Population Abundance Indices

LO: evaluate the ability to estimate population abundances

‘Managing’ Fish Populations

For mature animals, need to know rate of renewal

To determine stock-recruitment relationship measure:

- reproductive potential of population
- number of young that survive to maturity

If management goal is to maintain a target biomass, then fishing quotas can only harvest the ‘excess’ production

Reproductive Potential

Assumption

Reproductive potential = number above age or length threshold (i.e. recruited fish)

To quantitatively estimate mature animal abundance:

fishery-dependent: commercial catch per unit effort (CPUE)

fishery-independent: scientific acoustic and/or trawl surveys

How do the two types differ?

- sample location (i.e. where fish are vs. domain of interest)
- even sampling effort and standardized gear
- temporal coverage

Estimating Stock Abundance

When is cohort established?

Estimate once or many times? If once when to sample?

1. Sample once just before enter fishery (depends on available gear)
2. Sample several times during ELH

Hjort (1914): post critical stage indicator of year class strength.

So it may be easier to sample plankton stages compared to adults.

If relationship between eggs or larvae and adult, then plankton surveys can be used to estimate spawning adult abundance

Stock Abundance INDEX Elements

To quantitatively estimate stock abundance from eggs or larvae:

1. temporally sample plankton during entire reproductive period
2. spatially sample over entire spawning range
3. survey design to weight contributions from each sample to index
4. target stage that can be effectively and consistently sampled

Index goal: high index value = large spawning stock

Spawning Biomass & Offspring

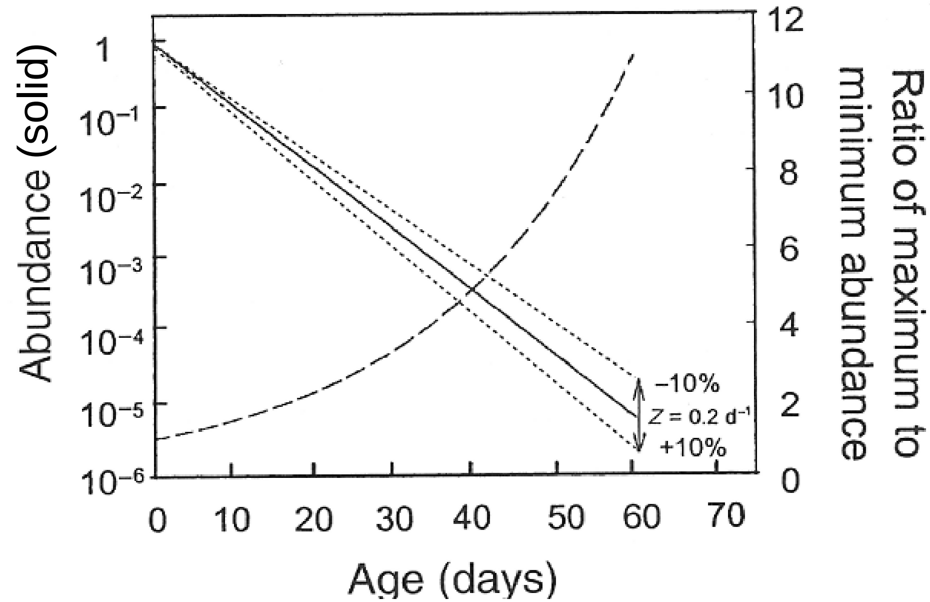
$$P_0 = (B \times R) \times E$$

P_0 production of offspring

B stock biomass

R % reproducing females

E number of eggs/female



Number of offspring P at time t

$$P_t = P_0\, e^{-Zt} \quad \log10\, P_t = \log10\, P_0 - Zt$$

where Z is daily mortality rate

Sum P_t over all surveys to get an index of spawner abundance

Assumes growth, mortality, egg production are constant

Spawning-Stock Index Estimates

Eggs

Annual Egg Production Method (AEPM)

Daily Egg Production Method (DEPM)

Larvae

Larval Abundance Index (LAI)

Larval Production Method (LPM)

Adults (mass) and Egg (density)

Daily Fecundity Reduction Method (DFRM)

(Lo et al. 1992; Zeldis et al. 1997)

