Stream and Watershed Restoration: guidance for restoring riverine processes and fish habitat

Philip Roni
Watershed Sciences Lab
Cramer Fish Sciences
and
School of Aquatic and Fishery Sciences
University of Washington
Seattle, WA
River Restoration is a Growth Industry

• How many dollars annually?

• Ecosystem restoration initiatives
  – Everglades
  – Chesapeake Bay
  – Great Lakes
  – Puget Sound
  – Pacific Coastal Salmon Recovery
  – & others
<table>
<thead>
<tr>
<th>What is Restoration?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Protection</strong></td>
</tr>
<tr>
<td><strong>Restoration</strong></td>
</tr>
<tr>
<td><strong>Rehabilitation</strong></td>
</tr>
<tr>
<td><strong>Improvement</strong></td>
</tr>
<tr>
<td><strong>Reclamation</strong></td>
</tr>
<tr>
<td><strong>Mitigation/Creation</strong></td>
</tr>
</tbody>
</table>

* Also called habitat enhancement
<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protection</td>
<td>Protect existing high quality habitats</td>
</tr>
<tr>
<td>Restoration</td>
<td>To return an aquatic system or habitat to its original, undisturbed state</td>
</tr>
<tr>
<td>Rehabilitation</td>
<td>To restore or to improve some aspects of an ecosystem but not fully restore all components</td>
</tr>
<tr>
<td>Improvement</td>
<td>To enhance quality of habitat but not necessarily restore all functions</td>
</tr>
<tr>
<td>Reclamation</td>
<td>To attempt return an area to previous state but not necessarily restore all functions</td>
</tr>
<tr>
<td>Mitigation/Creation</td>
<td>Actions taken to compensate for adverse impacts of construction etc.</td>
</tr>
</tbody>
</table>

* Also called habitat enhancement
Process-Based Restoration

**Landscape**
Geology, Vegetation, Climate

**Natural Processes**
Transport of water, sediment, nutrients, organic material

**Habitat conditions**
Channel morphology, pools, riffles, glides, and complexity

**Biotic response**
Flora and fauna abundance, diversity, etc.

**Human Impacts**

**Restoration**

**Rehabilitation**
Reconnect Isolated Habitats
Floodplain Restoration
Roads, Hydrology and Sediment Delivery

Urban Roads

Forest Roads
Riparian Restoration Techniques
Not All Projects Are Successful
Some common problems

- Inadequate habitat assessments
- Ecosystem processes
- Limiting factors
- Design of projects
- Prioritization of projects
- Monitoring and evaluation
- Total amount of restoration
Key Steps in Restoration

1. Set watershed restoration goals
2. Assess & inventory watershed conditions
3. Identify problems & potential actions
4. Review & select appropriate restoration techniques
5. Prioritize restoration actions
6. Design restoration project & monitoring
7. Implement restorations & monitoring
8. Publish results & modify goals

Adaptive management
Goals & Objectives

- For restoration
- For assessment
- For restoration design
- For prioritization
- For monitoring & evaluation
Assessments – identifying problems & actions

- Historical habitat
- Current habitat
- Habitat loss
- Disrupted processes
  - Connectivity
  - Hydrology
  - Riparian
  - Sediment
  - Nutrients
- Causes of degradation
Assessments – data collection & analysis

• Remote Sensing

• Field Data Collection

• Analysis & Interpretation
Broad Scale - Land Use Impacts & Processes

A. Sediment supply

B. Hydrology

C. Riparian function

D. Floodplain function

E. Migration barriers

F. Impairment score

Skagit Basin, WA  Beechie et al. 2013
Reach Scale – local impairments and restoration opportunities

Fine Sediment
Riparian Cover
Grazing/Bank Erosion

Eden River, UK - Beechie et al. 2013
Biological Assessment – IBI Example

A

B

Legend:
1. Not polluted or altered
2. Moderately altered or polluted
3. Polluted or altered
4. Very polluted or altered
5. Heavily polluted or altered
Limiting Factors Analysis to Identify Restoration

Spawning habitat

Summer rearing

Winter rearing

Smolt (juvenile migrants)

Photo by John McMillan
What Habitat is Limiting?

