Quest for the holy grail: the stock-recruitment curve in fishery stock assessment

Mark Maunder and Kevin Piner
Outline

• What is productivity?
• What influences productivity?
• Does the stock-recruitment relationship make sense?
• Is there a stock-recruitment relationship?
• Can we estimate the stock-recruitment relationship?
• Do we need to worry about the stock-recruitment relationship?
• Recommendations
What is productivity?
Is it the surplus production function?
Stock Assessment Requirements

![Graph showing stock assessment requirements with biomass depletion and yield axes, illustrating production function and absolute scaling.](image)
Production function: a combination of YPR and S-R

*Figure 3* YPR, yield, and recruitment as a proportion of their maximum realized under equilibrium fishing mortality plotted against the equilibrium biomass as a fraction of the carrying capacity. The yield decreases faster than YPR at low biomass levels because the recruitment reduces as the biomass decreases.
Components of the production function

• YPR
  – Natural mortality
  – Growth
  – Selectivity

• Recruitment
  – The stock-recruitment relationship
  – $R_0$
  – (temporal variation in recruitment)
What influences productivity?
How sensitive is the production function to steepness?

Table 1
The shape parameter \( (B_{MSY}/B_0) \) estimated from an age-structured model for different values of natural mortality \( (M) \), growth rate \( (K) \), and the steepness of the stock recruitment relationship \( (h, \) the percentage of virgin recruitment that will be produced when the biomass level is 20% of the virgin biomass)\(^a\)

<table>
<thead>
<tr>
<th></th>
<th>( M = 0.10 )</th>
<th>( M = 0.20 )</th>
<th>( M = 0.30 )</th>
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<tbody>
<tr>
<td>( h = 1.00 )</td>
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<tr>
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<td>0.27</td>
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<tr>
<td>0.30</td>
<td>0.38</td>
<td>0.37</td>
<td>0.36</td>
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\(^a\) The age at maturity is set equal to the age at recruitment to the fishery (4 years) and fecundity is proportional to weight.

\[ \text{MSY}/B_{\text{MSY}} \approx F_{\text{MSY}} = f(r) \]

### $h = 1.00$

<table>
<thead>
<tr>
<th>M</th>
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<tbody>
<tr>
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### $h = 0.75$

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### $h = 0.50$

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<td>0.30</td>
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### Table 1

Estimates of reference points using different values for \( h, K \) (y\(^{-1}\)), length at age 6 (L\(^2\), cm) and \( M \) (y\(^{-1}\)). Biological parameter values refer to females, and males are a fixed multiplicative offset from females (male – female \( \times \) offset). The default values are female \( M = 0.2 \) y\(^{-1}\), male \( M = 0.3 \) y\(^{-1}\), female \( K = 0.2 \) y\(^{-1}\), male \( K = 0.21 \) y\(^{-1}\).

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<td>( \text{SPR}<em>{\text{MSY}}/\text{SPR}</em>{0} )</td>
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- **Steepness**
- **Estimation**
- **Natural mortality**

Management: yellowfin tuna selectivity

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<th>Fishing method</th>
<th>MSY</th>
<th>S/S₀</th>
<th>Effort multiplier</th>
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<td>Current mixture</td>
<td>248</td>
<td>0.23</td>
<td>1.19</td>
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<tr>
<td>Longline</td>
<td>425</td>
<td>0.26</td>
<td>66.47</td>
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<td>Dolphin associated</td>
<td>337</td>
<td>0.26</td>
<td>3.06</td>
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<tr>
<td>Free-swimming schools</td>
<td>199</td>
<td>0.14</td>
<td>4.72</td>
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<tr>
<td>Floating objects</td>
<td>144</td>
<td>0.13</td>
<td>7.60</td>
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How much loss in yield is due to the stock-recruitment curve?

