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Concurrent Sessions C: Prioritization - On The Cutting-Edge: Optimizing Fish Passage Mitigation Decisions in California Watersheds

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Presenter Information
Jesse R. O’Hanley, Paul Kemp, Donald Ratcliff, Robin Carlson, Brett Holycross, and Martina Koller
On the Cutting-Edge: Optimizing Fish Passage Mitigation Decisions in California Watersheds

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Fish Passage 2013 Conference
Corvallis, Oregon
Overview

• Background

• A quick look at APASS

• Illustrative results from California
The California Fish Passage Forum
The Forum in a nutshell

• Mission:
  “to protect and restore listed anadromous salmonid species, and other aquatic organisms, in California by promoting the collaboration among public and private sectors for fish passage improvement projects and programs”

• Species of concern:
  ▫ Coho salmon
  ▫ Chinook salmon
  ▫ Steelhead trout
The first-cut approach

• Create a “barrier ranking matrix”, aka a **Scoring & Ranking** system for prioritizing mitigation actions

• Scores assigned based on:
  1. Barrier order
  2. Barrier extent (total vs partial/temporal ± assessment protocol)
  3. Habitat length (i.e., stream miles above barriers)
### Scoring method

<table>
<thead>
<tr>
<th>Order</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

Barrier Score = Barrier Extent + Barrier Order

**Total Score = Barrier Score + Habitat Score**

<table>
<thead>
<tr>
<th>Habitat Length (mi)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 10</td>
<td>length to the nearest 0.1</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Barrier Extent</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total + Protocol</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>4</td>
</tr>
<tr>
<td>Partial/Temporal + Protocol</td>
<td>3</td>
</tr>
<tr>
<td>Partial/Temporal</td>
<td>2</td>
</tr>
<tr>
<td>Unknown</td>
<td>0</td>
</tr>
</tbody>
</table>

Protocol = DFG Restoration Manual or FishXing was used
Don’t score & rank, optimize!

- **Optimization** based methods provide an ideal solution for dealing with the problem of barrier mitigation planning
- Offers an objective and systematic framework for thinking about the problem
- Makes the most efficient use of limited resources
- Can balance multiple, possibly competing, objectives and constraints
- Key uncertainties can even be incorporated in a coherent fashion
Framing the problem

• **Goal**: maximize the amount of accessible (possibly quality weighted) upstream habitat for one or more species

• **Constraint**: limited budget

• **Problem statement**: which barriers should be repaired/removed in order to maximize net habitat gain subject to a budget?
Example barrier network

- Cumulative passability
- Current passability
- Cost of repair/removal
- Net upstream habitat

Fish Migration Path

River Flow

<table>
<thead>
<tr>
<th>Location</th>
<th>Cumulative Passability</th>
<th>Current Passability</th>
<th>Cost of Repair/Removal</th>
<th>Net Upstream Habitat</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.4</td>
<td>$250K</td>
<td>2.1 km</td>
<td>NA</td>
</tr>
<tr>
<td>B</td>
<td>0.2</td>
<td>$120K</td>
<td>0.9 km</td>
<td>0.04</td>
</tr>
<tr>
<td>C</td>
<td>0.3</td>
<td>$70K</td>
<td>4.3 km</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>0.5</td>
<td>NA</td>
<td>1.7 km</td>
<td>0.4</td>
</tr>
<tr>
<td>E</td>
<td>0.1</td>
<td>$100K</td>
<td>0.5 km</td>
<td>0.02</td>
</tr>
<tr>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Drum roll please ...

- **APASS (Anadromous Fish Passage Optimization Tool)** is a decision support tool for optimizing barrier mitigation
  - Note the word “Anadromous”
- Identifies cost-efficient mitigation actions to maximize the amount of accessible, possibly quality-adjusted, habitat above barriers
  - Uses a mixed integer linear programming (MILP) formulation of the O’Hanley and Tomberlin (2005) model
How does it work?

- Integrates information on
  - Barrier passability
  - Potential habitat
  - Mitigation cost
- Crucially, accounts for:
  - Spatial structure of barrier networks
  - Interactive effects of mitigation decisions on longitudinal connectivity
A peak under the hood

\[
\max z = \sum_{s \in S} \theta_s \sum_{j \in J} v_{sj} \alpha_{sj} \quad \text{Maximize connectivity-weighted habitat}
\]

\[
s.t. \quad \alpha_{sj} = \prod_{k \in D_j} \left( p_{sk}^0 + \sum_{i \in A_k} p_{ski} x_{ki} \right) \quad \forall j \in J, s \in S
\]

\[
\sum_{i \in A_j} x_{ji} \leq 1 \quad \forall j \in J^{Art} \quad \text{Can only carry out one mitigation project at an artificial barrier } j
\]

\[
\sum_{j \in J^{Art}} \sum_{i \in A_j} c_{ji} x_{ji} \leq b \quad \text{Limited budget for mitigation}
\]

\[
x_{ji} \in \{0,1\} \quad \forall j \in J^{Art}, i \in A_j \quad \text{Either mitigate a barrier or not}
\]
For those who prefer a picture