Adults

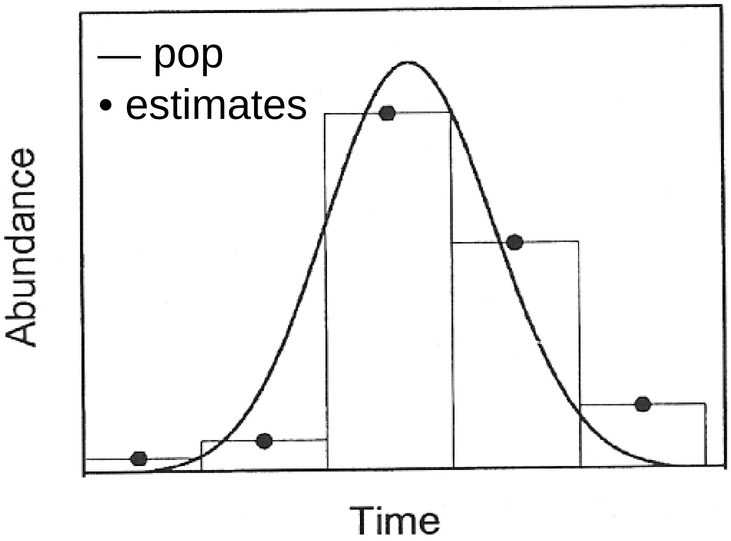
Surplus Production Model

Schaefer Production Model

Egg Production Methods

AEPM: Annual Egg Production Method

assume $P_o = B \times R \times E$, at $t=0$ within $P_t = P_o \times e^{-Zt}$



P_0 production of offspring

B stock biomass

R % reproducing females/total biomass

E number of eggs/female

if determinate number of eggs in ripe females, then

$$B = P_o/E \times R$$

- measurements apply to season, have to sample over season

Egg Production Methods

DEPM: Daily Egg Production Method

if indeterminate number of eggs in ripe females, then

$$R' = R \times f$$

where R' is % females reproducing, f is % spawning females observed

$$B = P_o/E' \times R \times f = P_o/E' \times R'$$

where E' # eggs kg^{-1} $batch^{-1}$ during survey

Advantage: don't have to sample over entire spawning period, just need to determine number of eggs per batch (Lasker 1985)

Disadvantage: eggs are patchier and last a shorter time period than larvae, so require many samples to increase precision

