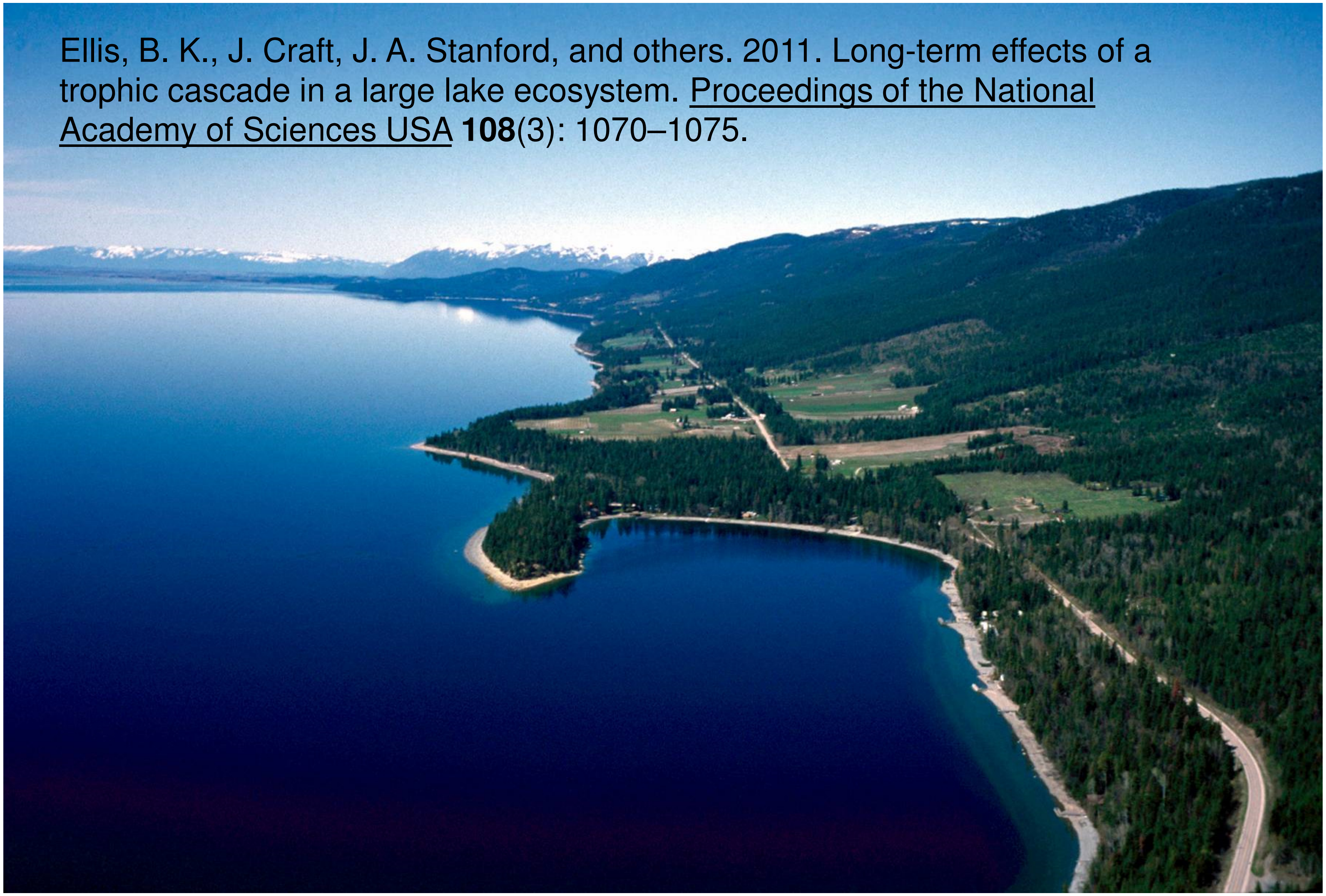
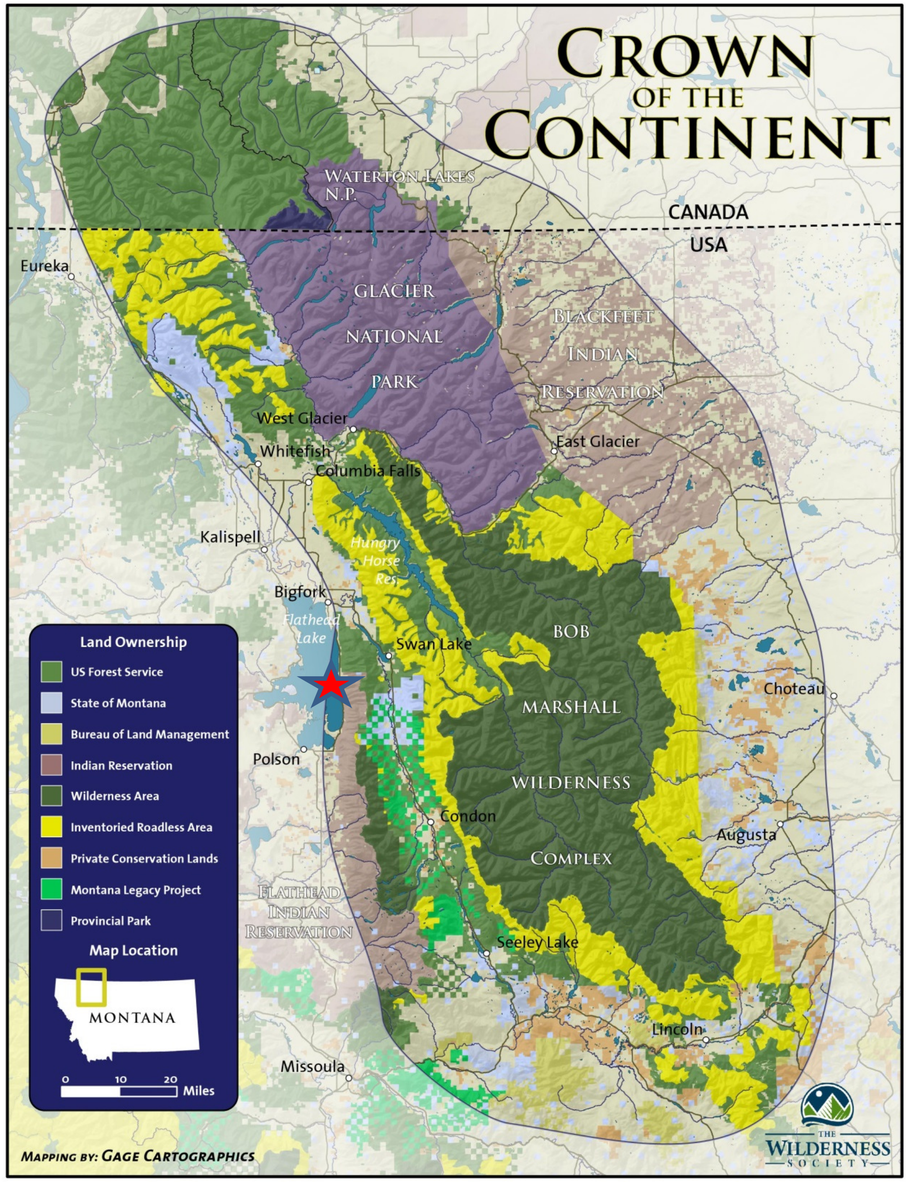


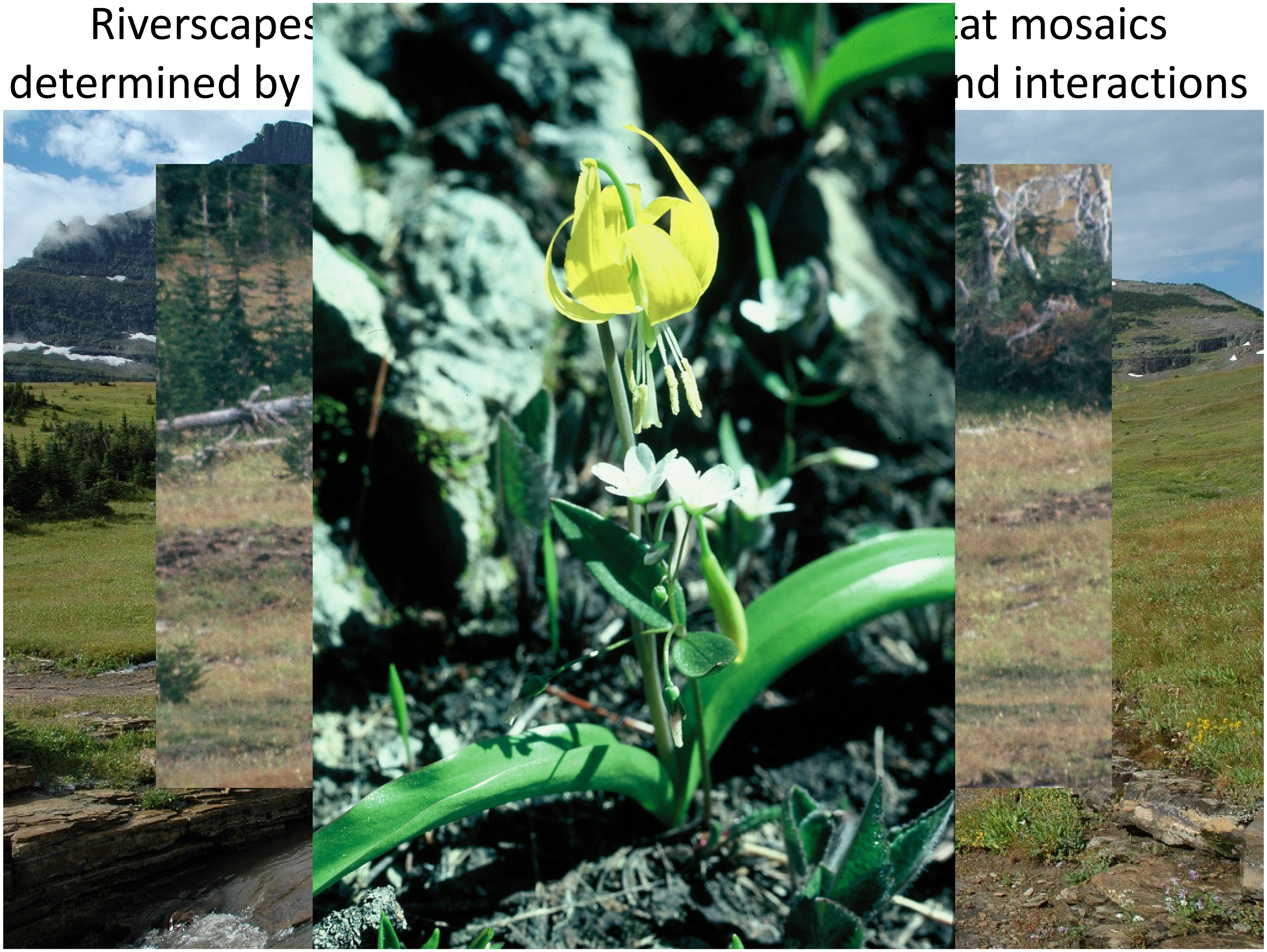
Ellis, B. K., J. Craft, J. A. Stanford, and others. 2011. Long-term effects of a trophic cascade in a large lake ecosystem. Proceedings of the National Academy of Sciences USA **108**(3): 1070–1075.

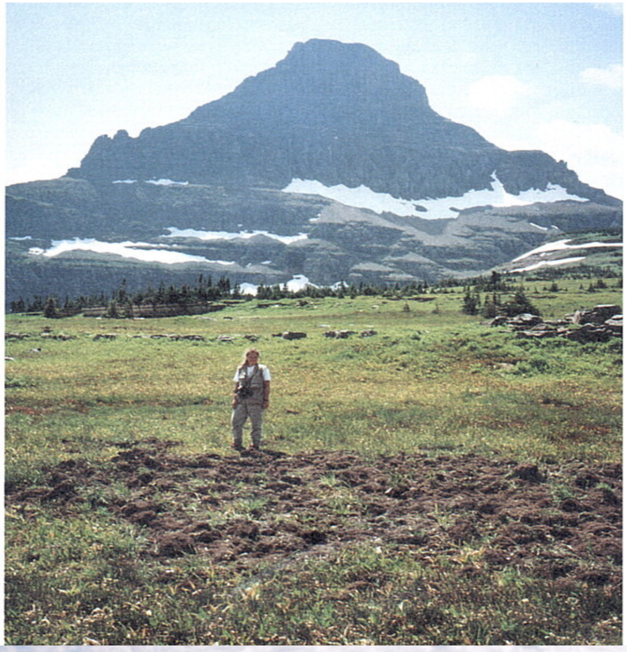
The Flathead Lake Biological Station at Yellow Bay

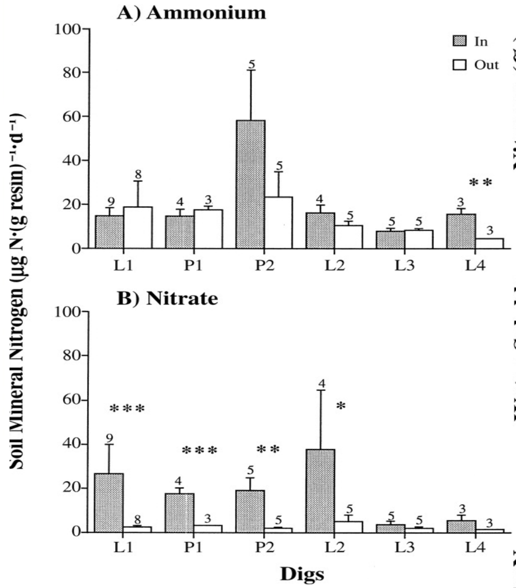

CROWN OF THE CONTINENT
WATERTON LAKES N.P.
CANADA
USA
Eureka
GLACIER NATIONAL PARK
BLACKFEET INDIAN RESERVATION
West Glacier
Whitefish
Columbia Falls
East Glacier
Kalispell
Hungry Horse Res.
Bigfork
Flathead Lake
Swan Lake
BOB MARSHALL WILDERNESS COMPLEX
Choteau
Polson
Condon
Augusta
FLATHEAD INDIAN RESERVATION
Seeley Lake
Lincoln
Missoula
Land Ownership
US Forest Service
State of Montana
Bureau of Land Management
Indian Reservation
Wilderness Area
Inventoried Roadless Area
Private Conservation Lands
Montana Legacy Project
Provincial Park
Map Location
MONTANA
0 10 20 Miles
MAPPING BY: GAGE CARTOGRAPHICS
THE WILDERNESS SOCIETY

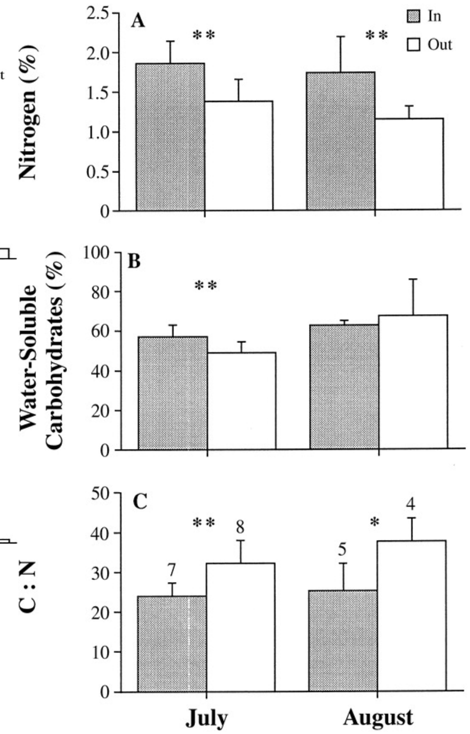
FLBS

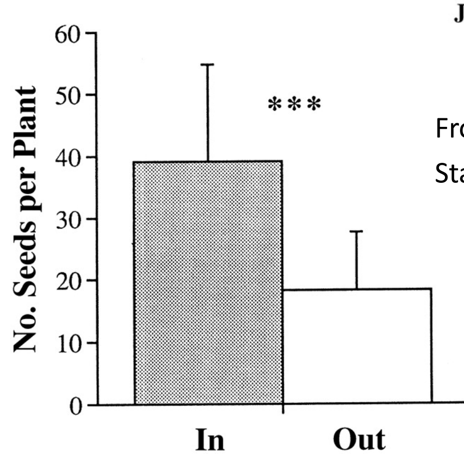
Riverscapes … tat mosaics
determined by … nd interactions











From Tardiff and Stanford. 1998. Ecology.

Nyack Floodplain Research Natural Area

Middle Fork, Flathead River

5th order

Northwest Montana

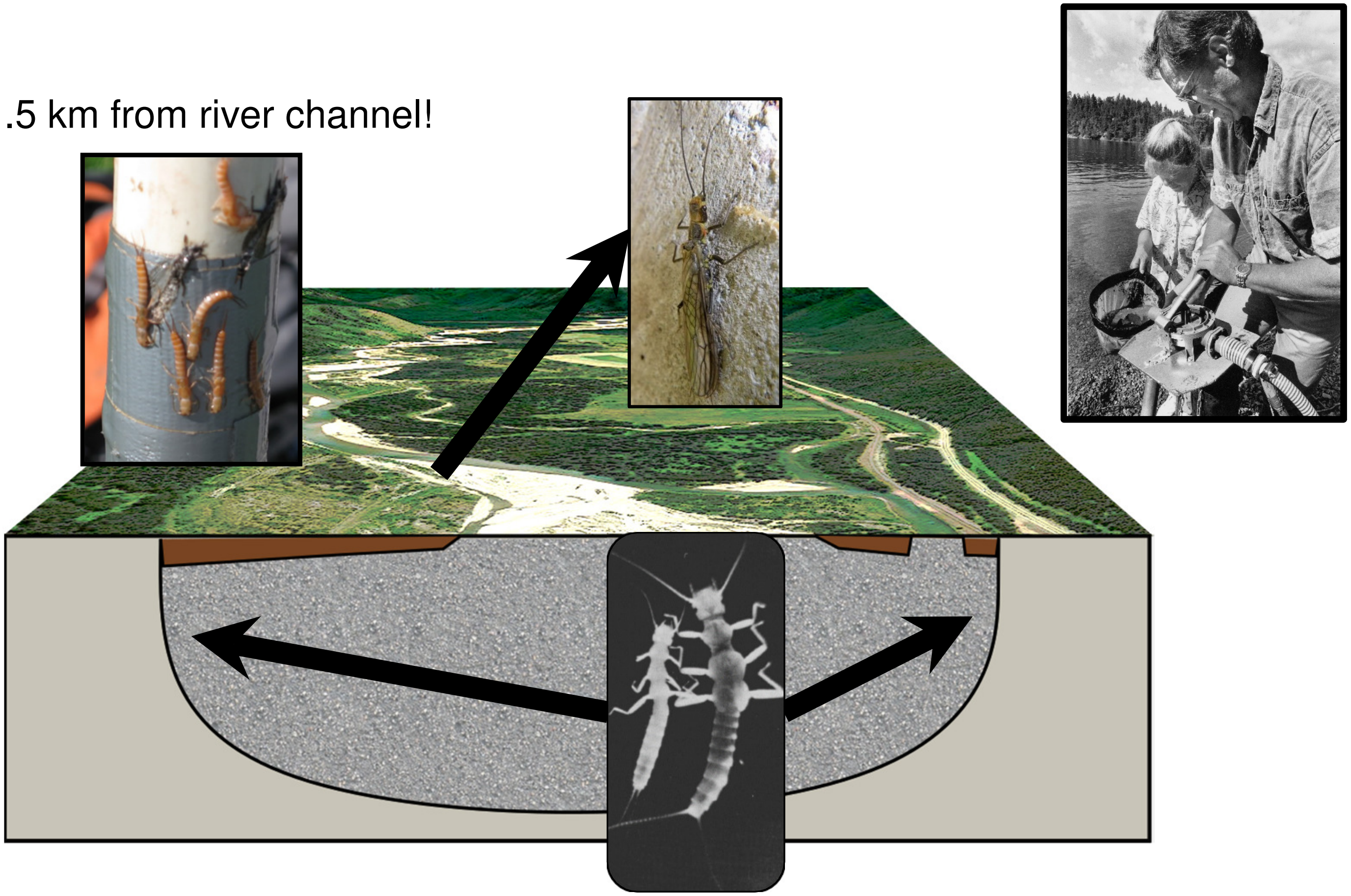
SaRON reference site: ultra-oligotrophic, protected, no salmon.

Funded by –

NSFawards:
Biocomplexity in the Environment; Microbial Observatory; Ecology programs

