Effect of Mining on Gravel-bed Rivers
and
Why You Should Care

Ric Hauer
Professor Emeritus, Flathead Lake Biological Station
University of Montana

"……look at streams not as purely aquatic phenomena, ……., but rather view them as parts of the valleys that they drain."

H.B.N. Hynes 1975. Edgard Baldi Memorial Lecture: The stream and its valley.

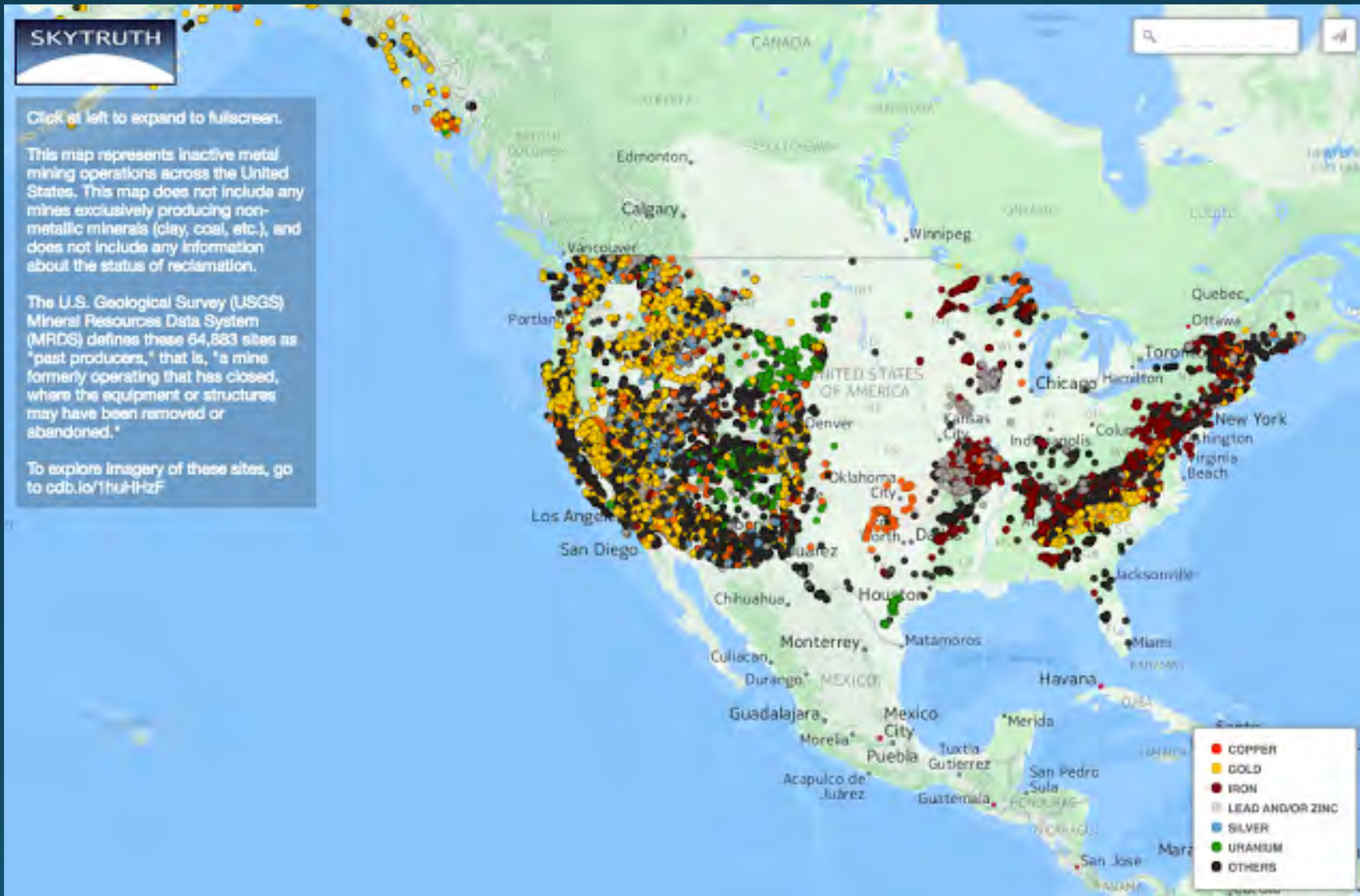
Internationale Vereinigung für Theoretische und Angewandte Limnologie: Verhandlungen
Volume 19, 1975

