Estimating mortality

Supplemental Readings:

Millar 2015 (CJFAS)

Kenchington 2014 (Fish and Fisheries)

Acknowledgements: M. Wilberg, D. Ward, D. Secor

Announcements

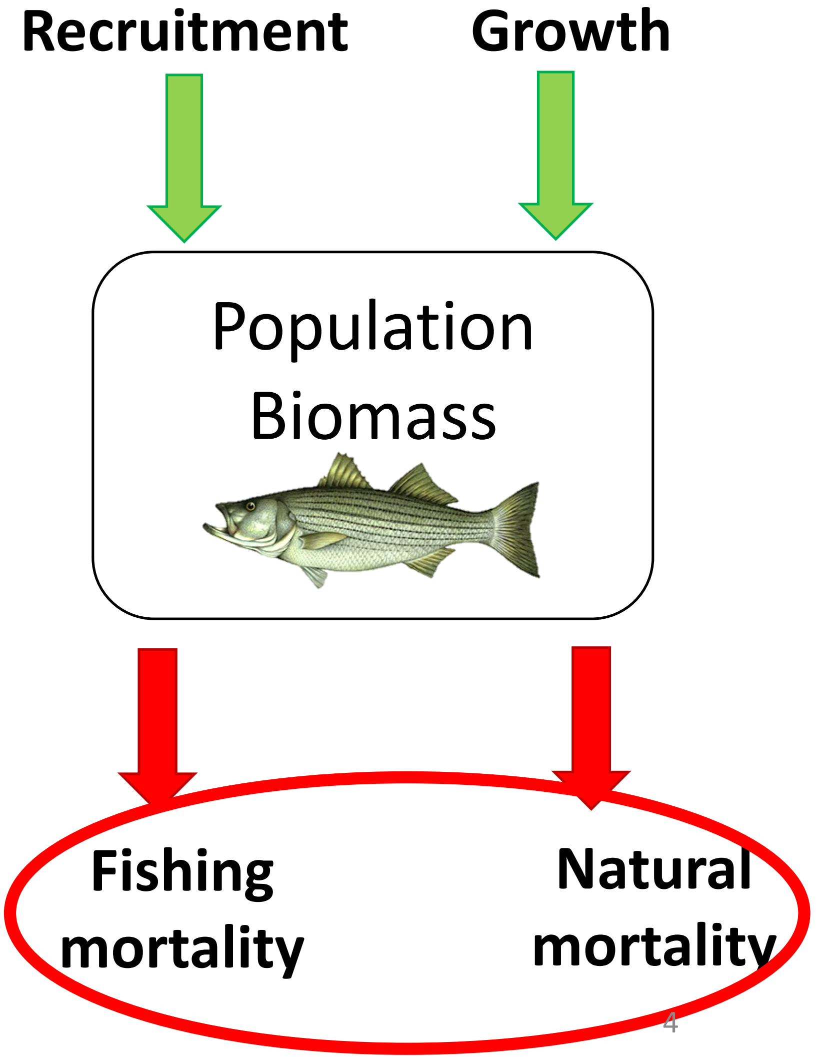
- **Grad students, please review the requirements for your project (see canvas)**
  - **will discuss on Friday**
  - **Synopsis Due: March 18**