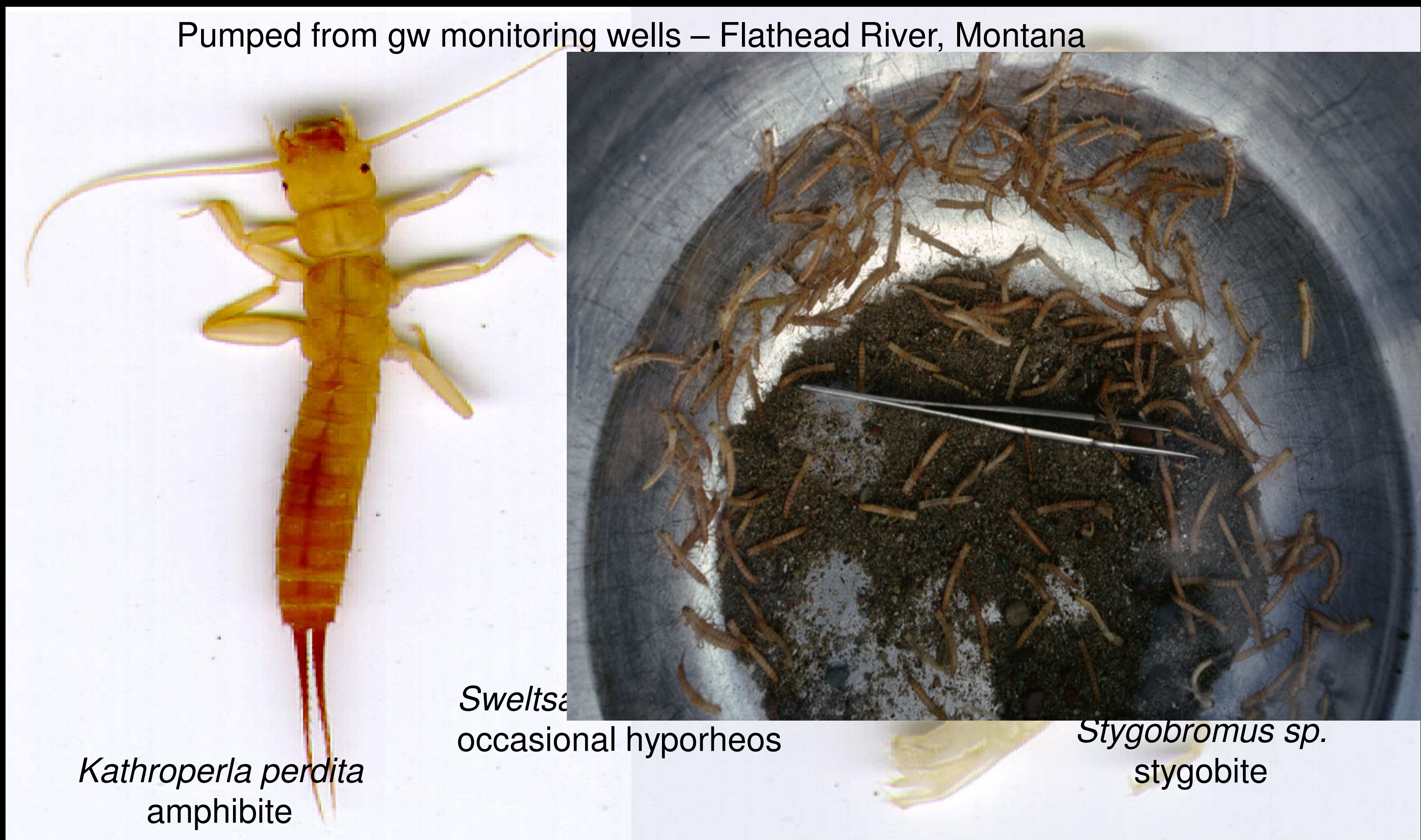
GB Moore Foundation

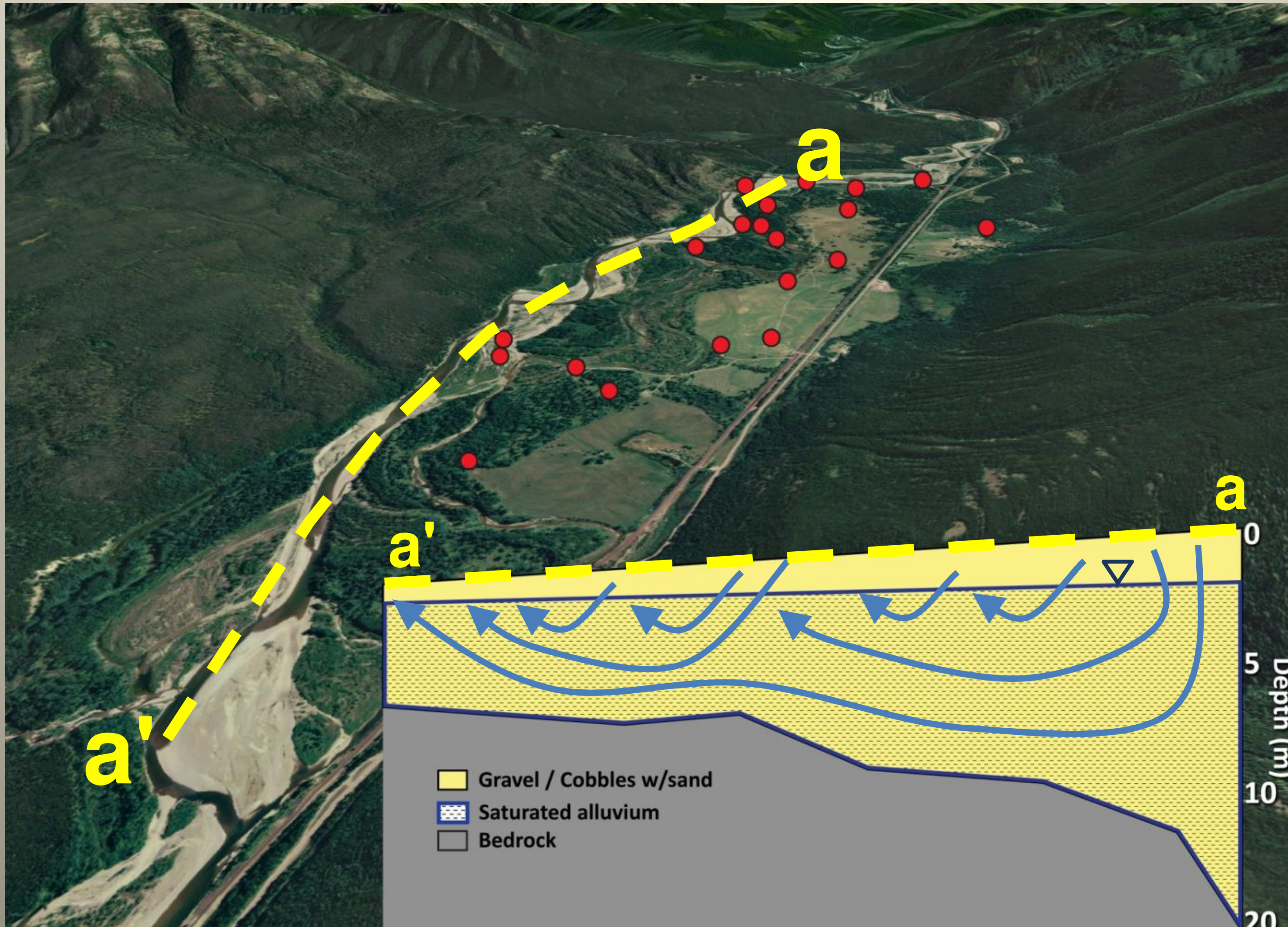
National Park Service



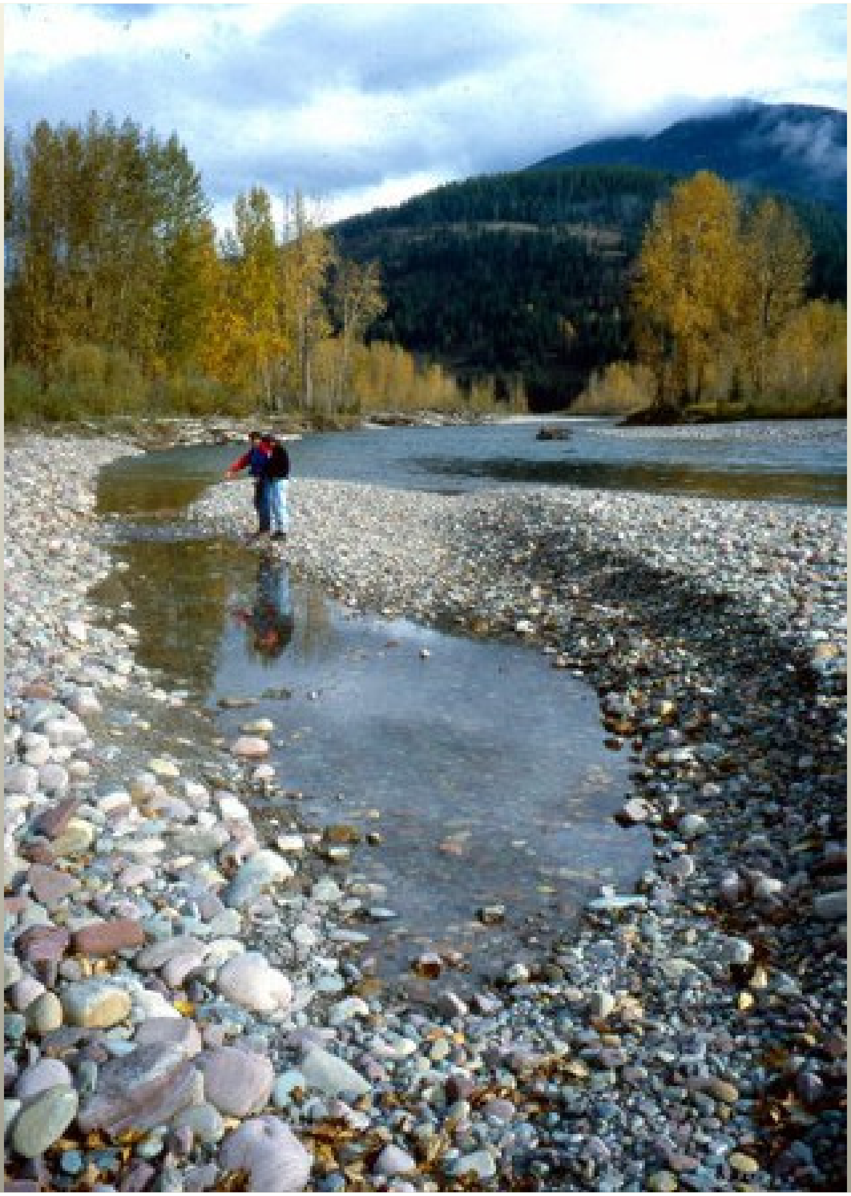
Stanford and Gaufin
(1974) *Science*

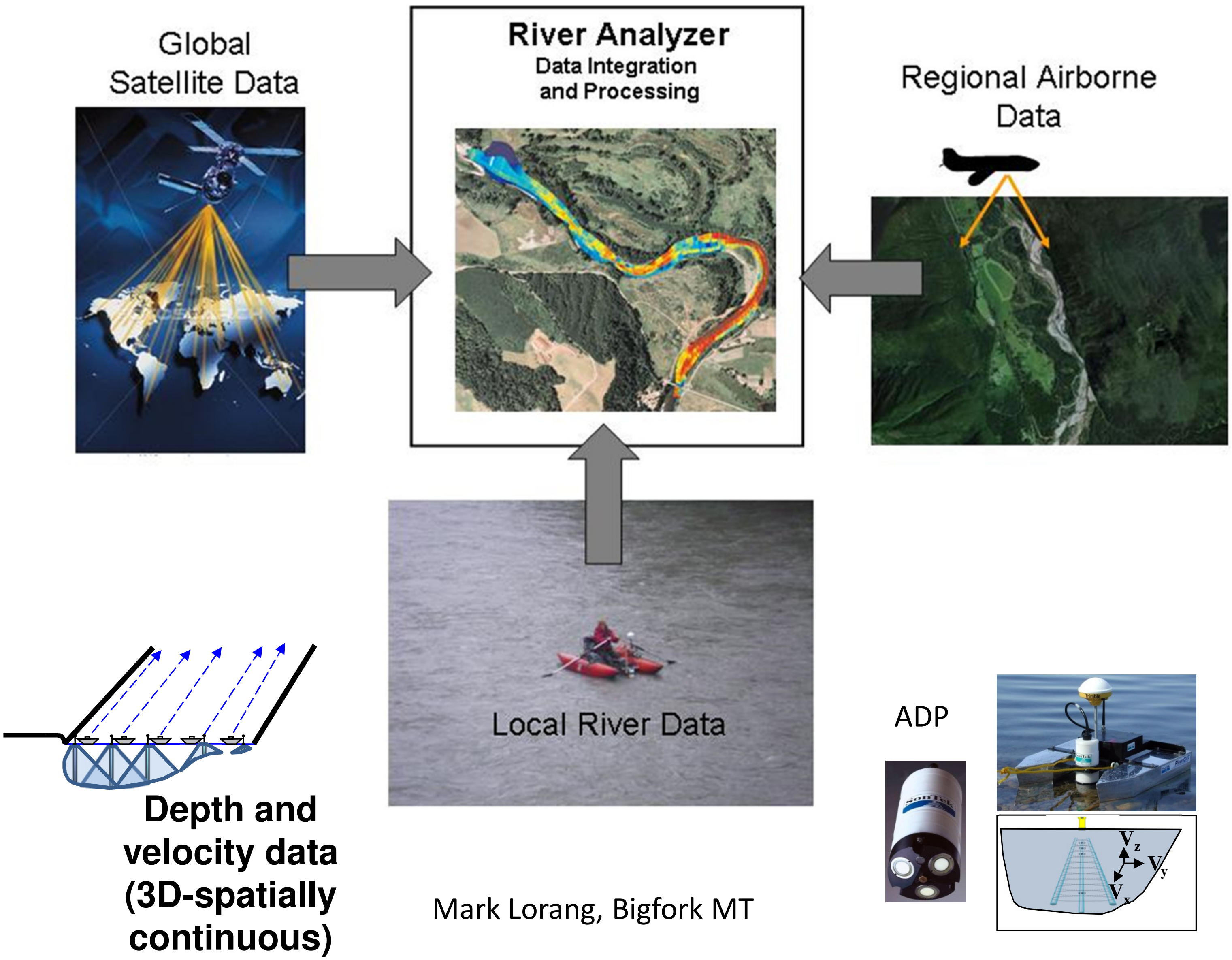
Presence of abundant, large invertebrates shows that zones of preferential flow (rapid gw-sw exchange) characterize alluvial aquifers of gravel-bed rivers.





a
a'
a
a'
0
5
10
20
Depth (m)
Gravel / Cobbles w/sand
Saturated alluvium
Bedrock

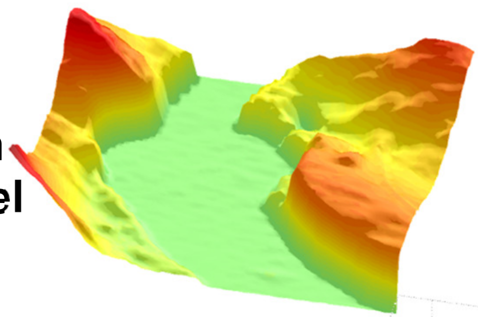


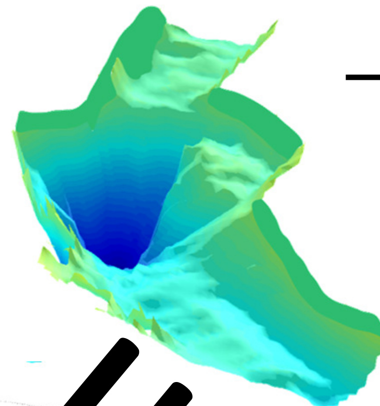


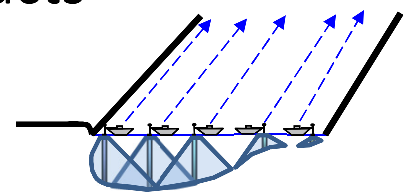
Global
Satellite Data
River Analyzer
Data Integration
and Processing
Regional Airborne
Data
Local River Data
Depth and
velocity data
(3D-spatially
continuous)
ADP
Mark Lorang, Bigfork MT

River Analyzer: data fusion and products

Lidar Digital Elevation Data/Model (DEM)



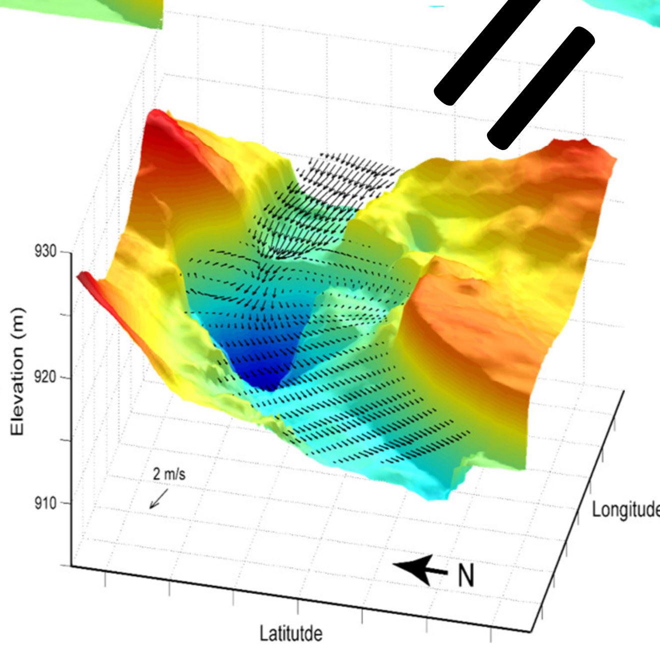




Depth and velocity data (3D-spatially continuous)

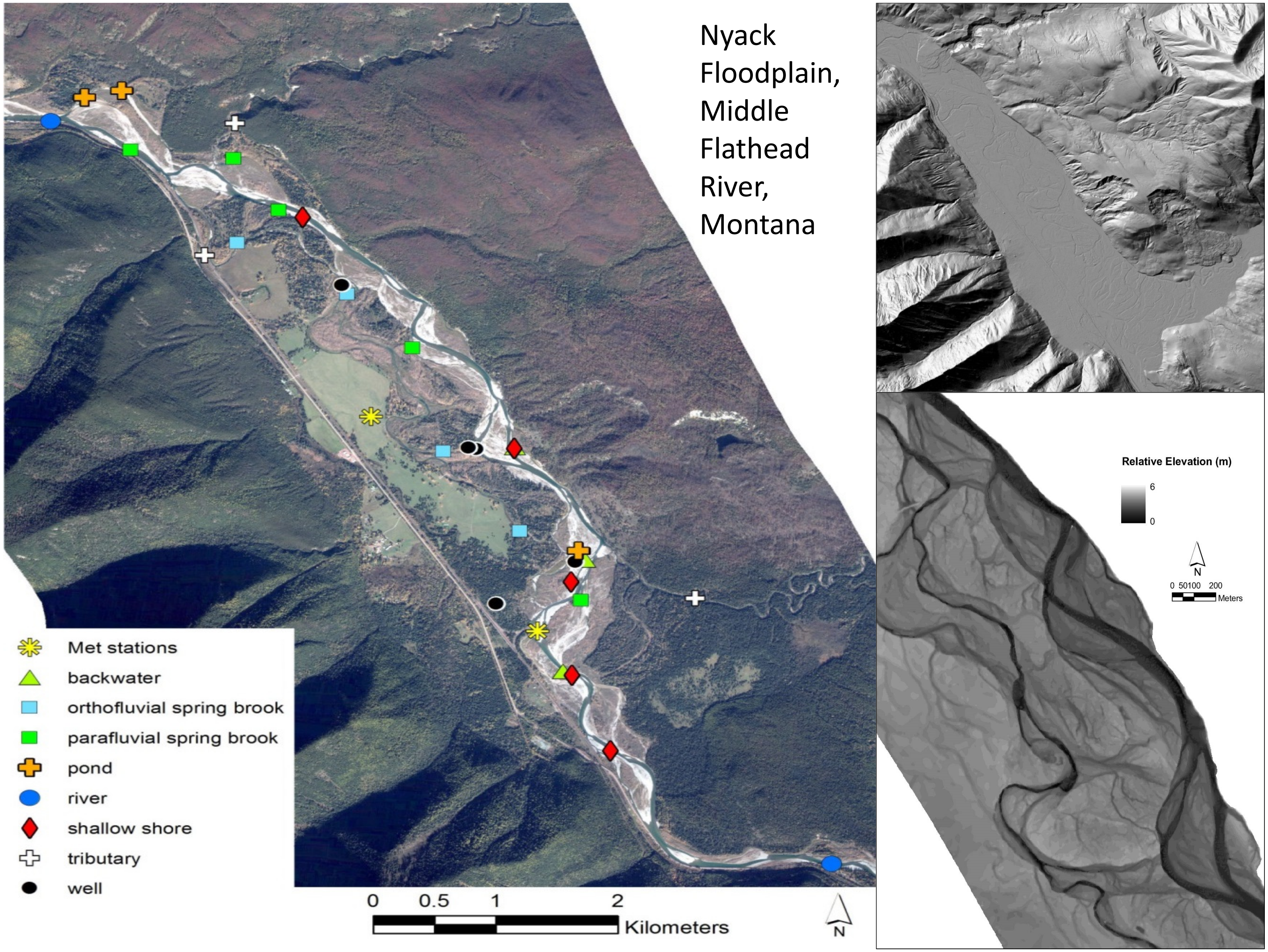
River Analyzer Data Products:

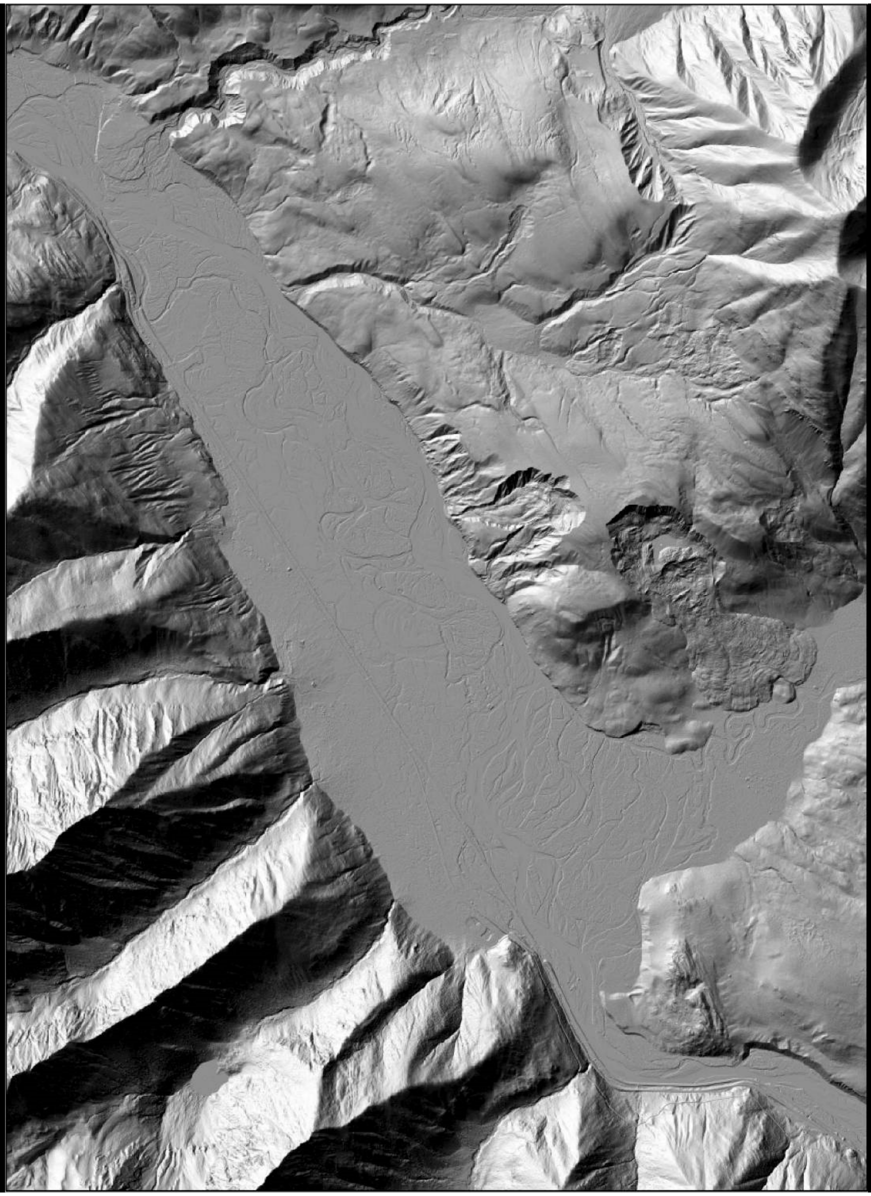
- **3D Flow hydraulics for all active channels**
- **Location and volume of ground-surfacewater interactions**
- **Bedload: real time cut and fill documentation**



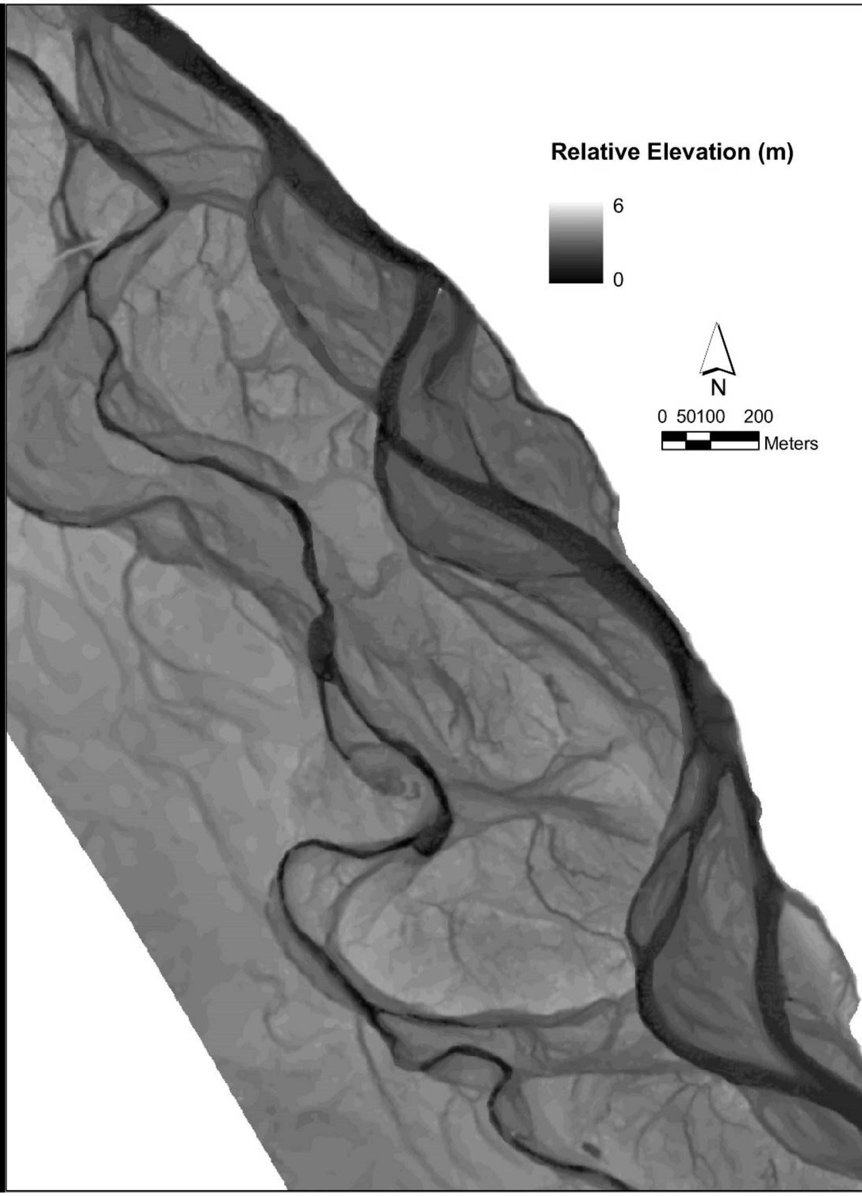
Add DIDSON sonar to get particle size (fish, substratum)

Nyack Floodplain, Middle Flathead River, Montana



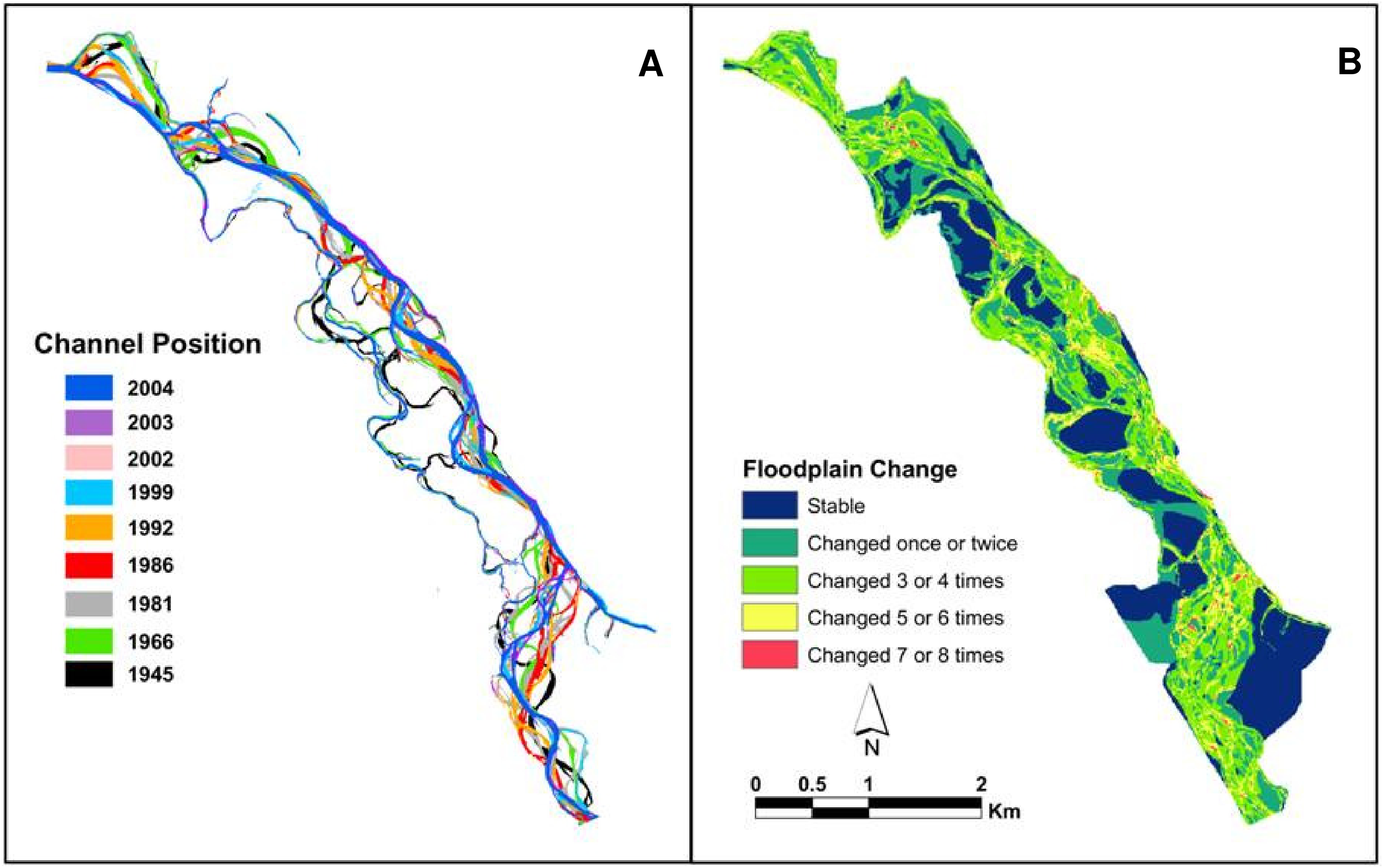


A LIDAR image of The Nyack Flood Plain showing the landscape features, including the channel network and the mass wasting on the GNP (right) side.



A portion of the LIDAR image in the previous slide that has been processed to finer detail using a GIS. Here the water is dark black and dry flood-and paleo-channels show up as dark grey channels that bisect lighter-colored benches. These benches are covered by riparian forests.

