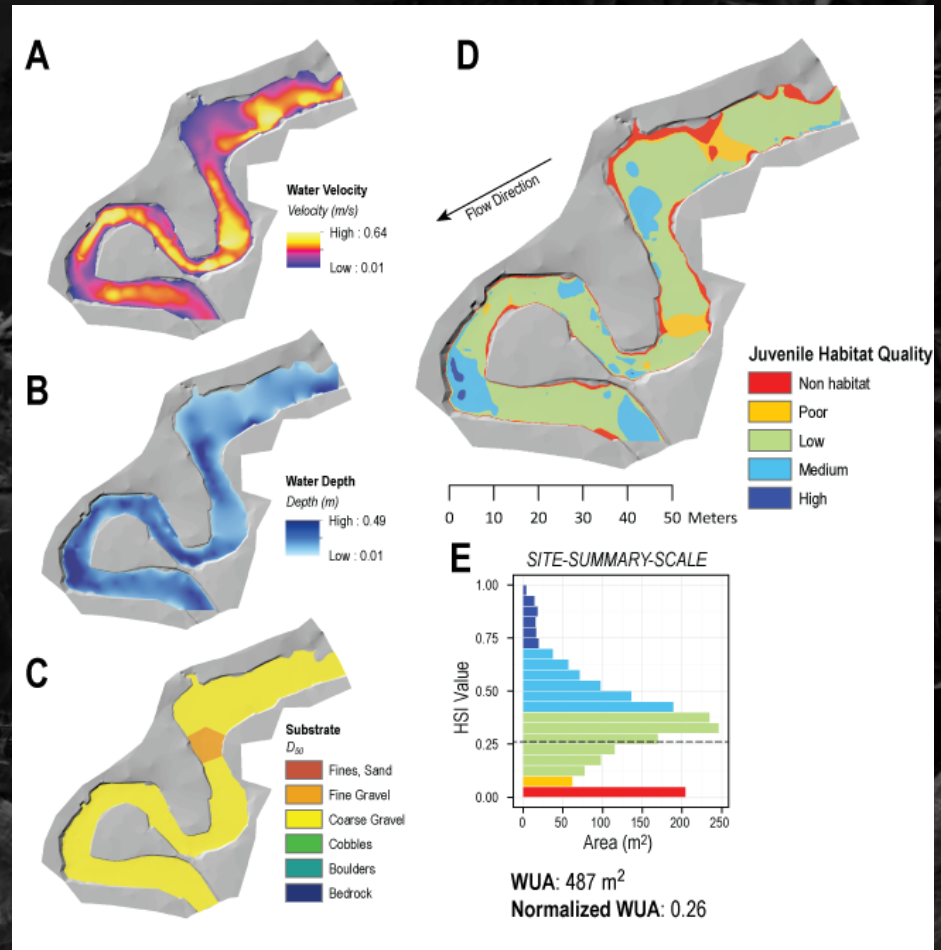


WATS 6900 – Ecohydraulics

WEEK 1: Intro & Hydraulics



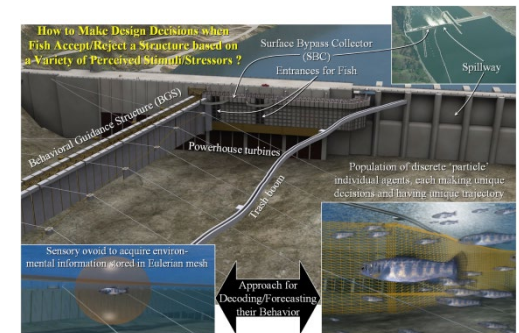
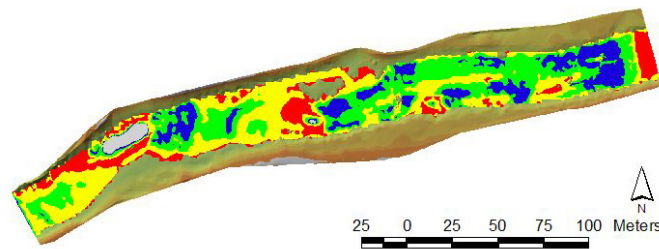
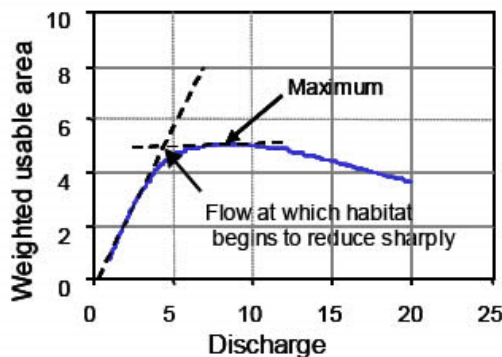
Thanks for your emails. We Wanted to Know:

- Your math and physics background
- What you think ecohydraulics is...
- How you think this might relate to your research
- What you want to learn
- What you think you already know
- Modeling experience
- Field experience
- Fisheries Background



Your Definitions of Ecohydraulics

- “Ecohydraulics is the interdisciplinary study of the interaction between aquatic ecosystems and physical processes (streamflow). I think of PHABSIM/IFIM type analyses when I think of ecohydraulics”
- “Linking hydraulic action within riverine systems to biological and ecological feedbacks”
- “The interaction between the physical stream characteristics of hydraulics and geomorphology and ecology.”
- “The study of the how fluvial hydraulics and geomorphology interact with their surrounding ecosystems.”
- “*Very* generally: studying the role of flowing water in ecosystems (?)”



From Andy Goodwin & Dave Smith (ERDC):
<http://el.ercd.usace.army.mil/emrrp/nfs/individualfish.html>

ECOHYDRAULICS

- The discipline's own definition has evolved...



- Made up word.... But real discipline

hydraulics [har'drɒlɪks]

n

(Physics / General Physics) (*functioning as singular*) another name for [fluid mechanics](#)

Collins English Dictionary – Complete and Unabridged © HarperCollins Publishers 1991, 1994, 1998, 2000, 2003

hydraulics  (hī-drô'līks)

1. The scientific study of water and other liquids, in particular their behavior under the influence of mechanical forces and their related uses in engineering.
2. A mechanical device or system using hydraulic components.

The American Heritage® Science Dictionary Copyright © 2005 by Houghton Mifflin Company. Published by [Houghton Mifflin Company](#). All rights reserved.

flu·vi·al  (flōō'vē-əl)

adj.

1. Of, relating to, or inhabiting a river or stream.
2. Produced by the action of a river or stream.

[Middle English, from Latin *fluviālis*, from *fluvius*, *river*, from *fluere*, *to flow*; see *bleu-* in Indo-European roots.]

The American Heritage® Dictionary of the English Language, Fourth Edition copyright ©2000 by Houghton Mifflin Company. Updated in 2009. Published by [Houghton Mifflin Company](#). All rights reserved.

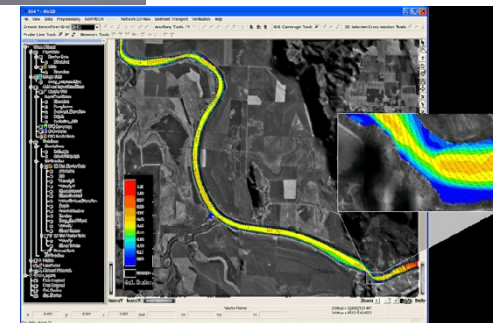
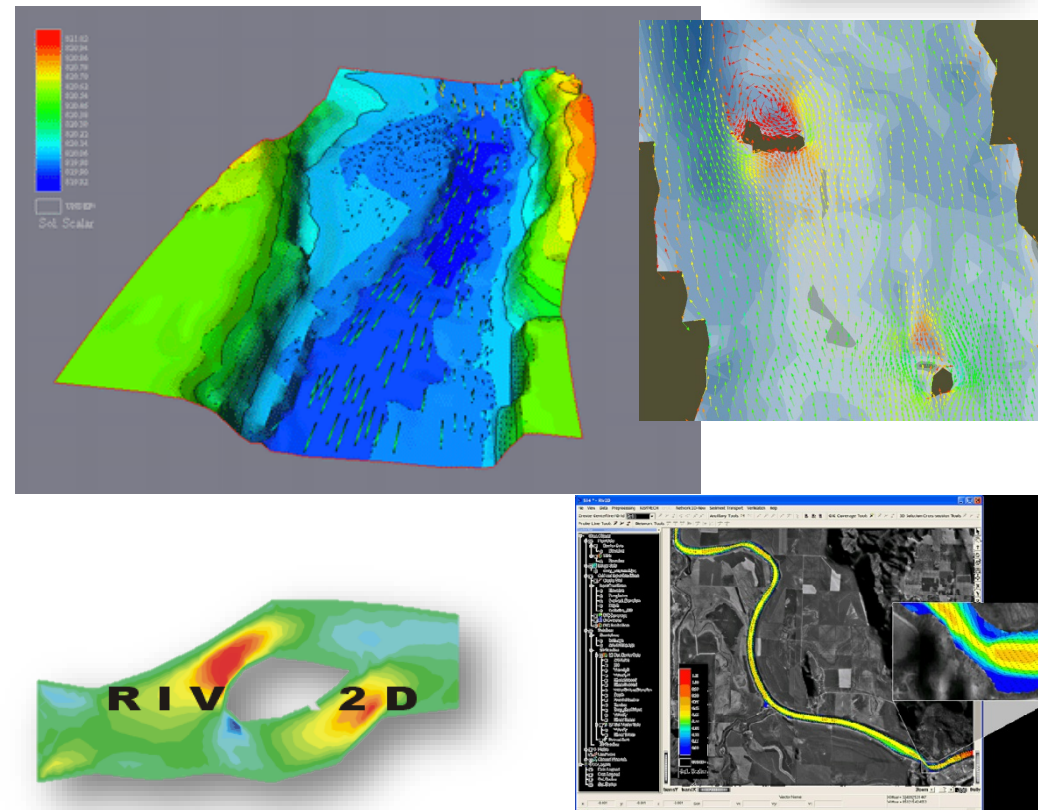
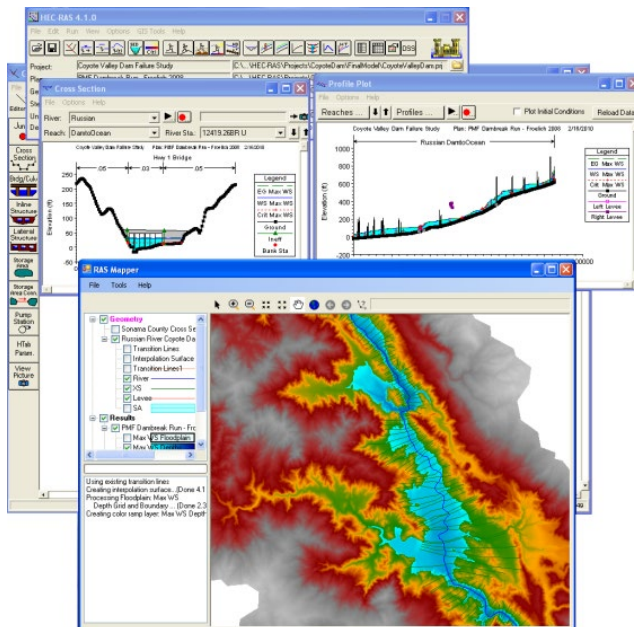
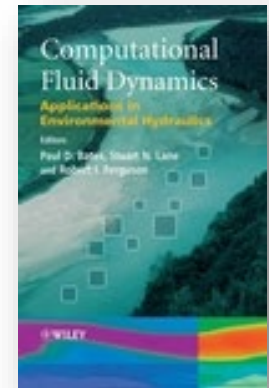
1.2 The Role of Fluvial Hydraulics

The term **fluvial** means “of, pertaining to, or inhabiting a river or stream.” This book is about **fluvial hydraulics**—the internal physics of streams. In the civil engineering context, the subject is usually called **open-channel flow**; the term “fluvial” is used here to emphasize our focus on natural streams rather than design of structures.

- From www.thefreedictionary.com
- From Dingman (2009)

Hydraulics Is Not... But Depends On


- Hydraulics is $f(\text{climate, hydrology, geology, geomorphology})$
- But hydraulics \neq climate, hydrology, geology, geomorphology
- What does hydraulics =?
- What are the primary hydraulic variables?
 - Velocity & Depth



A Different Class taught in 2011 & 2014

FLUVIAL HYDRAULICS & ECOHYDRAULICS

WATS 6900



Fluvial Classroom

[Home](#)
[About the Course \(Syllabus\)](#)
[Assignments](#)
[Class Announcements](#)
[Class Calendar](#)
[Course Discussion Boards](#)
[Fluvial Hydraulics Library Guide](#)
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Utah State University Links

[Department of Watershed Sciences](#)
[Banner Access](#)
[Current Students](#)
[Prospective Students](#)
[Open Course Ware](#)

Other Links

[Joe Wheaton's Website](#)
[ET-AL \(Lab\)](#)
[Links](#)


Welcome to the *Fluvial Hydraulics & Ecohydraulics* course website.

Enrolled Students:

This website is the primary distribution point of information for the course. Unlike [Blackboard](#), this site will be a resource you can return to after you are done with the course.

Prospective Students

This course is being offered during spring semester 2011 as WATS 6900 (special topics). To learn more about whether this course is right for you, see the [About the Course pages](#).



Potholes and flutes along Tromie River gorge.


Recent Announcements

[Get a New Quinney Computer Lab Account](#)
You will need a Quinney computer lab account to participate in labs. **Please do this before you come to your first lab!** Lab accounts are reset every semester. To request ...
Posted Jan 4, 2011 10:21 PM by Joseph Wheaton

[First Class on January 11th!](#) Our first class will meet in the Quinney Library 204 on January 11th at 2:00. If you're considering taking the course for credit and you can't decide ...
Posted Dec 3, 2010 2:42 PM by Joseph Wheaton

Showing posts 1 - 2 of 2. [View more »](#)

Homework Assignments

**[Reading / Homework for Thursday, January 13th](#)**
Read: Skim the Preface to Dingman (2009) Read thoroughly Chapter 1: Introduction to Fluvial Hydraulics (pp 3-19) of Dingman (2009) Read :
Lederc M. 2005. Ecohydraulics: A New Interdisciplinary Frontier ...
Posted 23 hours ago by Joseph Wheaton

Showing posts 1 - 1 of 1. [View more »](#)

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<http://fluvial.joewheaton.org>

Rough Schedule

- Mondays (n = 13) → 1 hour (Mainly Lecture and Intro of Topics)
- Wednesdays (n = 14) → 2 hours (Mix of Student Led Discussion & Labs)
- A Few Field Trips (TBD)

3 Credits

- Generally: Reading & Discussion from Mon to Wed
- Assignments:
 - Lab Write Ups
 - Essays
 - Final

WATS 6900; Spring 2020, Ecohydraulics Syllabus

Date		hrs	Lead Instru	Topic
1/6/2020	M	1	JW	Intro to Ecohydraulics
1/8/2020	W	2	JW	geomorph/hydraulics
1/13/2020	M	1	JW	geomorph/hydraulics
1/15/2020	W	2	JW	Topo/GUT
1/20/2020	M	no class		
1/22/2020	W	2	JW	Geomorphic Units as Building Blocks
1/27/2020	M	1	JW	Traditional Ecohydraulics: H S I
1/29/2020	W	2	JW	H S I
2/3/2020	M	1	JW	FIS Ecohydraulics
2/5/2020	W	2	JW	FIS Ecohydraulics
2/10/2020	M	1	NB	Bionergetic Models
2/12/2020	W	2	NB	Bionergetic Models
2/17/2020	M	no class		President's Day
2/19/2020	W	2	NB	Bioenergetic Models
2/24/2020	M	1	NB	Bioe/IFD
2/26/2020	W	2	NB	Foraging Theory/NREI
3/2/2020	M	no class		
3/4/2020	W	no class		
3/9/2020	M	1	NB	NREI
3/11/2020	W	2	NB	NREI model demo
3/16/2020	M	1	JW	River Styles
3/18/2020	W	2	JW	River Styles
3/23/2020	M	1	JW	Network tools
3/25/2020	W	2	JW	Network tool demo
3/30/2020	M	1	NB	Temp/GPP
4/1/2020	W	2	NB	Management/restoration strategies
4/6/2020	M	1	NB	Intro LCM
4/8/2020	W	2	NB	LCM Demo
4/13/2020	M	1	NB	Upscaling
4/15/2020	W	2	NB	Upscaling
4/20/2020	M	1	NB/JW	Review?

Lots of Ways we Could Tackle Ecohydraulics

We'll use the Wheaton et al. (2017) paper as a roadmap for exploring:

- Salmonids as example
- Traditional Ecohydraulics @ "Reach Scale"
 - Requires understanding
 - Hydraulics, shaped by topography & geomorphology
 - Abiotic controls on habitat
- More advanced ecohydraulics
 - Bioenergetics, Mechanistic, NREI
- But, how do we take details (@ a site) and upscale to ecologically meaningful (i.e. population scale)?

EARTH SURFACE PROCESSES AND LANDFORMS
Earth Surf. Process. Landforms (2017)
Copyright © 2017 John Wiley & Sons, Ltd.
Published online in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/esp.4137

State of Science

Upscaling site-scale ecohydraulic models to inform salmonid population-level life cycle modeling and restoration actions – Lessons from the Columbia River Basin

Joseph M. Wheaton,^{1,2a} Nicolaas Bouwes,^{3,1,2} Peter Mchugh,^{1,3} Carl Saunders,^{1,3} Sara Bangen,^{1,3} Phillip Bailey,⁴ Matt Nahorniak,⁵ Eric Wall,^{1,3} and Chris Jordan⁶

¹ Utah State University, Department of Watershed Sciences, Logan, Utah USA

² Anabran Solutions LLC, Newton, Utah USA

³ Eco Logical Research, Inc., Providence, Utah USA

⁴ North Arrow Research, Inc., Vancouver, British Columbia Canada

⁵ South Fork Research, Inc., Seattle, Washington, USA

⁶ Northwest Fisheries Science Center, National Marine Fisheries Service, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112, USA

Received 10 May 2016; Revised 15 January 2017; Accepted 28 February 2017

*Correspondence to: Joseph M. Wheaton, Utah State University, Department of Watershed Sciences, Logan, Utah, USA. E-mail: joe.wheaton@usu.edu

ESPL
Earth Surface Processes and Landforms

ABSTRACT: With high-resolution topography and imagery in fluvial environments, the potential to quantify physical fish habitat at the reach scale has never been better. Increased availability of hydraulic, temperature and food availability data and models have given rise to a host of species and life stage specific ecohydraulic fish habitat models ranging from simple, empirical habitat suitability curve driven models, to fuzzy inference systems to fully mechanistic bioenergetic models. However, few examples exist where such information has been upscaled appropriately to evaluate entire fish populations. We present a framework for applying such ecohydraulic models from over 905 sites in 12 sub-watersheds of the Columbia River Basin (USA), to assess status and trends in anadromous salmon populations. We automated the simulation of computational engines to drive the hydraulics, and subsequent ecohydraulic models using cloud computing for over 2075 visits from 2011 to 2015 at 905 sites. We also characterize each site's geomorphic reach type, habitat condition, geomorphic unit assemblage, primary production potential and thermal regime. We then independently produce drainage network-scale models to estimate these same parameters from coarser, remotely sensed data available across entire populations within the Columbia River Basin. These variables give us a basis for imputation of reach-scale capacity estimates across drainage networks. Combining capacity estimates with survival estimates from mark-recapture monitoring allows a more robust quantification of capacity for freshwater life stages (i.e. adult spawning, juvenile rearing) of the anadromous life cycle. We use these data to drive life cycle models of populations, which not only include the freshwater life stages but also the marine and migration life stages through the hydropower system. More fundamentally, we can begin to look at more realistic, spatially explicit, tributary habitat restoration scenarios to examine whether the enormous financial investment on such restoration actions can help recover these populations or prevent their extinction. Copyright © 2017 John Wiley & Sons, Ltd.

KEYWORDS: salmon recovery; stream and river restoration; *Oncorhynchus* sp; fish habitat; population modeling

Introduction

Globally, native anadromous salmonid populations are in decline and several face the threat of extinction (Gustafson et al., 2007; Rand et al., 2012). Given the cultural, economic, and ecological importance of these populations, numerous efforts are underway to mitigate impacts that lead to their decline and facilitate their recovery (e.g. conservation hatcheries (Maynard and Trial, 2013), habitat restoration (Barnas et al., 2015)). For example, in the Columbia River

Basin, there are eleven evolutionarily significant units of salmon or steelhead (*Oncorhynchus* sp.) listed as threatened and two as endangered under the US Endangered Species Act (ESA) (Ruckelshaus et al., 2002; Gustafson et al., 2007). According to the ESA review on the risks posed to anadromous salmonids by the Columbia Basin's federally administered hydropower dam system (NOAA, 2008), three action agencies are required to make costly dam retrofits and operational changes (i.e. to improve passage) and/or mitigate dam impacts via offsite actions (i.e. tributary habitat restoration). The

2. Riverscapes: a framework for understanding rivers

2.1. *The riverscape concept*

The concept of the “riverscape” dates to at least the 1960s, when Leopold and Marchand (1968) used the term to describe the large-scale physical, biological, and aesthetic nature of rivers. The most common use of the term today, originating in the early 2000s (Fausch et al., 2002; Poole, 2002; Ward et al., 2002b; Wiens, 2002) represents an ecological perspective that portrays rivers as a combination of broad scale trends in energy, matter, and habitat structure as well as local discontinuous zones and patches. The large and local extent variations affect the movement and dynamics of biological popula-

The term has become explicitly multi-scalar, and explicitly inter-disciplinary...

