# Fisheries Biology, Assessment & Management

Lecture 2 (part 2)

How Many Fish could there be ?

(The Science of Fish Stock **Management**)

# Stock Assessment (2)

- "Tuning" of VPA (using CPUE & Survey indices)
  - Extended Survivors Analysis
- Yield-per-Recruit Calculations
- Stock-Recruitment Relationships
- Catch Forecasts (for TAC's)

# Remembering ...

- Processes
  - “Birth”, Growth, Maturation, Reproduction, Death (due to fishing and natural causes)
- Stock abundance
  - as numbers, or as biomass
  - by age, and by year (yearclasses/cohorts)
- Yield : catches and death rates due to fishing
  - the effect of **various levels** of fishing effort
  - on yield and (spawning stock) biomass
- Recruitment : dependence on spawning stock

# Questions asked by “managers”

- The effects of current exploitation rates ?
- Potential for improvement ?
  - Increased yields and/or biomass
    - **now** (short-term) or **future** (long-term)
- Possibility of “Optimal” Exploitation ?
- Sustainability ?
- Desirable Conservation Measures ?
  - direct (controls on catch or effort)
  - “technical” (mesh sizes, closed areas)

# Assessing the effects of exploitation

- on Yield, and on SSB
- at the current level of Fishing Mortality
- with the current **exploitation pattern**
  - (ie. pattern of F as a function of age/size)
- at higher and lower levels of F
- with alternative exploitation patterns
  - achieved by "Technical" Conservation Measures (mesh size limits, closed areas)

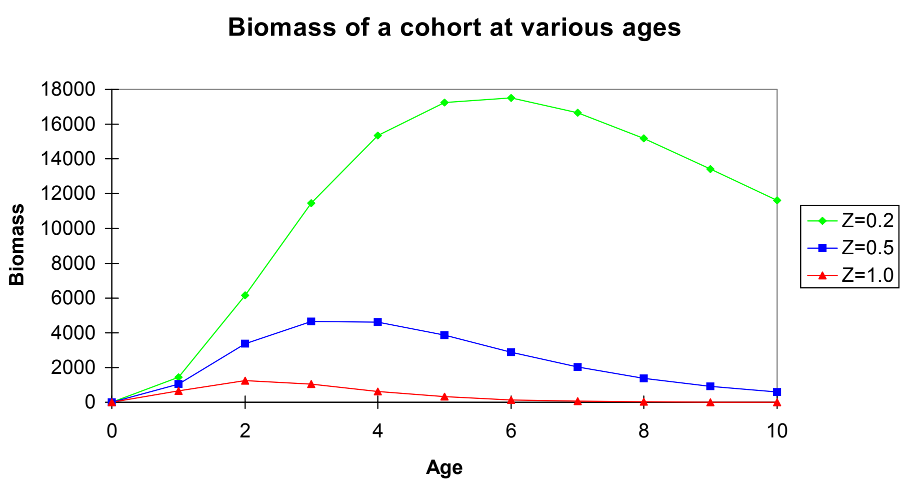
# Stock-Production Models

- Work with whole **Stock** (biomass), and **Production**
  - i.e. Biomass growth, due to recruitment **and** individual growth
- Do not use age/size data
- Usually steady-state (but need not be so)
- Models of **Schaefer** and **Fox**
- Are generally unreliable
- Possibility of stock collapse is included

# "Dynamic Pool" Models

- Beverton & Holt (1957)
- "cleave" the problem into two parts
- Analysis of **Yield** (and Biomass) **per Recruit**
- Analysis of the **Stock-Recruitment Relationship**
- N.B. other factors affecting recruitment are unpredictable : so do the analysis assuming
  - "other things being equal"
  - in effect, for (at) constant recruitment

# Biomass as a function of age



## YPR & SBPR as mathematics

$$Y = \int \frac{dC}{dt} w(t)dt$$
$$= \int F(t)P(t)w_c(t)dt$$
$$\approx \sum_a F(a)P(a)w_c(a)\frac{[1-\exp\{-Z(a)\}]}{Z(a)}$$

where

$$P(a) = \exp\{-Z(a)\}P(a-1)$$
$$= R\exp\{\text{-cum}Z(a)\}$$

$$Y = R\sum_a F(a)\exp\{-\text{cum}Z(a)\}w_c(a)\frac{[1-\exp\{-Z(a)\}]}{Z(a)}$$

$$B = R\sum_a \exp\{-\text{cum}Z(a)\}w_s(a)f_{mat}(a)$$

# Biomass-per-Recruit (pseudocode)

- Work with a single cohort (1 recruit !)
- For each level of Fishing Mortality
- and for each age
  - Calculate stock numbers-at-age
  - Use (stock) weights & maturity-at-age
  - Calculate spawning biomass-at-age
- Sum for all ages (sum of products)
- Plot BPR as a function of F
- Have already done most of this !

