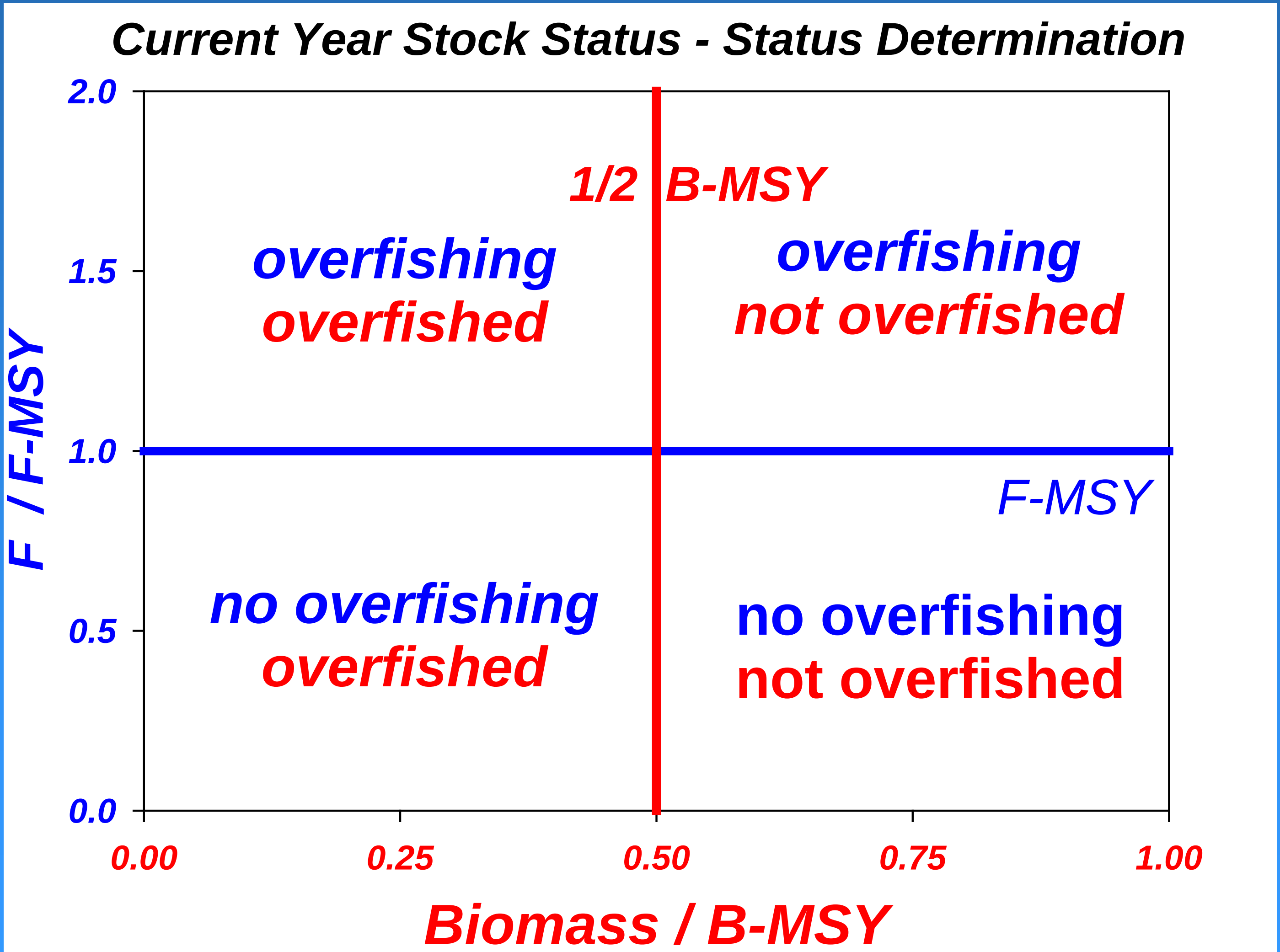
- Maximum Sustainable Yield
- Optimum Yield
- Status Determination
- Forecasting
- Rebuilding

# Long-Term Management Advice

- **Maximum Sustainable Yield:**
  - What harvest strategy would maximize long-term average yield?
- **Optimum Yield:**
  - What harvest strategy would maximize long-term benefits while protecting marine ecosystem?
- **Rebuilding:**
  - What harvest strategy will allow a stock to rebuild to its target abundance level?

# Status Determinations

- Did overfishing occur last year?
- Is abundance below the overfished limit?




Status determination is based on a comparison of current estimates of fishing mortality and spawning stock biomass with their respective biological reference points. The comparison is based on the ratio of the current value to the reference value. There are 4 possible categories based on overfishing and overfished status.

# Pro-Active, Short-Term Advice

What level of catch next year would correspond to the limit (OFL) harvest policy?

What level of catch next year has no more than a XX% (<=50%) chance of causing overfishing?

Control Rule: Formula that calculates future target catch level from expected biomass level

# Stock Assessment Defined

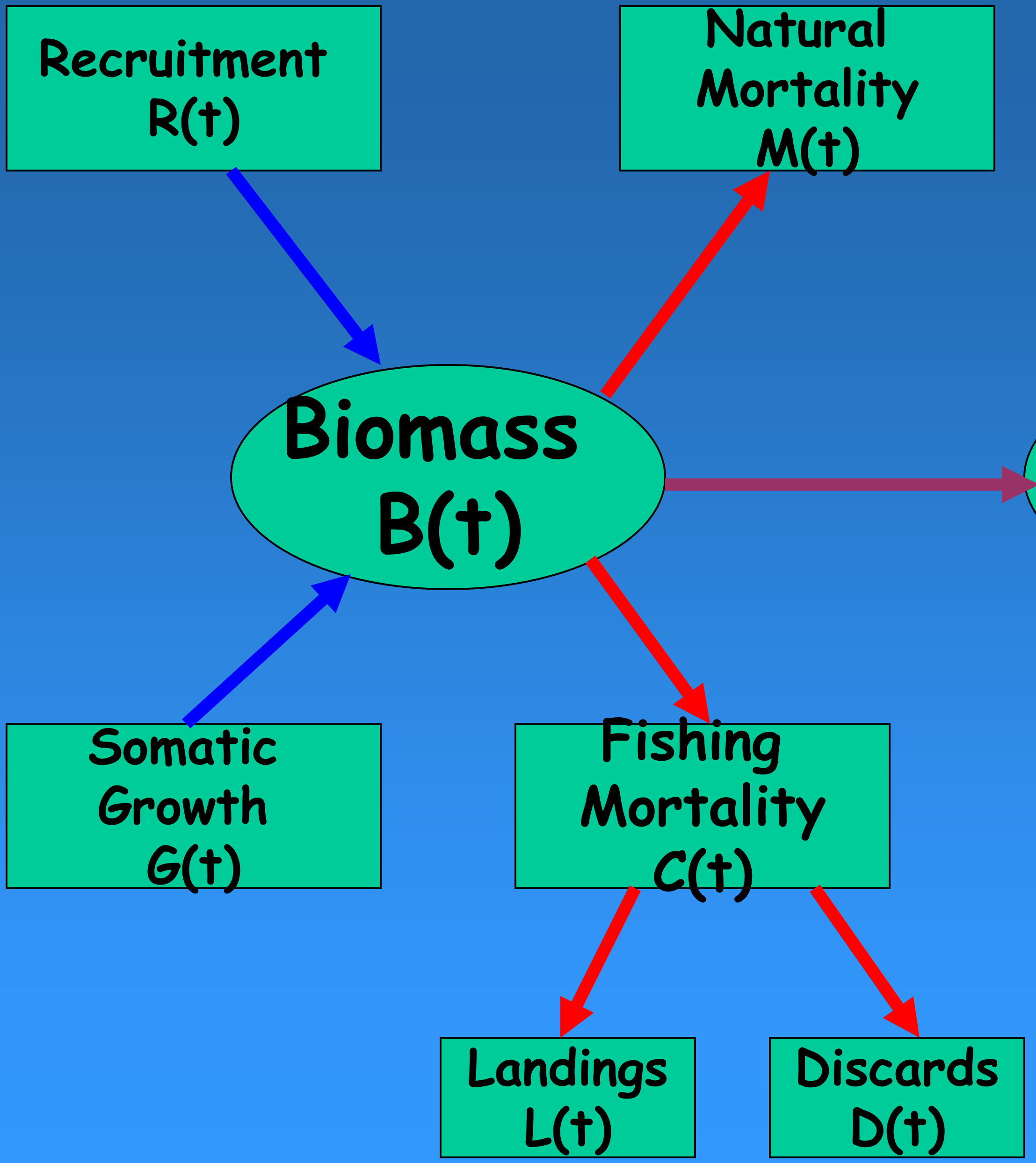
- Collecting, analyzing, and reporting demographic information for the purpose of determining the effects of fishing on fish populations
- Key Concepts / Jargon
  - Stock; Population; Unit
  - Abundance; Biomass
  - Reproductive Potential; Spawning Biomass
  - Recruitment; Yearclass; Cohort
  - Fishery
  - Fishing mortality (F); Exploitation Rate

Stock Assessment—an integration of measures of trend and scale that allows for the reconstruction of historical biomass and fishing mortality, the estimation of biological reference points, and provision of scientific advice on harvest policy. Results of stock assessments are a primary source of information on the dynamics of exploited fish populations.

Measure of Scale: Catch = Landings + Discard

Measure of Trend: Survey Indices

# The Basic Population Model



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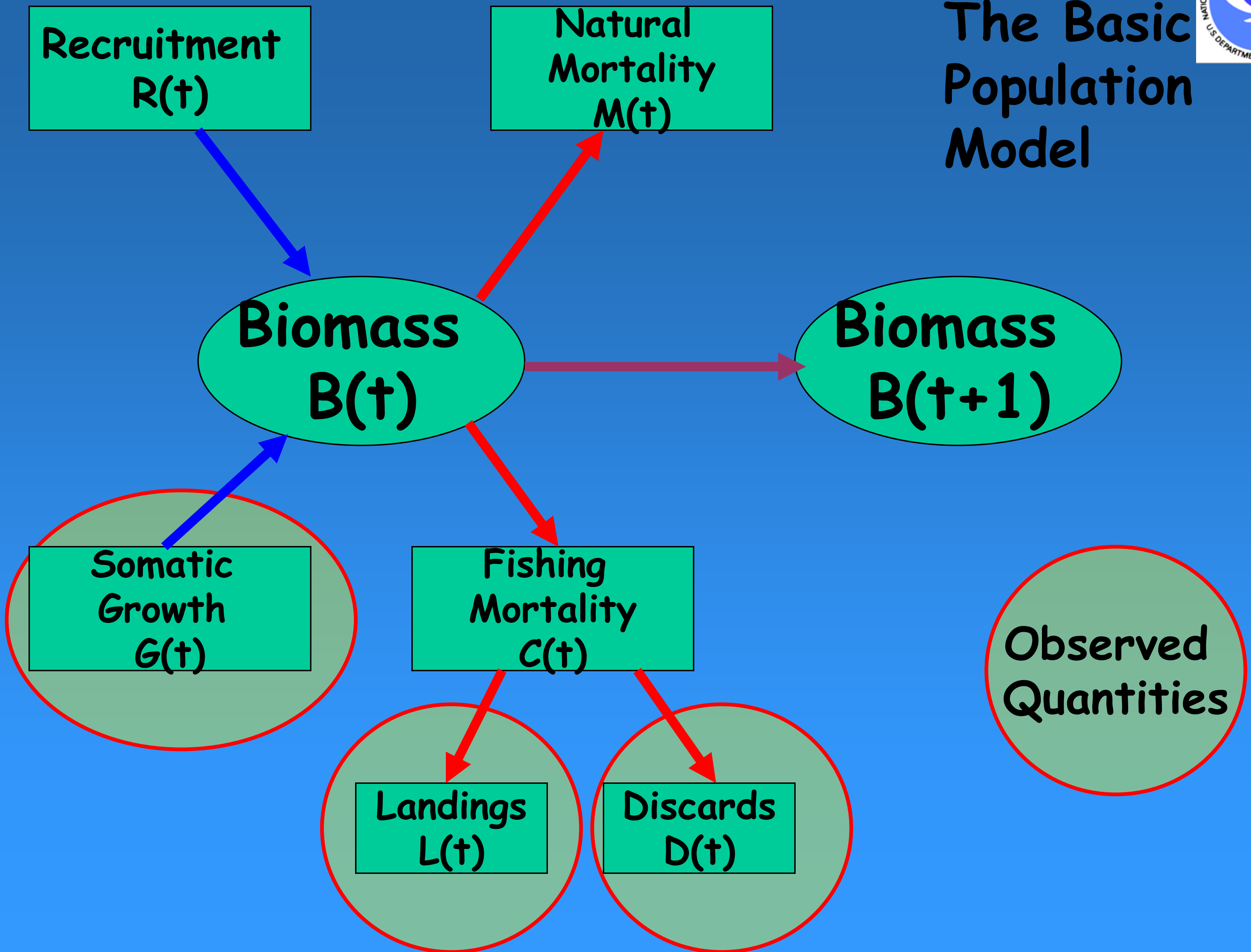

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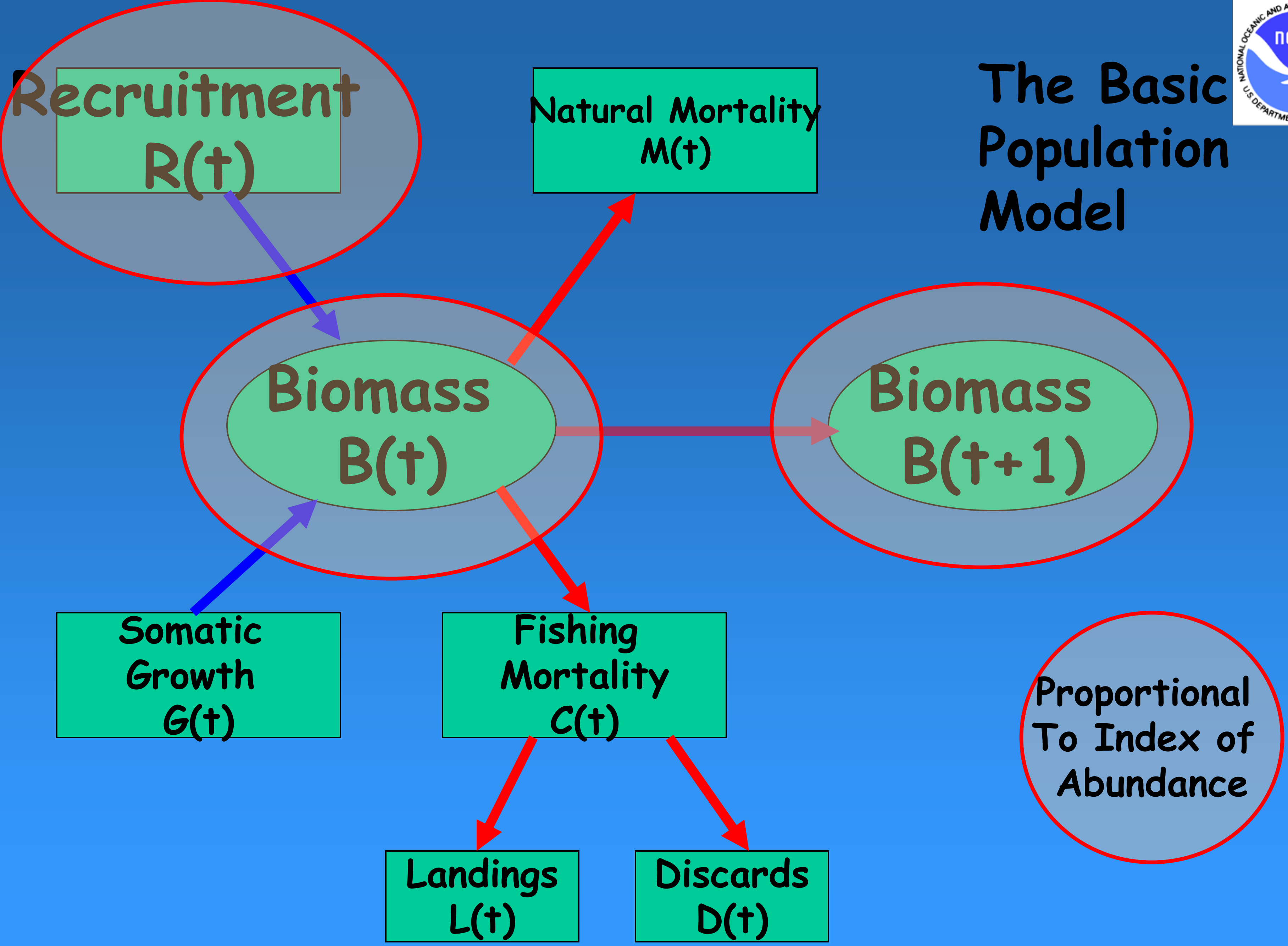

