Recruitment Assessment

LO: interpret stock and recruitment relationships using commercial fish stock examples

Recruitment Model Types

1. Spawner – Recruit or Surplus Production: Beverton – Holt

2. Age – Structured: VPA, Cohort Analysis

3. Yield per Recruit (an intermediate approach)

Need to be able to differentiate between categories

1. Spawner-Recruit

Beverton and Holt: based on growth and mortality

- originated from observations of no fishing in North Sea during WW II

$$S_2 = S_1 + (R + G) - (M + C)$$

where:

S_t = spawning biomass at time t

R = recruitment

G = growth

M = natural mortality

C = catch (F = fishing mortality)

How are these quantities related and how can they be estimated?

Estimating Recruitment

- assume steady state (i.e. constant recruitment), examine yield per recruit

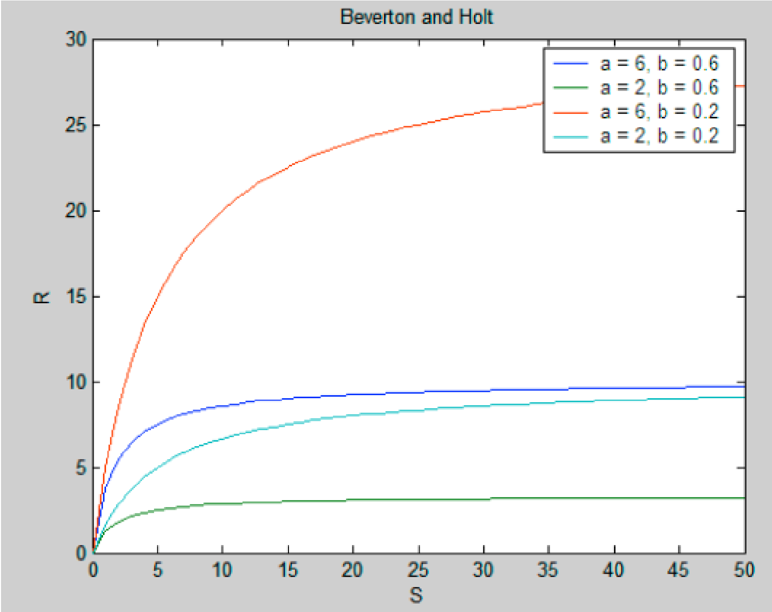
Beverton & Holt

$$R = \frac{aS}{1 + bS}$$

R = recruits, S = spawners

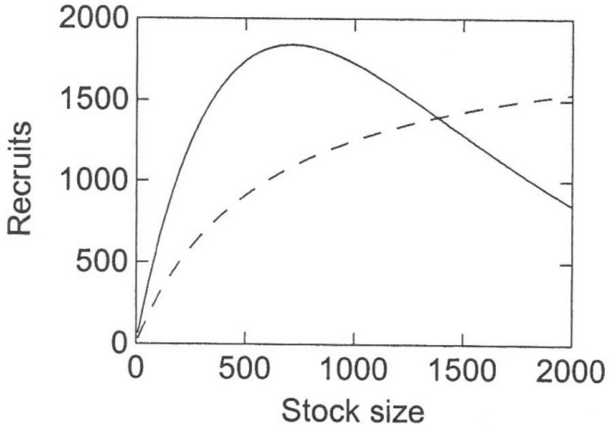
a increases height of asymptote, reduces curvature

b increases slope



Ricker

$$R = aSe^{-bs}$$



where a density-independent, b density-dependent

Estimating Growth

- assume von Bertalanffy growth (not always true)
- asymmetric sigmoid
- proposed as biological theory of growth:

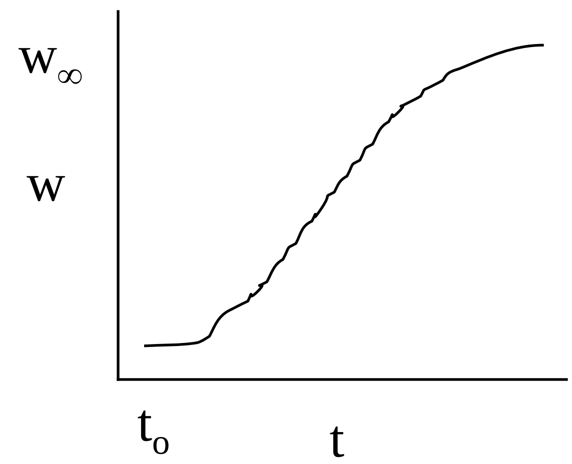
growth = anabolism (i.e. absorbing surface, s) - catabolism (i.e. mass)