# Biomass-per-recruit calculation

**North Sea Cod : Yield & Biomass Per Recruit Analysis**

**M =** 0.2 N.B. ICES WG uses an age-dependent natural mortality

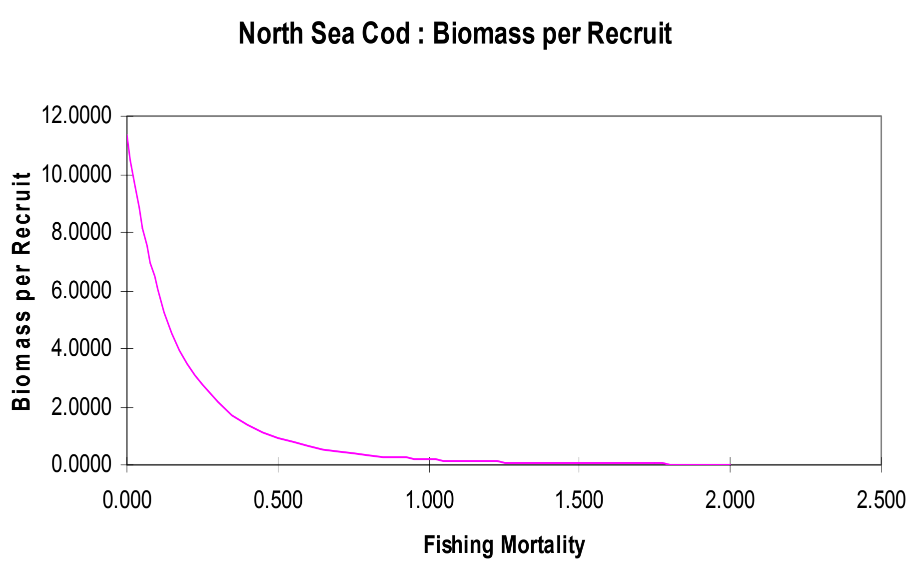
| Age | Weight | F | Mat | Population | Biomass | Catch(Num) | Catch(Wt) |
|---|---|---|---|---|---|---|---|
| 1 | 0.69 | 0.09 | 0.01 | 1000 | 7 | 78 | 54 |
| 2 | 1.08 | 0.64 | 0.05 | 748 | 40 | 324 | 350 |
| 3 | 2.29 | 0.83 | 0.23 | 323 | 170 | 167 | 383 |
| 4 | 4.30 | 0.81 | 0.62 | 115 | 307 | 59 | 253 |
| 5 | 6.64 | 0.76 | 0.86 | 42 | 240 | 21 | 136 |
| 6 | 8.38 | 0.81 | 1.00 | 16 | 135 | 8 | 69 |
| 7 | 9.80 | 0.87 | 1.00 | 6 | 57 | 3 | 31 |
| | | | **Total** | | 957 | | 1276 |
| | | | | **BPR=** | 0.957 | YPR= | 1.276 |

N.B. Divide by assumed Number of Recruits

Both are expressed as kg/recruit

Note : Both YPR and BPR are approximately equal to the weight of a (young) fish

# Biomass-per-recruit



## YPR & SBPR as mathematics

$$Y = \int \frac{dC}{dt} w(t)dt$$

$$= \int F(t)P(t)w_c(t)dt$$

$$\approx \sum_a F(a)P(a)w_c(a)\frac{[1-\exp\{-Z(a)\}]}{Z(a)}$$

where

$$P(a) = \exp\{-Z(a)\}P(a-1)$$

$$= R\exp\{\text{-cum}Z(a)\}$$

$$Y = R\sum_a F(a)\exp\{-\text{cum}Z(a)\}w_c(a)\frac{[1-\exp\{-Z(a)\}]}{Z(a)}$$

$$B = R\sum_a \exp\{-\text{cum}Z(a)\}w_s(a)f_{mat}(a)$$

# Yield-per-Recruit Analysis (pseudocode)

- Work with a single cohort (1 recruit !)
- Use the Catch Equation
- For each level of Fishing Mortality
- and for each age
  - Calculate **catch** numbers-at-age
  - Use (catch) weights-at-age
  - Calculate yield (in weight) at this age
- Sum for all ages (sum of products)
- Plot YPR as a function of F