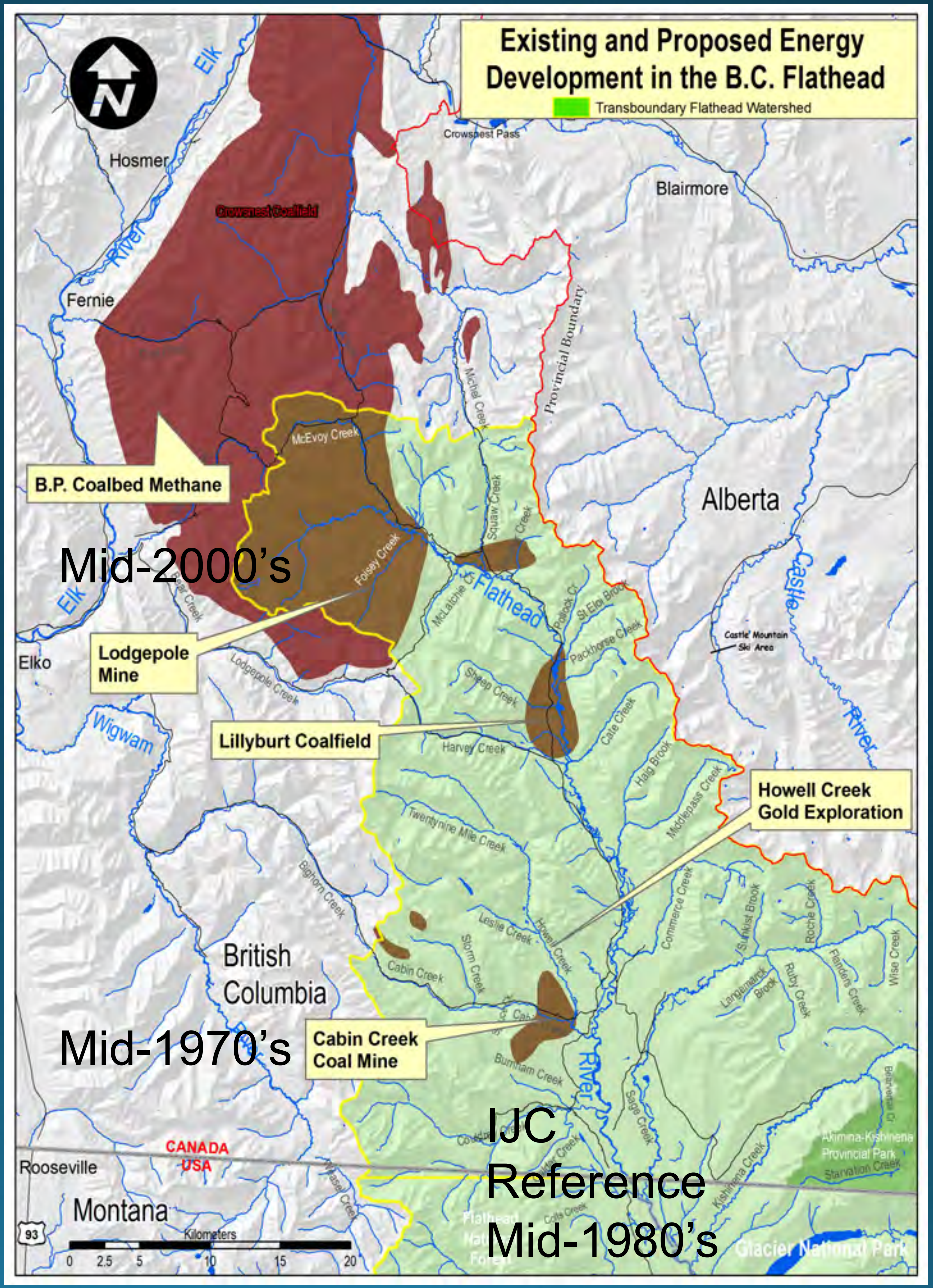
Threat

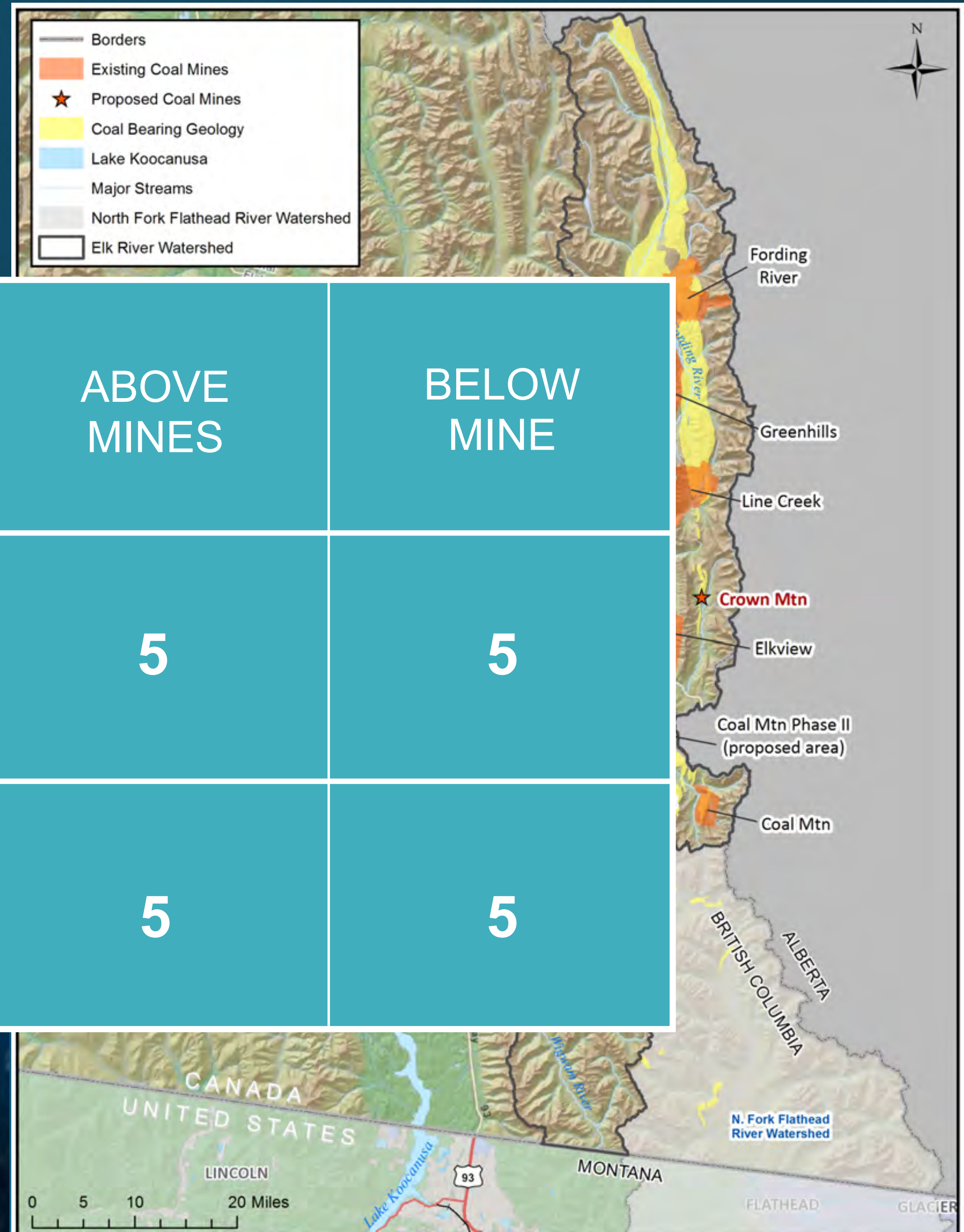
Rio Tinto, Spain

Mining Pollution – there is no known case of mining occurring in a wet environment where toxic waste has no gotten into and polluted the water