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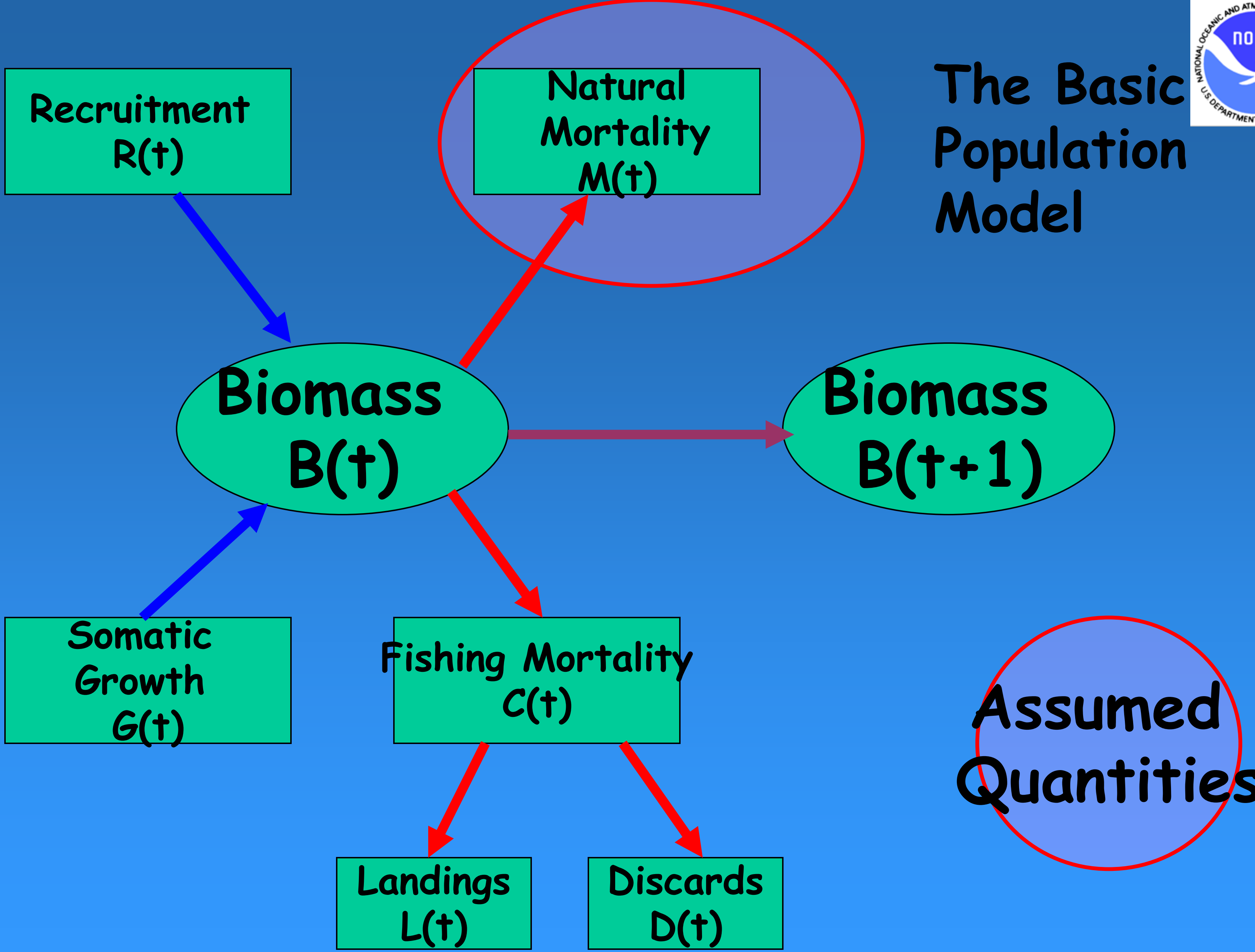

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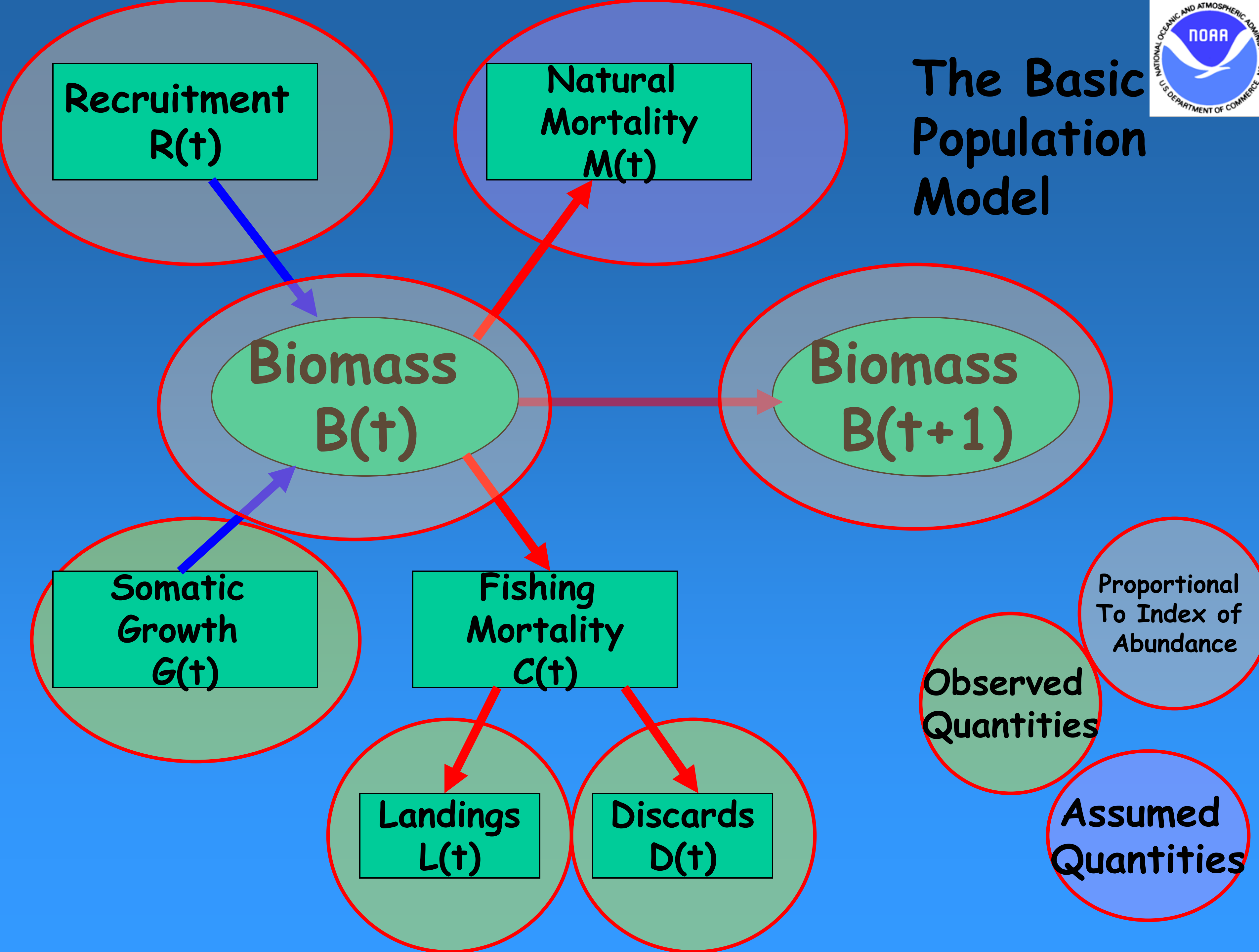
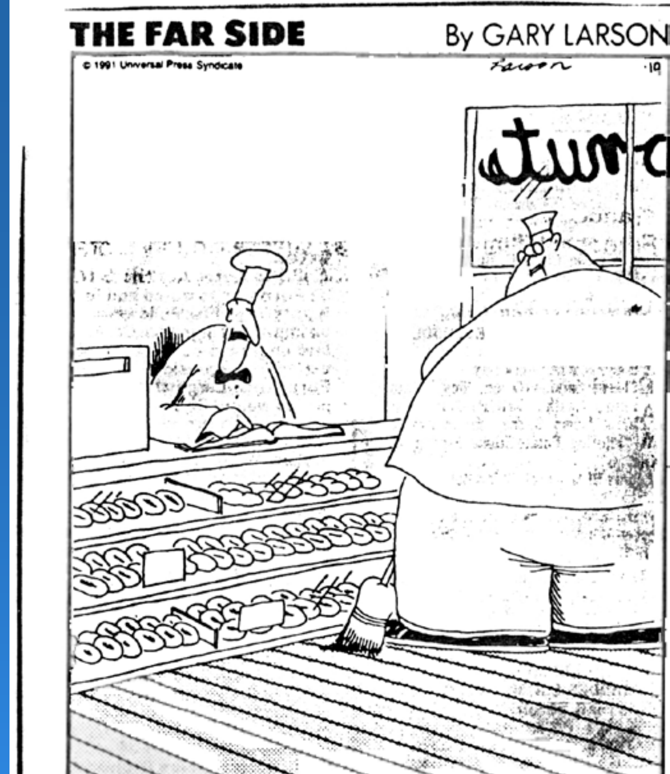


# Measures of Trend and Scale: A simple ATM example

- Suppose the local ATM machine is on the fritz and cannot report your balance. Instead it can only report the fraction of your initial daily balance.
- Suppose you want to figure out how much money you have in the account and make a withdrawal of $20.
- The ATM tells you that your account balance is now 0.8. In other words a $20 withdrawal reduced your balance by 20%
- You quickly surmise that you have $100 in the account since $20/(1-0.8) =$100.
- Now suppose you withdraw $20 and the ATM tells you that your new balance is 0.99998.
- Using the same logic, your balance is $1,000,000;
- Do you
  - Check your math and eyesight
  - Book a flight to the Cayman Islands
  - Immediately resign from Government Service

# Measures of Trend and Scale: ATM example—some complications

- Suppose your teenager or an embezzler, but I repeat myself, makes an equal withdrawal for every one you make.
- You don't know about these withdrawals, but you interpret the results in the same way you've done in the past.
- You make a withdrawal of $20 and the embezzler takes another $20.
- The ATM tells you that your account balance is now 0.8. In other words a $20 withdrawal reduced your balance by 20%
- You quickly surmise that you have $100 in the account since $20/(1-0.8) =$100.



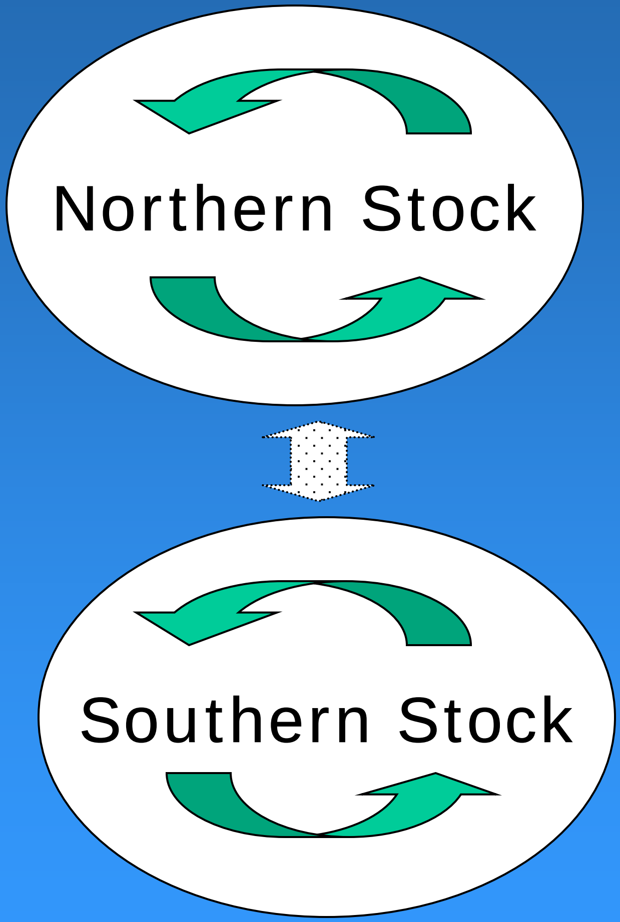

Well, shoot. I just can't figure it out. I'm movin' over 500 doughnuts a day, but I'm still just barely squeakin' by.

- HOWEVER, in reality, $40 was removed, so your balance was $40/(1-0.8)=$200.
- By looking at incomplete data, you underestimate your wealth.
- By ignoring bycatch, you underestimate the productivity of the ecosystem.

# Data Requirements

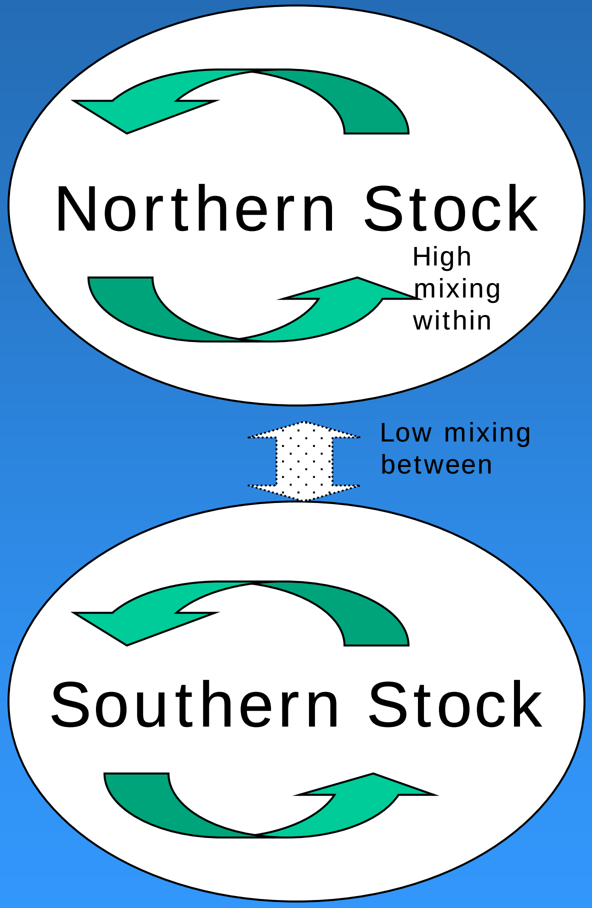
# What is a “Stock”?

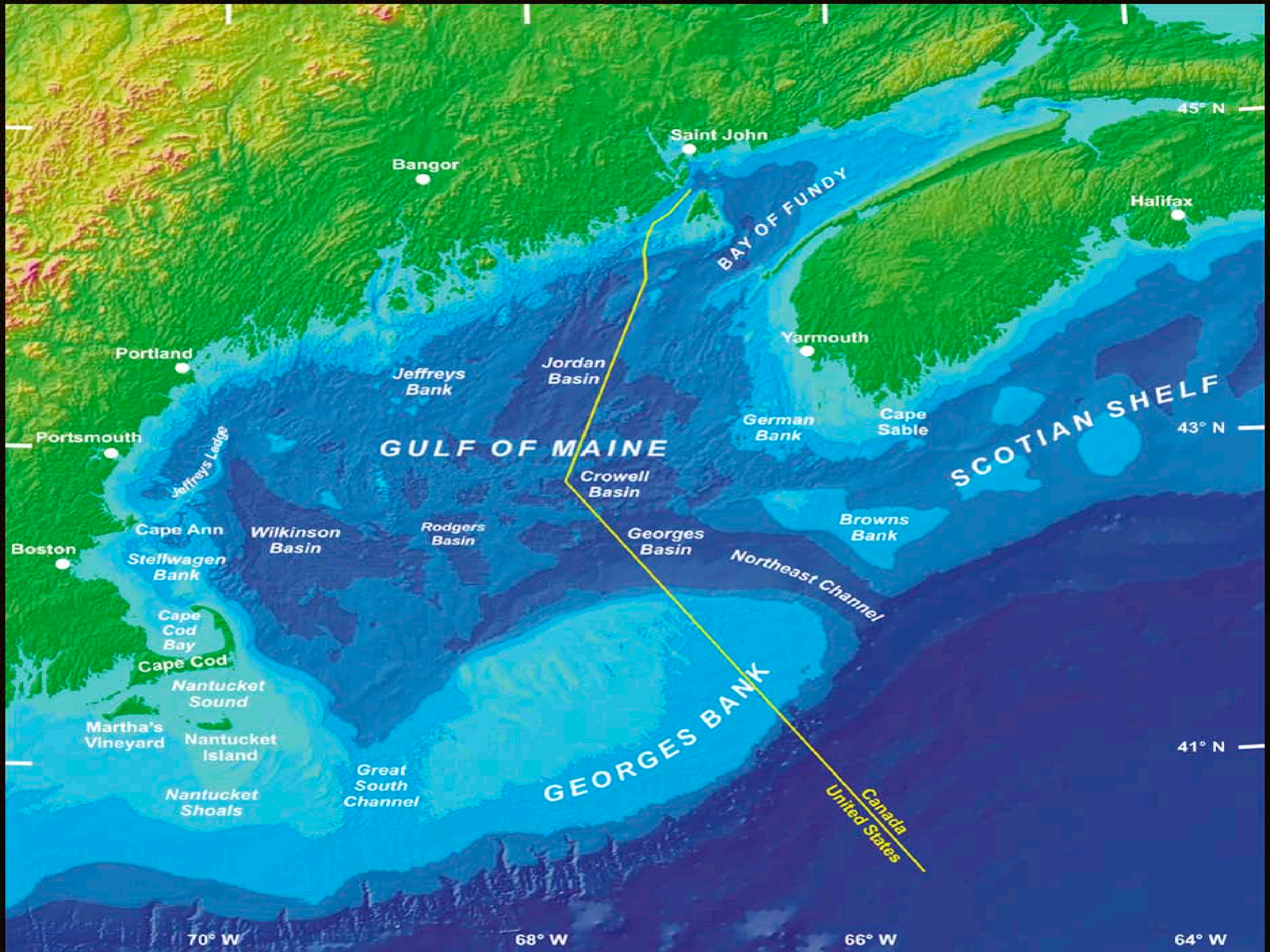
- A group of individuals of the same species
- That inhabit the same geographic region
- And that interbreed when mature
- Multi-species complex ≠ true biological stock



# "Stock" Issues

- Assessment models assumes high mixing within stock and negligible mixing between stocks
- Smaller management units guard against localized depletion, but assessment data needs go up
- Larger management unit still needs some localized analysis




Saint John
Bangor
BAY OF FUNDY
Halifax
45° N
Yarmouth
Portland
Jordan Basin
Jeffreys Bank
SCOTIAN SHELF
German Bank
Cape Sable
43° N
Portsmouth
Jeffreys Ledge
GULF OF MAINE
Crowell Basin
Cape Ann
Wilkinson Basin
Rodgers Basin
Browns Bank
Georges Basin
Boston
Stellwagen Bank
Northeast Channel
Cape Cod Bay
Cape Cod
Nantucket Sound
GEORGES BANK
Martha's Vineyard
Nantucket Island
41° N
Great South Channel
Nantucket Shoals
Canada
United States
70° W
68° W
66° W
64° W