Making riverscapes real

Patrice Carbonneau ^a, Mark A. Fonstad ^{b,*}, W. Andrew Marcus ^c, St

Landscapes to Riverscapes: Bridging the Gap between Research and Conservation of Stream Fishes

KURT D. FAUSCH, CHRISTIAN E. TORGERSEN, COLDEN V. BAXTER, AND HIRAM W. LI

Rivers and streams, by their very nature long ribbons of aquatic habitat, are inherently difficult to study. Approaching the banks of a flowing-water (lotic) system, one can see only a short fragment of the entire stream, from one bend to another, and can gain little appreciation for important features that lie beyond view. Moreover, materials transported downstream by the flow, and organisms traveling up or down the hydraulic highway, are soon gone from the reach and the opportunity to study them is often lost. Lakes present their own challenges for study, but by contrast to streams, one can usually see large expanses from shore that encompass all major habitats needed for aquatic organisms to complete their life history, such as gravel shoals, beds of aquatic vegetation, and open water habitats. Much of our knowledge of the ecology of rivers and streams is based on observations and experiments on organisms and habitat in the short fragments we can view or quickly traverse on foot, and this limited understanding underpins our efforts at conservation of stream fishes. Here, we argue that this understanding is incomplete, like viewing only disjoint parts of a landscape painting through small holes in a curtain draping it. We propose that a continuous view of rivers is essential for effective research and conservation of their fishes and other aquatic biota—a view not just of disjoint reaches but of the entire spatially heterogeneous scene of the river environment, the riverscape, unfolding through time.

One symptom of our incomplete understanding is the alarming rate of decline over the last 50 years of fishes that inhabit rivers and streams of North America. The public is aware that salmon are disappearing from the Pacific Northwest, with about a quarter of the 214 stocks of anadromous salmon and trout imperiled a decade ago (Nehlsen et al. 1991). Even little-known small fishes native to Great Plains and southwestern desert streams have suffered drastic declines

A CONTINUOUS VIEW OF THE RIVER IS
NEEDED TO UNDERSTAND HOW PROCESSES
INTERACTING AMONG SCALES SET THE
CONTEXT FOR STREAM FISHES AND THEIR
HABITAT

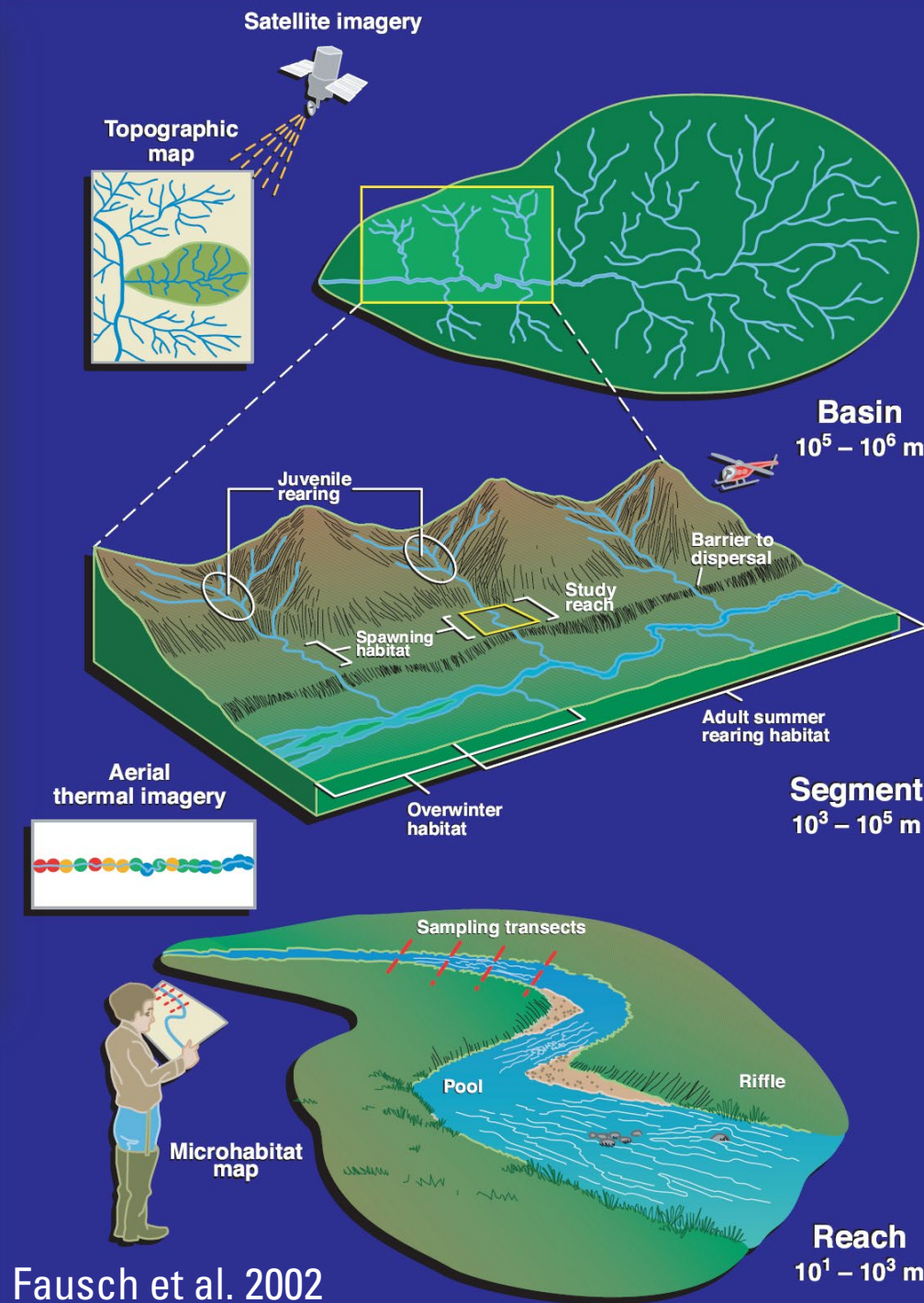
(Minkley and Douglas 1991, Fausch and Bestgen 1997), and many are now either protected by federal or state listing as endangered or threatened species or are being considered for such protection. North America harbored the greatest diversity worldwide of temperate freshwater fishes (Warren and Burr 1994), crayfishes (Taylor et al. 1996), and mussels (Williams et al. 1993), but about 30% to 75% of the taxa in each group are at increased risk of extinction (i.e., categorized as rare, threatened, or endangered species). Fishes are also the most imperiled vertebrates worldwide (Allan and Flecker 1993, Leidy and Moyle 1998) and a large proportion spend at least part of their lives in streams.

Kurt Fausch (e-mail: kurtf@colorado.edu) is a professor in the Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins, CO 80523. Christian Torgersen and Colden Baxter are graduate students, and Hiram Li is a professor, in the Department of Fisheries and Wildlife, Oregon State University, Corvallis, OR 97331. Li is also assistant unit leader of the Oregon Cooperative Fish and Wildlife Research Unit, Biological Resources Division, US Geological Survey. © 2002 American Institute of Biological Sciences.

June 2002 / Vol. 52 No. 6 • BioScience 483

Landscapes to riverscapes: by conservation of stream fishes we understand how ...

KD Fausch, CE Torgersen, CV Baxter...
Fisheries ecologists have attempted to populations and assemblages by conduct...
Typical studies have consisted of obser...
Cited by 1032 Related articles All 16



A grayscale topographic map of a mountainous region. The terrain is characterized by numerous ridges and valleys. A network of rivers is visible, flowing through the valleys. The text "Lets start with some basics" is overlaid in a dark gray rounded rectangle at the top left.

Lets start with some basics

Is this a riverscape?

A grayscale topographic map of a mountainous region, with blue lines tracing the paths of numerous rivers and streams across the terrain. The map shows a complex network of waterways flowing through valleys and around mountain peaks.

Is this a **Riverscape** ?

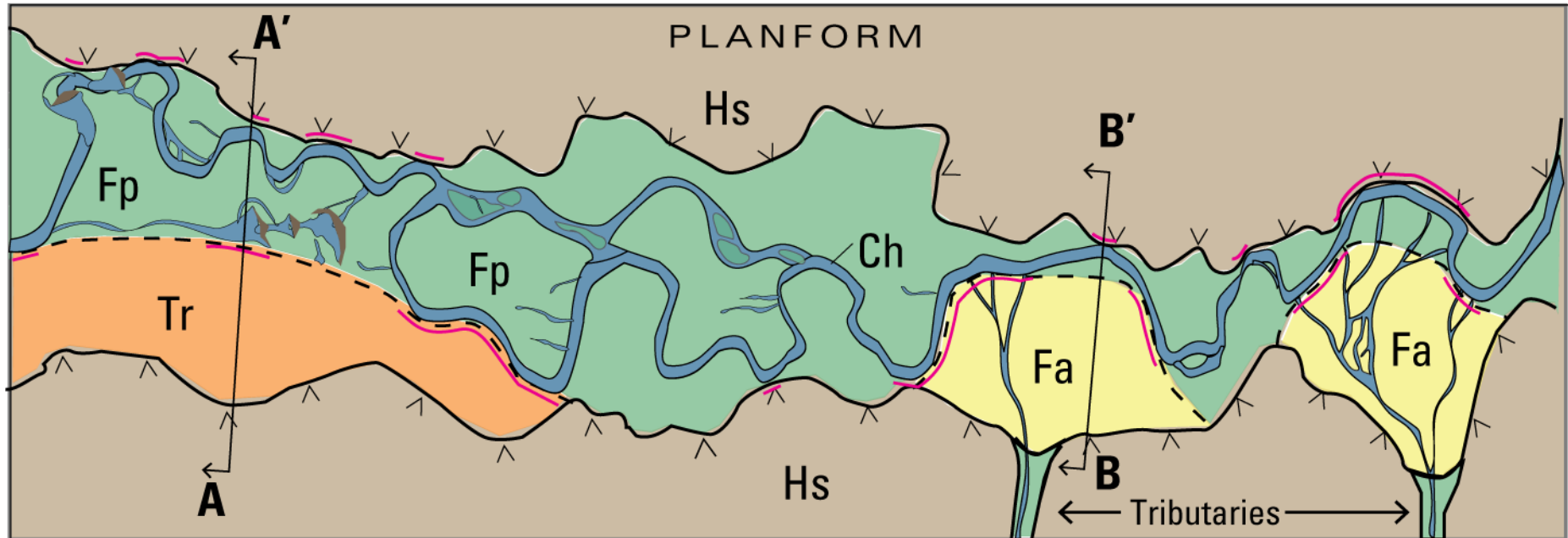
We know that our rivers and streams are critically important to our fresh-water ecosystems

A topographic map of a watershed, showing a network of rivers and streams. The rivers are highlighted in blue, and the floodplains are highlighted in green. The map is overlaid with a semi-transparent grey box containing text.

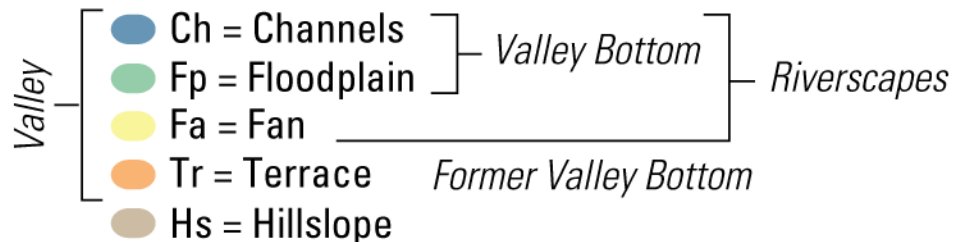
Riverscapes span the network across a watershed

Riverscapes are the part of the landscape that could plausibly flood by their rivers & streams in contemporary flow regime.

Reading your riverscape...



GEOMORPHIC UNIT KEY



The valley bottom is comprised of areas that could plausibly flood in the contemporary flow regime.

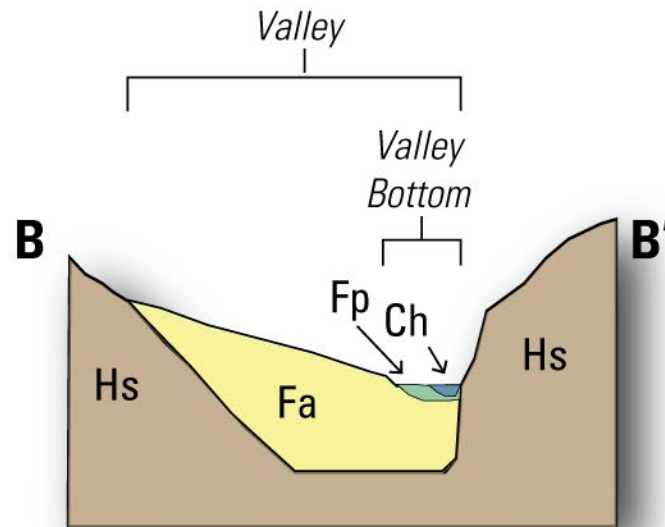
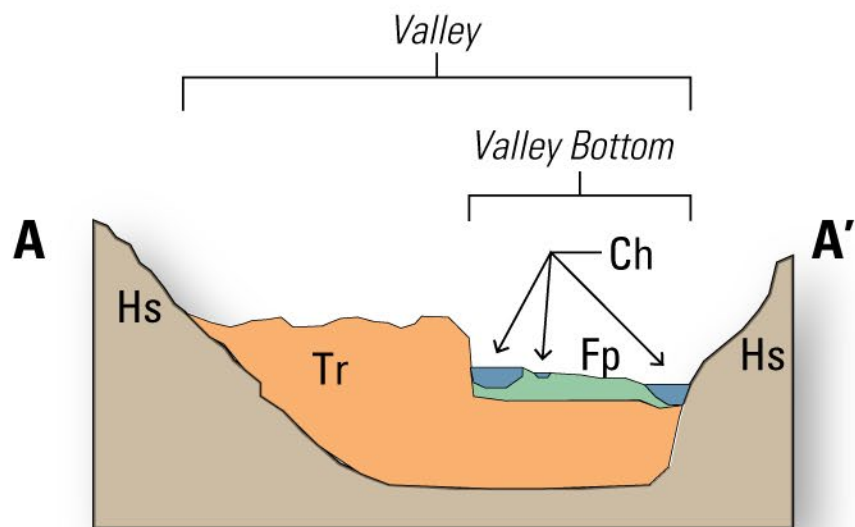
MARGIN TYPES

- Valley Margin
- - Valley Bottom Margin
- Active Confining Margin

Where are their riverscape & riparian restoration or conservation opportunities?

Contrasting Valley Settings Lead to Different Hydraulics

VALLEY CROSS SECTIONS

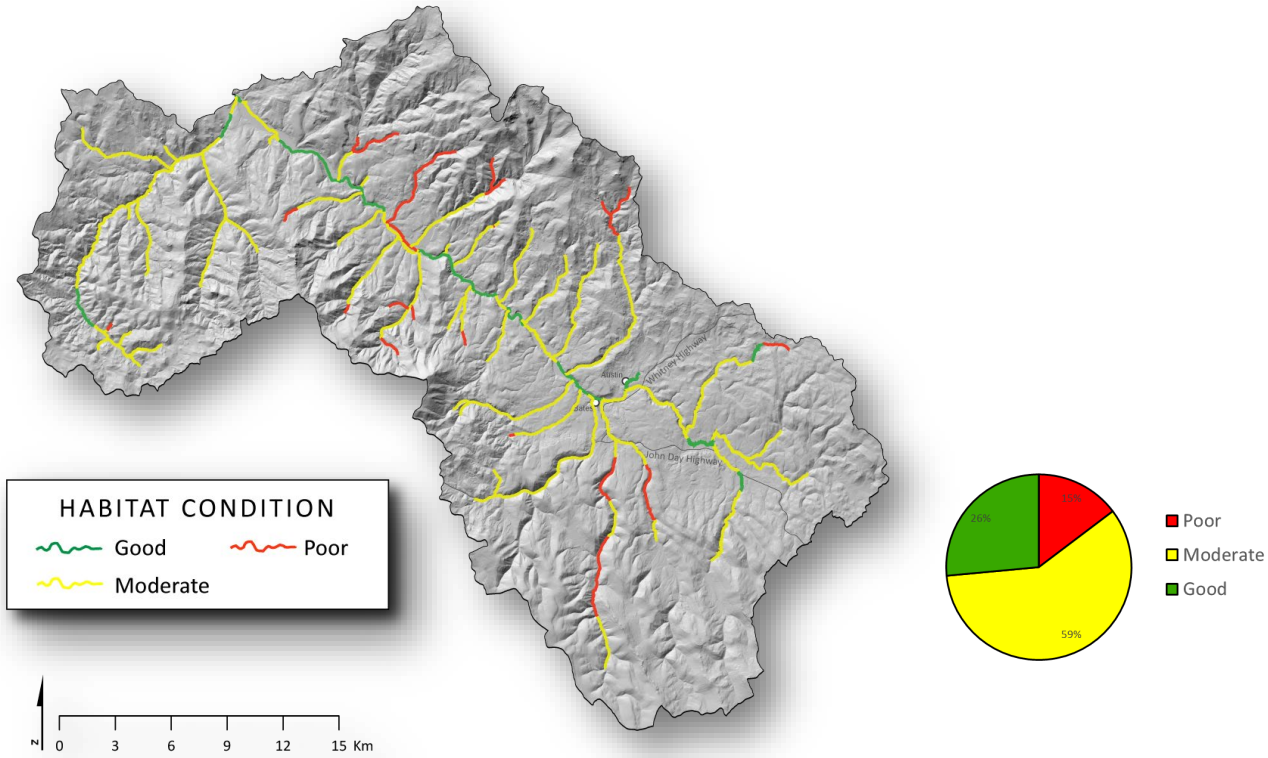


From page 10 of Pocket Guide; Wheaton et al. (2019)

DOI: [10.13140/RG.2.2.28222.13123/1](https://doi.org/10.13140/RG.2.2.28222.13123/1)