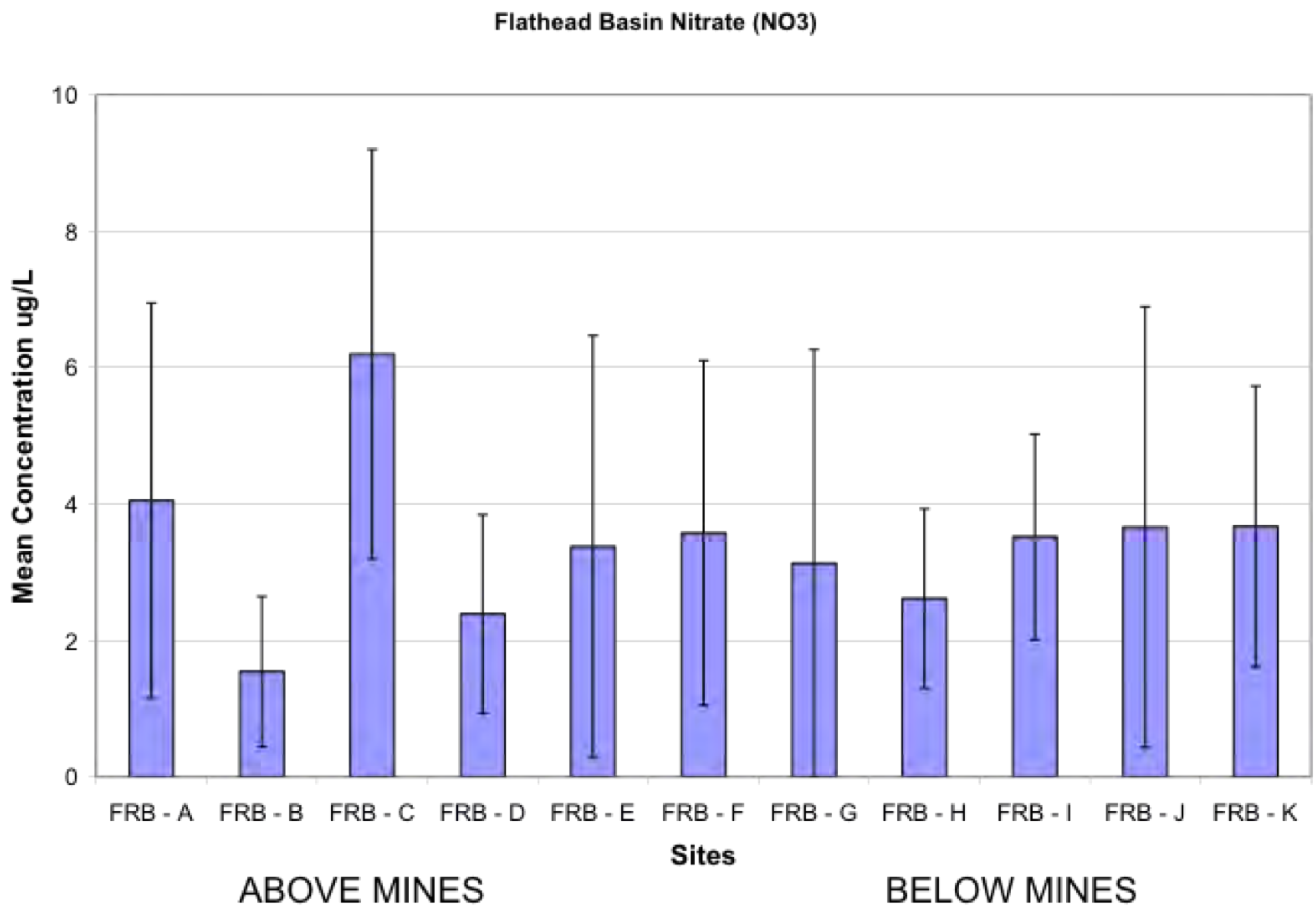
Direct Toxicity to Aquatic Life
Cascading consequences to terrestrial organisms

