Modeling Salmonid Habitat for Restoration

A Concurrent Session at the 36th Annual Salmonid Restoration Conference held in Fortuna, California from April 11 – 14, 2018.
Session Overview

- **Session Coordinator:**
  - James Graham, Ph.D., Humboldt State University

The session will focus on presenting modeling methods available for habitat modeling and applications of modeling to specific areas for restoration. This would focus on modeling the environmental and anthropomorphic elements that affect salmonid habitat including: topography, hydraulic dynamics, bottom composition, shading, and aquatic temperature. This session would bring together examples of the wide variety of methods available. A panel at the end of the session will discuss steps forward.
Presentations

(Slide 4) Flow, Form, and Function: Integrated Hydro-geomorphic Modeling Reveals Opportunities and Trade-offs for River Restoration
Belize Lane, PhD, Utah State University

(Slide 31) Integrating Hydraulic Modeling Based Simulations of Salmonid Habitat Suitability with Geomorphic, Hydrologic, and Fisheries Data for Restoration Prioritization, Russian River Watershed
Jeremy Kobor, MS, PG, Senior Hydrologist, O'Connor Environmental

(Not Posted) Increasing the Availability of Spawning Habitats through Building Base Flow Patterns as Found in Natural Flow Regimes
Damon Goodman, USFWS

(Slide 58) A Streamlined Modeling Approach Quantifying Existing Habitat Conditions and Guiding Restoration
Brian Cluer, PhD, NOAA Fisheries

(Slide 107) Modeling Stream Temperatures with the Inclusion of Irradiance Change Due to Forest Biomass Shifts
Jonathan James Halama, PhD, ORISE Fellow with Environmental Protection Agency

(Slide 141) What’s in a Number: Southern Steelhead Population Viability Criteria?
Mark Capelli, PhD, Steelhead Recovery Coordinator, Southwest Fisheries Center, NOAA Fisheries
Flow, Form, and Function
An extensible framework for regional environmental flows

Belize Lane, PhD
Dept. of Civil and Environmental Engineering
Utah State University

April 14, 2018
Acknowledgements
California’s river ecosystems are in a critical state

50% of salmonids expected to be extinct within 50 years

95% of native riparian vegetation has been lost

Rising level of concern

Endangered aquatic species

Foothill Yellow Legged Frog, USFW 2017

USFS 2009

Moyle et al. 2017
Need to identify and promote critical ecosystem functions

Ecological processes

Geomorphic processes

Biogeochemical processes
Site-specific approach

South Fork Eel River Watershed

However, given the rate and scale of degradation, and the desire for coordinated regional management, we need an upscaling method...
Statewide approach

Hydrologic classification

Seasonal and inter-annual flow patterns

- Geomorphic setting
- Water quality
- Biological context

Ecosystem functions
Regional approach
Flow, Form, Function Framework

Geomorphic classification

Site- and species-specific studies

Characterize essential patterns & processes

Key ecosystem functions

Final Outcome: A tool for generating spatially-explicit, biologically & physically informed regional environmental flow targets
1. Define key ecosystem functions

Species-focused management goals

Ecosystem functions

Site-specific studies:
- Flow
- Hydraulics
- Water Quality
1. Define key ecosystem functions

Bed Occupation  Bed Preparation

Hydraulic threshold

<table>
<thead>
<tr>
<th>Month</th>
<th>Functional</th>
<th>Non-functional</th>
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<tr>
<td>Sep</td>
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</table>

Biological threshold

Fall-run Chinook salmon

Escobar and Pasternack 2015
2. Characterize geomorphic patterns & processes

Field Surveying

- Cross-section morphology
- Sub-reach variability
- Sediment composition

Statistical Analysis

Archetype Development

Pasternack and Arroyo 2018
Regional geomorphic classification

South Fork Eel River
Regional geomorphic classification

- Semi-confined pool-riffle
  - Sinuous
  - Low-mid slope
  - High depth and width variability
  - Gravel

- Upland confined plane bed
  - Confined
  - High slope
  - Low depth and width variability
  - Large cobble
Generate synthetic river archetypes

River Builder User’s Manual

River Builder Overview

- Start
  - Conceptualize the desired river
  - Determine reach average values of geometric elements
- End
  - Iterative revision (if necessary)
  - Run Program
    - Determine cross sectional shape
    - Select and parametrize geometric element equations

Figure 2. Simplified representation of the workflow for SRV design.
Generate synthetic river archetypes

- Upland confined plane bed
- Semi-confined pool-riffle
3. Hydrodynamic modeling

Assessment Mode

- Geomorphic classification
- River Builder
- Digital terrain model
- 2D hydraulic model
- Hydraulic rasters \((d, v, \tau)\)
- Suitable area
- Streamflow time series
- Function time series
- Performance metrics
- Ecosystem function

PROPOSE

ASSESS
3. Hydrodynamic modeling

Sediment Mobility
- No mobility ($t^* < 5$)
- Mid mobility ($5 < t^* < 24$)
- Partial mobility ($24 < t^* < 48$)
- Full mobility ($t^* > 48$)