DEPM Pacific Sardine Estimate

TABLE 1

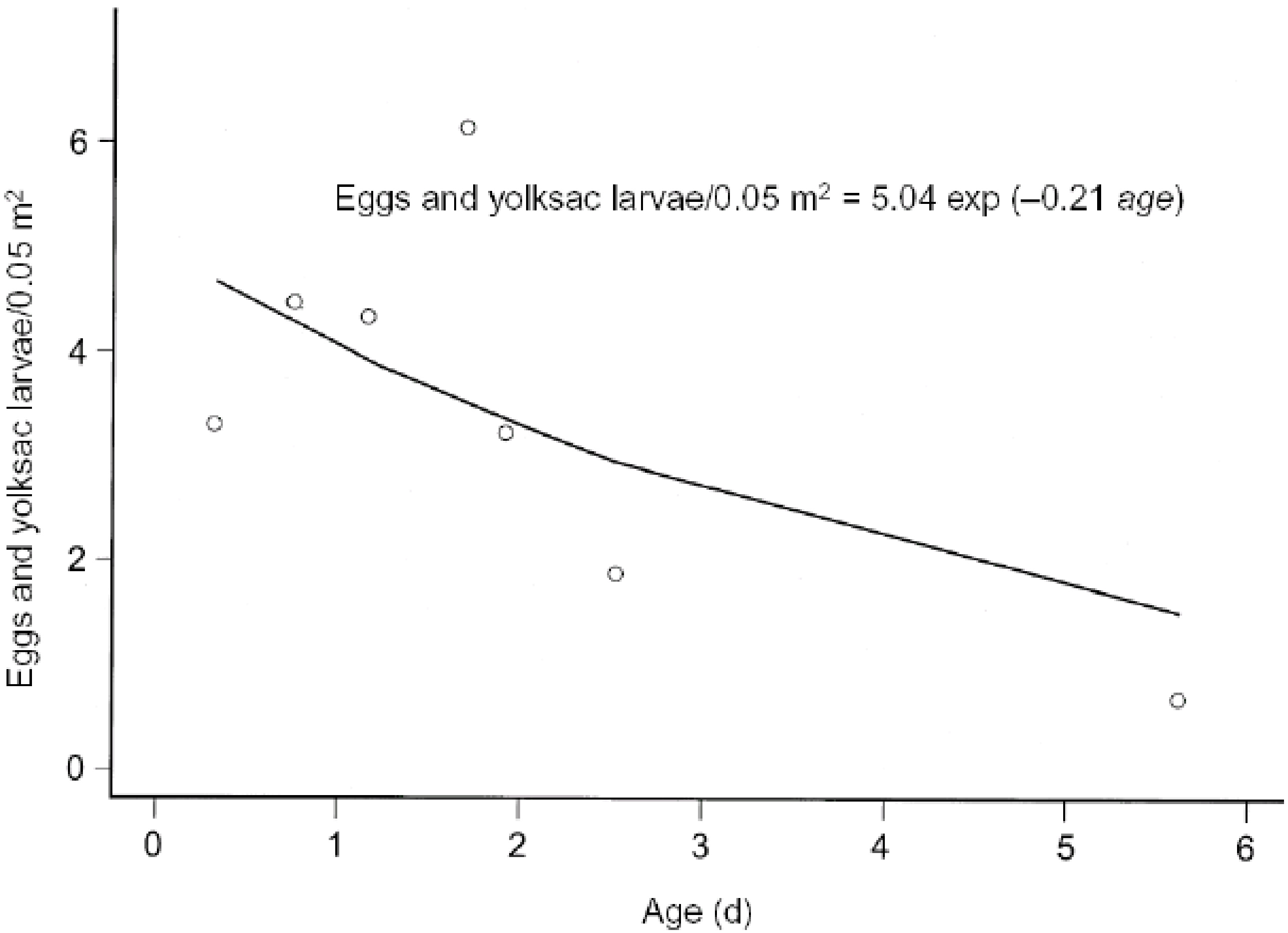
Estimates of Egg Production Rates and Adult Reproductive Parameters for Daily Egg Production Method Surveys, 1986–88, 1994

	1986[a]				
Parameters	North	South	1987[b]	1988[c]	1994
Egg production (P_0) (eggs/0.05 m^2/day)	0.276 (.557)[d]	0.513 (.322)	0.657 (.945)	0.33 —	0.169 (0.22)
Area of survey (A) (km^2)	6,616	10,774	37,605	44,339	380,175
Average female weight (W) (gm)	199.9	154.8	163.8	166.3	82.5 (0.07)
Batch fecundity (F)	71,382 (.049)	51,743 (.086)	62,289 (.111)	61,147 (.066)	24,282.52 (0.11)
Spawning fraction (S) (fraction of mature females spawning per day)	.038 (.467)	.189 (.283)	.125 (.062)	.144 (.182)	.0729 (.23)
Sex ratio (R)	.559 (.117)	.603 (.052)	.664 (.062)	.493 (.128)	.537 (.067)
Spawning biomass (B_s) (metric tons)	4,756 (.792)	2,903 (.349)	15,685 (.912)	13,514 —	111,493 (.32)
Daily egg mortality (Z)	Fixed at .05	Fixed at .05			.12 (.97)

[a]Scannell et al. 1996 [b]Wolf 1988a [c]Wolf 1988b [d]Coefficients of variation in parentheses