# Yield-per-recruit calculation

**North Sea Cod : Yield & Biomass Per Recruit Analysis**

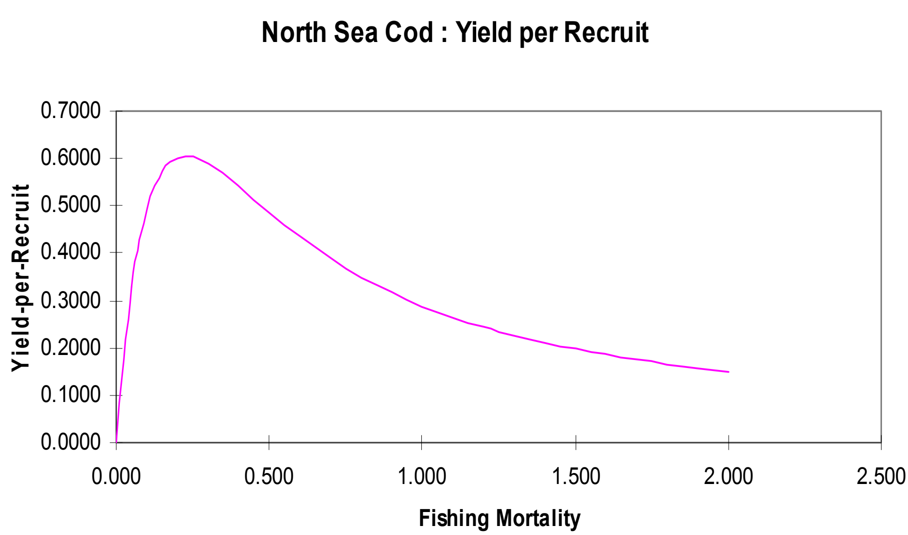
**M =** 0.2 N.B. ICES WG uses an age-dependent natural mortality

| Age | Weight | F | Mat | Population | Biomass | Catch(Num) | Catch(Wt) |
|---|---|---|---|---|---|---|---|
| 1 | 0.69 | 0.09 | 0.01 | 1000 | 7 | 78 | 54 |
| 2 | 1.08 | 0.64 | 0.05 | 748 | 40 | 324 | 350 |
| 3 | 2.29 | 0.83 | 0.23 | 323 | 170 | 167 | 383 |
| 4 | 4.30 | 0.81 | 0.62 | 115 | 307 | 59 | 253 |
| 5 | 6.64 | 0.76 | 0.86 | 42 | 240 | 21 | 136 |
| 6 | 8.38 | 0.81 | 1.00 | 16 | 135 | 8 | 69 |
| 7 | 9.80 | 0.87 | 1.00 | 6 | 57 | 3 | 31 |
| | | | **Total** | | 957 | | 1276 |
| N.B. Divide by assumed Number of Recruits | | | | **BPR=** | 0.957 | **YPR=** | 1.276 |