• Components
  – Stock-recruitment steepness
  – Fishing mortality based loss in YPR
  – Selectivity based loss in YPR
  – (Assessment error due to misspecified steepness)

• Method
  – Estimate maximum YPR from knife edge selectivity and varying age at entry to the fishery
  – Calculate YPR versus F for different age at entry to the fishery
  – Calculate the loss in recruitment corresponding to the F for different Stock-recruitment steepness
Model

- $M = 0.2$
- $K = 0.2$
- $Amat = 4$
- $Avuln \text{ max } YPR = 7 \ (F = \infty)$
- Beverton-Holt
Hilborn’s “Pretty Good Yield” = 80%
Age at first entry = 5
Sensitivity of sock assessments

• Does steepness influence estimates of depletion?
Catch curve: depletion

\[ Z = M \]

\[ Z = M + F \]

Stock-recruitment

Fishing Mortality
Catch curve: depletion

Stock-recruitment

Z = M

Z = M + F (h=0.75)

Z = M + F (h=1)

Fishing Mortality + recruitment
Information on h

- No direct information in catch curve on h
- More direct information on M
- Why we have a better chance at estimating M compared to h (see Lee et al. papers)
Steepness’ double whammy

• Makes the stock more depleted
• Makes Bmsy/B0 reference point higher
Sensitivity of sock assessments

• YPR depletion
  – Composition data
  – CPUE decline due to C (C/B = F)
• S-R = recruitment reduction
• Relative index for full catch history time series constrains depletion
• Total catch history model versus starting from exploited population size.
TABLE 1. MSY and related quantities for the base case and the stock-recruitment relationship sensitivity analysis, based on average fishing mortality ($F$) for 2012-2014. $B_{\text{recent}}$ and $B_{\text{MSY}}$ are defined as the biomass, in metric tons, of fish 3+ quarters old at the start of the first quarter of 2015 and at MSY, respectively, and $S_{\text{recent}}$ and $S_{\text{MSY}}$ are defined as indices of spawning biomass (therefore, they are not in metric tons). $C_{\text{recent}}$ is the estimated total catch for 2014.

TABLA 1. RMS y cantidades relacionadas para el caso base y el análisis de sensibilidad a la relación población-reclutamiento, basados en la mortalidad por pesca ($F$) media de 2012-2014. Se definen $B_{\text{recent}}$ y $B_{\text{RMS}}$ como la biomasa, en toneladas, de peces de 3+ trimestres de edad al principio del primer trimestre de 2015 y en RMS, respectivamente, y $S_{\text{recent}}$ y $S_{\text{RMS}}$ como índices de biomasa reproductora (por lo tanto, no se expresan en toneladas). $C_{\text{recent}}$ es la captura total estimada de 2014.

<table>
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<th>YFT</th>
<th>Base case Caso base</th>
<th>$h = 0.75$</th>
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<tbody>
<tr>
<td>MSY-RMS</td>
<td>275,258</td>
<td>297,677</td>
</tr>
<tr>
<td>$B_{\text{MSY}} - B_{\text{RMS}}$</td>
<td>368,336</td>
<td>556,279</td>
</tr>
<tr>
<td>$S_{\text{MSY}} - S_{\text{RMS}}$</td>
<td>3.469</td>
<td>5.990</td>
</tr>
<tr>
<td>$B_{\text{MSY}}/B_0 - B_{\text{RMS}}/B_0$</td>
<td>0.32</td>
<td>0.37</td>
</tr>
<tr>
<td>$S_{\text{MSY}}/S_0 - S_{\text{RMS}}/S_0$</td>
<td>0.27</td>
<td>0.35</td>
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<tr>
<td>$C_{\text{recent}}/MSY - C_{\text{recent}}/\text{RMS}$</td>
<td>0.86</td>
<td>0.80</td>
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<tr>
<td>$B_{\text{recent}}/B_{\text{MSY}} - B_{\text{recent}}/B_{\text{RMS}}$</td>
<td>1.12</td>
<td>0.73</td>
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<tr>
<td>$S_{\text{recent}}/S_{\text{MSY}} - S_{\text{recent}}/S_{\text{RMS}}$</td>
<td>0.99</td>
<td>0.57</td>
</tr>
<tr>
<td>$F$ multiplier-Multiplificador de $F$</td>
<td>1.11</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Scur/S0 0.27 0.20
Scur 3434 3414
Bigeye tuna in the EPO

**TABLE 1.** Estimates of the MSY and its associated quantities for bigeye tuna for the base case assessment and the sensitivity analyses. All analyses are based on average fishing mortality during 2012-2014. $B_{\text{recent}}$ and $B_{\text{MSY}}$ are defined as the biomass of fish 3+ quarters old (in metric tons) at the beginning of 2015 and at MSY, respectively. $S_{\text{recent}}$ and $S_{\text{MSY}}$ are in metric tons. $C_{\text{recent}}$ is the estimated total catch in 2014. The $F$ multiplier indicates how many times effort would have to be effectively increased to achieve the MSY in relation to the average fishing mortality during 2012-2014.