$dW/dt = H\,W^n - KW^m$ H = Assimulation constant; K = Brody growth coefficient

$dW/dt = H\,s - K\,W^m$

$W_t = W_\infty(1 - e^{-K(t-t_o)})^b \quad L_t = L_\infty(1 - e^{-K(t-t_o)})$

(b is from L-W relationship $\cong$ 3)



High K: low age @ maturity, high reproductive output, short life span, low max length

- need to estimate L_∞ and K
- used for population but will fit individual growth

Estimating Mortality

- assume mortality (M and F) constant with age

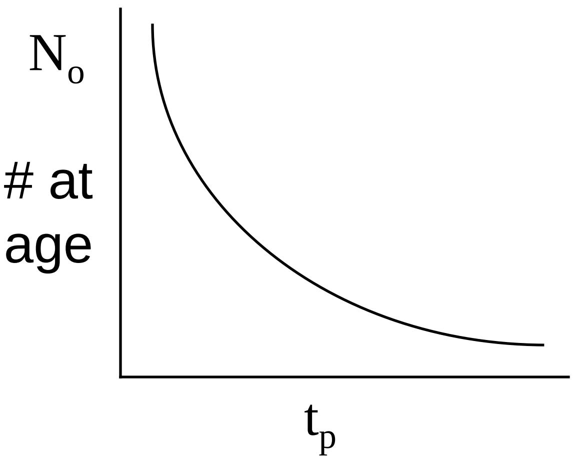
$N_t = N_o\, e^{-Mt}$ N = number, M = natural mortality

$R = N_o\, e^{-Mtp}$ R = number of recruits, tp = time to recruitment

$N_t = Re^{(-(F+M)\,(t-tp))}$ and $dN/dt = -(F+M)N$

If recruitment postponed to time t_p'

$R' = Re^{(-M(tp'-tp)}$



F = qf q = catchability coefficient,

f = % spawning females

Estimating Biomass of Year Class

$N_t W_t = RW_\infty \exp(-(F+M)(t-t_{p'}))\,(1-e^{-K(t-to)})^3$

numbers mass

1. Yield (Y) change due to fishing:

$$dY/dt = F \times N_t \times W_t$$

2. Catch (C) in #'s

$$C = F \times R \int_{t=p'}^{\lambda} e^{-Z(t-t_{p'})} dt$$

Catch = Fish mort x Recruits

3. Integrate yield in weight:

$$Y = F \times R \int_{t=p'}^{\lambda} \boxed{W_t} e^{-Z(t-t_{p'})} dt$$

Yield = Fish mort x Recruits x weight

$$Y = F \times RW_\infty \int_{t=p'}^{\lambda} e^{-Z(t-t_{p'})} (1-e^{-K(t-t_0)})^3$$

Yield = Fish mort x Recruits x Weight (growth + age)

Data & Methods to Regulate Yield

K, W_∞, t_0 determined from growth data

R from cohort analysis or cancelled by using Y/R data

F, $t_{p'}$ controlled by fishery managers

F estimated from mortality or cohort analysis

F regulated via f ($F = qf$) q = catchability coefficient,

f = % spawning females

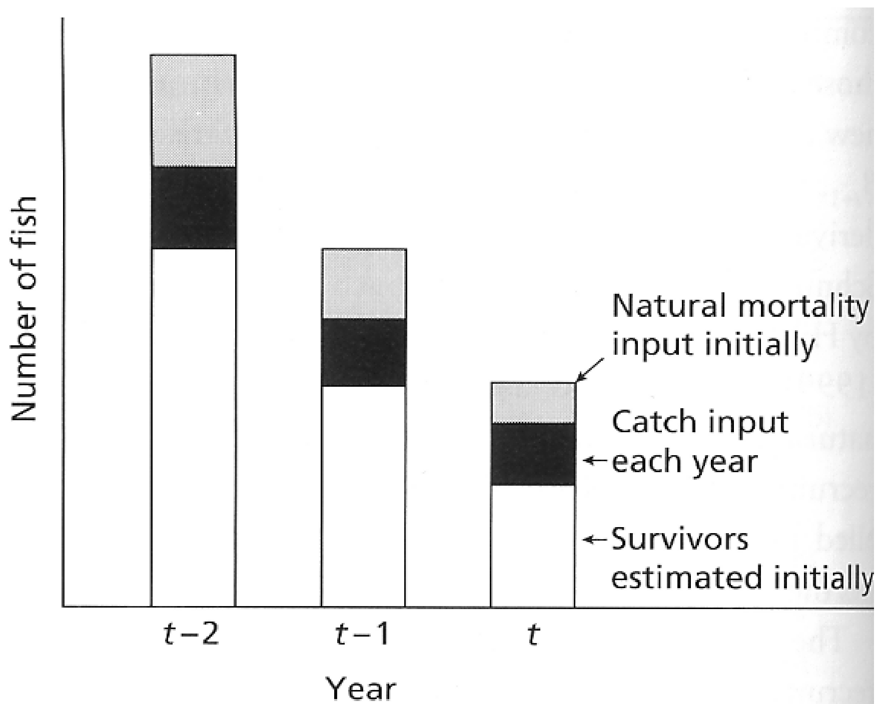
$t_{p'}$ mesh size regulation for trawl fisheries