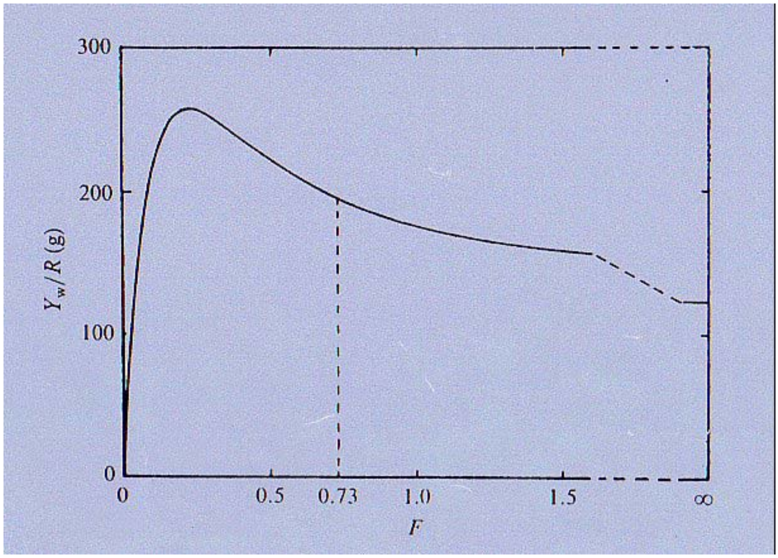
Both are expressed as kg/recruit

Note : Both YPR and BPR are approximately equal to the weight of a (young) fish

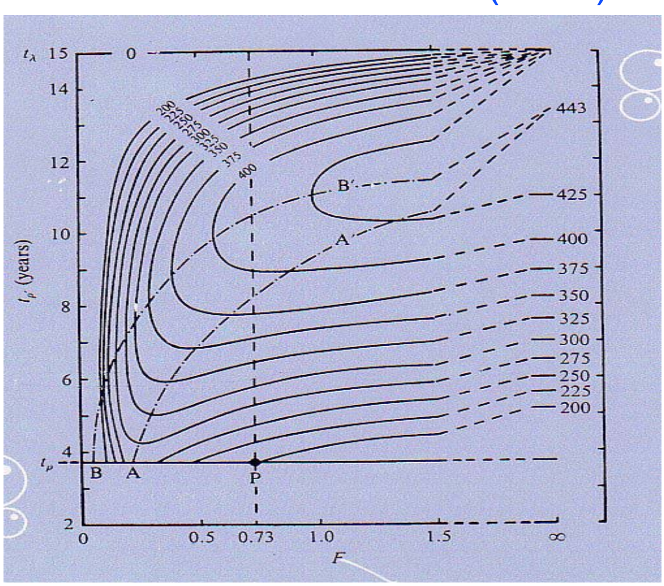
# Yield-per-recruit curve (The "Yield Curve")



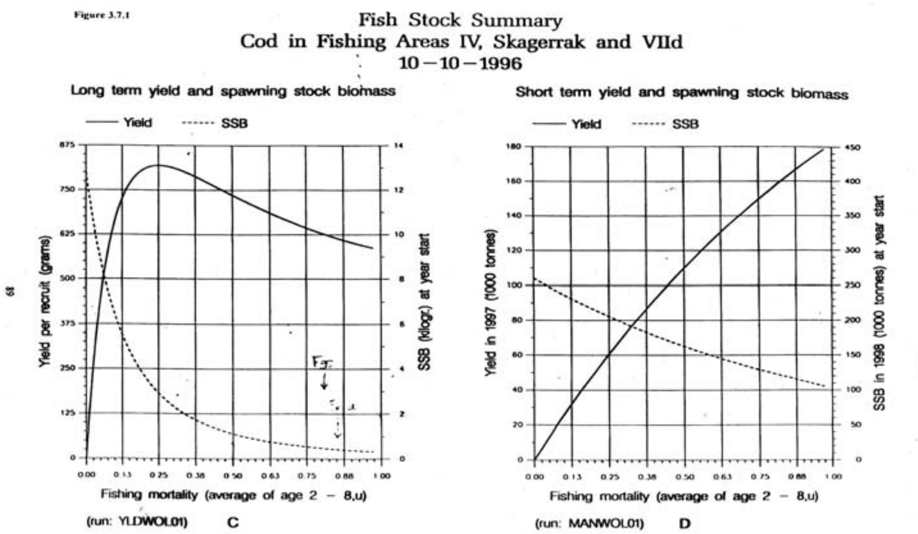
## Yield-per-recruit curve from Beverton & Holt (1957)




## Yield-per-recruit isopleth diagram from Beverton & Holt (1957)



## YPR & SBPR: actual ICES WG results for North Sea cod




## Practical Session

Yield-per-recruit calculation

# Features of YPR/BPR analysis

- Concentrates on effects of fishing
- De-emphasises environmental influence
  - on growth, maturity, natural mortality, etc
- Diverts attention from recruitment
- Is a long-term, steady-state calculation
- Does not depend (much) on current state
- Can be done using biological data only
  - does not require results of VPA etc
  - can evaluate changes of mesh size, etc

# More features of YPR/BPR analysis

- Applicable when fishery data is limited
  - e.g. catch data incomplete, or no age data
- Can compare current F with $F_{max}$
- Indicates whether under/over-exploited
  - w.r.t. "growth overfishing"
- Sufficient for Effort Control (?)
  - increase/decrease by some amount
- Optimum yield (not MSY) occurs at $F_{max}$
- But this may not be a realistic estimate