Mortality

Sources of mortality

- Exploitation
- Predation
- Disease
- Starvation
- Senescence

- Grouped into fishing and natural mortality



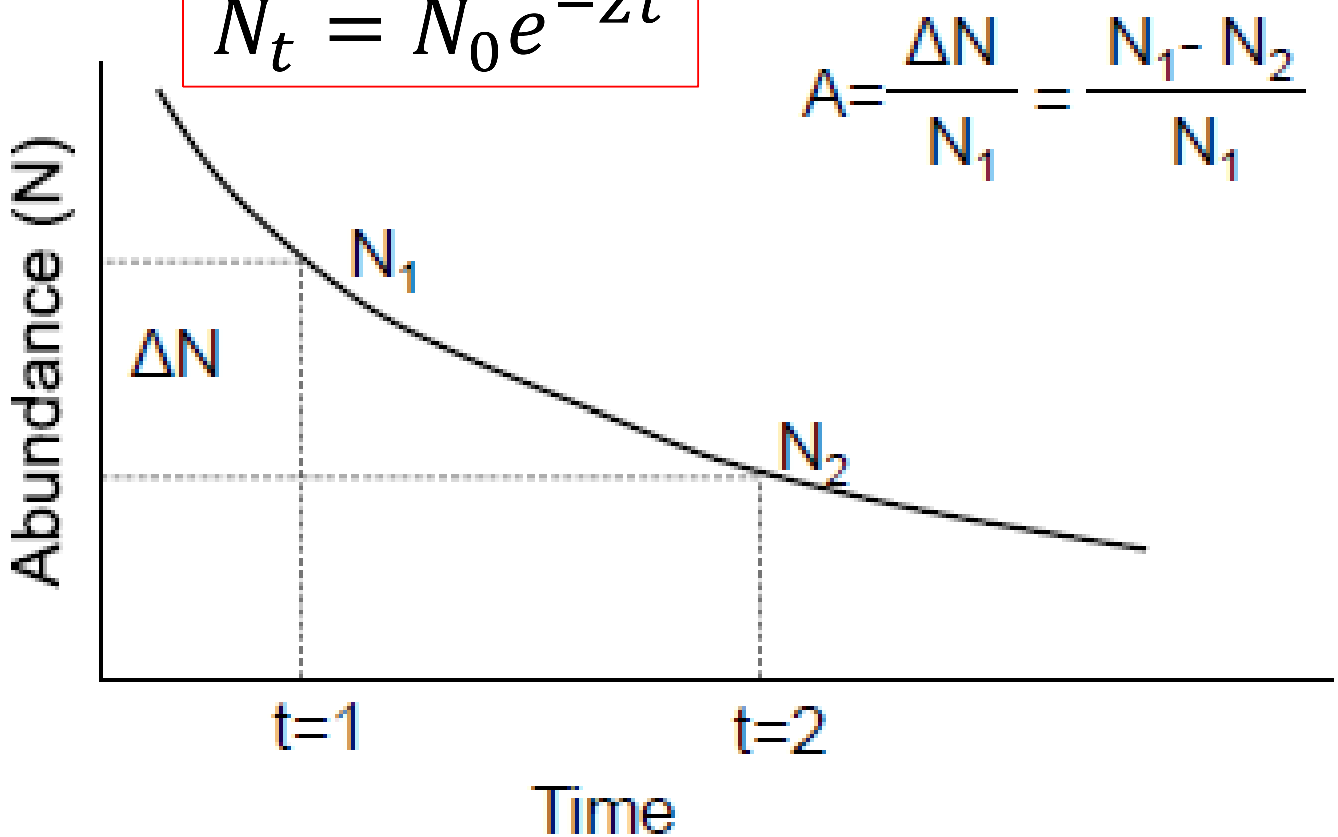
Russell 1931

"MY PARENTS DIED. THEIR PARENTS DIED. THEIR PARENTS DIED...
IT RUNS IN THE FAMILY."

Exponential mortality model

- Assume exponential decline in abundance over time (ie, constant proportional change)

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



How to estimate total instantaneous mortality Z?

How to estimate Z?

1. Catch curve and related methods Will focus on this
2. Length-based estimators
3. Mark-recapture
4. Population models (or two population size estimates)

How to estimate Z?

1. **Catch curve and related methods**
    - Basic catch curve
        - Cohort or year-specific method
    - Related methods:
        - Chapman and Robson 1960
        - Maceina and Bettoli 1998
        - Mixed-effects Poisson log-linear model (Millar 2015)

1. Catch curve method

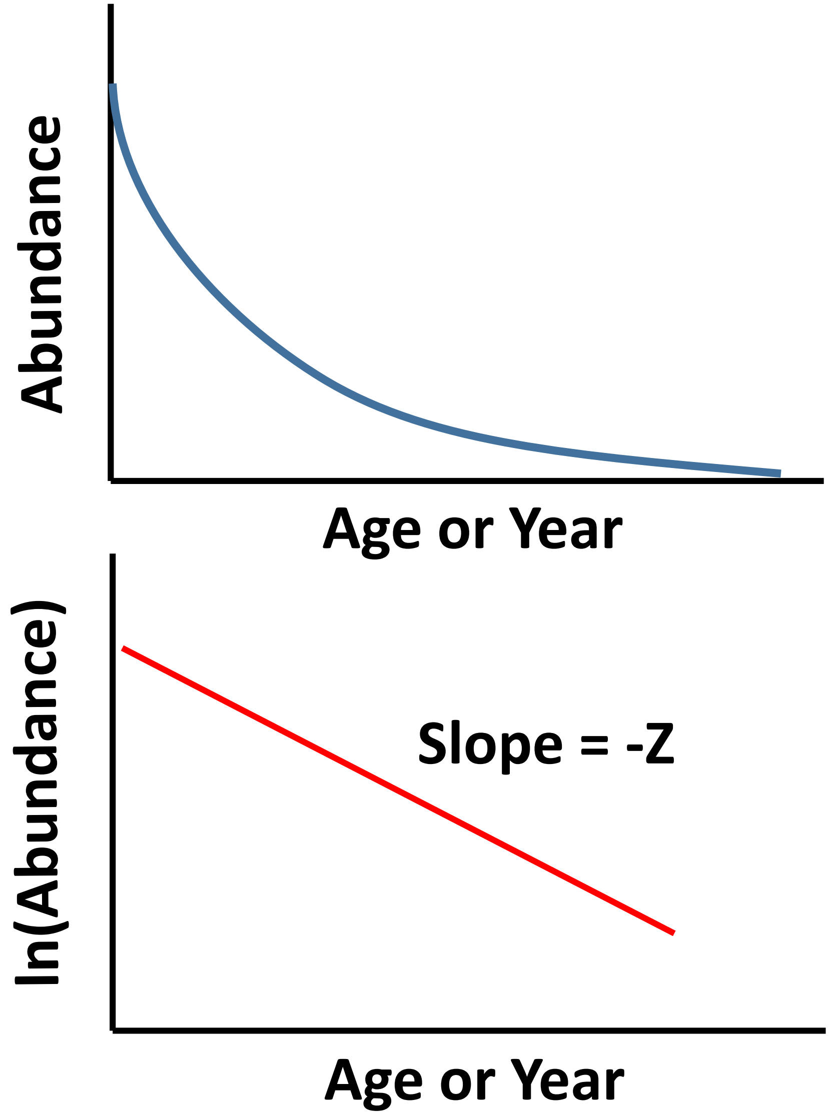
- General idea
  - Look at changes in relative abundance
  - Requires catch-at-age data
  - Linearize exponential mortality model

$$\boxed{N_t = N_0 e^{-Zt} e^{\varepsilon_t}}$$

Log transform

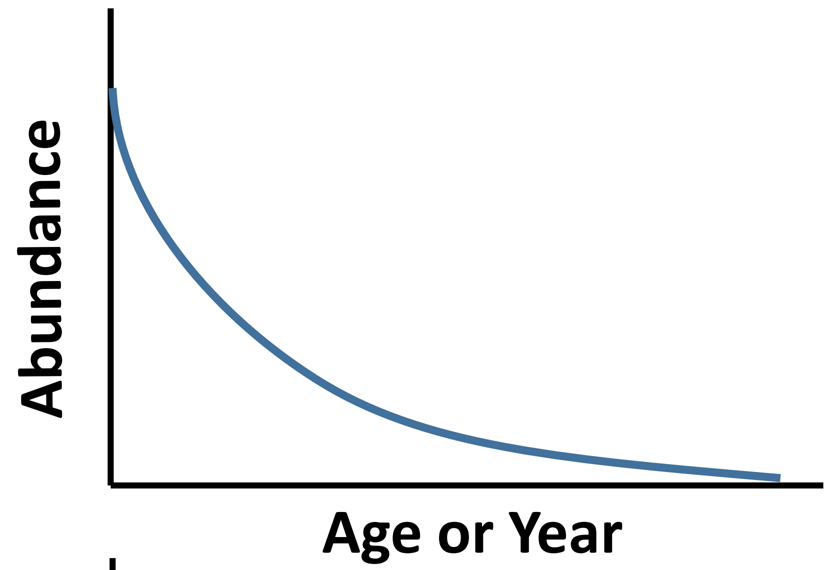
$$\boxed{\ln(N_t) = \ln(N_0) - Zt + \varepsilon_t}$$

