Assessment & Management of Fisheries Based on Mean-Size Statistics: an expansive methodology

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More Fishing $\rightarrow$ Less Older Fish
More Fishing $\rightarrow$ Less Large Fish

Pauly (1984 p. 71) after Powell (1979)
What to do with length composition data?

- Convert to ages, then analyze age data

Mixture analysis

Cohort slicing (Ailloud et al. 2015)
What to do with length composition data?

- Convert to ages, then analyze age data

**Relative age** $t' = -\log(1 - \frac{L}{L_{\text{inf}}})$

banded grouper (*Epinephelus sexfasciatus*)

Pauly (1984)
What to do with length composition data?

- Convert to ages, then analyze age data
- Analyze multiple years simultaneously in integrated stock assessment model
What to do with length composition data?

- Convert to ages, then analyze age data
- Analyze multiple years simultaneously in integrated stock assessment model

These approaches look at SHAPE of the length frequency distribution
Alternative:

Look at (just) a summary, the mean length
Beverton-Holt mean length mortality estimator

\[
\bar{L} = \frac{\int_{t_c}^{\infty} N_t L_t \, dt}{\int_{t_c}^{\infty} N_t \, dt}
\]

\[
\bar{L} = L_\infty \left(1 - \frac{Z}{Z + K} \frac{L_\infty - L_c}{L_\infty}\right)
\]

growth rate \quad \text{maximum length}

total mortality

\[
Z = \frac{K(L_\infty - \bar{L})}{\bar{L} - L_c}
\]

mean length

length where all animals fully vulnerable
Tradeoffs

<table>
<thead>
<tr>
<th>More</th>
<th>Less</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assumptions,</td>
<td>Data &amp; poorer quality,</td>
</tr>
<tr>
<td>Sophistication,</td>
<td>Complex,</td>
</tr>
<tr>
<td>Detail</td>
<td>Sensitive to assumptions</td>
</tr>
</tbody>
</table>
Desiderata for mean-length-based methods

• Relaxing assumptions

• Diagnostics

• Incorporating more types of data

• Bridges to (more) data-rich methods
Desiderata for mean-length-based methods

• Relaxing assumptions

• Diagnostics

• Incorporating more types of data

• Bridges to (more) data-rich methods

Assumptions

• Growth known
• No variability in size-at-age
• Z constant w/age
• Z constant w/time
• constant recruitment
Desiderata for mean-length-based methods

- Relaxing assumptions
- Diagnostics
- Incorporating more types of data
- Bridges to (more) data-rich methods

Data Types
- mean length
- catch rate (cpue)
- recruit index (cpue by size)
- effort
- catch & cpue
- other species
Beverton-Holt mean length mortality estimator

5 assumptions:

1. Asymptotic growth, $K$ and $L_\infty$ known & constant over time
2. No individual variability in growth
3. Mortality constant with age (Selectivity, M)
4. Mortality constant over time $\rightarrow$ Population in equilibrium (mean length reflects mortality)
5. ‘Constant’ & continuous recruitment over time

\[ Z = \frac{K(L_\infty - \bar{L})}{\bar{L} - L_c} \]
Growth known: What if life history parameters questionable??

**Queen Snapper**
(hook and line in Puerto Rico)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lower bound</th>
<th>Base</th>
<th>Upper bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_c$</td>
<td>335mm</td>
<td>365mm</td>
<td>465mm</td>
</tr>
<tr>
<td>VBK</td>
<td>0.25</td>
<td>0.45</td>
<td>0.65</td>
</tr>
<tr>
<td>$L_\infty$</td>
<td>846mm</td>
<td>888mm</td>
<td>906mm</td>
</tr>
</tbody>
</table>
Using Proportional Change in Mortality

Proportional Change in $Z = \frac{Z_2 - Z_1}{Z_1}$

$Z_1 = \frac{K(L_\infty - \bar{L}_1)}{\bar{L}_1 - L_c}$

$Z_2 = \frac{K(L_\infty - \bar{L}_2)}{\bar{L}_2 - L_c}$

$Z_{prop.\ change} = \frac{\frac{K(L_\infty - \bar{L}_2)}{\bar{L}_2 - L_c} - \frac{K(L_\infty - \bar{L}_1)}{\bar{L}_1 - L_c}}{\frac{K(L_\infty - \bar{L}_1)}{\bar{L}_1 - L_c}}$
5 assumptions:

1. Asymptotic growth, $K$ and $L_\infty$ known & constant over time

2. No individual variability in growth

3. Mortality constant with age (Selectivity, $M$)

4. Mortality constant over time $\rightarrow$ Population in equilibrium (mean length reflects mortality)

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Beverton-Holt mean length mortality estimator

$$Z = \frac{K(L_\infty - \bar{L})}{\bar{L} - L_c}$$
Ehrhardt-Ault (EA) mortality estimator

\[
\bar{L} = \frac{\int_{t_c}^{t_\lambda} N_t L_t \, dt}{\int_{t_c}^{t_\lambda} N_t \, dt}
\]
Chapter 2

