The Role of Population Dynamics in Recovery Planning for Atlantic Salmon Populations

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Units: 100’s of Fish
What is Population Dynamics?

• Population dynamics is the sub-discipline of ecology dealing with factors that influence population growth.

• Ideal for evaluating questions like:
  – Is a population expected to extirpate or recover?
  – How much of a change in a life history parameter is required to recover a population?
  – How long will it take a population to recover?
  – Will a proposed recovery action be sufficient to recover a population or will other interventions be required?
Overview

• Population dynamics and models for Atlantic Salmon

• Applications:
  – Past and present dynamics and population viability
  – Implications for stocking programs
  – Differences in dynamics among DU’s and populations
  – Evaluating linkages between survival and environmental conditions

• Summary
Why Use Models?

• Models are mathematical or conceptual representations of a system that allow us to explore how the system will respond to changes in the inputs.
• Humans use models all the time.
• A population model can be used to explore how a population will increase or decrease in size with changes in survival rates, carrying capacity of watersheds, proportions maturing as 1SW or 2SW salmon, etc.
• Population models are always simplified representations of life, which is very complicated.
• Models are not right or wrong, just more useful or less useful.
Conceptual Framework: Equilibrium Analysis

• Begin by dividing the life cycle into two parts
  – eggs to smolt (assumed density dependent)
  – smolt to eggs (lifetime egg production: assumed density independent)

• Equilibrium population size occurs where the number of smolt/egg equals the inverse of number of eggs/smolt

• The equilibrium is an attractor towards which the population will move if the life history parameters do not change

• Recovery planning is about choosing actions that will move this attractor to a level above the recovery target
**Egg to Smolt Survival**

- **Beverton-Holt Stock-Recruitment Model**
- 2 Parameters:
  - slope at the origin
  - asymptotic recruitment level (carrying capacity)
- Further detail possible
Parameters:
- survival at sea
- post-spawning survival
- sex ratio
- fecundity
- maturity probabilities

Lifetime Egg per Smolt Production

Lifetime Egg Production

Egg Production (Millions)

Thousands of Smolt

increasing survival

decreasing survival
Number of Eggs

Number of Smolts

Carrying Capacity

Slope at origin

Increasing or decreasing habitat quantity

Increasing or decreasing habitat quality

Increasing smolt-to-adult survival, fecundity or number of spawnings

Decreasing smolt-to-adult survival, fecundity or number of spawnings

Equilibrium Points

Decreasing smolt-to-adult survival

Equilibrium Points

Number of Smolts

Number of Eggs
Equilibrium Points

C) Decreasing smolt-to-adult survival

Equilibrium Points

Number of Smolts

Number of Eggs

Increasing or decreasing habitat quantity

Increasing or decreasing habitat quality

Increasing smolt-to-adult survival, fecundity or number of spawnings

Decreasing smolt-to-adult survival, fecundity or number of spawnings

Number of Smolts

Number of Eggs

Equilibrium Points
Equilibrium Points as Attractors

- Increasing or decreasing habitat quantity:
  - Carrying Capacity
- Increasing or decreasing habitat quality:
  - Number of Eggs
  - Number of Smolts

- Increasing smolt-to-adult survival, fecundity or number of spawnings:
  - Number of Eggs
  - Number of Smolts

- Decreasing smolt-to-adult survival:
  - Number of Eggs
  - Number of Smolts

Equilibrium Points

C) Decreasing smolt-to-adult survival

Equilibrium Points

Decreasing smolt-to-adult survival
Changes in Dynamics of Populations from Past to Present

• For recovery planning, it is of interest to know how the dynamics of a population has changed

• In the Maritimes Region, changes in at-sea survival has been a focus

• Little information to quantify these changes
  – Wild smolt monitoring programs only extend back to the mid-1990’s (Big Salmon River is an exception)
  – Most longer term inferences are from hatchery return rate time series

• Solution: Model the available data to evaluate past and present dynamics and quantify these changes
Example: LaHave River Atlantic Salmon

- Population above Morgan’s Falls (at least a partial barrier to upstream migration)

- Abundance increased rapidly in the 70’s and 80’s due to:
  - Installation of a fish ladder
  - Stocking
  - Commercial fishery closures

- Declining trend in abundance since the mid-80’s

- Acidification is not as significant as in some other rivers
LaHave River: Smolt-to-Adult Return Rates

- 1SW return rates declined from an average of 7.3% in the 1980’s to 2.2% in the 2000’s
- 2SW return rates declined from an average of 0.7% in the 1980’s to 0.3% in the 2000’s
- Post-spawning survival has decreased from an average of 0.31 in the 1980’s to 0.20 in the 2000’s
LaHave River Atlantic Salmon Population Dynamics: Past and Present

<table>
<thead>
<tr>
<th></th>
<th>1980's</th>
<th>2000's</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min.</td>
<td>Mean</td>
</tr>
<tr>
<td>Max. Egg-Smolt Survival</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td>Carrying Capacity (smolts)</td>
<td>147,700</td>
<td></td>
</tr>
<tr>
<td>Lifetime EPS</td>
<td>87</td>
<td><strong>218</strong></td>
</tr>
<tr>
<td>Max. Lifetime Reprod. Rate</td>
<td>1.44</td>
<td><strong>3.59</strong></td>
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</table>
LaHave River
Equilibrium Analyses

- Equilibrium occurs where the rate at which eggs produce smolts equals the rate at which smolts produce eggs throughout their lives.