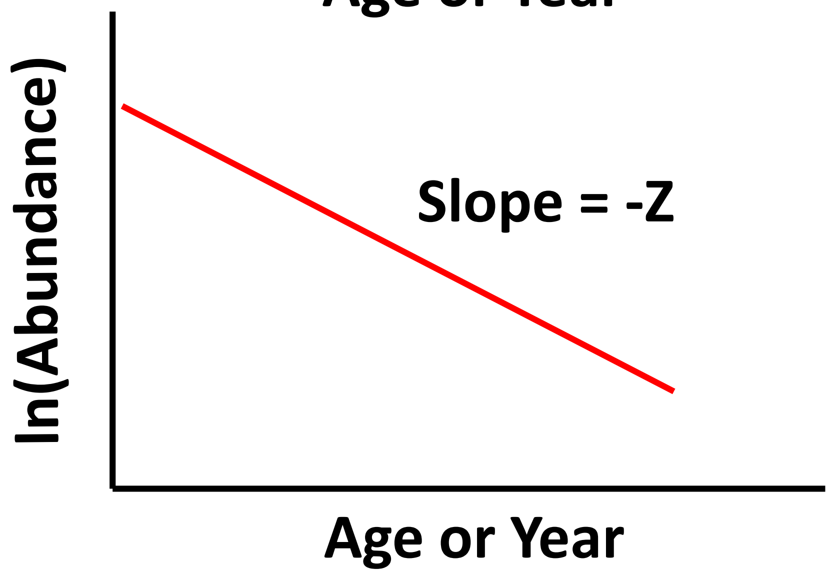
Note inclusion of error term



1. Catch curve method

- 2 options:
  - Cohort-specific: Track cohort abundance through time
  - Year-specific: Look at age distribution snapshot in 1 year





Cohort vs. year specific

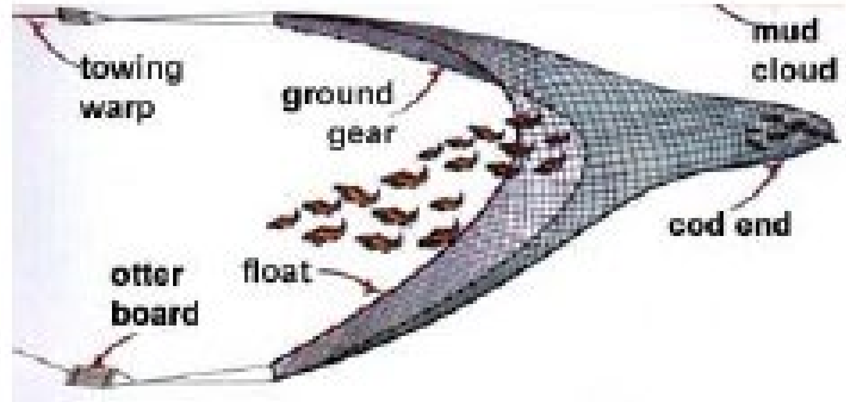
	Ages						
Year	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1978	13	129	646	954	99	19	4
1979	19	169	416	1031	243	47	18
1980	40	354	606	479	152	18	7
1981	32	606	1424	644	157	23	17
1982	0	226	1178	1156	116	16	5
1983	2	165	593	982	428	22	11
1984	53	209	560	410	30	1	4
1985	0	105	674	446	16	2	2
1986	46	422	838	726	70	4	4
1987	3	310	1224	1068	65	0	0
1988	14	354	1264	1172	69	0	6
1989	6	429	1222	1067	192	0	0