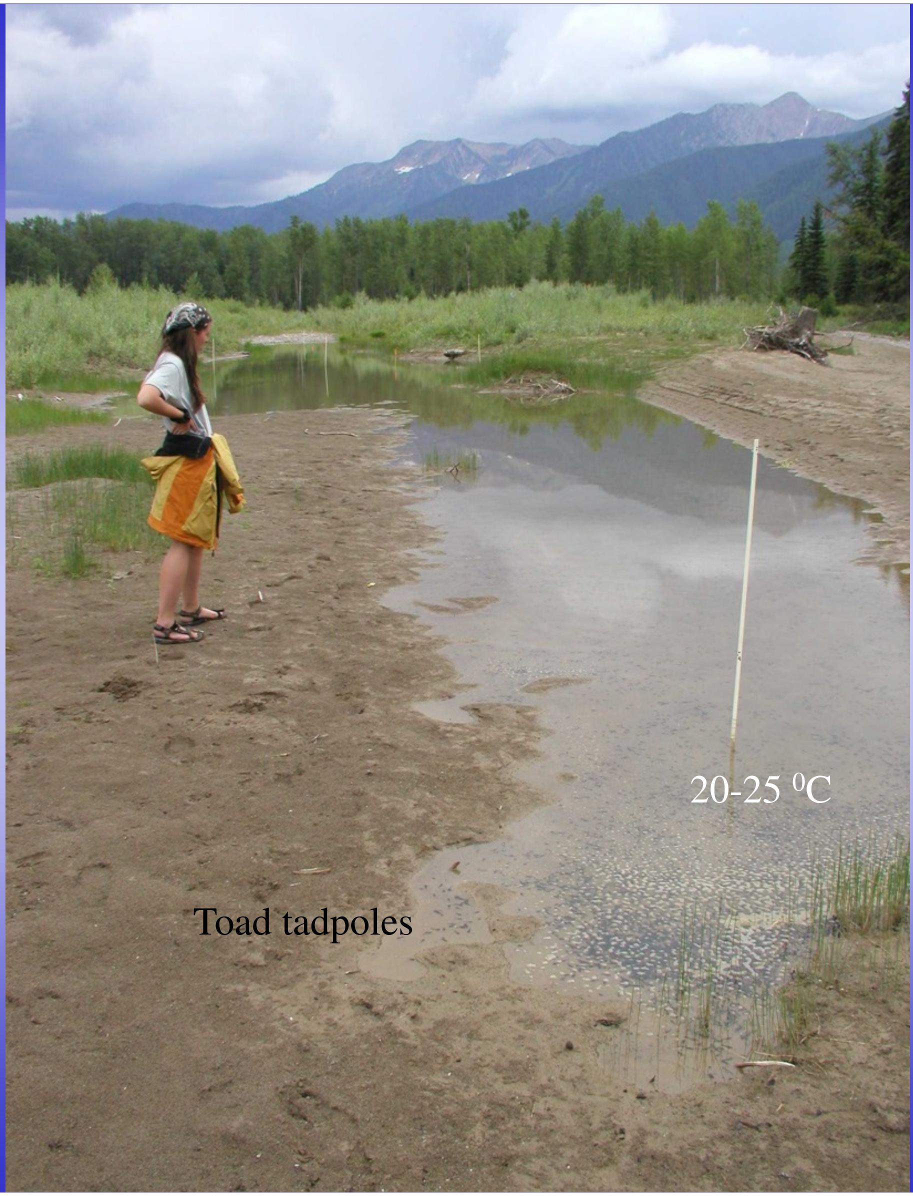
Habitat change at the Nyack Flood Plain of the Flathead River, Montana
1945-2004



Whited et al.,2006. *Ecology*

Nyack Floodplain – Middle Flathead River, Montana


15 0C
10-12 0C
5-8 0C


20-25 °C
Toad tadpoles


7-18-13 ⁰C
5

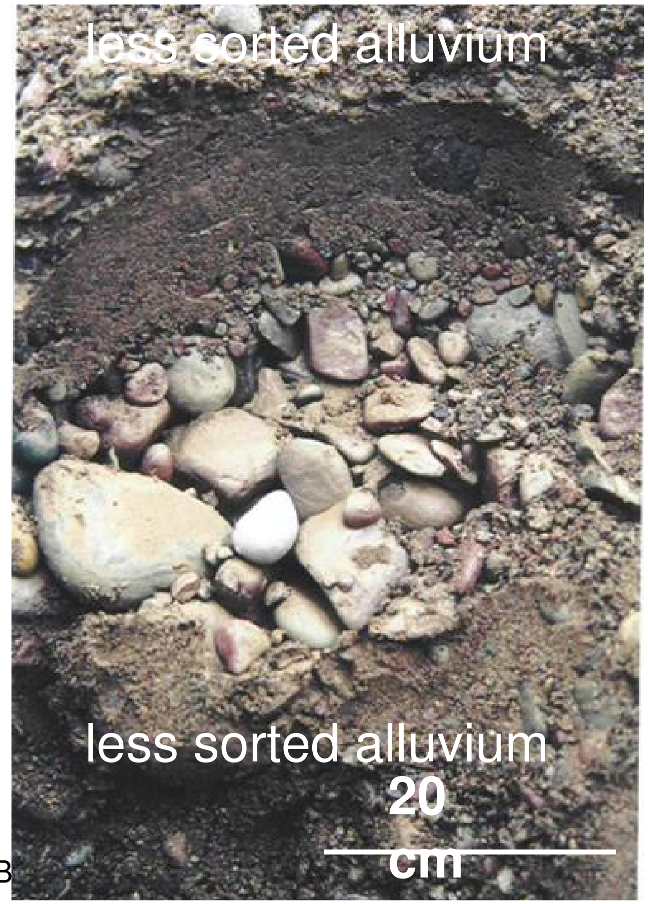
Bimodal gravel "tubes": open framework gravel-cobble in fining-upward sequences; attached bioflims – DOM limited; abundant mieofauna; 80+ species of amphibionts & stygobionts (hyporheos); occasional benthos.

<u>ZPF – gravel couplet</u>:

"pea" gravel

gravel – cobble

very high hydraulic conductance



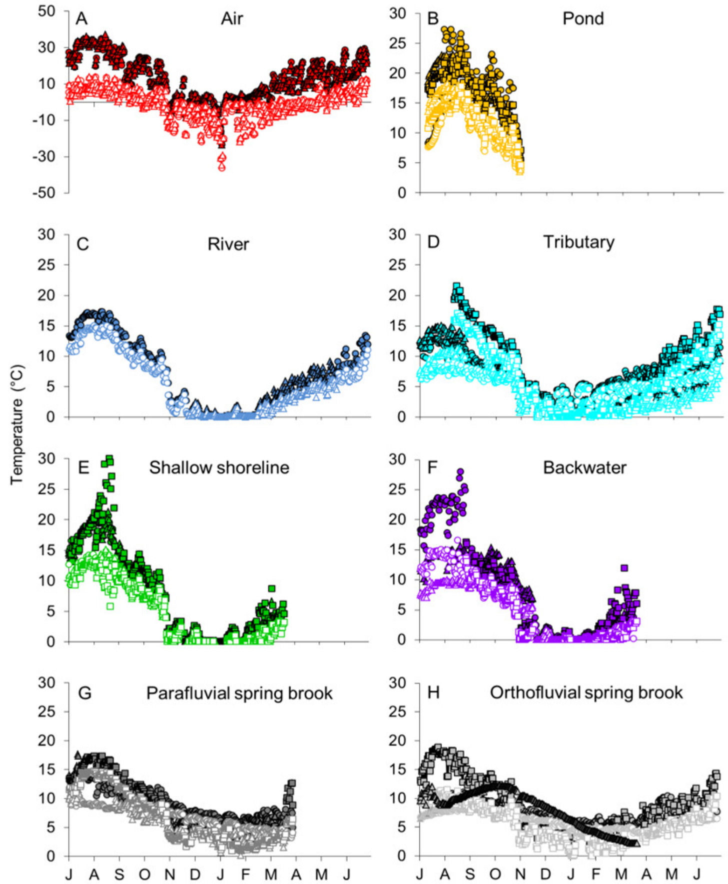
Huggenberger et al. 1998. FWB

<u>Meiofauna</u>
large protists
archiannilids
bathenellids
copepods

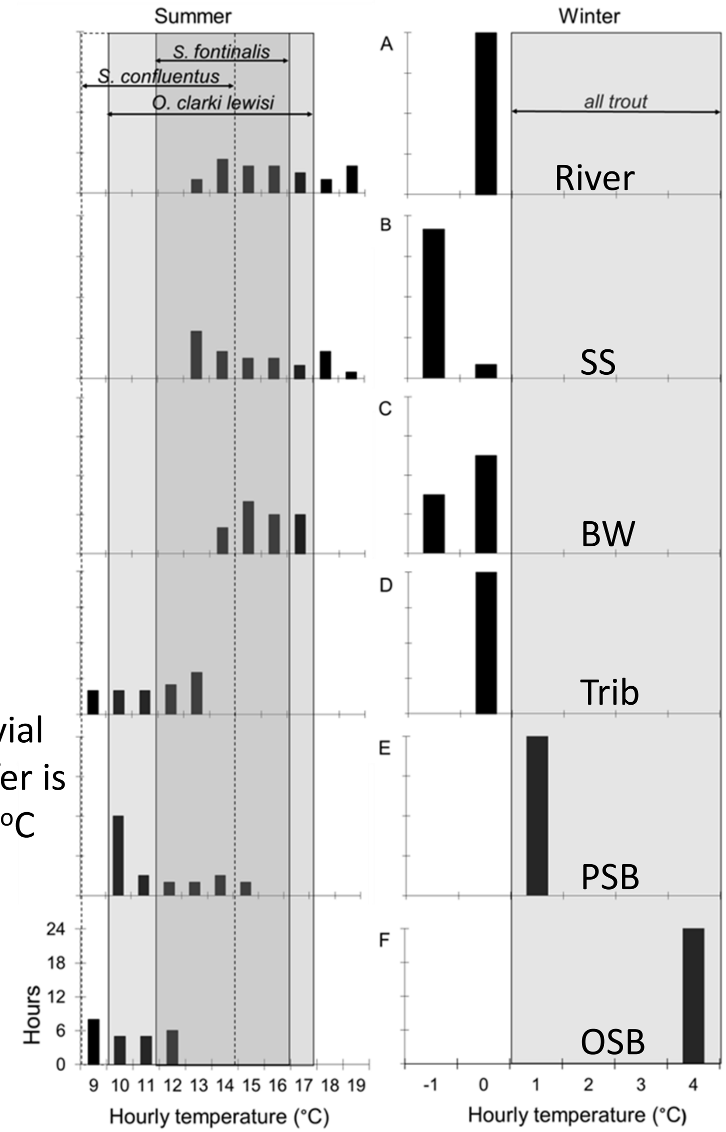
<u>Stygobionts</u>:
Stygobromus spp. and other amphipoda
Ascellus

<u>Amphibionts</u>:
Paraperla 2spp.
Katrhoperla 1sp
Isocapnia 6spp. and many benthic species in early life stages

Stanford and Gaufin. 1974. Science; Stanford and Ward 1988. Nature

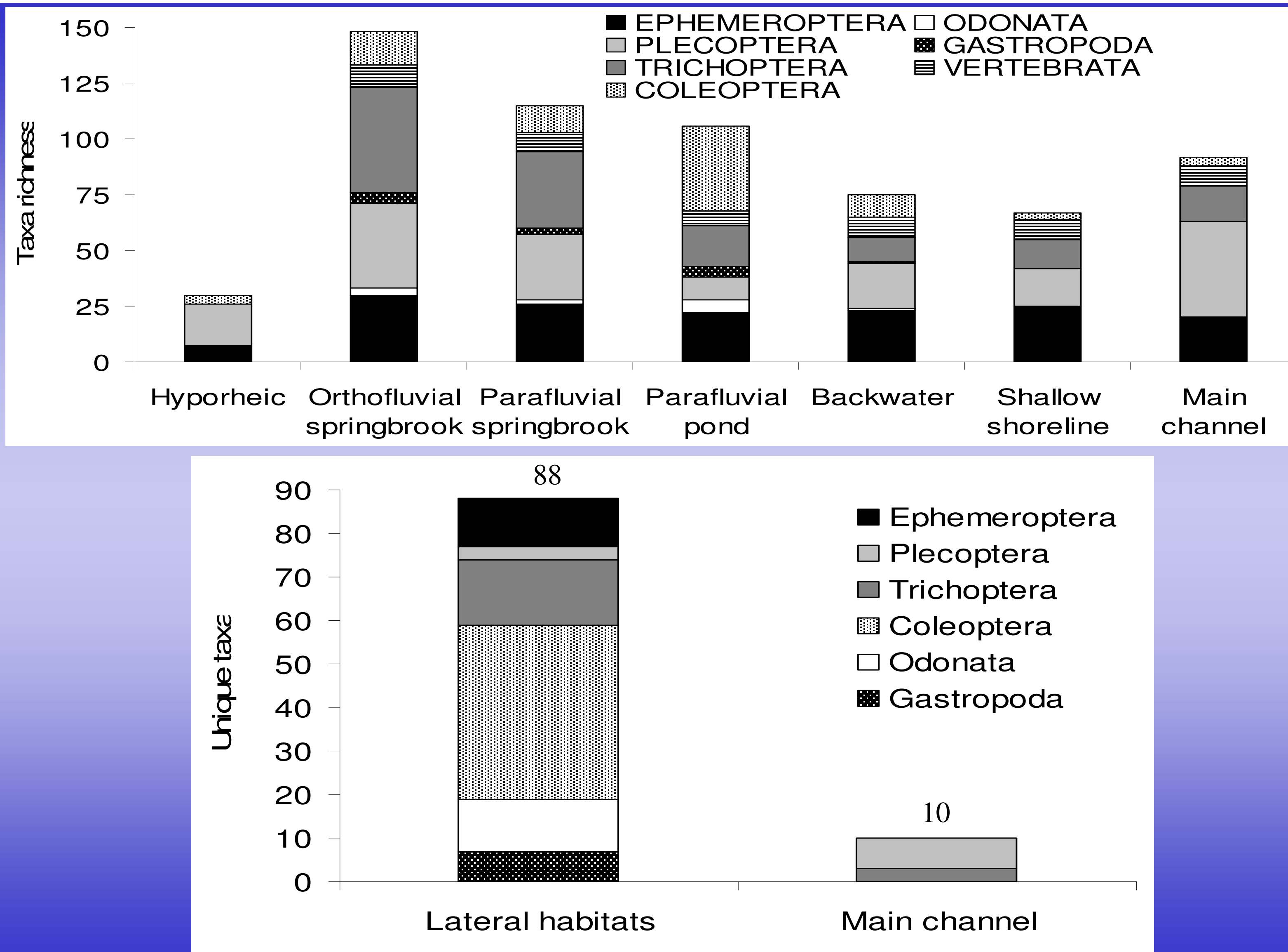


Allluvial aquifer is 5-10 ^{o}C

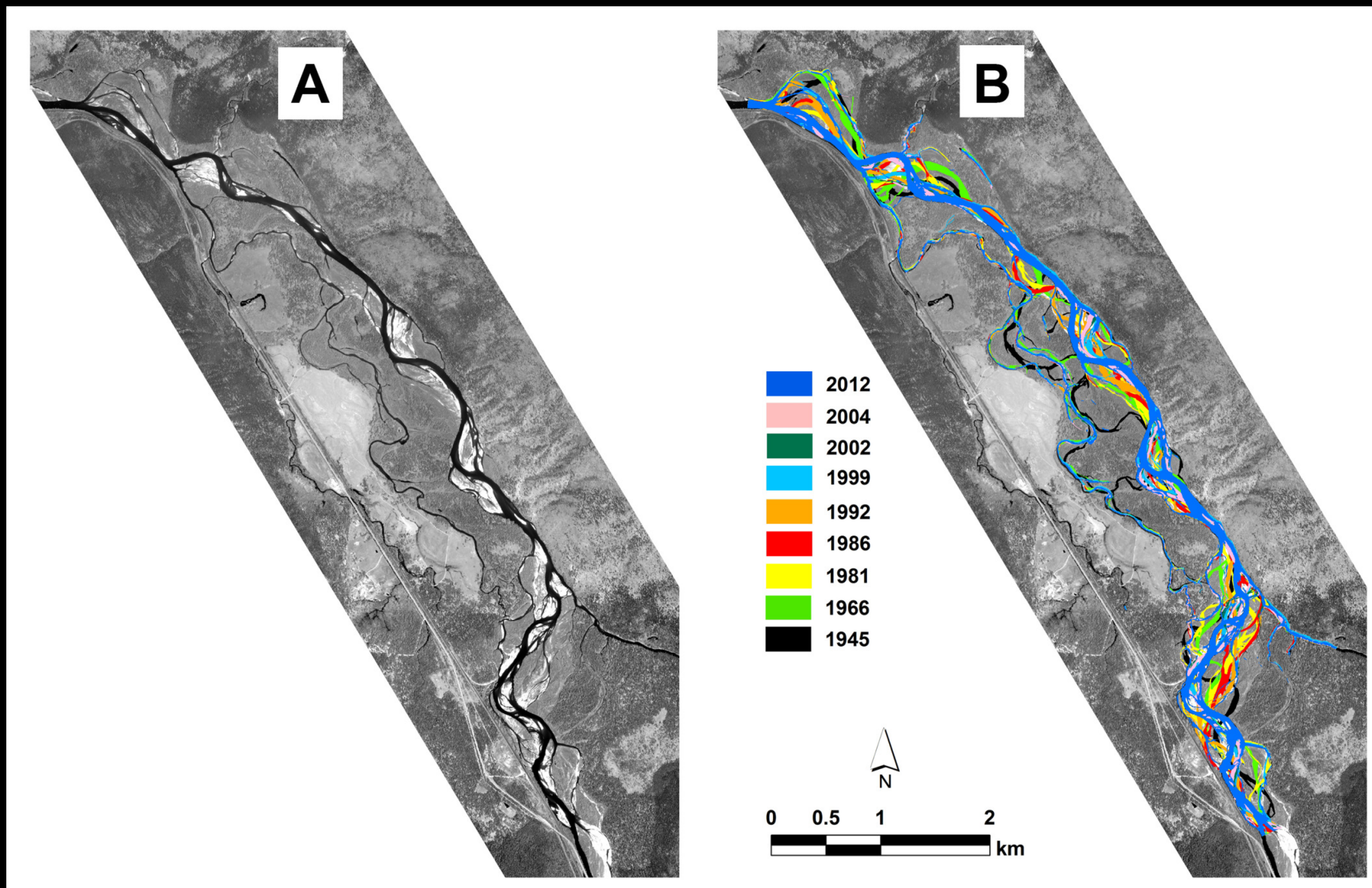


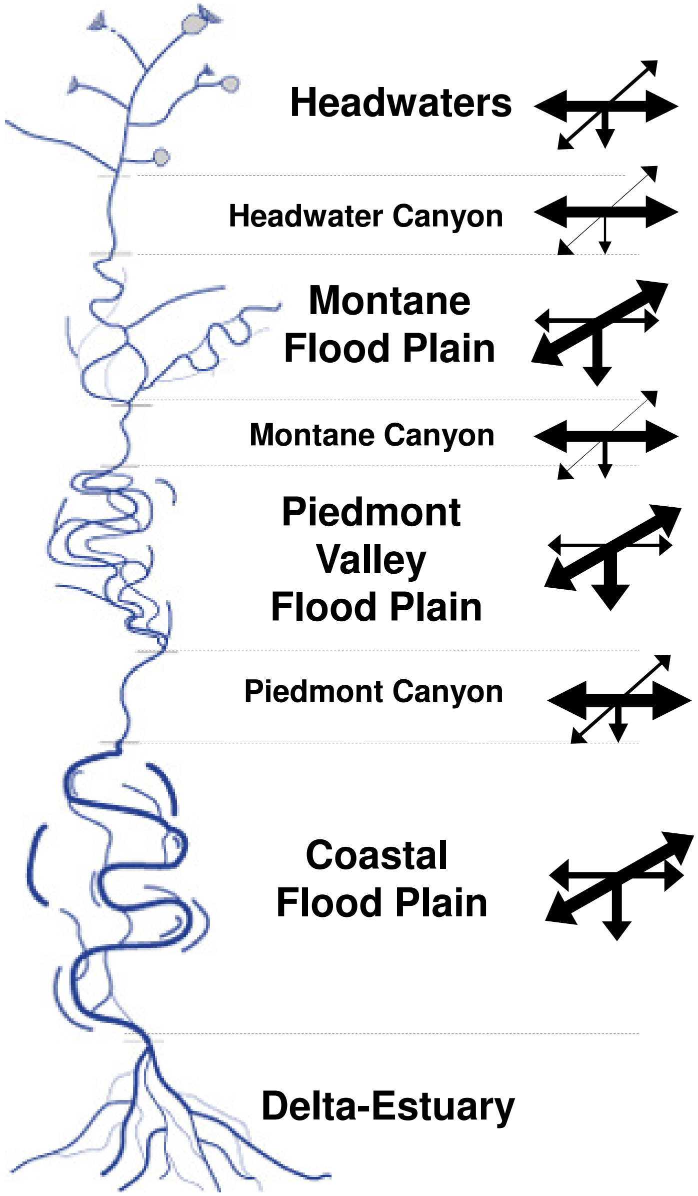
- **Fishes and other vertebrates can find optimal thermal conditions if are habitats are hydraulically connected and/or accessible**
- **Invertebrates limited by habitat-specific thermal conditions**
- **Stoneflies desynchronize life cycles in the aquifer (little temperature variation)**

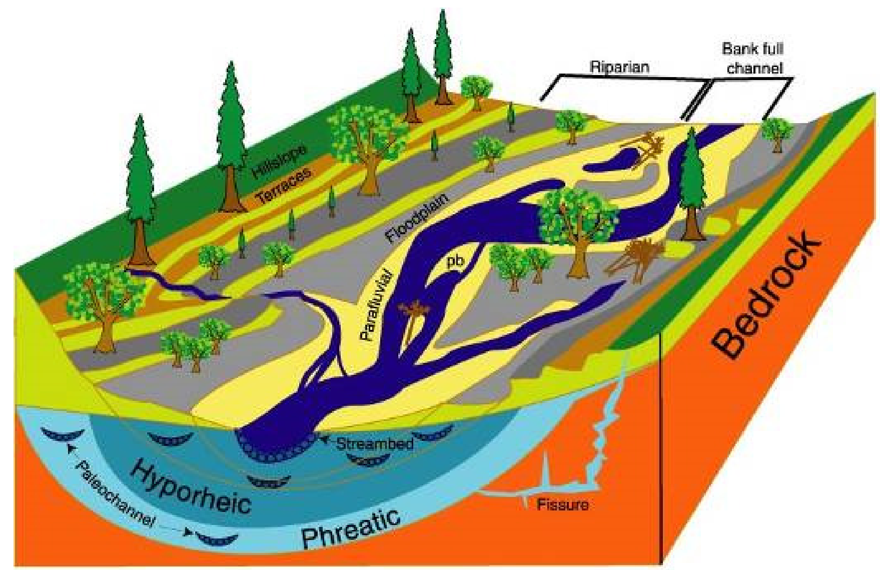
Stanford et al., in press



Stanford et al., unpubl. data


A
B
2012
2004
2002
1999
1992
1986
1981
1966
1945
N
0
0.5
1
2
km



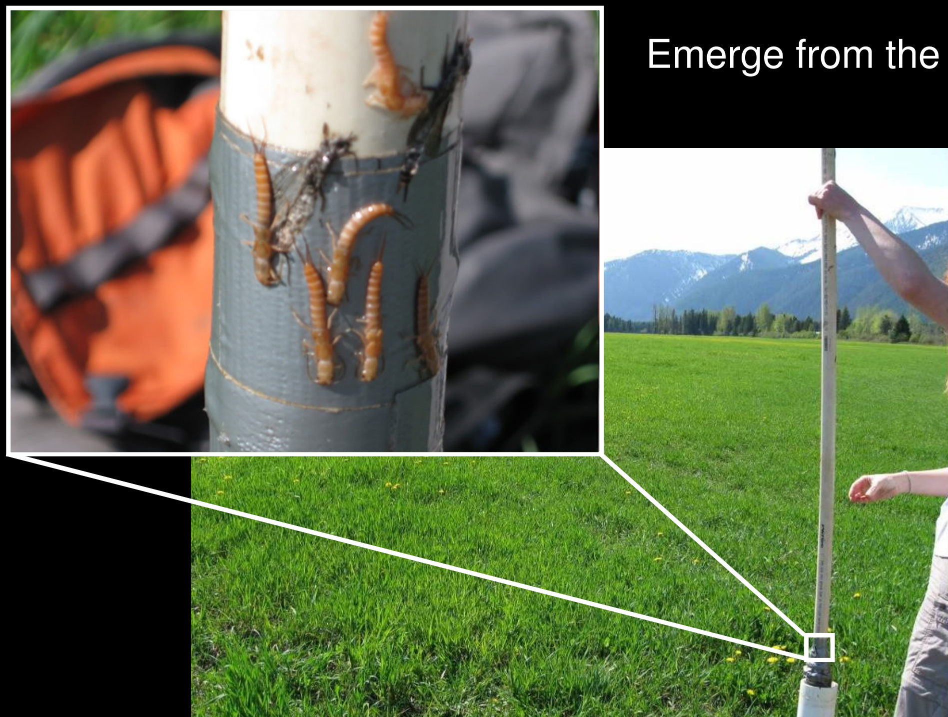


Primary drivers of the SHM:

- Geomorphic setting (slope, geologic legacies)
- Climate (flow, temperature, fire)
- Cut and fill alluviation (sediments and wood)
- Ground- surface water interactions
- Plant succession
- Animal modifications (including humans)

Dynamic, inter-connected habitats

Emerge from the river and wells in huge numbers



Migrate within the aquifer

Tolerent to hypoxia

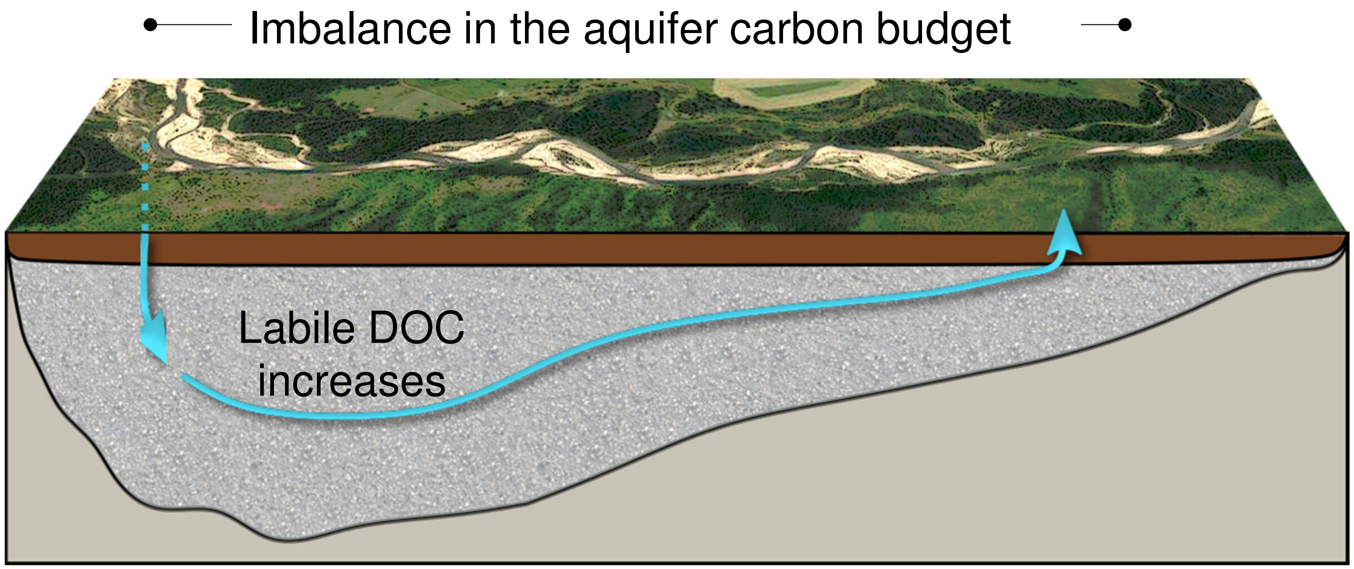
delta13C: -20 to - 70

Nyack HA 7 well, 2km from river channel

Flooding paleochannel (aquifer outwelling) at Nyack at HA 7 well - Helton, Wright