# Cod

***Gadus morhua***

***--Gulf of Maine***

***--Georges Bank***

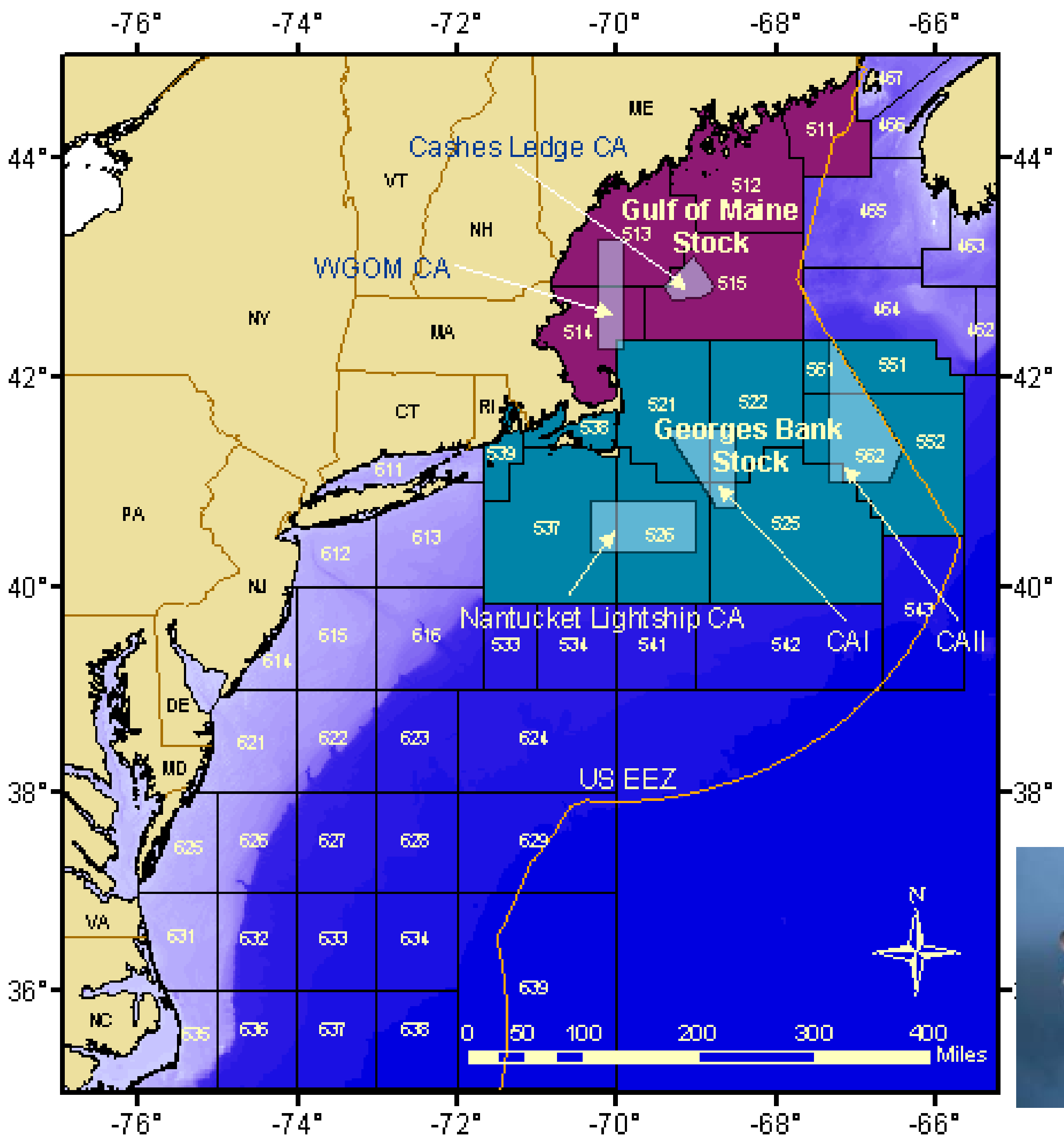
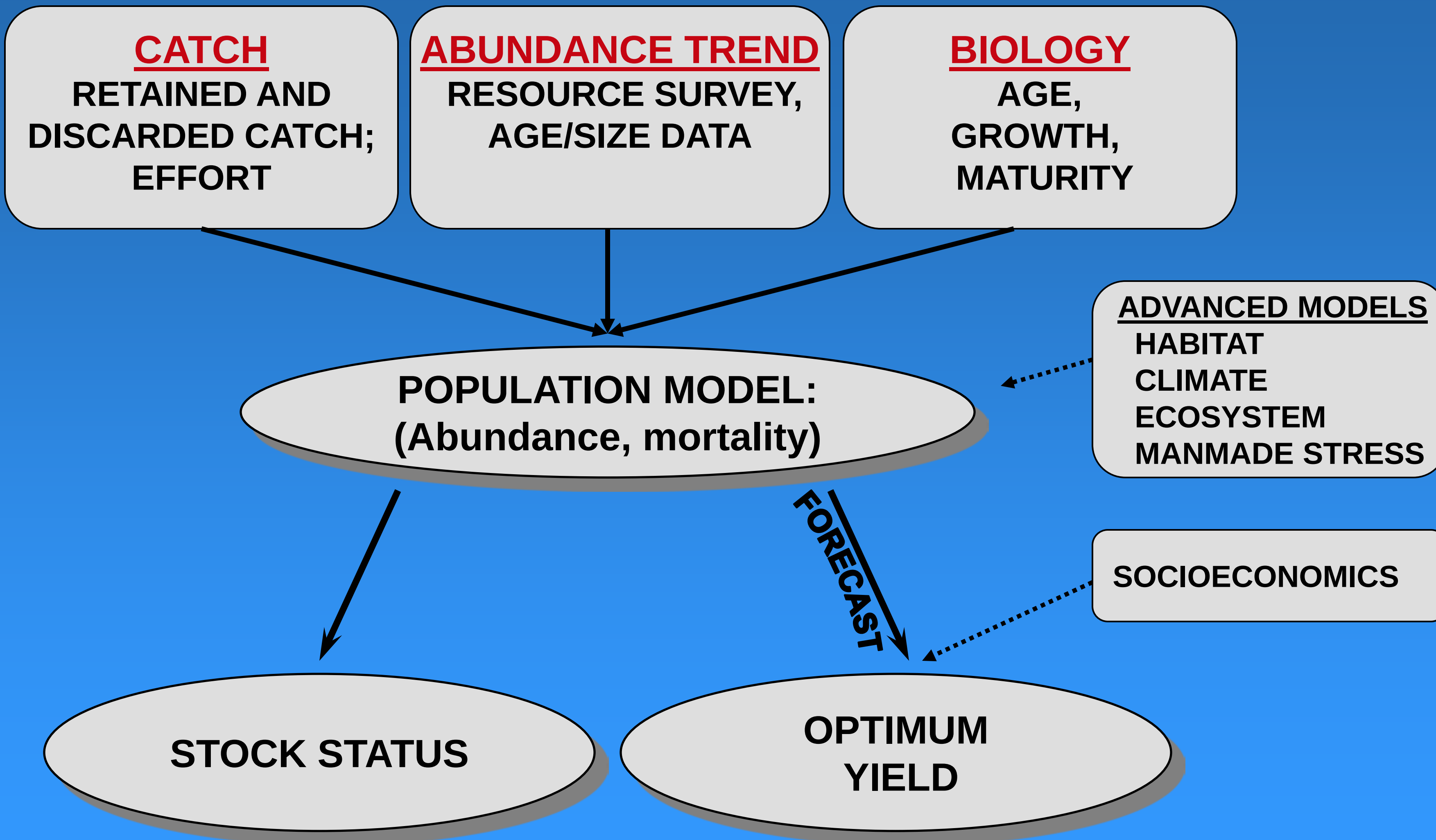



Figure 1.1. Statistical areas used to define the Gulf of Maine and Georges Bank cod stocks.

# Stock Assessment Requirements

- Biology: 2 yr old anchovy or 60 yr old rockfish?
- Catch: What's being removed by fishing?
- Abundance: Stable, or trending?

# Stock Assessment Process



# Total Catch

- A dead fish is a dead fish; count 'em all
  - Commercial retained
  - Commercial discard
  - Recreational kept
  - Recreational released
  - %Survival of discard & released
  - Research take

# Fisheries Information System

- Commercial fishing effort, catch, and value
  - Dealer reports (fish tickets)
  - Vessel trip reports (logbooks)
- Usually based on a census of all landings
- Size and age structure of catch
- Electronic dissemination of data
- Serves:
  - stock assessment
  - fishery monitoring
  - economic analysis

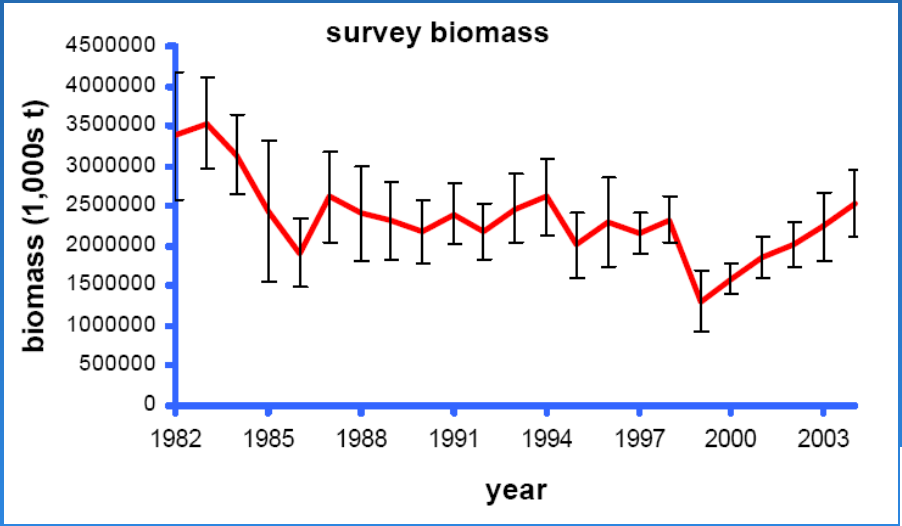
# Marine Recreational Information Program (MRIP)

- Recreational fishing effort and catch using:
  - Angler registry
  - Telephone surveys
  - Shoreside sampling surveys and interviews
- Based on a sample of all trips

# Fishery Observers

- **NOAA Fisheries deploys fishery observers to collect catch and bycatch data from commercial fishing and processing vessels.**
  - Annually 42 fisheries are monitored by observer programs logging over 60,000 observer days at sea.
  - NOAA Fisheries has been using observers to collect fisheries data from 1972 to the present.
  - Observers have monitored fishing activities on all US coasts, collecting data for a range of conservation and management issues.

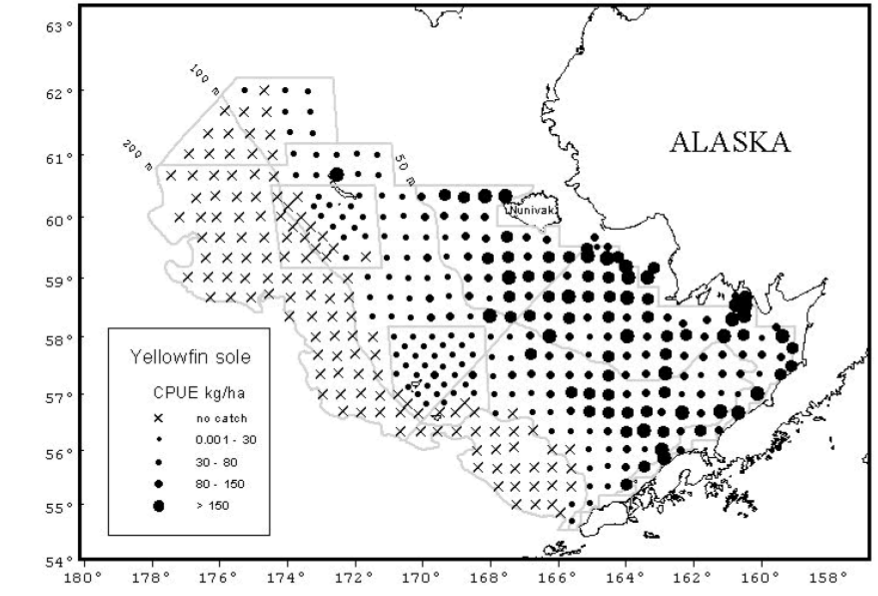
# Fishery-Independent Survey: Bering Sea yellowfin sole




**Stocks that span multiple habitats are MUCH more difficult to survey;**

**Advanced tech is helping**

**Fishery CPUE can sometimes substitute, but standardization and spatial coverage are difficult to achieve and validate**



# Abundance Index
# Fishery-Independent Surveys

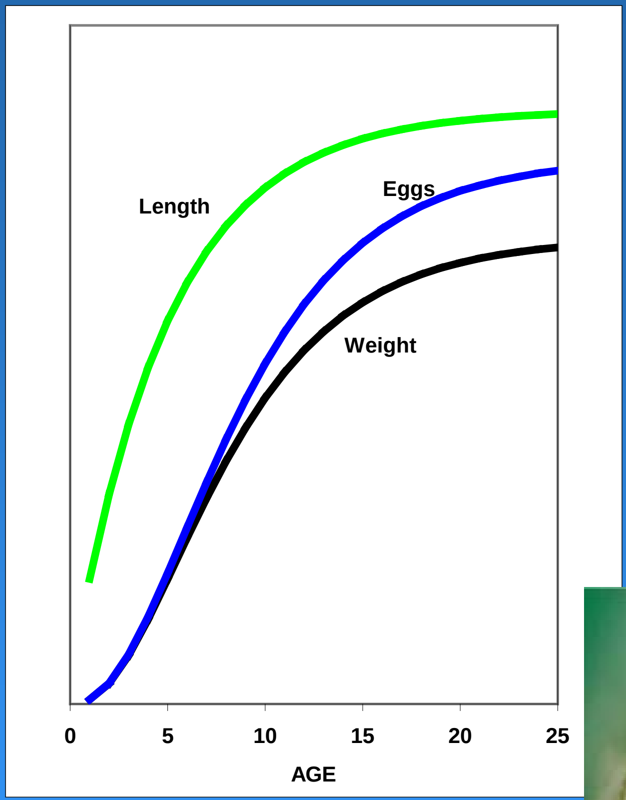
- Catch Rate = *q* x Abundance
- Key is stable *q* over many years
  - Sampling gear and protocol is highly standardized;
  - Sampling locations follows a statistical design

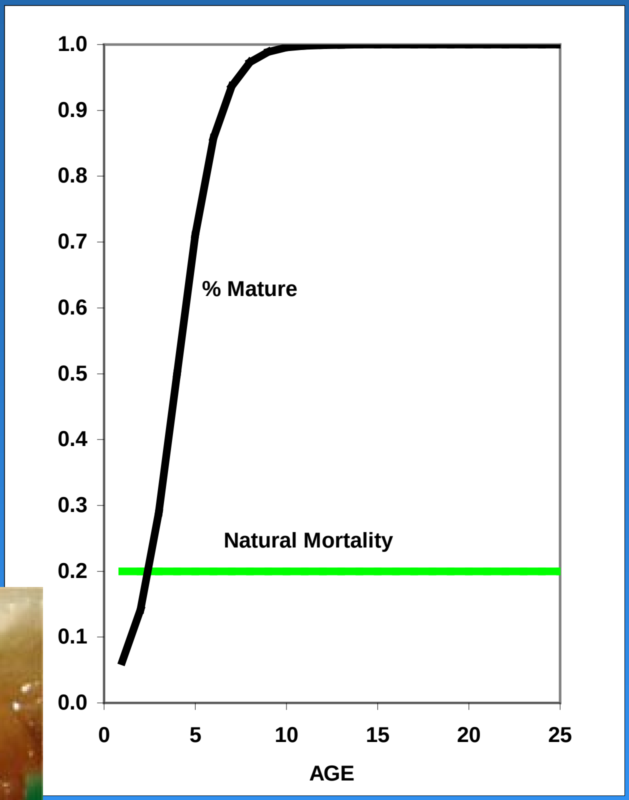
- Most survey methods produce relative time series, so information is only in the trend (*q* is constant, but scale is not important)
- Some methods (acoustics, visual, tag-recapture, some trawl surveys) can independently calibrate absolute *q* so each year's survey directly estimates abundance

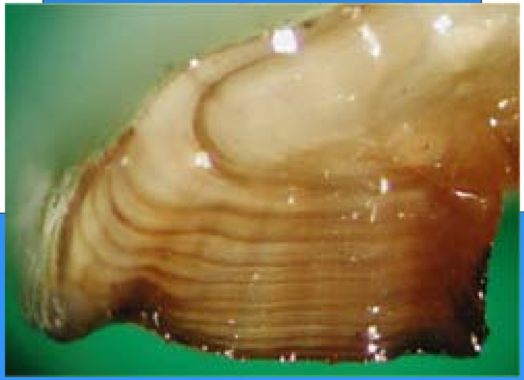
# Assessment – Survey Linkage

| | | 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 |

# Fish Biology and Life History



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

# Lots of Observations!

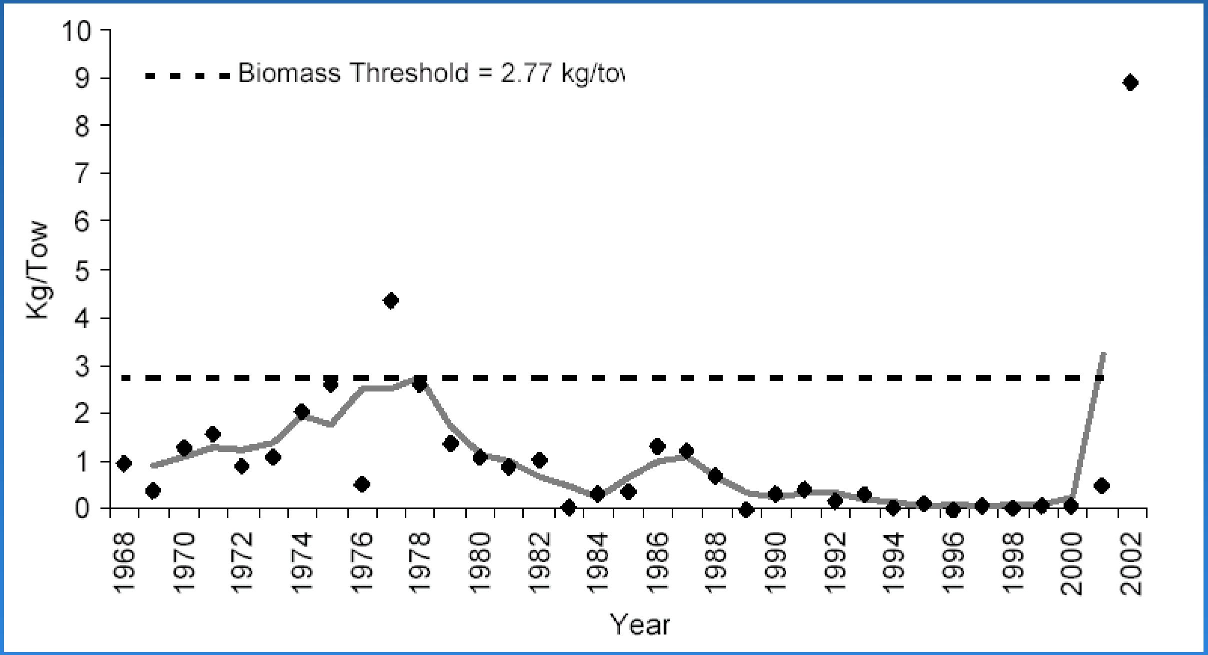
| NE Data Source | Ave # Records per year (2002-2007) |
|---|---|
| Dealer Transactions (Federal) | 170,197 |
| Observer Trips | 2,677 |
| Observer Days | 4,577 |
| Port Samples | 1,309 |
| Comm. Lengths | 88,201 |
| # Fish Aged | 21,173 |
| Tagging Databases | 2 |
| NEFSC Survey Stations | 811 |