Discharge (cfs)
1000
2000
3000
4000
4500
6000
8000

Lane et al. 2018 Ecohydrology
3. Hydrodynamic modeling

**Sediment Mobility**
- No mobility ($t^* < 5$)
- Mid mobility ($5 < t^* < 24$)
- Partial mobility ($24 < t^* < 48$)
- Full mobility ($t^* > 48$)

**Unimpaired Wet**

**Altered Wet**

Suitable area, % of spawnable channel

Lane et al. 2018 *Ecohydrology*
4. Quantify function performance

**Unimpaired Wet**

- **Discharge (cfs)**
  - Flood flow
  - Bankfull flow
  - Base flow

**POOL - RIFFLE**

Bed preparation
Bed occupation

Lane et al. 2018 *Ecohydrology*
4. Quantify function performance

Unimpaired

Altered

Lane et al. 2018 *Ecohydrology*
**Performance Metrics**

\[ Rel^i_{vol} = \frac{\sum_{t=1}^{n} Altered^i_{t}}{\sum_{t=1}^{n} Unimpaired^i_{t}} \]

\[ Rel^i_{time} = \frac{\# \text{ of } D^i_{t} = 0}{n} \]

\[ Vul^i = \frac{(\sum_{t=0}^{n} D^i_{t})}{\# \text{ of } D^i_{t}} \cdot \frac{Avg(Unimpaired^i_{t})}{Avg(Unimpaired^i_{t})} \]

\[ SI^i = \left[ \prod_{m=1}^{M} C^i_{m} \right]^{1/M} \]
Monthly/annual performance metrics

\[ Rel_{vol}^i = \frac{\sum_{t=1}^{t=n} Altered_t^i}{\sum_{t=1}^{t=n} Unimpaired_t^i} \]

\[ Rel_{time}^i = \frac{\# of D_t^i = 0}{n} \]

\[ Vul^i = \frac{(\sum_{t=0}^{t=n} D_t^i)}{\# of D_t^i} \]

\[ SI^i = \left[ \prod_{m=1}^{M} C^l_{m} \right]^{1/M} \]

Lane et al. In Review JWRPM
Spatial performance

- Salmonid bed preparation
- Riparian recruitment
- Hydraulic diversity

Adapted from Carolli et al. 2017
Hydrodynamic modeling
Prediction Mode

What flow regimes are capable of meeting performance targets?
Prediction Mode

Adapted from Carolli et al. 2017
**Next Steps:** User-friendly tool for watershed-scale environmental flows testing and prescription

For each function:

<table>
<thead>
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<th>Function suitability</th>
<th>Timing suitability</th>
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<tr>
<td>Channel type</td>
<td>Month</td>
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<tr>
<td>Q</td>
<td>0</td>
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<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>F</td>
<td>1</td>
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Daily streamflow time series at a site (e.g., diversion point)

**Performance**
- Month: 80%
- Annual: 20%
Key ecosystem functions

Performance

Flow, Form, Function Framework

Geomorphologic classification

Site- and species-specific studies
Integrating Hydraulic Modeling-based Simulations of Salmonid Habitat Suitability with Geomorphic, Hydrologic, and Fisheries Data for Restoration Prioritization, Russian River Watershed, CA

Jeremy Kobor, MS, PG
Senior Hydrologist
O’Connor Environmental, Inc.
Healdsburg, CA
www.oe-i.com

April 14, 2018
Acknowledgements

Project Partners
- Pepperwood Foundation

Funding
- CDFW Fisheries Restoration Grant Program

Technical Work Group
- SeaGrant
- CDFW
- NOAA Fisheries
- Sonoma RCD
**Motivation**

**The Challenge**
- Recovery plans have identified hundreds of river miles of high priority Coho habitat - thousands of parcels
- Generally limited information, limited funding

**Landowner-driven Approach**
- identify cooperative landowners
  - develop projects to fit a given site

**Habitat Potential-driven Approach**
- identify the best places for projects
  - perform targeted landowner outreach
  - develop projects where most needed/most suitable
Project Overview

- Characterize geomorphic and hydrologic conditions using LiDAR and hydrologic/hydraulic models
- Relate hydraulic and geomorphic variables to Coho rearing habitat suitability
- Quantify existing habitat availability and identify sites/reaches for habitat enhancement projects
- Integrate SeaGrant monitoring data
- Prioritize identified candidate project sites/reaches
- Develop conceptual designs
Hydrology

- Empirical rainfall-runoff models (NAM) – 32-yr daily simulation
- Flood frequency analyses – 3 USGS gauges
Hydrology

Simulated Flows

- **Winter Baseflow** (median Nov-Mar)
  - 8 to 48 cfs

- **10% Exceedance Flow**
  - 51 to 198 cfs

- **Bankfull Flow** (1.5-yr flood)
  - 1,024 – 3,933 cfs

- **10-yr Flood**
  - 2,975 to 8,039 cfs
Hydraulics

- 1-dimensional hydraulic models (MIKE 11)
- 4,300 LiDAR-derived cross sections (81.3 river miles)
- 2-dimensional mapping (conveyance distribution/LiDAR)
Calibration

- Calibrated to gauge data from USGS, TU, and NOAA
Habitat Suitability Indices

- Juvenile coho salmon curves - Beecher et al., 2002 (western WA streams)
Habitat Suitability

