Methods for Evaluating the Biological Success of Restoration: Space, Time, and Virtual Animals

Bret Harvey
USFS Redwood Sciences Lab
Arcata CA 95521 USA
bch3@humboldt.edu

Alternative titles...

The Biological Success of Restoration: Practitioners Can Provide Evidence

The Biological Success of Restoration: Can Anybody Provide Evidence?
Objective: Provide some suggestions for addressing the biological success of restoration efforts, given the challenges...

• Biological parameters vary tremendously: e.g. “You cannot step twice into the same river.” (Heraclitus)

• Biological measurements are costly and time consuming to obtain: “There’s no money for monitoring” (everybody else)

Part I: The challenges of SPATIAL VARIABILITY and SCALE, an example:

Stream Ecosystem Response to Increased Light and Salmon Carcass

Introduction

a collaborative project by the California Cooperative Fishery Research Unit, Green Diamond Resource Co. and the U.S.F.S. Redwood Sciences Lab
Objective:
To measure the effects of increased light and nutrients from salmon carcasses on:
- growth and abundance of juvenile salmonids
- the structure of stream food webs

(Heraclitus: “Corpses should be thrown out quicker than dung.”)

Study Sites
*SF Rowdy Savoy
Little Mill
*Peacock
*Tarup
Tectah

* Received carcasses
100-m-long study reaches

200+ m buffer between reaches

The original experimental design, a “split-plot”

- Canopy removal
- Carcass addition

buffer
Tectah Creek, control canopy
Change in biomass after manipulation (grams m⁻²)

### Carcass treatment

<table>
<thead>
<tr>
<th>Date</th>
<th>Control</th>
<th>Carcasses added</th>
</tr>
</thead>
<tbody>
<tr>
<td>June02</td>
<td>-4</td>
<td>-3</td>
</tr>
<tr>
<td>Oct02</td>
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<td>-1</td>
</tr>
<tr>
<td>June03</td>
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<td>0</td>
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<tr>
<td>Oct03</td>
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<td>1</td>
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### Canopy removed

<table>
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<tr>
<th>Carcass treatment</th>
<th>None</th>
<th>Added</th>
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</thead>
<tbody>
<tr>
<td>Change in biomass (g · m⁻²)</td>
<td>0</td>
<td>0</td>
</tr>
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</table>

### Carcass added

<table>
<thead>
<tr>
<th>Carcass treatment</th>
<th>None</th>
<th>Added</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in biomass (g · m⁻²)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
A key difference between tests of the carcass and canopy effects:

- Carcass effect tested with an error term that reflects variation among streams

- Canopy effect tested with an error term that reflects variation among streams in their influence on the canopy effect
Consequently:

• Tests for differences between canopy treatments: 4 – 6X more powerful than tests of the carcass effect
The new experimental design

Canopy removal
Carcass addition

Change in biomass between reaches (Lower - upper, g · m^-2)

Spring Fall
Two common relationships with spatial scale?

- Increasing spatial scale
- Increasing ability to detect differences (variation, replication)
- Increasing biological significance (consider population-level effects)

Part II: Emphasis on TIME…

### Table

<table>
<thead>
<tr>
<th>Stream</th>
<th>Area</th>
<th>Length</th>
<th>Length treated</th>
<th>Width</th>
<th>Gradient</th>
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<tr>
<td>EF Lobster</td>
<td>14.2</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
<td>4.0</td>
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<td>Upper Lobster</td>
<td>12.4</td>
<td>4.7</td>
<td>3.2</td>
<td>3.2</td>
<td>2.6</td>
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<tr>
<td>Moon</td>
<td>13.2</td>
<td>3.8</td>
<td>3.6</td>
<td>1.8</td>
<td></td>
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<tr>
<td>East</td>
<td>17.5</td>
<td>5.0</td>
<td>2.4</td>
<td>4.0</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Upper Lobster: 23 dams and 8 alcoves in 3.2 km
East Creek: 29 dam pools and 13 alcoves in 2.4 km
Basic approach: compare the relationship between two watersheds before and after one of them is treated

Study covered 8 years

Measured: summer populations, outmigrants, and overwinter survival

<table>
<thead>
<tr>
<th>Year</th>
<th>Smolt Population</th>
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<tr>
<td>1986</td>
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<td>1988</td>
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<td>1992</td>
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<td>1994</td>
<td>8000</td>
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</table>

Alsea

Smolt Population

Year


Treatment
Reference
15

Nestucca

Year

Smolt Population

0 500 1000 1500 2000 2500 3000


1+ Summer Pop.