- Spawning
- Summer rearing
- Winter rearing

Coho smolts (juvenile migrants)

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Historical</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spawning</td>
<td>40,000</td>
<td>30,000</td>
</tr>
<tr>
<td>Summer rearing</td>
<td>25,000</td>
<td>20,000</td>
</tr>
<tr>
<td>Winter rearing</td>
<td>35,000</td>
<td>15,000</td>
</tr>
</tbody>
</table>

G. Pess unpublished
Selecting Restoration Techniques

• Process-based restoration vs. improvement

• Effectiveness of different techniques

• Restoration and Climate change
## Time and Duration of Restoration

<table>
<thead>
<tr>
<th>Restoration action</th>
<th>Restores Processes</th>
<th>Years till response</th>
<th>Duration of action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrier removal</td>
<td>Yes</td>
<td>&lt;1</td>
<td>50+</td>
</tr>
<tr>
<td>Floodplain connectivity</td>
<td>Yes</td>
<td>&lt;1</td>
<td>50+</td>
</tr>
<tr>
<td>Restore in-stream flow</td>
<td>Yes</td>
<td>&lt;1</td>
<td>50+</td>
</tr>
<tr>
<td>Riparian planting</td>
<td>Yes</td>
<td>25-50</td>
<td>100+</td>
</tr>
<tr>
<td>Road removal</td>
<td>Yes</td>
<td>10-50</td>
<td>100+</td>
</tr>
<tr>
<td>*Instream habitat improvement</td>
<td>N</td>
<td>1-5</td>
<td>20-30</td>
</tr>
<tr>
<td>*Nutrient enrichment</td>
<td>N</td>
<td>&lt;1</td>
<td>?</td>
</tr>
</tbody>
</table>

* NEED TO BE COUPLED WITH PROCESS BASED RESTORATION

Roni et al. 2013
# Restoration Actions & Climate change

<table>
<thead>
<tr>
<th>Restoration action</th>
<th>Does Project Ameliorate -</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temperature increase</td>
<td>Low flow decrease</td>
<td>Peak flow increase</td>
</tr>
<tr>
<td>Barrier removal</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Floodplain connectivity</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Restore in-stream flow</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Riparian rehabilitation</td>
<td>Y</td>
<td>M</td>
<td>N</td>
</tr>
<tr>
<td>Road removal</td>
<td>M</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Instream habitat</td>
<td>M</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Nutrient enrichment</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>

Beechie et al. 2012
Beaver & Floodplain & Riparian Restoration

Beechie et al. 2008

~3 cm/yr

Pollock et al. 2007

10-40 cm/yr
Prioritization or Sequencing Restoration

• A variety of approaches
  – Project type
  – Location
  – Complex models
  – Multi-criteria scoring systems

Roni et al. 2013
## Prioritization – Common Approaches

<table>
<thead>
<tr>
<th>Technique</th>
<th>Length treated</th>
<th>Fish/yr</th>
<th>Cost</th>
<th>Cost/Fish</th>
<th># Species benefiting</th>
<th>Restores process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood placement</td>
<td>2 km</td>
<td>500</td>
<td>$100K</td>
<td>$200</td>
<td>2</td>
<td>no</td>
</tr>
<tr>
<td>Floodplain reconnection</td>
<td>1 km</td>
<td>5,000</td>
<td>$500K</td>
<td>$100</td>
<td>5</td>
<td>yes</td>
</tr>
<tr>
<td>Riparian planting</td>
<td>5 km</td>
<td>?</td>
<td>$10K</td>
<td>?</td>
<td>4</td>
<td>yes</td>
</tr>
<tr>
<td>Road removal</td>
<td>8 km</td>
<td>?</td>
<td>$750K</td>
<td>?</td>
<td>4</td>
<td>yes</td>
</tr>
</tbody>
</table>