- **Combined Habitat Suitability Index (HSI)**

\[ HSI_{\text{Combined}} = \sqrt{HSI_{\text{Depth}} \times HSI_{\text{Velocity}}} \]

- **Weighted Useable Area (WUA)**

\[ WUA = HSI_{\text{Combined}} \times \text{Area} \]
Results – Mill Creek @ Winter Baseflow

- Water Depth (ft):
  - < 0.1
  - 0.1 - 0.5
  - 0.5 - 1
  - 1 - 2
  - 2 - 3
  - 3 - 5
  - 5 - 7
  - > 7

- Velocity (ft/s):
  - < 0.2
  - 0.2 - 0.5
  - 0.5 - 1
  - 1 - 2
  - 2 - 3
  - 3 - 5
  - 5 - 7
  - > 7

- Habitat Suitability Index:
  - 0
  - < 0.2
  - 0.2 - 0.4
  - 0.4 - 0.6
  - 0.6 - 0.8
  - 0.8 - 1.0
Results – Mill Creek @ Bankfull

Water Depth (ft)
- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- 3 - 5
- 5 - 7
- > 7

Velocity (ft/s)
- < 0.2
- 0.2 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- 3 - 5
- 5 - 7
- > 7

Habitat Suitability Index
- 0
- < 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0
- > 1
Results – Mill Creek @ 10-yr Flood

Water Depth (ft)

- < 0.1
- 0.1 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- 3 - 5
- 5 - 7
- > 7

Velocity (ft/s)

- < 0.2
- 0.2 - 0.5
- 0.5 - 1
- 1 - 2
- 2 - 3
- 3 - 5
- 5 - 7
- > 7

Habitat Suitability Index

- 0
- < 0.2
- 0.2 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0
- 1
Habitat Suitability (Depth & Velocity)

- Mill Creek @ bankfull flow
Habitat Suitability (Flow Regime)

- Mill Creek – SeaGrant Wet/Dry Mapping (2013 – 2017)
Coho Distribution

- Mill Creek – SeaGrant Snorkel Surveys (2014 – 2017)
In-stream Project Prioritization

• Initial Prioritization Based on WUA
  - Low - reaches with WUA < average
  - Medium – reaches with WUA > average (2 of 4 flows)
  - High – reaches with WUA > average (3 of 4 flows)
  - Very High – reaches with WUA > average (all flows)

• Adjust for Flow Regime
  - Exclude - reaches with disconnected pools in most years
  - Increase priority – reaches with connected pools even in drought years

• Adjust for Coho Abundance
  - Decrease priority - reaches with no Coho
  - Increase priority – reaches with above average number of Coho
Instream Project Prioritization

- Mill Creek – WUA, Flow Regime, Coho Counts
Ease of Implementation

- **Equipment Access**
  - distance <200-ft & slopes <30% from nearest road to top of bank

- **Anchoring Sites**
  - sample LiDAR-derived canopy height along banklines
Instream Project Prioritization

- Mill Creek – Good Anchoring Sites/Equipment Access
Instream Project Prioritization

- Pena Creek – Good Anchoring Sites/Equipment Access
Identification of Off-channel Project Sites

- Scan model results for:
  - Side channels, alcoves, frequently activated floodplains

- 590-ft multi-thread side channel
- 870-ft multi-thread side channel
- 1,380-ft multi-thread side channel
- 830-ft multi-thread side channel
- 3.4 acre floodplain
- 3.7 acre floodplain with alcove
### Prioritization of Off-channel Project Sites

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<thead>
<tr>
<th>ID</th>
<th>Type</th>
<th>Size</th>
<th>Access</th>
<th>Location</th>
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<tbody>
<tr>
<td>EA1</td>
<td>Floodplain</td>
<td>0.8 acres</td>
<td>1</td>
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<tr>
<td>EA2</td>
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<td>1</td>
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<td>EA3</td>
<td>Side-channel</td>
<td>300-ft</td>
<td>1</td>
<td>1</td>
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<tr>
<td>EA4</td>
<td>Floodplain with alcove</td>
<td>3.7 acres</td>
<td>1</td>
<td>1</td>
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<tr>
<td>EA5</td>
<td>Floodplain</td>
<td>1.7 acres</td>
<td>1</td>
<td>1</td>
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<tr>
<td>EA6</td>
<td>Floodplain</td>
<td>1.6 acres</td>
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<td>1</td>
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<td>EA7</td>
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<td>350-ft</td>
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<td>EA8</td>
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<td>3.4 acres</td>
<td>0</td>
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<td>EA9</td>
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<td>0.8 acres</td>
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<td>1</td>
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<td>EA10</td>
<td>Multi-thread Side-channel</td>
<td>830-ft</td>
<td>0</td>
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<td>EA11</td>
<td>Floodplain with alcove</td>
<td>0.8 acres</td>
<td>0</td>
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<td>EA12</td>
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<td>0</td>
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<tr>
<td>EA13</td>
<td>Floodplain with alcove</td>
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### Gray Creek

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<td>Gr1</td>
<td>Side-channel</td>
<td>70-ft</td>
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<td>GR2</td>
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<td>220-ft</td>
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- Access
- Proximity to high priority reaches
Comparisons Between Streams