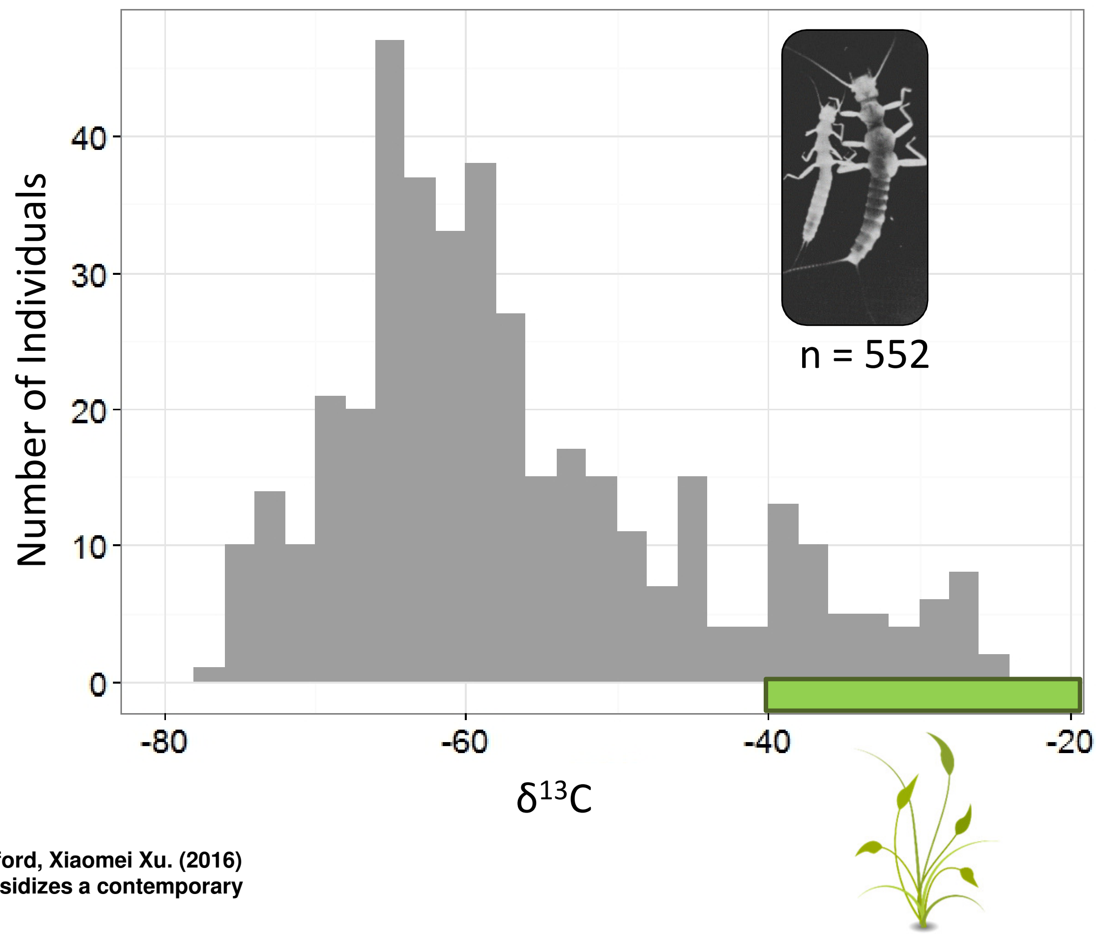
CH_4: BDL – 10% saturation in the wells coming from contemporary, ancient (methanogenic) and fossil (thermogenic) sources: Amanda DelVecchia

Dr. Amanda Delvecchia
Postdoctoral Research Scholar
North Carolina State University

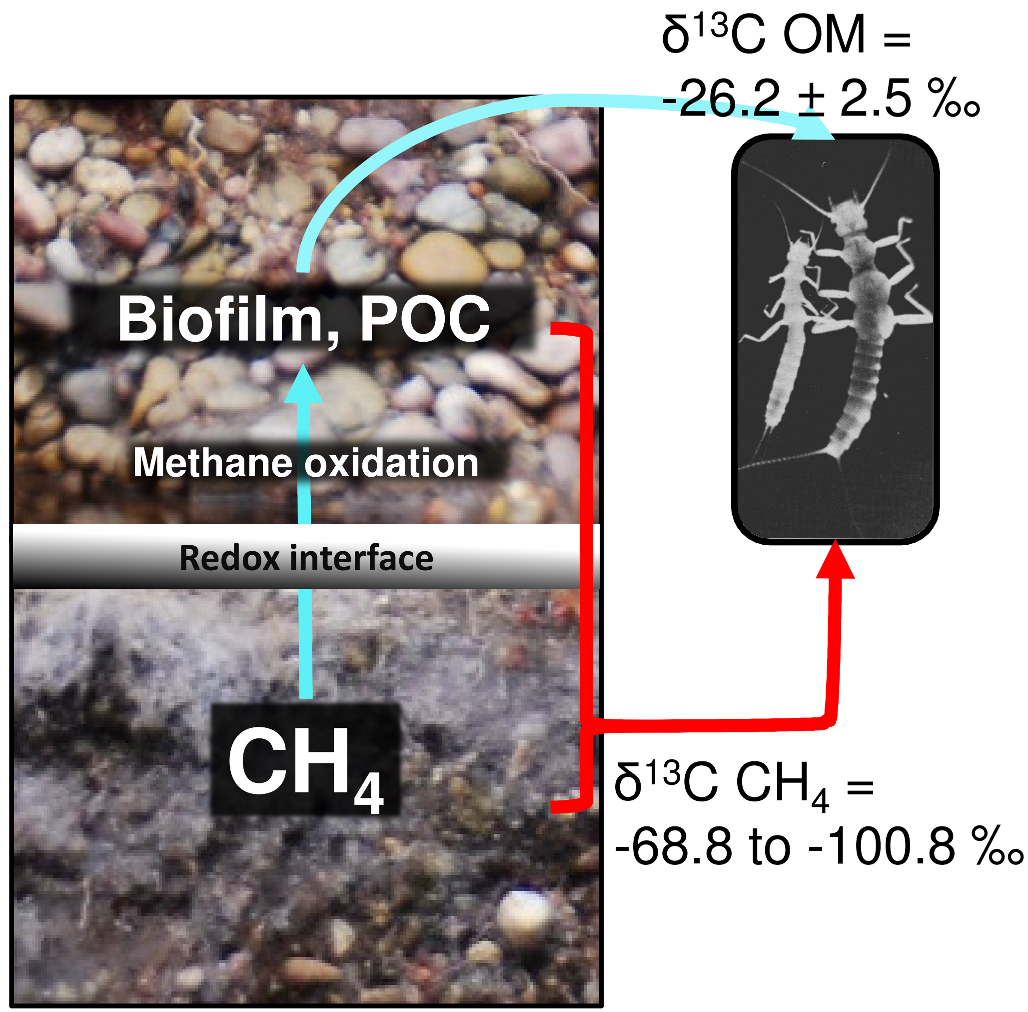


Appling (2012) Duke University
Reid (2007) U. of Montana
Helton et al. (2015) *L & O*

$\delta^{13}C$ values in stonefly biomass suggest methane contribution

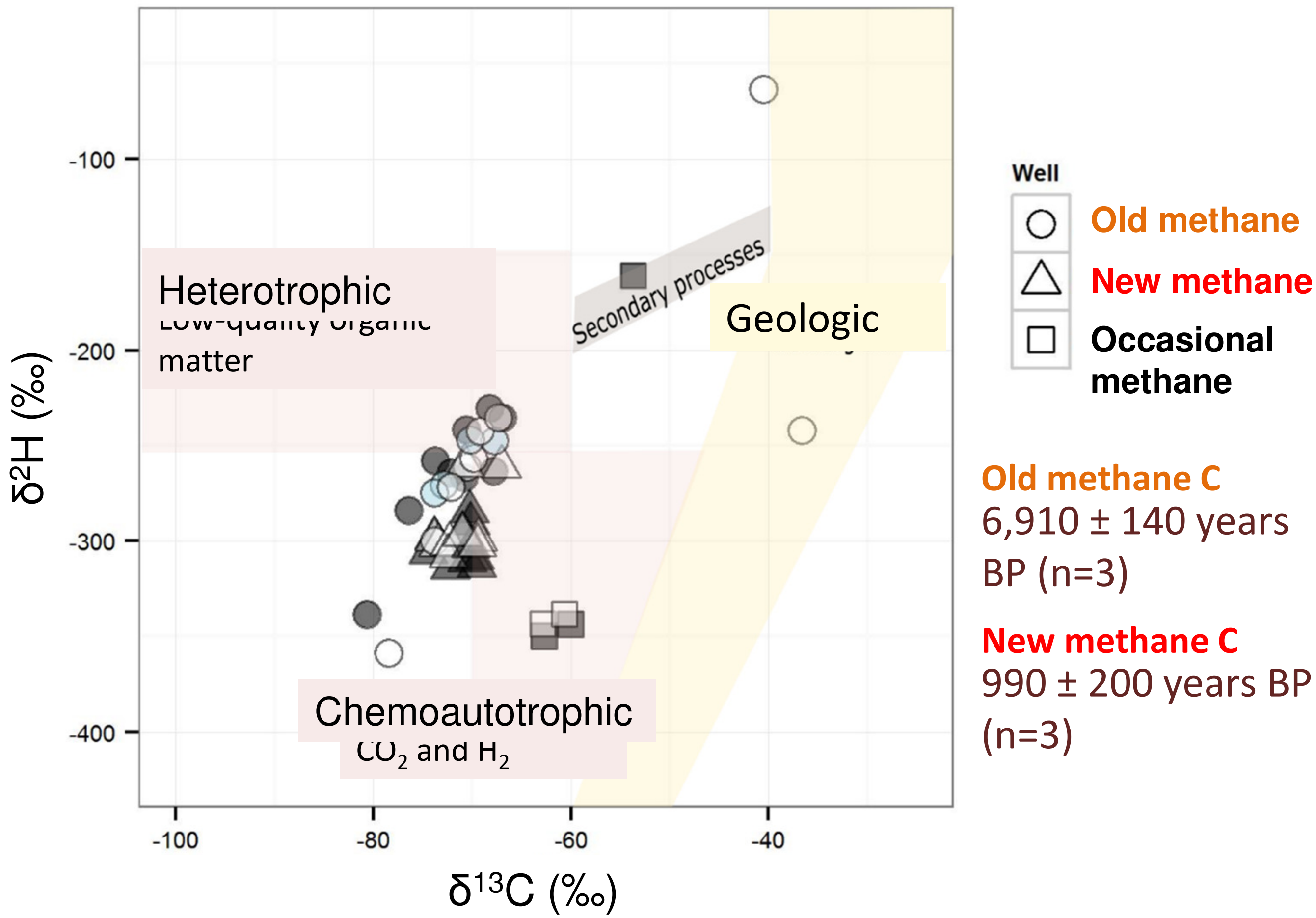


DelVecchia, Amanda G., Jack A. Stanford, Xiaomei Xu. (2016) 'Ancient methane-derived carbon subsidizes a contemporary food web'. *Nature Communications.*
doi:10.1038/ncomms13163



δ13C OM =
-26.2 ± 2.5 ‰
Biofilm, POC
Methane oxidation
Redox interface
CH4
δ13C CH4 =
-68.8 to -100.8 ‰

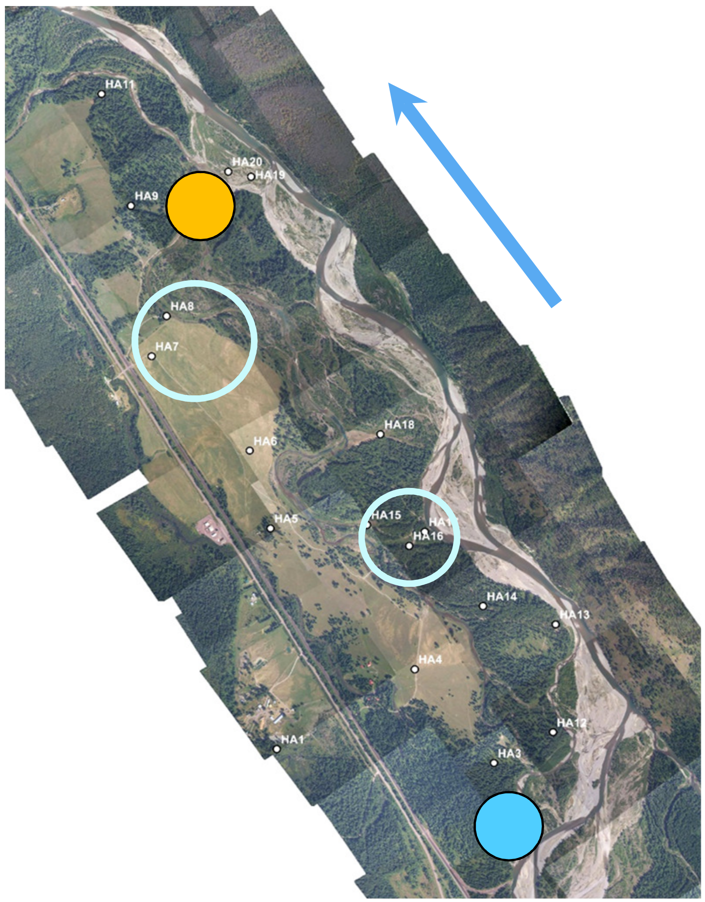
Methane mostly methanogenic (microbial)

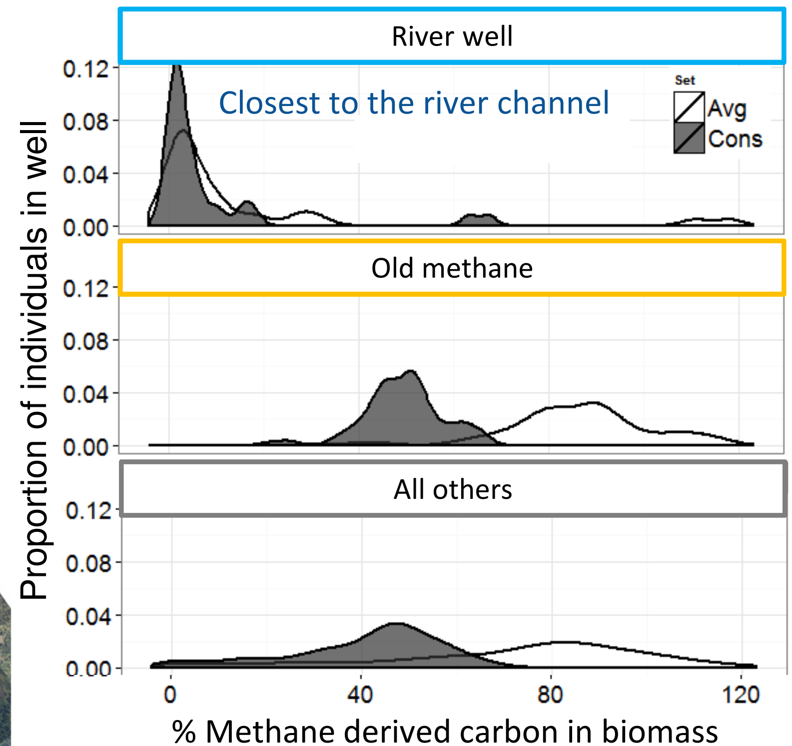


Old methane C
6,910 ± 140 years BP (n=3)

New methane C
990 ± 200 years BP (n=3)

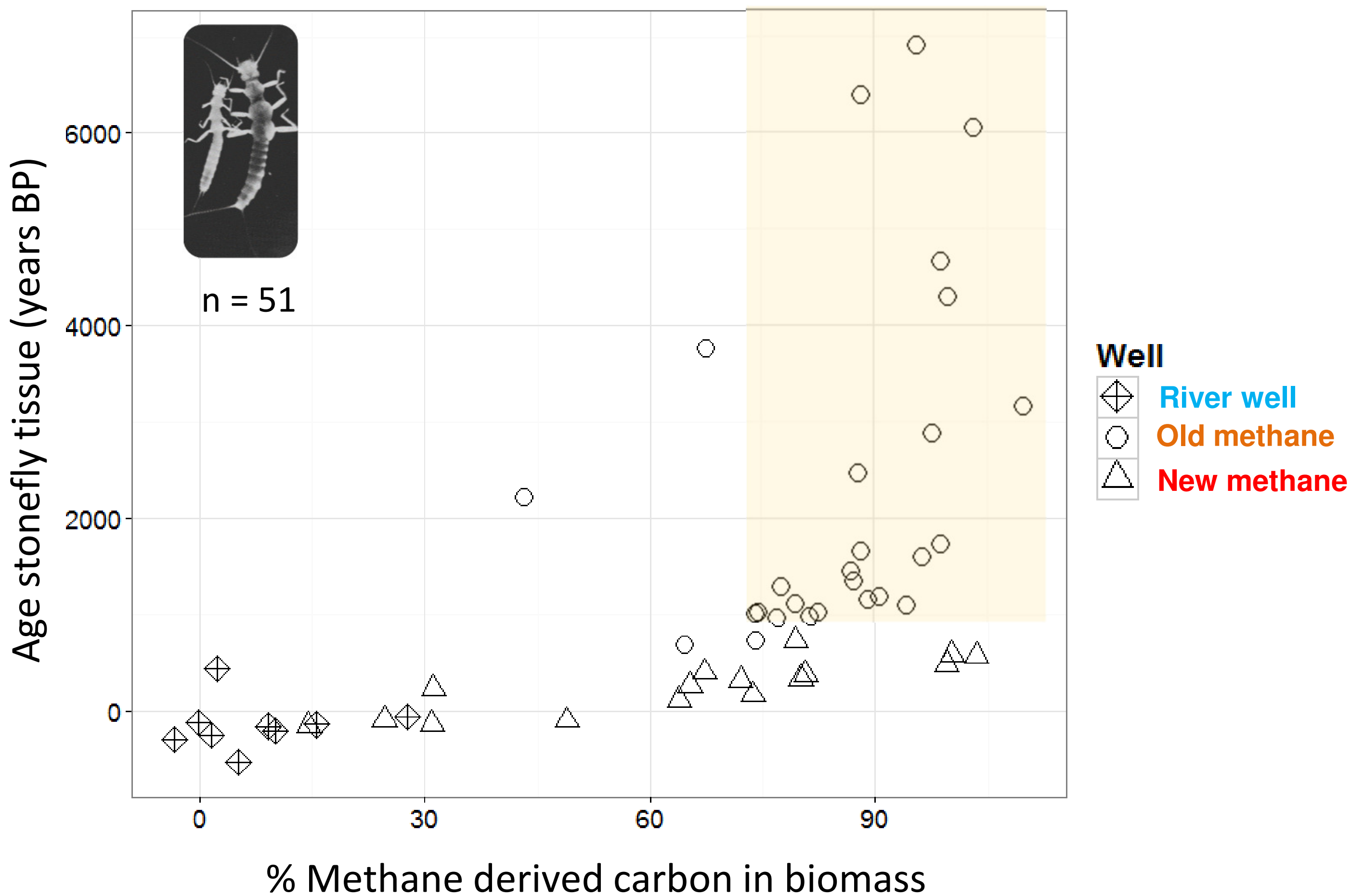
Methane-derived C in stonefly biomass across Nyack



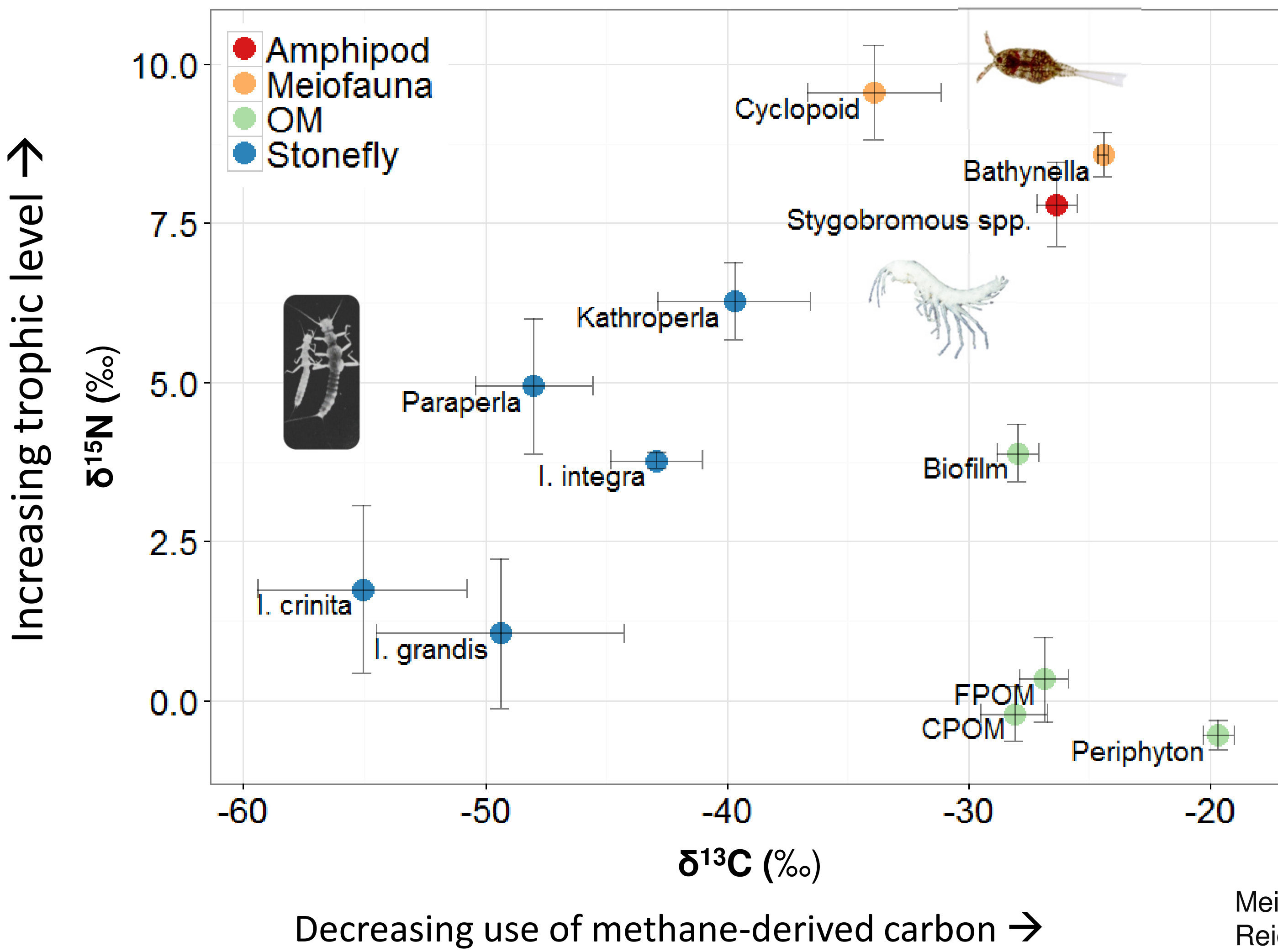


n=528

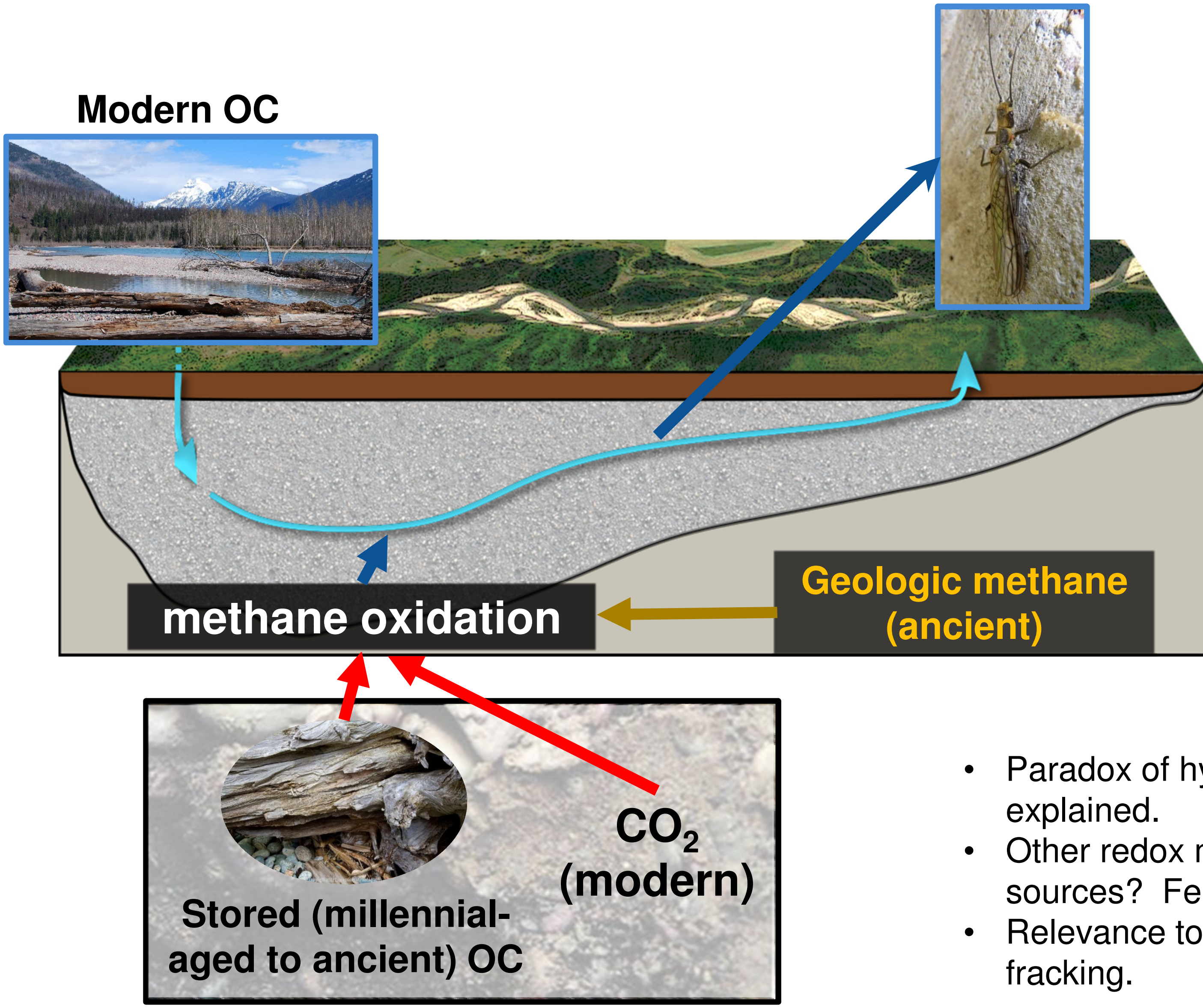
Stonefly tissue has millennial-aged methane-derived C



Methane-based food web

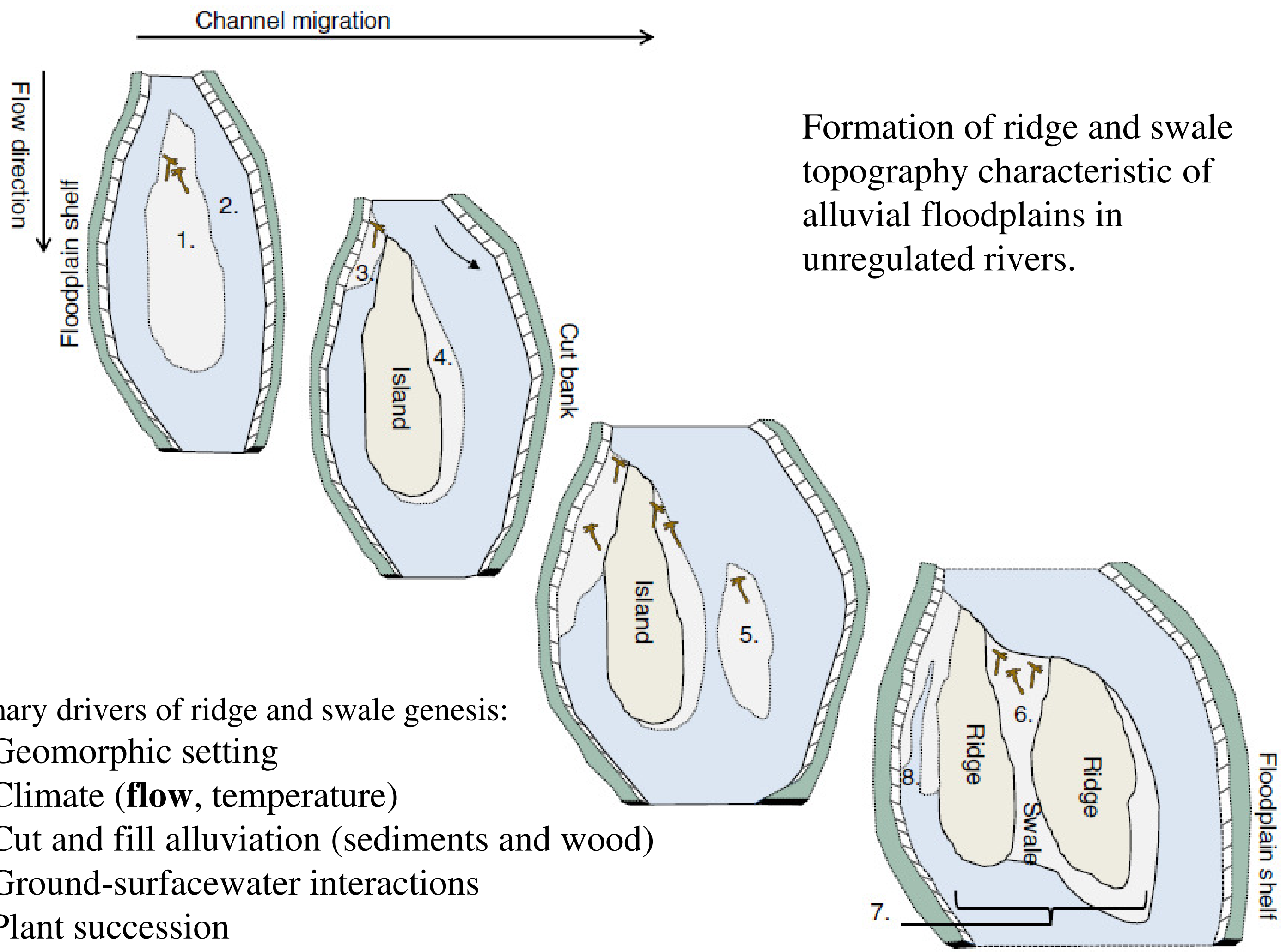


Meiofauna:
Reid (2007)



- Paradox of hyporheic explained.
- Other redox mediated carbon sources? Fe, Mn pathways
- Relevance to pollutant toxicity, fracking.