**EA: Varying imposed $L_\lambda$**

**Age:**
- 'Actual' $t_\lambda$

---

**Graph:**
- **Length** vs **Age**
- Parameters: $Z$, $K$, $\sigma$, $t_\lambda$
**Chapter 2**

**Introduction**

- **Method**
- **Results**
- **Conclusions**

**EA: Varying imposed \( L_\lambda \)**

**Age:**
- ‘Actual’ \( t_\lambda \)

**‘Actual’ \( L_\lambda \)**

**Length vs. Age**

- \( Z, K, \sigma, t_\lambda \)
Chapter 2

**Introduction**

- **Method**
- **Results**
- **Conclusions**

**Simulation approach**

- **EA**: Varying imposed $L_\lambda$

**Age**: 'Actual' $t_\lambda$

**Undertruncation**

- 'Actual' $L_\lambda$

**Overtruncation**

- $Z, K, \sigma, t_\lambda$
Data analyst specifies a $t_\lambda$ which corresponds to an $L_\lambda$

varying imposed $L_\lambda$, $Z$ & $K$ ($\sigma = 7$)

$Z = 0.1$  $Z = 0.25$  $Z = 0.5$  $Z = 1.0$

$K = 0.1, 0.4, 0.7, 1.0$

$A, B, C, D$
Take Home Message:

growth variability not a problem for BH;
Truncation $\rightarrow$ overestimate of $Z$

EA Model:
- complex behavior, unpredictable bias
- RMSE much better or much worse than BH, depending on $Z, \sigma, & L_\lambda$
- Use not advised (Then et al. in revision)
Dome-shaped selectivity

no general solution

- Live with positive bias
- Evaluate sensitivity to suspected selectivity pattern
- Treat as Index of Z & Look at relative change in Z
- Incorporate selectivity into the model
Beaveron-Holt mean length mortality estimator

5 assumptions:

1. Asymptotic growth, $K$ and $L_\infty$ known & constant over time
2. No individual variability in growth
3. Mortality constant with age (eg. Selectivity, M)
4. Mortality constant over time $\rightarrow$ Population in equilibrium (mean length reflects mortality)
5. ‘Constant’ & continuous recruitment over time

$$Z = \frac{K(L_\infty - \bar{L})}{\bar{L} - L_c}$$
First expansion: multiple years

Change in Z causes *gradual* (transitional) change in mean length to new equilibrium value.
The derivation

\[ \overline{L}_d = \frac{\int_{t_c}^{g} N_o \exp(-Z_2(t-t_c)) L_z dt + \int_{t_c}^{g} N_o \exp(-Z_2 t) \exp(-Z_1(t-g)) L_z dt}{\int_{t_c}^{g} N_o \exp(-Z_2(t-t_c)) dt + \int_{g}^{\infty} N_o \exp(-Z_2 t) \exp(-Z_1(t-g)) dt} \]

**In English:**

Mean Length =

\[ \frac{\text{SUM # of younger animals at each age (Z}_2 \text{ only)} \cdot \text{Length at age}}{\text{SUM # of older animals at each age (both Z}_1 \text{ and Z}_2 \text{ )} \cdot \text{Length at age}} + \frac{\text{SUM # of younger animals at each age (Z}_2 \text{ only)} \cdot \text{Length at age}}{\text{SUM # of older animals at each age (both Z}_1 \text{ and Z}_2 \text{ )}} \]
Simplified Equation (at least relatively)

\[
\bar{L}_d = L_\infty - \frac{Z_1 Z_2 (L_\infty - L_c) \{Z_1 + K + (Z_2 - Z_1) \exp\left( -(Z_2 + K) d \right) \}}{(Z_1 + K)(Z_2 + K)(Z_1 + (Z_2 - Z_1) \exp\left( -Z_2 d \right))}
\]

\(d = \text{number of years since change in mortality}\)
Maximum likelihood estimation

Means distributed normally (Central Limit Theorem)

\[
\ln (\Lambda) \propto -n \cdot (\ln \sigma) - \frac{1}{2\sigma^2} \cdot \sum_{y=1}^{n} m_y \cdot [\bar{L}_y - L_{\text{pred},y}]^2
\]
Goosefish (*Lophius americanus*)
Gedamke and Hoenig (2006)
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</thead>
<tbody>
<tr>
<td>Mean Length (cm)</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>70</td>
<td>80</td>
</tr>
</tbody>
</table>

Goosefish (*Lophius americanus*)
Gedamke and Hoenig (2006)

**Diagnostic – pattern to residuals**

\[ Z_1 = 0.15 \]
\[ Z_2 = 0.48 \]
Goosefish (*Lophius americanus*)
Gedamke and Hoenig (2006)
Barndoor skate NMFS survey

Barndoor skate (Dipturus laevis) Gedamke et al. (2008)
2\textsuperscript{nd} expansion: Using an index of recruitment

Equate observed mean length with predicted; predicted computed as sum (not integral) and constant recruitment replaced by year-specific index.
What if you don’t have an index of recruitment?