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Winter Baseflow</th>
<th>10% Exceedance Flow</th>
<th>Bankfull Flow</th>
<th>10-yr Flood Flow</th>
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<tr>
<td>Mill Creek</td>
<td>11.7</td>
<td>16.4</td>
<td>18.2</td>
<td>20.2</td>
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<tr>
<td>Pena Creek</td>
<td>11.1</td>
<td>15.1</td>
<td>16.9</td>
<td>22.3</td>
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<td>East Austin Creek</td>
<td>16.5</td>
<td>17.0</td>
<td>15.1</td>
<td>16.6</td>
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<tr>
<td>Redwood Creek</td>
<td>2.5</td>
<td>2.9</td>
<td>4.3</td>
<td>5.2</td>
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## Comparisons Between Streams

<table>
<thead>
<tr>
<th>Watershed</th>
<th>WUA (ac/ml)</th>
<th>% Connected Pools</th>
<th>Coho (#/mi)</th>
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<tr>
<td>Mill</td>
<td>0.74</td>
<td>83%</td>
<td>37</td>
</tr>
<tr>
<td>Wallace</td>
<td>0.98</td>
<td>0%</td>
<td>2</td>
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<tr>
<td>Felta</td>
<td>0.68</td>
<td>47%</td>
<td>26</td>
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<tr>
<td>Palmer</td>
<td>0.83</td>
<td>100%</td>
<td>19</td>
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<td>Pena</td>
<td>0.90</td>
<td>14%</td>
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<td>Pechaco</td>
<td>0.32</td>
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<td>Redwood Log</td>
<td>0.77</td>
<td>na</td>
<td>na</td>
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<tr>
<td>Woods</td>
<td>0.68</td>
<td>73%</td>
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<td>East Austin</td>
<td>1.01</td>
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<tr>
<td>Gray</td>
<td>0.38</td>
<td>94%</td>
<td>90</td>
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<td>Gilliam</td>
<td>0.45</td>
<td>100%</td>
<td>120</td>
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<tr>
<td>Thompson</td>
<td>0.17</td>
<td>na</td>
<td>2</td>
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<tr>
<td>Redwood</td>
<td>0.49</td>
<td>60%</td>
<td>4</td>
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<tr>
<td>Kellogg</td>
<td>0.38</td>
<td>na</td>
<td>na</td>
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<tr>
<td>Yellowjacket</td>
<td>0.18</td>
<td>na</td>
<td>na</td>
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### Highest Value
- Mill, Palmer, East Austin, Woods

### Flow-limited
- Felta, Wallace, Pena, Pechaco

### WUA-limited
- Gray, Gilliam, Thompson, Redwood, Kellogg, Yellowjacket
Thank you!

jeremyk@oe-i.com
A Streamlined Modeling Approach for Quantifying Existing Habitat Conditions and Guiding Restoration

Brian Cluer, Charleen Gavette, Bryan Pestone
NOAA Fisheries - West Coast Region
brian.cluer@noaa.gov
16.4 river km
12.9 valley km
sinuosity 1.3
2500 acres pasture
Using Available Data:

- 3’ LiDAR (fall of 2012)
  - Bare earth
  - Highest hits
- USGS gage record
  - 35 years
    - Peak flows
    - Daily flows
    - Example annual hydrograph
5 cover classes
Channel (0-0.08)  n0.04
Forest (+10)      n0.07
High shrub (3.0-10.0) n0.15
Low shrub (1.0-3.0)  n0.1
Grass (0.08-1.0)    n0.03
Gage record: 35 yrs
Velocity shear zones, eddies, 0v
Computational Mesh:
13 million cells (3’x3’)
8.7 million wet at Qmax
HecRas 2d

- Run model for a wide range of flows
- Extract model output for each flow
  - Depth
  - Velocity [0 to 1 fps]
- Quantify habitat areas (GIS)
  - Areas that meet specified range
- Create Habitat / Flow relationship

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<td>500 mid-May</td>
<td>1000 Apr</td>
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<tr>
<td>1000 Apr</td>
<td>1500 Nov, Feb</td>
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<td>1500 Nov, Feb</td>
<td>2000 Dec - Jan</td>
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<tr>
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<tr>
<td>2500</td>
<td>3000</td>
</tr>
<tr>
<td>3000</td>
<td>3500</td>
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<table>
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<td>4200 Q1</td>
<td>10000 Q1.5</td>
</tr>
<tr>
<td>10000 Q1.5</td>
<td>13000 Q2</td>
</tr>
<tr>
<td>13000 Q2</td>
<td>18000 Q5</td>
</tr>
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Graph showing flow vs. depth with increasing flow indicating changes in depth.
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**RESULTS**

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April 1,000 cfs

USGS 14303600
Flow cfs

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Peak Flow cfs

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**Winter**

2,500 cfs

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Winter 3,000 cfs

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Winter 3,500 cfs

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Q1: 4,200 cfs

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USGS 14303600
Flow cfs
- 500 mid-May
- 1000 Apr
- 1500 Nov, Feb
- 2000 Dec - Jan
- 2500
- 3000
- 3500
Peak Flow cfs
- 4200 Q1
- 10000 Q1.5
- 13000 Q2
- 18000 Q5
- 21000 Q10
- 30000 Q40