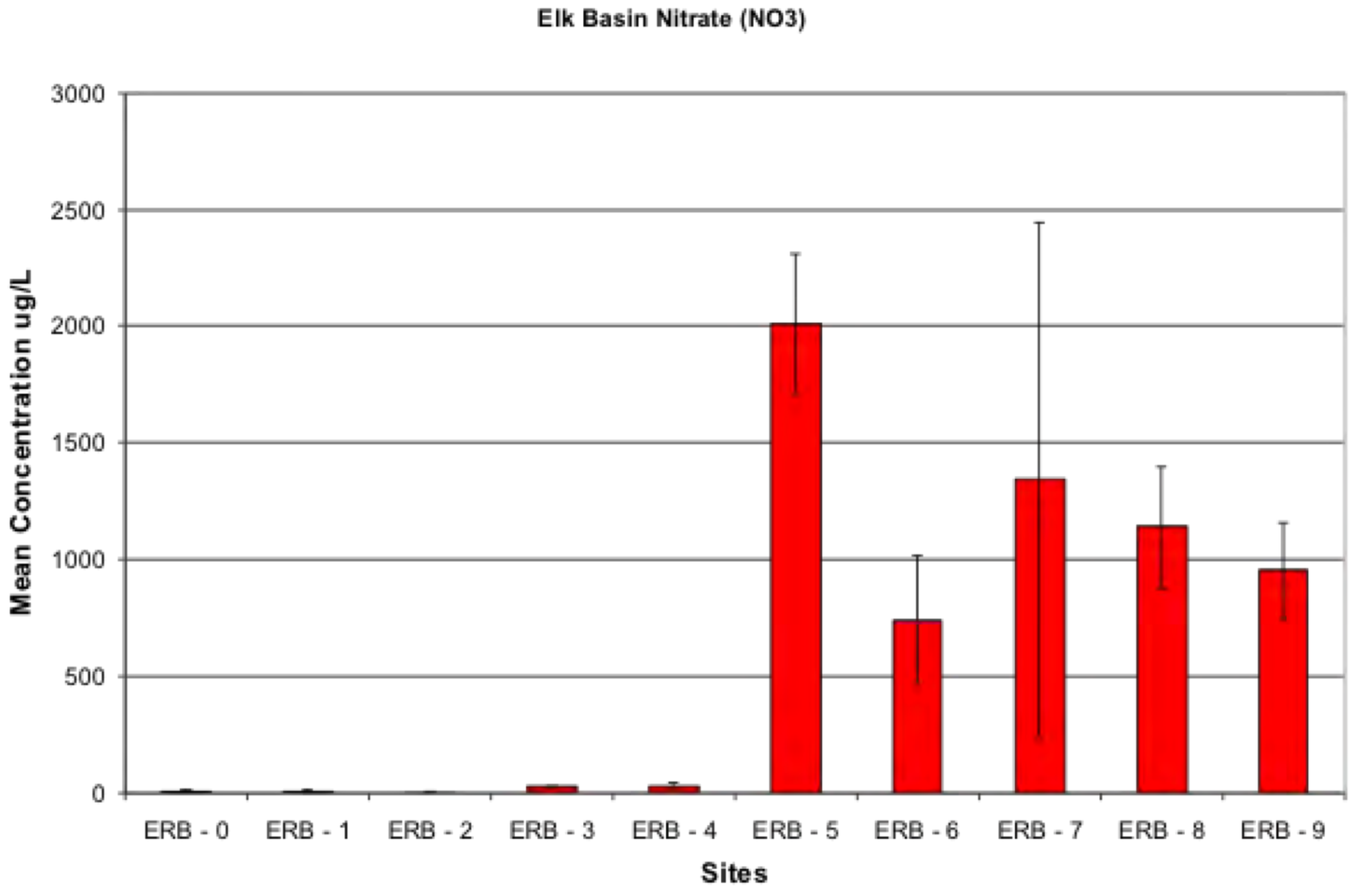

SKYTRUTH
Click at left to expand to fullscreen.
This map represents inactive metal mining operations across the United States. This map does not include any mines exclusively producing non-metallic minerals (clay, coal, etc.), and does not include any information about the status of reclamation.
The U.S. Geological Survey (USGS) Mineral Resources Data System (MRDS) defines these 64,883 sites as "past producers," that is, "a mine formerly operating that has closed, where the equipment or structures may have been removed or abandoned."
To explore imagery of these sites, go to cdb.io/1huHHzF
COPPER
GOLD
IRON
LEAD AND/OR ZINC
SILVER
URANIUM
OTHERS


Existing and Proposed Energy Development in the B.C. Flathead
Transboundary Flathead Watershed
B.P. Coalbed Methane
Mid-2000's
Lodgepole Mine
Lillyburt Coalfield
Howell Creek Gold Exploration
Mid-1970's
Cabin Creek Coal Mine
IJC Reference Mid-1980's
Hosmer
Fernie
Elko
Blairmore
Alberta
British Columbia
Montana
Rooseville
CANADA
USA
Provincial Boundary
Flathead
Kilometers
0 2.5 5 10 15 20