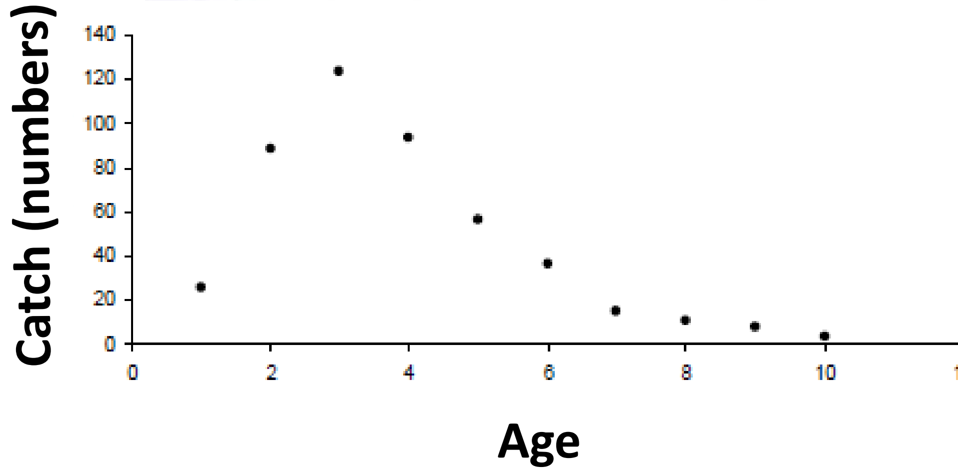
Year

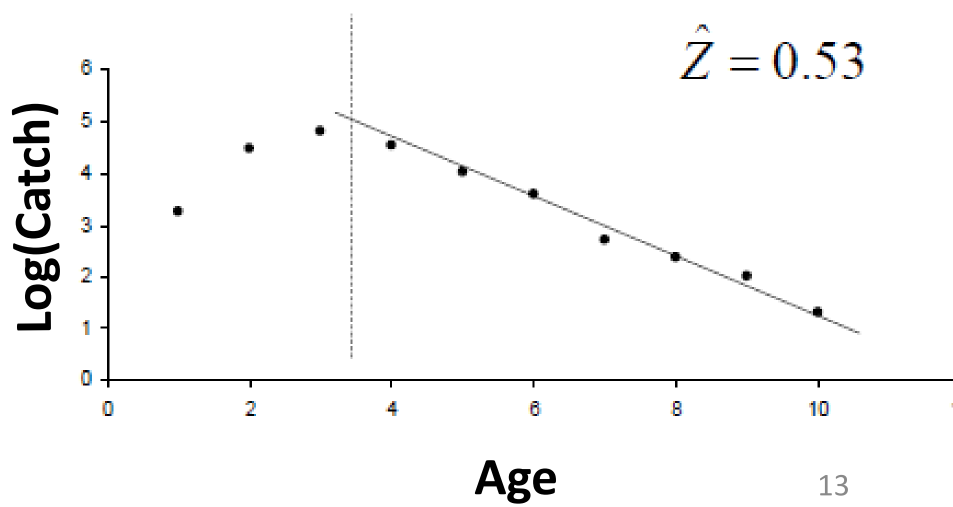
Cohort

Approach

1. Log transform abundance index data
   - Or use catch-at-age from fisheries data
2. Plot log(catch) vs. age
3. Select the first "fully selected age"
   - Typically the peak or next value
4. Fit regression using selected ages
   - Ie, use first fully selected age and older







Examples

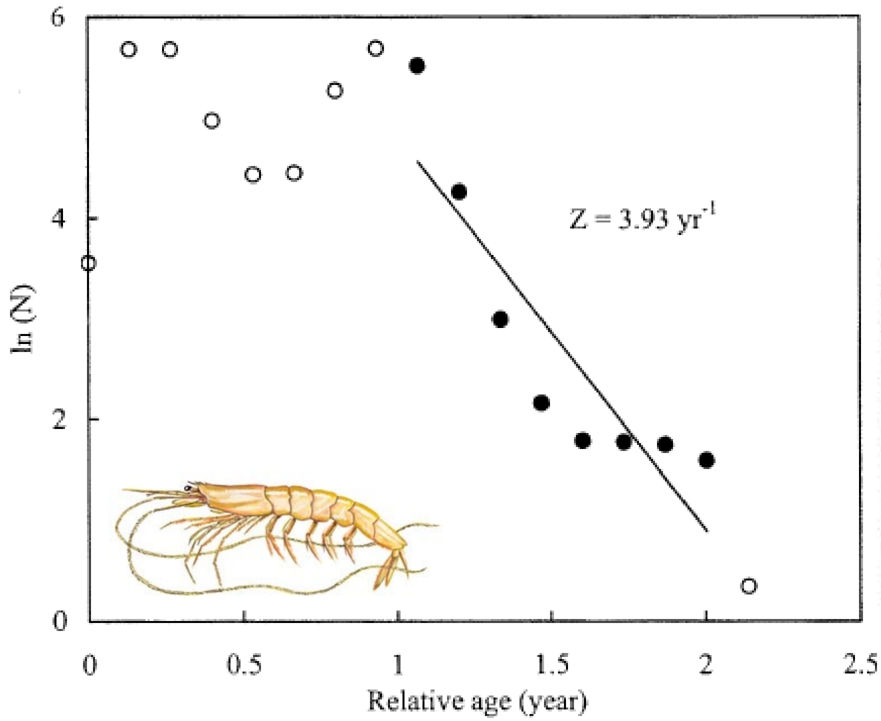
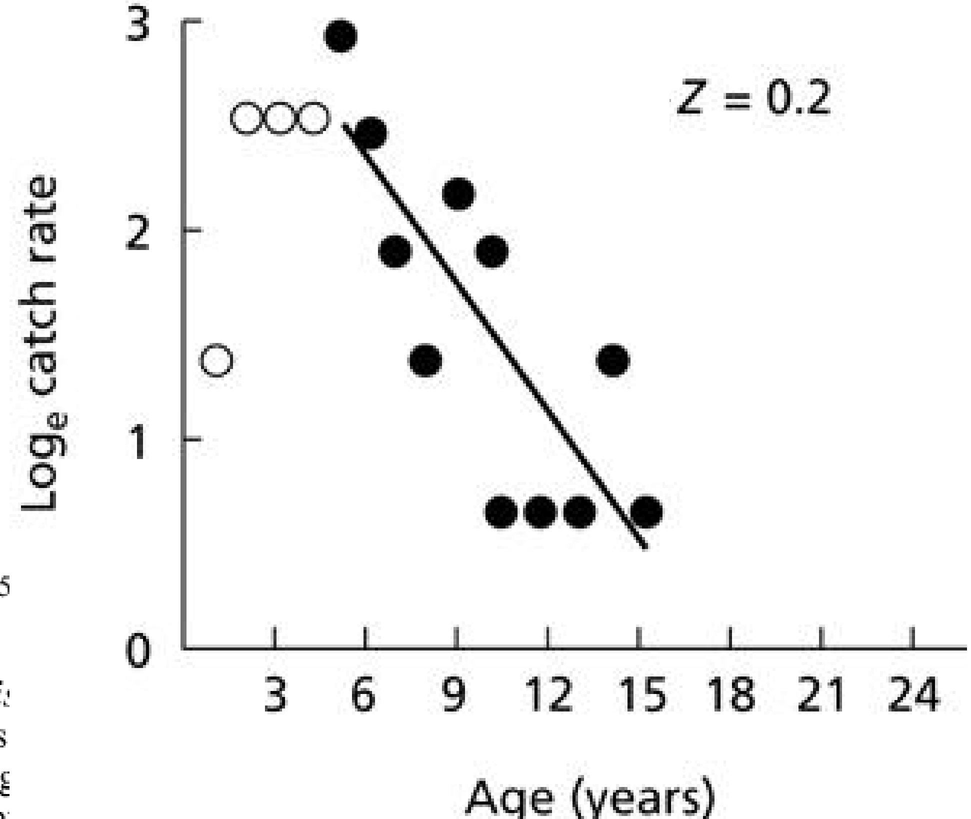


Fig. 9. Length-converted catch curve of *Acetes chinensis* based on length-frequency data during the study periods The darkened circles represent the points used in estimating Z through regression analysis. The open circles represent points either not fully recruited or nearing L_∞, hence discarded from the calculation.