Q5: 18,000 cfs

Velocity fps
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Q10: 21,000 cfs

Velocity fps

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Q40:
30,000 cfs

Peak Flow cfs
- 4200 Q1
- 10000 Q1.5
- 13000 Q2
- 18000 Q5
- 21000 Q10
- 30000 Q40

Flow cfs
- 500 mid-May
- 1000 Apr
- 1500 Nov, Feb
- 2000 Dec - Jan
- 2500
- 3000
- 3500

Velocity fps

0.00
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Mid-May
500 cfs

USGS 14303600
Flow cfs

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Peak Flow cfs

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<td>4200 Q1</td>
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<td>21000 Q10</td>
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<td>30000 Q40</td>
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Velocity fps

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2.5 - 3
3 - 3.5
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4 - 4.5
4.5 - 5
5 - 5.5
5.5 - 6
6 - 6.5
April
1,000 cfs

USGS 14303600
Flow cfs
- 500 mid-May
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- 3000
- 3500
Peak Flow cfs
- 4200 Q1
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Velocity fps

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- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 - 5
- 5 - 5.5
- 5.5 - 6
- 6 - 6.5
Nov-Feb
1,500 cfs

USGS 14303600
Flow cfs

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<td>500</td>
<td>mid-May</td>
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Peak Flow cfs

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<td>4200</td>
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<tr>
<td>13000</td>
<td>Q1.5</td>
<td>10000</td>
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<td>Q10</td>
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<tr>
<td>30000</td>
<td>Q40</td>
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Velocity fps

- 0 - .5
- .5 - 1
- 1 - 1.5
- 1.5 - 2
- 2 - 2.5
- 2.5 - 3
- 3 - 3.5
- 3.5 - 4
- 4 - 4.5
- 4.5 - 5
- 5 - 5.5
- 5.5 - 6
- 6 - 6.5
Dec-Jan
2,000 cfs
USGS 14303600

Flow cfs
- 500 mid-May
- 1000 Apr
- 1500 Nov, Feb
- 2000 Dec - Jan
- 2500
- 3000
- 3500

Peak Flow cfs
- 4200 Q1
- 10000 Q1.5
- 13000 Q2
- 18000 Q5
- 21000 Q10
- 30000 Q40

Winter
2,500 cfs

Velocity fps
Winter 3,000 cfs
Winter
3,500 cfs

Velocity fps

USGS 14303600
Flow cfs
500 mid-May
1000 Apr
1500 Nov, Feb
2000 Dec - Jan
2500
3000
3500

Peak Flow cfs
4200 Q1
10000 Q1.5
13000 Q2
18000 Q5
21000 Q10
30000 Q40
Q1.5: 10,000 cfs

Velocity fps

<table>
<thead>
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<th>Value</th>
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<td>10000</td>
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<td>Q5</td>
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<td>Q10</td>
<td>21000</td>
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<tr>
<td>Q40</td>
<td>30000</td>
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Flow cfs

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<th>Value</th>
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</thead>
<tbody>
<tr>
<td>500 mid-May</td>
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<tr>
<td>1000 Apr</td>
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</tbody>
</table>
Q2:
13,000 cfs
Q5:
18,000 cfs
Q10: 21,000 cfs
Q40
30,000 cfs

USGS 14303600
Flow cfs
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Peak Flow cfs
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13000 Q2
18000 Q5
21000 Q10
30000 Q40

Velocity fps
Habitat / Flow

- X Y graph of habitat area vs flow
Apply results:

- Integrate H/Q relationship over any flow period
- Example: Oct 2012 – May 2013 (avg. year)
- Quantify Habitat on Daily Time Step
- Accumulate Habitat Over a Relevant Juvenile Rearing Season to Evaluate Reach Performance
Integrate habitat over a flow time-series
Objective-Based Scenario Modeling

Current Condition

Restoration Scenario #1: sloping floodplain; 20-160 acres, 500-2500 cfs
Restoration Scenario #1: sloping floodplain; 20-160 acres, 500-2500 cfs
Coho Salmon Intrinsic Potential Model

Historic vs. Current [ground-truth]

Intrinsic Potential Habitat  Current Habitat
Procedure:

**GIS**
- Obtain LiDAR
- Create DEM
- Create land cover layer

**HEC-RAS**
- Create HecRas 2-dimensional hydraulic model
  - TIN LiDAR data
  - Assign land cover values
  - Build boundary conditions
  - Create Flow File

**GIS**
- Post Processing
  - Sort cells by velocity
  - Quantify habitat

**Spreadsheet Model**
- Habitat / Flow Curve
- Integrate with any hydrologic record
- Evaluate different hydrologies and objectives
Summary:

• Analysis takes 1 day - analyze many reaches or many watersheds quickly
• Results are
  • Quantified and Repeatable
  • Habitat vs Flow Model is Adaptable
  • Can Simulate Past or Future Conditions
    • Flow
      • Past, future, climate scenarios, change in water diversions
    • Terrain
      • Restoration work or geomorphic processes
      • Changes in land use
  • Prioritize restoration actions
    • Restoration work effectiveness
    • Target high value areas; conservation and enhancement
Key idea:

• Most (all?) habitat modeling attempts precision in all the variable parameters.
  • Requires oodles of field data
  • Species-specific preferences
  • Seeking answers - misunderstanding models and how they are useful
• Departing from the basis of the hydraulic model, and forsaking insight.
  • Relationships between parameters
  • Differences between scenarios
  • System vs. site responses
  • Reach-scale comparisons
  • Watershed-scale comparisons
• The simplified inexpensive model is better than no model.
Modeling Stream Temperatures with the Inclusion of Irradiance Change Due to Forest Biomass Shifts

Jonathan Halama, MPH, PhD

VELMA Modeling Team:
Bob McKane, Brad Barnhart, Paul Pettus, Kevin Djang, Allen Brookes

U.S. Environmental Protection Agency
Western Ecology Division
Corvallis, OR.