# Stock Assessment Methods

# Basic Assessment Approaches

- Index Methods
  - Is stock abundance:
    - Increasing, decreasing, or stable?
- Equilibrium Methods
  - On average, is fishing mortality:
    - too high, too low, or just right?
- Dynamic Population Methods
  - Measures stock abundance and mortality
  - Forecast stock abundance and catch level that maintains mortality target
- Choice depends on data availability and complexity of management questions

# Index Methods




- Running average of survey or fishery CPUE
- Compare to a benchmark level
- May also compute ratio of catch to index to get relative exploitation rate

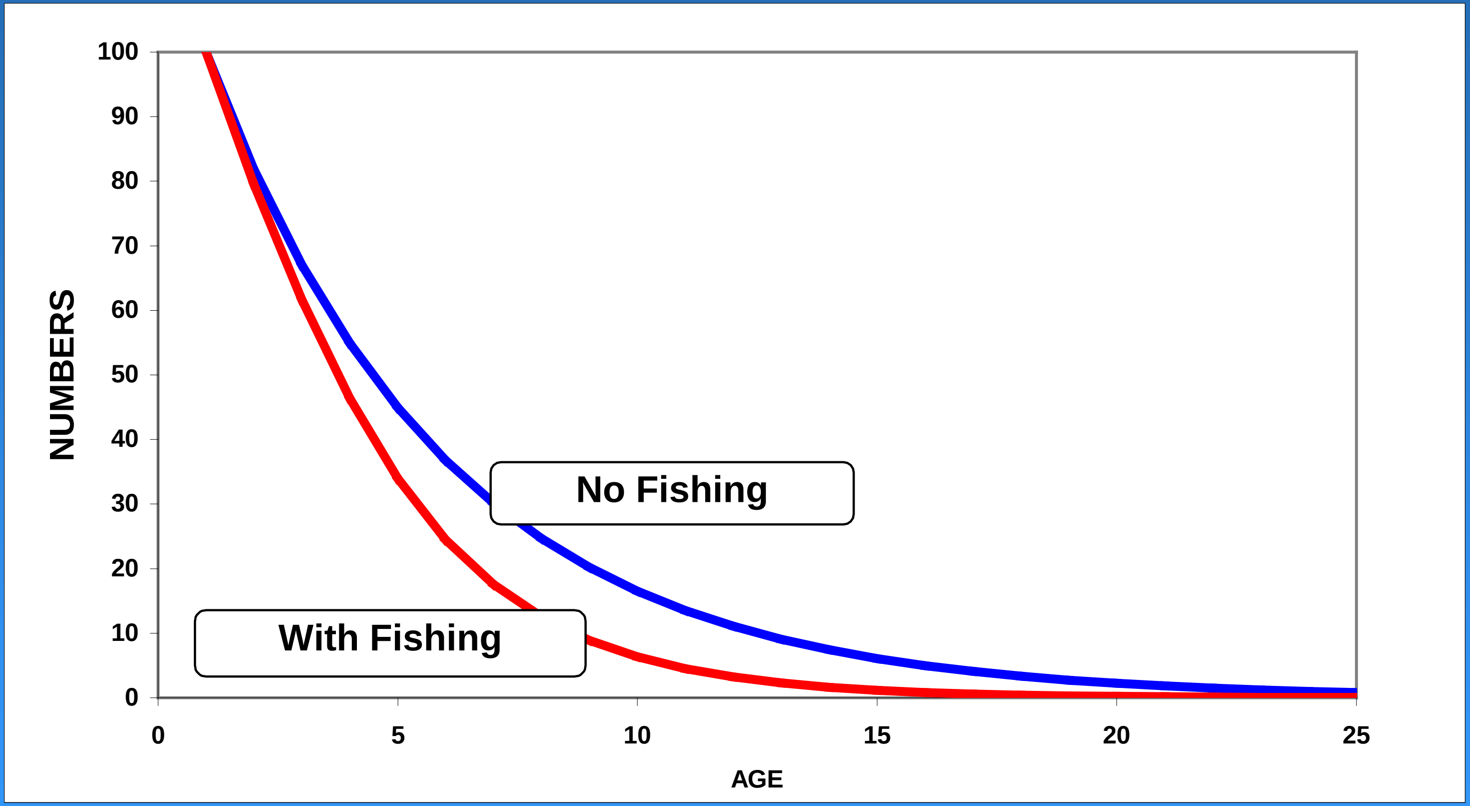
# Index Methods: pros & cons

- <u>Advantages</u>:
  - Requires only an index of stock size and catch.
  - Able to detect substantial changes in stock size and exploitation.
- <u>Disadvantages</u>:
  - Imprecise (large sampling uncertainty)
  - Status can only be related to proxy reference points (e.g., historical averages).
  - Cannot reliably project stock size.
  - Difficult to provide objective management advice.

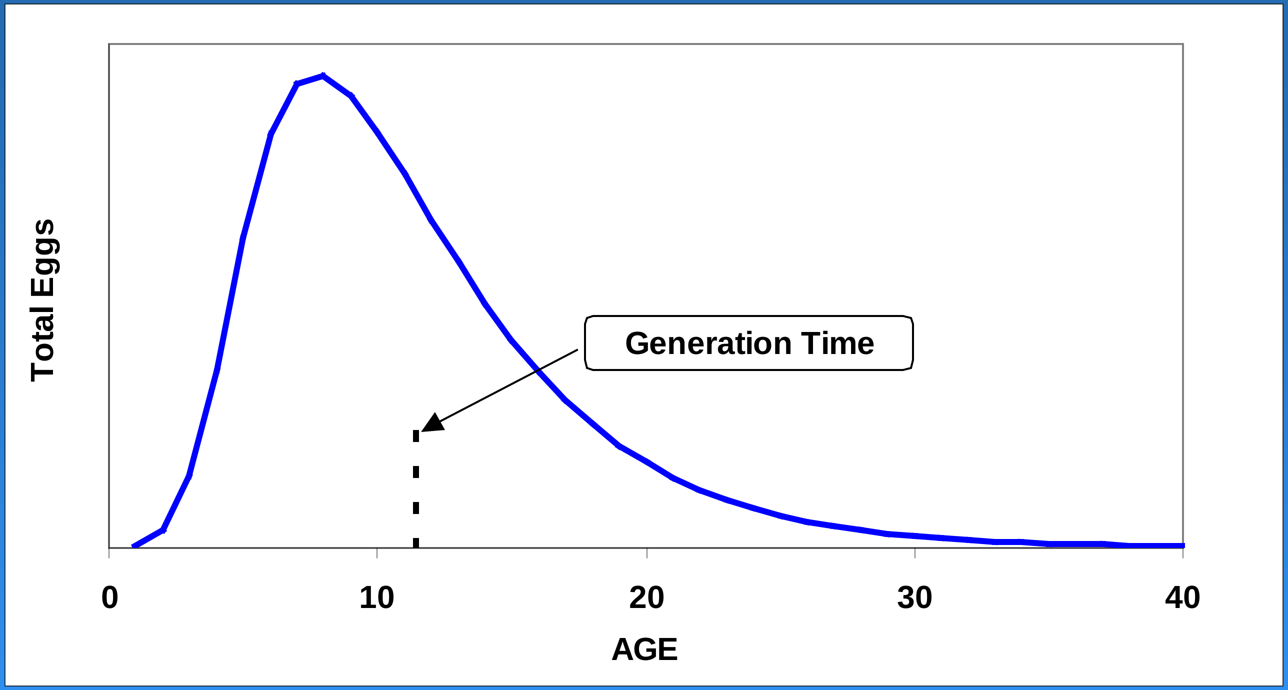
# Equilibrium Models Relate Fishing Rates to Effect On Reproductive Potential

- Reproductive Potential Per Recruit is sometimes presented as:
  - SPR
  - 1-SPR
  - Spawning potential ratio
  - Spawners per recruit
  - $F_{xx\%}$
- It is an index of the intensity of the effect of fishing on the reproductive potential of the stock

# Direct Fishing Effects on Numbers at Age



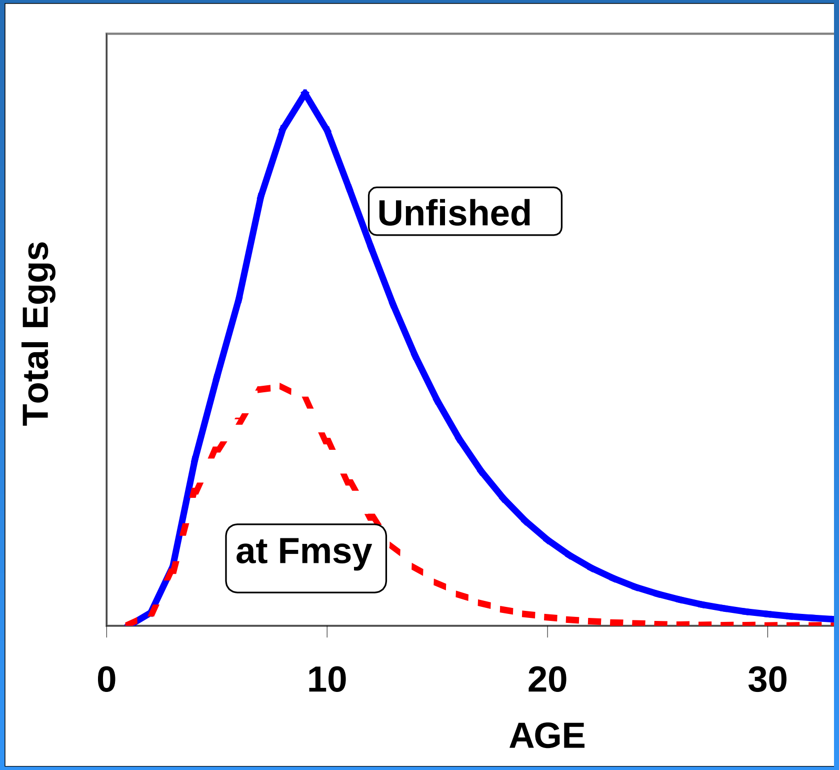
# Generation Time




Weighted mean age of spawners; same as:

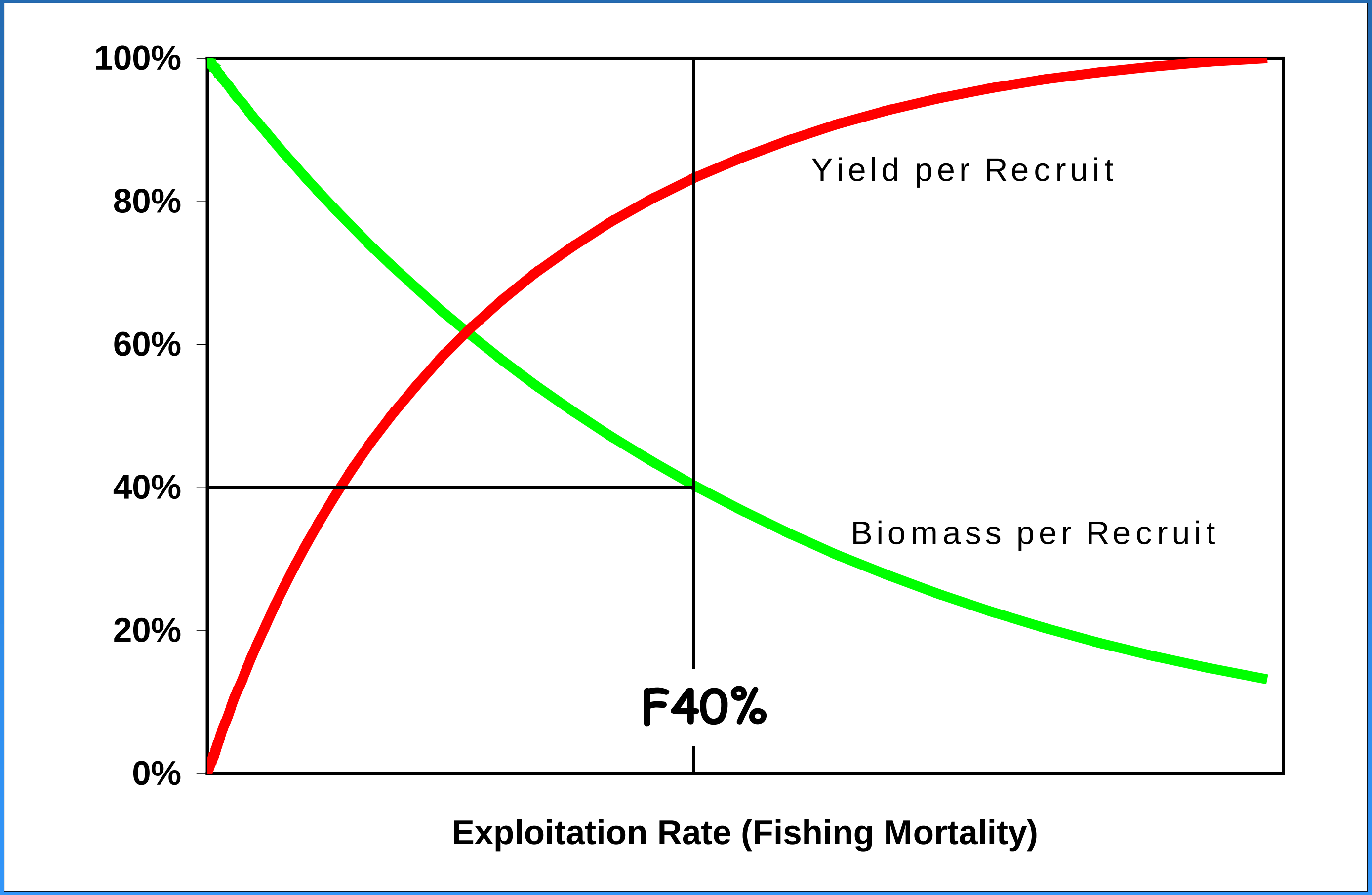
Mean time from birth to production of offspring

# Fishing Reduces Mean Age




- Fewer old/large fish; some say “truncated”
  - Fewer large, more predatory individuals
  - Fewer repeat spawners
- Smaller mean body size
- Shorter generation time
- Total stock dominated by younger fish, so fluctuates more with recruitment

# Fishing Effects on Yield and Eggs (Spawning Biomass) Per Recruit



# Reproductive Potential

- Best: age-specific fecundity, including maternal effects on egg vitality
- OK: female spawning biomass or combined gender spawning biomass
- Weak: fishable biomass

- Complications:
  - Hermaphrodites
  - Density-dependent changes in life history over time

# Equilibrium Methods: Pros & Cons

- **Advantages**:
  - Requires only age or size composition of catch
  - Provides direct information on relative fishing mortality level.
- **Disadvantages**:
  - Status can only be related to proxy reference points
  - Cannot estimate or project abundance
  - Difficult to provide objective management advice.

# Dynamic Assessment Methods

**Stock Net Production =**

**recruitment + growth - natural mortality – catch**

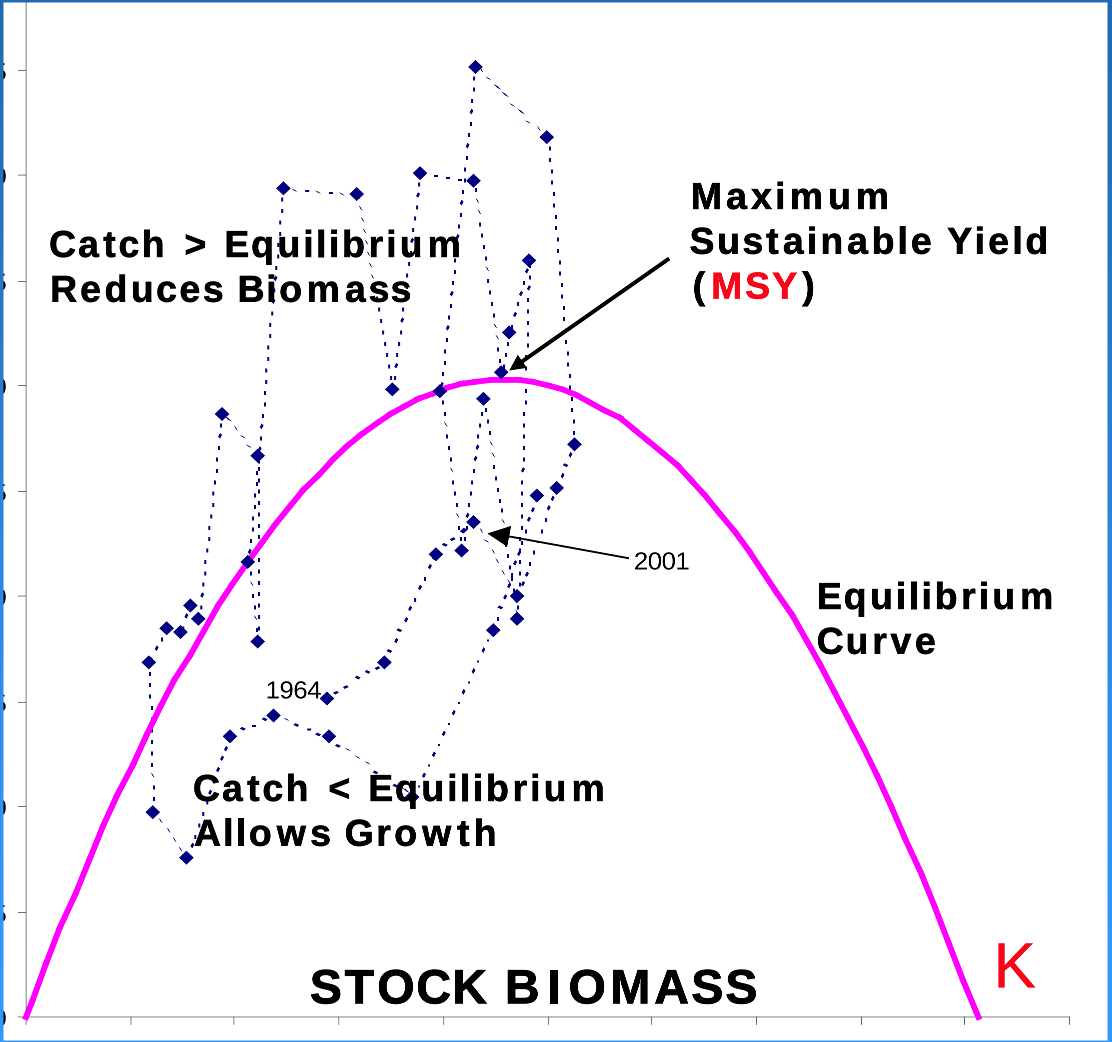
- Recruitment: production of eggs & larvae increases as spawner abundance increases, but their survival may decrease with crowding, cannibalism.
- Growth: body growth of individuals adds mass to the the entire stock, but slows as fish age, starve, crowd;
- Natural Mortality (M): background level due to predation, disease, etc.; link to ecosystem
- Production Models treat recruitment, growth, and natural mortality as a combined process because no data about the details

# Production Model

-Population increase is proportional to its biomass, but the rate of increase slows as the population approaches its carrying capacity (K).