**TABLA 1.** Estimaciones del RMS y sus cantidades asociadas para el atún patudo para la evaluación del caso base y los análisis de sensibilidad. Todos los análisis se basan en la mortalidad por pesca promedio de 2012-2014. Se definen $B_{\text{recent}}$ y $B_{\text{RMS}}$ como la biomasa de peces de 3+ trimestres de edad (en toneladas métricas) al principio de 2015 y en RMS, respectivamente. Se expresan $S_{\text{recent}}$ y $S_{\text{MSY}}$ en toneladas métricas. $C_{\text{recent}}$ es la captura total estimada en 2014. El multiplicador de $F$ indica cuántas veces se tendría que incrementar el esfuerzo para lograr el RMS en relación con la mortalidad por pesca media durante 2012-2014.

<table>
<thead>
<tr>
<th></th>
<th>Base case-Caso base</th>
<th>$h = 0.75$</th>
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</thead>
<tbody>
<tr>
<td>MSY-RMS</td>
<td>113,730</td>
<td>110,075</td>
</tr>
<tr>
<td>$B_{\text{MSY}}-B_{\text{RMS}}$</td>
<td>433,396</td>
<td>778,733</td>
</tr>
<tr>
<td>$S_{\text{MSY}}-S_{\text{RMS}}$</td>
<td>108,502</td>
<td>216,205</td>
</tr>
<tr>
<td>$B_{\text{MSY}}/B_0-B_{\text{RMS}}/B_0$</td>
<td>0.25</td>
<td>0.33</td>
</tr>
<tr>
<td>$S_{\text{MSY}}/S_0-S_{\text{RMS}}/S_0$</td>
<td>0.21</td>
<td>0.30</td>
</tr>
<tr>
<td>$C_{\text{recent}}/\text{MSY}-C_{\text{recent}}/\text{RMS}$</td>
<td>0.87</td>
<td>0.90</td>
</tr>
<tr>
<td>$B_{\text{recent}}/B_{\text{MSY}}-B_{\text{recent}}/B_{\text{RMS}}$</td>
<td>1.03</td>
<td>0.82</td>
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<tr>
<td>$S_{\text{recent}}/S_{\text{MSY}}-S_{\text{recent}}/S_{\text{RMS}}$</td>
<td>1.06</td>
<td>0.82</td>
</tr>
<tr>
<td>$F$ multiplier-Multiplicador de $F$</td>
<td>1.14</td>
<td>0.92</td>
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Scur/S0 0.22 0.25  Scur 115012 177288

Assessment impact
Mispecifying steepness can influence estimates of abundance, important for decision rules: Pacific cod
Does the stock-recruitment relationship make sense?
It's only a model.
Traditional models: Beverton-Holt and Ricker

Their derivation is based on solving the differential equation for the abundance, $N$, as a function of mortality, $Z$.

$$\frac{dN}{dt} = -Z_t N$$

**Beverton-Holt model**
$Z$ is a linear function of the cohort abundance, which represents process like intra-cohort competition,

$$Z_t = a + bN$$

**Ricker**
$Z$ is a linear function of the spawner abundance, which represents process like cannibalism, ($E$ is eggs or adults)

$$Z_t = a + bE$$
Traditional models: Beverton-Holt and Ricker

These differential equations are solved to produce equations that calculate recruitment as a function of spawning biomass.

**Beverton-Holt**

\[ R = \frac{\alpha E}{1 + \beta E} \]

**Ricker**

\[ R = \alpha E \exp(-\beta E) \]
Recruitment in terms of survival: Beverton-Holt and Ricker

The stock recruitment relationships can be described in terms of survival, \( S \), from birth to the age at recruitment

\[
R = SE
\]

**Beverton-Holt**

\[
S = \frac{\alpha}{1 + \beta E}
\]

**Ricker**

\[
S = \alpha \exp(-\beta E)
\]
Survival implications of the Beverton-Holt and Ricker models
Problems with Beverton-Holt and Ricker stock-recruitment models

- Density dependence is unlikely to be linear
- Density dependence is not continuous at a constant rate
- Density dependence probably occurs at a critical stage/period
- Changes in survival due to density dependence should be strongest close to the carrying capacity
- Despite the above, the general shapes of the Beverton-Holt and Ricker make intuitive sense
\[ S_y = \exp \left( -z_0 + (z_0 - z_{min}) \left( 1 - \left( \frac{B_y}{B_0} \right)^\beta \right) \right) \]