36th Annual Salmonid Restoration Conference on April 14, 2018
• Research Question
  • How may forest management practices impact stream water **quantity** and **quality**, specifically temperature?

• Methodology
  • Spatial Model Integration and Simulation

• Preliminary Results
  • Landscape ground-level irradiance
  • Water quantity
  • Water temperature quality

• Future Research
  • Dynamic stream temperature model that responds to a spatial system through mechanistic behavior.
Summaries of Each Process-based Model

• VELMA (Visualizing Ecosystem Land Management Assessments)
  • Hydrology:
    • Upland water moving on surface
    • Upland water moving through subsurface layers
  • Soil Temperature

• Penumbra: Ground-level Shade and Irradiance
  • Light reduction (Shade):
    • Landscape objects
    • Topography

• Version 1 - VELMA-Stream Temperature Model (VELMA-STM, beta)
  • Per VELMA “stream” cell, using Adams & Sullivan Model (USFS, 1989)

• Version 2 - Stream Temperature Model
  • Overcome some limitations of the VELMA-STM
VELMA Overview
Soil Column Scale

VELMA Soil Drainage & Runoff Parameters

Drivers & Specified Parameters
- P = daily total precipitation (P_r = rain, P_s = snow)
- T = daily mean temperature, Varied Soil Temperature
- \( \Phi \) = soil porosity
- fc = soil field capacity
- \( Z_i \) = thickness of soil layer I
- bd = bulk density

Calibration Parameters
- \( K_{s_i} \) = saturated hydraulic conductivity
- \( K_{sv_i} \) = vertical sat. hydraulic conductivity
- \( K_{sl_i} \) = lateral sat. hydraulic conductivity

Response Variables
- m = snow melt
- \( S_{SWE} \) = snow water equivalent
- \( S_{STW} \) = standing water amount
- I = infiltration of \( S_{STW} \) into soil
- \( D_i \) = vertical drainage
- \( Q_s \) = surface runoff in or out
- \( Q_i \) = subsurface runoff in or out of layer i
- \( s_i \) = soil water storage in layer i
- \( ET_i \) = evapotranspiration from layer i

Abdelnour, Stieglitz, Pan & McKane (2011)

https://www.epa.gov/water-research/visualizing-ecosystem-land-management-assessments-velma-model-20
VELMA: fate & transport of water & nutrients
Plots → watersheds; days → centuries

Climate & Land Use Effects Simulated

- **Hydrology**: streamflow, vertical & lateral flow, evapotranspiration, available soil moisture...
- **Plants & Soils**: uptake, transformation and transport of carbon, nutrients and toxics from terrestrial to aquatic systems
VELMA: fate & transport of water & nutrients
Plots → watersheds; days → centuries

Climate & Land Use Effects Simulated
- **Hydrology**: streamflow, vertical & lateral flow, evapotranspiration, available soil moisture...
- **Plants & Soils**: uptake, transformation and transport of carbon, nutrients and toxics from terrestrial to aquatic systems
VELMA: fate & transport of water & nutrients
Plots → watersheds; days → centuries

Ecosystem Services Simulated
- Water quality & quantity
- Food & fiber production
- Carbon sequestration
- Greenhouse gas control ($CO_2$, $N_2O$, $NO_x$)
- Fish & wildlife habitat (links to population models)
Primary upland sources & flow paths by which nitrate is flushed to marsh
(arrows size and background color indicate amount of nitrate flushed per day)

For this talk, video highlights that VELMA does model the fate and transport of properties tracked in the soil column.

ANIMATION – wiggle mouse over image & click run arrow.
VELMA Validation Examples

HJ Andrews Experimental Forest, Watershed 10 (Abdelnour et al. 2011 and 2013, in *Water Resources Research*)

Streamflow

Forest Growth

Stream Chemistry

Stream Nitrogen Response to Harvest and Riparian Buffers
Penumbra
Stream Shade & Irradiance

http://ii8.piedn.net/shutterstock
Per cell, spatially explicit assessment of Object shade and Topographic shade

Shade & Solar Energy Processes

- **Object shade**: intensity based on object type and height
- **Topological shade**: intensity based on distance
- **Net-Irradiance**: total irradiance per time-step reduced by the total shade intensity
Penumbra Testing
Varied Forest Stand Heights at 1-m resolution

EPA Crest to Coast – Moose Mountain Open and Forest Sites

Forest Site
Open Site

Tree Heights (feet)

229.789993
114.894997
0.000000

Younger Forests
Penumbra Model
Varied Forest Stand Heights at 1-m resolution
Penumbra Model
Varied Forest Stand Heights at 1-m resolution

Moose Mountain initial results, and calibrated results.