River/Barrier Network

Graph Representation

Node = Barrier
Data formatting requirements

APASS requires the following data fields:

- **BARID**: barrier ID
- **BASIN**: watershed, subwatershed, etc.
- **DSID**: immediate downstream barrier ID
- **USHAB**: net upstream habitat (up to the next set of barriers or the limits of anadromy)
- **PREPASS**: current barrier passability
- **NPROJ**: number of mitigation projects that can be carries out (normally 0 for natural barriers)
- **COST**: the cost to repair/remove/mitigate a barrier
- **POSTPASS**: barrier passability following mitigation
APASS demo
Key APASS functionalities

- Friendly graphical user interface (GUI)
- Easy upload of barrier datasets
- Performs optimization runs for any desired budget
- Performs batch runs (i.e., run the model across a range of budget values in set increments)
- Saves solutions as simple text files
- Carry out basic “what-if” analyses
  - Limit analyses to a subset of selected watersheds
  - Create user-defined solutions in which one or a handful of barriers are forced in or forced out of the final solution
- Handles
  - Multiple species, guilds, etc. (aka restoration targets)
  - Multiple alternative mitigation projects at any given barrier (e.g., fix the barrier a little or fix a lot)
Passage Assessment Database

- At the state level, the Passage Assessment Database (PAD) is *the* go-to resource for barrier data
- PAD contains geospatially referenced data on barriers throughout the state
  - More than 6000 barriers in total
  - Compiled from more than one hundred agencies, organizations and landowners throughout California
  - Includes key info like structure type, ownership and passability (i.e., impassable/partial/temporal)
# PAD Scenario Manager

An Excel based interface for working with PAD and APASS

## PAD-APASS Data Constructor

### Barrier passability values

<table>
<thead>
<tr>
<th>Barrier Status</th>
<th>Passability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partial</td>
<td>0.50</td>
</tr>
<tr>
<td>Total</td>
<td>0.00</td>
</tr>
<tr>
<td>Temporal</td>
<td>0.50</td>
</tr>
<tr>
<td>Temporal &amp; Partial</td>
<td>0.50</td>
</tr>
<tr>
<td>Temporal &amp; Total</td>
<td>0.00</td>
</tr>
</tbody>
</table>

### Species weightings

<table>
<thead>
<tr>
<th>Species A</th>
<th>Species B</th>
<th>Preference</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coho</td>
<td>Chinook</td>
<td>A</td>
<td>1</td>
</tr>
<tr>
<td>Coho</td>
<td>Steelhead</td>
<td>A</td>
<td>1</td>
</tr>
<tr>
<td>Chinook</td>
<td>Steelhead</td>
<td>A</td>
<td>1</td>
</tr>
</tbody>
</table>

Consistent weightings? Yes

### Species weightings meanings

<table>
<thead>
<tr>
<th>Value</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Both species equal</td>
</tr>
<tr>
<td>3</td>
<td>Preferred species weakly more important</td>
</tr>
<tr>
<td>5</td>
<td>Preferred species strongly more important</td>
</tr>
<tr>
<td>7</td>
<td>Preferred species very strongly more important</td>
</tr>
<tr>
<td>9</td>
<td>Preferred species absolutely more important</td>
</tr>
<tr>
<td>2, 4, 6, 8</td>
<td>Intermediate values</td>
</tr>
</tbody>
</table>
Scenario Manager functionalities

- Designed to generate APASS formatted files and subsequently summarize/analyze APASS results
- Helpful for carrying out more specialized what-if type analysis
- Allows users to optionally assign:
  - Barrier passability values
  - Mitigation costs
  - Species weights (i.e., relative importance of increasing habitat for Coho vs Chinook vs Steelhead vs “other”)  
- Also provides a filter for
  - Focusing on specific regions of the state (Central Coast, Central Valley, North, South)
  - Specific ownership types (e.g., city, county, state, federal, private)
## APASS - turbo injected with all the extras!