Oh and Jeong J Crust Bio 2003

Surgeonfish (*Acanthurus nigrofuscus*)

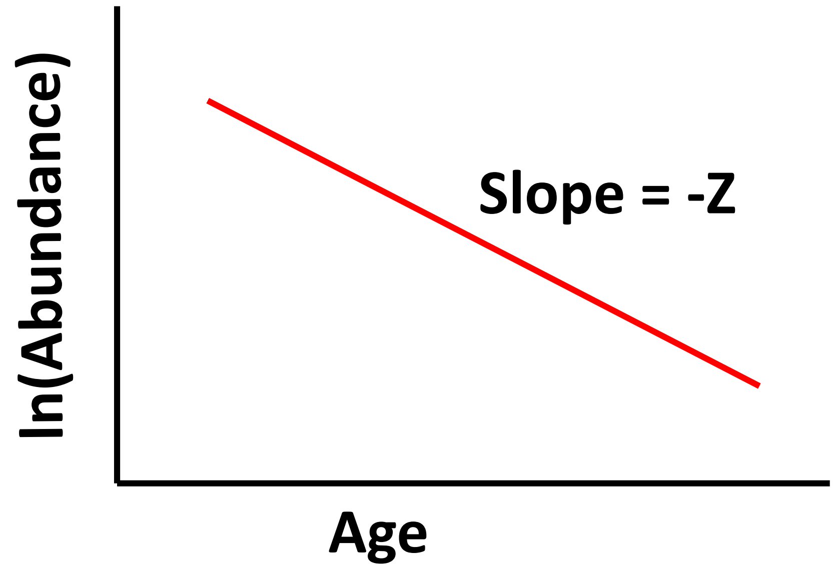


Hart and Russ 1996
(in Jennings et al. 2001)

1. Catch curve method

<u>Assumptions</u>

- cohort-specific
  - **No errors in ages estimates**
  - **Constant mortality** in all years and age classes
  - **Constant catchability**, or vulnerability to gear, over ages and years
- Year-specific
  - **Constant recruitment**
  - (rest are same as above)



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If recruitment is not constant, what type of pattern would be most problematic?

Advantages/disadvantages of each approach

- Cohort-specific
  - PRO: No need to assume constant recruitment
  - PRO: Allows estimation of mortality rates for individual cohorts
  - CON: many years of data needed
  - CON: It is in the past
- Year-specific
  - PRO: Only one year of data is needed
  - PRO: Represents what is occurring in recent time
  - CON: Need to assume constant recruitment

Other catch-curve-like methods

- Chapman and Robson 1960
- Weighted regression (Maceina and Bettoli 1998)
- Mixed-effects Poisson log-linear model (Millar 2015)
- Modifications
  - E.g., logistic selectivity & age-specific M (Thorson and Prager 2011)

Chapman & Robson (CR) method

Extra

- Uses mean age, age at full selection, and the number of samples (above the age of full selection)

$$\hat{S} = \frac{\bar{a} - a_r}{a_r - \bar{a} + \frac{n-1}{n}} \qquad \hat{Z} = -\log(\hat{S})$$

  - S is survival
  - a_r is the age at full selection
  - $\bar{a}$ is the mean age of the sample
  - n is the sample size

How is the numerator reflective of survival?

- Notes:
  - assumes duration of life follows a geometric distribution
  - Variance estimate should be corrected for bias from overdispersion

Chapman and Robson 1960; Millar 2015

Weighted linear regression (Maceina and Bettoli 1998)

Extra

- Two-step process
- 1) do the normal regression estimate (i.e., catch curve)
- 2) Use the estimated $\log(C_a)$ values from the first regression to do a weighted regression
  - Essentially, this is an *ad hoc* method to give higher weight to ages with higher abundances

Extra

Mixed effects Poisson Model

- Uses GLMM (generalized, linear, mixed-effects model) and maximum likelihood
- Builds in recruitment variability using a random intercept
- Assumes a Poisson distribution with log link

Millar 2015

Recommendations for catch-curve-like methods

- For year-specific approach (ie “cross-sectional”)
  - Basic catch curve should <u>**not**</u> be used
  - Smith et al. 2012 (TAFS) recommended the Chapman Robson method corrected for overdispersion
    - Use: age of max catch + 1 as the lower age limit
  - Millar 2015 recommended Poisson GLMM

2. Length-based estimators for Z

Extra

- Use length as a proxy for age
- When is this useful?
- Resources:
  - Reviews:
    - Hoenig et al. 1983;
    - Shepherd and Breen 1992
  - Examples:
    - Beverton and Holt 1957; Ehrhardt and Ault 1992; Gedamke and Hoenig 2006; Then et al. 2015

2. Length-based estimators for Z

Extra

- Example: Beverton and Holt (1957)
  - Assumptions: Von Bert growth; knife edge selectivity at L_c; constant mortality

$$Z = K \frac{L_{inf} - \bar{L}}{\bar{L} - L_c}$$

  - K & L_{inf} from von Bertalanffy model;
  - Lbar is mean length in sample
  - L_c is length at first capture

How to estimate Z?