Age scrolled point bar – Krutogorova River, Kamchatka

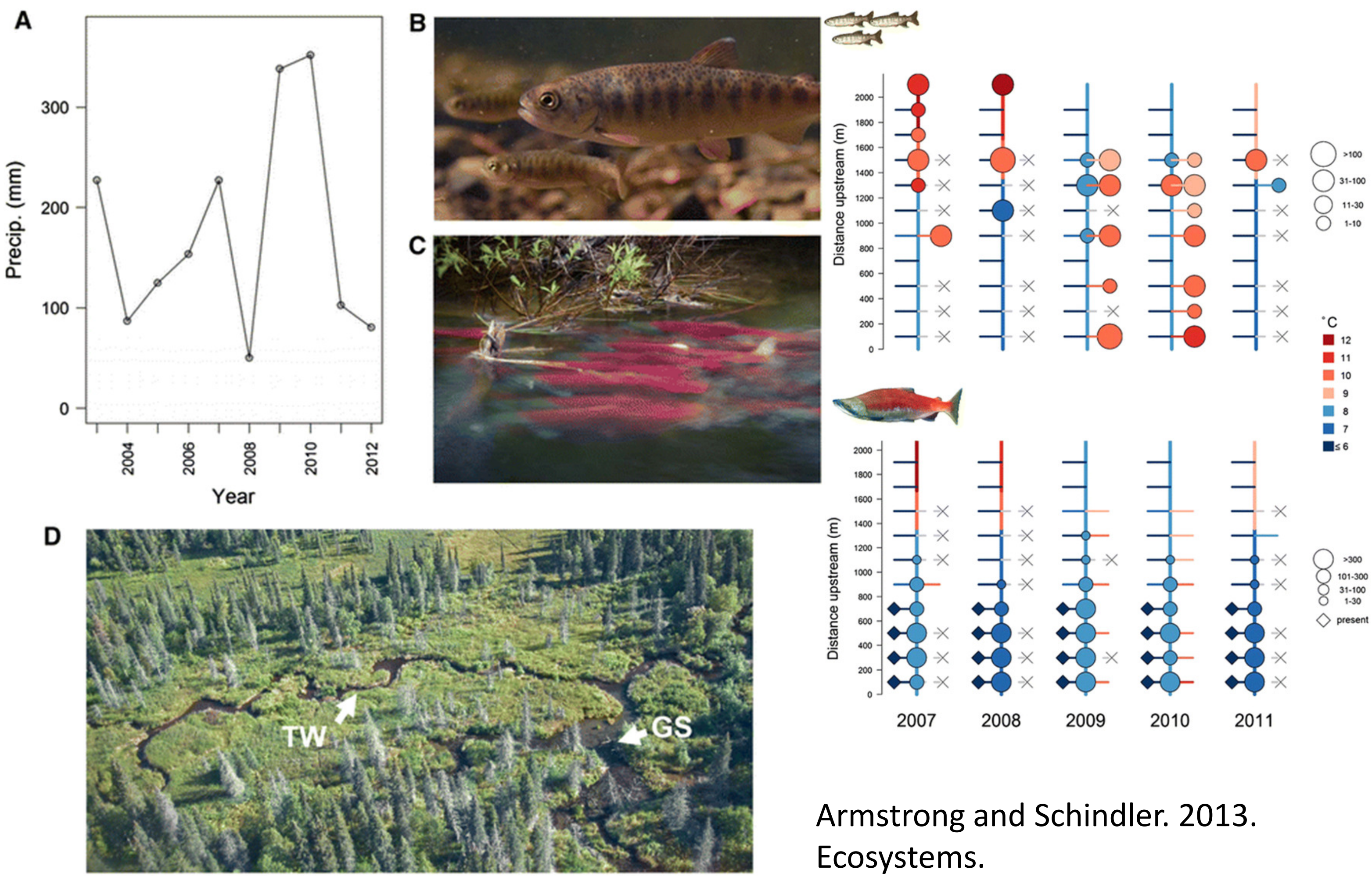


Formation of ridge and swale topography characteristic of alluvial floodplains in unregulated rivers.

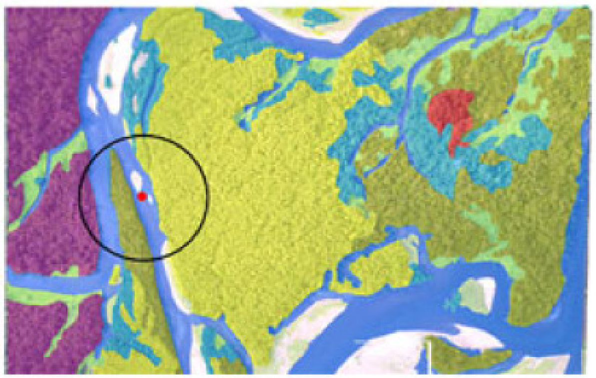
Primary drivers of ridge and swale genesis:

- Geomorphic setting
- Climate (**flow**, temperature)
- Cut and fill alluviation (sediments and wood)
- Ground-surfacewater interactions
- Plant succession
- Animal modifications
- Biophysical connectivity

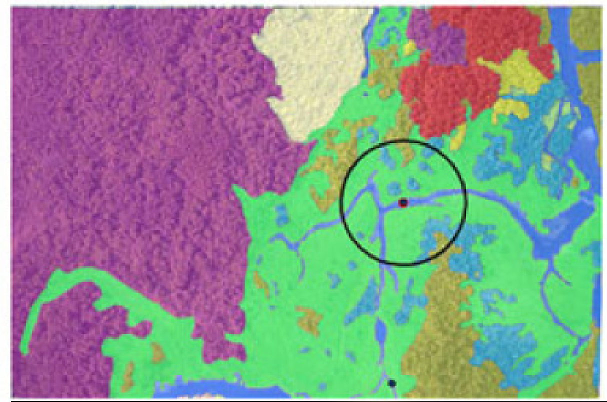
Mouw et al., 2014. RRA



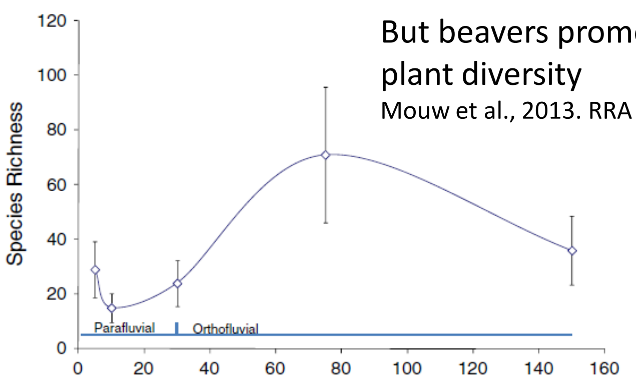
Armstrong and Schindler. 2013.
Ecosystems.



Riparia substantially modifed by beavers (A versus B)
Mouw et al., 2013. RRA



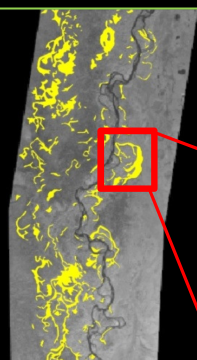
But beavers promote plant diversity
Mouw et al., 2013. RRA



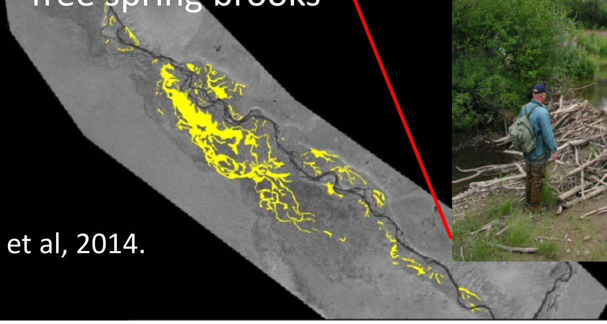
Floodplain Modification By Beavers

12% of entire study reach is beaver influenced habitat

55% of aquatic off-channel habitats modified by beavers



Beaver –free spring brooks



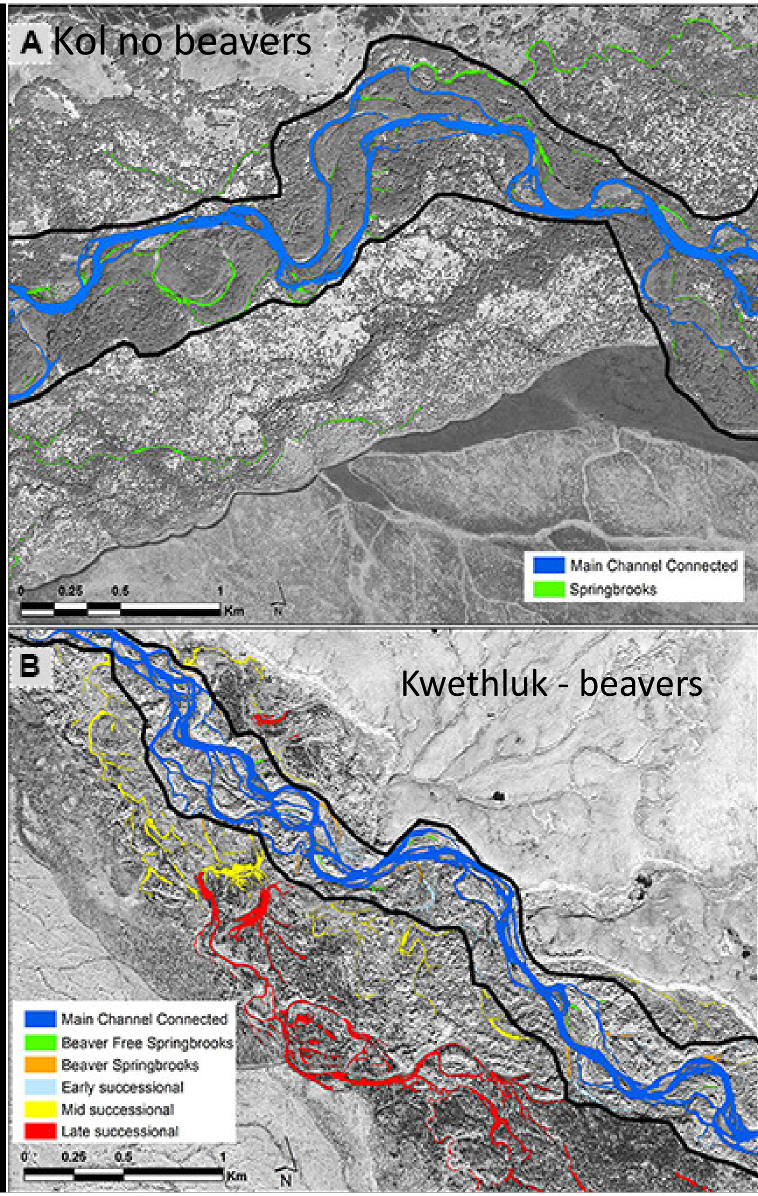
Beaver –influenced spring brooks

Early

Mid

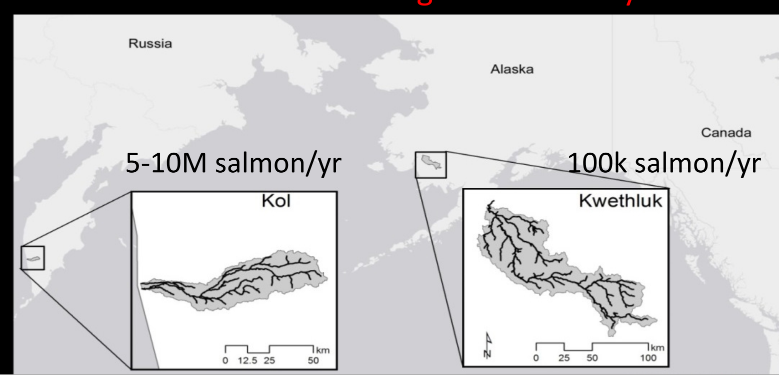
Late

Malison et al, 2014. FWB

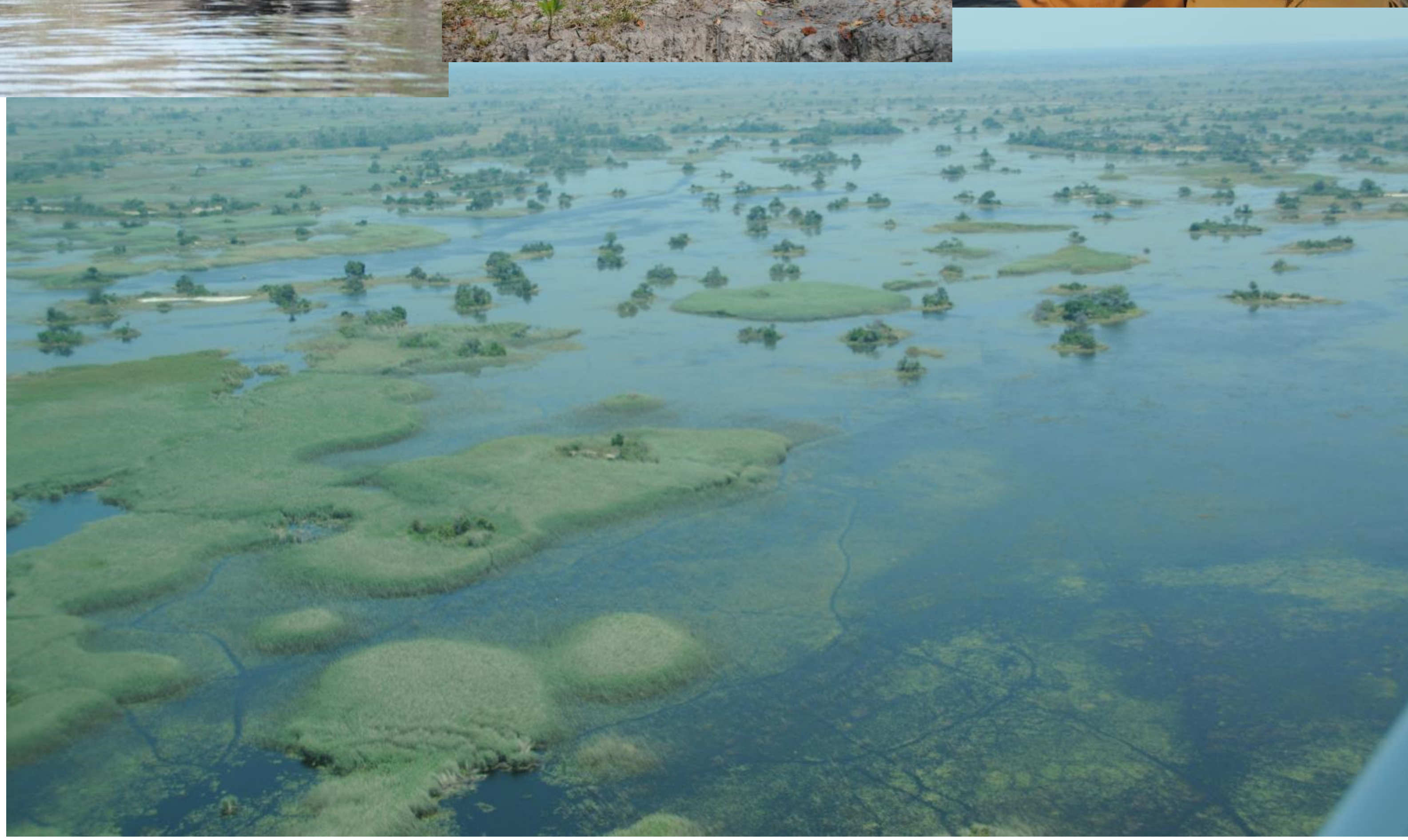


	Kwethluk	Kol
Floodplain slope	0.0020	0.0022
River width	42m	50m
Watershed area	3846 km^2	1502 km^2
Total Floodplain area	2.49×10^8 m^2	1.04×10^8 m^2
Total aquatic habitat	283 ha	409 ha
Main Channel total area	219 ha	325 ha
Off-channel habitat area	64 ha	84 ha
Spring brook total area	11 ha	83 ha
% off-channel spring brook area	0.17	0.99
Beaver pond area	51 ha	0

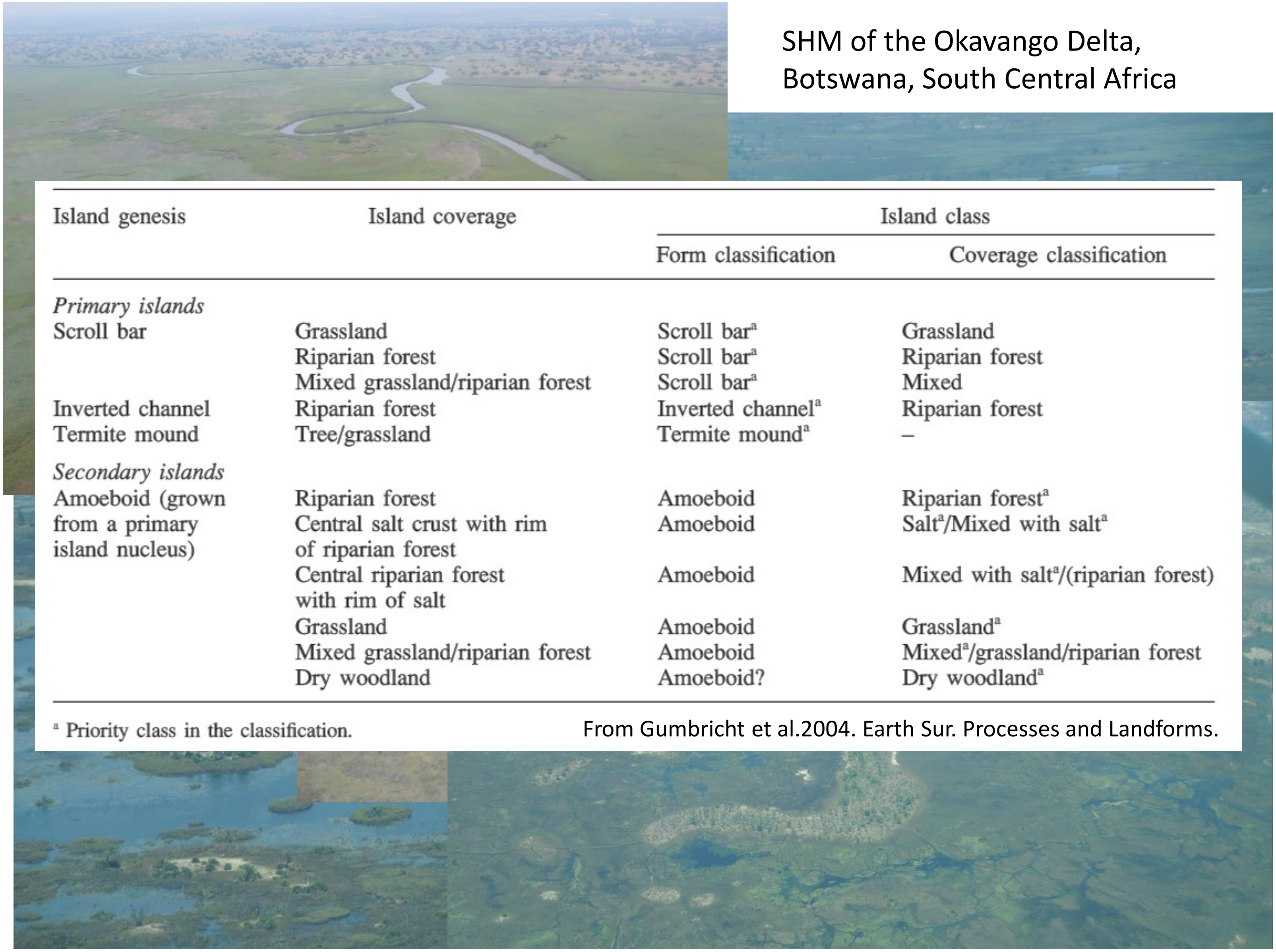
Huge mdn subsidy in the Kol





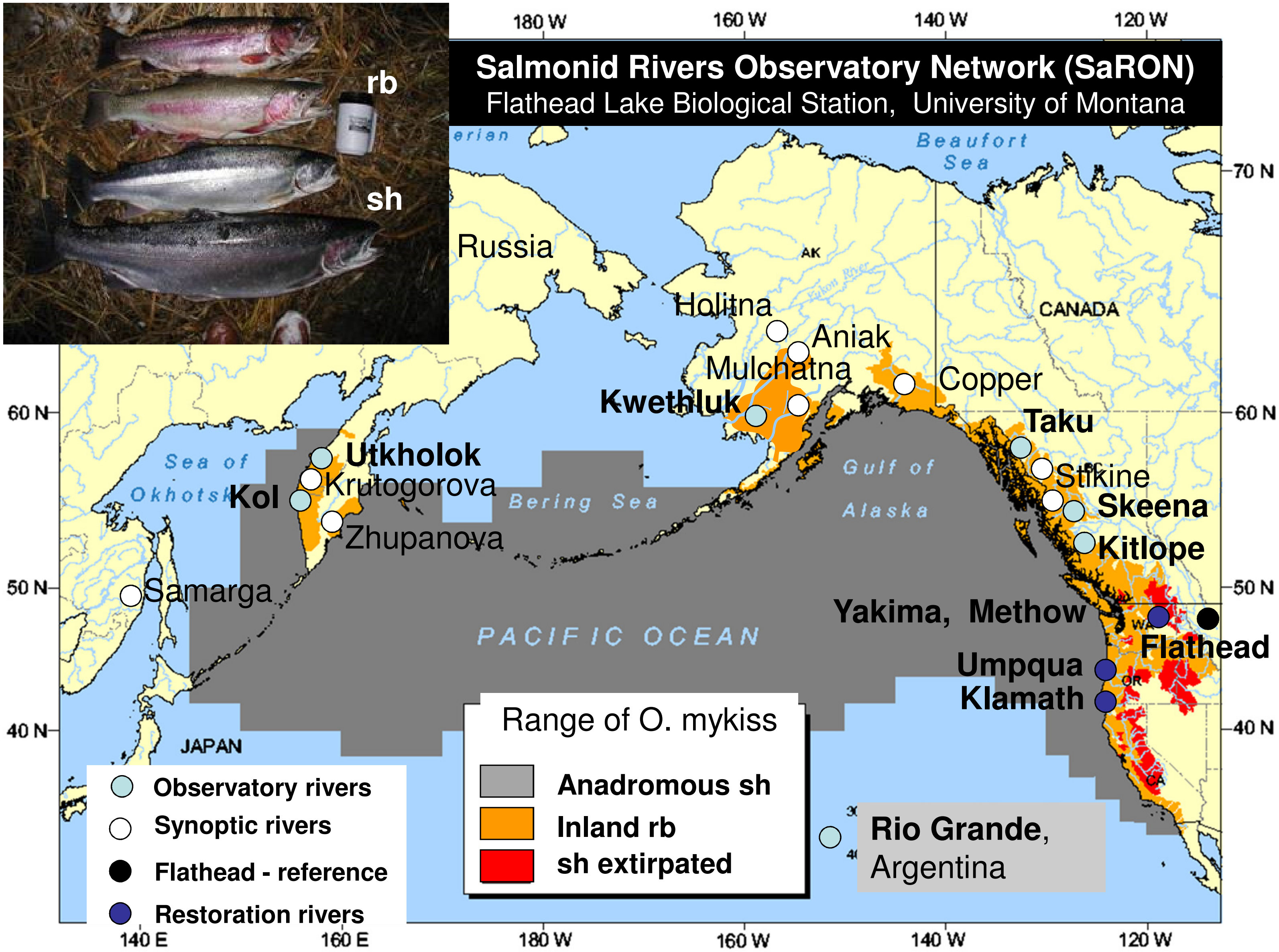
SHM of the Okavango Delta, Botswana, South Central Africa