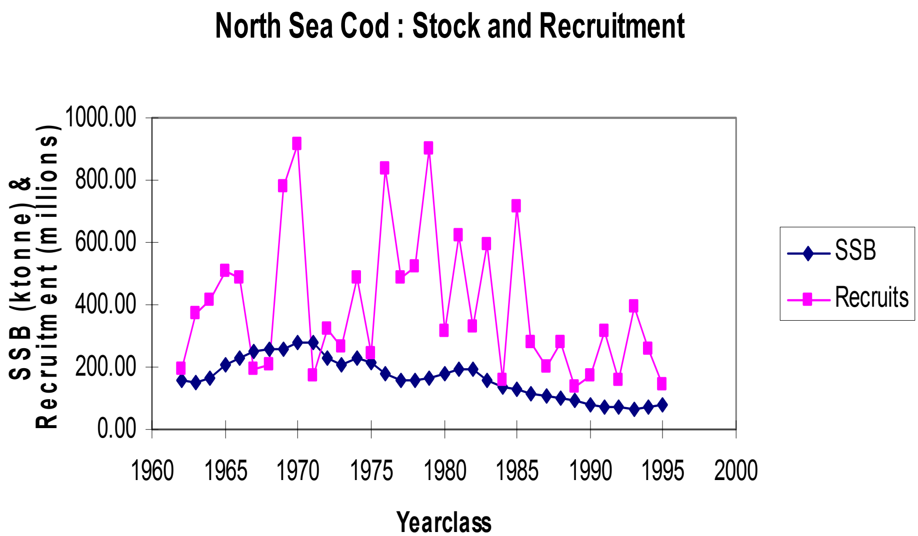
## But ...

What about recruitment
if the stock size is reduced ???

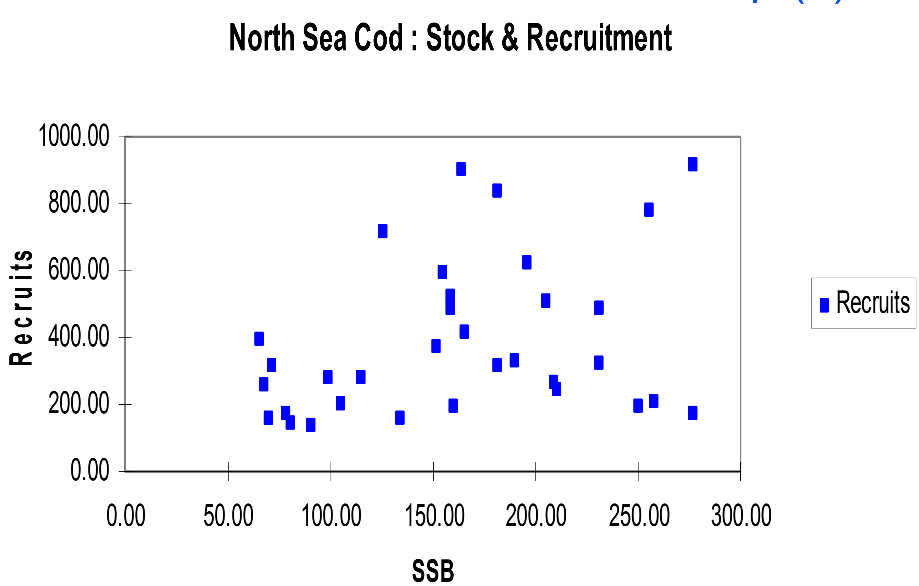
## Stock-Recruitment Analysis

- Requires time-series of recruitment and spawning stock biomass estimates
- VPA is necessary (and ideal for this task)
- Data is highly scattered ("noisy")
  - due to real variability (process noise)
  - not to errors (measurement noise)
- Statistical analysis is necessary
  - but tricky
- Problems are still not entirely solved