1. Catch curve method
2. Length-based estimators
3. Mark-recapture
   - Estimate disappearance of marked individuals over time
   - Need multiple detection events
   - Assume survival of marked individuals = survival of unmarked individuals
   - *Future lecture…*
4. Population models
   - Survival = N_{t+1}/N_t (if no recruitment)
   - *Future lectures on stock assessment models…*

Estimating instantaneous natural mortality (M)

Estimating natural mortality (M)

1. Catch curve analysis
2. Length-based estimators
3. Mark recapture methods
4. Life-history methods (empirical methods)
5. Population models (Multispecies VPA)
6. Pope's derivation

Will focus on this

Estimating natural mortality

1. Catch curve analysis

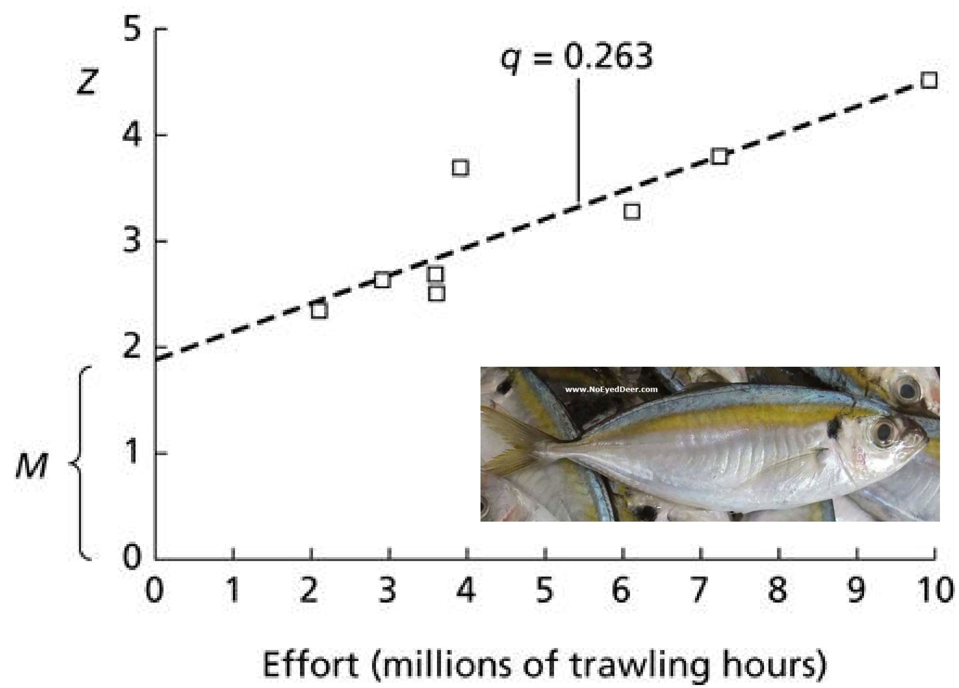
A. Catch curve on population with no fishing
   - Restricted applicability given our interest in fishing

B. Use relationship of Z to fishing effort (E)

$$Z = M + F \qquad F = qE$$

$$Z = M + qE$$

- M=natural mortality (y intercept)
- q=catchability coefficient
- E=fishing effort
- Requires wide range of fishing effort



Smooth-tailed trevally (*Selaroides leptolepis*)
(Pauly 1982, in Jennings et al. 2001)

Estimating natural mortality

2. Length based estimators

- Good for data-limited fisheries
- Use estimates of Z (as described before) and F to get M
- See Hoenig et al. 1983; Shepherd and Breen 1992

Estimating natural mortality

3. **Mark-recapture**

- Estimate disappearance of marked individuals over time
- Need multiple detection events
- Assume survival of marked individuals = survival of unmarked individuals
- Partition total mortality into fishing and natural