-If removals can be replaced by stock production each year, on average, the fishery is sustainable.

-If stock size is maintained near half its carrying capacity, the population growth rate is fastest, and sustainable yield is greatest (*MSY*).



# Production Models

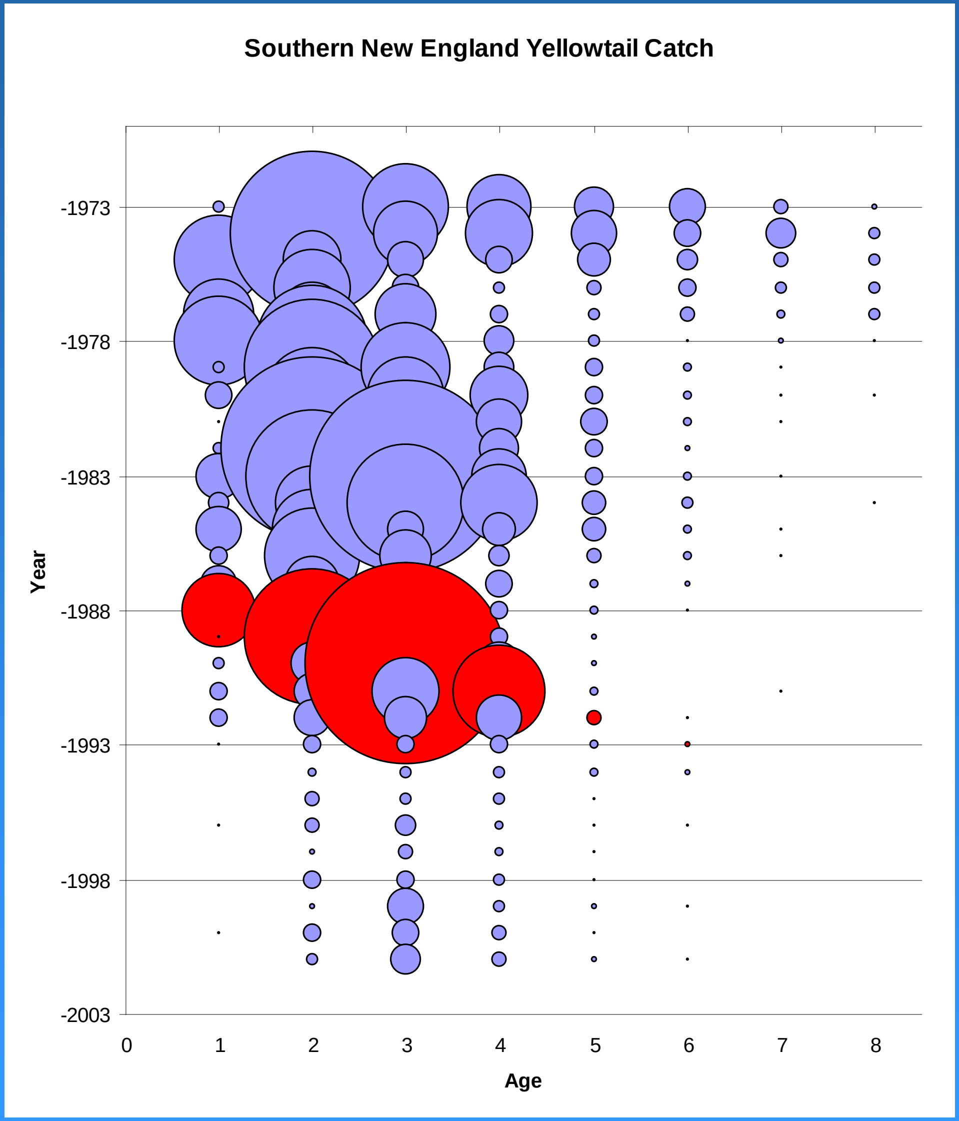
- **Advantages**:
  - Estimates abundance and mortality
  - Can do limited projections (forecasts)
  - Does not require intense catch sampling.
- **Disadvantages**:
  - Requires a long time series of accurate catch and reliable survey data – representing a wide range of stock and harvest conditions;
  - Not sensitive to demographic changes (e.g., recruitment events, truncated age structure, immature-mature components);
  - Scaling of absolute estimates may not be reliable because model is very simple;
  - Projections are simplistic (no information on incoming recruitment).

# Age-Based Dynamic Models

- Adding age data allows:
  - Estimating age-specific fishing mortality
  - Including details on demographics (e.g. age at maturity differs from age at entry to fishery)
  - Estimating year-to-year fluctuations in recruitment of young fish

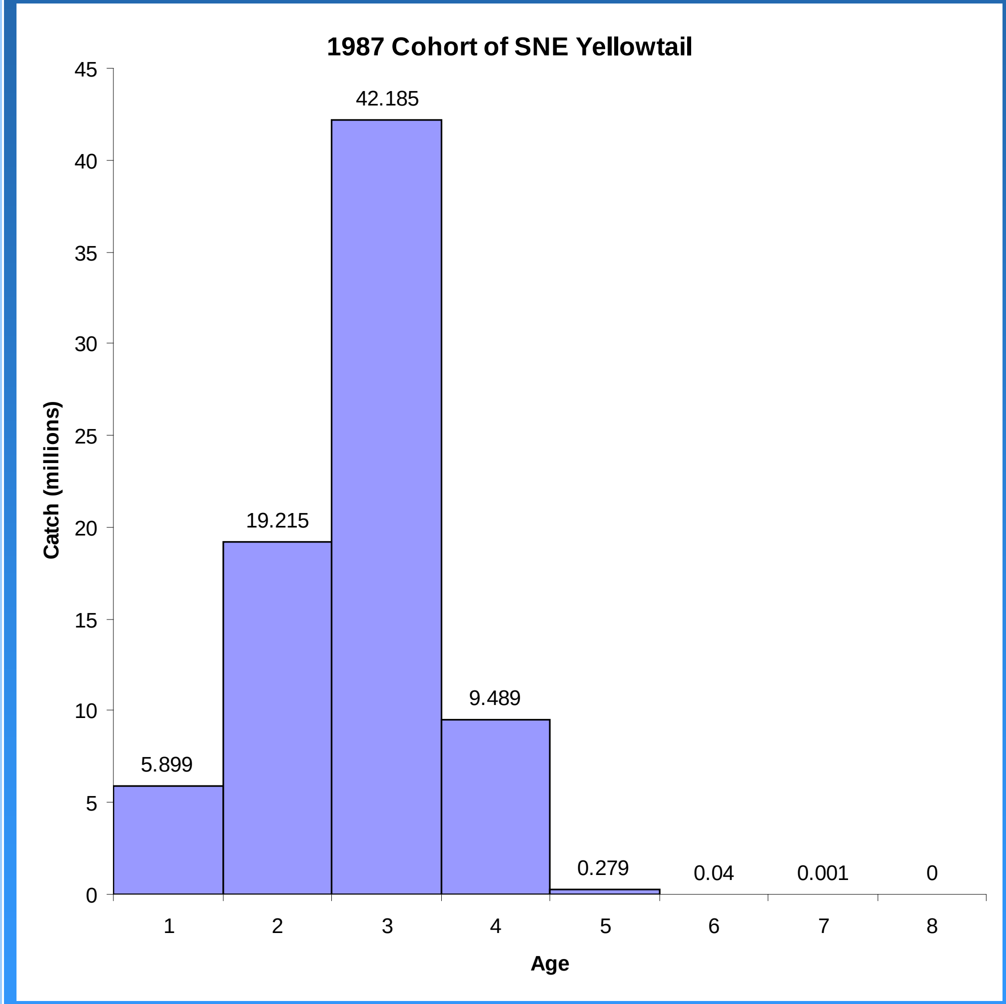
# Age-Based Methods

- Age distribution of the catch estimated from census of total catch biomass and port samples.
- Example:
  - F on age 1 declined after 1989
  - Survival to older ages has declined
  - 1987 yearclass dominated the catch in the late 80s early 90s.



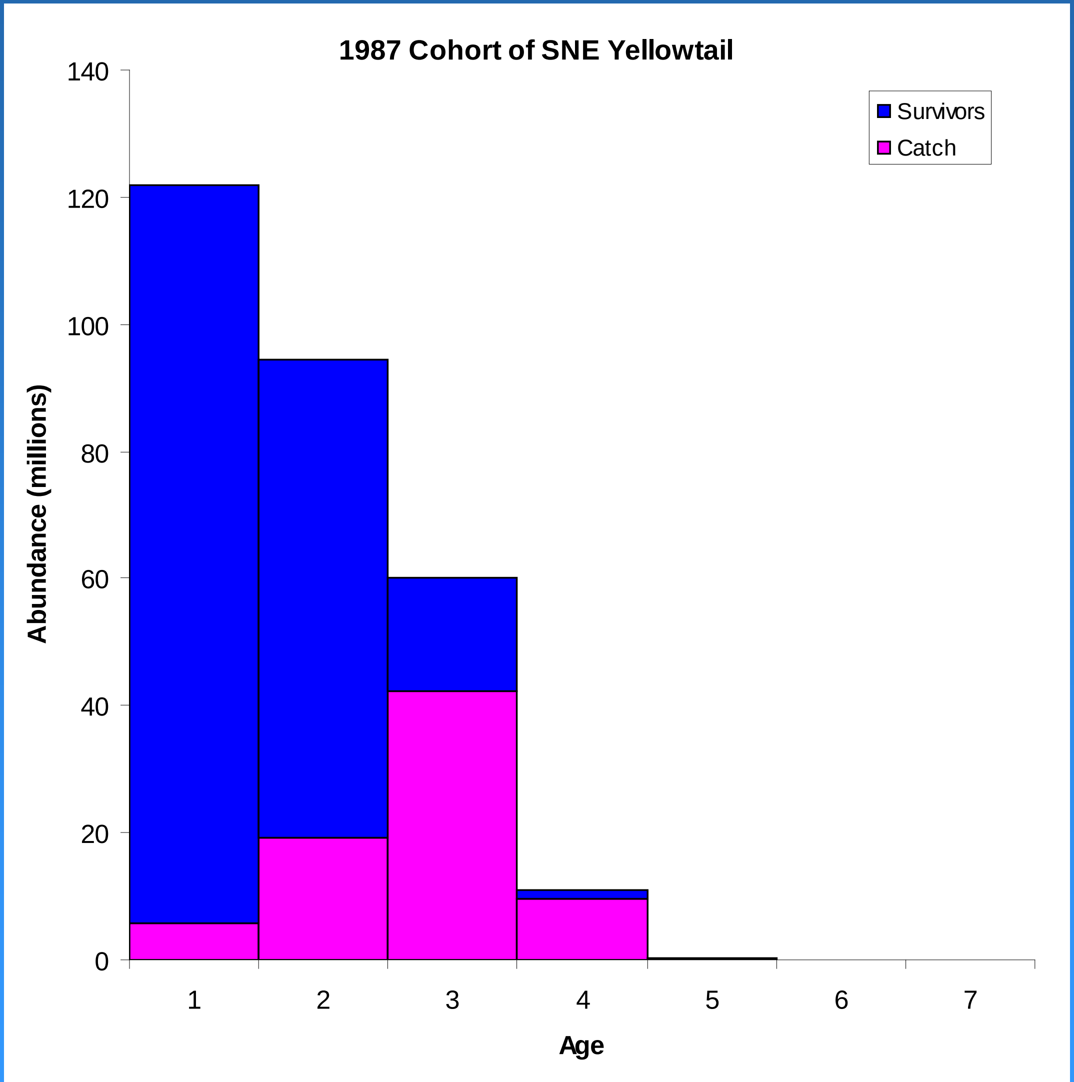
# Virtual Population Analysis

- Over the lifespan of the 1987 yearclass, 77 million fish were caught.
- We also know that some fish died from natural mortality.
- So, *at a minimum*, there were 77 million fish when they were 1 year olds.
- But this is just the population we "saw" (*the virtual population*) from the underlying true population.
- *VPA* reconstructs the true population from the virtual population.



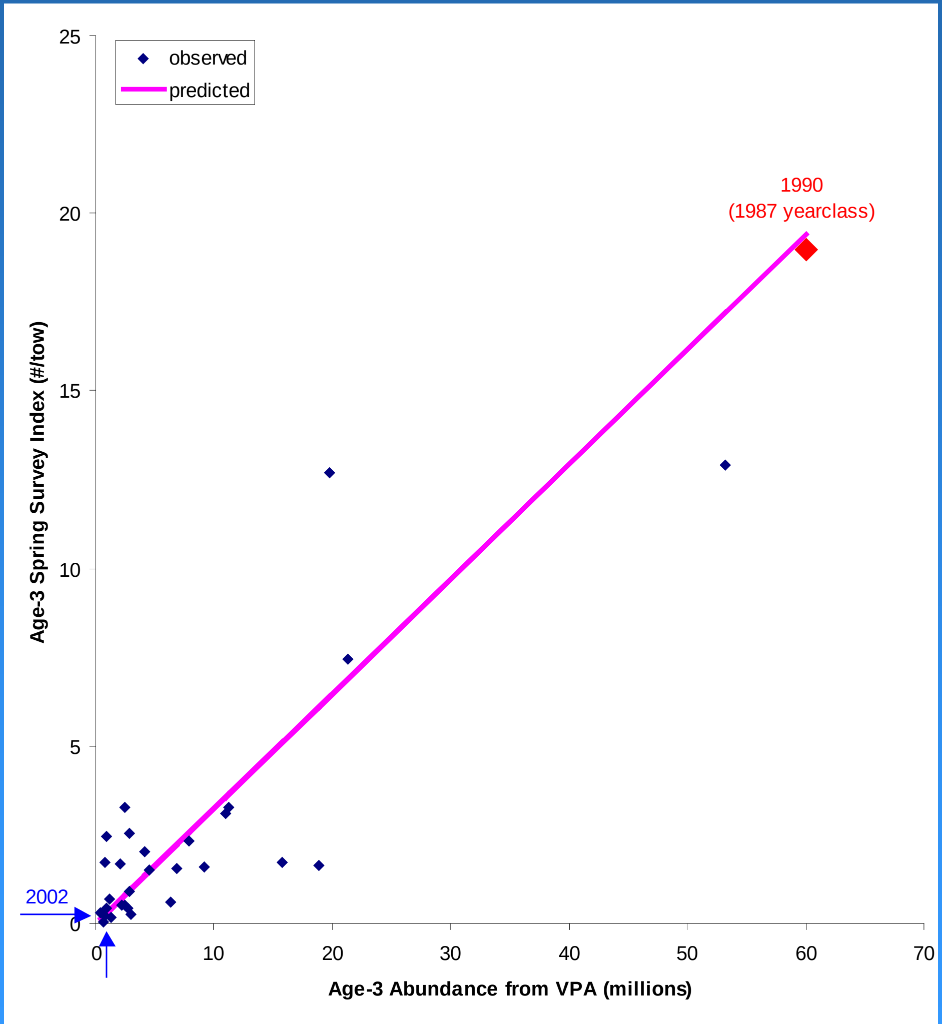
# Virtual Population Analysis

- By accounting for observed catch over the lifetime of the cohort (77 million) and natural mortality,
- the age-1 abundance estimate is 122 million.