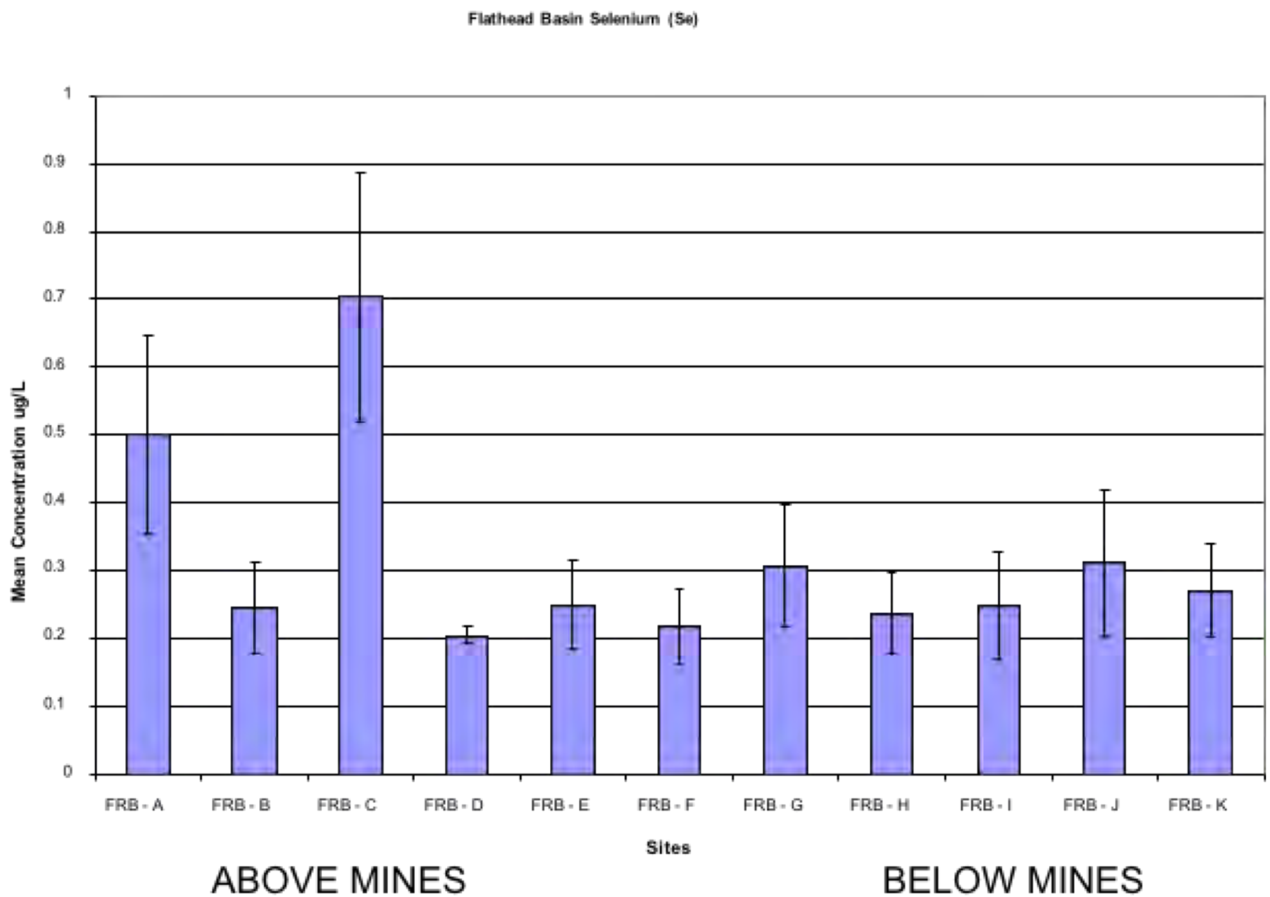
	ABOVE MINES	BELOW MINE
FLATHEAD BASIN	5	5
ELK BASIN	5	5

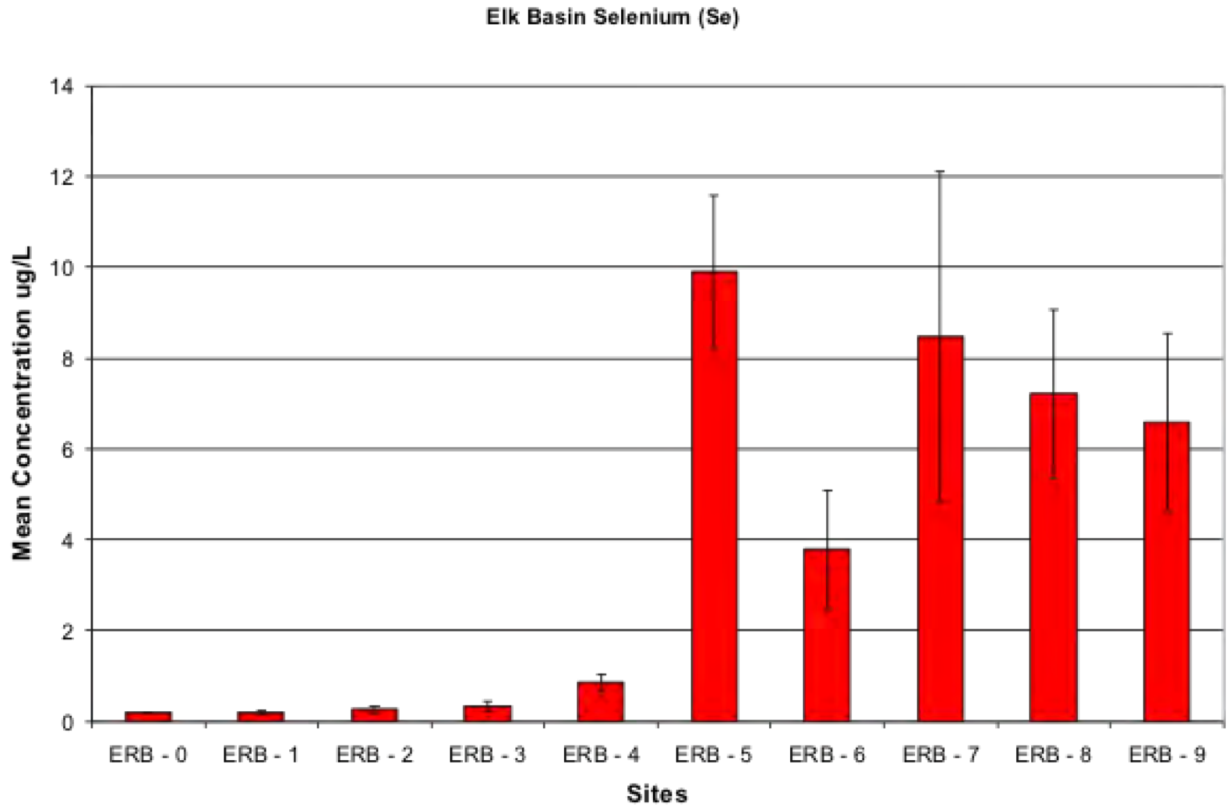

Flathead Basin Nitrate (NO3)
Mean Concentration ug/L
10
8
6
4
2
0
FRB - A
FRB - B
FRB - C
FRB - D
FRB - E
FRB - F
FRB - G
FRB - H
FRB - I
FRB - J
FRB - K
Sites
ABOVE MINES
BELOW MINES



ABOVE MINES

BELOW MINES

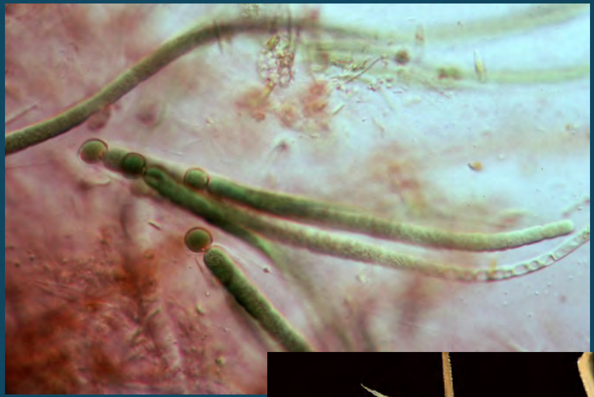

Flathead Basin Selenium (Se)
Mean Concentration ug/L
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
FRB - A
FRB - B
FRB - C
FRB - D
FRB - E
FRB - F
FRB - G
FRB - H
FRB - I
FRB - J
FRB - K
Sites
ABOVE MINES
BELOW MINES