- \( B_y \) is the biomass in year \( y \)
- \( B_0 \) is the unexploited biomass (carrying capacity)
- \( Z_0 \) is the mortality rate at unexploited biomass \((= \ln(B_0/R_0))\)
- \( Z_{min} \) is the mortality rate at zero biomass \((z_{min} = z_0 (1 - z_{frac}))\)
- \( \beta \) is a parameter controlling the shape of the density-dependent relationship (with limit \( \beta > 0 \))

The Low fecund stock-recruitment relationship

The Low fecund stock-recruitment relationship

Adult carrying capacity versus egg carrying capacity

![Diagram showing adult and egg survival curves]

- **Survival** as a function of **B/B0**
  - **Adult survival** curve
  - **Egg survival** curve
  - **Egg carrying capacity** indicated by a dashed vertical line
Survival: hockey stick S-R model

![Graph showing survival and recruitment against S/S0 ratio.](image-url)
A stock–recruitment model for highly fecund species based on temporal and spatial extent of spawning

Expansion into unfavorable spawning habitat

Recruitment

Spawning biomass

Unproductive habitat
Strong density dependence
Strong density dependence?
Is there a stock-recruitment relationship?
Crusade against steepness deniers

More witches!
Pacific Sardine

Recruitment
Spawning biomass


0 0.5 1 1.5 2 2.5 3 3.5 4
Pacific Sardine

![Graph showing recruitment and spawning biomass of Pacific Sardine from 1990 to 2020. The graph indicates fluctuations in both parameters over the years, with notable peaks and troughs.](image-url)
Pacific Sardine

![Graph showing the relationship between spawning biomass and recruitment for Pacific Sardine. The x-axis represents spawning biomass ranging from 0 to 900,000, and the y-axis represents recruitment ranging from 0 to 16.]
Yellowfin tuna in the EPO

![Graph showing spawning biomass and recruitment over time.](image-url)
Yellowfin tuna in the EPO

![Graph showing spawning biomass and recruitment over time.]
Yellowfin tuna in the EPO

![Graph showing recruitment vs. spawning biomass from 1985-2015, with data points for different decades: 1985-2003 in blue diamonds, 1975-1984 in red squares, and 2004-2015 in green triangles.](image-url)
Bigeye tuna in the EPO

![Graph showing spawning biomass and recruitment over time.]

- Spawning biomass (blue line)
- Recruitment (red line)

The graph indicates fluctuations in spawning biomass and recruitment over the years, with notable peaks and troughs. Arrows highlight significant changes in the data.
Bigeye tuna in the EPO

![Graph showing spawning biomass and recruitment over time from 1970 to 2020. The x-axis represents years from 1970 to 2020, and the y-axis represents spawning biomass and recruitment values ranging from 0 to 3.5. The graph includes data points for spawning biomass and recruitment, with trends indicating fluctuations over time.](image-url)
Bigeye tuna in the EPO

![Graph showing recruitment and spawning biomass with data points for 1975-1993 and 1994-2015.]
Summer flounder

Spawning biomass
Recruitment

High F
Summer flounder

![Graph showing the relationship between recruitment and spawning biomass. The x-axis represents spawning biomass, ranging from 0 to 50,000. The y-axis represents recruitment, ranging from 0 to 120,000. The data points are scattered across the graph, indicating a possible trend but no explicit correlation is indicated.]
Pacific cod

Graph showing spawning biomass and recruitment from 1975 to 2020.
Pacific cod

![Graph showing spawning biomass and recruitment trends from 1975 to 2020. The x-axis represents years from 1975 to 2020, and the y-axis represents spawning biomass and recruitment levels. The graph includes lines for spawning biomass and recruitment, with notable fluctuations over the years.](image-url)
Pacific cod

![Plot showing the relationship between recruitment and spawning biomass for Pacific cod. The x-axis represents spawning biomass, while the y-axis represents recruitment. The plot contains a scatter of data points indicating a positive correlation between the two variables.](image-url)
Pollock
Pollock

Recruitment vs. Spawning biomass
Vert-pre et al. 2013. Frequency and intensity of productivity regime shifts in marine fish stocks
PNAS 110: 1779–1784

to year. We found that the abundance hypothesis best explains 18.3% of stocks, the regimes hypothesis 38.6%, the mixed hypothesis 30.5%, and the random hypothesis 12.6%. Fisheries management

• Based on surplus production not just stock-recruitment
Can we estimate the stock-recruitment relationship?
Bias in estimating steepness

Fig. 4. Distribution of steepness estimated from the simulated data where converged simulations were selected based on the positive definite Hessian matrix. Dashed lines represent true or assumed values of steepness from original assessments. Dots represent estimated values of steepness from original data sets and bold dash lines represent confidence intervals around estimates.