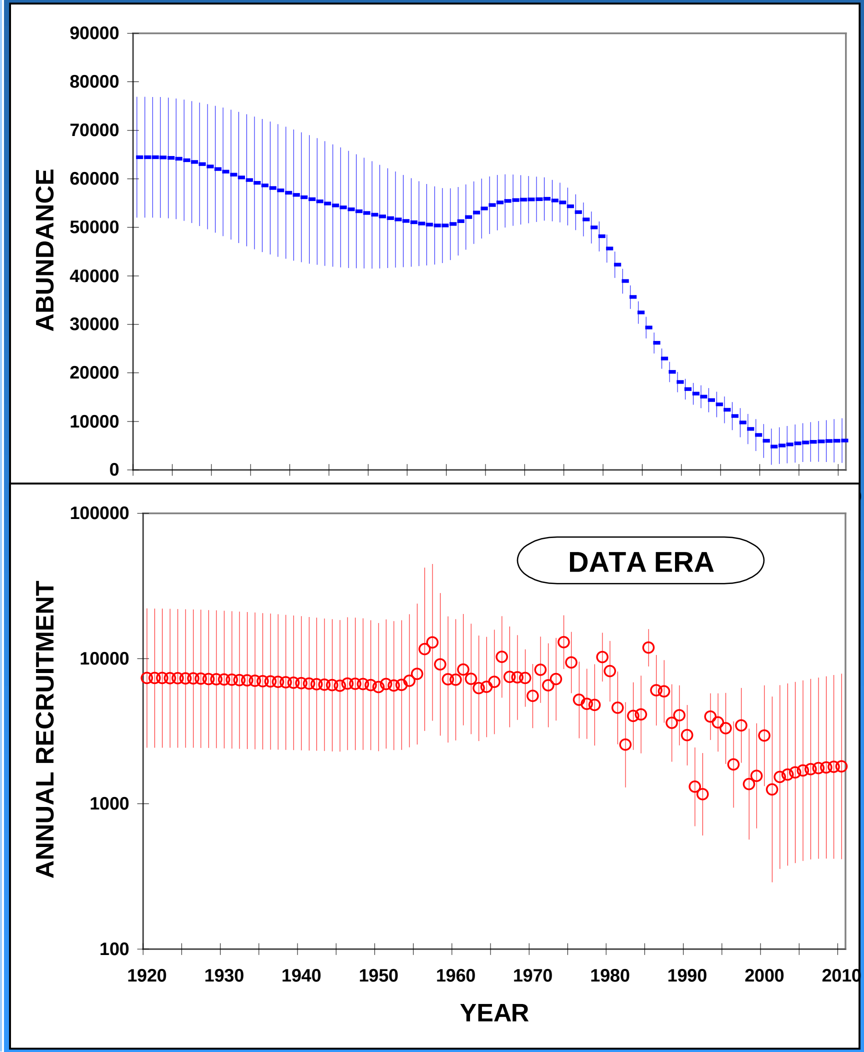
# VPA Calibration

- VPA is calibrated by adjusting parameters of the model to produce a good match to abundance estimated from surveys

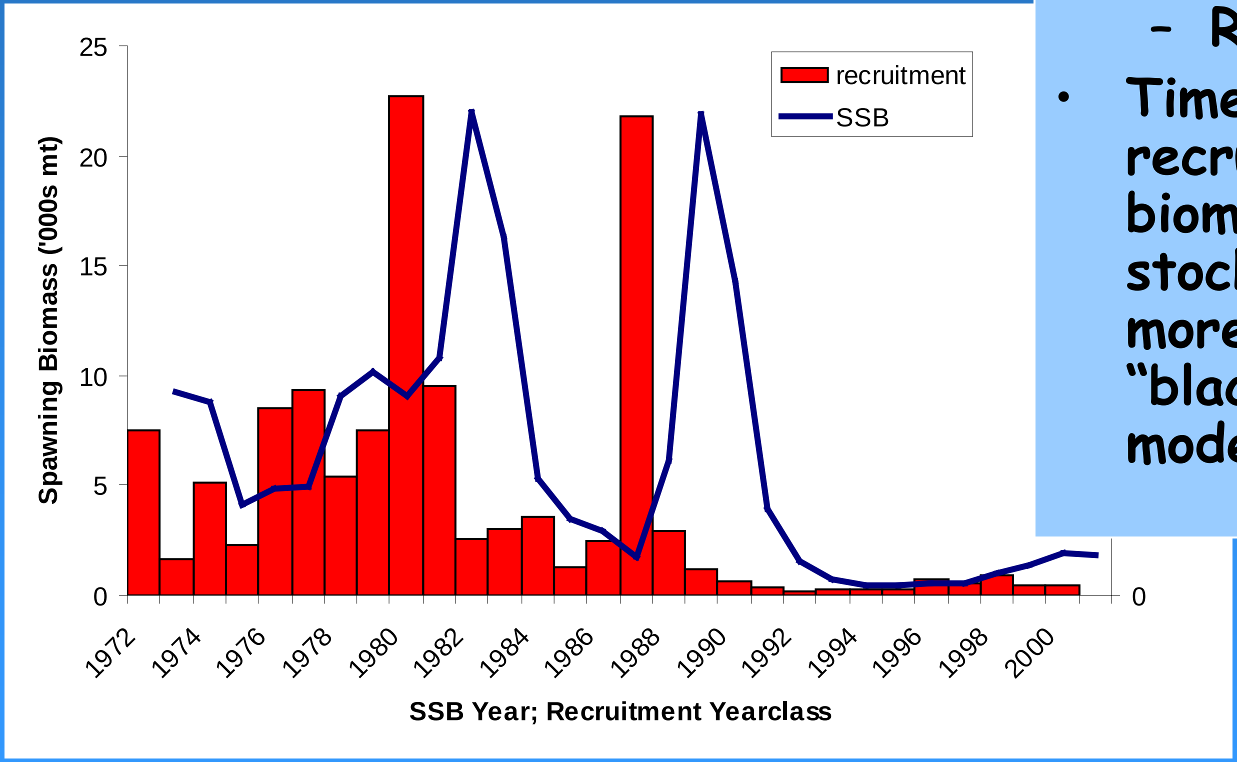


# Integrated Analysis

- Age-based internal model, but rather than work backwards with each virtual cohort, it works forward as a simulation
- Able to use various age, length, abundance data to calibrate model
- Better able to deal with missing data and balance lack of fit across all available data
- Produces comprehensive estimates of model uncertainty
- Smoothly transitions from pre-data era, to data-rich era, to forecast within a single model



# Age-Based Assessment Results




- **Annual estimates:**
  - **stock size (SSB)**
  - **Fishing mortality**
  - **Recruitment**
- **Time series of recruitment and spawning biomass allows a look at stock productivity that is more detailed than the "black box" production model**

# Age-Based Assessments

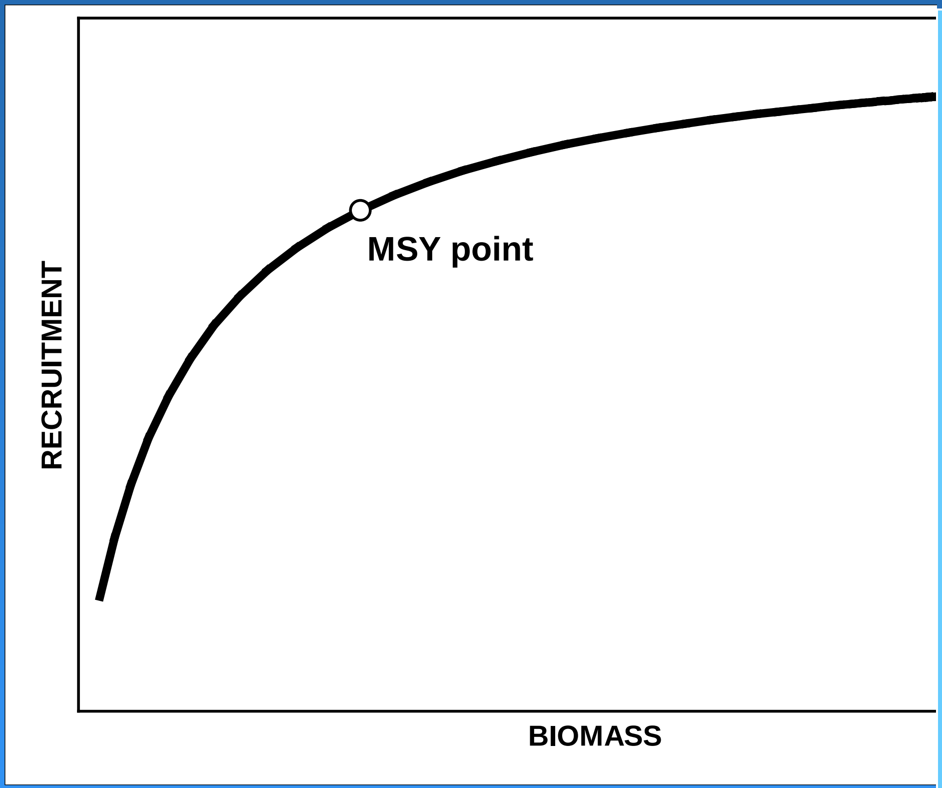
- <u>Advantages:</u>
  - detailed information about the population (recruitment, age structure, mortality)
  - Age-structure allows non-equilibrium forecasts
- <u>Disadvantages</u>:
  - More complicated to use
  - requires more data, particularly accurate catch at age
  - may be a limited time series for VPA type models
  - Integrated Analysis can be best mix of Production model and age-structured model

# Data, Model Choice, Outputs

- Index Method: relative biomass trend only, no F estimate
- Equilibrium Method:  average F only, no trend and no biomass
- Dynamic Methods: produces trend and absolute level of biomass and F, adding age data provides more detailed tracking of stock and forecasting of changes

# Stock Productivity; Fishery Control Rules and Risk Assessment

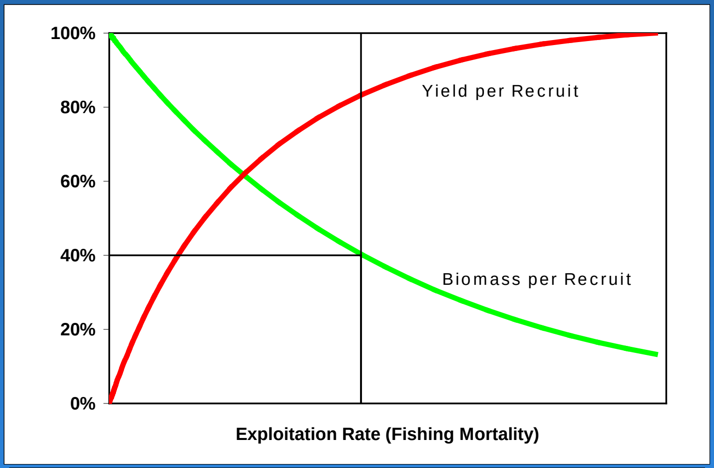
# Spawner-Recruitment

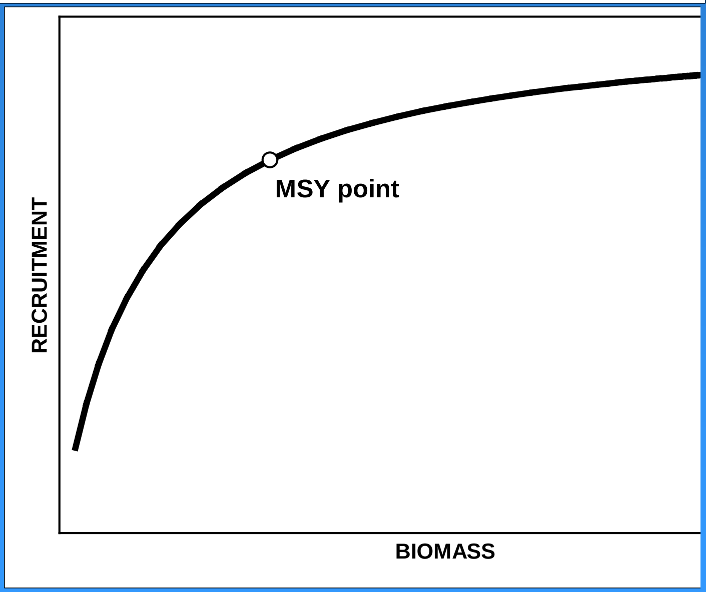



- Beverton-Holt curve shown; other shapes possible
- Stocks with high productivity/resilience keeps R high as B declines, but no spontaneous generation!
- Environment causes year-to-year deviations from this average curve, sometimes extreme and with trends
- Long-term climate pattern and ecosystem shifts can change the curve

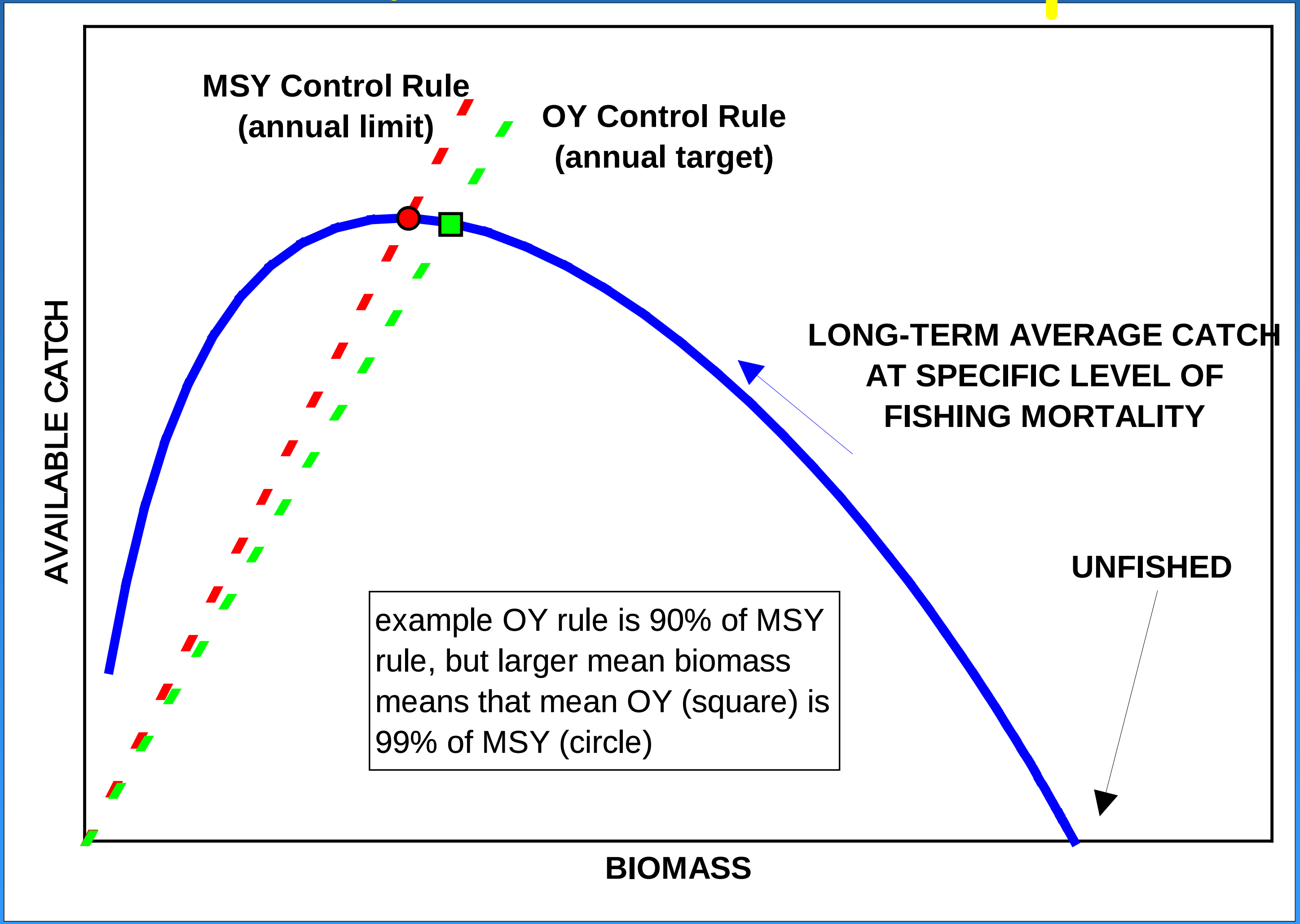
# Combine Spawner-Recruitment And Direct Fishing Effects

- Direct Fishing effect:
  - Increases catch per recruit (until growth overfishing)
  - Decreases biomass per recruit
- Spawner-Recruitment effect:
  - Decreases recruitment when biomass is reduced
- Combining the two effects:
  - Produces dome-shaped catch vs. biomass curve
  - Basis for MSY calculations



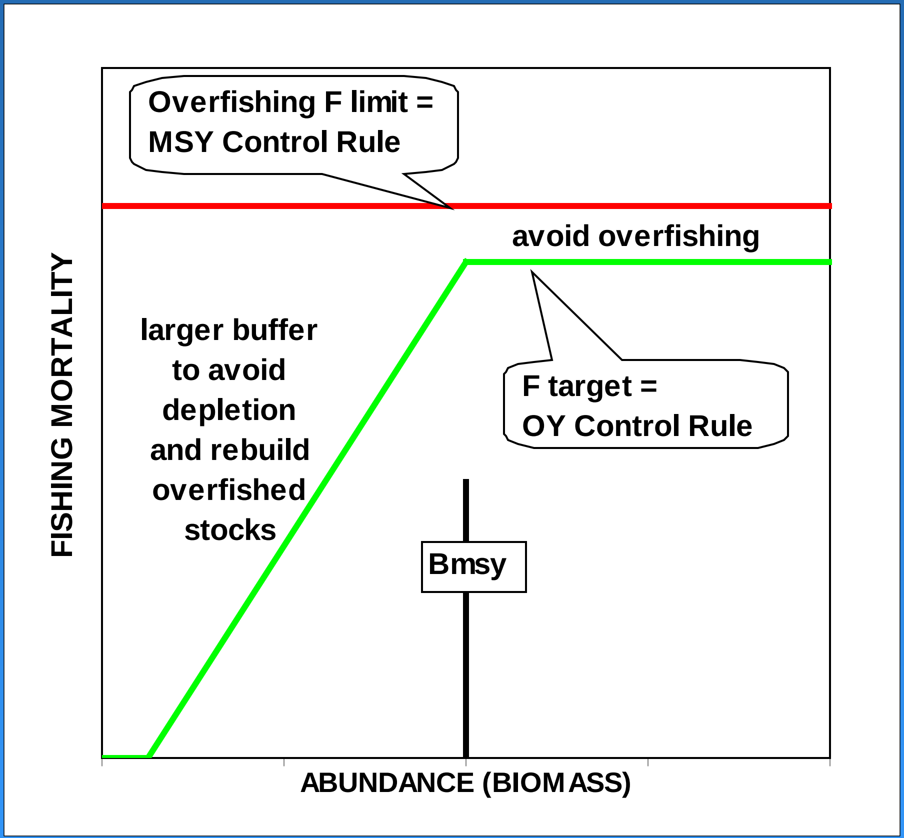



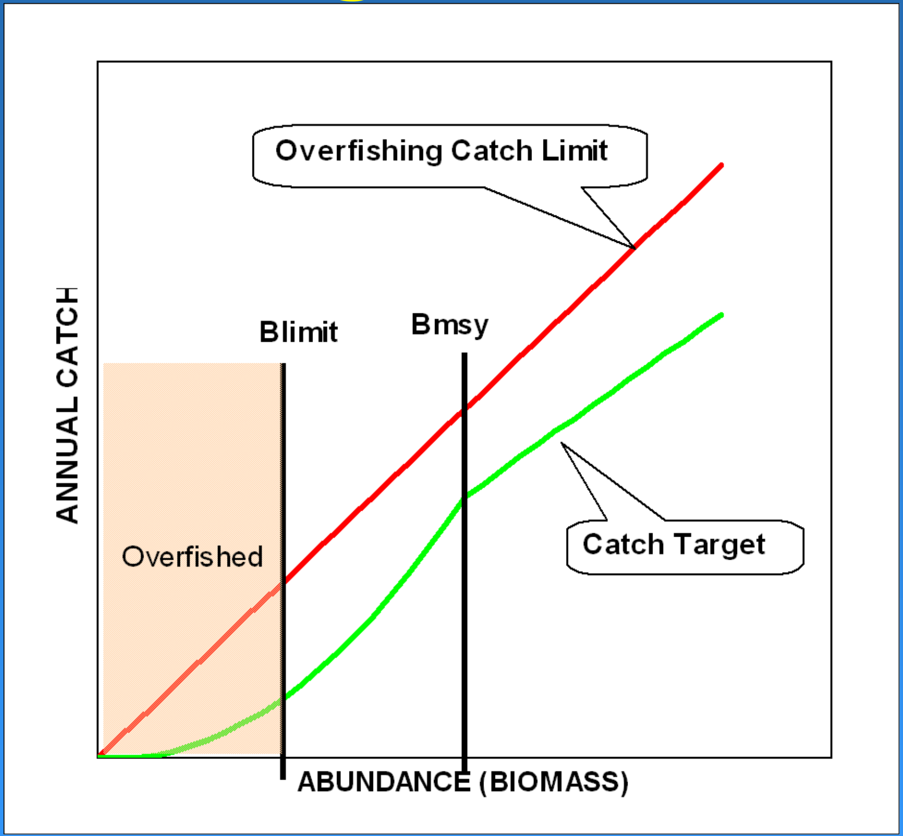
# MSY and Dome-Shaped Catch-Biomass Relationship