<table>
<thead>
<tr>
<th>Barriers Removed</th>
<th>APASS Accessible Habitat (mi)</th>
<th>APASS Habitat Gain (mi)</th>
<th>Ranking Matrix Accessible Habitat (mi)</th>
<th>Ranking Matrix Habitat Gain (mi)</th>
<th>Ranking Matrix (without Protocol) Accessible Habitat (mi)</th>
<th>Ranking Matrix (without Protocol) Habitat Gain (mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>9,030</td>
<td>–</td>
<td>9,030</td>
<td>–</td>
<td>9,030</td>
<td>–</td>
</tr>
<tr>
<td>1</td>
<td>10,650</td>
<td>1,620</td>
<td>9,056</td>
<td>26</td>
<td>10,650</td>
<td>1,620</td>
</tr>
<tr>
<td>2</td>
<td>12122</td>
<td>3092</td>
<td>9097</td>
<td>67</td>
<td>11923</td>
<td>2893</td>
</tr>
<tr>
<td>3</td>
<td>13395</td>
<td>4365</td>
<td>9115</td>
<td>85</td>
<td>13014</td>
<td>3984</td>
</tr>
<tr>
<td>4</td>
<td>14487</td>
<td>5457</td>
<td>9124</td>
<td>94</td>
<td>13920</td>
<td>4890</td>
</tr>
<tr>
<td>5</td>
<td>15393</td>
<td>6363</td>
<td>9138</td>
<td>108</td>
<td>14510</td>
<td>5480</td>
</tr>
<tr>
<td>6</td>
<td>16159</td>
<td>7129</td>
<td>9161</td>
<td>131</td>
<td>14846</td>
<td>5817</td>
</tr>
<tr>
<td>7</td>
<td>17250</td>
<td>8220</td>
<td>9167</td>
<td>137</td>
<td>15106</td>
<td>6076</td>
</tr>
<tr>
<td>8</td>
<td>18156</td>
<td>9126</td>
<td>9170</td>
<td>140</td>
<td>15279</td>
<td>6249</td>
</tr>
<tr>
<td>9</td>
<td>18746</td>
<td>9716</td>
<td>9192</td>
<td>162</td>
<td>15467</td>
<td>6437</td>
</tr>
<tr>
<td>10</td>
<td>19447</td>
<td>10417</td>
<td>9213</td>
<td>183</td>
<td>15632</td>
<td>6602</td>
</tr>
</tbody>
</table>
Put another way …

Habitat Gain

Stream Length (mi)

Bars: APASS, Matrix w/Protocol, Matrix w/out Protocol

Bars Removed: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Or on the flip side ...
What’s wrong with Scoring & Ranking?

- Usually ignores **spatial structure**
  - Connectivity invariably affected by passability at barriers downstream!
  - In this regard, the ranking matrix is way better than most in that it considers barrier order as a criterion
- Repair decisions made **independently**
  - Assumes passability at other barriers remains fixed
  - Doesn’t allow for coordinated planning
- Put another way, S&R ignores the **interactive** effects that multiple barrier mitigation actions have on cumulative passability
- Optimization overcomes all this in spades
Is there an economist in the room?

- In the previous analysis we were completely ignoring the cost of repairing/removing barriers.
- Factoring in costs, however, can make a big difference as to which barriers you choose to fix.
- **Question:** Would you rather remove the barrier that gets you the single biggest habitat gain of 50 miles at a cost of $200K or remove 3 different barriers for the same cost but that combined get you 80 miles of habitat?
- **Answer:** ... I know what I’d choose.
Understanding the impact of costs

• Carried out experiments looking at prioritization based on:
  ▫ Habitat alone (all barriers have the same cost of removal) versus
  ▫ Combination of habitat and estimated mitigation cost

• Cost estimates generated at random from a distribution fitted to a sample of 40 culvert mitigation projects obtained from the California Habitat Restoration Project Database (CHRPD)
Distribution of costs

Generated cost estimates ranged from $8,600 to $1.26M with an average of $258k and were right skewed
### Surprise, surprise

<table>
<thead>
<tr>
<th>Barriers Removed</th>
<th>Excluding Costs</th>
<th>Including Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cost ($000s)</td>
<td>Habitat Gain (mi)</td>
</tr>
<tr>
<td>1</td>
<td>117</td>
<td>1620</td>
</tr>
<tr>
<td>2</td>
<td>336</td>
<td>3092</td>
</tr>
<tr>
<td>3</td>
<td>808</td>
<td>4365</td>
</tr>
<tr>
<td>4</td>
<td>1,012</td>
<td>5457</td>
</tr>
<tr>
<td>5</td>
<td>1,058</td>
<td>6363</td>
</tr>
<tr>
<td>6</td>
<td>1,327</td>
<td>7129</td>
</tr>
<tr>
<td>7</td>
<td>1,531</td>
<td>8220</td>
</tr>
<tr>
<td>8</td>
<td>1,577</td>
<td>9126</td>
</tr>
<tr>
<td>9</td>
<td>1,750</td>
<td>9716</td>
</tr>
<tr>
<td>10</td>
<td>1,911</td>
<td>10417</td>
</tr>
</tbody>
</table>
Any way you slice it, ignoring costs leaves a lot on the table

Habitat Gain-Cost Curves

For the same amount of money, get significantly less habitat

To get the same amount of habitat costs considerably more
Thank you ...

I’m here all week!
Encore?
“We spawned once, but I only pretended to die.”
“Next year, I'm pleasuring myself.”
“Well, you have three hundred miles and two more waterfalls to get in the mood!”