<table>
<thead>
<tr>
<th>Open Site</th>
<th>Initial Run</th>
<th>Calibrated Run</th>
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</thead>
<tbody>
<tr>
<td>Percent Agreement</td>
<td>0.52</td>
<td>1.03</td>
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<tr>
<td>RMSE</td>
<td>506.0</td>
<td>224.6</td>
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<tr>
<td>Mean Error</td>
<td>286.1</td>
<td>-17.3</td>
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</table>

<table>
<thead>
<tr>
<th>Forest Site</th>
<th>Initial Run</th>
<th>Calibrated Run</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Agreement</td>
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<td>1.86</td>
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<tr>
<td>RMSE</td>
<td>77.8</td>
<td>53.8</td>
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<tr>
<td>Mean Error</td>
<td>-10.0</td>
<td>-15.6</td>
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Figure 4-1: Penumbra-VELMA tightly-coupled model integration.

Presented in this research, VELMA initial 1990 biomass and 1990-2008 historic harvest patterns are defined by LandTrendr. Simulation outputs displayed by VISTAS v1.10.
**VELMA - Penumbra Interaction**

**VELMA-AST and VELMA-AST3 O’CCMoN results.**

<table>
<thead>
<tr>
<th>O’CCMoN Paired Site Locations</th>
<th>Sites</th>
<th>Soil Layer 1</th>
<th>Soil Layer 2</th>
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<tr>
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<td>AST3 (r²)</td>
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<tr>
<td>Cascade Head</td>
<td>Open Site (CHO)</td>
<td>0.8279</td>
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<tr>
<td></td>
<td>Forest Site (CH14)</td>
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<td>Moose Mountain</td>
<td>Open Site (MMO)</td>
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<td>0.9202</td>
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<td>Forest Site (SGF)</td>
<td>0.6869</td>
<td>0.9175</td>
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<td>Toad Creek</td>
<td>Open Site (TCO)</td>
<td>0.8213</td>
<td>0.8257</td>
</tr>
<tr>
<td></td>
<td>Forest Site (TCF)</td>
<td>0.8318</td>
<td>0.8984</td>
</tr>
</tbody>
</table>
1) Click link to navigate this floodplain in 3D: [https://www.google.com/maps/@47.6319956,-121.9250542,801a,35y,12.19h,49.46t/data=!3m1!1e3?hl=en](https://www.google.com/maps/@47.6319956,-121.9250542,801a,35y,12.19h,49.46t/data=!3m1!1e3?hl=en)

2) See next page for Penumbra model analysis of changes in floodplain shading as vegetation increases in height during 2000 – 2275.

---

**Engaged Stakeholders**

- Seattle Public Utility
- King County, WA
- Seattle City Light
- City of Carnation, WA
- Snoqualmie Tribe
- EPA - Region 10
Penumbra Animation of Projected Changes in Floodplain Shading
Tree Height Growth from years 2000 to 2275

- Notes: Maximum tree height is attained throughout the floodplain by 2100.
- Vegetation height changes outside the floodplain were not simulated.
Stream Temperature Modeling

Single Location Stream Temperature Model
Adams and Sullivan (USFS, 1989)

\[
\frac{d(T_w)}{dt} = \frac{q_{\text{net}} + G_{gw} C_w (T_{gw} - T_w) + G_e L_v}{\rho C_w D}.
\]

VELMA Provides
- Disturbance
  - Biomass Growth and Loss
- Surface Water Runoff
  - Volume
  - Temperature
- Ground Water Runoff
  - Volume
  - Temperature

Penumbra Provides
- Stream surface Irradiance due to:
  - Open full exposure, or Riparian shade
- Upland ground-level Irradiance due to:
  - Open full exposure, or Forest Canopy
- Influences VELMA’s Soil Temperature
  - Could influence:
    - Snow melt rate
    - Canopy light on photosynthesis

VELMA and Penumbra Interaction

\[ q_{\text{net}} = q_{\text{solar}} + q_{\text{sky}} + q_{\text{veg}} + q_{\text{conv}} + q_{\text{sb}} \]
Preliminary Stream Temperature Modeling
January 01, 1998
HJ Andrews WS1 Simulation
VELMA - Penumbra
VELMA HJA-WS1 Simulated Versus Observed Stream Temperature

\[
\frac{d(T_w)}{dt} = \frac{q_{net} + G_g w C_w (T_{gw} - T_w)}{\rho C_w D} + G_e L_v
\]

- Ignore VELMA’s First Year
- Water Balance is working out proper water volume
- Under Construction
  Agent based version of this approach

Depth!!!
**Figure 4-1: Penumbra-VELMA tightly-coupled model integration.**

Presented in this research, VELMA initial 1990 biomass and 1990-2008 historic harvest patterns are defined by LandTrendr. Simulation outputs displayed by VISTAS v1.10.
Tectah Stream Temperature

- Dry part of season: August 1\textsuperscript{st}, 2016
- Yet there is not a linear pattern of stream warming.
  - 15.2°C
  - 14.6°C
  - 13.1°C
  - 14.5°C
  - 12.5°C