Overestimate Z when recruitment is increasing & underestimate when declining
3rd expansion: Incorporating effort data THoG model (Then, Hoenig, Gedamke)

Simply replace $Z$ by $q f_t + M$ in “simplified equation”

same likelihood function

$$
\sum ( \bar{L}_{\text{pred}} - \bar{L}_{\text{obs}} )^2
$$

Estimate catchability, $q$, & natural mortality, $M$ → year-specific fishing & total mortality rates, $F$ & $Z$
Example: $Z_1 = 0.6$, $Z_2 = 1.0$, $K = 0.4$, $L_{\text{inf}} = 100$

Base Case: $q$ & $M$ estimates

\[ r^2 = -0.892 \]
\[ r^2 = -0.887 \]
\[ r^2 = -0.892 \]

$\sigma'$ depends on sample size & recruitment variability
Base Case: $Z_1$ & $Z_2$ estimates & ratios

$\sigma' = 1$

$\sigma' = 3$

$\sigma' = 5$

true $Z_2/Z_1 = 1.67$
4th expansion – use total catch & cpue data

Then-Hoenig-Gedamke (THoG)

effort = \( f = \text{catch/\text{cpue}} \)

\[ Z = q \text{ catch/\text{cpue}} + M \]

abundance = \( \text{cpue}/q \)

surplus production model

MSY, \( B_{\text{MSY}} \), \( F_{\text{MSY}} \), \( F_t \), \( B_t \)
mortality increases $\rightarrow$ fewer fish

Ratio of observed CPUE inverse to relative change in $Z$

$$\frac{CPUE_2}{CPUE_1} = \frac{Z_1}{Z_2}$$

cpue $\rightarrow$ same transitional behavior as mean length

(denominator in derivation of “simplified equation”)
Fit model to data

- Estimate total mortality in stanzas
- Specify number of changes in mortality
- Obtain maximum likelihood estimates of \( Z \), year(s) of change:

\[
\log \Lambda = \log \Lambda_L + \log \Lambda_{CPUE}
\]

both parts have \( \Sigma(\text{observed} - \text{predicted})^2 \)

- use AIC to find the best fitting model.
\[
\frac{cpue_2}{cpue_1} = \frac{Z_1}{Z_2} \quad \text{in equilibrium}
\]

\(cpue\) constrains magnitude of change in \(Z\), not absolute levels
Effects of recruitment

• Change in recruitment changes mean length & cpue

Expect:

Negative correlation of residuals & long runs
6th expansion – multi-species approach

- Multiple species $\rightarrow$ information on shared parameters
- Species ‘complexes’ subject to similar effort patterns

Example: 4 species w/ 3 changes in mortality

- Each species individually $\rightarrow$ 32 parameters
- Common change years $\rightarrow$ 23 parameters
- Common change years & proportional changes in $F$ $\rightarrow$ 14 parameters
Multispecies w/ Common Proportional Change in F

Common Year of Change = 1998.03
Common Proportional change in F = 0.57
Derivation of overfishing limit (OFL)

(1) \[ OFL = F_{MSY} N_{current} \]

- \( F_{MSY} \) & \( N_{current} \) difficult to obtain
- If recent (reference) average catch & \( F \) known:

(2) \[ C_{ref} = F_{ref} N_{ref} \rightarrow N_{ref} = \frac{C_{ref}}{F_{ref}} \]

(3) \[ OFL = F_{MSY} \frac{C_{ref}}{F_{ref}} \]

- Use a per-recruit statistic as proxy for \( F_{MSY} \):

(4) \[ OFL = \frac{F_{benchmark}}{F_{ref}} C_{ref} \]
Flow diagram of approach

Mean length $Z$ (Gedamke-Hoenig)

$\bar{L}, L_c, k, L_\infty$ → $Z$ by period, $F_{\text{ref}}$ & $C_{\text{ref}}$

(Most recent year of change to present)

External M $\downarrow$

$F_{\text{benchmark}}$ (e.g., $F_{0.1}$, $F_{\text{max}}$, $F_{30\%}$)

$OFL = \frac{F_{\text{benchmark}}}{F_{\text{ref}}} C_{\text{ref}}$

Per recruit analysis

External values: $M, w_a$, age-length, fecundity $\downarrow$
Example: Queen snapper in Puerto Rico

Data:
- lengths
- catches
Describe uncertainty in growth by simulation

Overfishing not occurring
Bottom line:

- Mean length $\rightarrow$ BH-Z $\rightarrow$ multiple years $\rightarrow$ GH (changing Z)

- Add additional data:
  - recruit index
  - effort
  - catch rate (cpue)
  - catch & cpue
  - other species

- Estimate $q$, $M$, $F_t$, $Z_t$; relax assumptions, obtain diagnostics
- Combine results with other analyses: yield per recruit, abundance estimation $\rightarrow$ OFL
- Bridge to production models & other models
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