## Stock & Recruitment Data

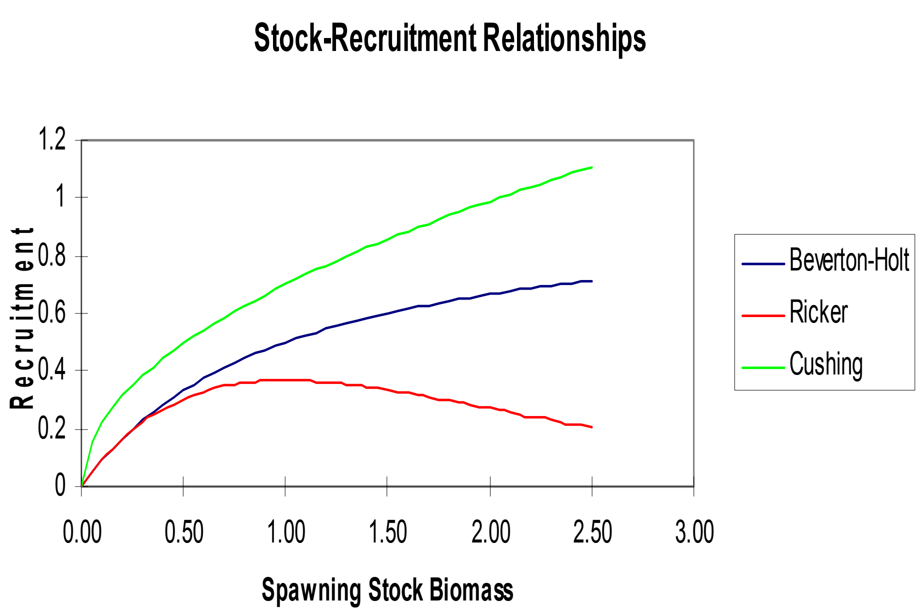



## Stock & Recruitment Relationship (?)



# Stock-Recruitment Relationships

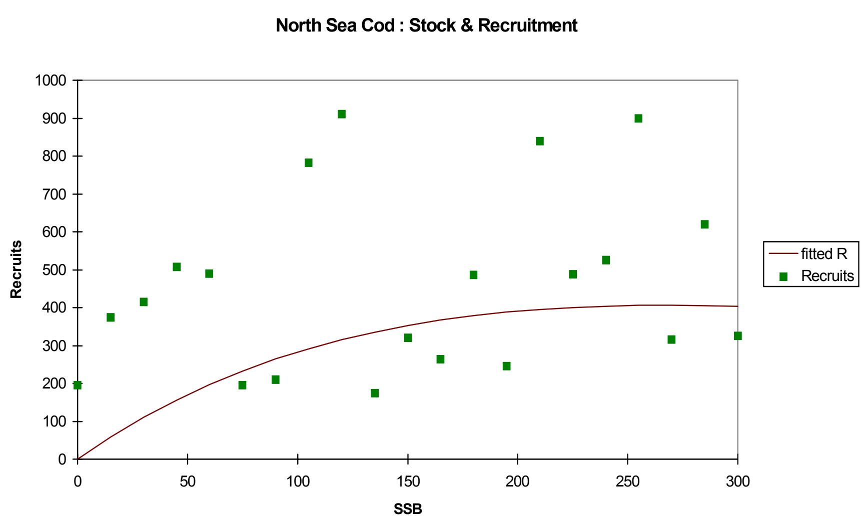
- Beverton-Holt
  - $R = a B / (1 + B/K)$ asymptotic
- Ricker
  - $R = a B \exp\{ -B/K \}$ domed
- Cushing
  - $R = a B^c$ power law
- Shepherd
  - $R = a B / [1 + (B/K)^c ]$ versatile



# Fitting SRR's by regression

- Beverton-Holt
  - Regress (B/R) versus B — dodgy
- Ricker
  - Regress ln{R/B} versus B — **recommended**
- Cushing
  - Regress ln{R} versus ln{B} — exploratory
    - – useful for exploratory analysis, but not for practical application : **not precautionary** (no collapse)
- Shepherd
  - need non-linear curve fitting routine
    - – data rarely adequate to fit 3 parameters