Roni et al. 2002, Beechie et al. 2008
## Prioritization – Scoring System

<table>
<thead>
<tr>
<th>Technique</th>
<th>Length treated</th>
<th>Fish/yr</th>
<th>Cost</th>
<th>Cost/Fish</th>
<th># species</th>
<th>Restore process</th>
<th>Total score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood placement</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Floodplain reconnection</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>18</td>
</tr>
<tr>
<td>Riparian planting</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>22</td>
</tr>
<tr>
<td>Road removal</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>18</td>
</tr>
</tbody>
</table>

Score of 1 to 5 – five being highest score
<table>
<thead>
<tr>
<th>Proposed Restoration Project</th>
<th>Final Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reconnect isolated habitat Rkm 57</td>
<td>25</td>
</tr>
<tr>
<td>Remove Forest Road 37</td>
<td>22</td>
</tr>
<tr>
<td>Plant riparian Deer Creek Rkm 25</td>
<td>21</td>
</tr>
<tr>
<td>Wood Placement Clear Beaver Creek</td>
<td>17</td>
</tr>
<tr>
<td>Stanwood Levee Setback</td>
<td>17</td>
</tr>
<tr>
<td>Replace Impassible Culverts – Boulder River</td>
<td>17</td>
</tr>
<tr>
<td>Resurface 10 miles forest Road 37</td>
<td>16</td>
</tr>
<tr>
<td>Forest Glen Side Channel Reconnection</td>
<td>15</td>
</tr>
<tr>
<td>McDonald’s farm conservation easement</td>
<td>14</td>
</tr>
<tr>
<td>Log Jam placement in Clear Fork</td>
<td>14</td>
</tr>
<tr>
<td>Wood placement in Urban streams</td>
<td>12</td>
</tr>
<tr>
<td>Bioengineering of South Fork Levee</td>
<td>11</td>
</tr>
<tr>
<td>Proposed Restoration Project</td>
<td>Final Score</td>
</tr>
<tr>
<td>-----------------------------------------------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Reconnect isolated habitat Rkm 57</td>
<td>25</td>
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<tr>
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<tr>
<td>Bioengineering of South Fork Levee</td>
<td>11</td>
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</tbody>
</table>
Need to Define Scores

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Score (1 to 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Restores processes</strong></td>
<td><strong>1</strong> Restores neither processes nor habitat</td>
</tr>
<tr>
<td></td>
<td><strong>2</strong> Restores physical habitat</td>
</tr>
<tr>
<td>(Based on Roni et al. 2013b)</td>
<td><strong>3</strong> Restores one or two processes</td>
</tr>
<tr>
<td></td>
<td><strong>4</strong> Restores more than two processes</td>
</tr>
<tr>
<td></td>
<td><strong>5</strong> Restores process and habitat or protects fully functioning habitat</td>
</tr>
<tr>
<td><strong>Site access &amp; logistics</strong></td>
<td><strong>1</strong> Helicopter only (no roads or staging)</td>
</tr>
<tr>
<td></td>
<td><strong>2</strong> No roads within 0.5 km of site, but staging area if equipment/supplies/LWD brought in by helicopter</td>
</tr>
<tr>
<td></td>
<td><strong>3</strong> Roads within 0.5 km of site. No staging area.</td>
</tr>
<tr>
<td></td>
<td><strong>4</strong> Roads within 0.5 km of site. Good staging area.</td>
</tr>
<tr>
<td></td>
<td><strong>5</strong> Roads and staging area adjacent to site</td>
</tr>
</tbody>
</table>
Prioritization Can Occur at Multiple Levels

Regional prioritization of watersheds

Regional prioritization of projects

Prioritization of projects within a watershed

Roni, Beechie, Schmutz & Muhar 2013
Prioritizing Sub-Watersheds Examples

Williams et al. 2007 Trout Unlimited

Timm and Roni 2018
Prioritizing Barrier Removals Across a Basin - the Danube River Basin
Restoration Design Steps

• Planning
  – Problem Identification
  – Context & assessment
  – Project goals & objectives
  – Alternatives evaluation

• Project design

• Implementation

• Monitoring & Evaluation

RiverRAT – Design Tool http://www.restorationreview.com
Project Design and Watershed Processes

• Target root causes of degradation
• Tailor actions to local potential
• Match scale of action scale of problem
• Predict restoration outcomes
• Build uncertainty into design
• Design monitoring into project

“Additional evaluation studies on stream improvement, especially with reference to the effect on the abundance of fish, are still urgently needed.”