Fig. 5. The relationship between precision and bias of estimated steepness and maximum depletion from the simulation analyses. Left panel represents the coefficient of variance of estimated steepness and right panel represents the median bias of estimates (absolute values). Numbers in the circles represent twelve stocks as follows: (1) arrowtooth flounder, (2) black rockfish north, (3) black rockfish south, (4) blue rockfish, (5) canary rockfish, (6) chilipepper rockfish, (7) darkblotted rockfish, (8) English sole, (9) hake, (10) sablefish, (11) shortbelly rockfish, and (12) yelloweye rockfish.

Information content

Table 4
Likelihood comparison from profile log-likelihood analysis across range of steepness (0.2–1.0) for the twelve assessment models. If a log-likelihood profile has a well-defined convex curve (see Section 2), likelihood component is informative about steepness (denoted by plus signs). Minus signs represent that likelihood component is uninformative and blank represent that data is not available.

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<th>Arrowtooth</th>
<th>Black RF.N</th>
<th>Black RF.S</th>
<th>Blue RF</th>
<th>Canary</th>
<th>Chilipepper</th>
<th>Darkblotted</th>
<th>English sole</th>
<th>Hake</th>
<th>Sable</th>
<th>Shortbelly</th>
<th>Yelloweye</th>
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<td>Mean body-weight</td>
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</tbody>
</table>

+, informative about steepness; −, uninformative about steepness.

Do we need to worry about the stock-recruitment relationship?
How sensitive is the production function to steepness?

Table 1
The shape parameter ($B_{MSY}/B_0$) estimated from an age-structured model for different values of natural mortality ($M$), growth rate ($K$), and the steepness of the stock recruitment relationship ($h$, the percentage of virgin recruitment that will be produced when the biomass level is 20% of the virgin biomass)$^a$

<table>
<thead>
<tr>
<th>$M$</th>
<th>$K$</th>
<th>0.10</th>
<th>0.20</th>
<th>0.30</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>0.27</td>
<td>0.23</td>
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<td>0.20</td>
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<td>0.30</td>
<td>0.23</td>
<td>0.11</td>
<td>0.15</td>
<td></td>
</tr>
</tbody>
</table>

$h = 1.00$

$h = 0.75$

$h = 0.50$

$^a$ The age at maturity is set equal to the age at recruitment to the fishery (4 years) and fecundity is proportional to weight.

Proxy reference points imply a value for steepness: summer flounder

Proxy reference points imply a value for steepness: Pacific cod

Steepness ($h$) of the B-H stock-recruitment relationship

$\frac{\text{SPR}_{\text{MSY}}}{\text{SPR}_0}$
Robust steepness assumptions

Yield curves

Yellowfin tuna

Base case—Caso base

Summer flounder

$h = 1.0$

$h = 0.75$

$h = 0.8$

$F$ relative to current $F$—$F$ relativo a $F$ actual

Relative yield or biomass

Fig. 5. Relative yield (yield/MSY: black line) and spawning biomass ratio (spawning biomass divided by spawning biomass from an unexploited stock: grey line) versus relative fishing mortality (fishing mortality divided by $F_{MSY}$ when $h = 1$) for $h = 0.8$ (bottom panel) and $h = 1.0$ (top panel). The vertical lines represent the fishing mortality rates corresponding to maximum sustainable yield ($F_{MSY}$) for $h = 1$ (dashed line) and $h = 0.8$ (dotted line).
Even if there is no stock-recruitment relationship the measure of fecundity influences reference point evaluation

- Spawning biomass is used in the stock –recruitment relationship
- Spawning biomass is used in the definition of biomass based reference points
- Spawning biomass definition
  - Mature biomass
  - Mature female biomass
  - Mature numbers
  - Total biomass
  - Fecundity
- The more weight given to younger fish in the spawning biomass definition, the more optimistic the results