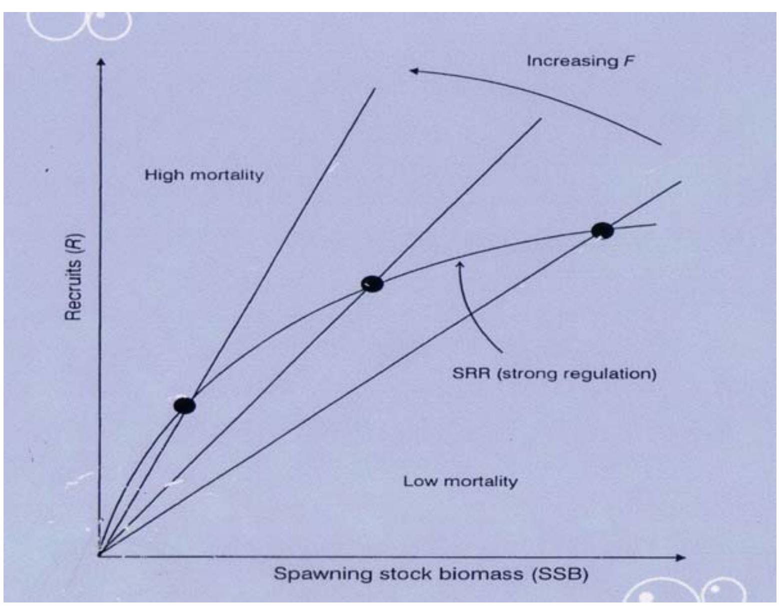
# North Sea cod SRR fitted Ricker Curve



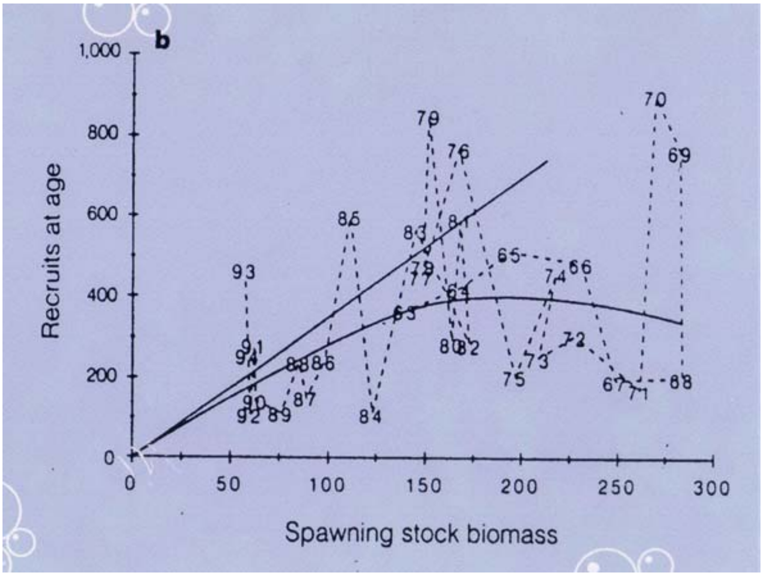
# The possibility of stock collapse...

- Slopes of survival lines (constant SBPR)
  - correspond to levels of Fishing mortality
- Slope at the origin is the vital factor
  - indicates level of F at which the stock is expected to collapse
  - due to "recruitment overfishing"
- It is difficult to estimate ...
- But it is **vitally necessary** for applying a precautionary approach to management

# Why fish stocks collapse…



## North Sea Cod : as assessed by Cook et al (Nature 1997)




## The foreseeable demise of the North Sea cod

- In 1997 Cook et al predicted
  - probable collapse at F = 0.9 to 1.1
  - *NB: current F is ~ 0.8 : has been ~ 1.0*
  - MSY is ~ 300kt (at F=0.65, SSB=300kt)
  - *c.f. recent average yield of about 100 kt (at F ~ 0.9, SSB < 100kt)*
  - *Present SSB is about 35 kt*
- Management advice from ICES has been (for many years…)
  - to reduce Fishing Mortality
    - by at least 30% (to ~ 0.6) ASAP
    - preferably by 50% (to <0.5) in the long-term

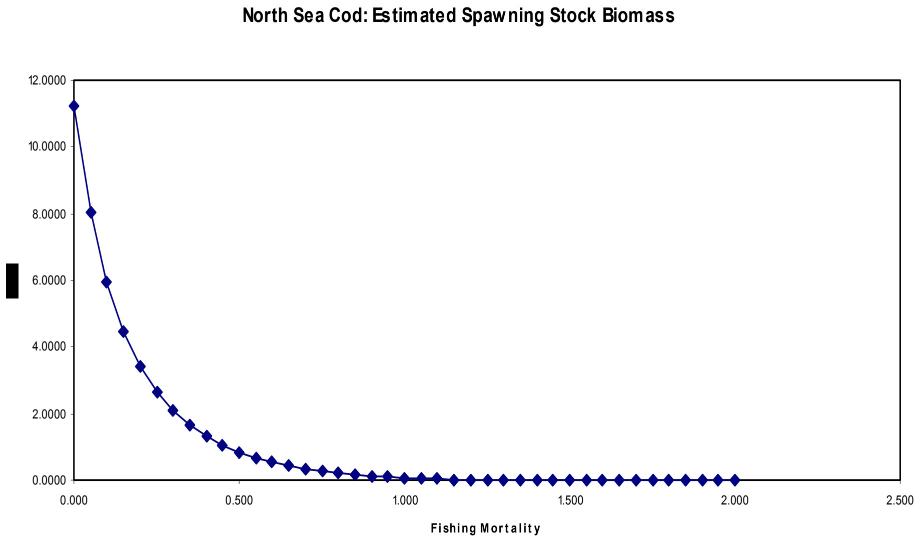
## Combined Yield Analysis (1) why do it ?

- Combine YPR/SBPR and SRR analyses
  - to give yields & biomasses in tonnes
  - to estimate MSY and $F_{msy}$
  - **taking account of possible collapse**
- Recreates the **whole** picture
- Reverses the Beverton-Holt "cleavage"
  - (clever but dangerous...)
- which was what was wanted !!