Clarence M. Tarzwell, U.S. Bureau of Fisheries, 1937
Steps for Designing a Effectiveness Monitoring Program

- Define project goals and objectives
- Define scale
- Define questions/hypotheses
- Determine monitoring design
- Spatial and temporal replication
- Select parameters
- Selecting sampling scheme/protocol
- Implement monitoring

Refine both management & future restoration projects
Key Questions or Hypotheses

Reach or Project Scale
• What is effect of project $x$ on local habitat conditions or fish?
• What is effect of project like $x$ on local habitat conditions or fish?

Watershed Scale
• What is effect of project $x$ on watershed conditions or a fish population?
• What is effect of a suite of projects on watershed conditions or a fish population?
Key Questions or Hypotheses

Reach or Project Scale

• What is effect of project like x on local habitat conditions or fish?

Watershed Scale

• What is effect of a suite of projects on watershed conditions or a population?
Experimental Designs

- Before-After (BA)
- Before-After Control-Impact (BACI)
- Multiple BACI
- Extensive Post-treatment (EPT or CI)
Wood Placement in Streams

- What is the average of effect of LWD placement on habitat and fish?
- Design Extensive post-treatment
- Scale - Reach scale (paired treat. and cont.)
- Replication – spatial n = 30
- Parameter – fish, habitat, macroinvertebrates
- Sampling - census of study reaches
Fish Response vs. Restoration Intensity

![Graph showing the relationship between change in pool area and change in lamprey #. The graph has a linear trend line with an $r^2 = 0.57$.](image-url)

- Change in pool area
- Change in lamprey #
# Strengths of Monitoring Designs

<table>
<thead>
<tr>
<th>Strength</th>
<th>BA</th>
<th>BACI</th>
<th>MBACI</th>
<th>EPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interannual variation</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Correlate to physical</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Broadly applicable results</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Length of monitoring</td>
<td>10+</td>
<td>10+</td>
<td>5+</td>
<td>1-3</td>
</tr>
<tr>
<td>Difficulty of implementation</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
</tbody>
</table>
When Selecting Parameters

- Linked to key question/hypothesis
- Change in measurable way linked to treatment
- Have limited/manageable variability
- Cost effective in space and time
# What to monitor for various actions?

<table>
<thead>
<tr>
<th>Restoration Technique</th>
<th>Habitat</th>
<th>Primary production</th>
<th>Inverts</th>
<th>Fish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Culvert/Passage</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Floodplain</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Riparian</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Sediment reduction</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>In-stream</td>
<td>X</td>
<td></td>
<td>?</td>
<td>X</td>
</tr>
<tr>
<td>Nutrients</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
Spatial and Temporal Replication

- How sites?
- How many years?

  5 years?  
  25 years?  
  50 years?
Estimating Sample Size

- Variance
- Effect size*
- $B = 0.80^*$
- $\alpha = 0.05^*$

* Determined by investigator (you!)
Wood Placement in Streams

- What is the average of effect of LWD placement on habitat and fish?
- Design Extensive post-treatment
- Scale - Reach scale (paired treat. and cont.)
- Replication – spatial  n = 30
- Parameter – fish, habitat, macroinvertebrates
- Sampling - census of study reaches
Post Treatment Design – Sample Size

- coho pre-smolt
- coho parr
- % pool
- invertebrates

Number of sites vs. Treatment/control
Common Sampling Schemes

- Census
- Simple random
- Systematic
- Stratified random
- Line transect
Key Questions or Hypotheses

Reach or Project Scale

• What is effect of project like x on local habitat conditions or fish?
  • Sample many projects

Watershed Scale

• What is effect of a suite of projects on watershed conditions or a population?
  • IMW
Watershed Scale vs. Reach Scale

- Watershed scale monitoring location
- Restoration site
Watershed-Scale Challenges

• Coordination of restoration, monitoring & other mgt. activities are critical to success!
Watershed-Scale Implementation Challenges?