Minte-Vera et al. (in prep) The influence of spawning biomass definition on stock assessment results and evaluation of reference points: an illustration with yellowfin tuna in the eastern Pacific Ocean
Limit reference point 50% reduction in recruitment

- Limit reference points designed to avoid something bad happening
- Something bad happening is often interpreted as recruitment collapse

\[ P(BH(d, h) < x\%R_0) > \pi \]

\[ d = \frac{0.2r(1 - h)}{0.8h - r(h - 0.2)} \]

\( r = R/R_0 \)

- \( h = 0.75 \)
- \( r = 0.5 \)
- \( d = 0.077 \)

**FIGURE 1.** The Beverton-Holt stock-recruitment relationship with three different values for steepness ($h$). The orange area represents recruitment below the LRP definition of $0.5R_0$.

**FIGURA 1.** La relación población-reclutamiento de Beverton-Holt con tres valores diferentes de inclinación ($h$). La zona naranja representa reclutamiento inferior a la definición del PRL de $0.5R_0$. 
FIGURE 2. The depletion level required to make expected recruitment equal to $0.5R_0$ for different values of steepness.

FIGURA 2. Nivel de merma necesario para que el reclutamiento esperado equivalga a $0.5R_0$ con distintos valores de inclinación.
Pretty good yield

• E.g. 95% of MSY (Maximum YPR)
• Does $F_{95\%C_{\text{Fmax}}}$ work if $h < 1$
• Short term losses rebuilding to $B_{95\%MSY}$
• Don’t manage on yield, manage on CPUE, consistency, size of fish, ....
• Use $F$ based management because of temporal variation in recruitment
• Limit reference points
  – Vulnerable biomass (CPUE) = 50% that at F95%
  – Average length = 50% that at F95%
  – Spawning biomass (CPUE) = 50% that at F95%
  – $R = 50\%R_{F95\%MSY} \ [h=0.75]$
Dynamic reference points: recruitment temporal variability in bigeye tuna

Fig. 2. Trajectory of the spawning biomass of a simulated population of bigeye tuna that was unexploited (dashed line) and that predicted by the stock assessment model (solid line). The shaded areas between the two lines show the portions of the impact attributed to each fishing method.
Main concepts
Catch curve: depletion

Catch curve

Z = M

Z = M + F (h=0.75)

Z = M + F (h=1)

Stock-recruitment

Mortality + recruitment

Relative abundance

Age
Steepness’ double whammy

• Makes the stock more depleted
• Makes Bmsy/B0 reference point higher
Adult carrying capacity versus egg carrying capacity

- **Survival**
  - Adult survival
  - Egg survival
  - Egg carrying capacity

- **B/B0**
  - 0
  - 1
Expansion into unsuitable spawning habitat

Recruitment

Spawning biomass

Unproductive habitat
Strong density dependence?
FIGURE 1. The Beverton-Holt stock-recruitment relationship with three different values for steepness \((h)\). The orange area represents recruitment below the LRP definition of \(0.5R_0\).

FIGURA 1. La relación población-reclutamiento de Beverton-Holt con tres valores diferentes de inclinación \((h)\). La zona naranja representa reclutamiento inferior a la definición del PRL de \(0.5R_0\).
The real holy grail

- Natural mortality
- Absolute abundance
Recommendations

• Don’t include the stock-recruitment relationship in the stock assessment
• Focus on estimating natural mortality and absolute abundance
• Don’t let (length) composition data drive abundance
• Change selectivity to improve yields (discard mortality)
• Fish at < Fmax (short term losses)
• Focus on non-MSY management goals
• Use effort or F based management
Workshop Announcement

Recruitment: theory, estimation, and application in fishery stock assessment models

The Center for the Advancement of Population Assessment Methodology (CAPAM) will host a technical workshop on *Recruitment: theory, estimation, and application in fishery stock assessment models* in Miami, FL, USA, October 30th-November 3rd, 2017.

The recruitment workshop is the fourth in a series organized by CAPAM as part of its Good Practices in Stock Assessment Modeling Program for improving fishery stock assessments. The workshop is sponsored by NOAA, the International Seafood Sustainability Foundation, and the University of Miami.

