Carrying Capacity
What Is It And Why Is It Important?

Photo from NOAA Science Center
Definition

Carrying Capacity = Number of individuals or biomass the resources of a given area can support usually through the most unfavorable period of the year.

- Maximum Environmental Load
- Linked to Tolerance Limits and Limiting Factors (aka ecological concerns)
- Habitat Capacity (C)
Definition

Population Capacity = Maximum equilibrium population size (K) estimated using population models such as the logistic equation or some stock-recruitment models.

- Defines an upper limit to population growth as density increases.
Population Regulation

- **Density Independent Factors** = Population growth is not affected by population density; population persistence is explained by unpredictable environmental variability (Andrewartha and Birch).

- **Density Dependent Regulation** = Population growth is affected by mechanisms whose effectiveness increases as population size increases (Nicholson, Lack, and Elton).
Evidence of Density Dependence

- Plot of population size and population growth rate (or surrogates such as survival rates, natality, productivity, recruits, individual growth rates, movement).
- There is a negative relationship between population size and growth rate.
Methods for Estimating Carrying Capacity

- Time series analysis
- Stock-recruitment modeling
- Habitat modeling
Time Series Analysis

- Plot population size over time.
- Logistic function

\[ N_t = \frac{K}{1 + [(K - N_0)/N_0]e^{-rt}} \]

\[ \frac{dN}{dt} = rN \left( 1 - \frac{N}{K} \right) \]
Stock-Recruitment Modeling

- Fit Ricker, Beverton-Holt, and Smooth Hockey Stick models to stock (spawners) and recruitment (fry, parr, smolts) data.

Ricker:
\[ E(R) = \alpha S e^{-\beta S} \]
\[ K = \left(\frac{\alpha}{\beta}\right) e^{-1} \]

Beverton-Holt:
\[ E(R) = \frac{\alpha S}{\beta + S} \]
\[ \alpha = K \]

Smooth Hockey Stick:
\[ E(R) = R_\infty \left(1 - e^{-\left(\frac{\alpha}{R_\infty}\right)S}\right) \]
\[ R_\infty = K \]
Habitat Models

- Habitat capacity can be estimated as the product of habitat area and fish/habitat relationships.
- Percent Habitat Saturation Model (PHS)
  \[ PHS = 100 \times \sum (D_i \times T_i) \]
- Others include Net Rate of Energy Intake (NREI) models, Habitat Suitability (HSI) models, and Quantile Regression Forest (QRF) models.

ISEMP/CHaMP (2015)
Assumptions

- Assume we can define a population unambiguously.
- Assume that we can measure population size accurately.
- Assume that we have a biologically relevant time-step over which to measure population growth rate.
- Assume a uniformity of nature.
Chiwawa Spring Chinook
Stock-Recruitment Models

- Stock-recruitment functions were fit successfully to parr and yearling smolt data.
# Chiwawa Spring Chinook Stock-Recruitment Models

## Parr:

<table>
<thead>
<tr>
<th>Model</th>
<th>Parameter</th>
<th>Population capacity (K)</th>
<th>Productivity</th>
<th>Stock size</th>
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<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td></td>
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<tr>
<td>Ricker</td>
<td>271.37</td>
<td>0.0009</td>
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<td>Hockey Stick</td>
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<td>144,927.36</td>
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</table>

## Smolt:

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<th>Parameter</th>
<th>Population capacity (K)</th>
<th>Productivity</th>
<th>Stock size</th>
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<tbody>
<tr>
<td></td>
<td>A</td>
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<tr>
<td>Ricker</td>
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<tr>
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Chiwawa Spring Chinook
Ricker Model: Quantile Regression

- Selecting 90% Reference Interval:
  - Carrying Capacity (K)
    90,557 vs 50,572
  - Stock Size
    833 vs 917
Chiwawa Spring Chinook
Habitat Model: Quantile Regression Forest Model
So What Do We Do With It?
Couples Counseling

- Used in life-cycle models to predict effects of different recovery scenarios.
- Used by hatchery managers to inform supplementation programs.
- Used by harvest managers to set appropriate escapement and harvest levels.
- Used by restoration practitioners to guide restoration actions.