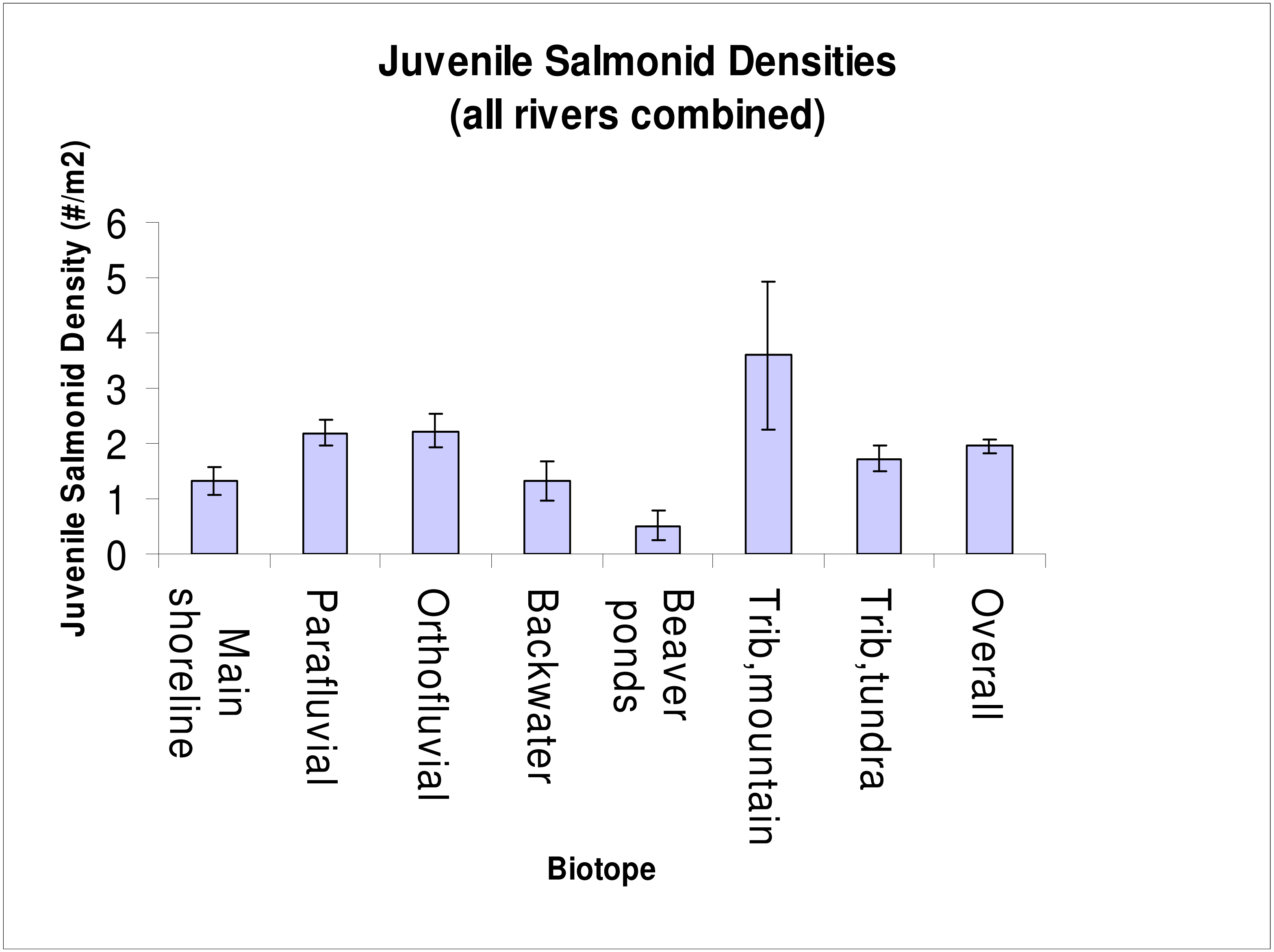
Island genesis	Island coverage	Island class	
		Form classification	Coverage classification
Primary islands			
Scroll bar	Grassland	Scroll bar[a]	Grassland
	Riparian forest	Scroll bar[a]	Riparian forest
	Mixed grassland/riparian forest	Scroll bar[a]	Mixed
Inverted channel	Riparian forest	Inverted channel[a]	Riparian forest
Termite mound	Tree/grassland	Termite mound[a]	–
Secondary islands			
Amoeboid (grown from a primary island nucleus)	Riparian forest	Amoeboid	Riparian forest[a]
	Central salt crust with rim of riparian forest	Amoeboid	Salt[a]/Mixed with salt[a]
	Central riparian forest with rim of salt	Amoeboid	Mixed with salt[a]/(riparian forest)
	Grassland	Amoeboid	Grassland[a]
	Mixed grassland/riparian forest	Amoeboid	Mixed[a]/grassland/riparian forest
	Dry woodland	Amoeboid?	Dry woodland[a]

[a] Priority class in the classification.

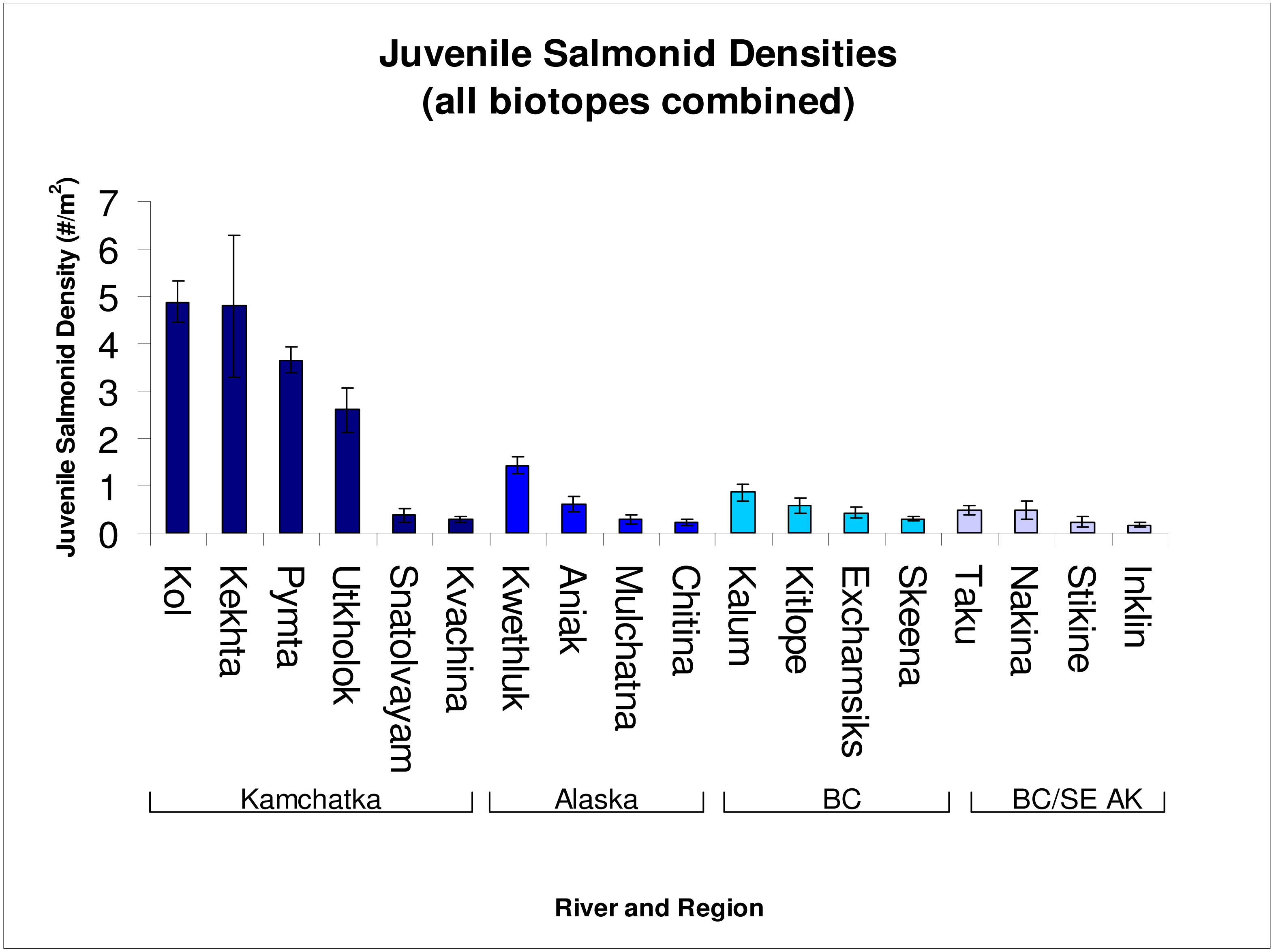
From Gumbricht et al.2004. Earth Sur. Processes and Landforms.



rb
sh
Salmonid Rivers Observatory Network (SaRON)
Flathead Lake Biological Station, University of Montana
Russia
Beaufort Sea
AK
CANADA
Holitna
Aniak
Mulchatna
Copper
Kwethluk
Taku
Stikine
Skeena
Kitlope
Utkholok
Krutogorova
Kol
Zhupanova
Sea of Okhotsk
Bering Sea
Gulf of Alaska
Samarga
PACIFIC OCEAN
Yakima, Methow
Flathead
Umpqua
Klamath
JAPAN
Observatory rivers
Synoptic rivers
Flathead - reference
Restoration rivers
Range of O. mykiss
Anadromous sh
Inland rb
sh extirpated
Rio Grande, Argentina
180 W
160 W
140 W
120 W
140 E
160 E
70 N
60 N
50 N
40 N



Juvenile Salmonid Densities
(all rivers combined)
Juvenile Salmonid Density (#/m2)
6
5
4
3
2
1
0
Main shoreline
Parafluvial
Orthofluvial
Backwater
Beaver ponds
Trib,mountain
Trib,tundra
Overall
Biotope

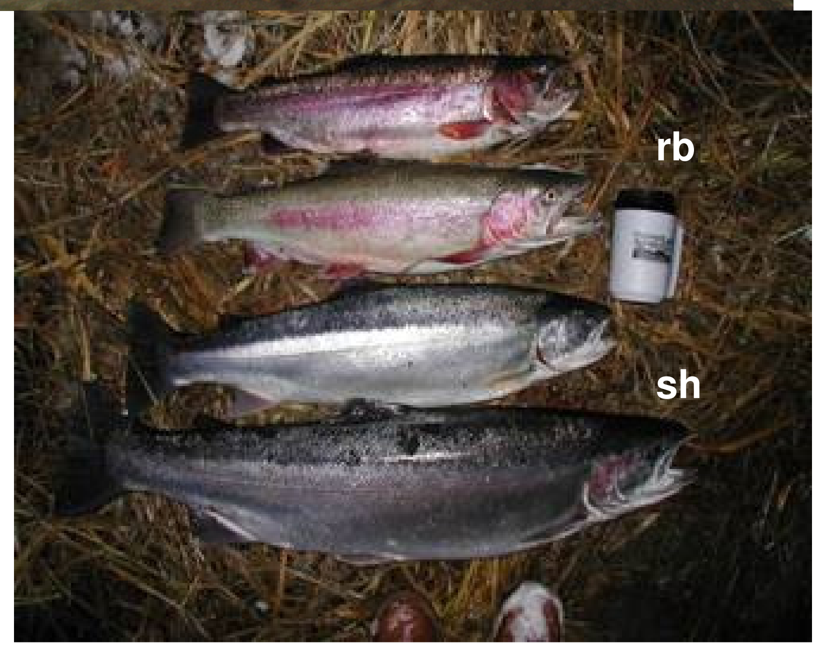


Juvenile Salmonid Densities
(all biotopes combined)
Juvenile Salmonid Density (#/m2)
7
6
5
4
3
2
1
0
Kol
Kekhta
Pymta
Utkholok
Snatolvayam
Kvachina
Kwethluk
Aniak
Mulchatna
Chitina
Kalum
Kitlope
Exchamsiks
Skeena
Taku
Nakina
Stikine
Inklin
Kamchatka
Alaska
BC
BC/SE AK
River and Region

Kol – *O. mykiss* resident (rainbow)

Utkholok – *O. mykiss* anadromous (steelhead)

Same species, 6 life history strategies





Salmon Subsidy of Foliar N

Morris and Stanford. 2011. Ecological Monographs

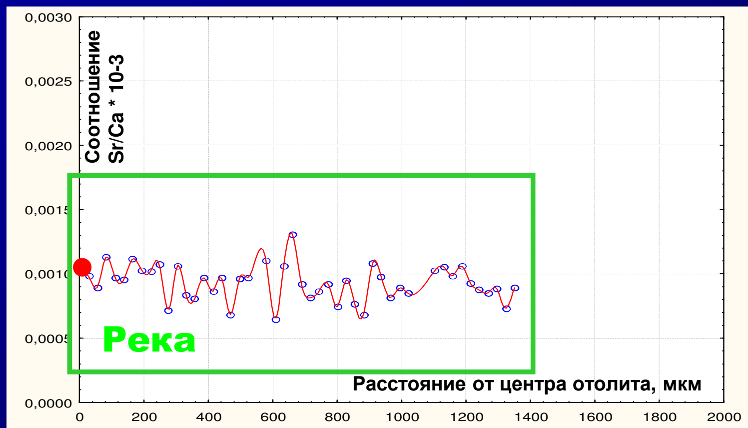
	molar C:N
• Kol floodplain	
– *Salix A*	13.7
– *Salix B*	12.6
– *F. camtschatica*	14.4
– Nettle	8.1
• Temperate broadleaf[1]	35.1
• Nyack cottonwoods[2]	38.1

1: McGroddy et al. 2004 *Ecology*, 2: Harner and Stanford 2003 *Ecology*


Разнообразие жизненных стратегий камчатской микижи
Типы чешуи
Типично проходная
5,7 кг (2,5 - 10,5)
Проходная-Б (включающая стадию «полуфунтовика»
4,9 кг (1,0 - 9,3)
Эстуарная
2,1 кг (0,6-3,2)
Речная эстуарная
1,3 кг (0,4 - 2,5)
Речная
1,4 кг (0,4 - 2,7)

Изменения типа жизненной стратегии

(по данным соотношения Sr/Ca в отолитах)



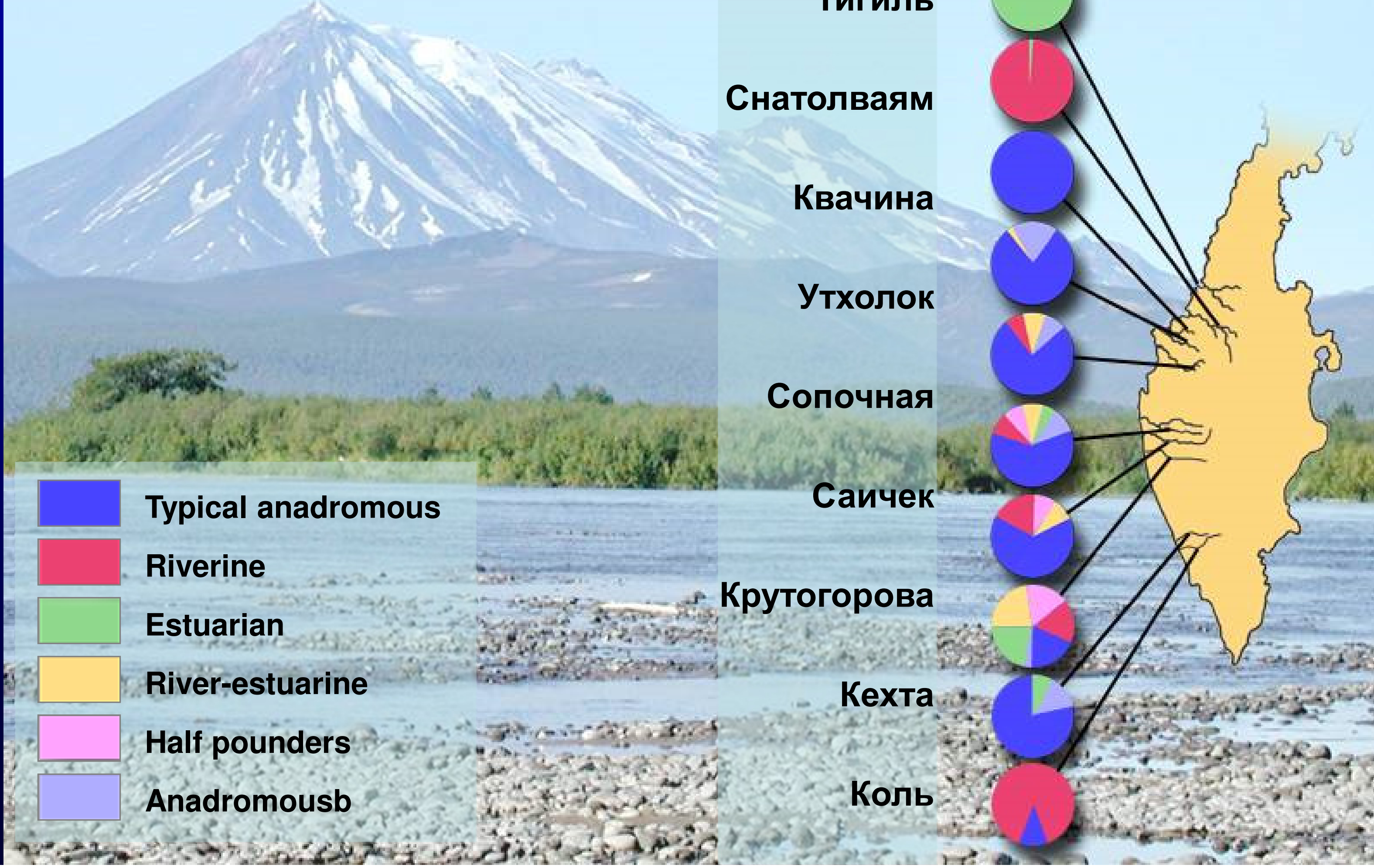
● Материнская особь – речная стратегия
— Потомок – речная стратегия

● Материнская особь – проходная стратегия
— Потомок – речная стратегия

● Материнская особь – речная стратегия
— Потомок – проходная стратегия

● Материнская особь – проходная стратегия
— Потомок – проходная стратегия

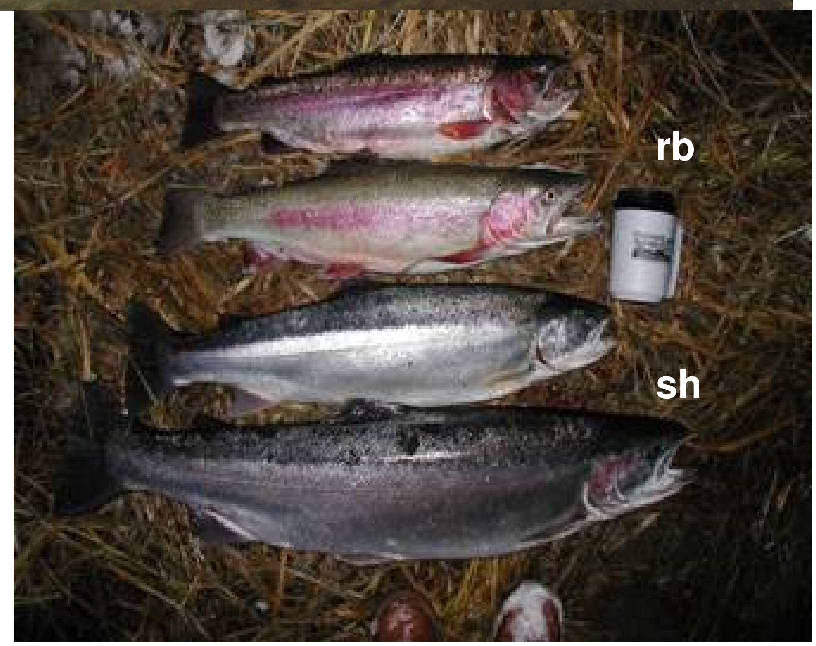
Соотношение рыб с разной жизненной стратегией на ареале

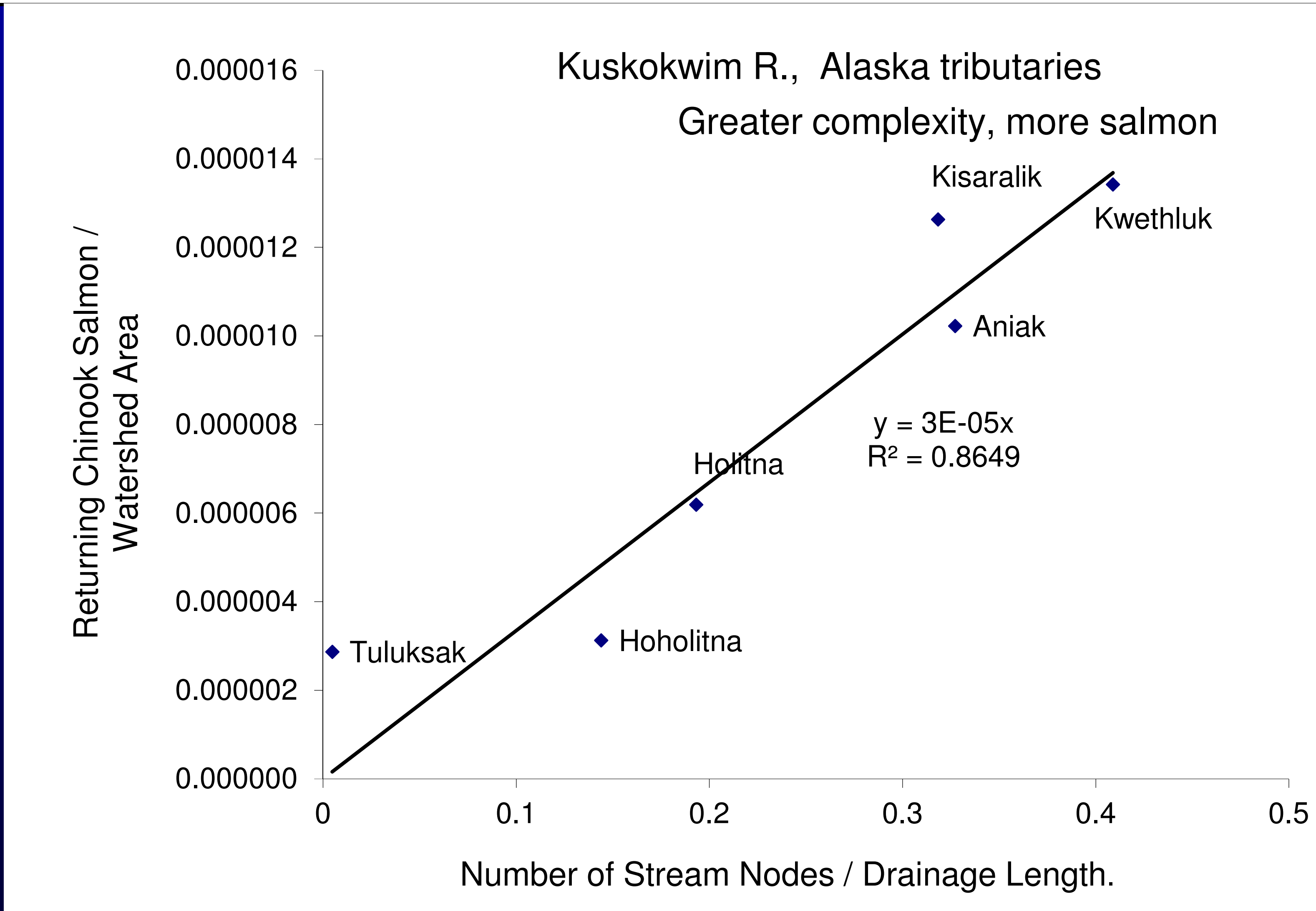


Kol – *O. mykiss* resident (rainbow)

Utkholok – *O. mykiss* anadromous (steelhead)

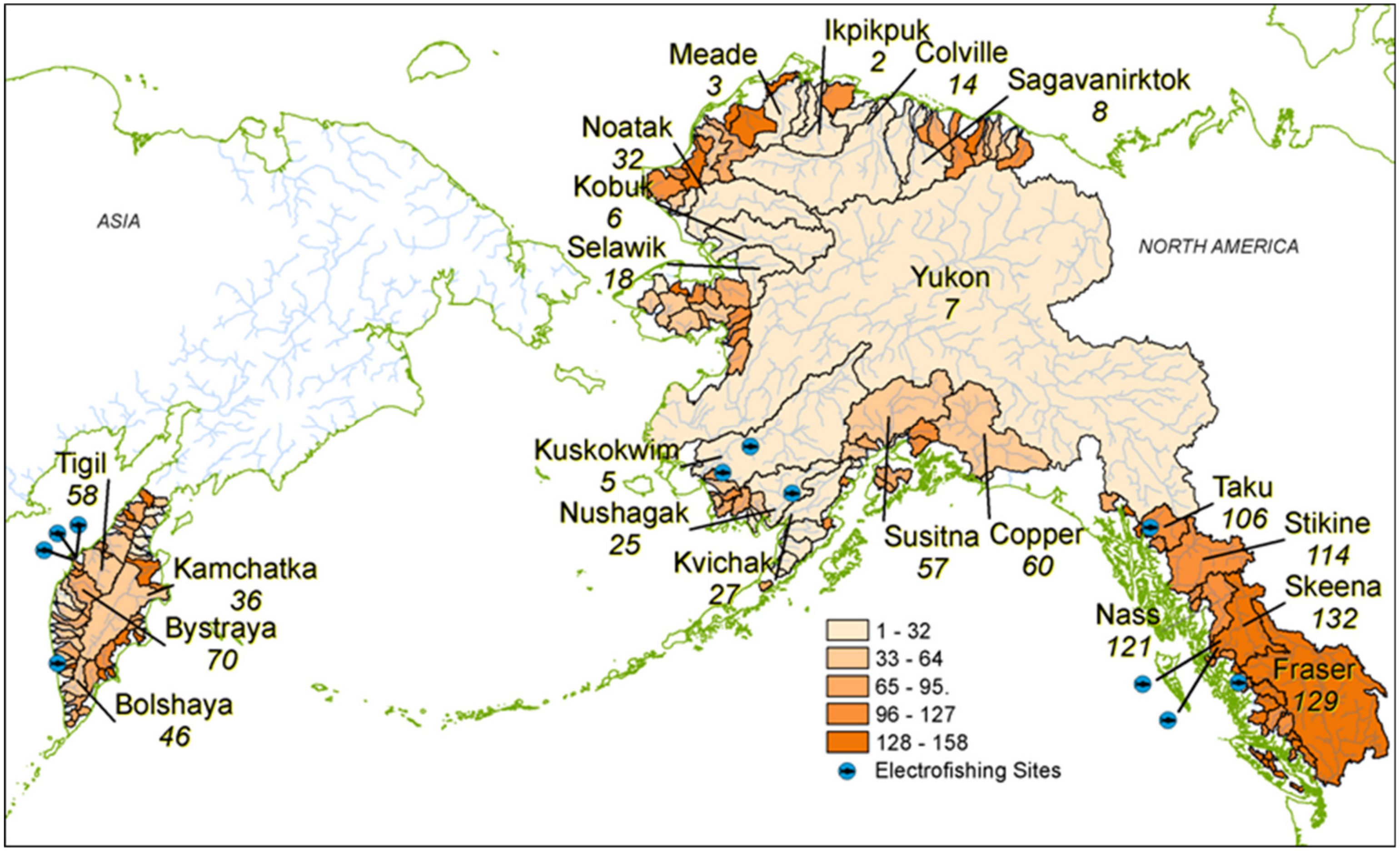
Same species, 5 life history strategies





See Whited et al., 2012. Fisheries……. for Riverscape Analysis Project (RAP) tools and data for 1500 Pacific Rim Rivers