The primary goal of the workshop is to provide advice and guidance on practices for modeling recruitment in fishery assessments. The focus is on model specification, parameter estimation, and management consequences. Presentations that cover species specific biological studies or recruitment estimates will not be considered, but broad reviews on these topics are encouraged. The 5-day forum will include an interactive modeling session, keynote and research presentations, and focused discussions. Major topics, the chair, and invited speakers include:

Chair – Clay Porch (SEFSC-NOAA)
- Underlying Biological processes - Ken Rose (LSU)
- The stock-recruitment relationship - Marc Mangel (UCSC)
- Temporal variation in recruitment - Mark Maunder (IATTC)
- Spatial and other considerations - Andre Punt (UW)
- Management implications of modelling recruitment - Eva Plaganyi (CSIRO)
- Modelling recruitment in tuna stock assessments – CSIRO (C. Davies/R. Hillary/D. Kolody)
- Modeling recruitment in stock assessments using the Stock Synthesis modeling framework (Ian Taylor). A half-day session held on Monday (October 30th) afternoon.

Scientists are encouraged to present work from both ongoing research efforts, as well as completed studies. Attendees who plan to present research need to submit a presentation title and abstract (one-page maximum) by August 31st, 2017 (earlier submission is encouraged). A special issue in the journal *Fisheries Research* is planned for papers developed from the workshop. Presentations will have a 20-minute maximum and 10-minute question period. For general information concerning the overall workshop, please contact SEFSC staff (rishi.sharma@noaa.gov), and also visit the CAPAM website (www.CAPAMresearch.org) for updated information.

Location: RSMAS (University of Miami) & Southeast Fisheries Science Center, Miami, FL 33149, USA.
Steepness believers
Other ideas
Steepness $< 1$ makes assessment hard

- Total catch history model
- If $h < 1$ only a very small range of $R_0$s work
- Convergence issues
Alternatives to precautionary reference points that include uncertainty about steepness

• Lower bound of the steepness confidence interval
  – Need to simulation test for bias

• Using the precautionary proxy reference point to generate a prior for steepness
  – See Martell’s method
  – Information in data pulls h away from conservative value

• Lower value for h may mean short term loss in yield even if equilibrium yield is similar

• Mis-specifying steepness may bias biomass estimates used in decision rules
Natural mortality may be more important: summer flounder

- No flat yield curve
- Very influential for exploitation rates

<table>
<thead>
<tr>
<th>Table 1</th>
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<tr>
<td>Estimates of reference points using different values for ( h, K (\text{y}^{-1}) ), length at age 6 (( L_2, \text{cm} )) and ( M (\text{y}^{-1}) ). Biological parameter values refer to females, and males are a fixed multiplicative offset from females (male = female ( \times ) offset). The default values are female ( M = 0.2 \text{y}^{-1} ), male ( M = 0.3 \text{y}^{-1} ), female ( K = 0.2 \text{y}^{-1} ), male ( K = 0.21 \text{y}^{-1} ).</td>
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<td>(a) ( h )</td>
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<tr>
<td>( S_{\text{MSY}/S_0} )</td>
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<td>( \text{MSY}/B_{\text{MSY}} )</td>
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<td>(b) ( h = 1.0 ) ( K )</td>
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<td>(c) ( h = 0.8 ) ( K )</td>
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<td>( \text{MSY}/B_{\text{MSY}} )</td>
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<tr>
<td>( \text{SPR}_{\text{MSY}}/\text{SPR}_0 )</td>
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</table>
Size of the fish caught may be more important

• It may be easier to improve yield by increasing the yield per recruit by catching larger fish than estimating steepness to optimize exploitation rates
Dynamic reference points

- Recruitment temporal variability
- Selectivity temporal variability
Dynamic reference points: recruitment temporal variability in bigeye tuna

Fig. 2. Trajectory of the spawning biomass of a simulated population of bigeye tuna that was unexploited (dashed line) and that predicted by the stock assessment model (solid line). The shaded areas between the two lines show the portions of the impact attributed to each fishing method.

Dynamic reference points: selectivity temporal variability in bigeye tuna
Another reason not to use surplus production models

- Interpretation of CPUE data needs recruitment estimates
- Illustrated using the production model diagnostic

- Standard stock-recruitment theory does not make sense
- Density dependence is not a constant continuous process, it happens in stages
- Survival as a function of spawning biomass
- Spatial argument
- There is no stock-recruitment relationship for most highly fecund species
- If there is a relationship it probably occurs at biomass levels where other factors are more important
- And you can't estimate it anyway
- Growth is relatively well known (if you are not using it to fit to length comps)
- So what we need for assessment and management is natural mortality and absolute abundance, which are both poorly determined
- Priority should be given to estimating these two parameters
- Under a good selectivity strategy, what is $S_{\text{maxypr}}/S_0$?
• Does including steepness in estimation model change estimates, or is it just for projections and reference points
• Is spawning biomass measurement important for stock-recruitment or just for reference point calculations
• Jiangfengs better to under assume
• Regime shifts in recruitment
• With S-R small changes in R0 cause the model to crash if there is a stock-recruitment relationship and the population is highly depleted.
What we need