Regulation through fishing mortality ($Z=F+M$) and recruitment ($t_p \rightarrow t_{p'}$)

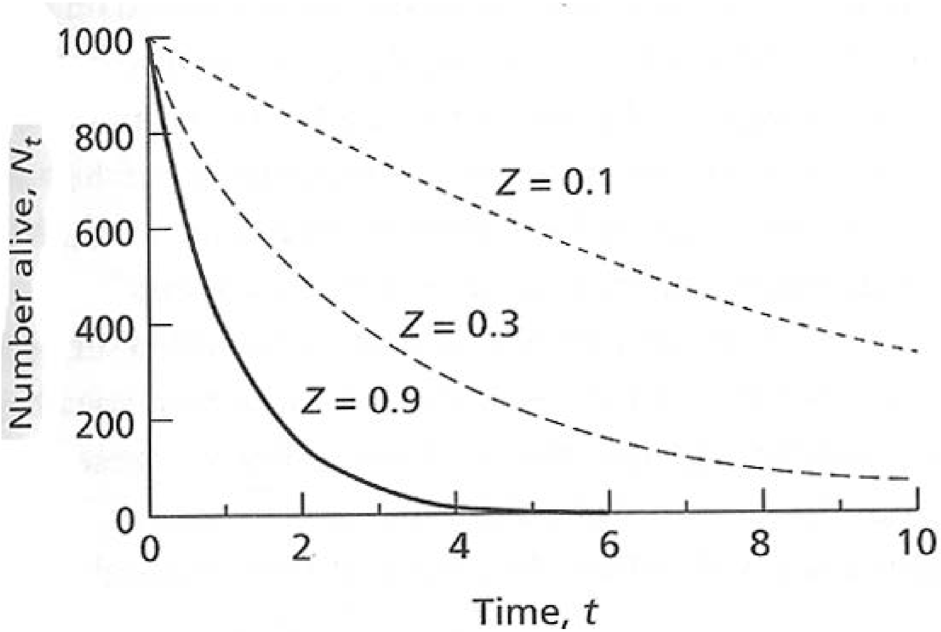
2. Age-Structured Models

Virtual Population Analysis (VPA)

- hindcast using commercial catch data to estimate stock size and mortality rates by cohort (length or age based)
- to estimate current population size (i.e. survivors), add in catch and natural mortality to get prior year's abundance
- does not estimate future numbers or potential quota