- Just like stream water quantity is influenced by ground water, stream temperature is at least partially influenced ground water.
Penumbra Simulation of:
Tectah Watershed - 1 meter
By: Jonathan Halama
August 15, 2010 05:39
Watts/m^2
1254.079956
642.989990
31.900000
Mashel Watershed Modeling

Stream temperature data provided to VELMA team via collaboration with Greg Brair of ICF as part of Ecosystem Diagnosis and Treatment system (EDT) modeling with VELMA

Mashel River Watershed

August 1st, 2006 Stream Temperature
Conclusions

• Penumbra is new way to model landscape irradiance to help with stream temperature research by modeling:
  • Object shadowing (forest and riparian zone)
  • Topographic shadowing (hills, mountains, canyons)
  • Provide high-resolution (1-m where LiDAR) stream surface solar energy loads.

• Penumbra-VELMA Integration provides:
  • Improved soil temperature estimates across watersheds.
  • A modeling method of spatially transporting ground-water temperature and volume through a system and into the stream.

• Integration allows dynamic forests simulations of solar energy on:
  • Riparian zone increase in shadowing through time.
  • Change in solar energy at the ground-level (open versus forest).
    • Variations in soil temperatures.
    • Variations in snow pack retention.
Questions?

Contact: Jonathan Halama
halama.jonathan@epa.gov
Or
jjhalama@Willamette.edu
Young vigorously growing forests can transpire up to three times more water than old forests.

Young Forest
Higher Transpiration

Old Forest
Lower Transpiration

Note: Perry & Jones (2016) report similar results for watershed-scale flow measurements.
Watershed 10, HJ Andrews, OR
- 0.1 km² headwater catchment
- 450 year-old conifer forest
- Clearcut in 1975
- Stream discharge data 1969-present

Streamflow, mm/day
- 3x more low flow with age effect

Gauge Observed (HJA)

VELMA
Jul-Sep BWC
Primary upland sources & flow paths by which nitrate is flushed to marsh
(arrows size and background color indicate amount of nitrate flushed per day)

**ANIMATION** – wiggle mouse over image & click run arrow
Next step: convert daily irradiance to water temperature (temperature of groundwater inflow also accounted for)
What’s In a Number: Southern Steelhead Population Viability Criteria?

National Marine Fisheries Service

36th Annual Salmonid Restoration Conference

Fortuna River Lodge, CA
April 11-14, 2018

Mark H. Capelli
Recovery Coordinator
Southern California Steelhead Recovery Planning

Southern California Steelhead DPS
Viable Salmonid Population (VSP)

Abundance

Biological Diversity

Biological Productivity

Spatial Distribution

Viable Steelhead Population Measures
National Marine Fisheries Service

Southern California Steelhead Recovery Planning

NMFS Technical Recovery Team: South-Central and Southern California Steelhead
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Population Characterization

Intrinsic Potential Ranking

Based on the Envelop Method
California Fire Frequency
Southern California Steelhead DPS

Largest Recent Southern California Wildfires


Southern California Steelhead DPS

Station Fire - 2009
Cedar Fire - 2003
Old Fire - 2003
Thomas Fire 2017
Harris Fire - 2007
National Marine Fisheries Service

Thomas Fire 2017

- Cuyama River
- Santa Ynez River
- Sespe Creek
- Santa Clara River
- Ventura River
Thomas Fire 2017

Thomas Fire Burn:
Ventura River/
Matilija Creek
Watershed
Thomas Fires 2017

USGS
Matilija Canyon Pre – Post Thomas Fire
National Marine Fisheries Service

Thomas Fire 2017

Matilija Canyon Pre – Post Thomas Fire
Before and After Fire Effects

Day Fire: 162,202 ac.

Sespe Creek 2002 - before fire

2008 - after fire
Before and After Fire Effects

Santa Ana River – Harding Creek

2006 - before fire

2007 - after fire
Southern California Steelhead DPS

Landscape Characterization

Biogeographic Groups
Southern California Steelhead DPS

Biogeographic Population Groups
DPS-Wide Viability

Goals

- Preserve over-all species diversity (genetic, phenotypic, life-history)
- Protect species from extinction due to catastrophic disturbance (wildfires, flooding, droughts)

Note: 1000-year time horizon
Southern California Fire Frequency

*Projected Thousand-Year Wildfire Burn Area

Based on 1910 – 2003 Data
DPS-Wide Viability

**Strategy**

- Minimum number viable in each biogeographic region
- Occupy watersheds with drought refugia
- Minimum geographic separation (wildland fire analysis)
- Exhibit life history diversity

< 5% extinction risk in 1000 years
Number of Populations Required for Recovery

Southern California Steelhead DPS
Southern California Steelhead DPS

Threats to Recovery

* Access to Spawning and Rearing Habitat
* Degradation of Instream/Riparian Habitat
* Spread of Non-Native Species
* Wildfires
* Loss of Estuarine Habitat
What’s In a Number: Southern Steelhead Population Viability Criteria?

36<sup>th</sup> Annual Salmonid Restoration Conference

Fortuna River Lodge, CA
April 11-14, 2018

Mark H. Capelli
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