Alsea Steelhead

Treatment
Reference

0 200 400 600 800 1000

One conclusion about TIME: Before-after, control-impact designs can be useful in measuring biological responses to restoration

- Strong temporal covariation is the key to selecting controls (detailed site-matching may not be necessary)

- Restoration projects often have longer “start-up” times than anticipated...
Finally: Estimating biological consequences of restoration with virtual animals?

A Spatially Explicit, Individual-based Model for Stream Trout

IBMs for Restoration Assessment?

• Useful in predicting the consequences of restoration activities and prioritizing alternatives

• IBMs can easily represent *cumulative effects* of multiple factors affected by restoration: temperature, channel morphology, turbidity

• IBMs produce outputs that are directly relevant to management
Stream Trout Model

**Habitat:**
- Water depths and velocities = $f(\text{flow})$
- Temperature
- Turbidity
- Food availability

**Fish:**
- Habitat selection (movement)
- Feeding and growth
- Mortality
- Spawning, incubation
Stream trout model: characteristics of habitat cells:

- Depths and velocities that depend on streamflow
- Distance to hiding cover
- Velocity shelters
- Spawning gravel

Habitat Selection

- Moving to new habitat is the primary way trout adapt to changes in conditions (flow, temperature, etc.)

- Model fish:
  - Move to the best nearby habitat available each day
  - Select the habitat that maximizes the probability of survival over a 90-d time horizon
Feeding & Growth

• Food intake depends on:
  – Fish size
  – Cell velocity & depth
  – Competition
    Smaller fish in each cell only get food that bigger fish don’t eat

• Growth is calculated using a bioenergetics model

Survival

– Depends on habitat variables: depth, velocity, hiding cover
– Depends on fish length, weight
– Mechanisms:
  • Poor condition (starvation)
  • Terrestrial predation (birds, otters)
  • Aquatic predation (adult trout)
  • Exhaustion at very high velocities
  • Stranding at very low depths
  • Scour
Individual-based Model
Data Requirements

- Stream reach hydraulic modeling very similar to PHABSIM except: more transects, cells selected using ecological criteria
- Daily flow, temperature, turbidity inputs
- One or several fish censuses for initialization, calibration
- Some understanding of what predators are important
Example Validation Studies: Habitat Selection

• We demonstrated the IBM’s ability to reproduce how real trout change habitat in response to:
  – Major flow changes
  – Interspecific competition
  – Predation levels
  – Temperature and season
  – Food availability


Example Validation Studies: Population Dynamics

• We demonstrated the IBM’s ability to reproduce population-level dynamics observed in real trout:
  – A realistic “self-thinning” relation between biomass and abundance
  – Negative relations between population density and trout size
  – Effects of habitat complexity on population structure
Potential applications…

When restoration results in:

- Altered turbidity or temperature regimes
- Greater habitat complexity
- Fewer barriers to movement
- Changes in scour depths
What consequences does an increase in turbidity have for fish in the model?

- Drift feeding efficiency declines because of a decrease in reactive distance
- Predation risk declines because fish are harder to detect by birds and mammals
Review: assessing the biological effects of restoration

• Analyses at large spatial scales are challenging because of high variability

• Selection of spatial scale influenced by:
  – the scale of the expected effects
  – the scale of the project
  – relevance to population dynamics
  – …
Review: assessing the biological effects of restoration

• Before-after, control-impact designs can address temporal variation, lessen the significance of spatial variation

• Individual-based modeling approaches may be useful in some restoration assessments (particularly in forecasting restoration effects)