VPA: Estimating Mortality



Number alive at Z=0.1, 0.3, 0.9

Number Alive

$$N_t = N_0 e^{-((Mt)+(Ft))}$$

$$N_t = N_0 e^{-Zt}$$

$Z = M+F$

Catch Equation

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

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

Using catch data and N_t, solve for M_t for each age class

Virtual Population Analytic Steps

Work backwards from present to past

1. Estimate 'terminal abundance', N_t of oldest cohort from catch and approximated F and M ($Z=F+M$)

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

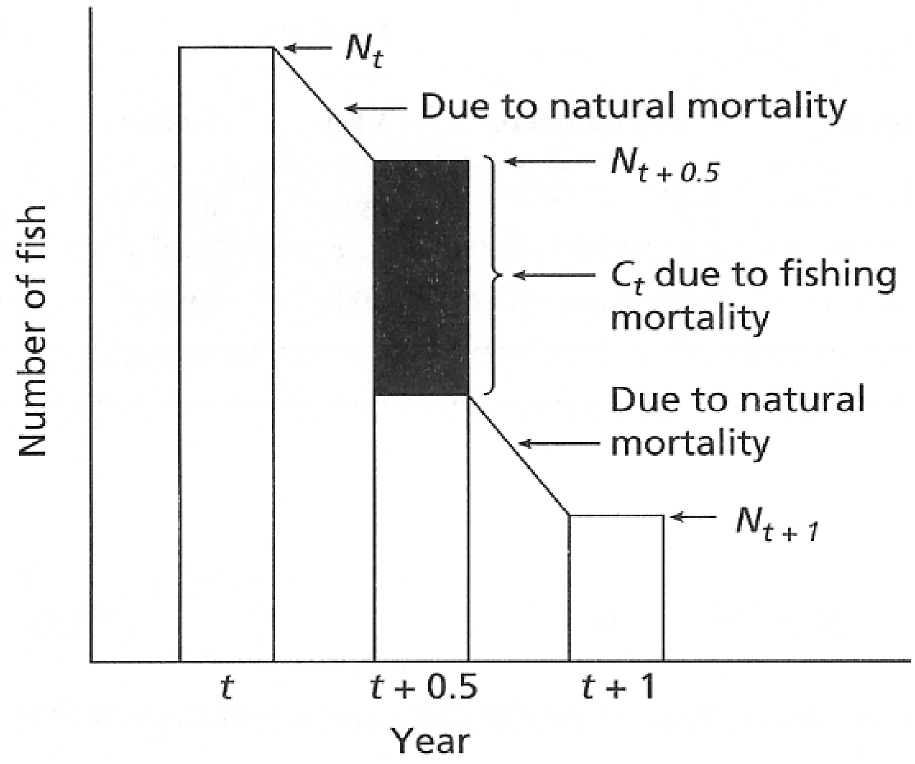
2a. Numerically calculate previous year's fishing mortality, F_t (derived in Jennings et al. 2001, pg. 140)

$$C_t = \frac{F_t}{F_t + M} N_{t+1} (e^{F_t + M} - 1)$$

2b. For pre-fishery cohorts, calculate N_t again by using F_t from above

$$N_t = N_{t+1}\,\mathrm{e}^{(F+M)}$$

Cohort Analysis: age-based



Pope 1972

- simplification of VPA
- does not require iterative determination of F
- assume all fish taken at middle of year
- use C, F, and M to reconstruct F and stock structure

Cohort Analysis Analytic Steps

1. Number alive just before fishing: $$N_{t+0.5} = N_t e^{-M/2}$$

2. Subtract year's catch (instantaneous): $$N_t e^{-M/2} - C_t$$

3. Add in natural mortality to survivors: $$N_{t+1} = \left(N_t e^{-M/2} - C_t\right) e^{-M/2}$$

4. Rearrange to estimate numbers in current year: $$N_t = \left(N_{t+1} e^{M/2} + C_t\right) e^{M/2}$$

Estimates number alive at start of year based on catch and number alive at end of year (i.e. start of following year)

Pope 1972

Cohort Analysis: length-based

- for stocks that are difficult or cannot be aged (e.g. tropical species)

- length groups converted to age groups using von Bertalanffy growth equation

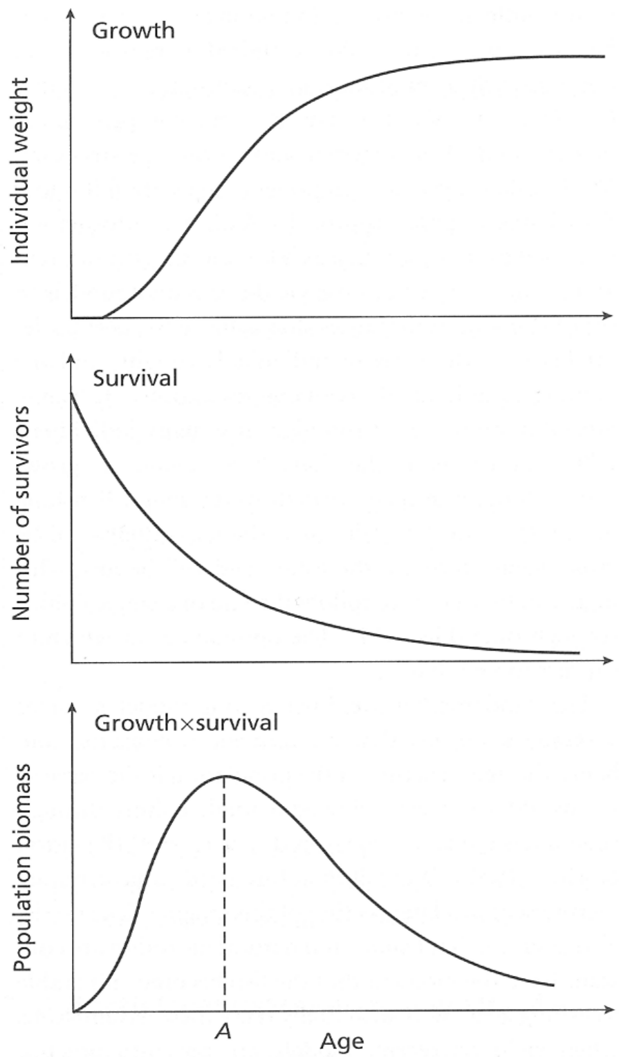
- modify age-based to replace time interval (i.e. 1 year) with age interval corresponding to time between Length_1 and Length_2