*asymmetric curve due to spawner-recruitment model, rather than simple production model

# Control Rule Calculates Catch Limit and Target

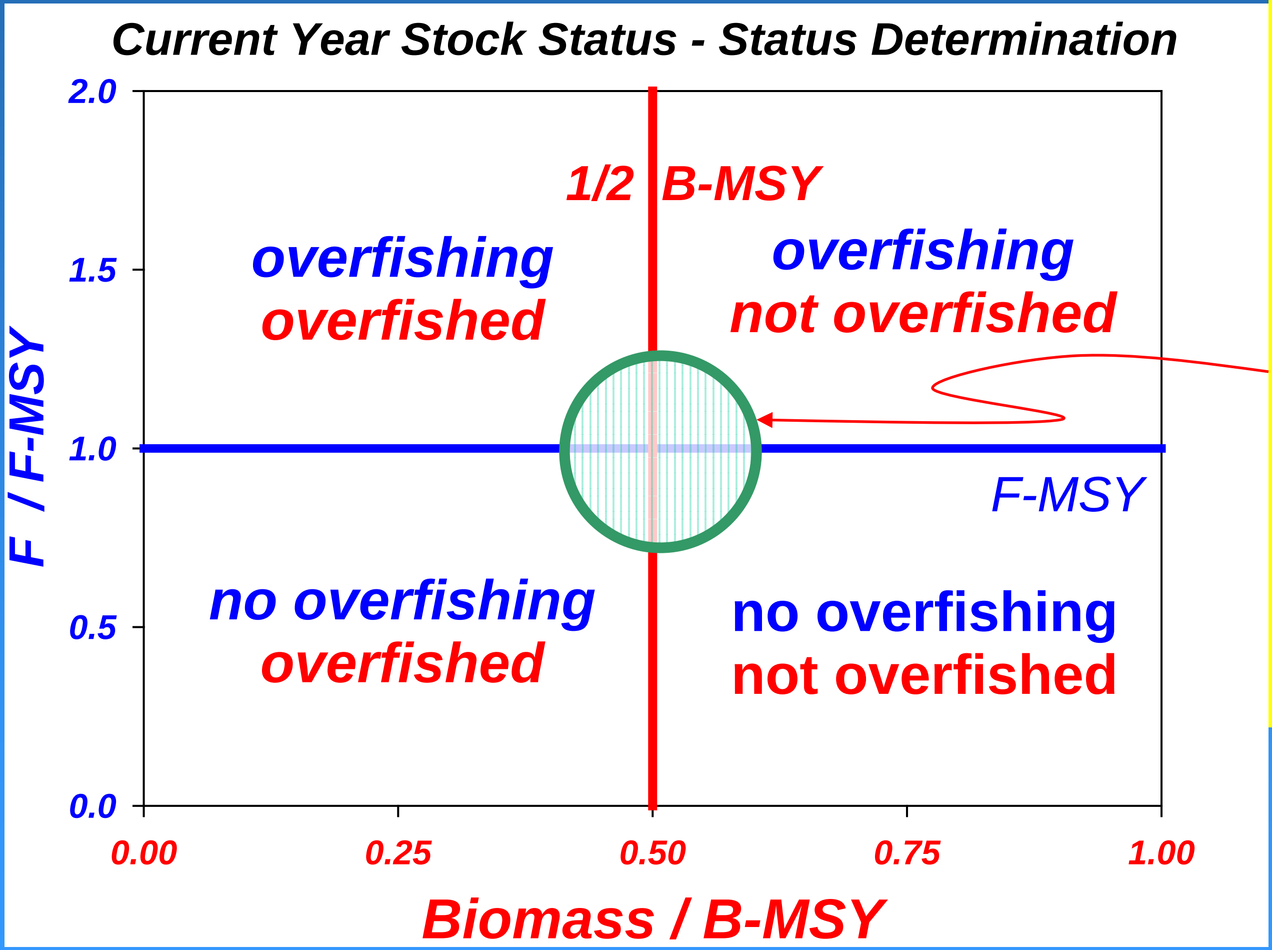


# Risk Assessment

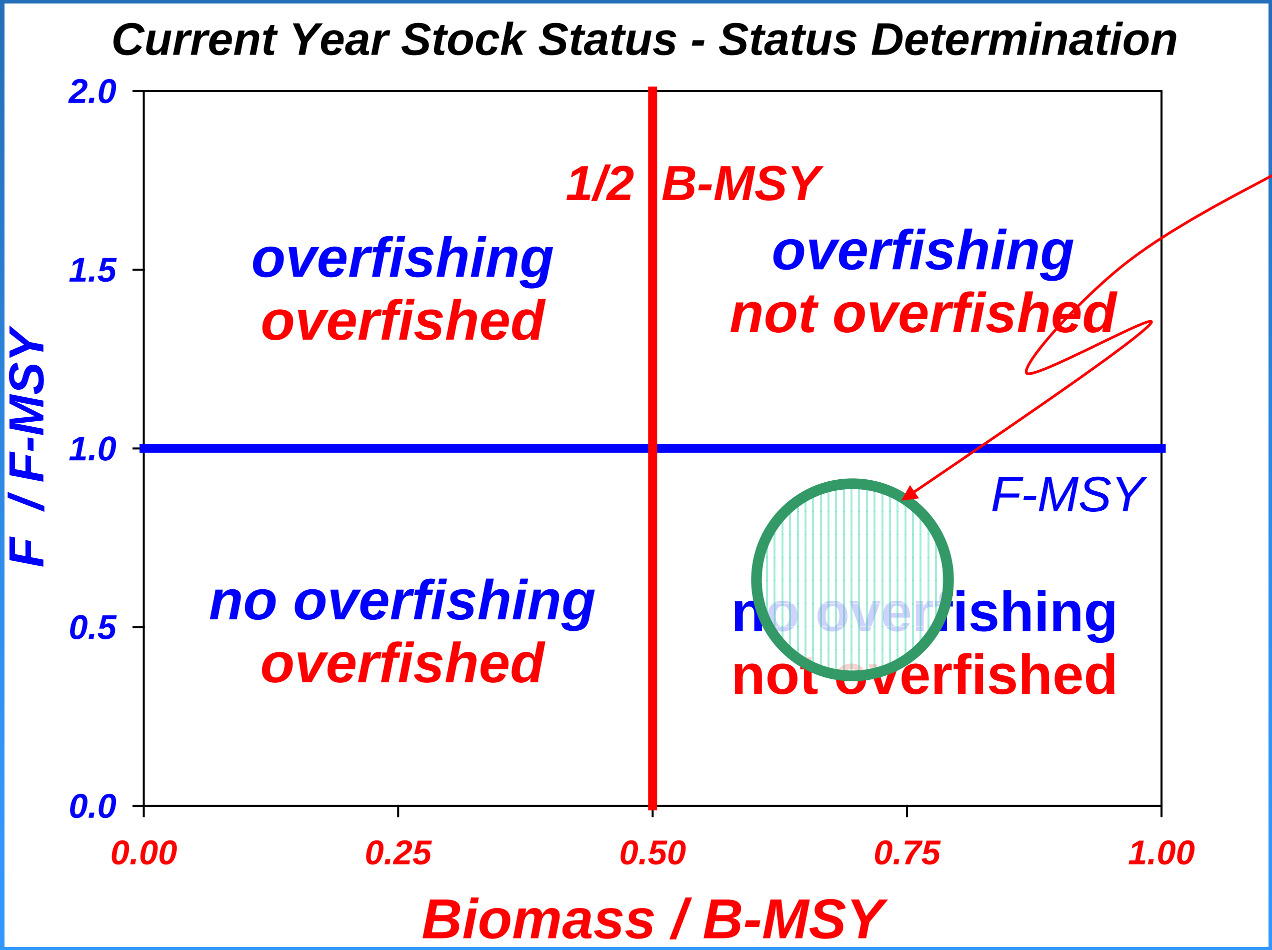
- Stocks fluctuate naturally
- Knowledge of these fluctuations never perfect and always lags
- So forecast catch is also imperfect
- Then control of fishery to that catch level is also imperfect
- So, MSRA's "set ACL such that overfishing does not occur" should be put in probabilistic, risk assessment terms

# Where do you want to manage the resource?




Managing at the margin makes changes in stock status very likely given the expected variation in assessments. In this instance, 75% of the outcomes are bad.

# Where do you want to manage the resource?

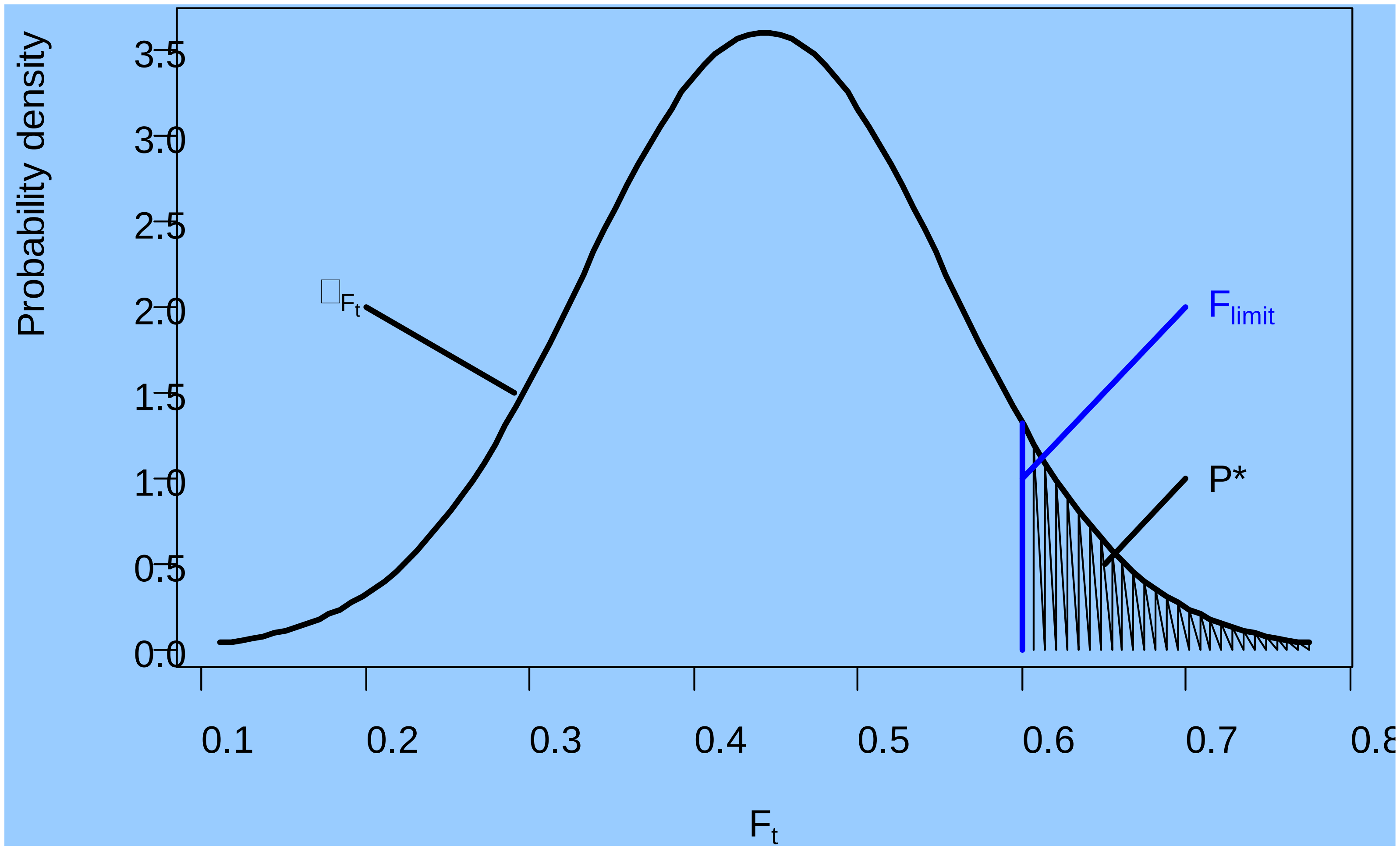



Managing AWAY from the margin makes changes in stock status less likely and increases planning time for management and business

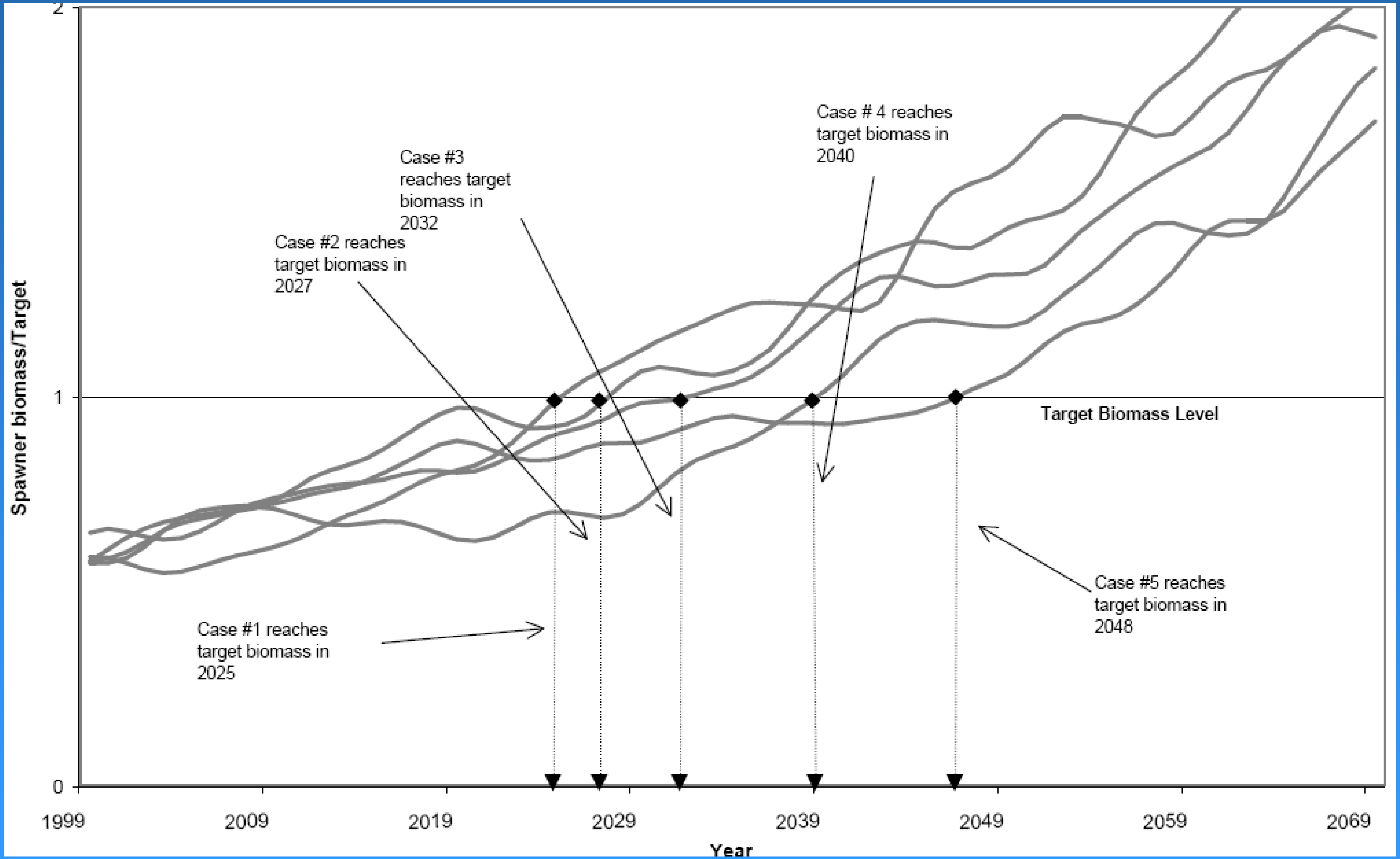
# Risk Assessment

- What harvest policy would:
  - Have no more than a Y% chance of exceeding the true overfishing level in each of the next several years, taking into account scientific uncertainty in calculating biomass and management uncertainty in controlling catch;
  - Have at least a X% of leaving the stock above the target level of abundance some specified year into the future;
  - Produce Z level of catch and benefits