Ranking Rivers of the Pacific Rim by Physical Complexity

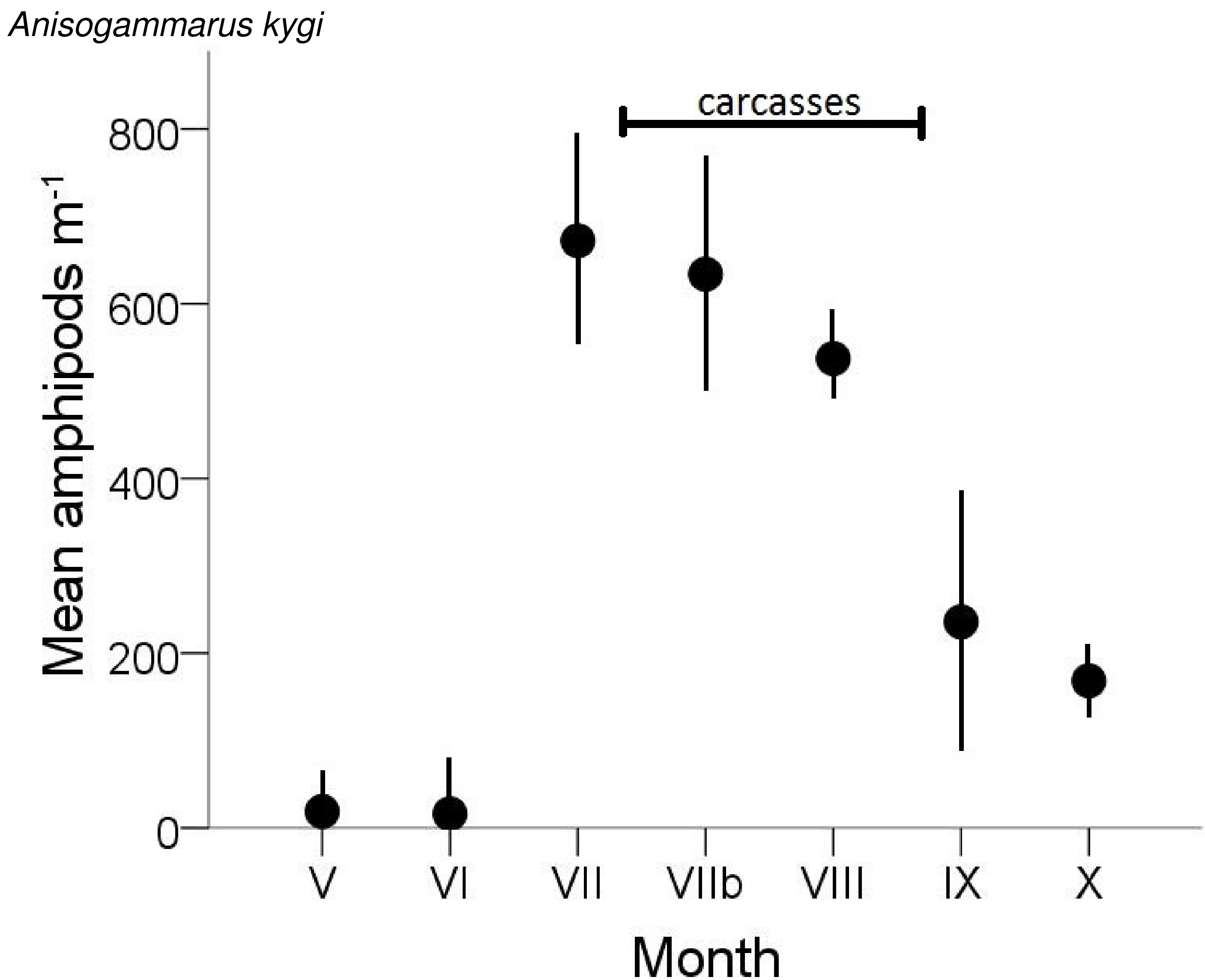


Rankings for the 158 catchments over 1,000 km² as mean of principal components and mean feature class physical complexity. Labels are for the 22 catchments larger than 10,000 km². Blue circles are SaRON sites.

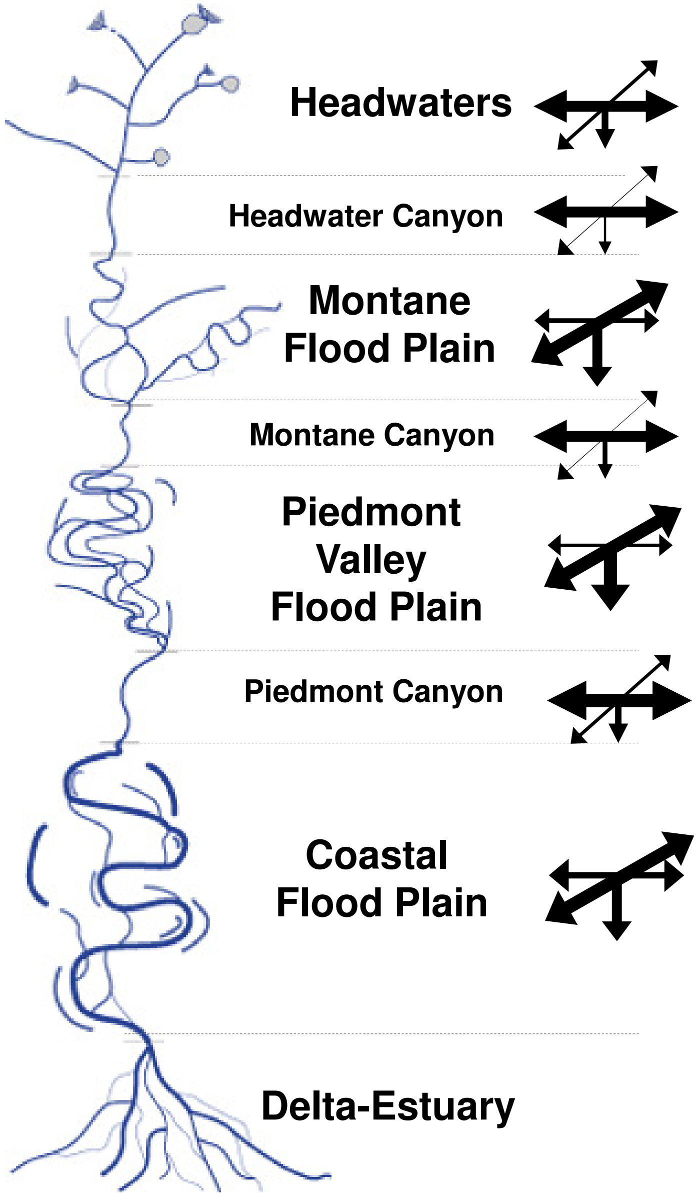
Luck et al., (FLBS). 2010. Earth Surface Processes and Landforms **35**(11): 1330–1343.

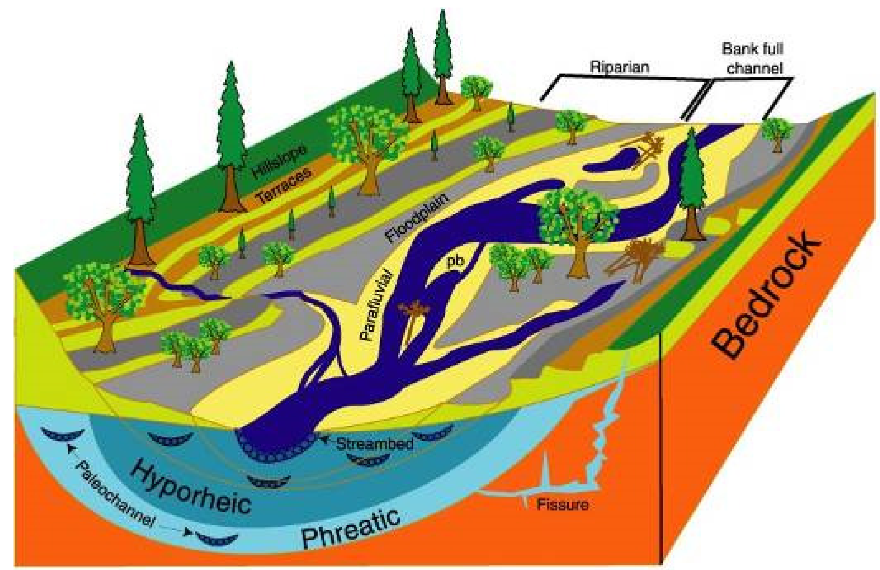
100% female (12.8 mm), migrating at 12.8 cm s^{-1}

67 neonates per female



Anisogammarus kygi
carcasses
Mean amphipods m-1
800
600
400
200
0
V
VI
VII
VIIb
VIII
IX
X
Month



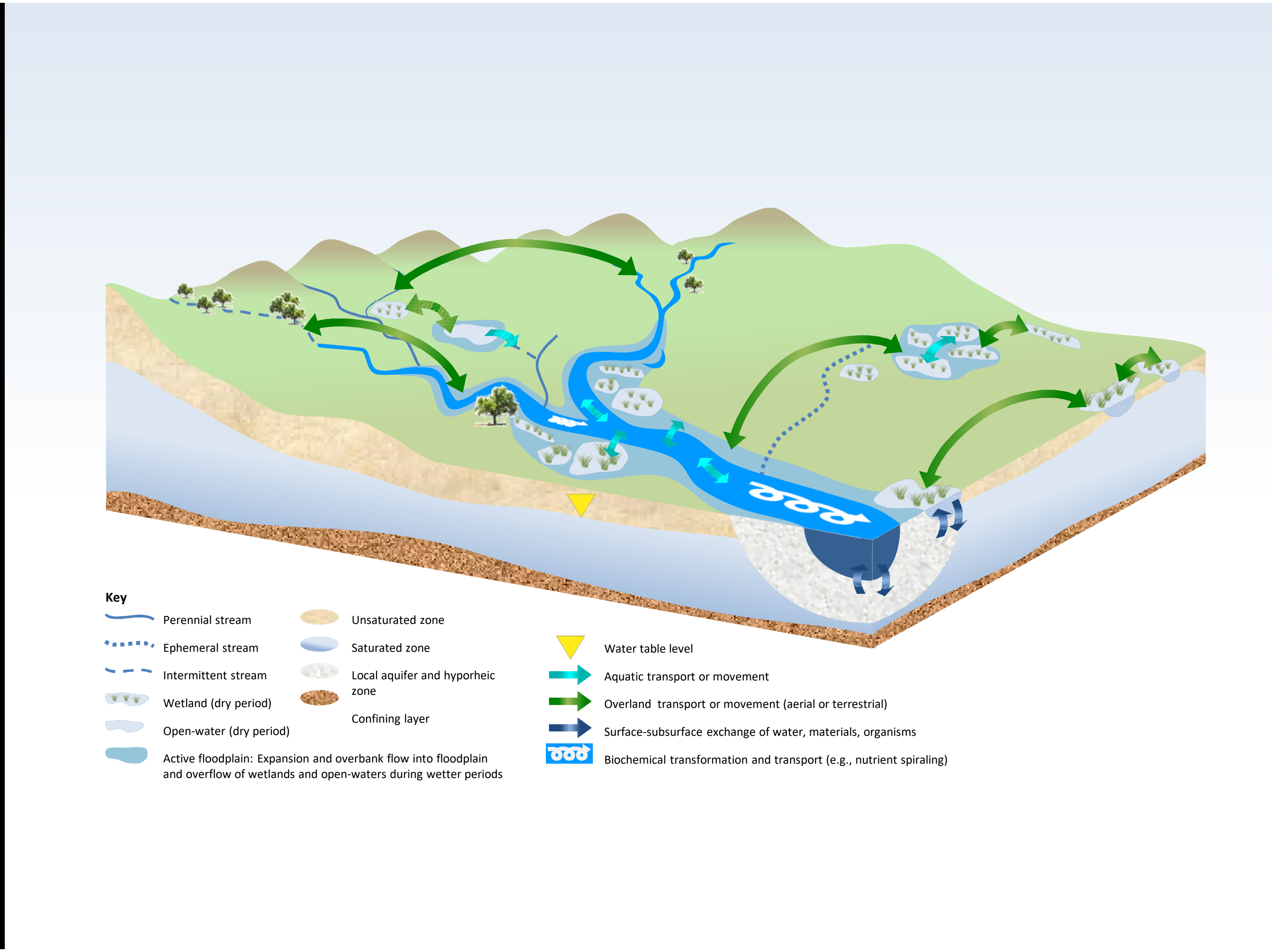


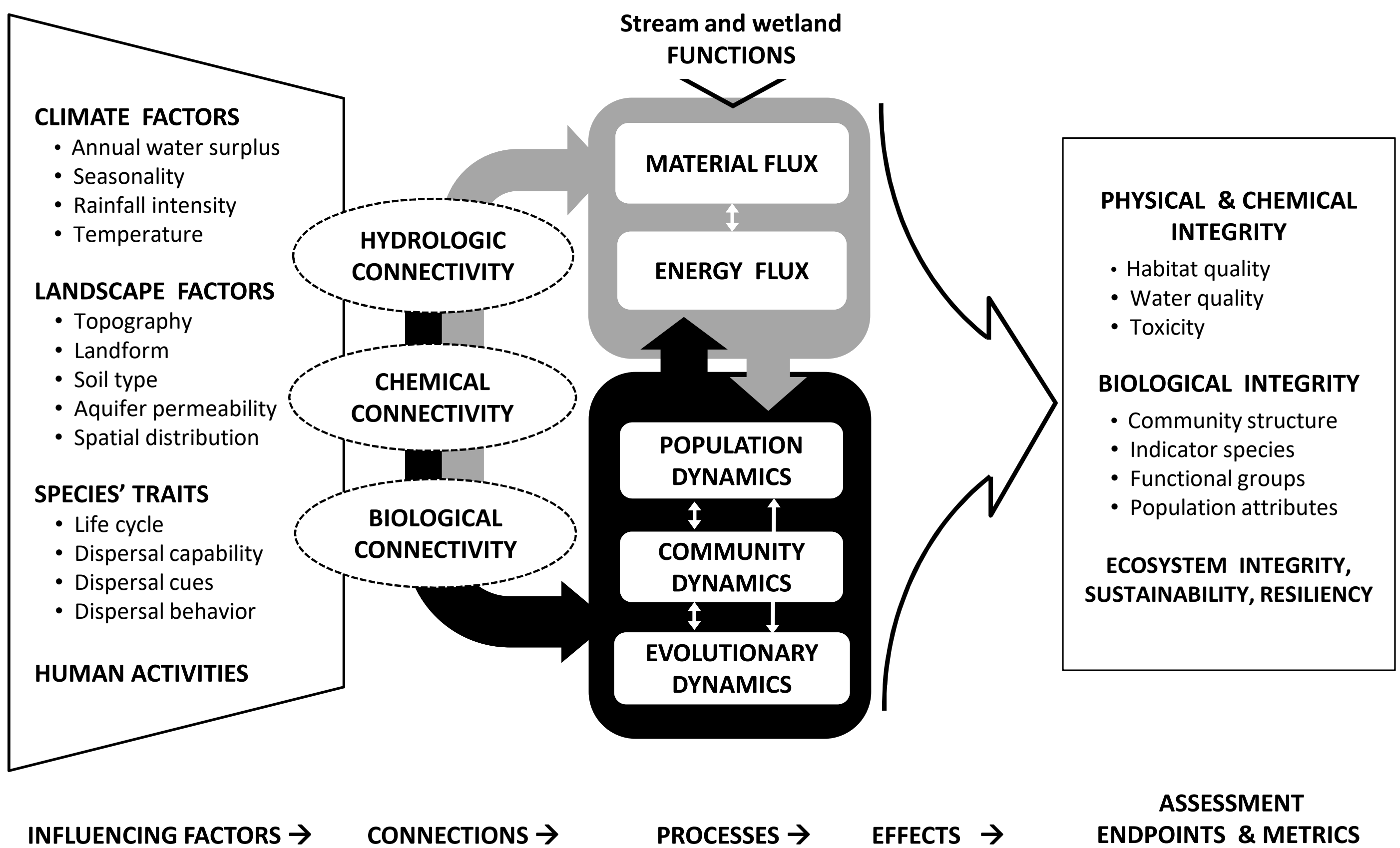
Primary drivers of the SHM:

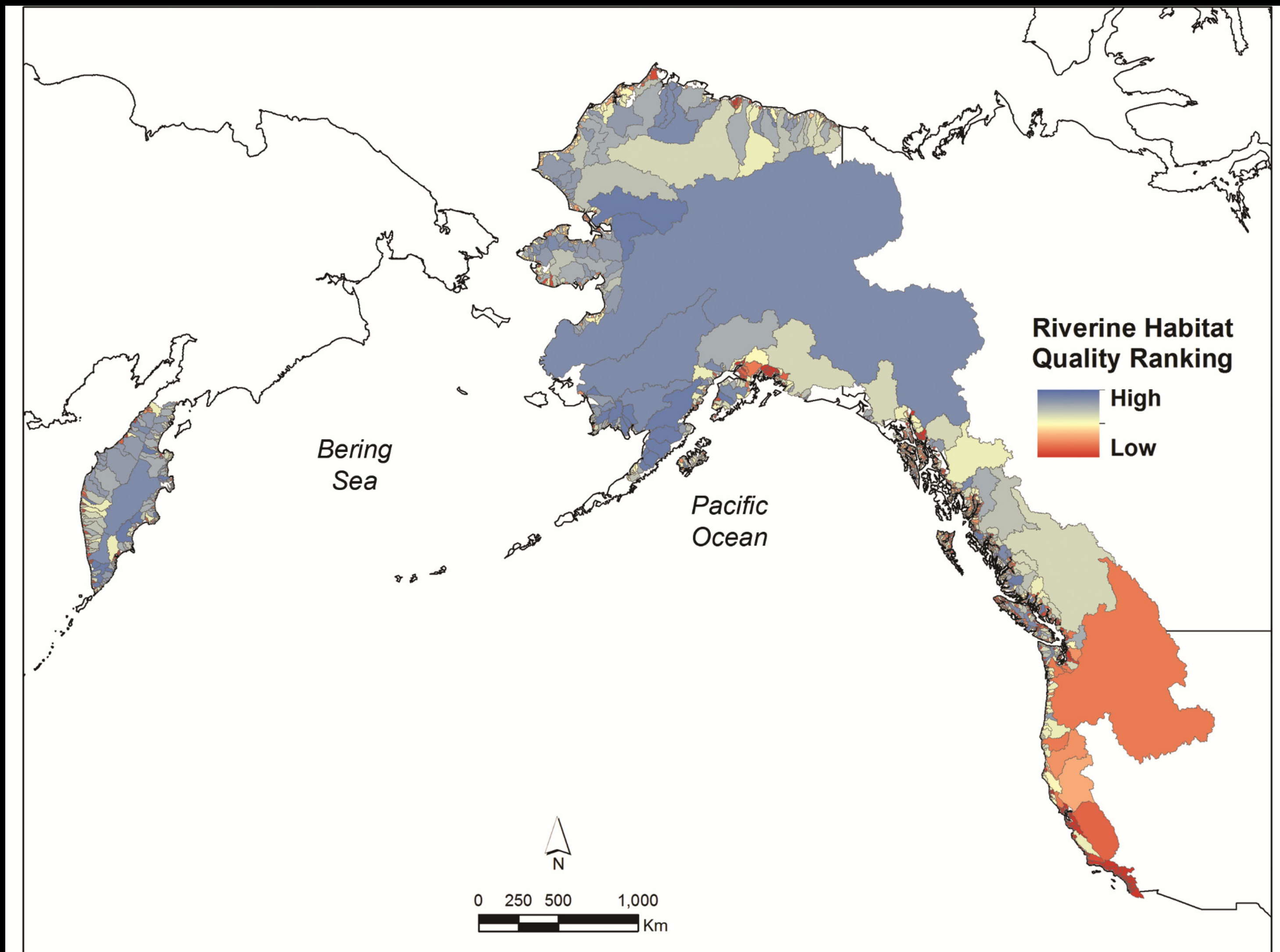
- Geomorphic setting (slope, geologic legacies)
- Climate (flow, temperature, fire)
- Cut and fill alluviation (sediments and wood)
- Ground- surface water interactions
- Plant succession
- Animal modifications (including humans)

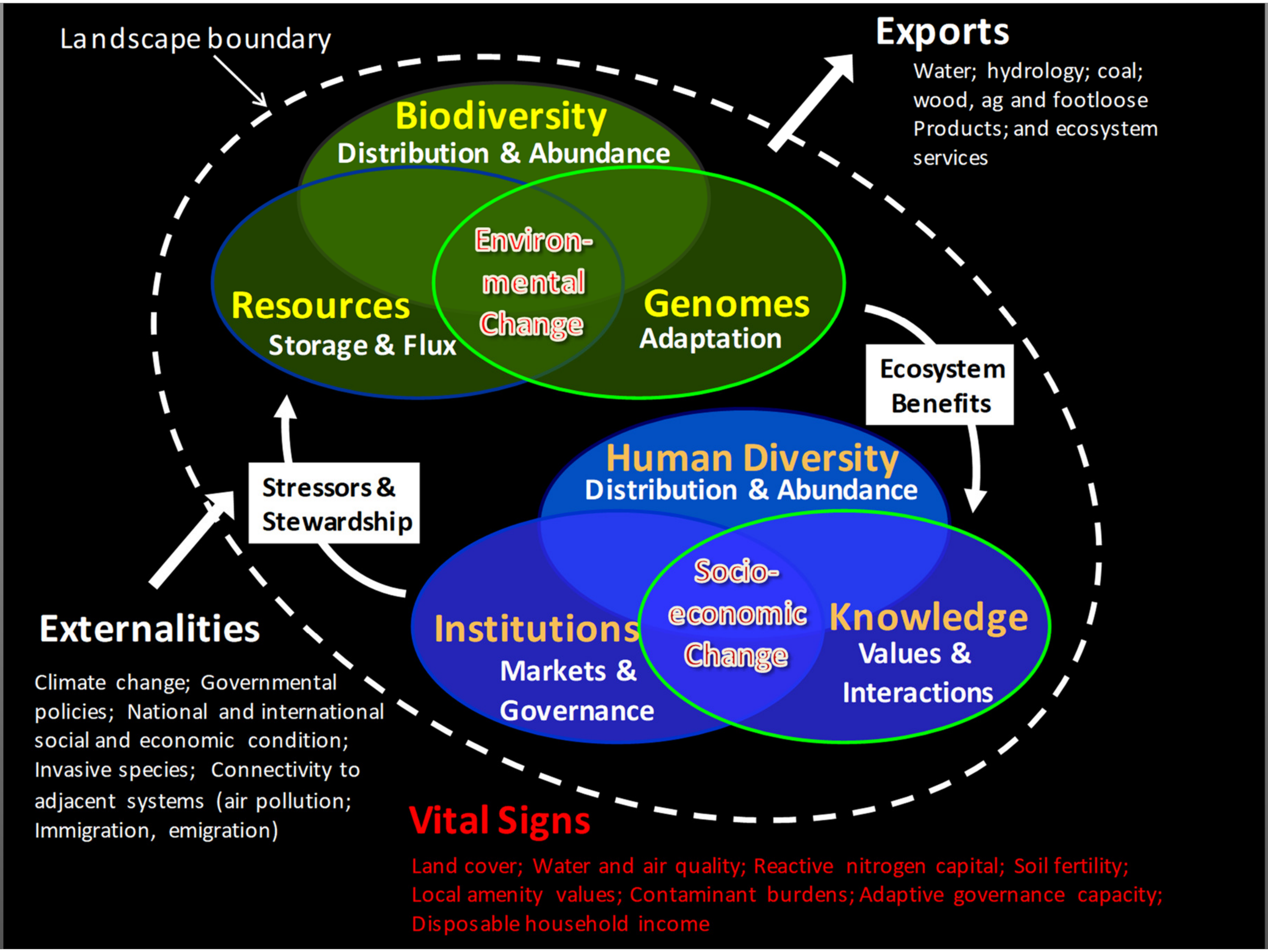
Dynamic, inter-connected habitats

Alexander, L.C., 2015. Science at the boundaries: scientific support for the clean water rule. Freshwater Science 34, 1588e1594.