(see Jennings et al. 2001, pg. 143)

Statistical Catch-at-Age Methods

- Still age-based (aka stock synthesis)
- Develop a population dynamics model, then parameterize using empirical data
- Provides better estimates of variables for most recent year classes than do most VPAs
- Don’t typically require estimates of M
- Computationally intensive (non-linear regressions for parameter estimation)
- Still ‘post hoc’ analysis

3. Yield-per-Recruit Models



- for sustainable harvest need balance among: reproduction, somatic growth, fishing mortality, natural mortality

- surplus production models group factors and ignore age

- yield-per-recruit models incorporate age (i.e. length) classes in fishing mortality

- balance numbers with sizes/ages of individuals

- if F too high, then too many small fish caught growth overfishing

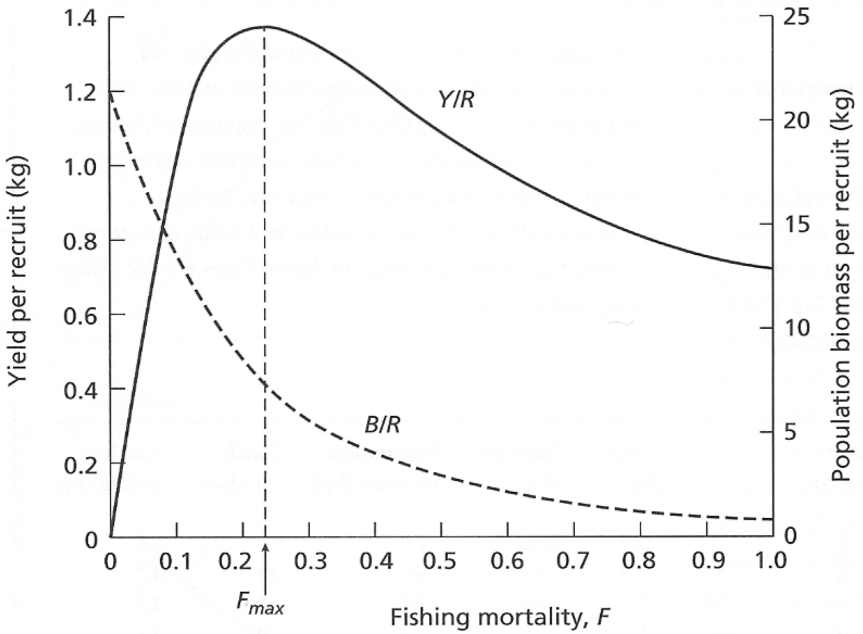
- if F too low, then only large individuals caught and yield low recruitment overfishing

A = optimal age for capture

Yield/Recruit, Biomass/Recruit

Goal: for a given F, how much yield for every fish recruited?