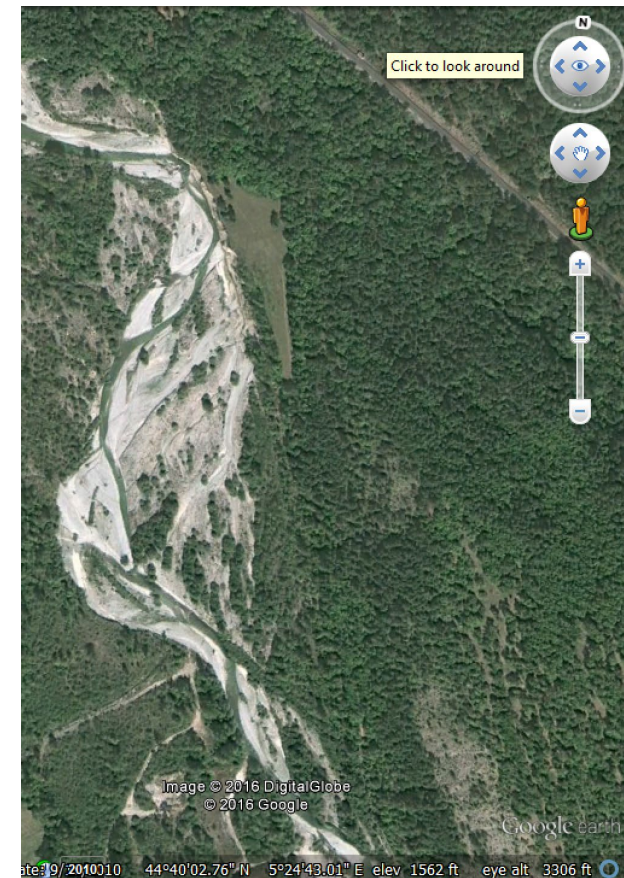
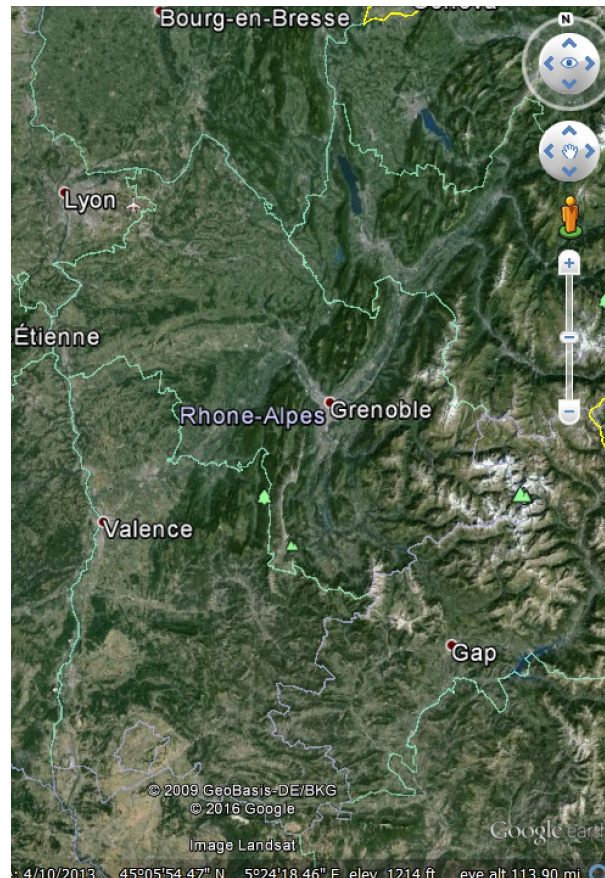
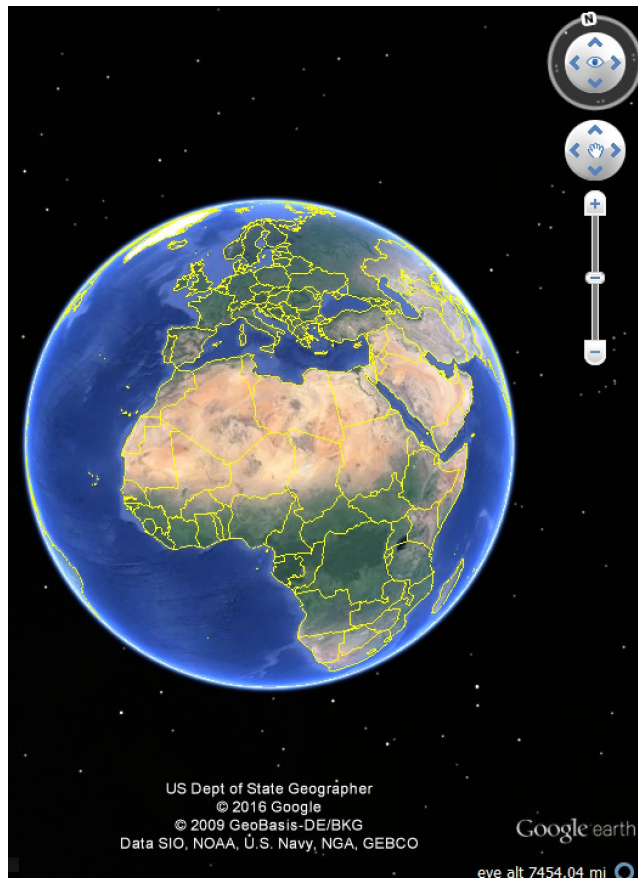
Argument For Network Scale

'A continuous view of the river is needed to understand how processes interacting among scales set the context for stream fishes and their habitat' – Fausch et al. (2002)

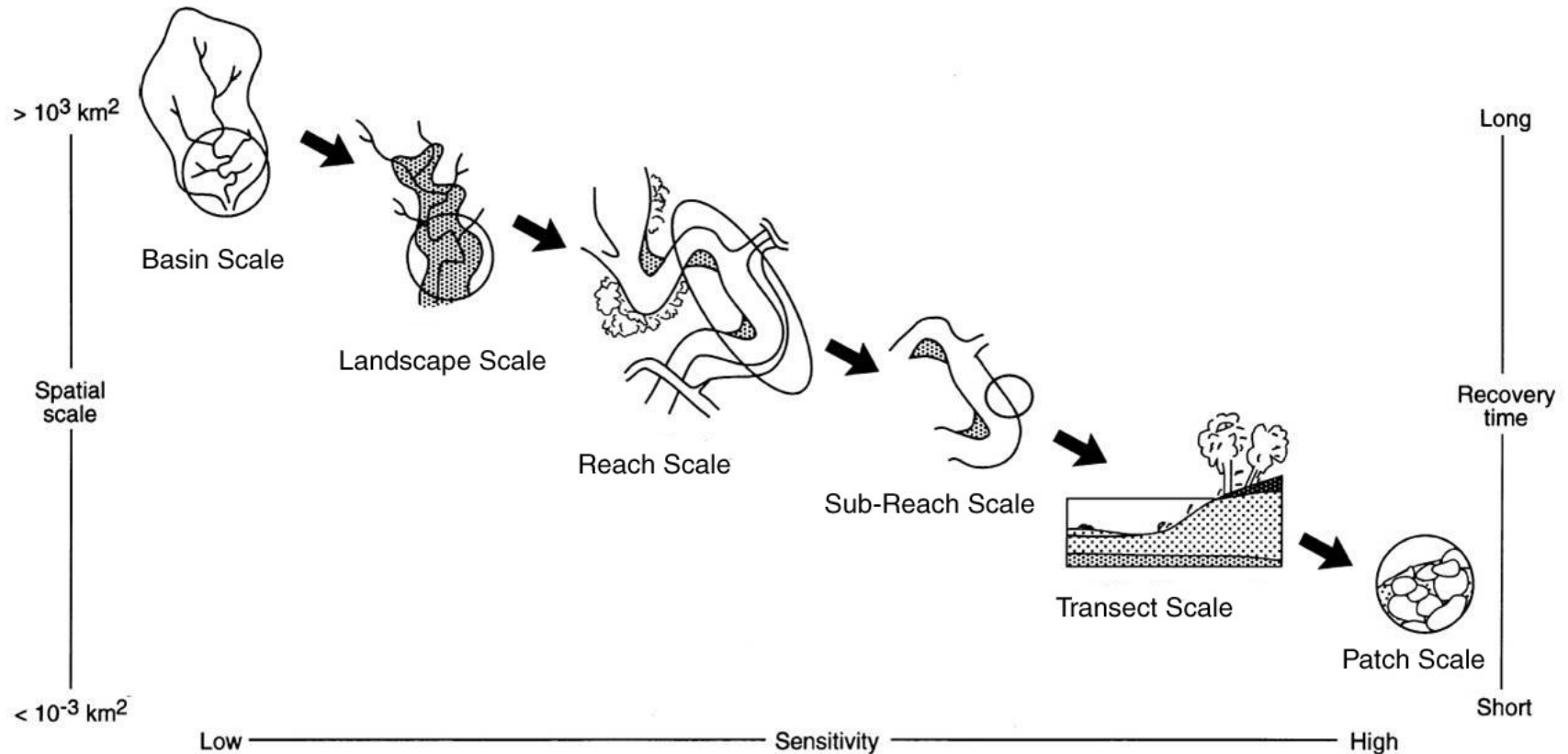


Transcending Scales

The lens we will bring to ecohydraulics this semester



The Space-time Assertion & Nested Spatial Scales

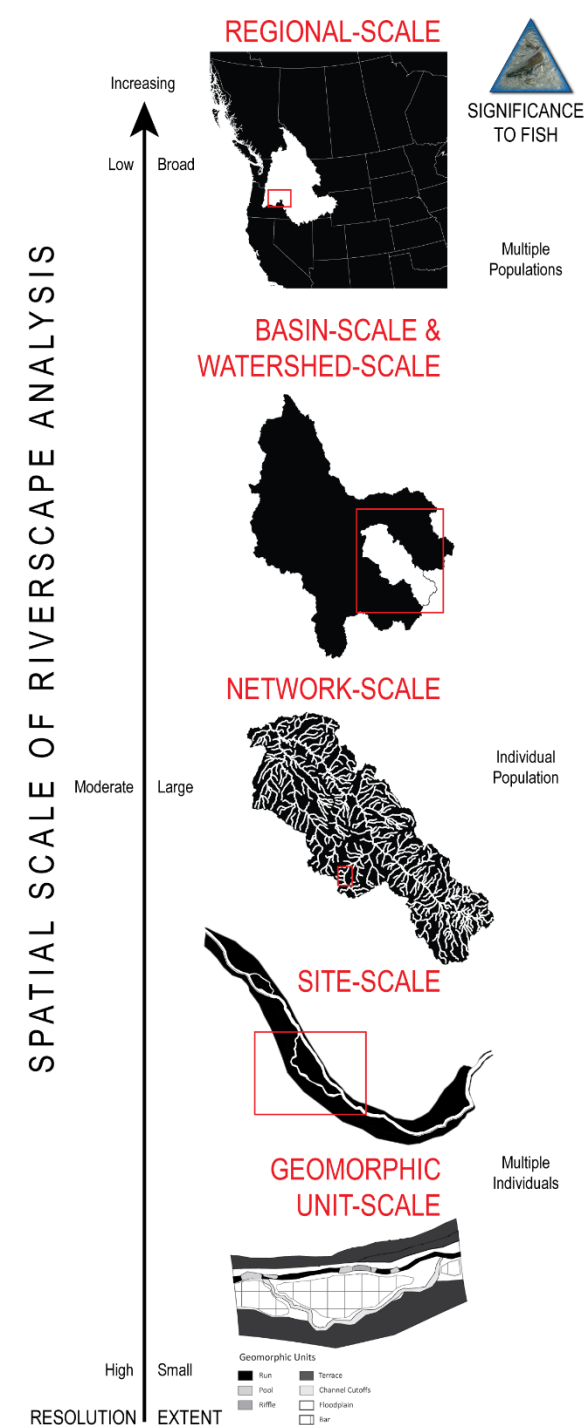


What scale are hydraulics at? Ecohydraulics?

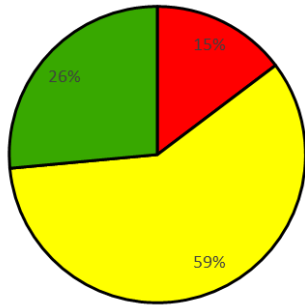
Let's Be Clear About Spatial Scale...

Scale Name	Extent	Resolution
Basin-Scale Region-Scale	Basin (10^2 to 10^3 km ²)	Watershed (10^2 to 10^3 km ²)
Watershed-Scale Sub-Basin-Scale	Watershed (10^1 to 10^2 km ²)	Watershed (10^1 to 10^2 km ²)
Network-Scale	Watershed (10^2 to 10^3 km ²)	Reach (10^2 to 10^3 m)
Reach-Scale	Reach (10^2 to 10^3 m)	Geomorphic Unit (10^0 to 10^2 m)
Sites-on-Network-Scale	Watershed (10^1 to 10^2 km ²)	Site Locations (points)
Site-Summary-Scale	Reach (10^2 to 10^3 m)	Reach (10^2 to 10^3 m)
Site-Scale (CHaMP Reach)	Reach (20 x Bankfull width; 160 m to 600 m)	Cell (10^{-1} to 10^0 m)
Geomorphic-Unit-Scale	Geomorphic Unit (10^0 to 10^2 m)	Hydraulic Unit (10^0 to 10^1 m) or Cell
Hydraulic-Unit-Scale	Hydraulic Unit (10^0 to 10^1 m)	Grain (10^{-2} to 10^0 m)
Cell-Scale	Cell (10^{-1} to 10^0 m)	Cell (10^{-1} to 10^0 m)

- Defined in terms of extent & resolution
- What scale is ecohydraulics studied at?



The Stop-Light Demand Dilemma

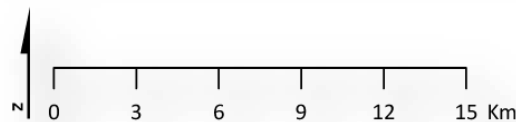


■ Poor
■ Moderate
■ Good

How to make *network scale* maps that make meaningful predictions of riverscapes, but still communicate message simply?

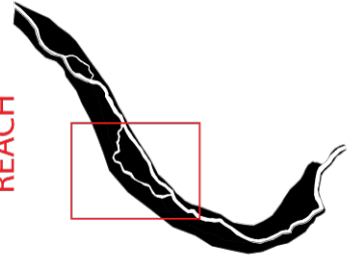
FOR CONCEPTUAL PURPOSES ONLY
NOT FOR DISTRIBUTION

CONDITION
MAPS



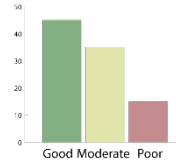
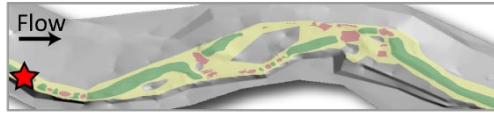
The Scale Crux...

REACH



①

SITE LEVEL



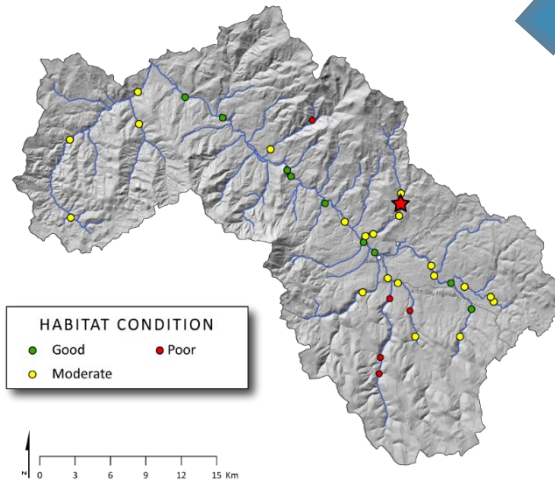
②

SITE SUMMARY:



③

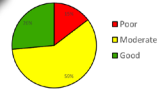
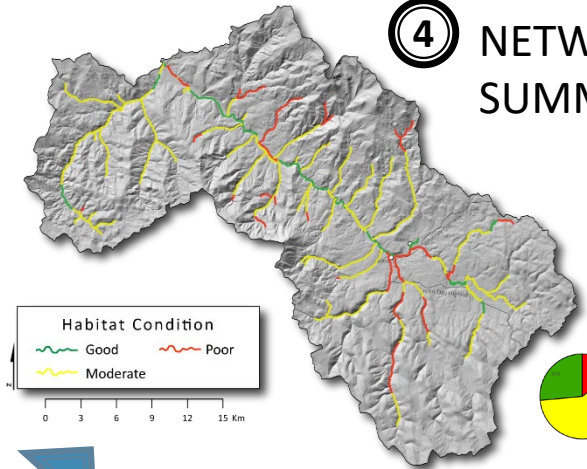
SITES ON NETWORK



NETWORK

④

NETWORK SUMMARY



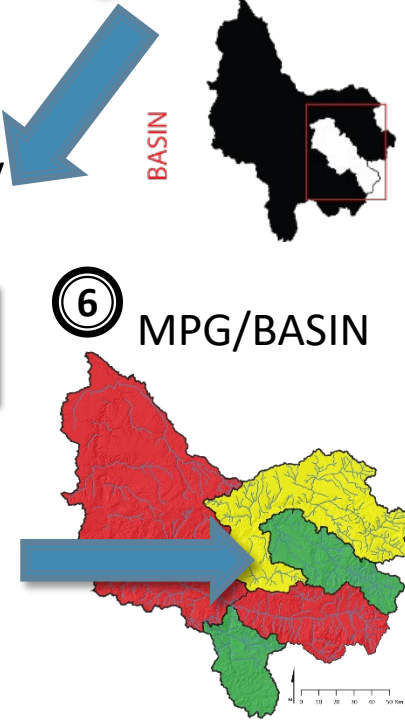
⑤

WATERSHED / POPULATION



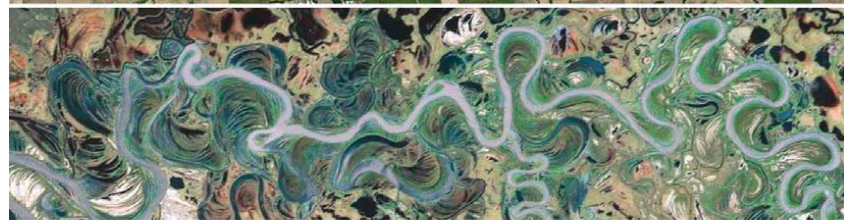
⑥

MPG/BASIN



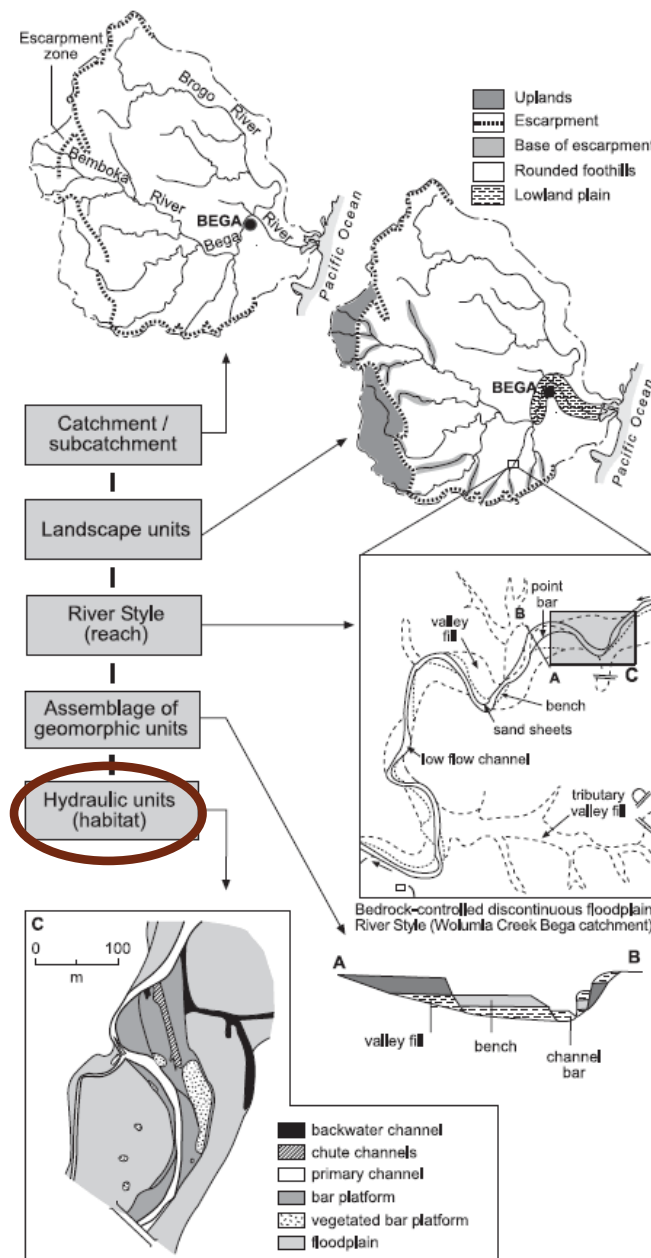
FOR CONCEPTUAL PURPOSES ONLY
NOT FOR DISTRIBUTION

Some Different Flavors Or



Nested-Hierarchical Scales

1. 'Reach Types' or 'River Styles' are flavors of riverscapes
2. Flavor based on physiography:
 1. Climate
 2. Geology
 3. Ecology
3. River Style predicts what you will find at finer-scale (i.e. habitat)