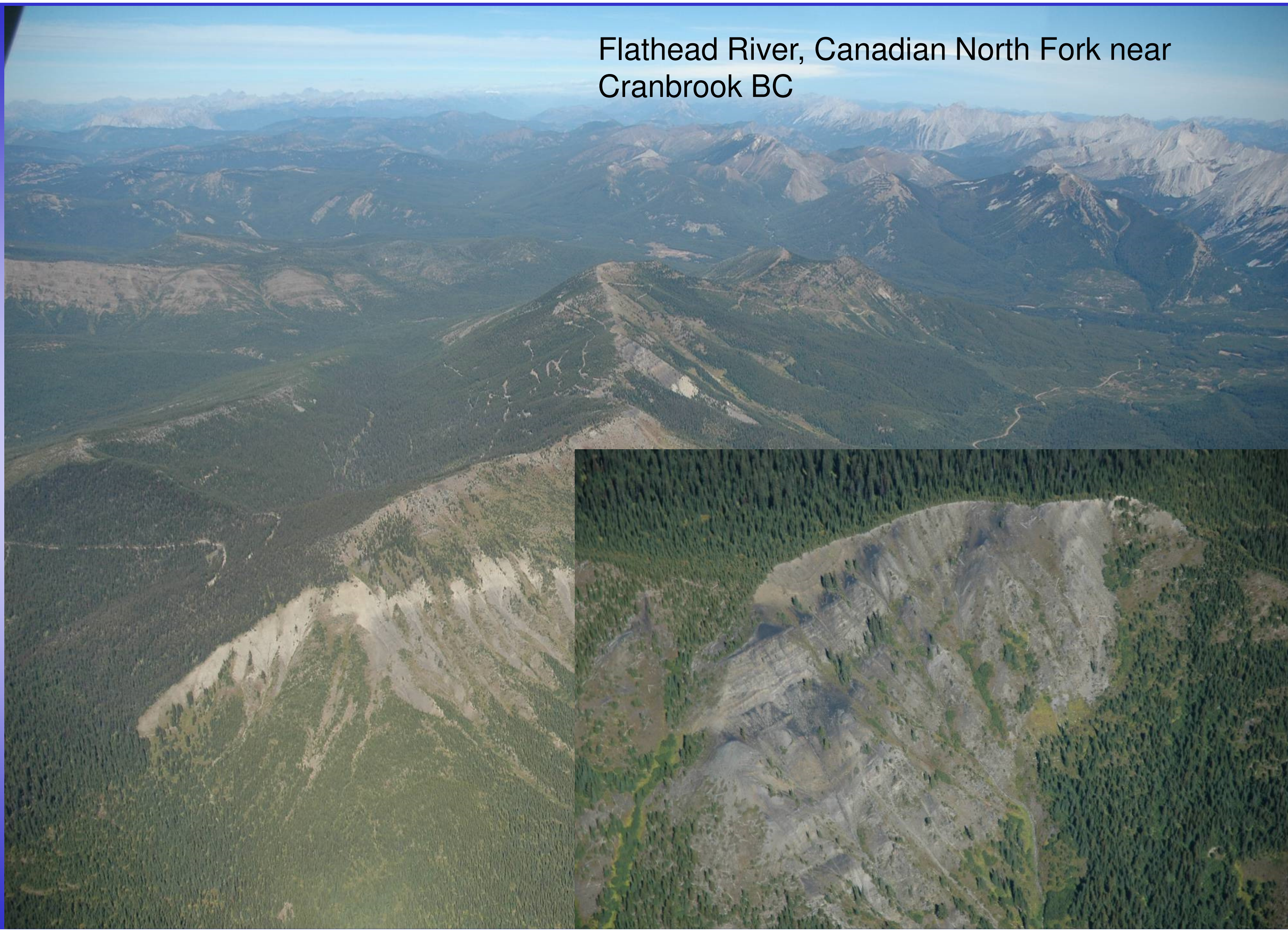

Key
Perennial stream
Ephemeral stream
Intermittent stream
Wetland (dry period)
Open-water (dry period)
Active floodplain: Expansion and overbank flow into floodplain and overflow of wetlands and open-waters during wetter periods
Unsaturated zone
Saturated zone
Local aquifer and hyporheic zone
Confining layer
Water table level
Aquatic transport or movement
Overland transport or movement (aerial or terrestrial)
Surface-subsurface exchange of water, materials, organisms
Biochemical transformation and transport (e.g., nutrient spiraling)


Stream and wetland
FUNCTIONS
CLIMATE FACTORS
• Annual water surplus
• Seasonality
• Rainfall intensity
• Temperature
LANDSCAPE FACTORS
• Topography
• Landform
• Soil type
• Aquifer permeability
• Spatial distribution
SPECIES' TRAITS
• Life cycle
• Dispersal capability
• Dispersal cues
• Dispersal behavior
HUMAN ACTIVITIES
HYDROLOGIC CONNECTIVITY
CHEMICAL CONNECTIVITY
BIOLOGICAL CONNECTIVITY
MATERIAL FLUX
ENERGY FLUX
POPULATION DYNAMICS
COMMUNITY DYNAMICS
EVOLUTIONARY DYNAMICS
PHYSICAL & CHEMICAL INTEGRITY
• Habitat quality
• Water quality
• Toxicity
BIOLOGICAL INTEGRITY
• Community structure
• Indicator species
• Functional groups
• Population attributes
ECOSYSTEM INTEGRITY, SUSTAINABILITY, RESILIENCY
INFLUENCING FACTORS →
CONNECTIONS →
PROCESSES →
EFFECTS →
ASSESSMENT ENDPOINTS & METRICS


Riverine Habitat Quality Ranking
High
Low
Bering Sea
Pacific Ocean
N
0 250 500 1,000
Km



Landscape boundary
Exports
Water; hydrology; coal; wood, ag and footloose Products; and ecosystem services
Biodiversity
Distribution & Abundance
Resources
Storage & Flux
Environ-mental Change
Genomes
Adaptation
Ecosystem Benefits
Stressors & Stewardship
Human Diversity
Distribution & Abundance
Institutions
Markets & Governance
Socio-economic Change
Knowledge
Values & Interactions
Externalities
Climate change; Governmental policies; National and international social and economic condition; Invasive species; Connectivity to adjacent systems (air pollution; Immigration, emigration)
Vital Signs
Land cover; Water and air quality; Reactive nitrogen capital; Soil fertility; Local amenity values; Contaminant burdens; Adaptive governance capacity; Disposable household income

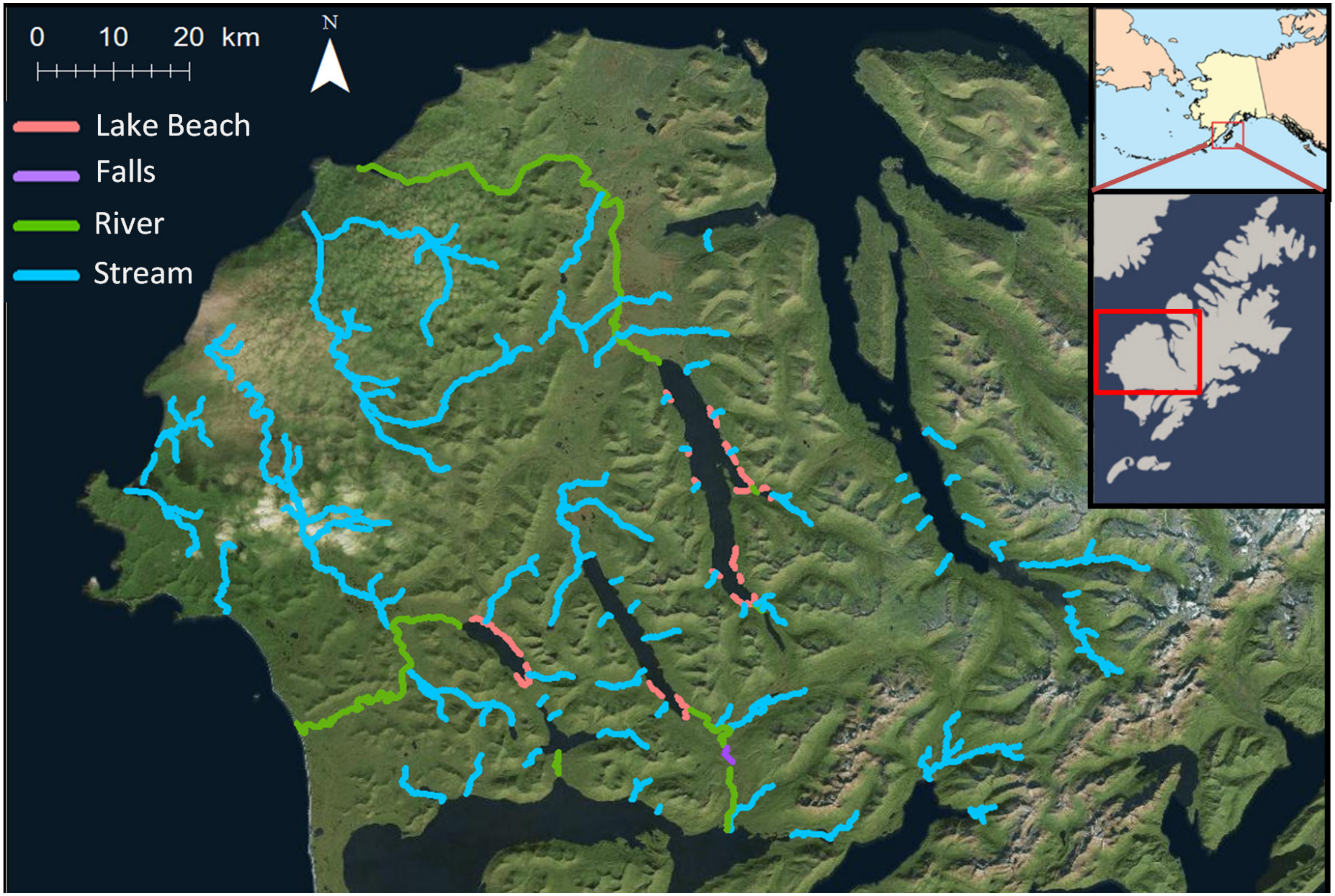

Flathead River, Canadian North Fork near
Cranbrook BC


Coal strip mine near Fernie BC – mountain destruction mining

Mt Polley Mine tailings blown into Quesnel Lake BC from failed tailing retention dam

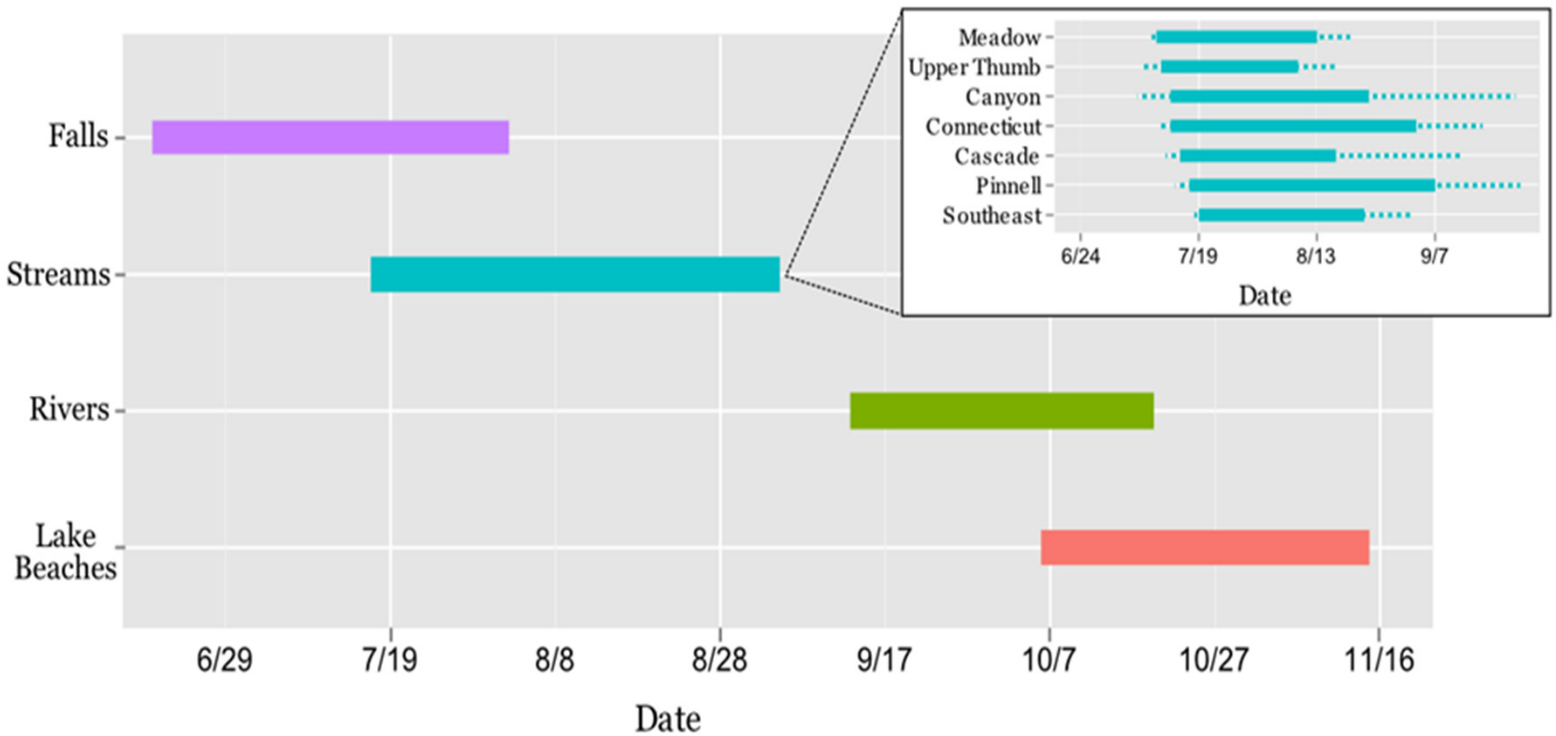
See also: Deacy, W.W., Armstrong, J.B., Leacock, W.B., Robbins, C.T., Gustine, D.D., Ward, E.J., Erlenbach, J.A. and Stanford, J.A., 2017. 2017. Phenological synchronization disrupts trophic interactions between Kodiak brown bears and salmon. *Proceedings of the National Academy of Science.* 114 (39) 10432-10437.

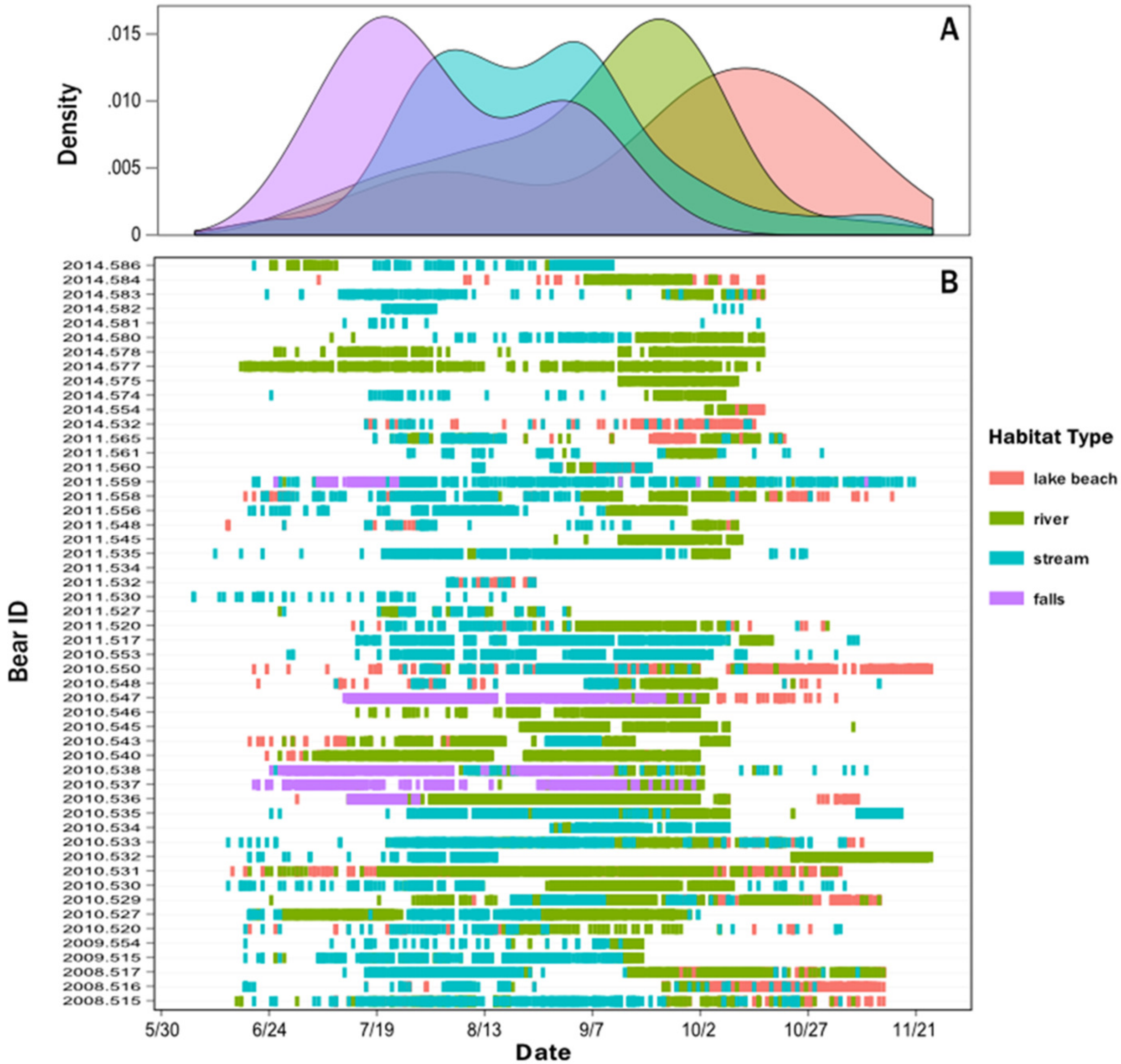
Kodiak Bears Surf the Red (Salmon) Wave – Deacy et al., 2016. Ecology.



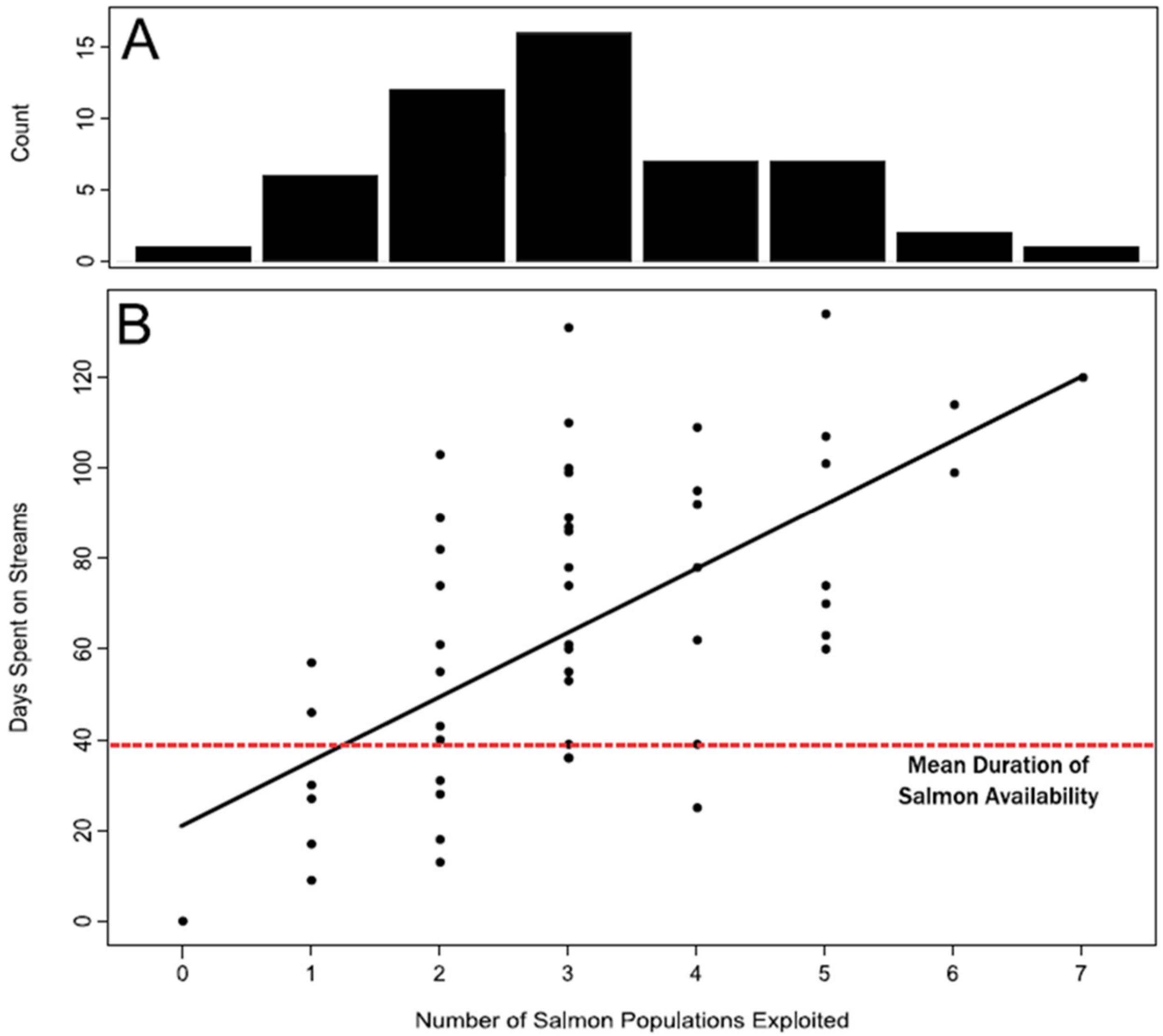

A
B
C
2014-08-06 17:25:00 T
km
0
1.5
3
6
N

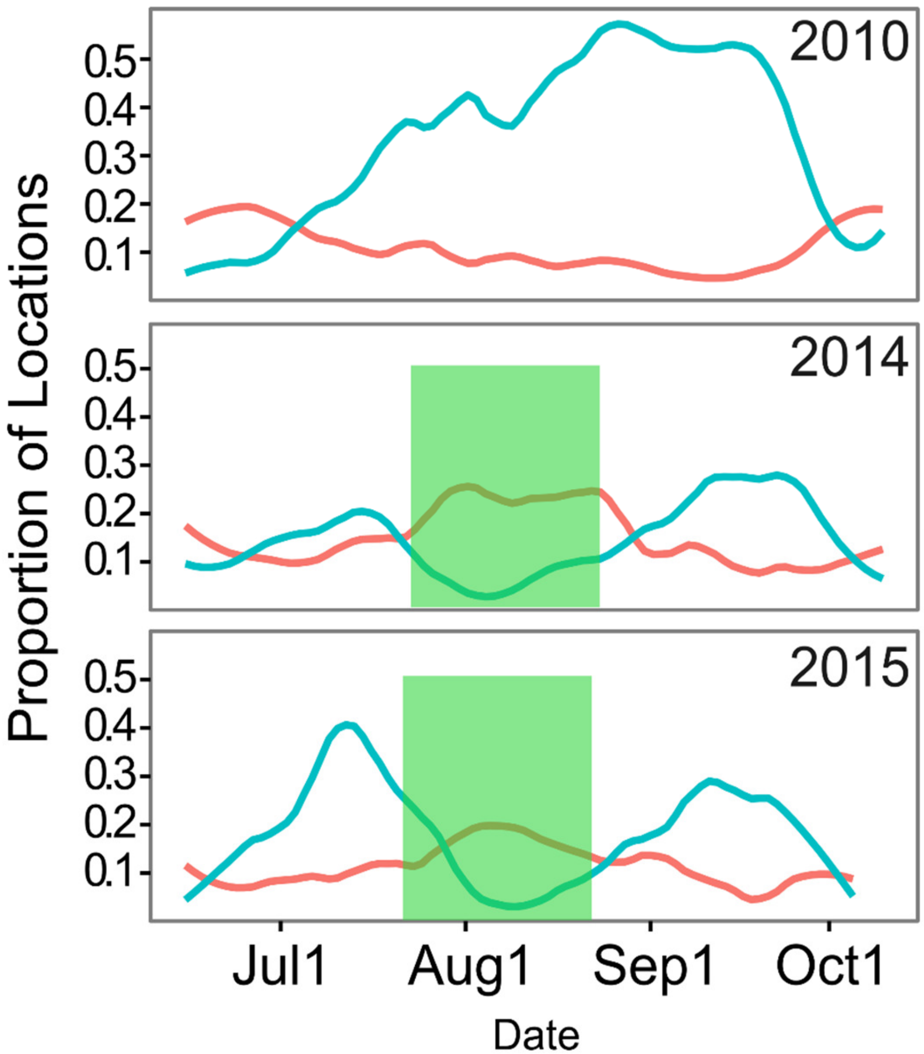
Salmon phenology varies across the landscape – adaptation to SHM that creates a regional salmon portfolio (see also Schindler et al. 2011. Nature)

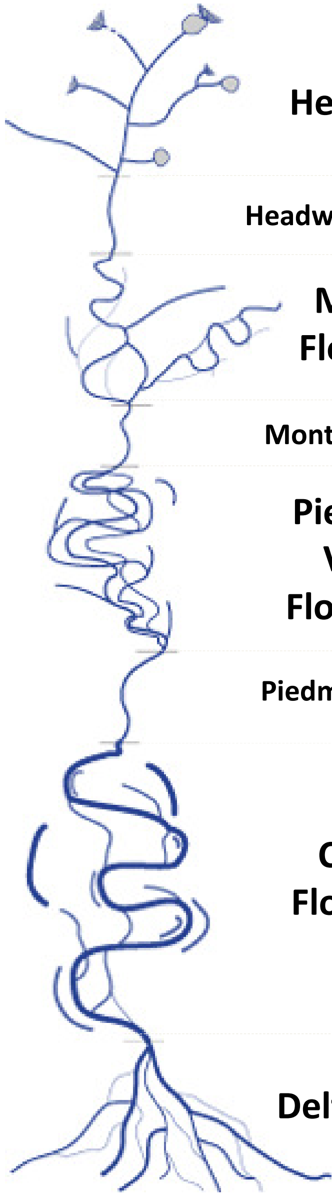




A
B
Density
.015
.010
.005
0
Bear ID
2014.586
2014.584
2014.583
2014.582
2014.581
2014.580
2014.578
2014.577
2014.575
2014.574
2014.554
2014.532
2011.565
2011.561
2011.560
2011.559
2011.558
2011.556
2011.548
2011.545
2011.535
2011.534
2011.532
2011.530
2011.527
2011.520
2011.517
2010.553
2010.550
2010.548
2010.547
2010.546
2010.545
2010.543
2010.540
2010.538
2010.537
2010.536
2010.535
2010.534
2010.533
2010.532
2010.531
2010.530
2010.529
2010.527
2010.520
2009.554
2009.515
2008.517
2008.516
2008.515
5/30
6/24
7/19
8/13
9/7
10/2
10/27
11/21
Date
Habitat Type
lake beach
river
stream
falls


A
Count
0
5
10
15
B
Days Spent on Streams
0
20
40
60
80
100
120
Mean Duration of
Salmon Availability
0
1
2
3
4
5
6
7
Number of Salmon Populations Exploited


2010
2014
2015
0.5
0.4
0.3
0.2
0.1
Proportion of Locations
Jul1
Aug1
Sep1
Oct1
Date



Headwaters

Headwater Canyon

Montane Flood Plain

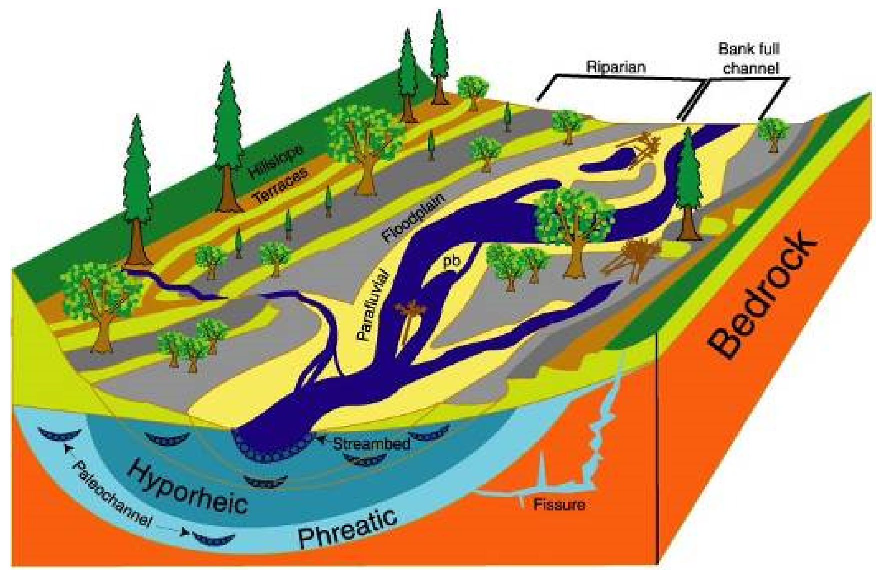
Montane Canyon

Piedmont Valley Flood Plain

Piedmont Canyon

Coastal Flood Plain

Delta-Estuary



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