$$Y = \sum_{t_c}^{t_{max}} F_t N_t W_t$$



= $\text{sum}_{\text{over time}}$ (mortality x biomass)

t_c = time 1st capture, t_{max} = max cohort age

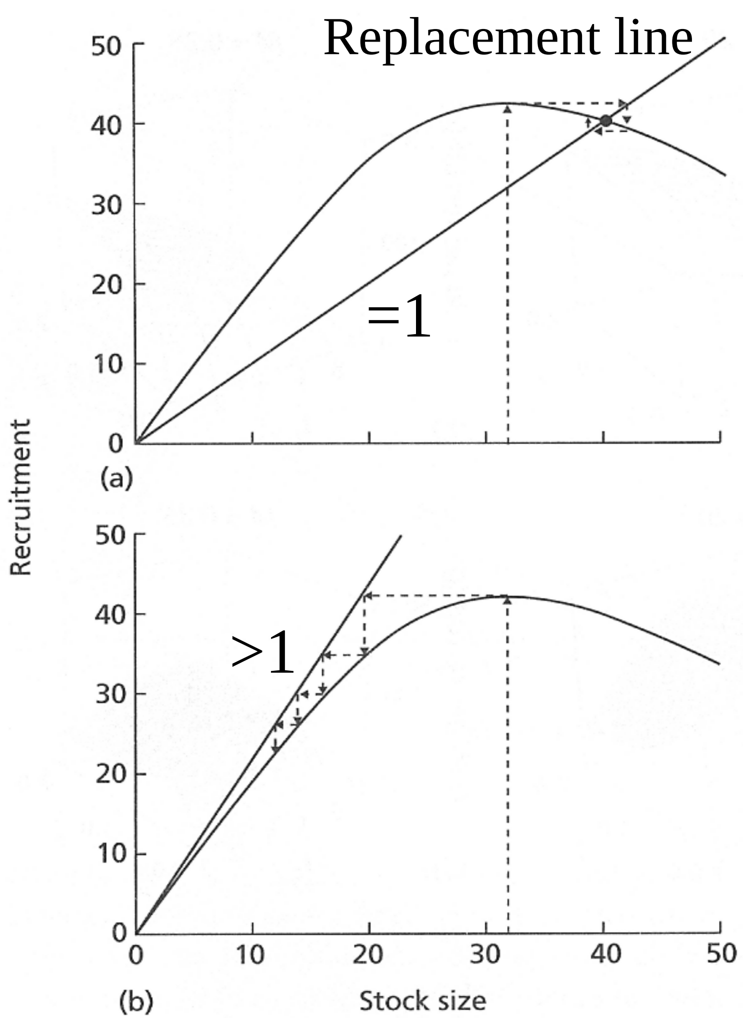
- ages 1-10, M = 0.2

- set F to ensure high yield but sustain biomass

- regulate F to regulate B

- assumes stable population structure

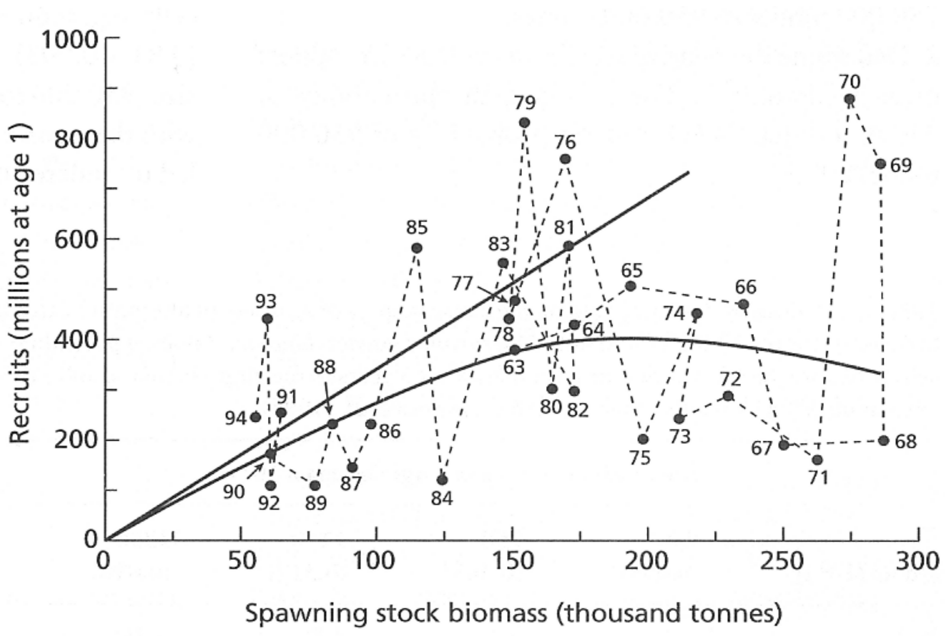
Incorporating Recruitment in Yield-per-Recruit Models