Lo et al. 1996

DEPM Pacific Sardine 1997

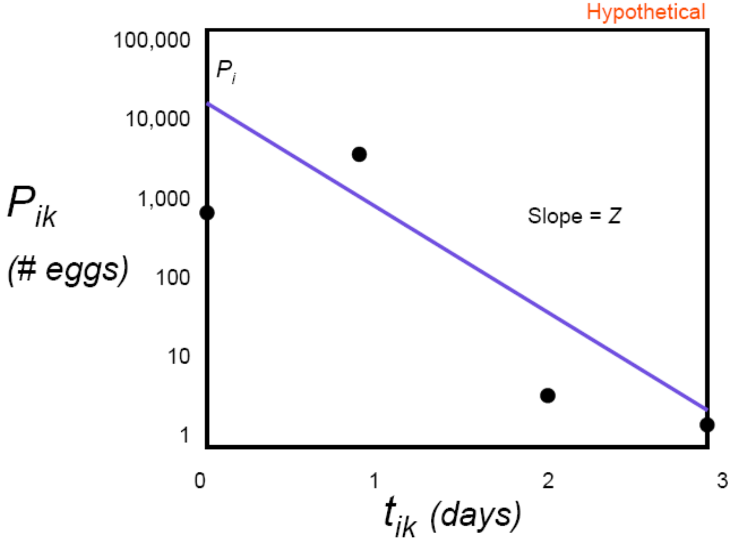


1994:

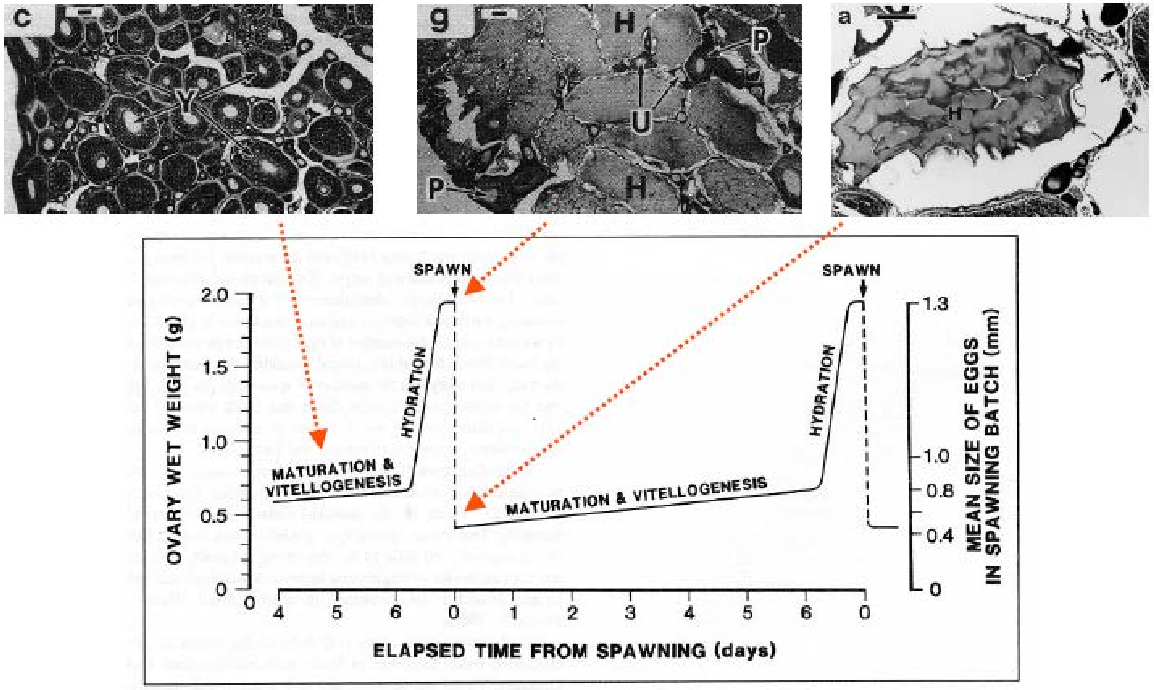
eggs = $0.169\, e^{-0.12\ \text{age}}$

Lo et al. 2001

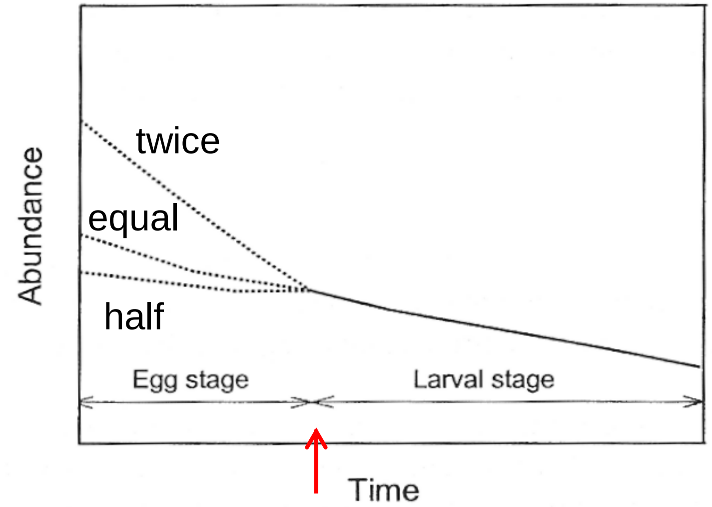
DEPM Illustrated



Northern Anchovy



Larval Abundance Methods



LAI: Larval Abundance Index

- species whose eggs can't be sampled: demersal, inter- or sub-tidal, redds
- use period between eggs and larvae
- target just hatched larvae to minimize larval mortality effect

$$I_t = \sum_{i=1}^{X} D_{\Delta L,i} \times a_i$$

where index I at time t calculated by summing density D at each length interval ΔL and weighting contribution of station i by area a over X stations

Multiple surveys over spawning period required

Larval Abundance Methods

LPM: Larval Production Method

- estimate # larvae hatched on successive days then back-calculate larval abundance at hatching length for each length interval
- assumes growth is known; mortality and emigration rates constant and independent of length; no immigration

Advantage: multiple surveys not required as long as survey conducted when production is complete and all length classes can be sampled

(see Heath 1993 for an example)

Adult + Egg Abundance Methods

DFRM: Daily Fecundity Reduction Method

- for determinate egg producing species (developed for Dover sole)
- based on daily decline in reproductive potential of the population and the numbers of planktonic eggs

reproductive potential = # oocytes x # ripe females (i.e. active ovaries)

production of eggs = daily egg samples in plankton tows

$$\mathrm{B} = \frac{P_0 \times A}{R/W \times D_t \times 10^6} = \frac{P_0 \times A}{K}$$

K = daily population fecundity (eggs mt^{-1} day^{-1})

B stock biomass

P_0 production of eggs/$10m^2$

A area

R % reproducing females

W average female weight

D_t daily fecundity at day t

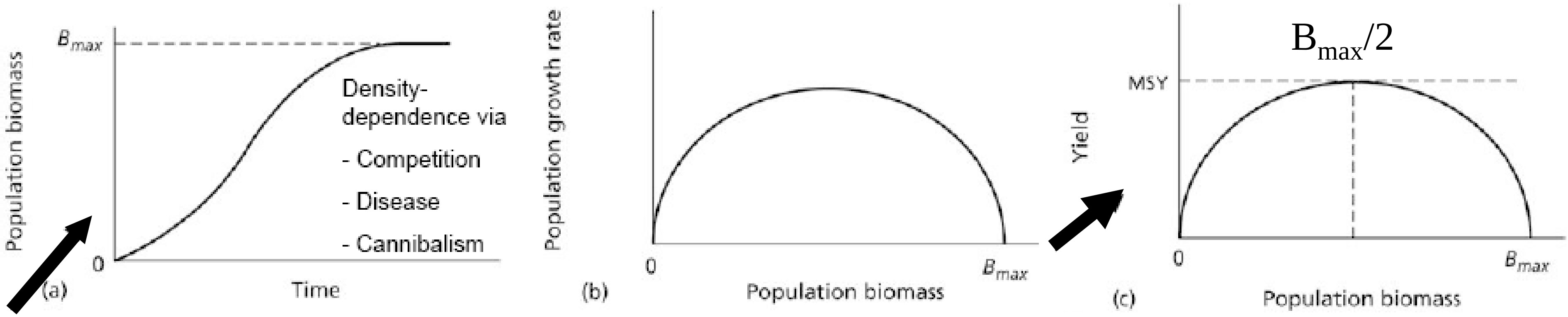
Lo et al. 1992, 1993

Adult Abundance Methods

Surplus Production Models:

- based on catch, effort, CPUE stats, and ecological principles using logistic model
- need mortality or recruitment estimates (simple data requirements)
- estimates largest fishing mortality F that is offset by biomass production
- assumes density-dependence (competition, disease, cannibalism)
- assumes logistic population growth model and $F \propto$ population biomass
- does not resolve age or length structure