• A test to determine between recruitment influencing spawning biomass and spawning biomass determining recruitment.
Abstract

- Specification of the stock-recruitment relationship in fisheries stock assessment models is like the quest for the holy grail as depicted in modern literature. Everyone believes it exists, but no one can find it amongst the noise in the data. Strong leads to its existence, which are pursued without caution, turn out to be just quirks in the data. If you get a glimpse, it is just an aberration that disappears as quickly as it appears as more data are collected or model assumptions are changed. However, the rewards are so high in terms of both academic achievement and management consequences, that we relentlessly continue the search ignoring everything else. Pieces of evidence, no matter how unreliable, are put together in meta-analysis, propagating the same deception, but with more power. The theory that directs our search is flawed and in reality there is only a weak relationship between recruitment and stock size for most highly fecund species. The stock-recruitment relationship is probably not important unless the population gets to such low levels that other factors should have already triggered management action. Therefore, research should focus rather on improving estimates of absolute abundance and natural mortality, and management strategies that are robust to uncertainty in these two quantities.
Reference points depend on steepness: summer flounder

Table 1
Estimates of reference points using different values for \( h, K \) (y\(^{-1}\)), length at age 6 (\( L_2 \), cm) and \( M \) (y\(^{-1}\)). Biological parameter values refer to females, and males are a fixed multiplicative offset from females (male = female \( \times \) offset). The default values are female \( M = 0.2 \) y\(^{-1}\), male \( M = 0.3 \) y\(^{-1}\), female \( K = 0.2 \) y\(^{-1}\), male \( K = 0.21 \) y\(^{-1}\).

<table>
<thead>
<tr>
<th></th>
<th>( h )</th>
<th>( S_{MSY}/S_0 )</th>
<th>( MSY/B_{MSY} )</th>
<th>( SPR_{MSY}/SPR_0 )</th>
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<tbody>
<tr>
<td>(a)</td>
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<td>0.12</td>
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<td>0.9</td>
<td>0.20</td>
<td>0.25</td>
<td>0.22</td>
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<tr>
<td></td>
<td>1.0</td>
<td>0.11</td>
<td>0.50</td>
<td>0.11</td>
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</table>

Sensitivity of sock assessments

• Does steepness influence estimates of depletion?
• Composition data = $F = YPR$ depletion
• CPUE decline due to $C = B$; $C/B = F = YPR$ depletion
• $S-R =$ recruitment reduction
• Relative index for full catch history time series = depletion is fixed.
• Total catch history model versus starting from exploited population size.
Age at first entry into the fishery = 4 = age at maturity???
Conclusions

– Stock-recruitment steepness, mortality based loss in YPR, and selectivity based loss in YPR can all have about the same impact on yield

– Sensitivity to other parameters greater at high steepness

– The relative impact of Stock-recruitment steepness interacts with the age at first entry into the fishery

– Loss due to YPR occurs at low fishing mortalities and loss due to S-R occurs at high fishing mortalities

– Stock-recruitment may or may not have an impact on assessment results dependent on the application and the quantity of interest
Conclusions

• Stock-recruitment relationships are much more complex than standard theory
• Density dependence may occur at much lower abundances than the unfished biomass
• The mechanisms for strong density dependence are unclear
Conclusions

• Annual recruitment variation drives fluctuations in spawning biomass
• Regime shifts in recruitment drive the apparent stock-recruitment relationship
• Autocorrelation/regime shifts in recruitment relative to age at maturity and maximum age will determine apparent stock-recruitment relationships
Conclusions

• The stock-recruitment curve, if it exists, is important for management

• Assuming a lower steepness may not reduce long term yield by much, but may cause short term losses

• The assumption of steepness influences both estimates of depletion and the reference points
Conclusions

• Even in simulated conditions estimation is problematic
• Estimates are probably an artifact of “quirks” in the data (e.g. regime shifts)
• In reality, we probably can’t estimate the stock-recruitment relationship