SPATIAL SCALE OF RIVERSCAPE ANALYSIS

Increasing
Low Broad



Multiple Populations

BASIN-SCALE & WATERSHED-SCALE

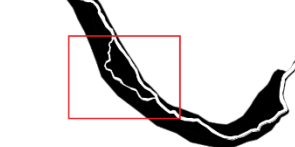


NETWORK-SCALE

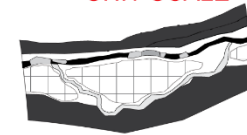


Individual Population

SITE-SCALE



GEOMORPHIC UNIT-SCALE



Multiple Individuals

High Small

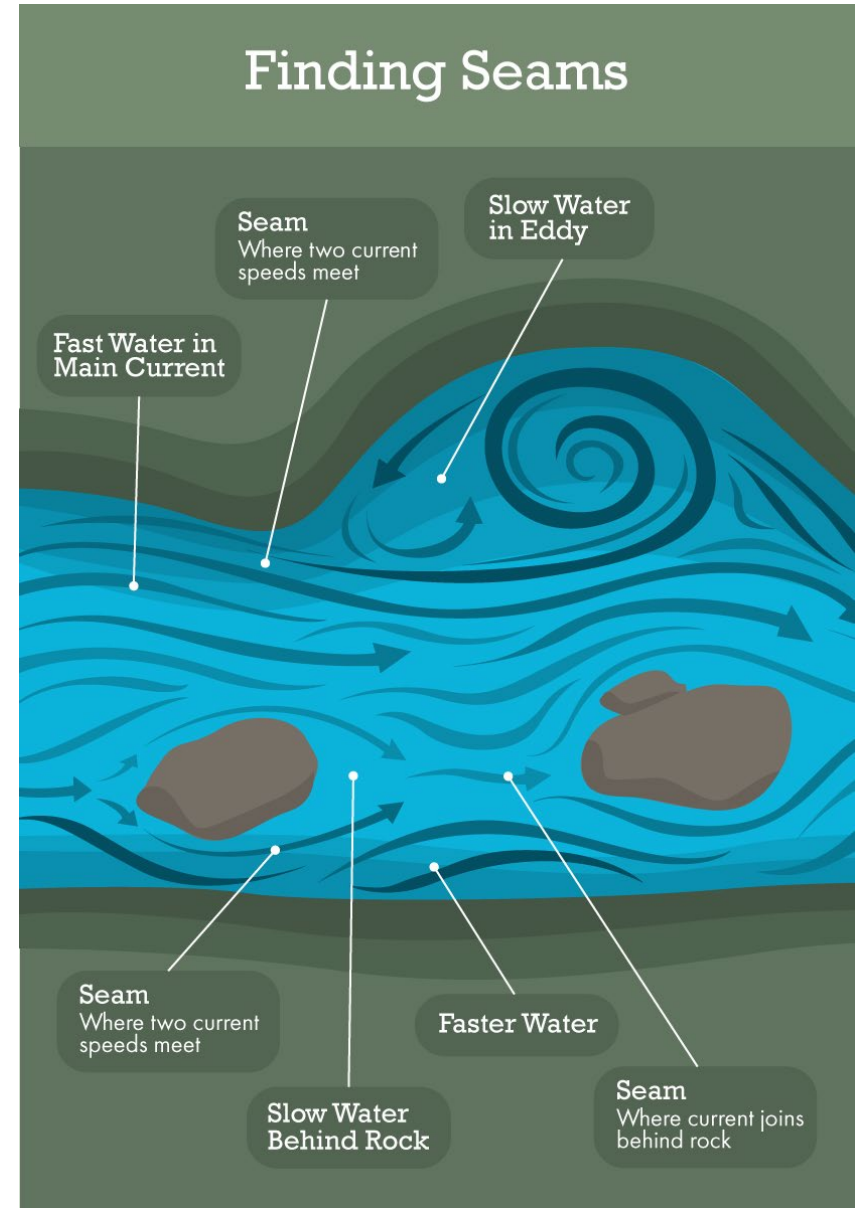
RESOLUTION EXTENT

Geomorphic Units

Run
Pool
riffle
Terrace
Channel Cuts
Floodplain
Bar

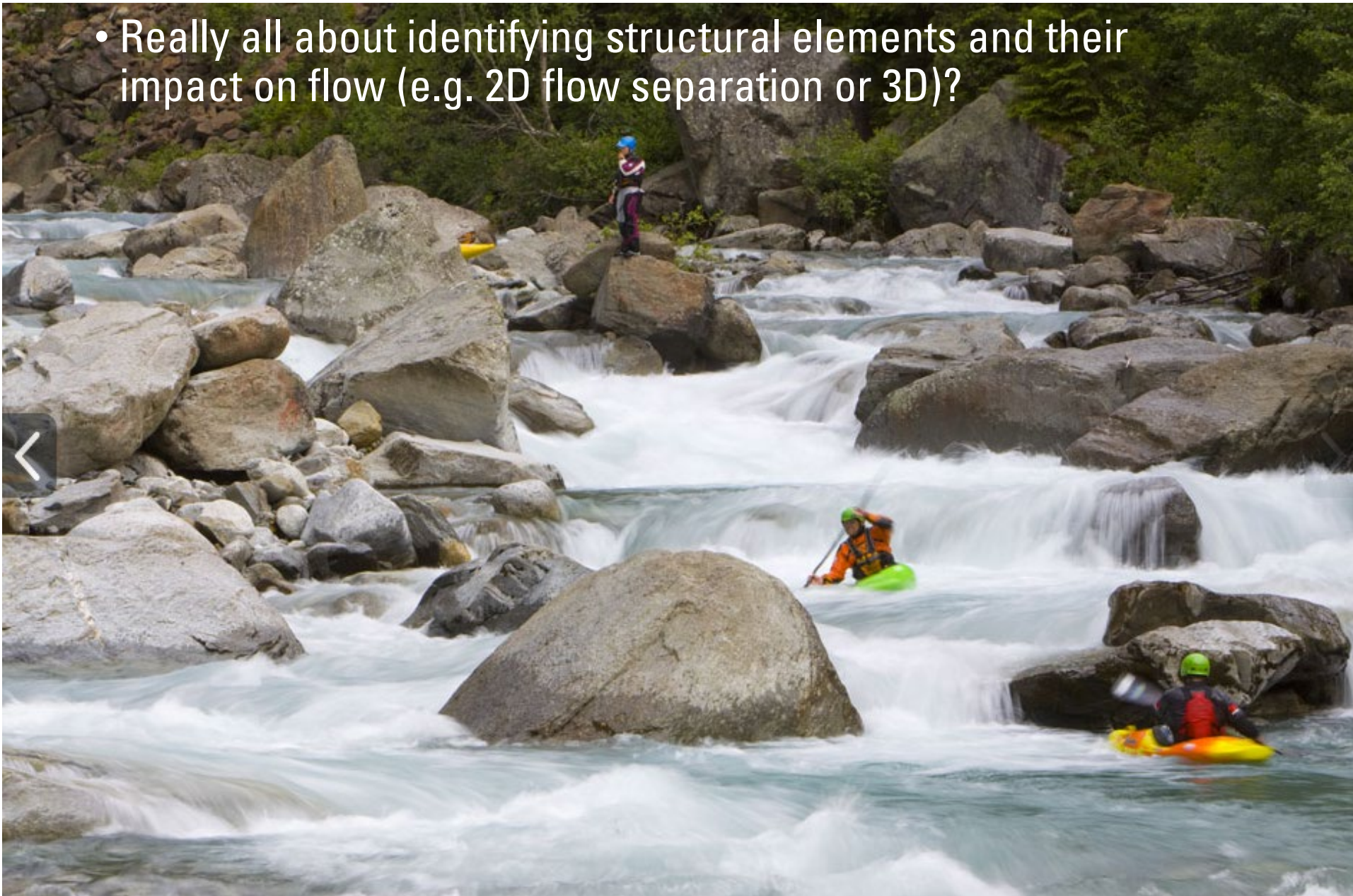
Reading The River... vs. The Riverscape?

- Hydraulics matter!
- Whether you're a:
 - Fly fishermen,
 - A whitewater kayaker
 - Or a fluvial geomorphologist



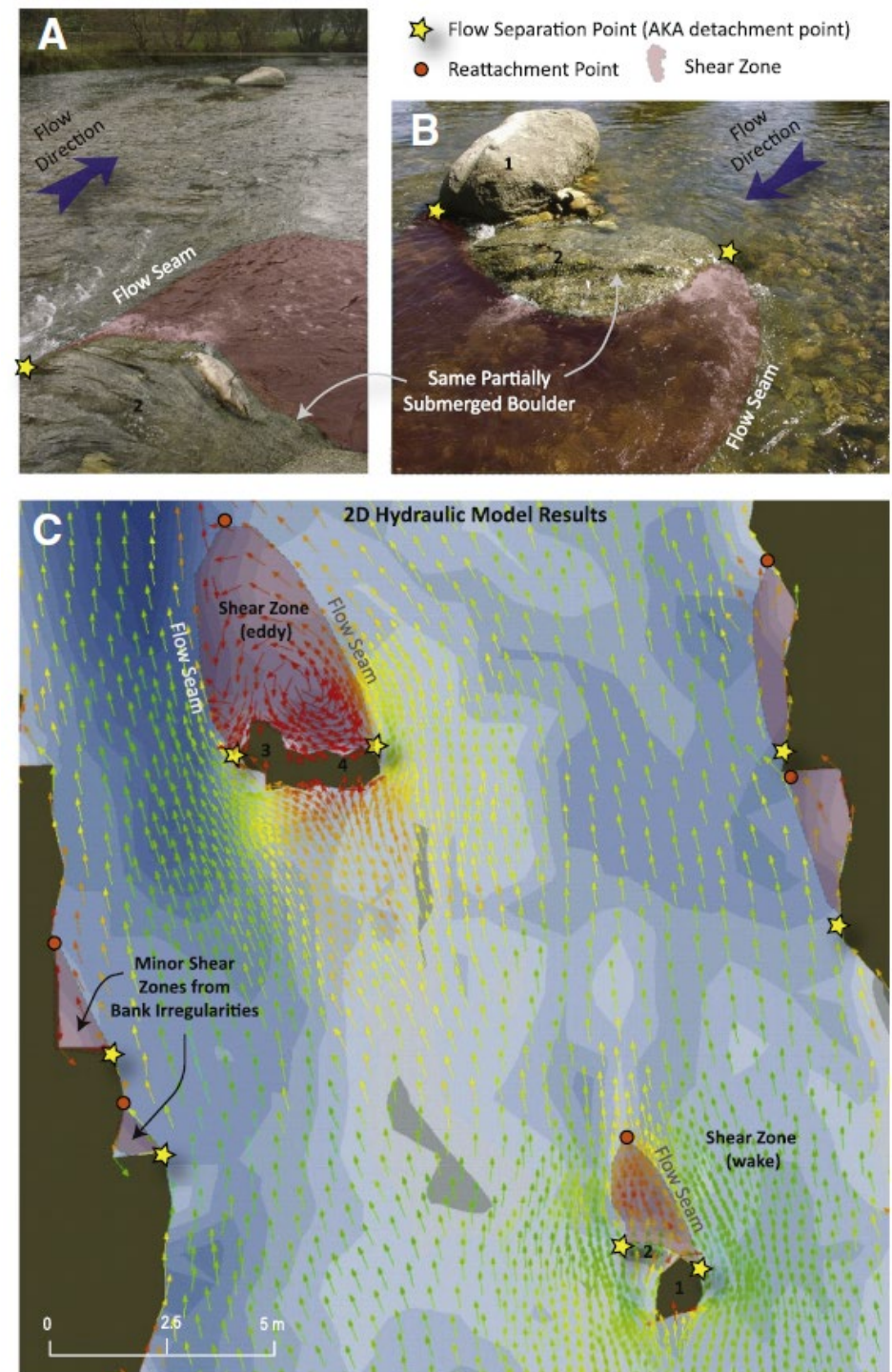
Reading Water (i.e. Hydraulics) Helps You Navigate Safely...

- Really all about identifying structural elements and their impact on flow (e.g. 2D flow separation or 3D)?



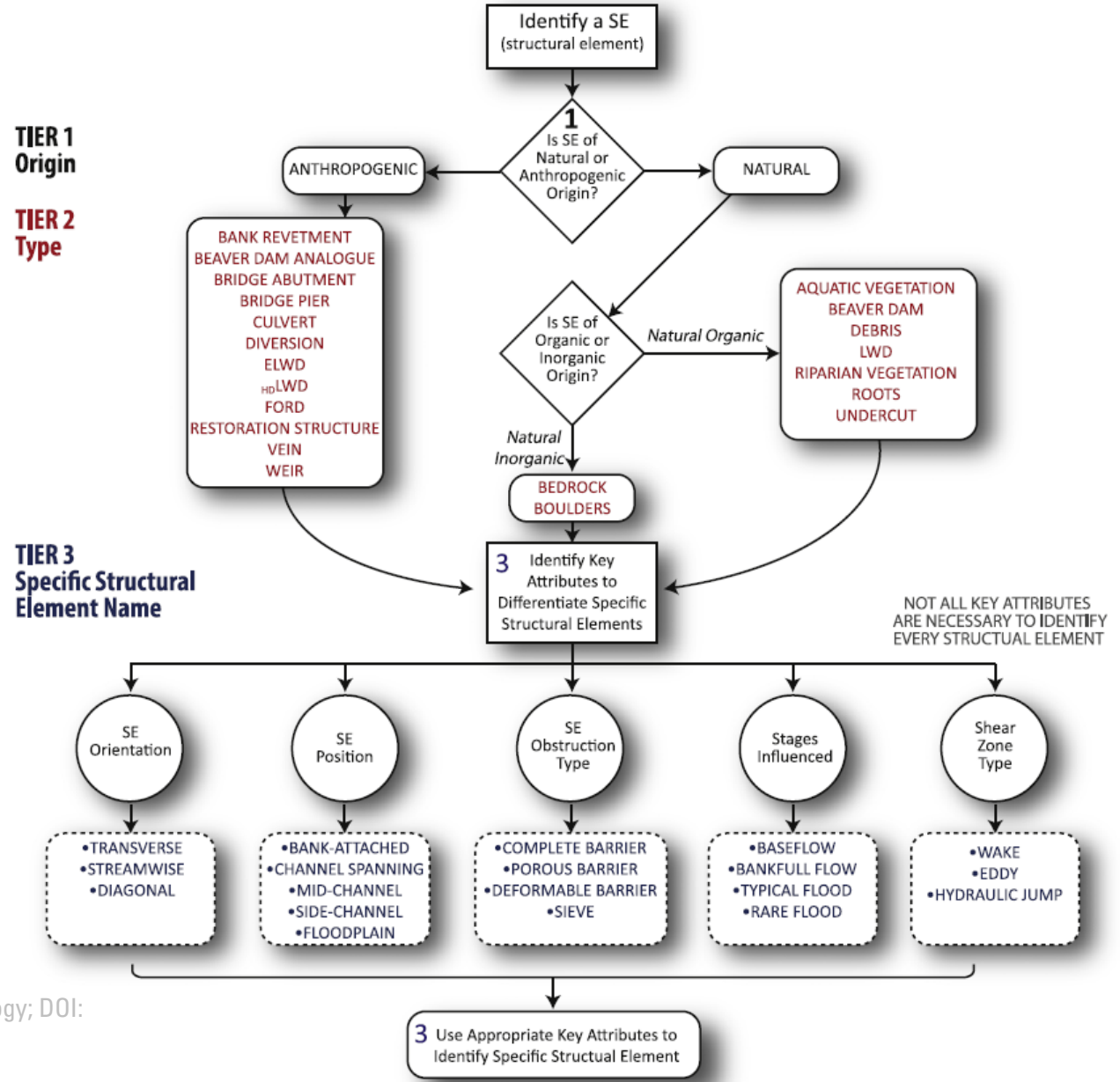
Some Definitions

- A structural element is a discrete object that directly influences hydraulics
- Structural elements produce:
 - Flow separation points
 - Flow seams
 - Shear zones
 - Reattachment point or zone
- Help predict zones of erosion, deposition, margins and 'forced' geomorphic units



Differentiating Structural Elements

- Helps predict its:
 - Hydraulic influence
 - geomorphic influence



Key Attributes of Structural Elements

Table 1
Key attributes that help differentiate tier 3 structural elements; abbreviations: SE (structural element).

Key Tier 3 attributes:	Types	Description
SE orientation		The orientation refers to the relative alignment of the structural element's long axis with respect to the dominant streamwise flow direction
	└Transverse	Transverse SEs are oriented perpendicular to the flow (e.g. <i>beaver dam</i>)
	└Streamwise	Streamwise SEs are oriented parallel to the flow (e.g. <i>a piece of LWD aligned with the flow</i>)
	└Diagonal	Diagonal SEs intersect the flow at an angle
SE Position		The position of the SE with respect to the channel(s); Note use consistency whether the 'channel' refers to the low flow channel or bankfull channel.
	└Bank Attached	Attached or connected to one side of the channel margin
	└Channel Spanning	Spanning across the entire channel from channel margin to channel margin
	└Mid Channel	Not attached or connected to either side of the channel margin
	└Side-Channel	Located in a side or secondary channel
	└Floodplain	Located on the floodplain
SE obstruction type		Refers to the type and nature of flow obstruction the SE object creates
	└Complete Barrier	When all flow is forced around or over top of the SE
	└Porous Barrier	When most flow is forced around or over top of the SE, but some flow can flow through the SE itself (e.g. a debris jam)
	└Deformable Barrier	When SE is non-rigid such that when subjected to flows it deforms in a streamwise fashion (e.g. grasses)
	└Sieve	When most flow is forced through various pathways through SE, but some can flow over or around
	└Funnel	When flow is funneled through the SE (e.g. a culvert)
	└Roughness	When flow is not obstructed by SE, but instead SE simply exerts more drag on the flow at the boundary than the typical boundary
Stages influenced		Refers to the flow/flood stage at which the SE exerts an influence on the flow
	└Baseflow	The mean low flow stage (note, this may be zero for intermittent and ephemeral channels)
	└Bankfull Flow	The discharge just before flow spreads out on to a floodplain (not present in all channels)
	└Typical Flood	The discharge associated with floods that occur regularly (e.g. 1 to 5 year recurrence intervals)
	└Rare Flood	The maximum probable or historically recorded flood
Shear zone type		Refers to the type of hydraulic impact induced by the downstream typically just downstream or on the lee side of the SE; the shear zone type is very stage dependent, but closely related to the obstruction type
	└Wake	A wake is a zone of slower moving water in the lee of an obstruction to the flow but that is still generally flowing in a streamwise direction
	└Eddy	An eddy is a flow recirculation cell downstream of a flow separation (often, but not always induced by SE) in which the flow direction varies (including flowing upstream) but generally makes a circular vortice
	└Hydraulic Jump	Represents a transition from subcritical to supercritical (typically over the SE) and back to subcritical flow; such hydraulic features can take various forms (e.g. wave trains, standing wave, submerged jump (i.e. drop))

Many Flavors... Make Hydraulics More Interesting



Table 2

Structural elements (SE) at tier 3 and their key attributes: note, any key attribute listed as 'varies' or 'NA' (not applicable) is not useful in differentiating that SE from other SEs; this list is complete at tiers 1 and potentially tier 2, but other specific SEs exist at tier 3.

Tier 1	Tier 2	Tier 3	Key attributes to differentiate specific structural elements				
Origin	Type	Specific structural element name	Geometry		Nature of flow impact		
			SE orientation	SE position	SE obstruction type	Stages influenced	Shear zone type
Anthropogenic							
L	Bank revetment	Bioengineered, Gabions, detroit rip rap, boulder rip rap, erosion control blanket	Streamwise	Bank-attached	Roughness	Varies	DS eddy
	Beaver dam analogue	Primary dam, secondary dam, reinforced existing dam		Channel-spanning	Porous barrier	All	US backwater
L	Bridge abutments	NA		Bank-Attached	Complete barrier	Varies	DS eddy
L	Bridge pier	NA		Mid-channel	Complete barrier	All	DS eddy
L	Culvert	Box, arch, pipe	Streamwise	Channel-spanning	Funnel	All	US backwater
L	Diversion	Irrigation, canal, pump point of diversion	Transverse	Bank-attached or channel-spanning	Complete barrier	Varies	US backwater
L	ELWD	Debris jam, bank deflectors	Varies	Varies	Porous barrier	Varies	Varies
L	LWD	Post-assisted log structure, constriction structure, mid-channel structure	Varies	Varies	Porous barrier	Varies	US & DS eddies
L	Ford	Concrete, native bed material	Transverse	Channel-spanning	Complete barrier	All	US backwater
L	Restoration structure	Many types	Varies	Varies	Varies	Varies	Varies
L	Rock vein	NA	Diagonal	Bank-attached	Porous barrier	All	DS & US eddy
L	Vortex weir	NA	Transverse	Channel-spanning	Porous barrier	All	Varies
Natural inorganic							
L	Bedrock						
L		Bedrock ledge	Varies	Varies	Complete barrier	Varies	DS eddy
L		Bedrock outcrop	Varies	Varies	Complete barrier	Varies	DS eddy
L	Boulder						
L		Boulder cluster	Varies	Mid-channel	Complete barrier	All	DS eddy
L		Boulder dam	Transverse or diagonal	Channel-spanning	Porous barrier	All	US backwater
L		Boulder ribs	Transverse or diagonal	Mid-channel	Porous barrier	Varies	DS eddy
Natural organic							
L	Aquatic vegetation	Many types	Varies	Varies	Porous barrier	All	DS Wake (occ. DS eddy)
Beaver dam							
L		Intact Dam	Transverse	Channel-Spanning	Porous Barrier	All	US Backwater & DS Wake
L		Breached dam	Transverse	Channel-spanning	Porous barrier	All	US backwater and DS eddies
L		Blown-out dam	Transverse	Channel-spanning or bank-attached	Porous barrier	All	DS & US eddy
LWD							
L		Individual root wad	Varies	Varies	Porous barrier	Varies	DS Eddy or wake
L		Debris jam	Transverse	Channel-spanning	Porous barrier	All	US backwater & DS wake
L		Channel spanning log Raft jams	Transverse or diagonal	Channel-spanning	Varies	Varies	Varies
L		Log	Varies	Varies	Varies	Varies	Varies
L	Riparian vegetation	Many types	Varies	Varies	Porous barrier	> Flood stage	Varies

As a boater, Identifying Structural Elements Is Critical!