<table>
<thead>
<tr>
<th></th>
<th>1980s</th>
<th>2000s</th>
</tr>
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<tbody>
<tr>
<td>mean</td>
<td>23.1</td>
<td>0</td>
</tr>
<tr>
<td>min</td>
<td>3.9</td>
<td>0</td>
</tr>
<tr>
<td>max</td>
<td>63.3</td>
<td>4.4</td>
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</table>
Evaluating Stocking Effectiveness with a Model

- Equilibrium shown in red; starting population in blue
- Stock 20,000 smolts/year (green lines)
- Assume no genetic effects of stocking
- Assume survival of wild and stocked smolts is the same
- Population grows to a new equilibrium of about 60% the CR

LaHave River: 2000's
Evaluating Stocking Effectiveness

- If stocking ceases, the population rapidly returns to its original equilibrium
- The underlying dynamics of the population are unchanged
- Abundance increases are less if survival of stocked smolts is lower
Fitness Effects

- Big Salmon River population dynamics assumed
- Smolts are collected as they leave river, raised to adults and bred in captivity
- Fitness effects modelled using the breeders equation
- Effects depend on the fitness decline per generation and heritability
- Effects only evident after a few generations

Bowlby and Gibson. 2011. Ecological Applications
Stocking Evaluation Summary

• A hatchery program alone is not a recovery program per se
  – Can mask issues with the population
  – The numbers alone don’t work out for many populations
  – Genetic effects may lead to fitness reductions

• Hatchery programs:
  – Do have a role in preventing extirpations
  – May have a role in reducing time to recovery if threats to populations are addressed
Comparison of Dynamics of Southern Upland and Outer Bay of Fundy Salmon Populations

- Population dynamics models developed for two populations in the Southern Upland and two in the Outer Bay of Fundy

- **Southern Upland:**
  - Lahave River (above Morgans Falls)
  - St. Mary’s River (West Branch)

- **Outer Bay of Fundy**
  - Nashwaak River
  - Tobique River

- Abundance is in decline in all 4 rivers
Comparison of Smolt-to-Adult Return Rates for 3 Populations

- Return rates are currently lowest for the St. Mary’s (West Br.) population and highest for the Nashwaak population
- Little long term change for the Nashwaak population in 1SW return rates
Comparison of Freshwater Production Curves for 4 Populations

- Both carrying capacity and max. egg-smolt survival is highest in the St. Mary’s followed by the LaHave
- Freshwater production appears quite low in Nashwaak and Tobique
- Whether FW production in the St. Mary’s and LaHave is also low is unclear
# Comparison of the Dynamics of Six Salmon Populations

<table>
<thead>
<tr>
<th>Population</th>
<th>LaHave (above Morgans Falls)</th>
<th>St. Mary's (West. Br.)</th>
<th>Nashwaak</th>
<th>Tobique</th>
<th>Middle</th>
<th>Baddeck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. egg-to-smolt survival</td>
<td>0.017</td>
<td>0.034</td>
<td>0.007</td>
<td>0.005</td>
<td></td>
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<tr>
<td>Smolt carrying capacity (number per 100 m² of habitat)</td>
<td>4.6</td>
<td>4.8</td>
<td>1.8</td>
<td>0.3</td>
<td></td>
<td></td>
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<tr>
<td>1SW return rate (%)</td>
<td>2.2</td>
<td>1.2</td>
<td>4.95</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2SW return rate (%)</td>
<td>0.3</td>
<td>0.1</td>
<td>1.29</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Lifetime egg production per smolt</td>
<td>63</td>
<td>30</td>
<td>151</td>
<td>83*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. lifetime reprod. rate (spawners/spawner)</td>
<td>0.84</td>
<td>1.01</td>
<td>1.13</td>
<td>0.41</td>
<td>3.22</td>
<td>1.61</td>
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<tr>
<td>Past max. lifetime reprod. rate</td>
<td>2.78</td>
<td>3.62</td>
<td>2.49</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
Comparison of Dynamics Summary

• Abundance declines similar for all four populations but the dynamics are very different

• Southern Upland:
  – Both populations have very low at-sea survival with the compounding effects of potentially low freshwater productivity

• Outer Bay of Fundy:
  – Both populations have quite low freshwater productivity with the compounding effects of low at-sea survival
  – Tobique River has the added issue of reduced survival of smolts due to hydro-electric development

• All are predicted to extirpate in the absence of human intervention or an increase in survival for some other reason (the Nashwaak more slowly)
LaHave River: Repeat Spawning Dynamics

- Frequency of repeat spawning has decreased
- 1\textsuperscript{st} year mortality trended upward through time
- 2\textsuperscript{nd} year mortality did not show a trend but was correlated with the NAOI
- 1\textsuperscript{st} year mortality may be occurring in freshwater or near shore

Investigating Hypotheses about Declines in At-Sea Survival for IBoF Salmon

- Developed a model to derive a mortality rate time series
- Compiled a set of 84 indices representative of:
  - Environmental conditions
  - Community changes
  - Human activities
- Few indices showed long-term increases similar to the mortality time series

Perspectives

• Useful for evaluating the effects of addressing well-studied threats (river acidification, fishing, fish passage, habitat loss)

• Not as useful for less well-studied threats (urbanization, agriculture, invasive species) because we can’t link recovery actions directly to changes in life history parameters

• Population models nearly always include an assumption that the near future will be similar to the recent past
  – Can’t be known \textit{a priori}

• Do provide a logical test of our belief systems
  – In recovery planning, they can be used to help us determine the consequences of various courses of action, and in that way are use as a guide