- *Future lecture…*

Estimating natural mortality

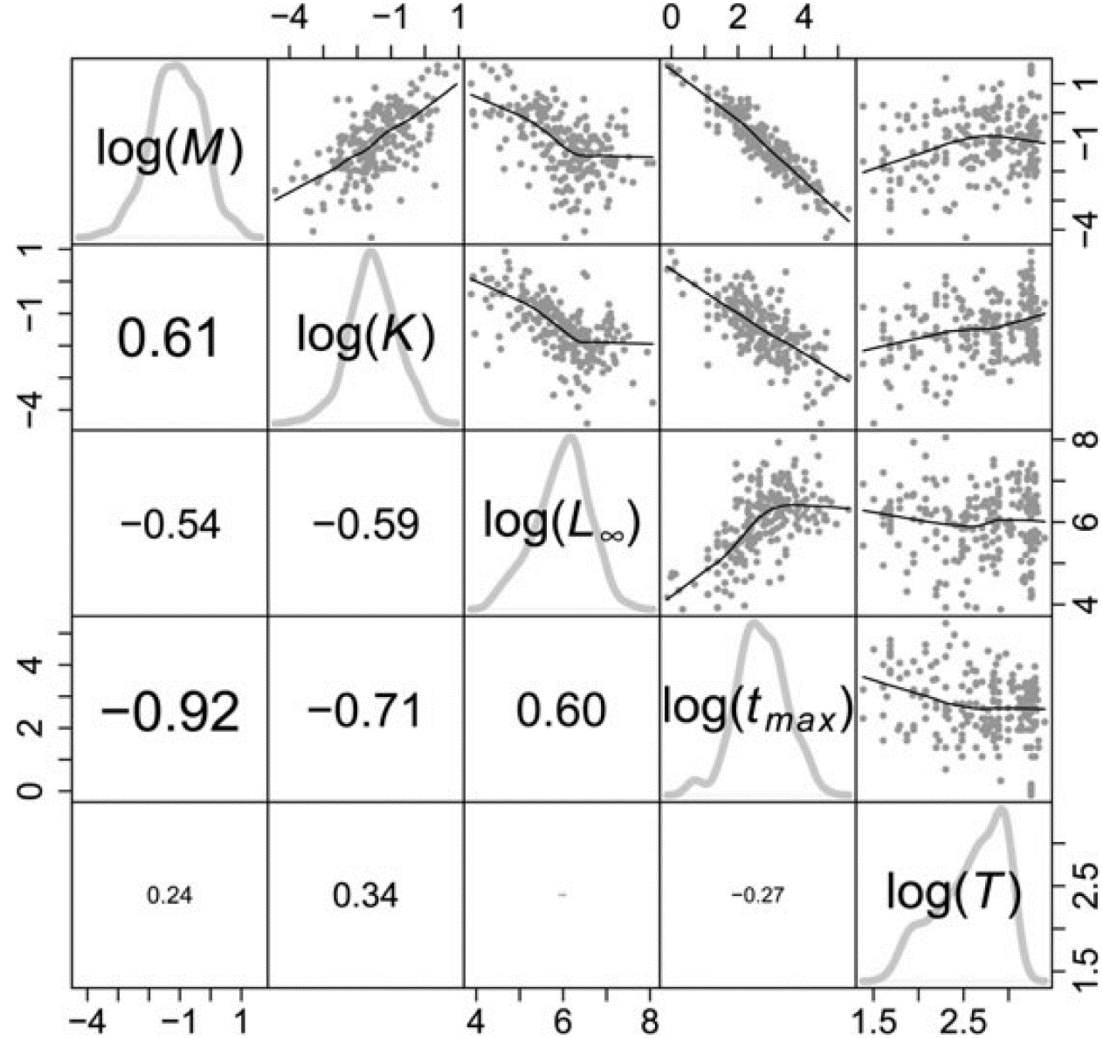
4. **Use empirical estimators**

What life history parameters do you think would be related to M?

Draw how you think M is related to:

- K (from von Bertalanffy model),
- Linf (from von Bert model; asymptotic max length)
- Max Age (t_{max}),
- mean temperature (T)

Figure 1. Scatterplot of pairs of log-transformed variables in the upper half of the panel, with LOWESS smooths. (>200 M estimates)



Then et al. 2015. ICES Journal of Marine Science, Volume 72, Issue 1, 20 August 2014, Pages 82–92,
https://doi.org/10.1093/icesjms/fsu136

Estimating natural mortality

4. Use empirical estimators

- Often used for information limited fisheries
- M related to life history parameters (e.g., K, Linf, mean Temp)
  - www.Fishbase.org is a great source of values!
- At least 30 equations proposed!
- 2 of the more robust models:
  - **Pauly 1980**:

$$\ln(M) = -0.0152 - 0.279 \ln(Linf) + 0.6543 \ln(K) + 0.4634 \ln(T)$$

  - **Jensen 1996**

$$M = 1.5K$$

Review: Kenchington 2014 (Fish and Fisheries)

Sidenote: Size/Age-specific M

- Many empirical relationships developed.
- Decent examples:
  - Lorenzen 1996

$$M_w = 3.00w^{-0.288}$$

  - Gislason et al. 2010

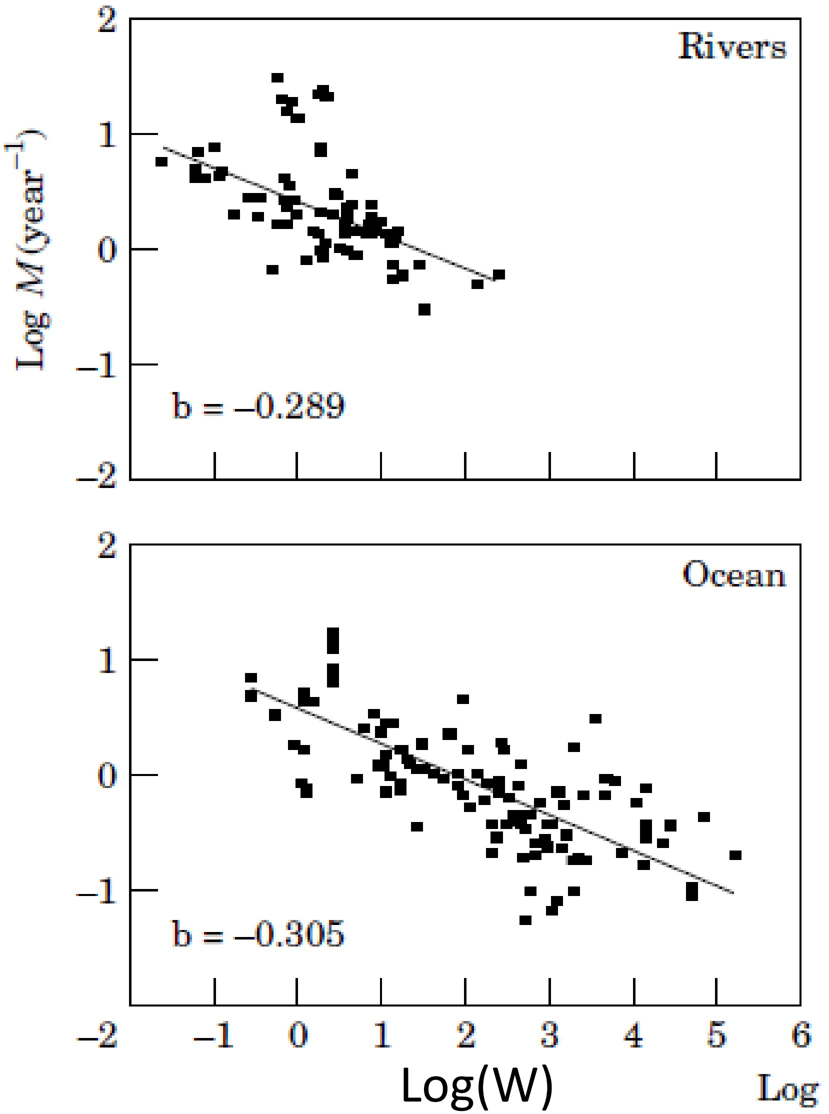
$$M_l = 1.73l^{-1.61}L_\infty^{1.44}K$$

  - Charnov et al. 2012

$$M_l = K\left(\frac{l}{L_\infty}\right)^{-1.5}$$

Kenchington 2014 (Fish and Fisheries)