Rio Ara – Above Broto

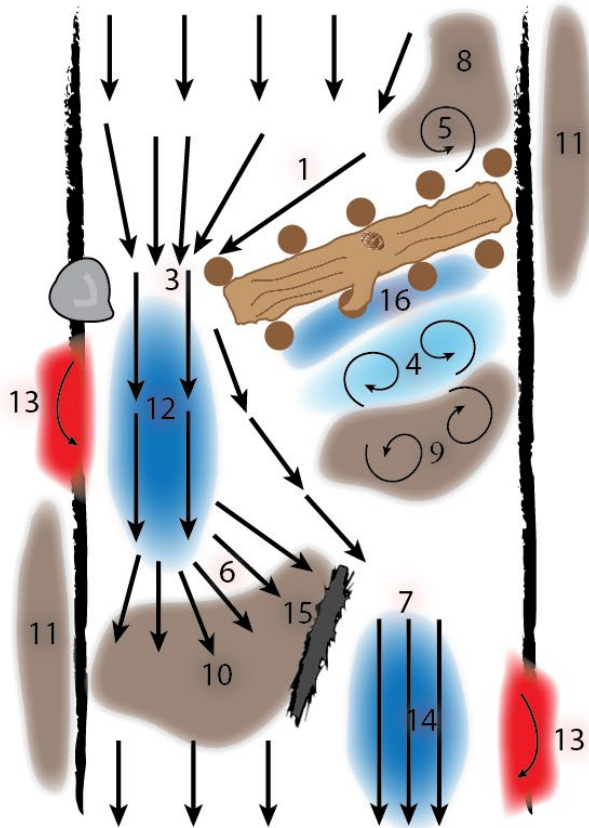


<https://vimeo.com/68327211>

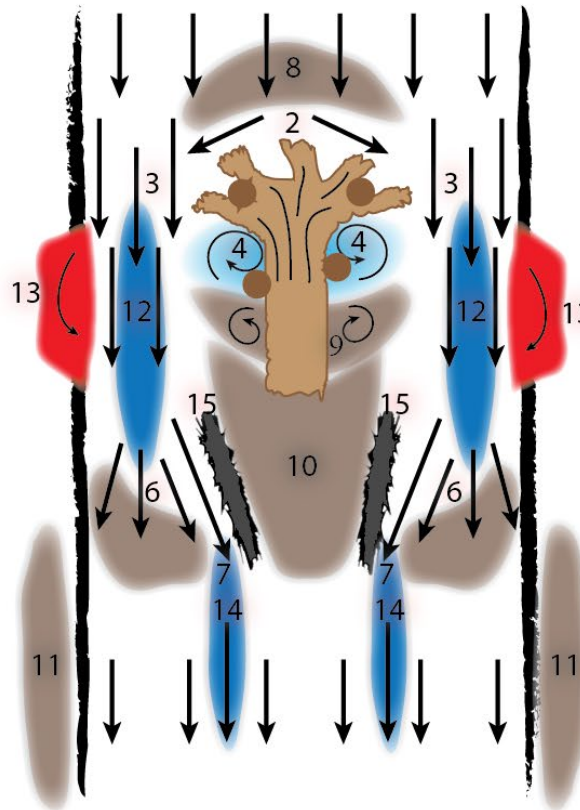
Also, if you are an aquatic organism (i.e. lets say a fish) it kind of matters

What are these? – Hypothesized _____ Responses

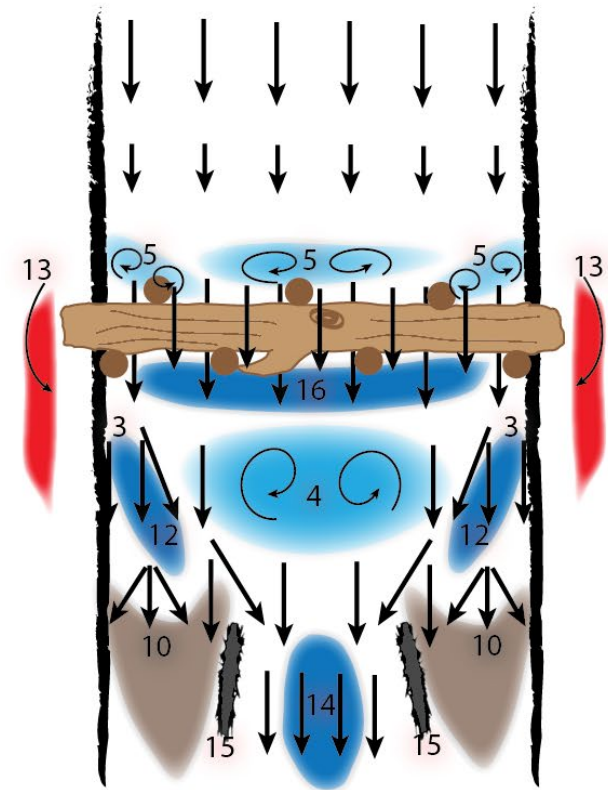
PALS - Bank Attached



PALS - Mid Channel

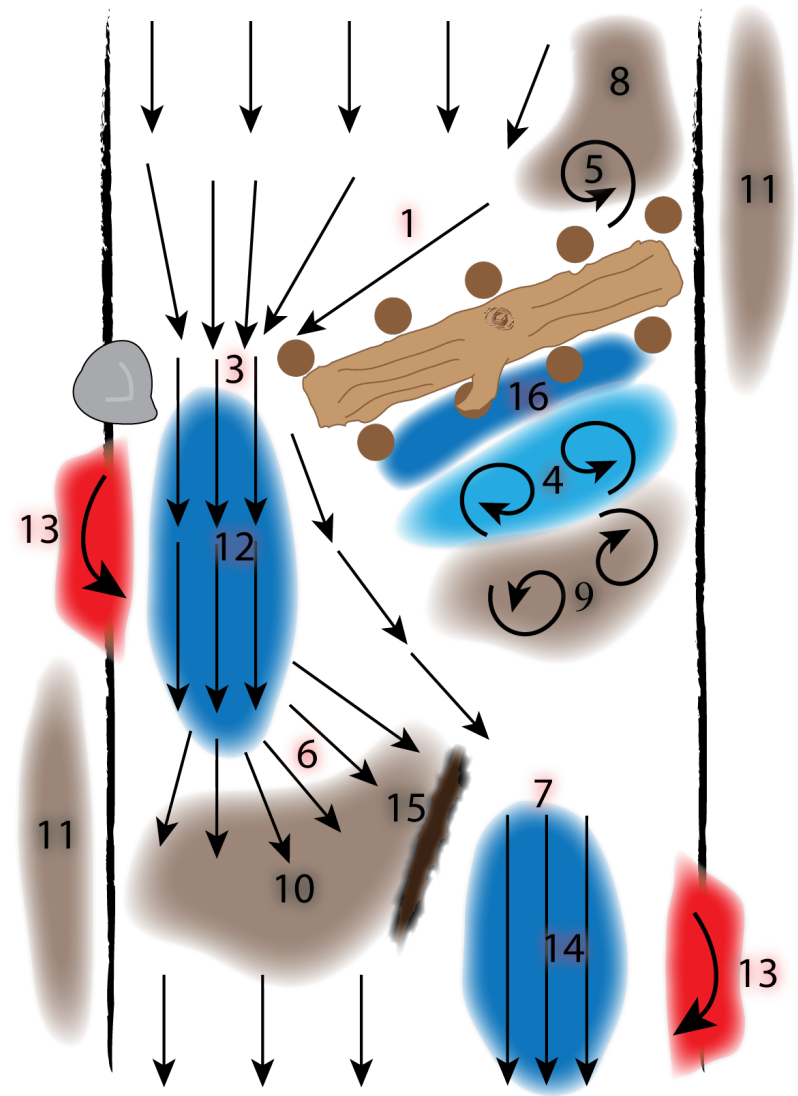
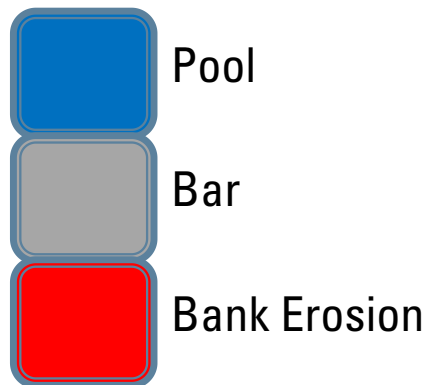


PALS - Debris Jam

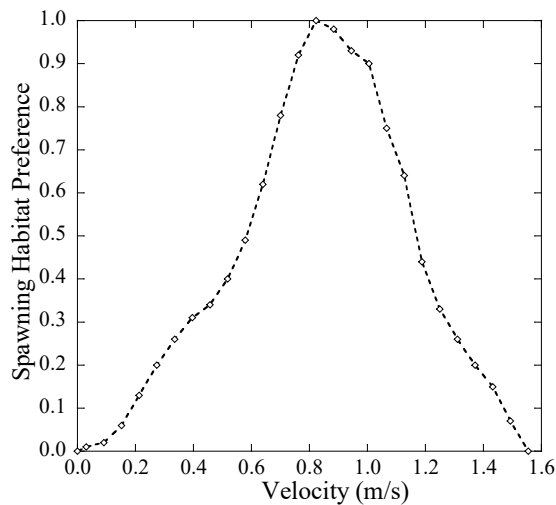
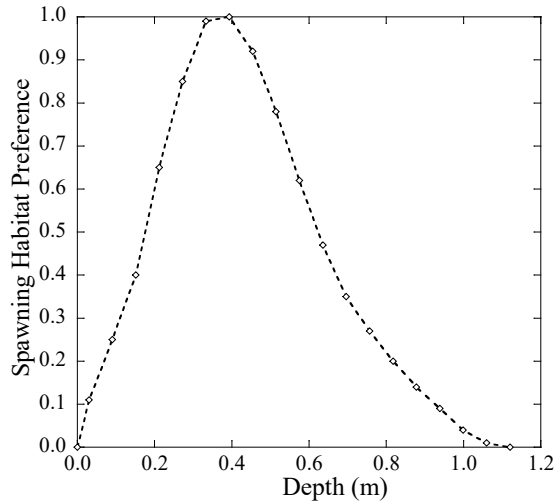


Prediction of Structurally Forced Responses, which shape habitat!

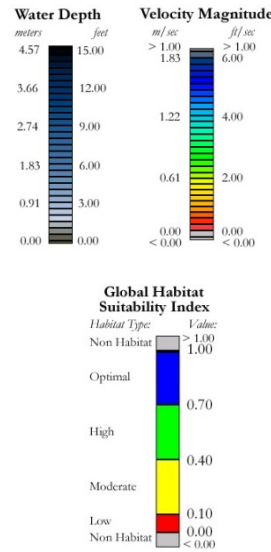
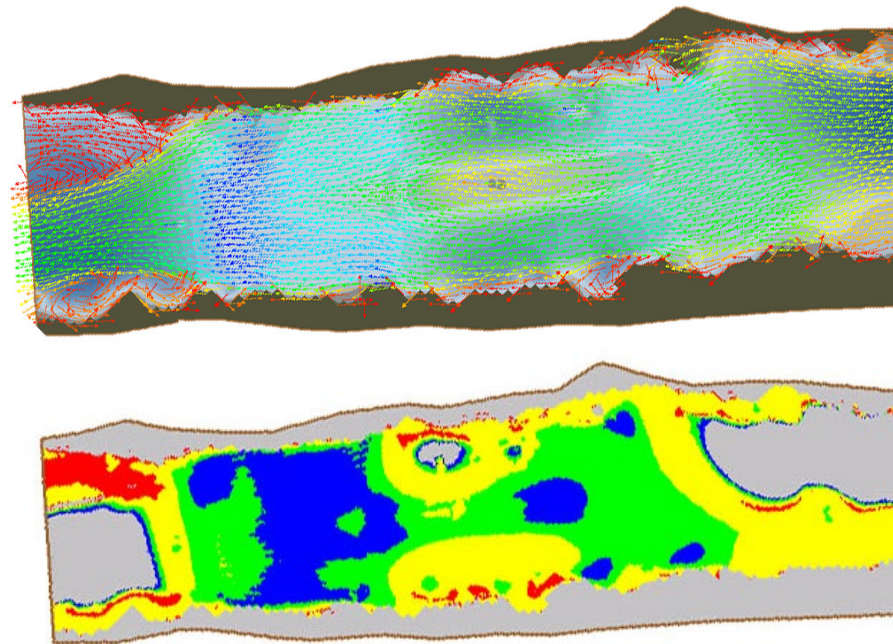
- Hydraulic Responses
 - Some are immediate
 - Structures 'settle'
 - + Hydraulic roughness
- Geomorphic Responses
 - Require high flows
 - Scour pools
 - Create bars



Traditional Ecohydraulic Models



- Relate physical habitat preferences (empirically through observations) to abiotic variables
- Habitat suitability curves are species and lifestage specific



What scale is this?

Back to How We Will Tackle Ecohydraulics

We'll use the Wheaton et al. (2017) paper as a roadmap for exploring:

- Salmonids as example
- Traditional Ecohydraulics @ "Reach Scale"
 - Requires understanding
 - Hydraulics, shaped by topography & geomorphology
 - Abiotic controls on habitat
- More advanced ecohydraulics
 - Bioenergetics, Mechanistic, NREI
- But, how do we take details (@ a site) and upscale to ecologically meaningful (i.e. population scale)?

EARTH SURFACE PROCESSES AND LANDFORMS
Earth Surf. Process. Landforms (2017)
Copyright © 2017 John Wiley & Sons, Ltd.
Published online in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/esp.4137

State of Science

Upscaling site-scale ecohydraulic models to inform salmonid population-level life cycle modeling and restoration actions – Lessons from the Columbia River Basin

Joseph M. Wheaton,^{1,2a} Nicolaas Bouwes,^{3,1,2} Peter Mchugh,^{1,3} Carl Saunders,^{1,3} Sara Bangen,^{1,3} Phillip Bailey,⁴ Matt Nahorniak,⁵ Eric Wall,^{1,3} and Chris Jordan⁶

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Received 10 May 2016; Revised 15 January 2017; Accepted 28 February 2017

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ABSTRACT: With high-resolution topography and imagery in fluvial environments, the potential to quantify physical fish habitat at the reach scale has never been better. Increased availability of hydraulic, temperature and food availability data and models have given rise to a host of species and life stage specific ecohydraulic fish habitat models ranging from simple, empirical habitat suitability curve driven models, to fuzzy inference systems to fully mechanistic bioenergetic models. However, few examples exist where such information has been upscaled appropriately to evaluate entire fish populations. We present a framework for applying such ecohydraulic models from over 905 sites in 12 sub-watersheds of the Columbia River Basin (USA), to assess status and trends in anadromous salmon populations. We automated the simulation of computational engines to drive the hydraulics, and subsequent ecohydraulic models using cloud computing for over 2075 visits from 2011 to 2015 at 905 sites. We also characterize each site's geomorphic reach type, habitat condition, geomorphic unit assemblage, primary production potential and thermal regime. We then independently produce drainage network-scale models to estimate these same parameters from coarser, remotely sensed data available across entire populations within the Columbia River Basin. These variables give us a basis for imputation of reach-scale capacity estimates across drainage networks. Combining capacity estimates with survival estimates from mark-recapture monitoring allows a more robust quantification of capacity for freshwater life stages (i.e. adult spawning, juvenile rearing) of the anadromous life cycle. We use these data to drive life cycle models of populations, which not only include the freshwater life stages but also the marine and migration life stages through the hydropower system. More fundamentally, we can begin to look at more realistic, spatially explicit, tributary habitat restoration scenarios to examine whether the enormous financial investment on such restoration actions can help recover these populations or prevent their extinction. Copyright © 2017 John Wiley & Sons, Ltd.

KEYWORDS: salmon recovery; stream and river restoration; *Oncorhynchus* sp; fish habitat; population modeling

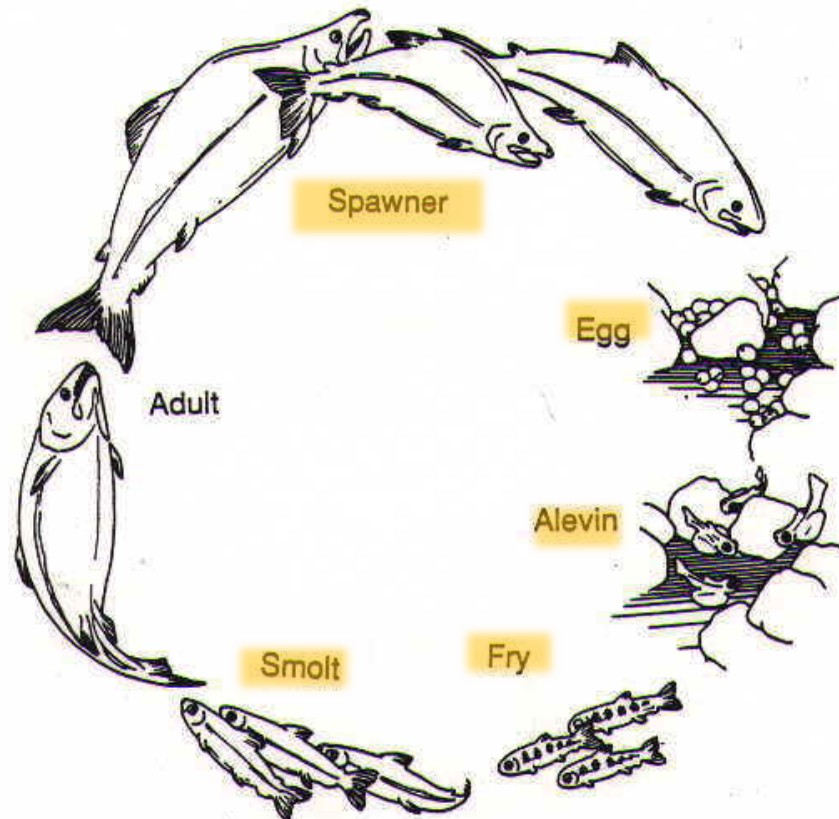
Introduction

Globally, native anadromous salmonid populations are in decline and several face the threat of extinction (Gustafson et al., 2007; Rand et al., 2012). Given the cultural, economic, and ecological importance of these populations, numerous efforts are underway to mitigate impacts that lead to their decline and facilitate their recovery (e.g. conservation hatcheries (Maynard and Trial, 2013), habitat restoration (Barnas et al., 2015)). For example, in the Columbia River

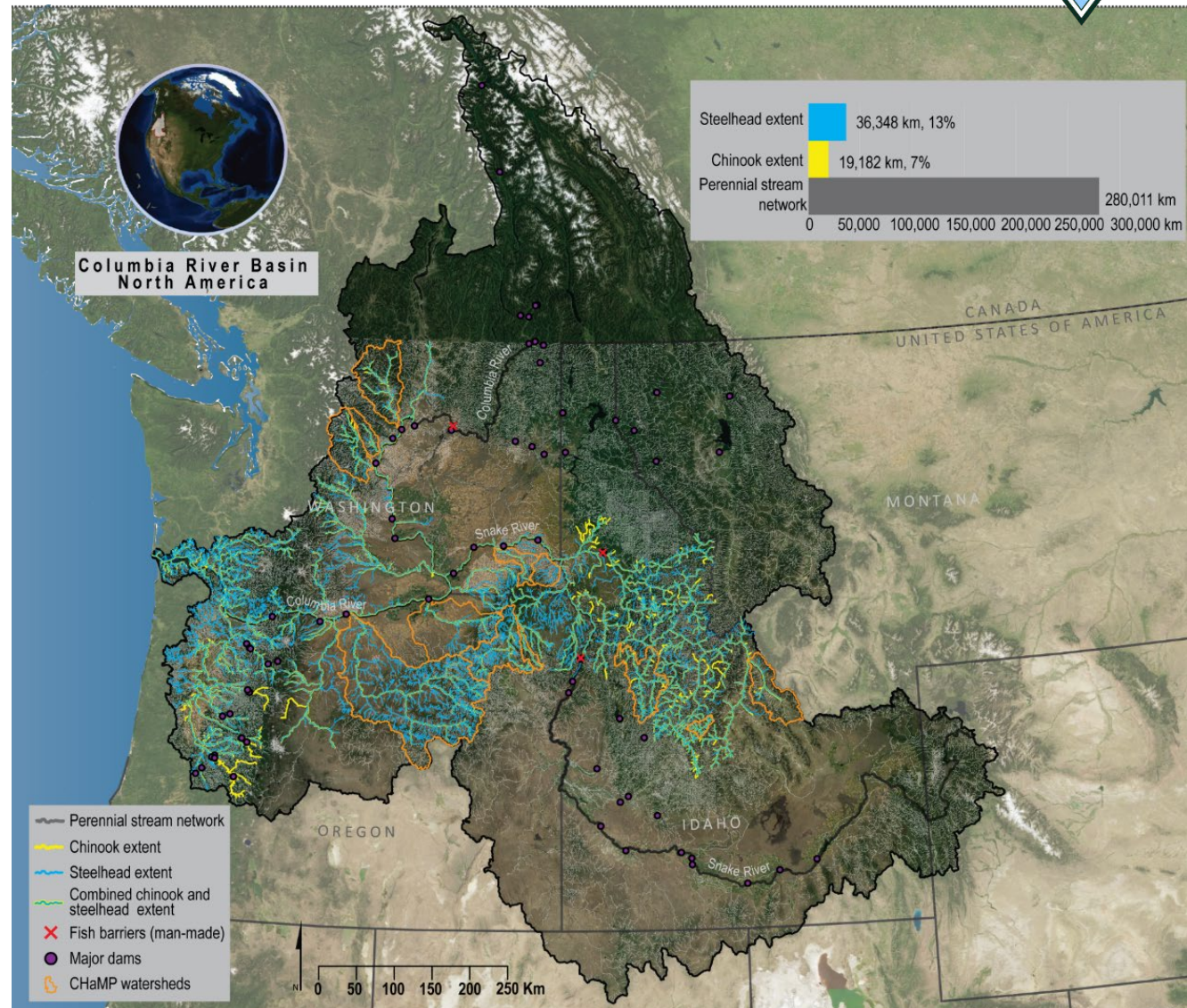
Basin, there are eleven evolutionarily significant units of salmon or steelhead (*Oncorhynchus* sp.) listed as threatened and two as endangered under the US Endangered Species Act (ESA) (Ruckelshaus et al., 2002; Gustafson et al., 2007). According to the ESA review on the risks posed to anadromous salmonids by the Columbia Basin's federally administered hydropower dam system (NOAA, 2008), three action agencies are required to make costly dam retrofits and operational changes (i.e. to improve passage) and/or mitigate dam impacts via offsite actions (i.e. tributary habitat restoration). The

Example of Ecohydraulic Inquiry

- What are the impacts of tributary habitat conditions on populations of **listed salmonids**?