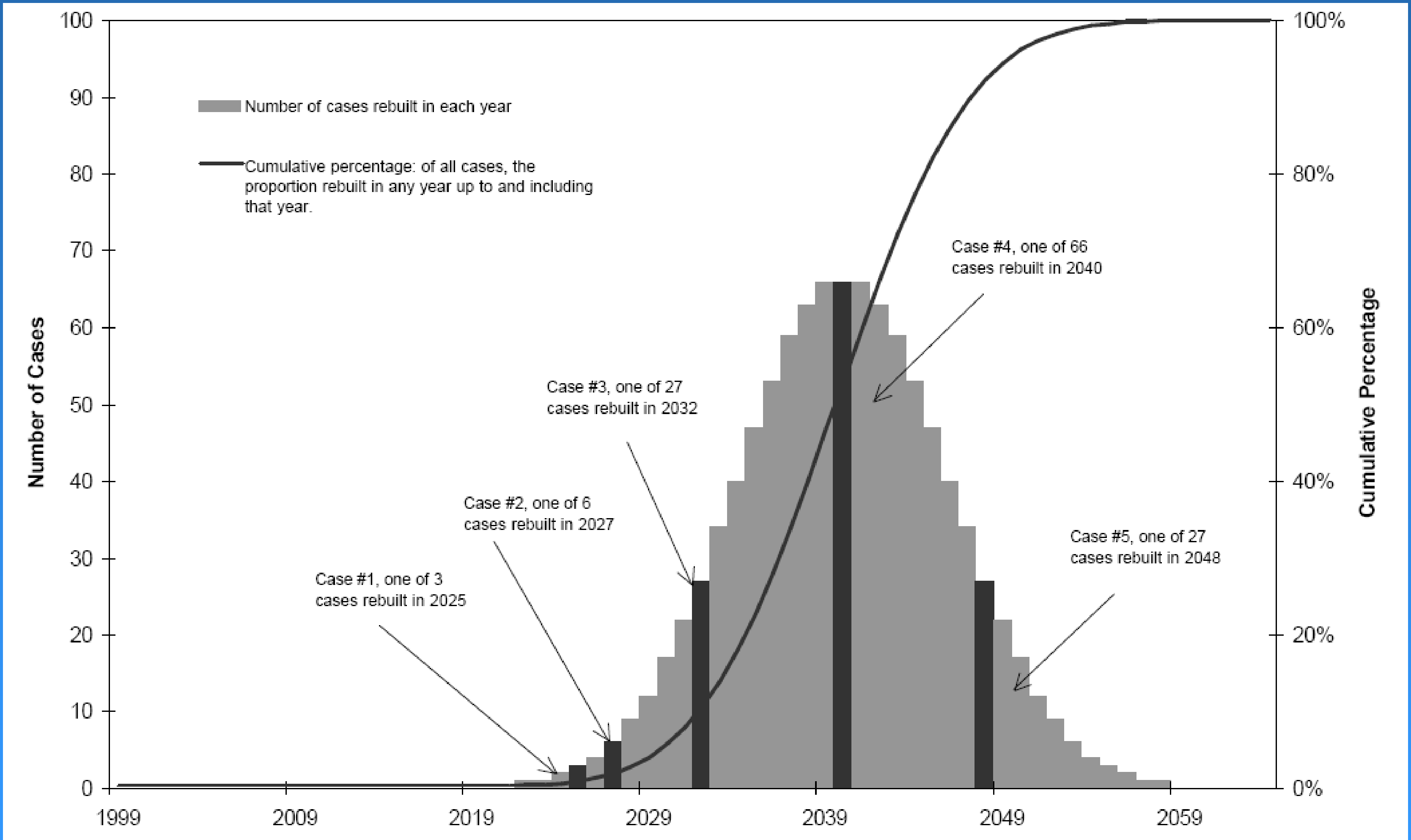
# Probability that F exceeds a fixed limit



# Rebuilding Projections Based on Probability Distribution of Forecasts

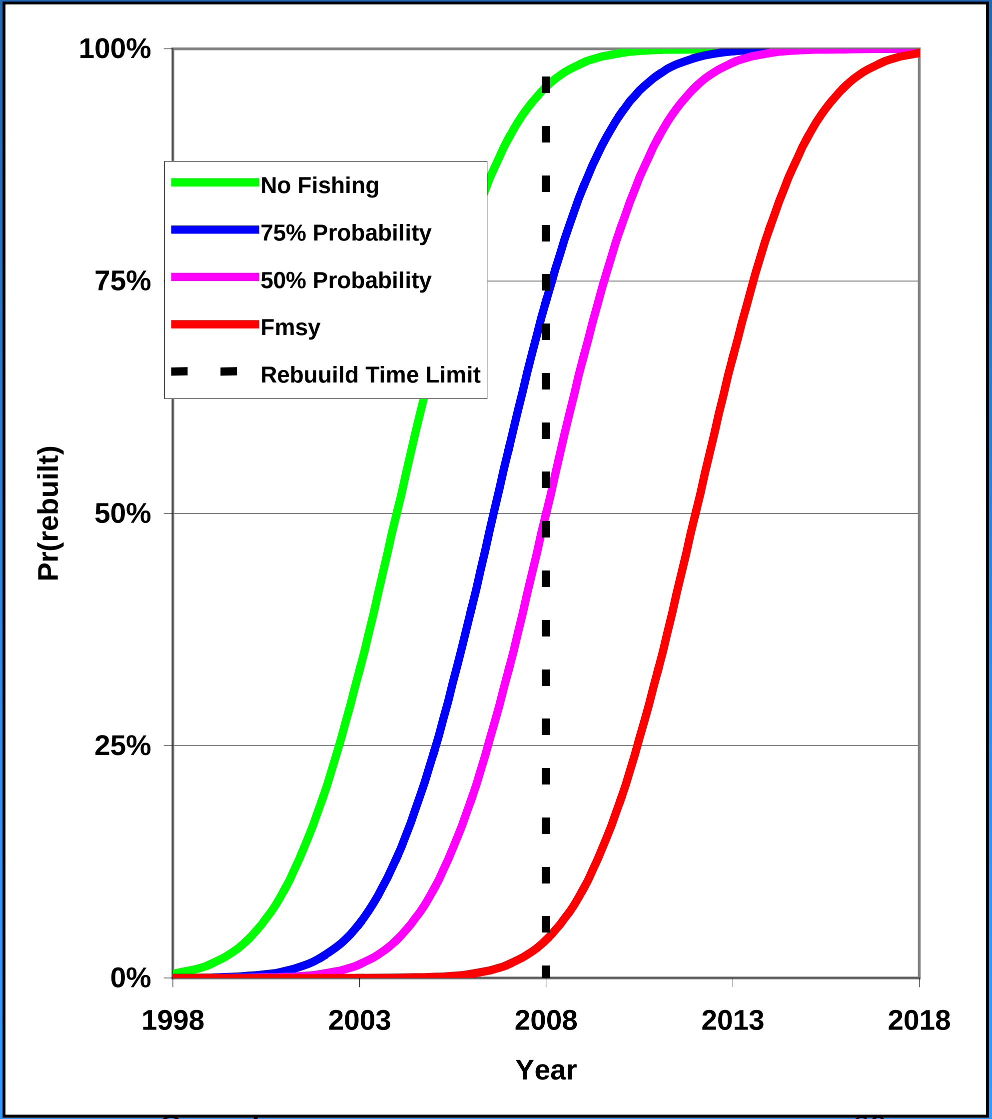


# Probability Distribution for Rebuilding



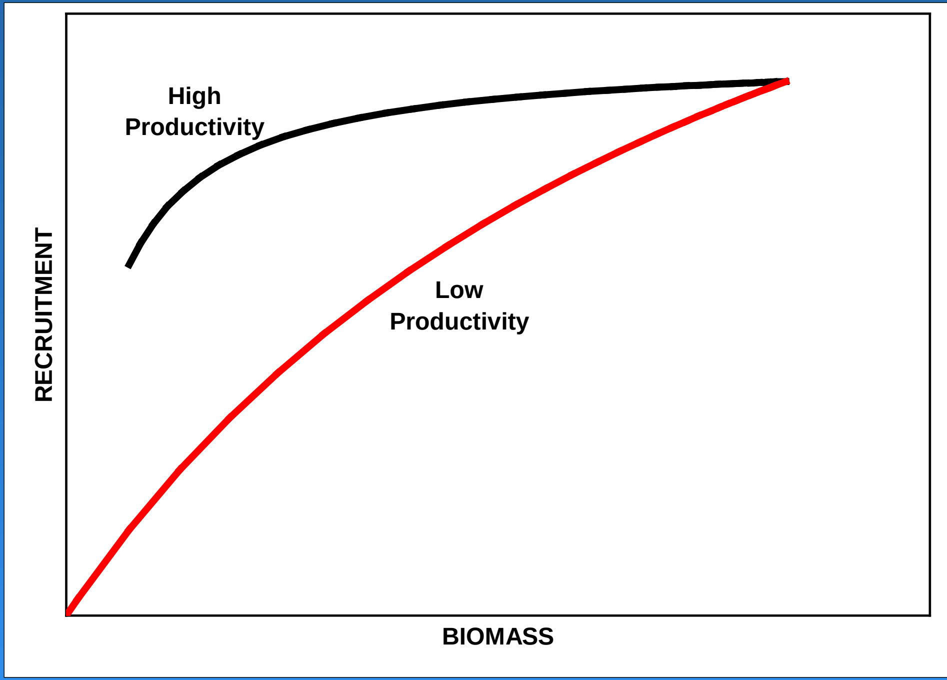
# Rebuilding Analysis

- For previously overfished stocks now on rebuilding plans, we typically calculate the sequence of future catches that will have an acceptable probability of allowing the stock to rebuild to its target level while taking into account various components of uncertainty



# Rebuilding Time Depends on Stock Productivity

High productivity stocks maintain high recruitment levels even as stock abundance declines (e.g. some New England groundfish). They rebuild quickly as fishing mortality is reduced.




Low productivity stocks can sustain only low fishing mortality rates and, if severely depleted, require multiple generations to rebuild even with minimal fishing mortality (e.g. west coast groundfish).

# Management Strategy Evaluation (MSE)

- Computer-intensive test of assessment and management performance
  - Simulate biology of stock
  - Generate estimate of index, including variability
  - Calculate management reaction to index (control rule), including time lags
  - Calculate response of stock to management
  - Repeat many times
- What kinds of index work best?
- What kinds of control rules work best?

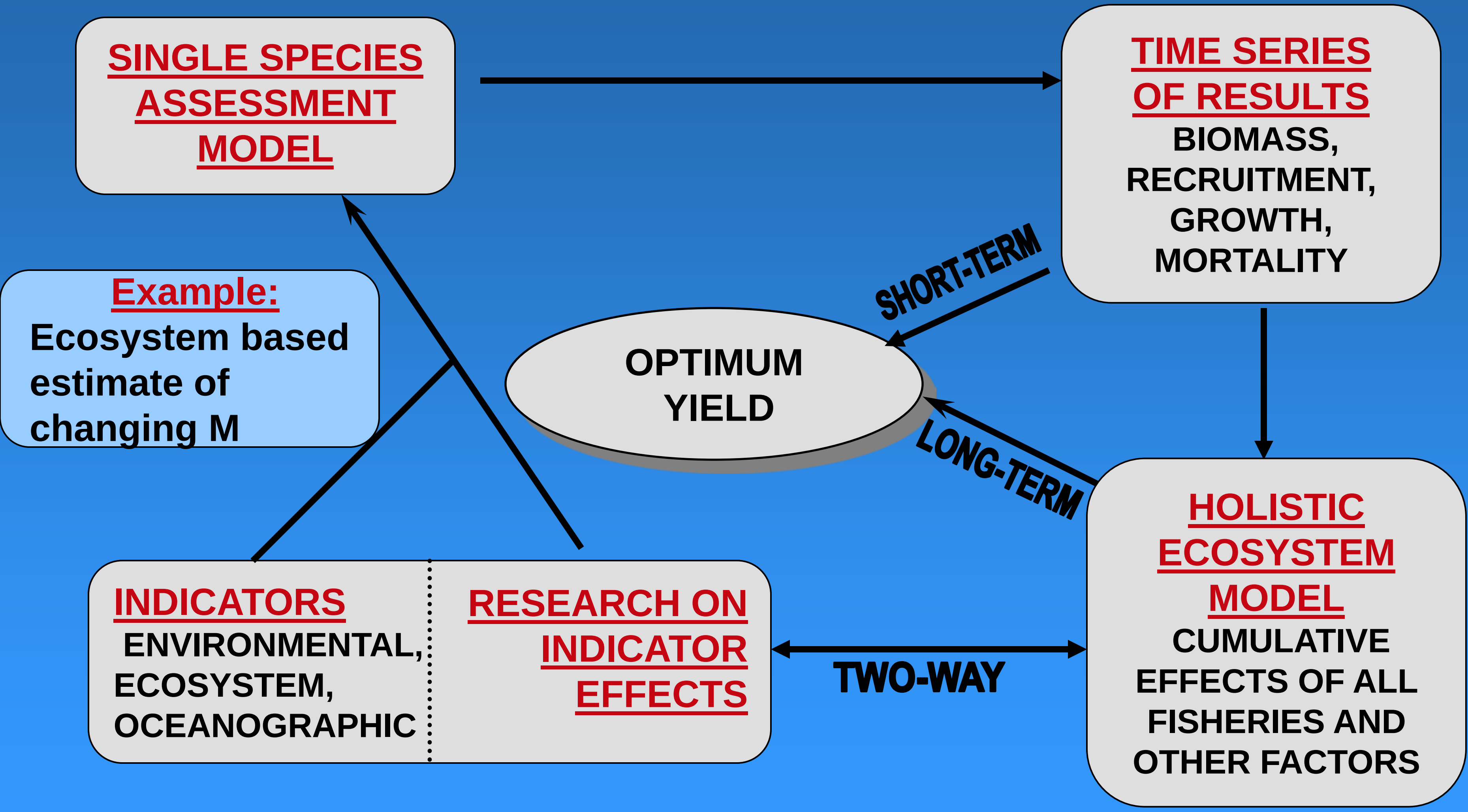
# Data-Poor Situation

- Fact: for data-poor stocks, there is a level of catch that would be overfishing and will eventually deplete the stock
  - We just don't know what it is;
- Estimate of uncertainty should reduce as we get more info, not get larger as we calculate more components of uncertainty;
  - So need proxy for unmeasured uncertainty;
- Data-poor approach to management should be at least as conservative as the approach used when a data-weak assessment can be done;
- Win-win when buffer is linked to total uncertainty.

# Stock Assessment Limitations

- Missing, Variable and Biased data affect results;
- Influence of non-fishery changes (habitat/ecosystem/climate) are mostly outside of knowledge base and models, hence:
  - natural mortality, growth, productivity often held constant
  - Overall results appear more precise than they really are, especially with simple models

# Stock Assessment – Ecosystem Connection



# Assessment Summary

- Assessments are designed to answer management questions
- Variety of methods tuned to diverse data availability scenarios
- Assessments produce estimates of stock abundance, mortality and productivity
- Forecasts provide probability distribution of future stock conditions and yield under alternative harvest scenarios

# End

- *"life does not stand still while specialists put their minds in order"*

  *Michael Graham, 1950.*

  *Address to United Nations*

# Extra slides

# Differing Perceptions of Reality

## *"No individual experiences the average condition"*

- ***FISHERMEN***
- Real-time Observations
- Clustered
- Direct Involvement
- Small Areas
- Goal-Oriented Sampling
- Year-round sampling

- ***SCIENTISTS***
- Lagged Observations
- Synoptic
- Indirect Involvement
- Large Areas
- Probablistic Sampling
- Intermittent Snapshots

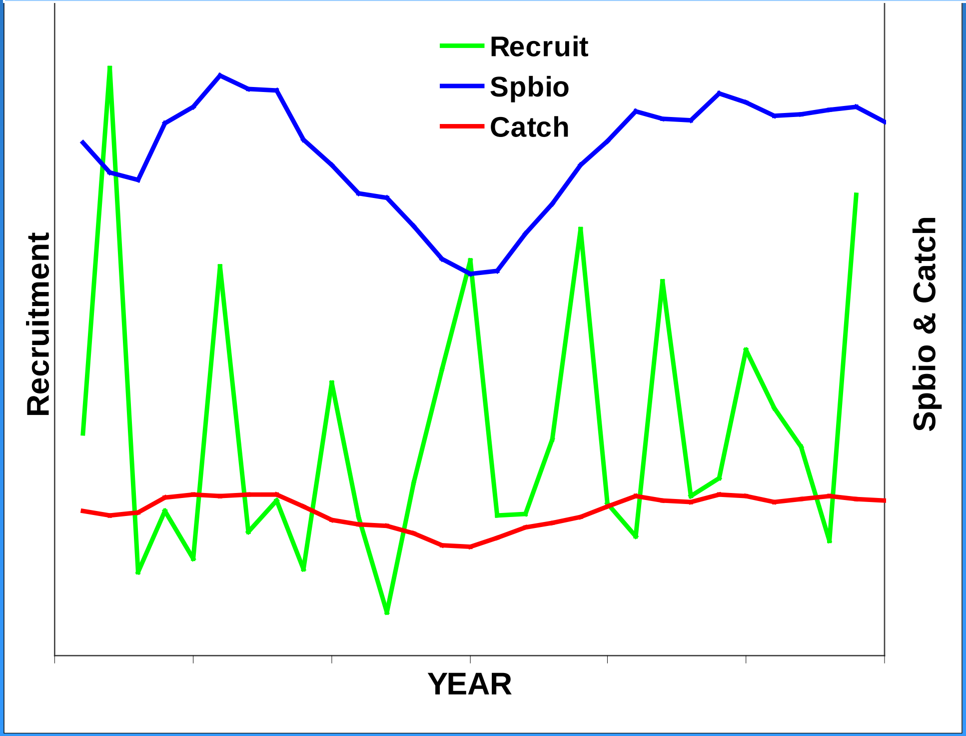
# Dynamic MSY from Control Rule

**$F_{msy}$** Fishing mortality that yields maximum average yield over the long term

**MSY** long-term average catch from fishing at $F_{msy}$

**$B_{msy}$** average stock biomass that results from fishing at $F_{msy}$

**OFL** fluctuates annually as the Fmsy is applied to B




To keep F constant, fishery managers either:

(a) forecast the biomass next year to adjust the Quota, or

(b) have good control on the effective fishing effort so that the fishing mortality stays constant, even as stock abundance changes.