Lorenzen 1996

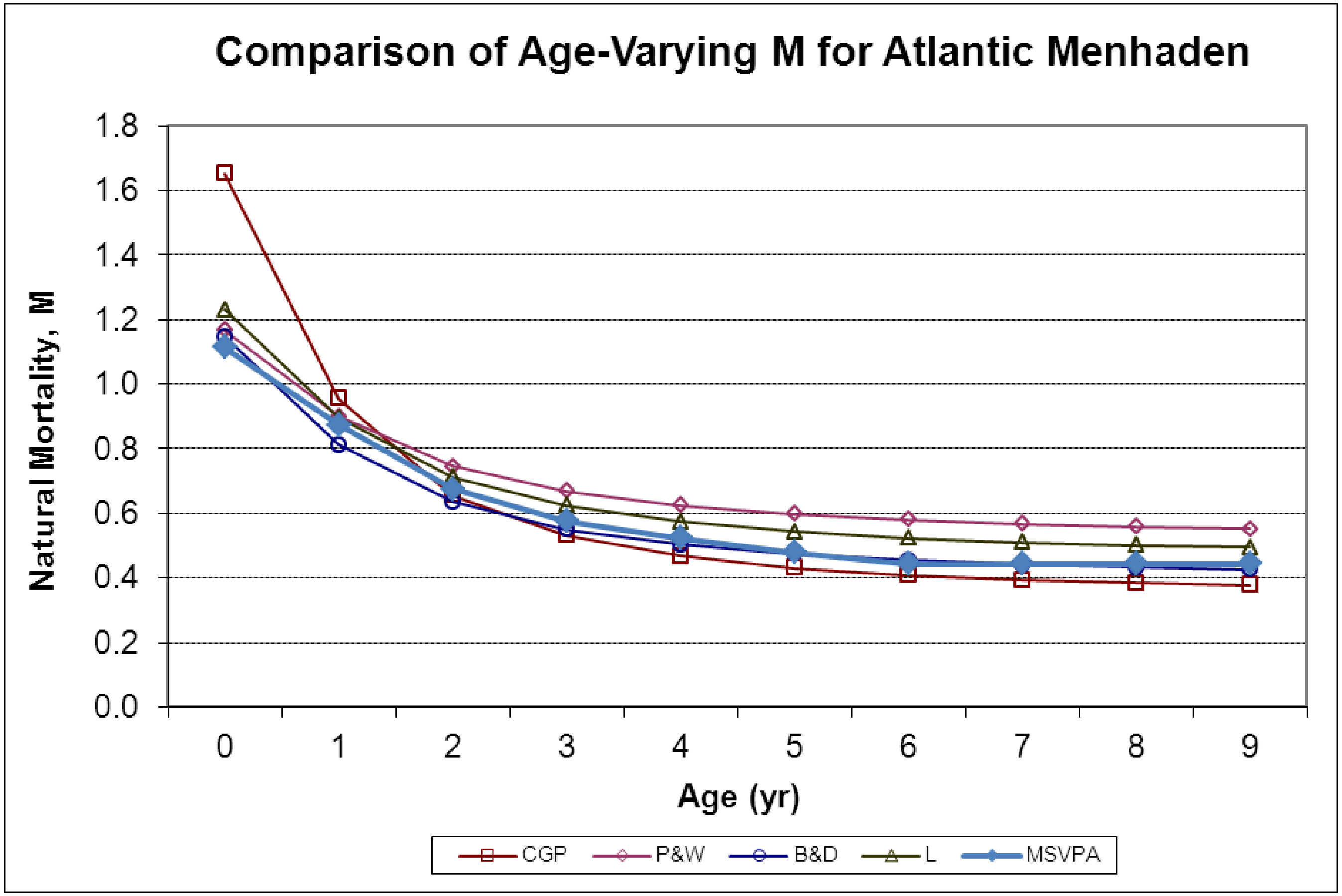


Log(W)

M_w = M at weight, *w*
M_l = M at length, *l*
Linf, K = Von Bert parms

Sidenote: Size/Age-specific M

- Example
  - More realistic biologically, but hard to estimate accurately
  - Can scale to other mortality estimates (e.g., tagging-based)



Estimating natural mortality

5. Population Models

- Multispecies models (e.g., MS VPA)
  - Multispecies models account for consumption by predator species
  - Use this info to estimate predation mortality
  - *Future lecture(s)*
- Estimate M within stock assessment (or ecosystem) models

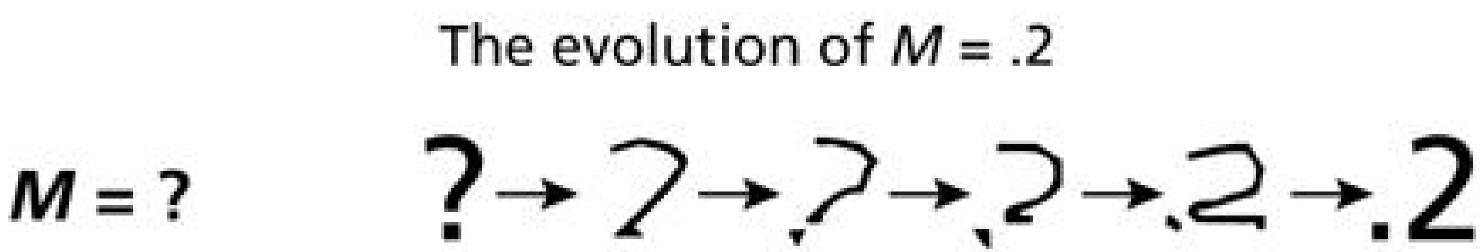
- Comments
  - Data intensive
  - Can be controversial given uncertainties

Kenchington 2014 (Fish and Fisheries)

Estimating natural mortality

6. Pope's Derivation

- Many models just assume M=0.2 if no other info available
- Not ideal, but common
- Note: this is NOT an "estimate" of M… just an assumption



Summary

- Mortality is critical component for population dynamics and management
  - → challenging to estimate precisely
- General approaches for estimating Z or M:
  - (Z or M) **Catch curve** and related methods
    - Know general catch curve process, diff btw cohort & year- specific
    - Chapman/Robson Method or Poisson GLMM recommended (for Z)
    - (M) Regress Z on Effort → intercept=M
  - (Z) Length-based estimators
  - (M) **Life-history methods (meta-analysis)** – for M only
    - Size/length specific estimates possible
  - (Z or M) Mark-recapture (*future lectures*)
  - (Z or M) Population models (*future lectures*)
  - (M) "Pope's derivation" → many just assume M=0.2 in the absence of other information. Not ideal. Also would <u>not</u> be considered a "<u>estimate</u> of M".