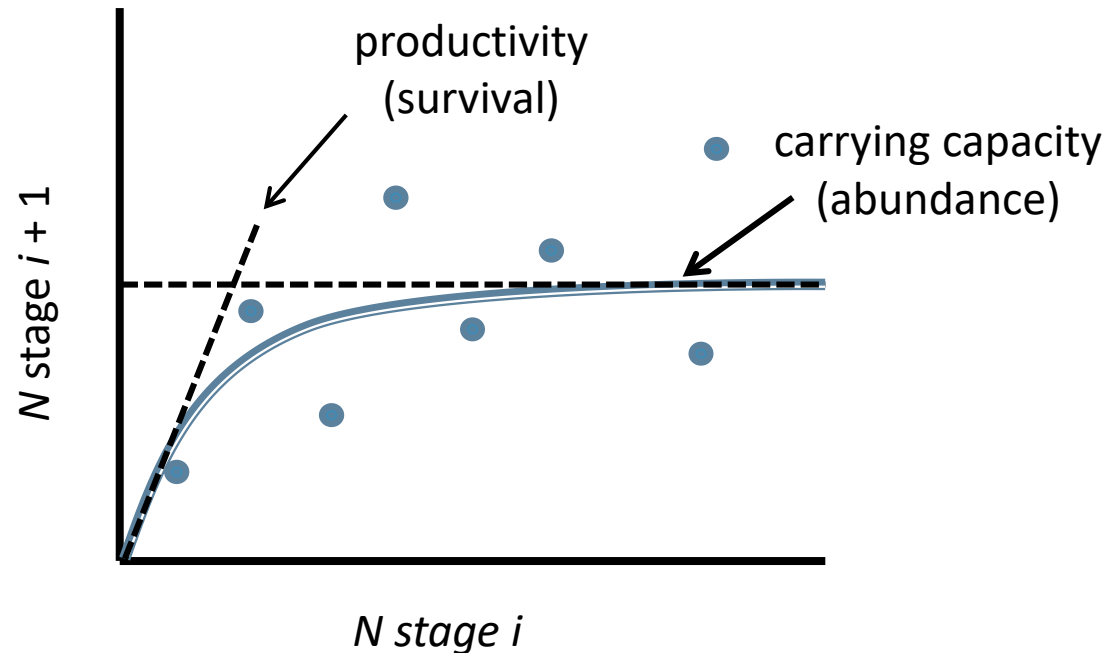


- A tributary, anadromous salmonid habitat monitoring program
- 14 Watersheds throughout the Columbia Basin
- ~5000 visits in 6 years to 962 sites
- Roughly 45-55 sites in each basin (10-15 annually)



LIFE-CYCLE MODEL BASICS

Beverton-Holt



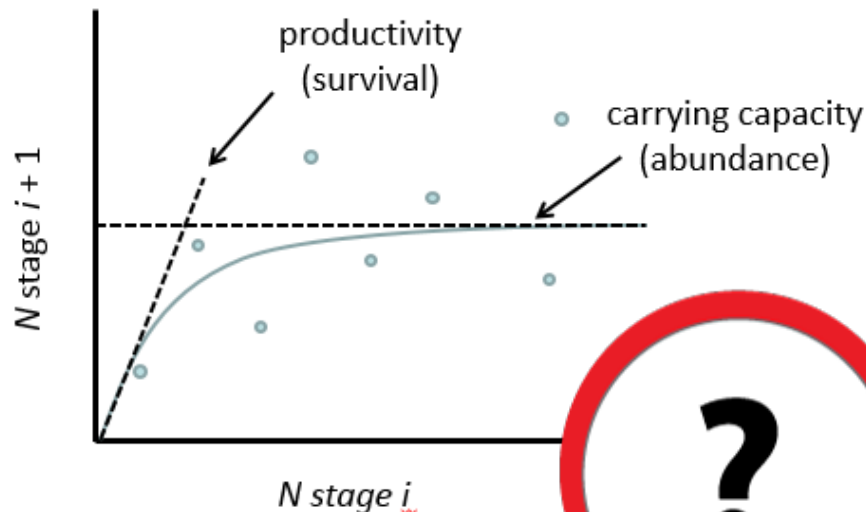
$$N_{i+1} = \frac{N_i}{\frac{1}{\text{prod.}} + \frac{1}{\text{capacity}} N_i}$$

Relate this to freshwater habitat

= juveniles / spawner

What We Need From CHAMP Visits To Inform Life Cycle Modelling

- A habitat-informed estimate of capacity!
- Insights into why (i.e. limiting factors)

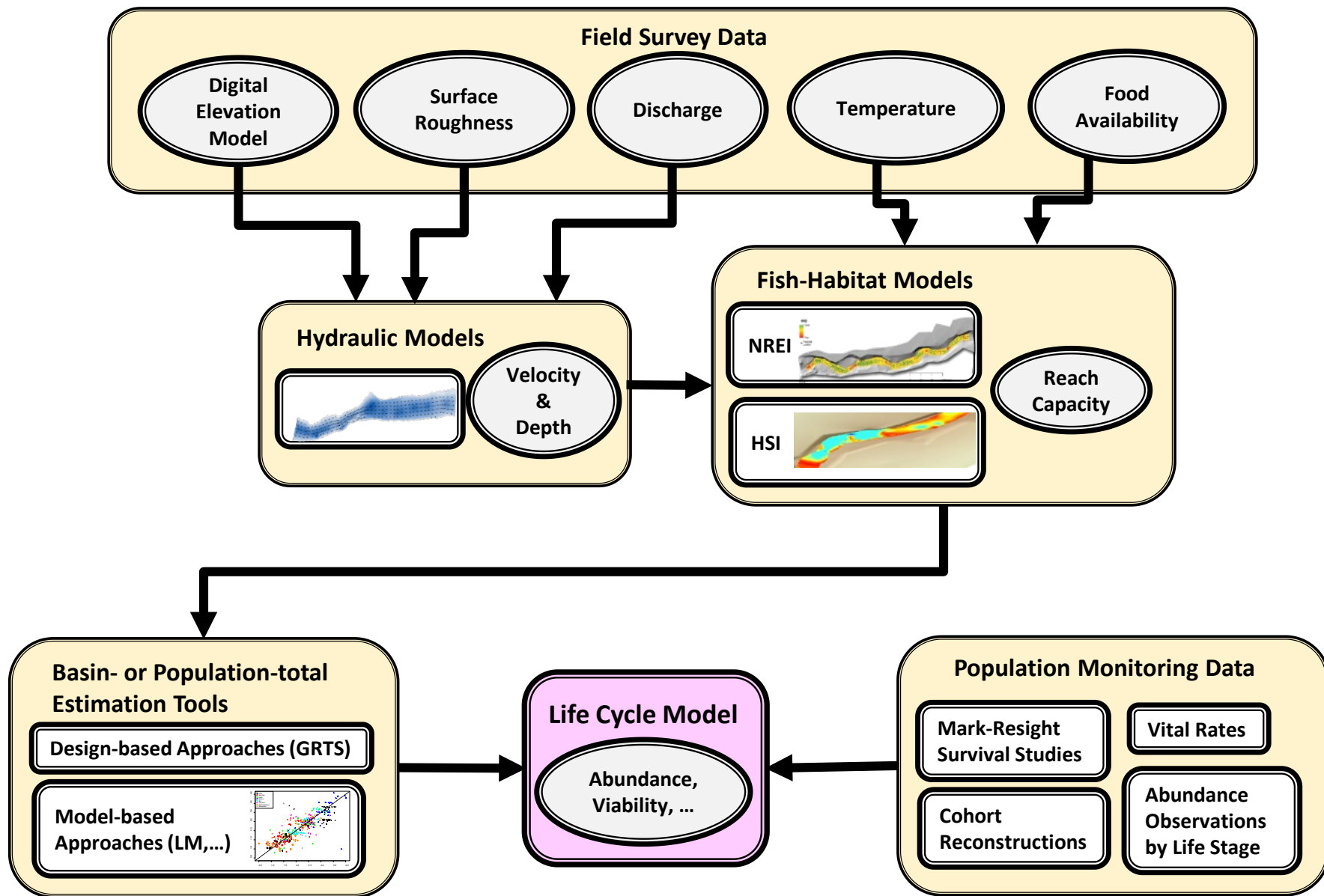


?

STATUS
&
TREND

KMQ 1

What are the tributary habitat limiting factors impacting the "HEALTH" of listed salmonids?

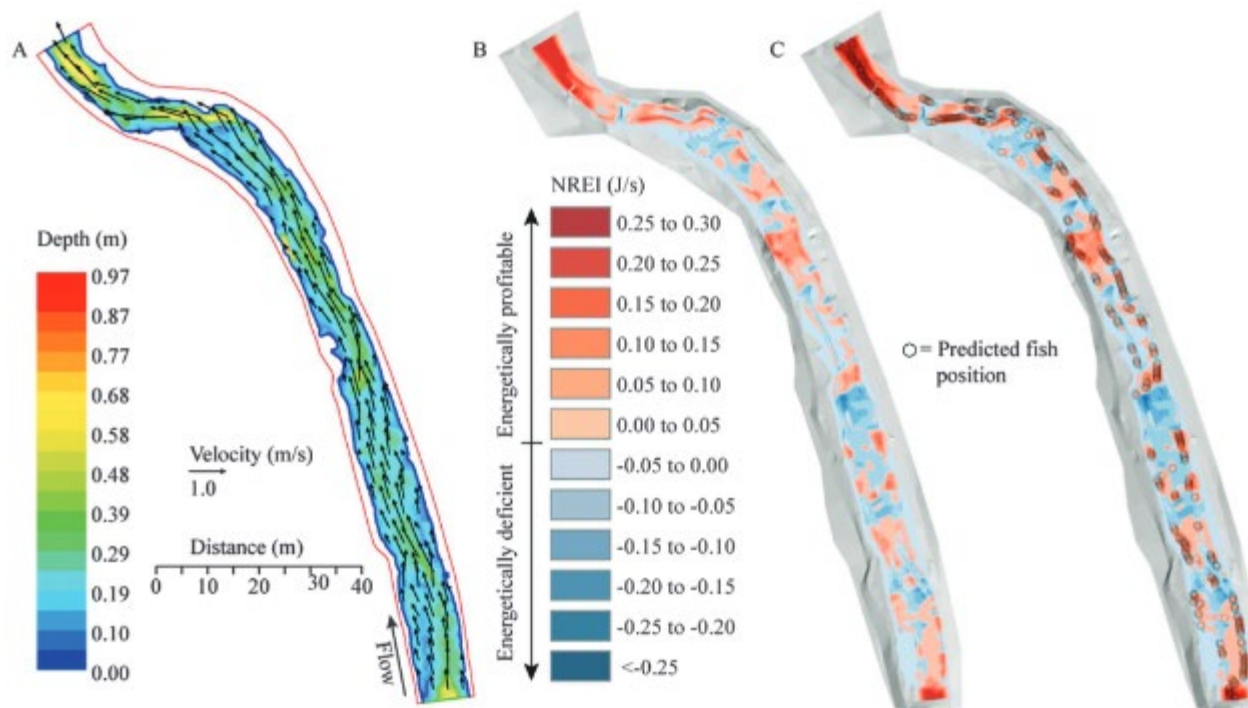


From: McHugh et al. (2017) – Ecological Modelling

Example Of Fish Habitat (ecohydraulic) Models

- Models can be mechanistic (e.g. NREI) or empirical (e.g. HSI)
- Output is reach-scale extent, cell-resolution

Fig. 2. River 2D depth and velocity predictions (A), predicted spatial variation in NREI (B), and predicted spatial variation in NREI showing predicted fish locations (C) for the NFACI reach. [Colour online.]



Net rate of energy intake predicts reach-level steelhead (*Oncorhynchus mykiss*) densities in diverse basins from a large monitoring program

C. Eric Wall, Nicolaas Bouwes, Joseph M. Wheaton, W. Carl Saunders, and Stephen N. Bennett

Abstract: Substantial research effort has been devoted to understanding stream-dwelling salmonids' use of summer rearing and growth habitat, with a subset of studies focusing on foraging position selection and the energetic trade-offs of differential habitat use. To date, however, cost-benefit analyses for most foraging model studies have focused on small sampling areas such as individual habitat units. To address this knowledge gap, we applied a mechanistic foraging model to 22 stream reaches (100–400 m) from two watersheds within the Columbia River Basin. We found a strong, positive correlation ($R^2 = 0.61$, $p < 0.001$) between predicted carrying capacities and observed fish densities. Predicted proportion of suitable habitat was weakly correlated with observed fish density ($R^2 = 0.18$, $p = 0.051$), but the mean net rate of energy intake prediction in sampling reaches was not a significant predictor of observed fish biomass. Our results suggest spatial configuration of habitat, in addition to quantity and quality, is an important determinant of habitat use. Further, carrying capacity predicted by the model shows promise as a habitat metric. We also evaluated the feasibility of applying this data-intensive modeling approach in a large-scale monitoring program. Though the approach can be computationally expensive, we feel the model's (e.g., depth, velocity) with important biological considerations like food availability and associated costs. We feel this modeling approach has great potential as a tool to fishes.

ont été voués à la compréhension de l'utilisation d'habitats estivaux d'alevinage et d'eau, dont un sous-ensemble d'études s'étant axé sur la sélection de la position énergétique associée à l'utilisation différentielle d'habitats. Les analyses coûts-des études de modèles d'approvisionnement se sont toutefois attardées à de petites d'habitat individuelles. Pour combler ce manque de connaissances, nous avons mécaniste à 22 tronçons de cours d'eau longs de 100 à 400 m dans deux bassins avons constaté une forte corrélation positive ($R^2 = 0.61$, $p < 0.001$) entre les capacités observées. La proportion prédite d'habitats convenables était faiblement corrélée ($p = 0.051$), mais le taux net moyen d'apport énergétique prédit dans les tronçons significative de la biomasse de poissons observée. Nos résultats donnent à habitat, combinée à sa quantité et sa qualité, est un important déterminant de acité de charge prédite par le modèle s'avère prometteuse comme paramètre de faisabilité d'appliquer cette approche de modélisation riche en données dans grande échelle visant à examiner la qualité et la quantité des habitats. Bien que cette imputationnel, nous estimons que la capacité du modèle à intégrer des paramètres élocité) et des considérations biologiques importantes comme la disponibilité de avantage qui compense amplement les coûts associés. Nous croyons que cette entiel comme outil pour aider à comprendre l'utilisation de l'habitat chez les nit par la Rédaction]

on suc-
the Co-
or listed
(mykiss)
gement
rearing
ve mon-
evaluate

whether habitat actions are resulting in habitat improvements and to increase our understanding of fish-habitat relationships (Bouwes et al. 2011; CHaMP 2014; Bennett et al. 2016). While this story is common to many imperiled species, the development of transferable fish-habitat relationships remains elusive, and our record for improving habitat quality via restoration or management is unclear (Rose 2000; Fausch et al. 2002; Roni et al. 2008).

A majority of the monitoring data collected to describe fish habitat has been linked to fish through empirical models (e.g.,

es Department, Utah State University, 5210 Old Main Hill, Logan, UT 84322, USA;
SA,
UT 84332, USA;
ersity, 5210 Old Main Hill, Logan, UT 84322, USA.
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Published at www.nrcresearchpress.com/cjfas on 10 December 2015.

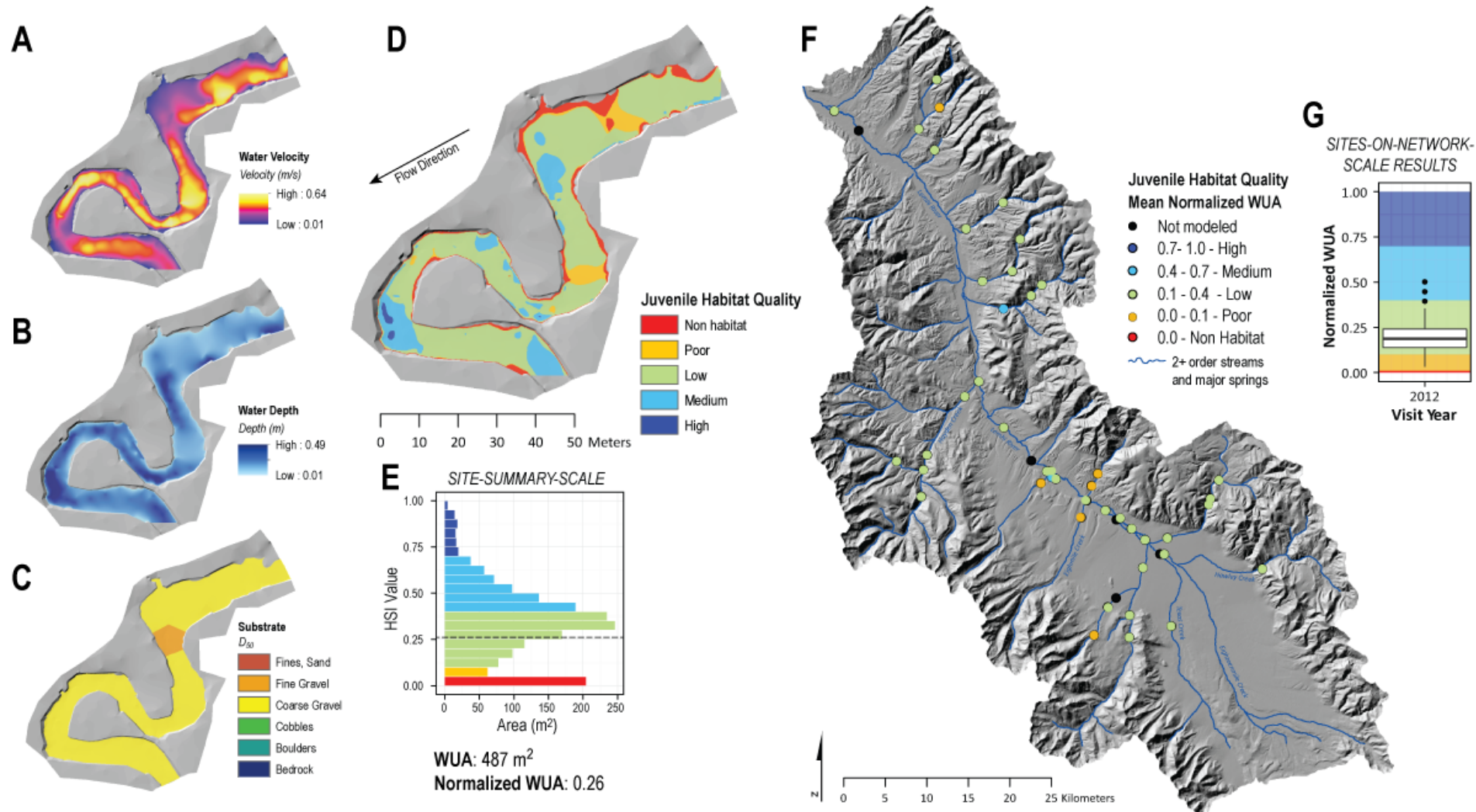
Example Of Outputs @ Site Summary Scale

Chinook Juvenile, 2012 Primary Visits

SITE-SCALE [Big Springs, Lemhi Watershed, ID]

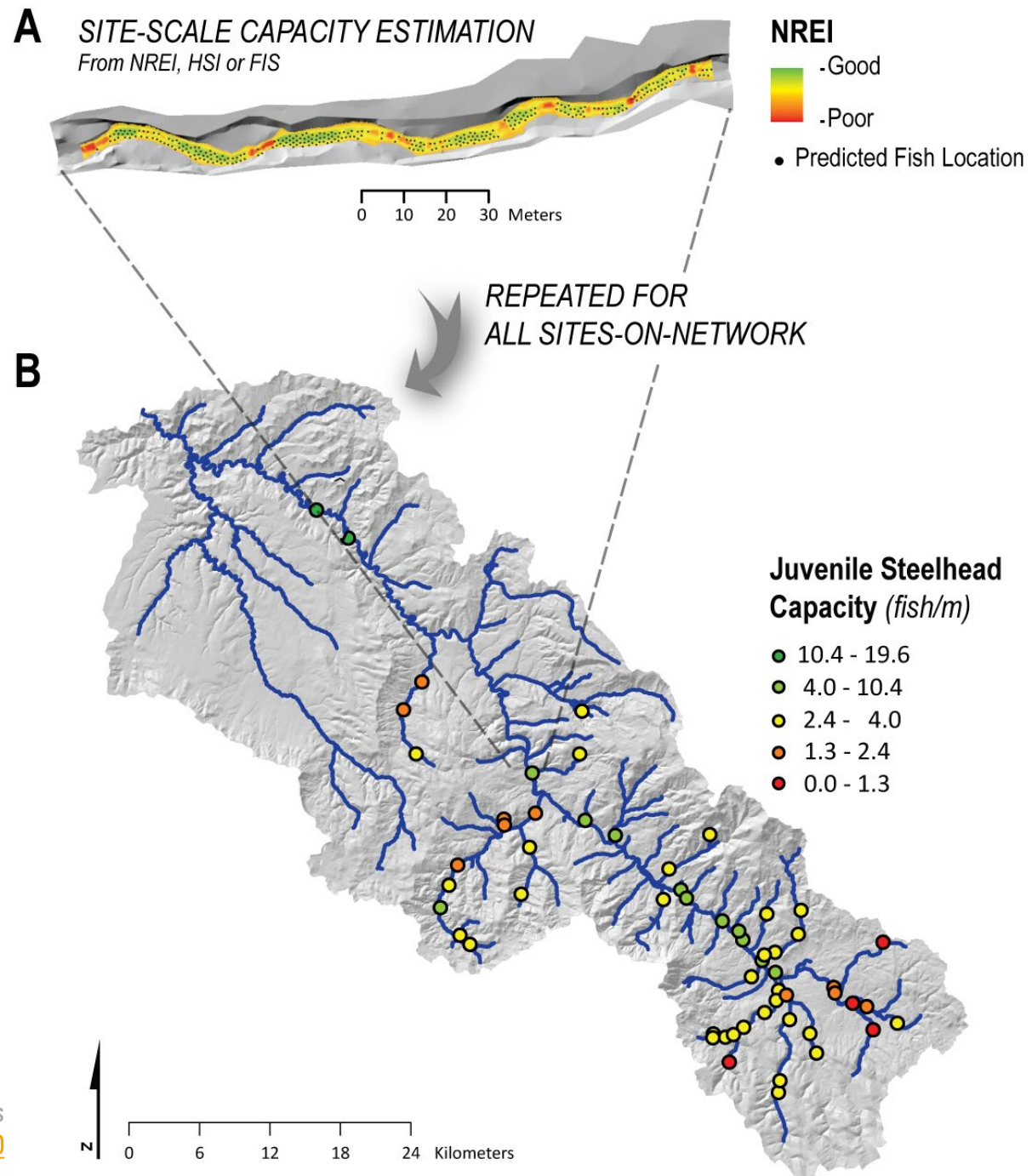
• Impressive, but...