- Design
- Coordination
- Implementation
- Analysis
- Reporting

Watershed Size

Less challenging

More challenging
Evaluating a Regional Restoration Program
How much restoration is needed?
## How Much Restoration Is Needed?

**Restoration Activities PCSRF 2000 to 2009**

<table>
<thead>
<tr>
<th>Metric or Restoration Activity</th>
<th>All PCSRF</th>
<th>Per Watershed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instream kilometers treated</td>
<td>1,413</td>
<td>3</td>
</tr>
<tr>
<td>Floodplain hectares treated</td>
<td>4,938</td>
<td>3</td>
</tr>
<tr>
<td>Barrier removal (km)</td>
<td>6,918</td>
<td>17</td>
</tr>
</tbody>
</table>
Mean Increase in Juvenile Migrants (smolts)

-0.30
-0.10
0.10
0.30
0.50
0.70
0.90

LWD Boulder weirs Logjams Floodplain Groundwater channels Barrier removal

Smolts per m or m²

Coho
Steelhead

Roni et al. 2010
# Restoration Actions Applied to Watershed

<table>
<thead>
<tr>
<th>Salmon Habitat</th>
<th>Restoration type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Streams/Rivers</td>
<td></td>
</tr>
<tr>
<td>small – inaccessible</td>
<td>Barrier removal</td>
</tr>
<tr>
<td>small - accessible</td>
<td>Wood (LWD) addition</td>
</tr>
<tr>
<td>medium</td>
<td>Boulder weirs</td>
</tr>
<tr>
<td>large</td>
<td>Logjams</td>
</tr>
<tr>
<td>Floodplain habitat</td>
<td></td>
</tr>
<tr>
<td>lost side channels</td>
<td>Groundwater channels</td>
</tr>
<tr>
<td>lost sloughs</td>
<td>Floodplain reconnection</td>
</tr>
</tbody>
</table>
Increase in Juvenile Salmon (smolts)
Scenario 1 – Restore All Habitat in a Watershed

Mean = 285,302

95% prediction interval

Estimated increase in coho salmon smolts

Roni et al. 2010
## Summary of Estimates in Model Watershed

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Coho Smolts (juvenile migrants)</th>
<th>Steelhead smolts (juvenile migrants)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-restoration production</td>
<td>230,501</td>
<td>22,386</td>
</tr>
<tr>
<td>Scenario 1 – Restore All</td>
<td>285,302</td>
<td>28,001</td>
</tr>
<tr>
<td>Scenario 2 - Historic</td>
<td>15,022</td>
<td>1,195</td>
</tr>
<tr>
<td>Minimum detectable difference (25%)**</td>
<td>57,625</td>
<td>5,596</td>
</tr>
</tbody>
</table>

** Need to restore about 20% of watershed to achieve this

Roni et al. 2010
Key Steps in Restoration

1. Set watershed restoration goals
2. Assess & inventory watershed conditions
3. Identify problems & potential actions
4. Review & select appropriate restoration techniques
5. Prioritize restoration actions
6. Design restoration project & monitoring
7. Implement restorations & monitoring
8. Publish results & modify goals

Adaptive management
Key Points

• Several Steps to Restoration Process
  • Successful restoration requires following all of them

• Assessment of Watershed Conditions Critical
  • Current, historic and habitat loss, causes of degradation

• Project selection
  • Processes, duration, longevity & climate change

• Prioritization
  • Multi-metric scoring systems most transparent

• Monitoring and evaluation
  • Defining questions/hypotheses is critical
  • Amount and intensity of restoration are important
Stream and Watershed Restoration
A Guide to Restoring Riverine Processes and Habitats
Edited by Philip Roni and Tim Beechie