- yield-per-recruit models don't incorporate impacts of F on recruitment
- recruitment overfishing: reduction in spawning stock biomass that reduces recruitment
- what level of recruitment is needed to maintain stock size (at a given F)?
- replacement lines: changes in F affects recruitment rates to spawning stock
- change F, change slope of replacement line
- use replacement lines to predict sustainability and yields

Ricker S-R curve; F in b > F in a

Example: North Sea Cod



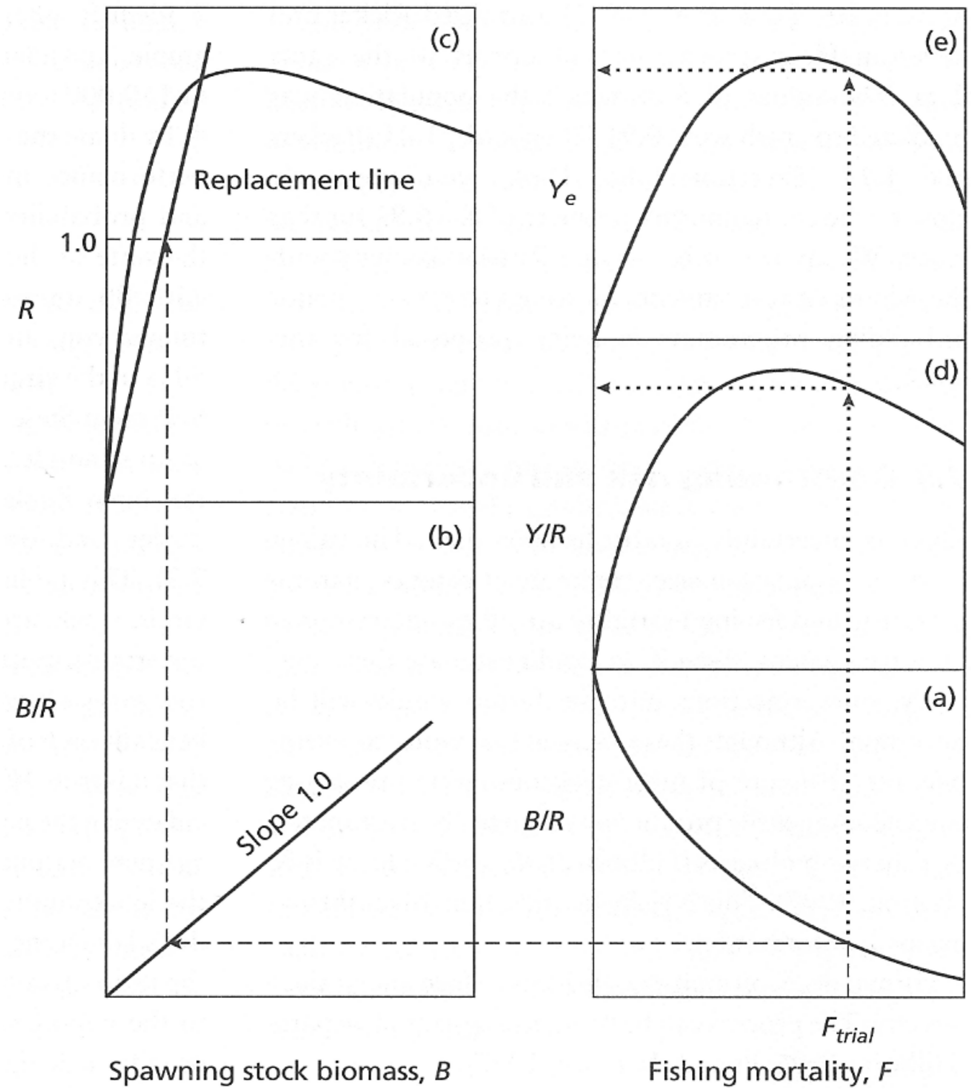
- spawner-recruit curve below replacement line
- stock size declined from early years
- only 8 years recruitment exceeded replacement line
- can use different spawner-recruit curves but all similar

estimated F = 0.91

What is inevitable result for this stock?
What are 2 ways to ‘save’ the fishery?

Cooke et al. 1997

Y/R: Setting F and predicting Y



Given an arbitrary F:

- a & d output of Y/R model
- c recruitment and stock size
- replacement line added to c from b
- equilibrium stock size at intersection
- multiply by Y/R (d) to give total yield

cf. Jennings et al. pp. 150-151