SITES-ON-NETWORK-SCALE [Lemhi Watershed, ID]



All FHM

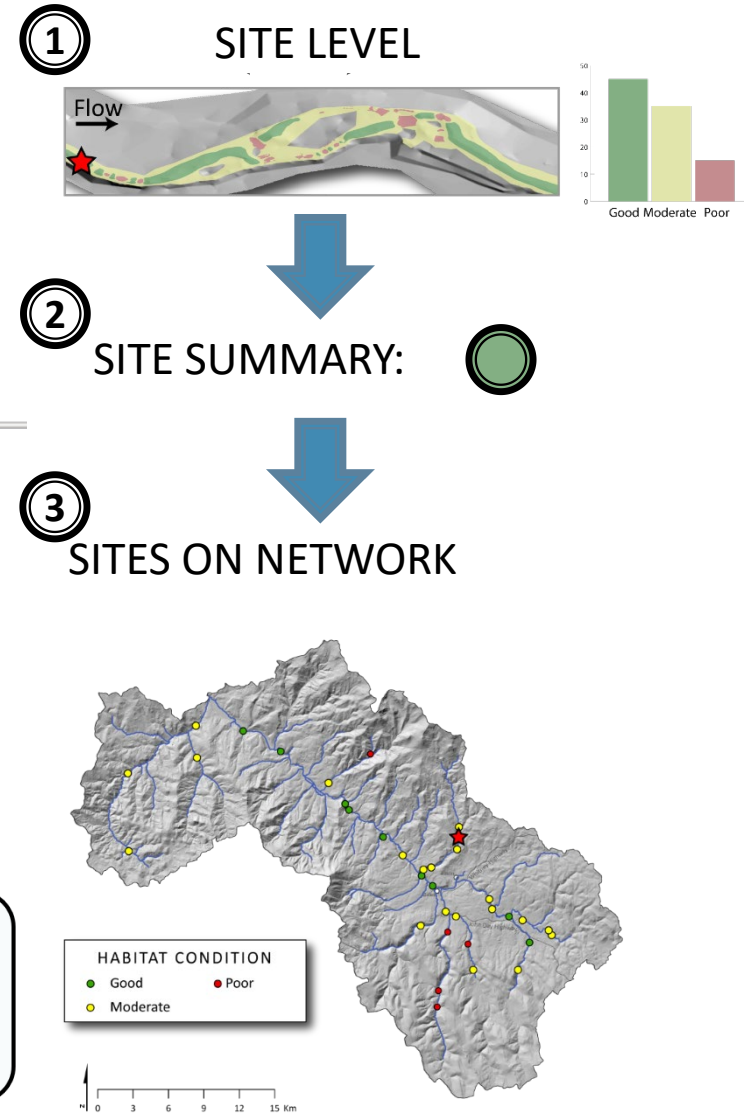
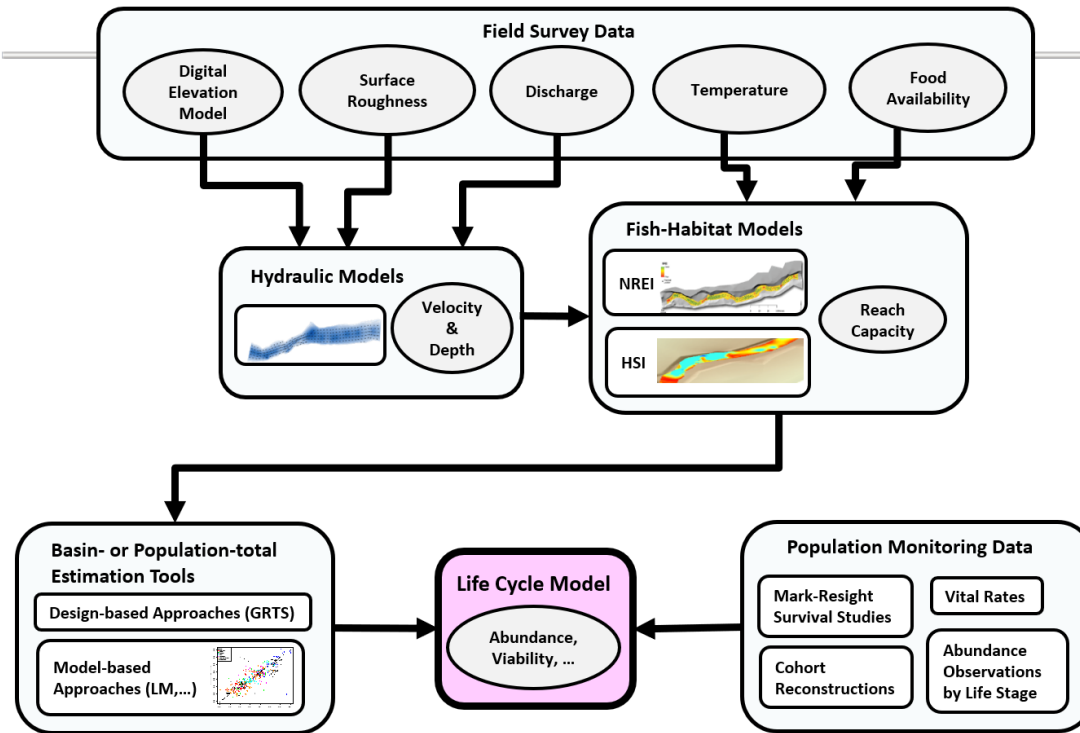
- The FHM are a vehicle for producing site-specific, species and life-stage specific capacity estimates.
- Capacity is our fish-habitat relationship currency



IN THE END... ALL THAT GIVES ME IS DOTS

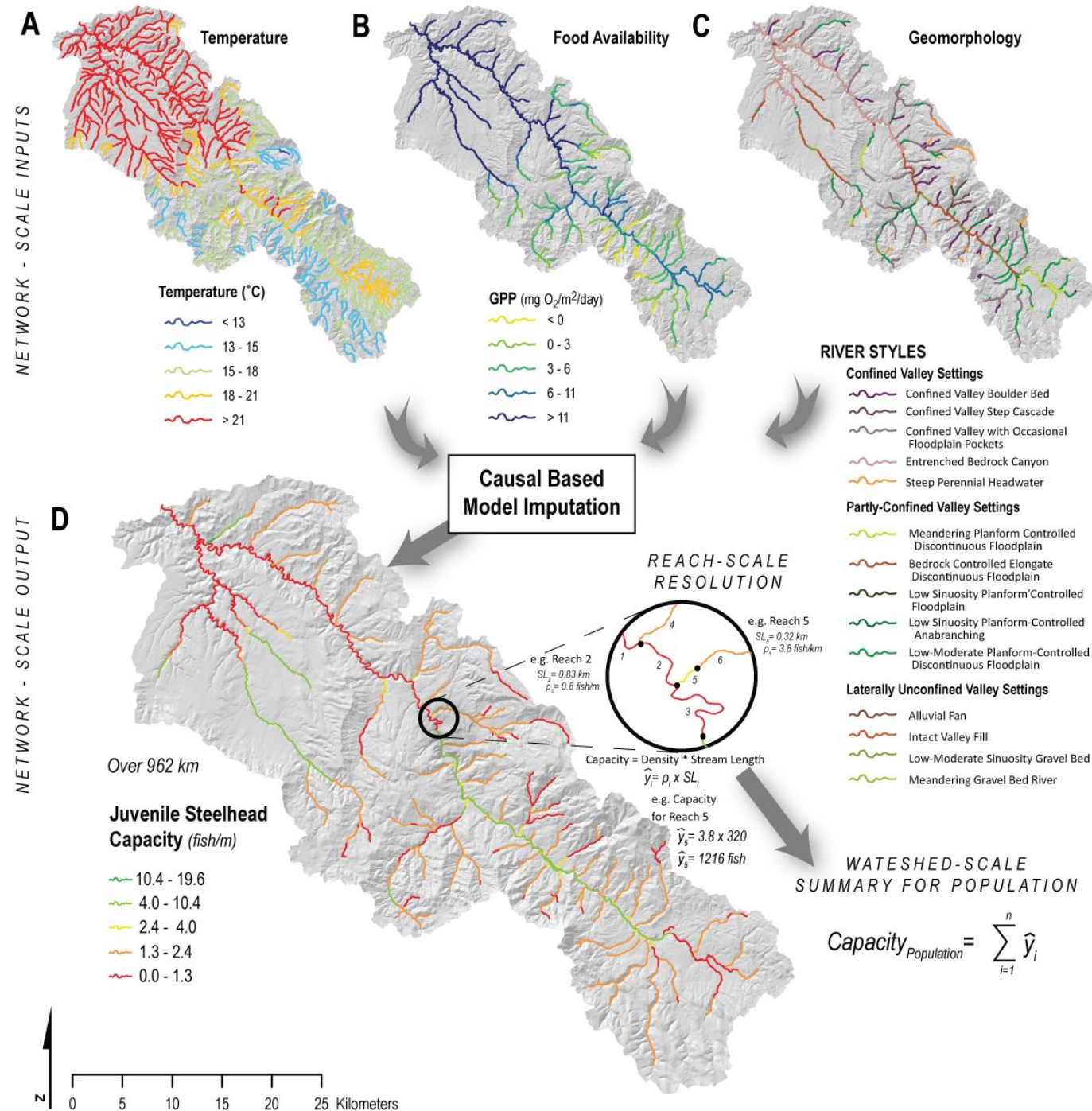
@ Every Site (800+)

- HSI for spawning (Adult) capacity
- NREI estimates for Juvenile Capacity



Magic Step

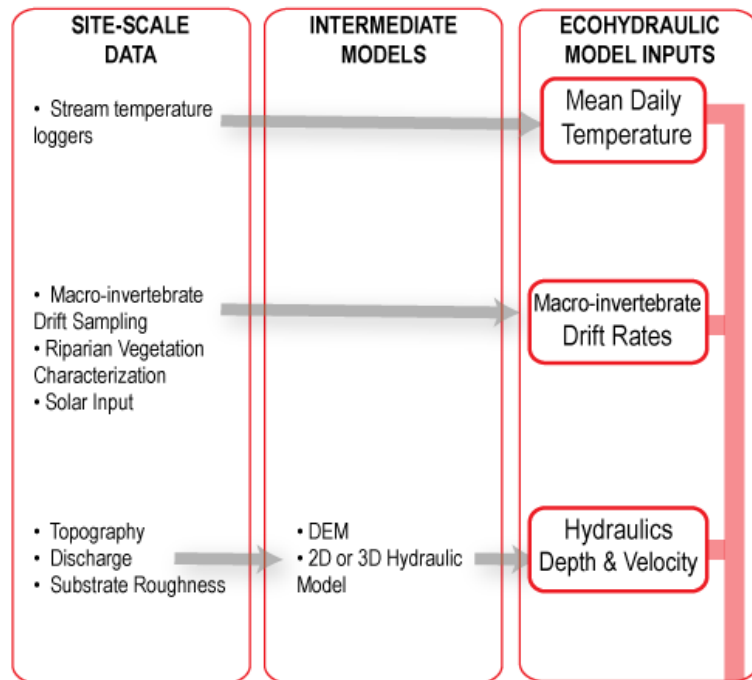
- Imputation
- This step is one of our biggest development hurdles...
- Can we predict site level summary from network level output?





SITE-SCALE

TRADITIONAL ECOHYDRAULIC ANALYSIS



REACH-SCALE CONCEPTUAL INTERFACE

e.g. Juvenile Rearing

Temperature

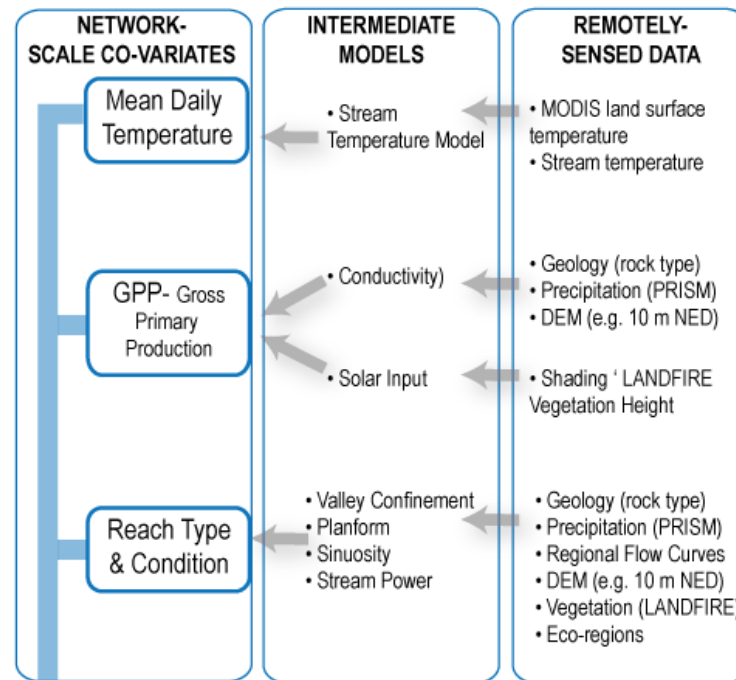
Food

Physical Habitat

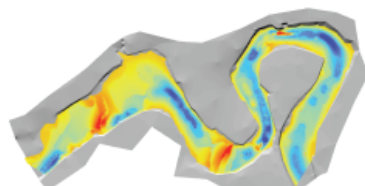
NETWORK-SCALE



REMOTE SENSING & SPATIAL ANALYSIS



SITE-SCALE



Resolved at every raster cell in a reach

Ecohydraulic Model
e.g. NREI

TRAINING/
CALIBRATION

VERIFICATION/
VALIDATION

SITE-SUMMARY-SCALE
CARRYING
CAPACITY

NETWORK-SCALE



Resolved at every reach in network

Causal Model-Based Imputation

NETWORK-SCALE
CARRYING
CAPACITY

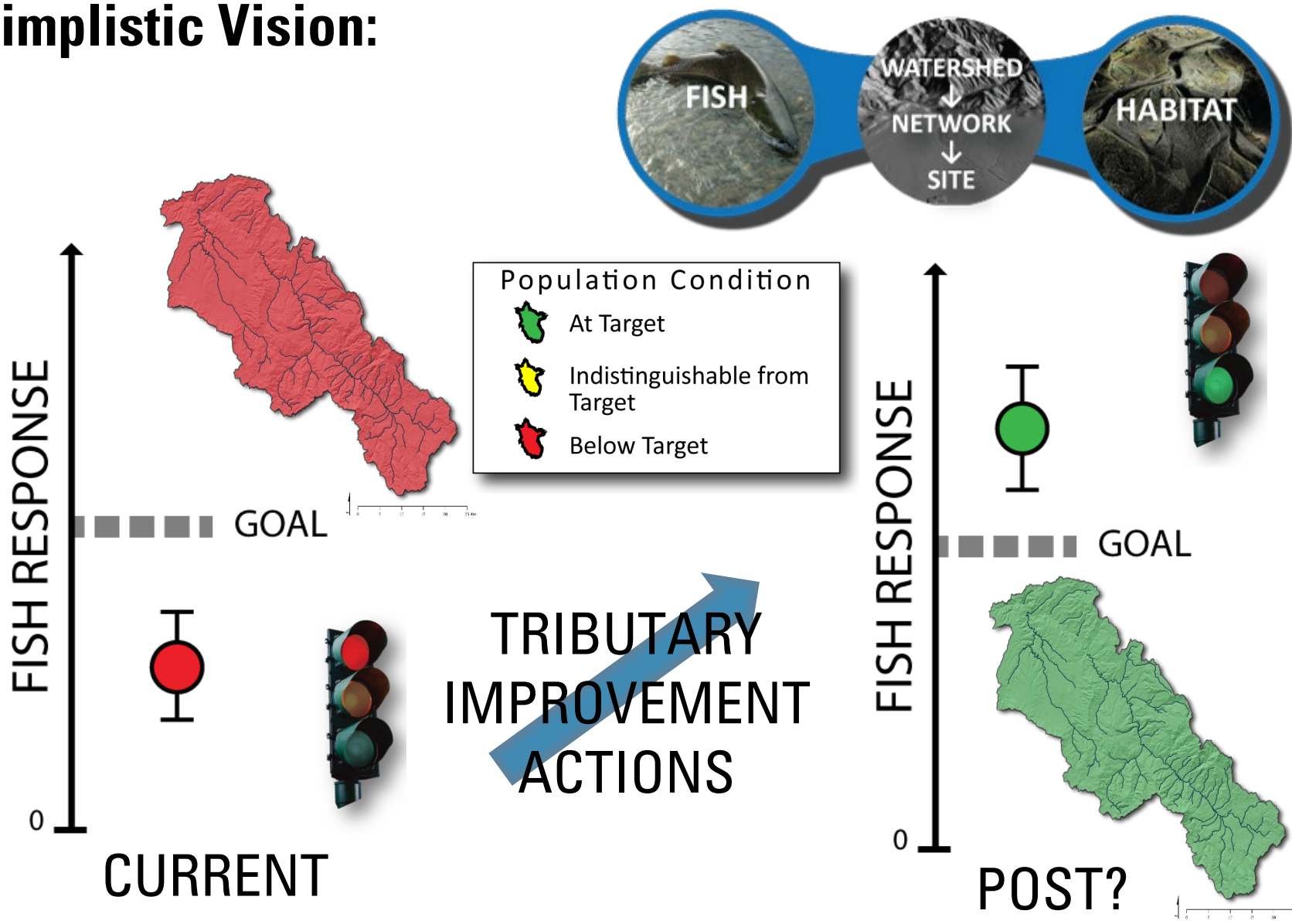
POPULATION-SCALE
SURVIVAL
ESTIMATES

BASIN-SCALE

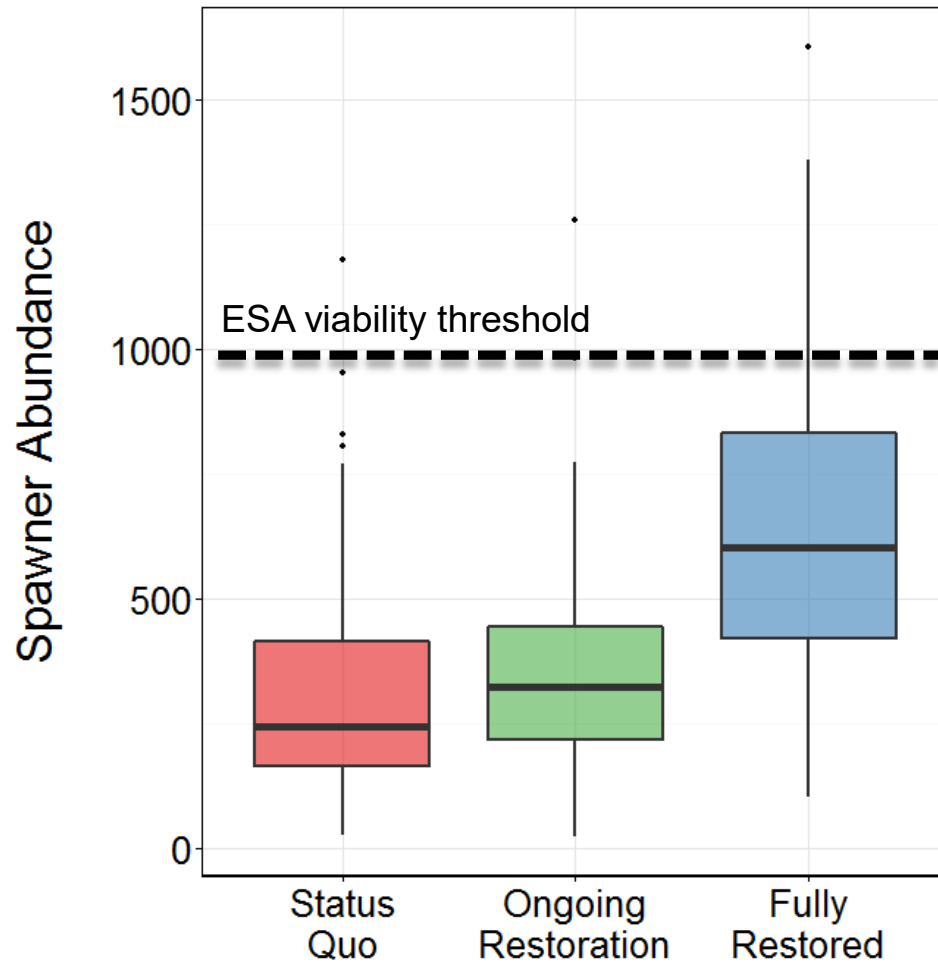


LIFE
CYCLE
MODELS

A Simplistic Vision:



Benefits Of Thermal Restoration?