ABOVE MINES BELOW MINES

Aquatic Life

- Algae



- Macroinvertebrates

Algal Diversity, Chlorophyll Content and Biomass

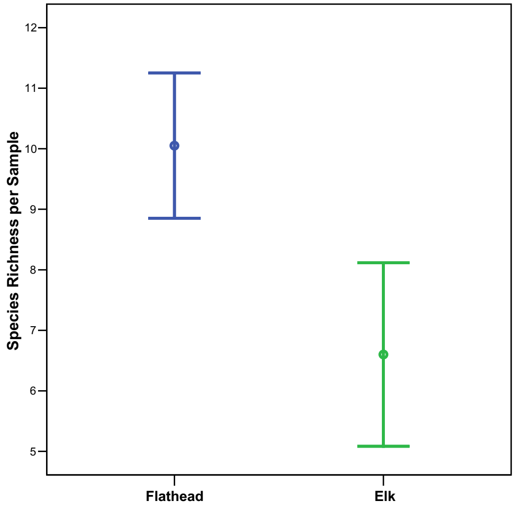
Algal Species Richness

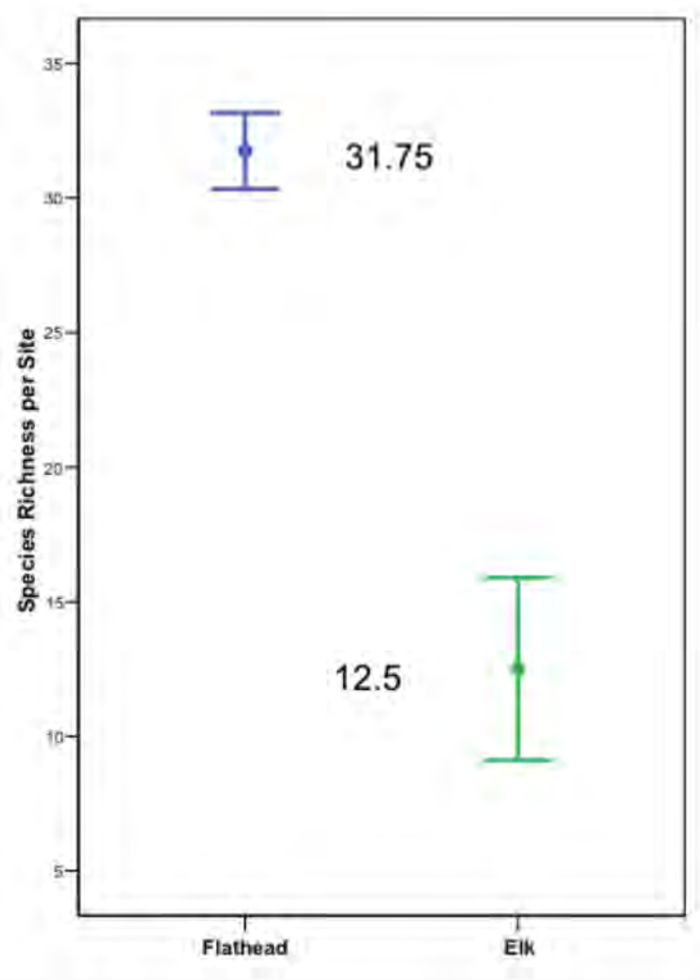
P<0.001

<u>Species Totals</u>

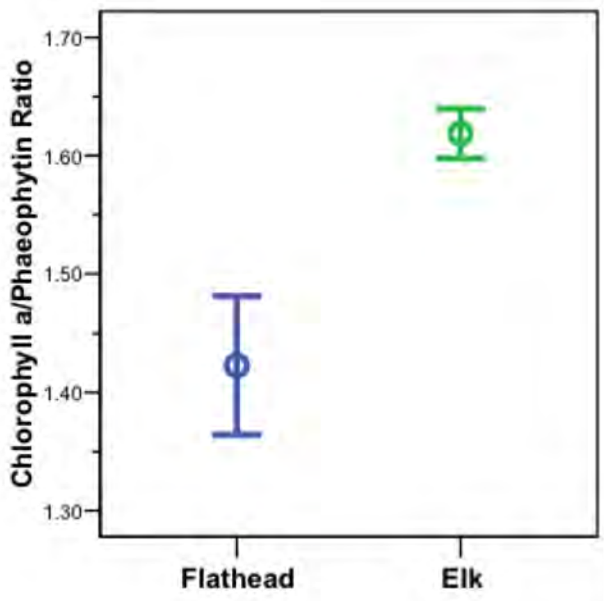