Surplus Production Model



Yield will increase until stock is half original

Assumes logistic growth:

$$B_t = B_{max}/(1 + e^{-r(t-t_o)})$$

B biomass

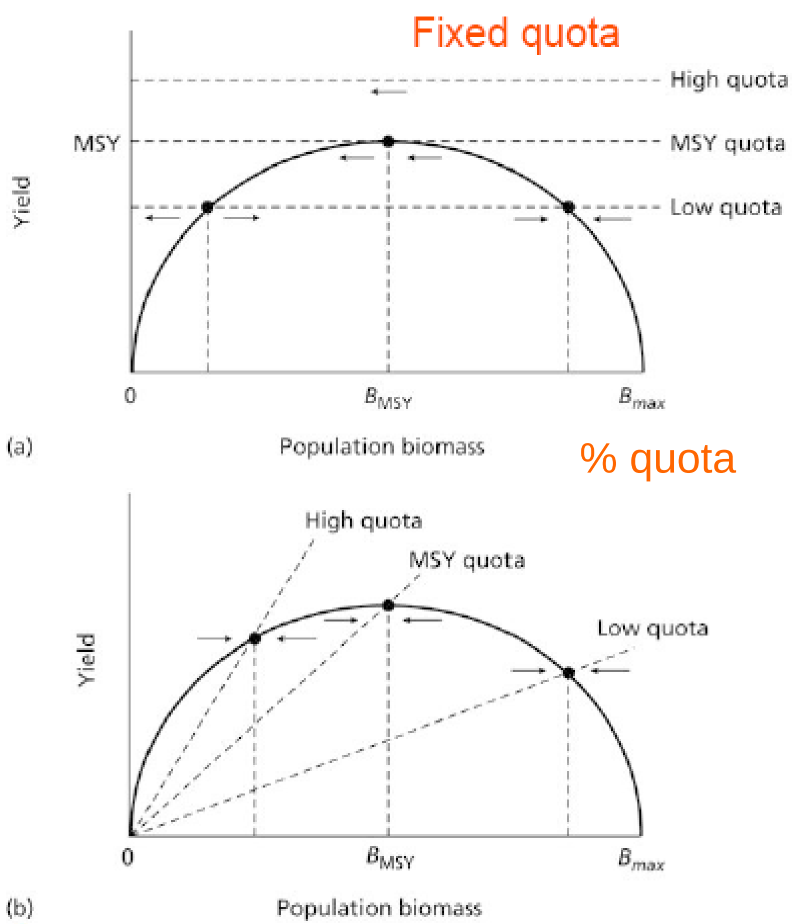
r intrinsic rate of increase (birth rate – death rate)

Characteristics and Rationale

- **P**roduction and **Y**ield is product of Δ**N**umbers & Δ**W**eight
- result: low **P** at low **N** (low #'s) and high **B**iomass (slow growth)
- maximum **Y** occurs at an intermediate **B**

Decreased **P** at high **B** is due to:
- density-dependent effects (decreased ration individual^{-1})
- increased use of energy for reproduction rather than growth
- possible stock-dependent effects (e.g. cannibalism)

Surplus Production Model Assumptions



- population in equilibrium with environment
- stable age distribution
- food, competitors, predators don't respond to abundance changes
- no time lags
- population single unit (i.e. stock)
- density dependence operates continuously
- fishery interacts with entire stock

If true, then can harvest at MSY

If not, then overfishing even below MSY

What is probability of all assumptions being met?
(slim to none)

Schaefer Production Model

Schaefer Curve: based on logistic equation, assumes equilibrium and equal contributions per individual

$$\frac{dB}{dt} = g(B) - Y$$

$$g(B) = rB\left[1 - \frac{B}{B_{\max}}\right]$$

where:

B = biomass

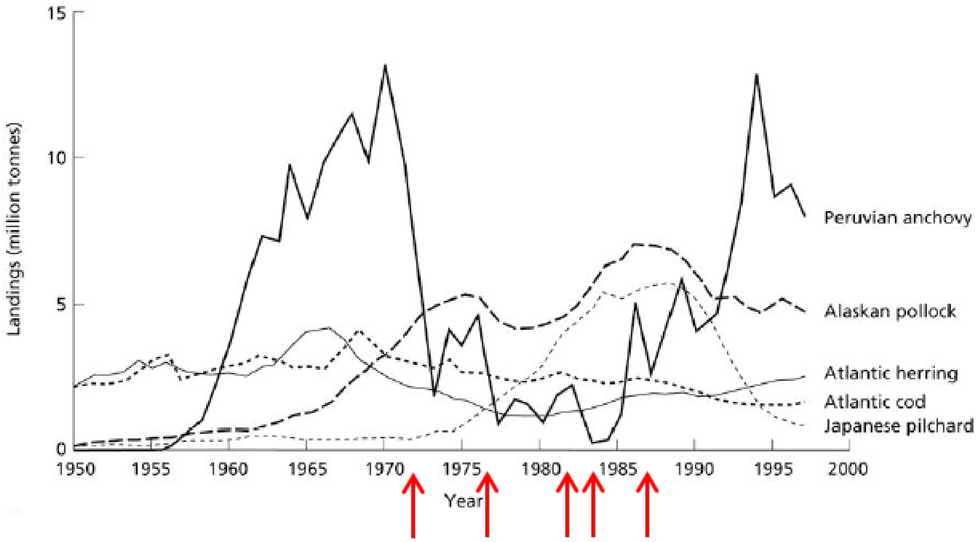
B_{max} = maximum biomass

g(B) = surplus production as a function of biomass

Y = yield

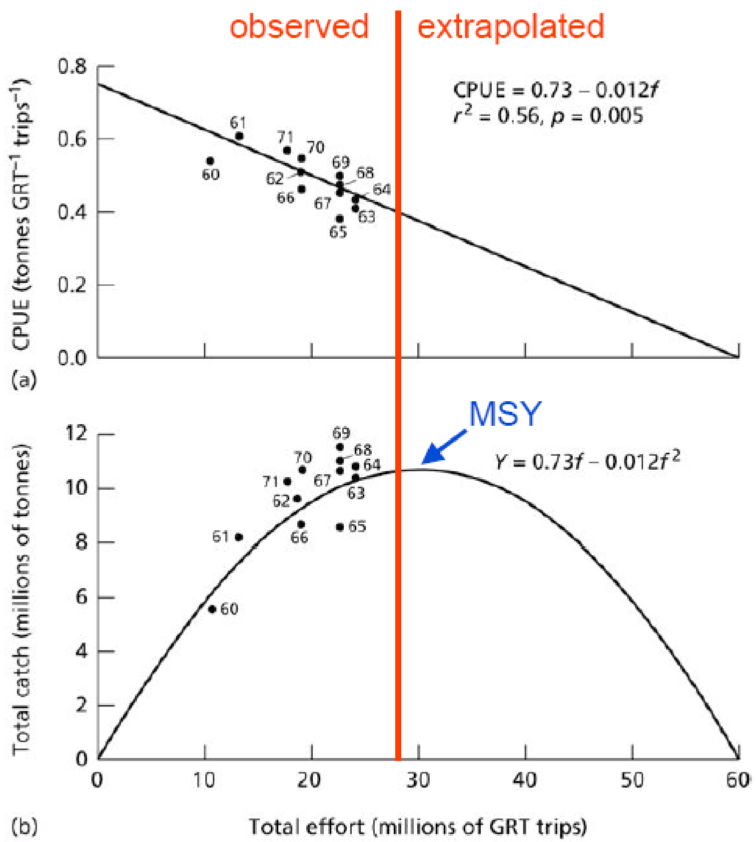
r = intrinsic rate of increase

Peruvian Anchovetta Example



Engraulis ringens

- fishery collapsed in 1970's probably due to combination of management and El Niňo



- catch and effort recorded since start of fishery
- Schaefer model assumed
- f = total effort (GRT year^{-1})
- includes seabirds = 18% of human catch

Production Model Reality Check

- fish stocks rarely (if ever) in equilibrium

- environment rarely (if ever) in equilibrium

- changes in age structure (growth, fecundity) can not be incorporated

- dependence on constant fishing efficiency (i.e. q)

- optimal fishing effort found by overfishing not wise policy or management

- models pool all processes affecting productivity, which increases estimate variances