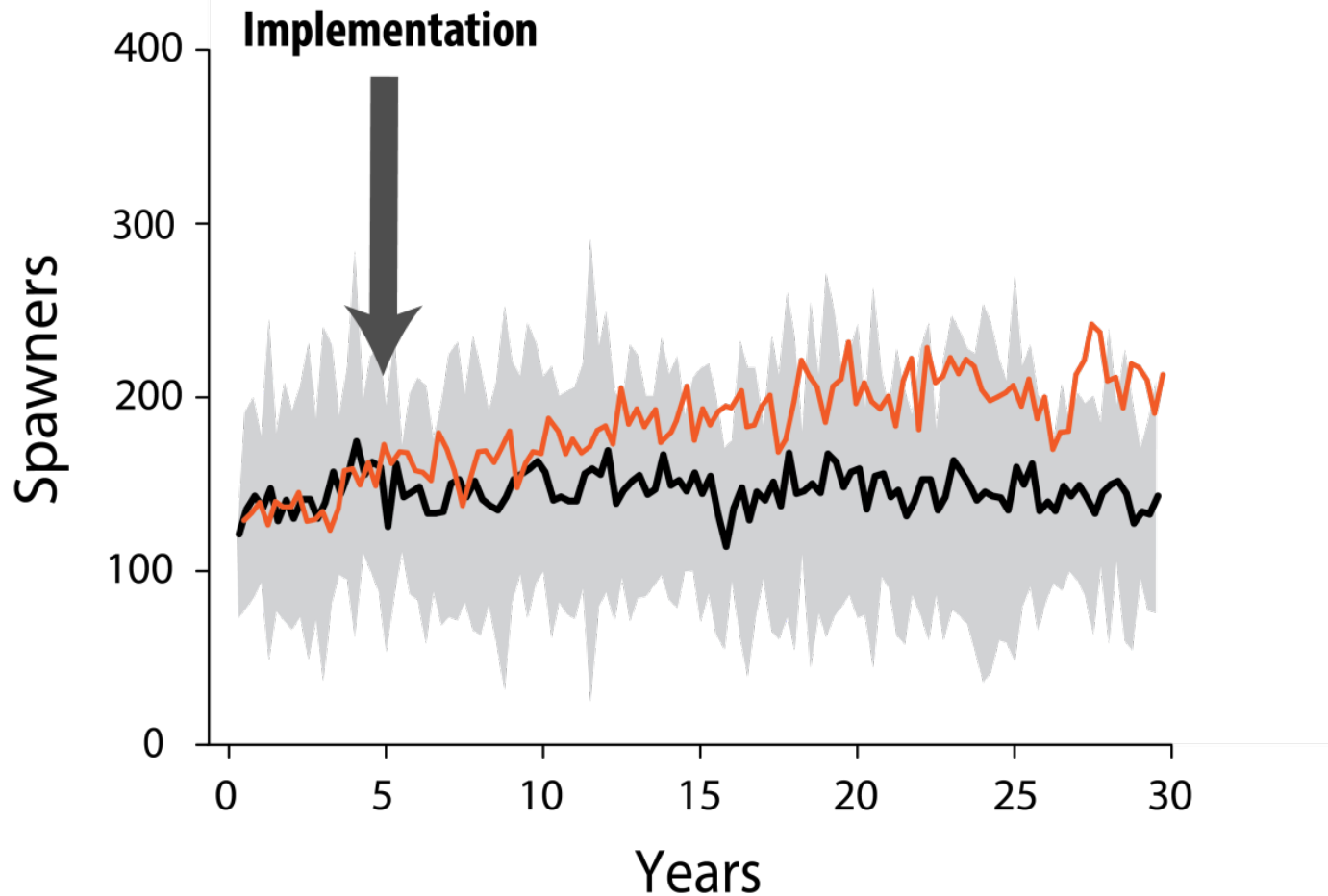


How to close the gap?

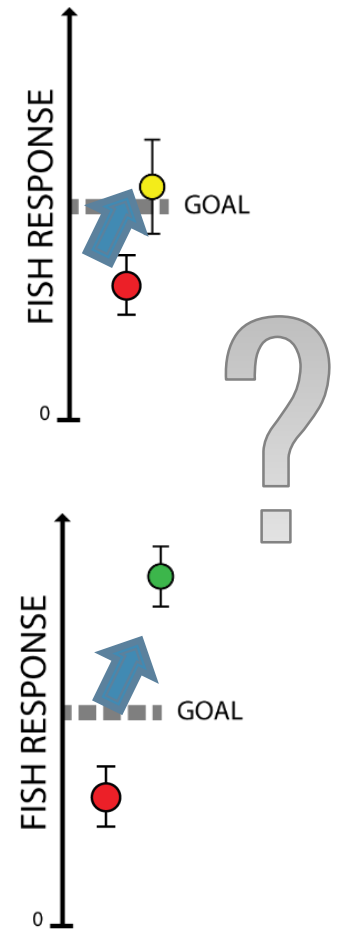
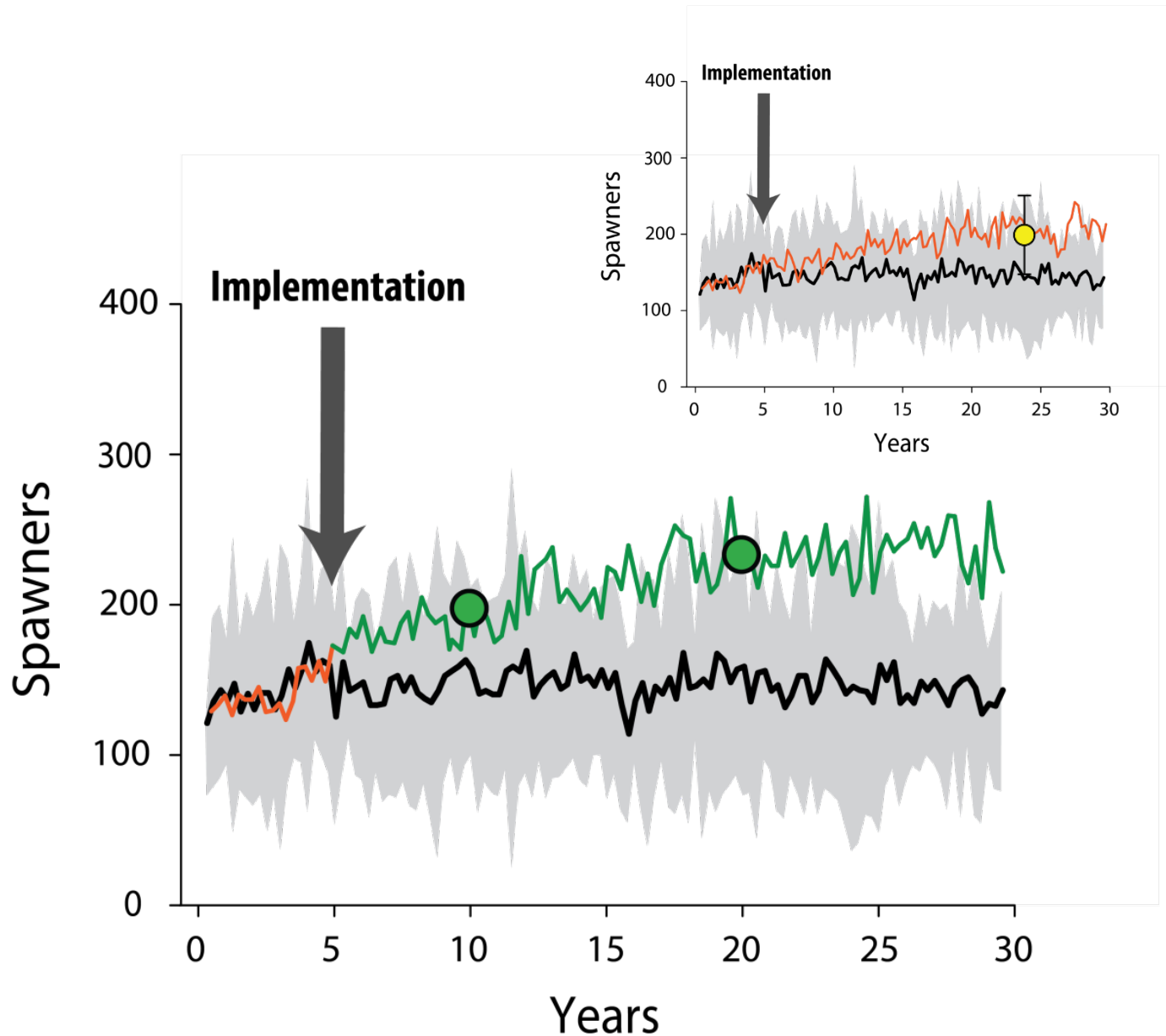
From: McHugh et al. (In Review) – Ecological Modelling

Will Restoration Just be Lost in Noise?

Using LCM in a sampling design to aggregate actions spatially and predict outcomes.

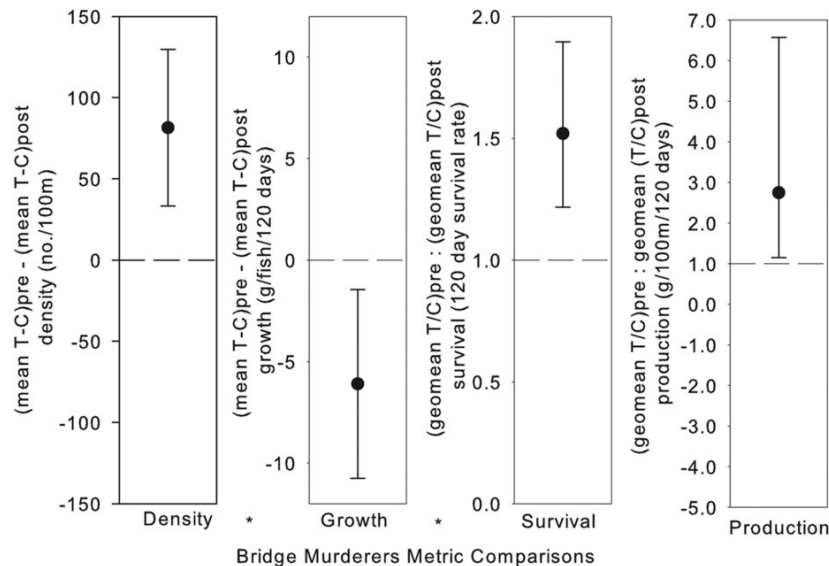


Or Will It Emerge as Significant?



An Example Where It Mattered...

- Restoration using beaver as restoration agent actually produced a population level increase in density, survival and production of ESA listed salmon



SCIENTIFIC REPORTS

OPEN

Ecosystem experiment reveals benefits of natural and simulated beaver dams to a threatened population of steelhead (*Oncorhynchus mykiss*)

Nicolaas Bouwes^{1,2}, Nicholas Weber³, Chris E. Jordan⁴, W. Carl Saunders^{5,2}, Ian A. Tattam⁴, Carol Volk⁴, Joseph M. Wheaton² & Michael M. Pollock³

Beaver have been referred to as ecosystem engineers because of the large impacts their dam building activities have on the landscape; however, the benefits they may provide to fluvial fish species has been debated. We conducted a watershed-scale experiment to test how increasing beaver dam and colony persistence in a highly degraded incised stream affects the freshwater production of steelhead (*Oncorhynchus mykiss*). Following the installation of beaver dam analogs (BDAs), we observed significant increases in the density, survival, and production of juvenile steelhead without impacting upstream and downstream migrations. The steelhead response occurred as the quantity and complexity of their habitat increased. This study is the first large-scale experiment to quantify the benefits of beavers and BDAs to a fish population and its habitat. Beaver mediated restoration may be a viable and efficient strategy to recover ecosystem function of previously incised streams and to increase the production of imperiled fish populations.

Beaver in Eurasia and North America were once abundant and ubiquitous¹. Their dense and barbed fur has great felting properties, and as early as the 1500s, intense trapping to provide pelts mainly for making hats occurred throughout Eurasia². By the early 1700s, beaver were nearly extirpated in Eurasia, and North America became the new source of pelts for international commerce. The exploration, settlement, and many territorial claims of North America by several European countries were driven mainly by the search for beaver-trapping opportunities³.

When Lewis and Clark explored the Pacific Northwest in 1805, salmon and steelhead coexisted with beavers in very high densities^{1,3}. Fur trade in this region began around 1810, attracting pioneers to settle the area. When the British and United States jointly occupied the Oregon Territories (which included the Columbia River Basin), the Hudson Bay Company implemented their "scorched earth" or "fur desert" policy to eliminate all fur-bearing animals. In an attempt to discourage American settlement^{4,5}. As a result, beaver were nearly extirpated from the region by 1900. Around this time, a decrease in the great harvests of Pacific salmon and steelhead was first perceived. Anadromous salmon and steelhead populations have since declined precipitously in the Columbia River Basin, leading to their listing under the U.S. Endangered Species Act (ESA)^{2,6}. Agriculture, timber harvest, mining, grazing, urban development, and water storage and hydroelectric dam construction are commonly cited as the causes for salmonid habitat degradation and population declines⁷, with rare mention of the loss of beaver and their ability to alter aquatic ecosystems with their dam-building activities⁸.

Human activities, including the removal of beaver, have exacerbated the occurrence of stream channel incision, where a rapid down-cutting of the stream bed disconnects the channel from its floodplain^{9,10}. Channel incision is a ubiquitous environmental problem in the Columbia River Basin and throughout the world^{10–12}.

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Main Focus of Ecohydraulic Models

- Most ecohydraulic models focus on fish
- Some attempt to look at macroinvertebrates (e.g. Jorde et al.)
- Some look at frog habitat (e.g. Yarnell et al. 2010: DOI 10.1002/rra.1447)
- Others:
 - Capacity models
 - Population dynamics
 - Stock recruitment
 - Nutrient dynamics
 - Individual-based ecological modeling

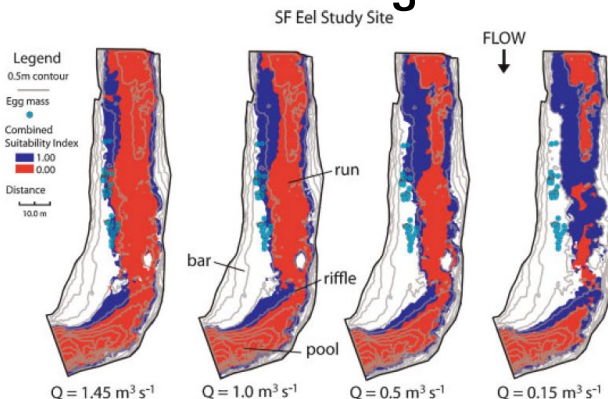


Figure 8. Suitability habitat at the SF Eel study site as modeled flows decrease from (a) $1.45 \text{ m}^3 \text{ s}^{-1}$ (2006 eggplanting discharge) to (b) $1.0 \text{ m}^3 \text{ s}^{-1}$, (c) $0.5 \text{ m}^3 \text{ s}^{-1}$, and (d) $0.15 \text{ m}^3 \text{ s}^{-1}$ (low summer flow). Upstream is at the top of each inset figure. Background shows 0.5 m bed elevation contours; Overlaid colours depict the extent of flow and habitat suitability [suitable in blue (dark grey) and unsuitable in red (light grey)]; Encircled dots indicate egg locations. This figure is available in colour online at wileyonlinelibrary.com



Homework Reading & Roadmap

We'll use the Wheaton et al. (2017) paper as a roadmap for exploring:

- Lets

State of Science

Upscaling site-scale ecohydraulic models to inform salmonid population-level life cycle modeling and restoration actions – Lessons from the Columbia River Basin

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Received 10 May 2016; Revised 15 January 2017; Accepted 28 February 2017

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ABSTRACT: With high-resolution topography and imagery in fluvial environments, the potential to quantify physical fish habitat at the reach scale has never been better. Increased availability of hydraulic, temperature and food availability data and models have given rise to a host of species and life stage specific ecohydraulic fish habitat models ranging from simple, empirical habitat suitability curve driven models, to fuzzy inference systems to fully mechanistic bioenergetic models. However, few examples exist where such information has been upscaled appropriately to evaluate entire fish populations. We present a framework for applying such ecohydraulic models from over 905 sites in 12 sub-watersheds of the Columbia River Basin (USA), to assess status and trends in anadromous salmon populations. We automated the simulation of computational engines to drive the hydraulics, and subsequent ecohydraulic models using cloud computing for over 2075 visits from 2011 to 2015 at 905 sites. We also characterize each site's geomorphic reach type, habitat condition, geomorphic unit assemblage, primary production potential and thermal regime. We then independently produce drainage network-scale models to estimate these same parameters from coarser, remotely sensed data available across entire populations within the Columbia River Basin. These variables give us a basis for imputation of reach-scale capacity estimates across drainage networks. Combining capacity estimates with survival estimates from mark-recapture monitoring allows a more robust quantification of capacity for freshwater life stages (i.e. adult spawning, juvenile rearing) of the anadromous life cycle. We use these data to drive life cycle models of populations, which not only include the freshwater life stages but also the marine and migration life stages through the hydropower system. More fundamentally, we can begin to look at more realistic, spatially explicit, tributary habitat restoration scenarios to examine whether the enormous financial investment on such restoration actions can help recover these populations or prevent their extinction. Copyright © 2017 John Wiley & Sons, Ltd.

KEYWORDS: salmon recovery; stream and river restoration; *Oncorhynchus* sp; fish habitat; population modeling

Introduction

Globally, native anadromous salmonid populations are in decline and several face the threat of extinction (Gustafson et al., 2007; Rand et al., 2012). Given the cultural, economic, and ecological importance of these populations, numerous efforts are underway to mitigate impacts that lead to their decline and facilitate their recovery (e.g. conservation hatcheries (Maynard and Trial, 2013), habitat restoration (Barnas et al., 2015)). For example, in the Columbia River

Basin, there are eleven evolutionarily significant units of salmon or steelhead (*Oncorhynchus* sp.) listed as threatened and two as endangered under the US Endangered Species Act (ESA) (Ruckelshaus et al., 2002; Gustafson et al., 2007). According to the ESA review on the risks posed to anadromous salmonids by the Columbia Basin's federally administered hydropower dam system (NOAA, 2008), three action agencies are required to make costly dam retrofits and operational changes (i.e. to improve passage) and/or mitigate dam impacts via offsite actions (i.e. tributary habitat restoration). The

Review

- Ecohydraulics started