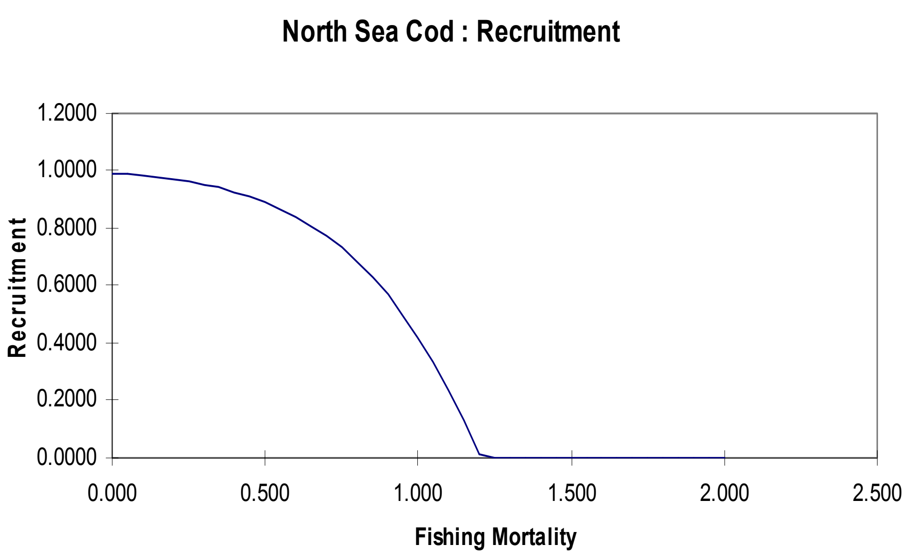
## Combined Yield Analysis (2) how to do it

- Suppose SRR is estimated as $R = a\,B\,f(B)$
  - Where $a$ and $f(B)$ are known
  - (because they have been fitted to the data)
- For each selected value of F
- use the YBPR calculation, to estimate
  $c=Y/R$, and $b = B/R$
- However, $R/B = af(B) = 1/b$, so one can solve for B, since $B = f^{-1}(1/ab)$
  - [e.g. : $B = K\ ln\{ab\}$ for a Ricker curve]
  - then calculate $R = B/b$
  - and finally, $Y = R\ (Y/R) = cR$

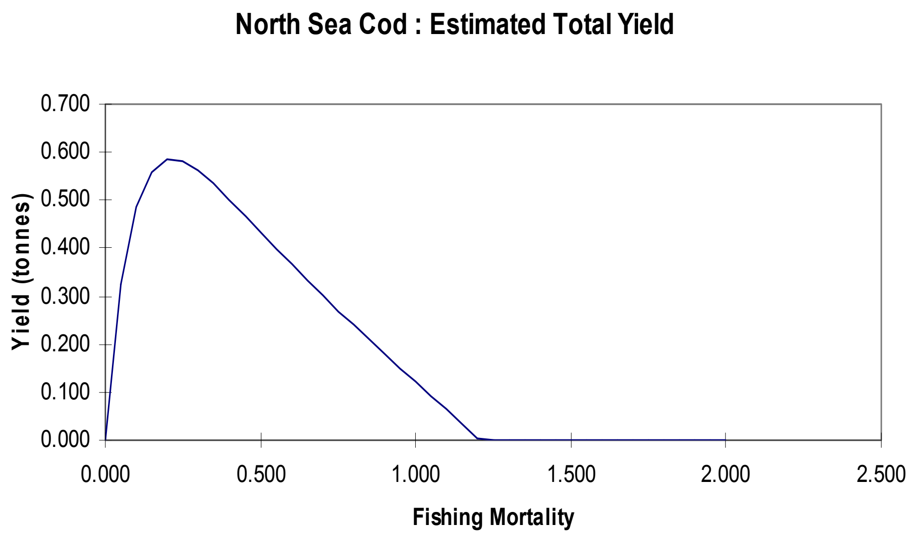
# Example of Combined Yield Analysis (1)
# Spawning Stock Biomass




# Example of Combined Yield Analysis (2)
# Recruitment



## Example of Combined Yield Analysis (3) Yield




## Overview

- What is the state of the stock ?
  - VPA/Cohort Analysis
- How could/should it be exploited ?
  - YPR/SBPR Analysis
- Might it collapse ??
  - Stock-Recruitment Analysis
- Overall synthesis
  - Combined Yield Analysis
- Compare actual with possible
- **Advise** on management measures needed

# Next Lecture

- What forms of management are possible ?
- How can they be implemented ?
  - Effort Regulation
  - Catch Forecasts for TAC's
    - (Total Allowable Catches)
  - Other possibilities
- Is Sustainable Exploitation Possible ???