Flathead - 74

Elk - 18



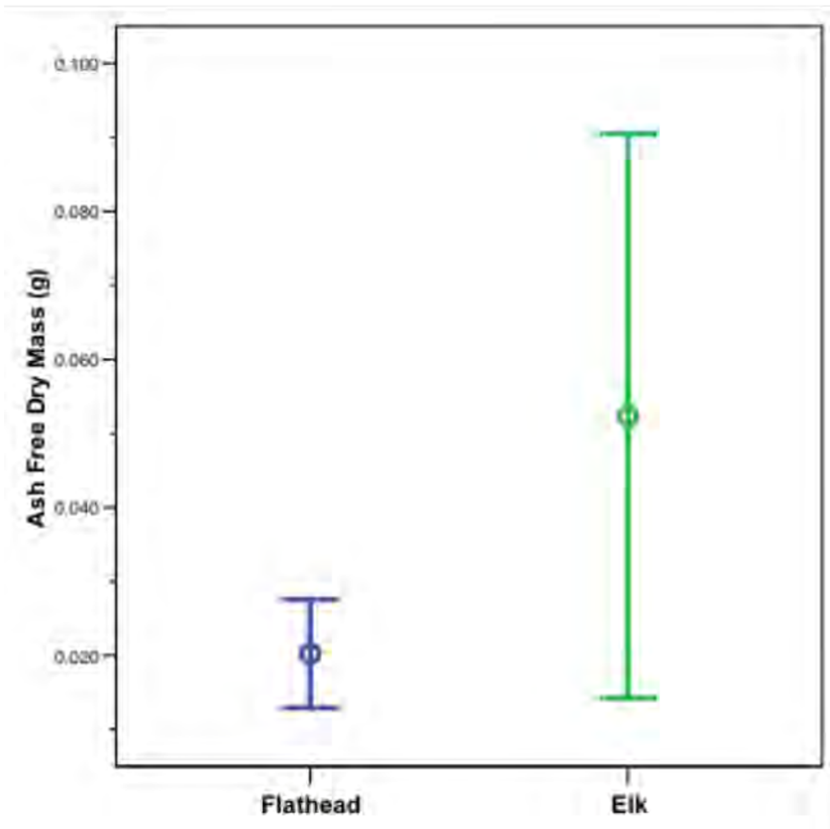


Chlorophyll Content



P<0.001

Biomass



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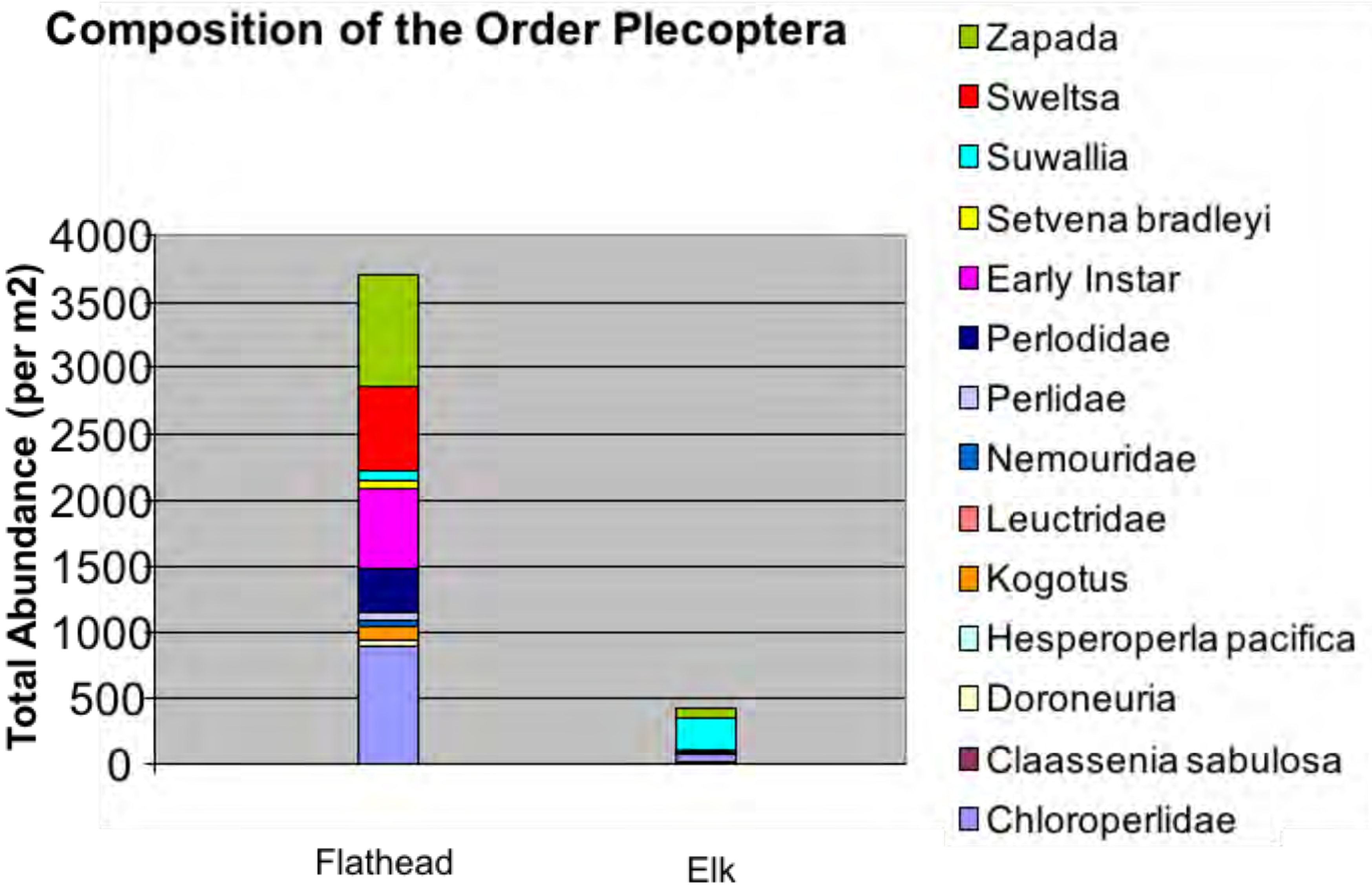
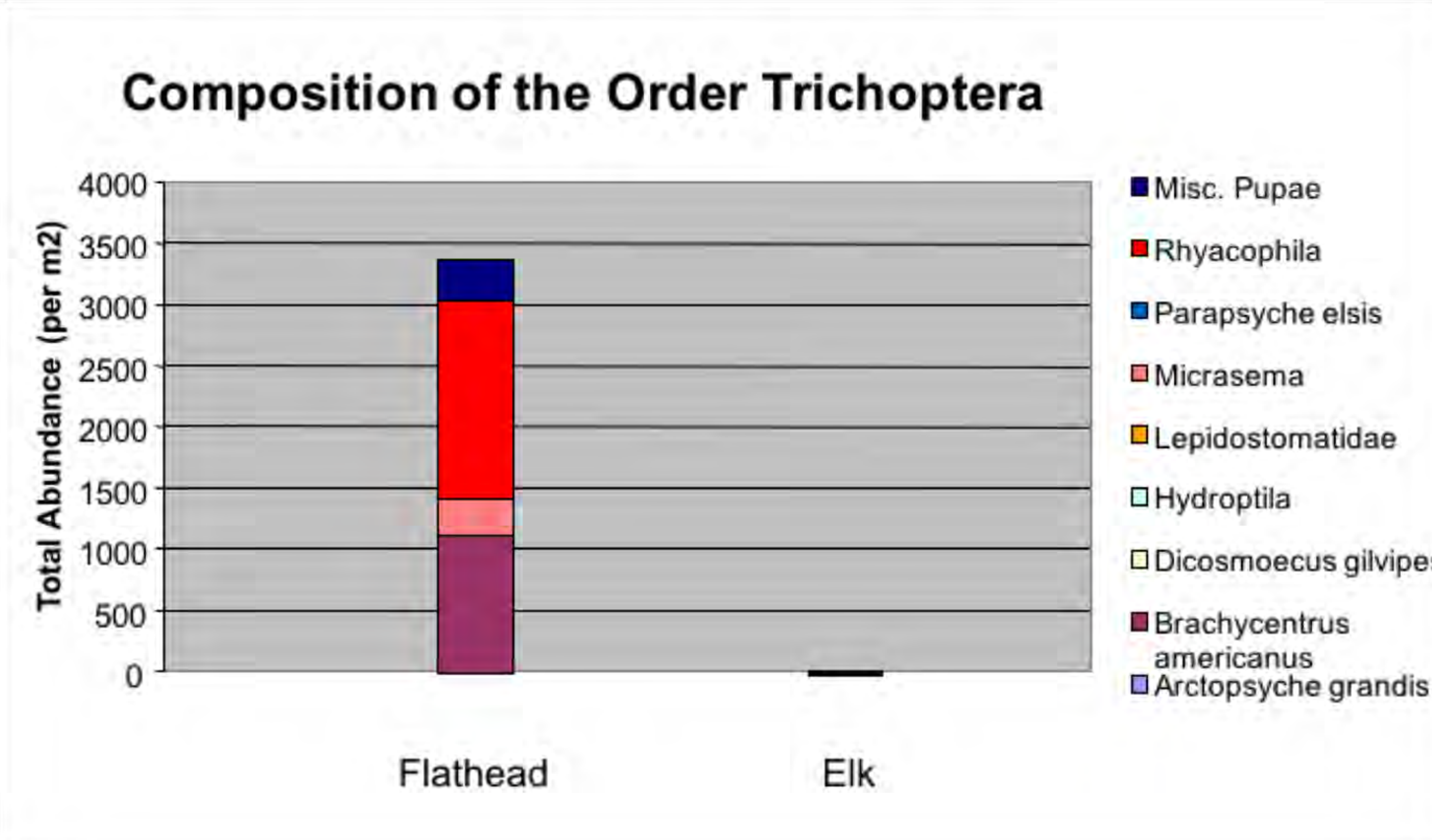
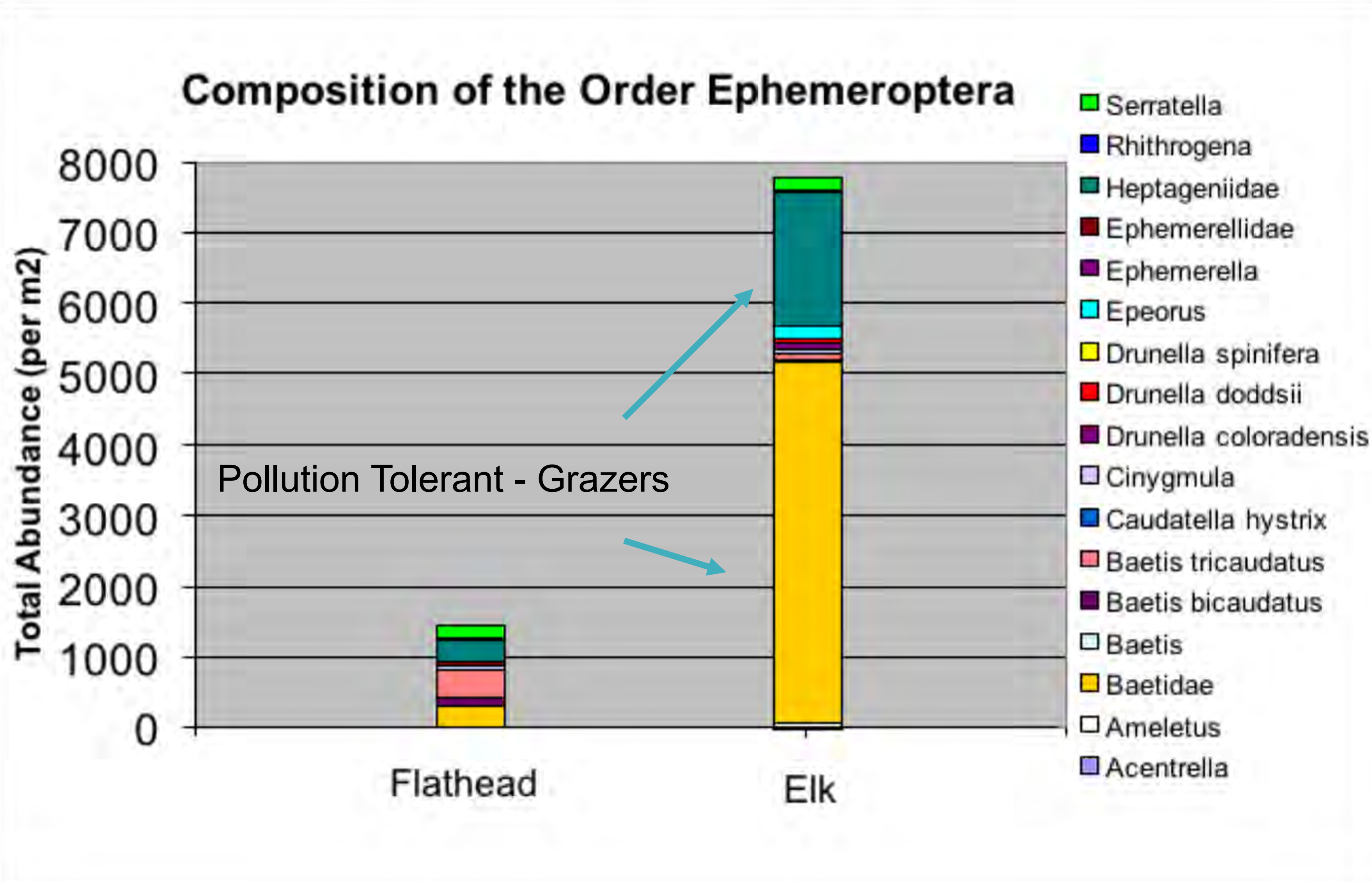
Macroinvertebrates


Composition of the Order Plecoptera
Total Abundance (per m2)
4000
3500
3000
2500
2000
1500
1000
500
0
Flathead
Elk
Zapada
Sweltsa
Suwallia
Setvena bradleyi
Early Instar
Perlodidae
Perlidae
Nemouridae
Leuctridae
Kogotus
Hesperoperla pacifica
Doroneuria
Claassenia sabulosa
Chloroperlidae

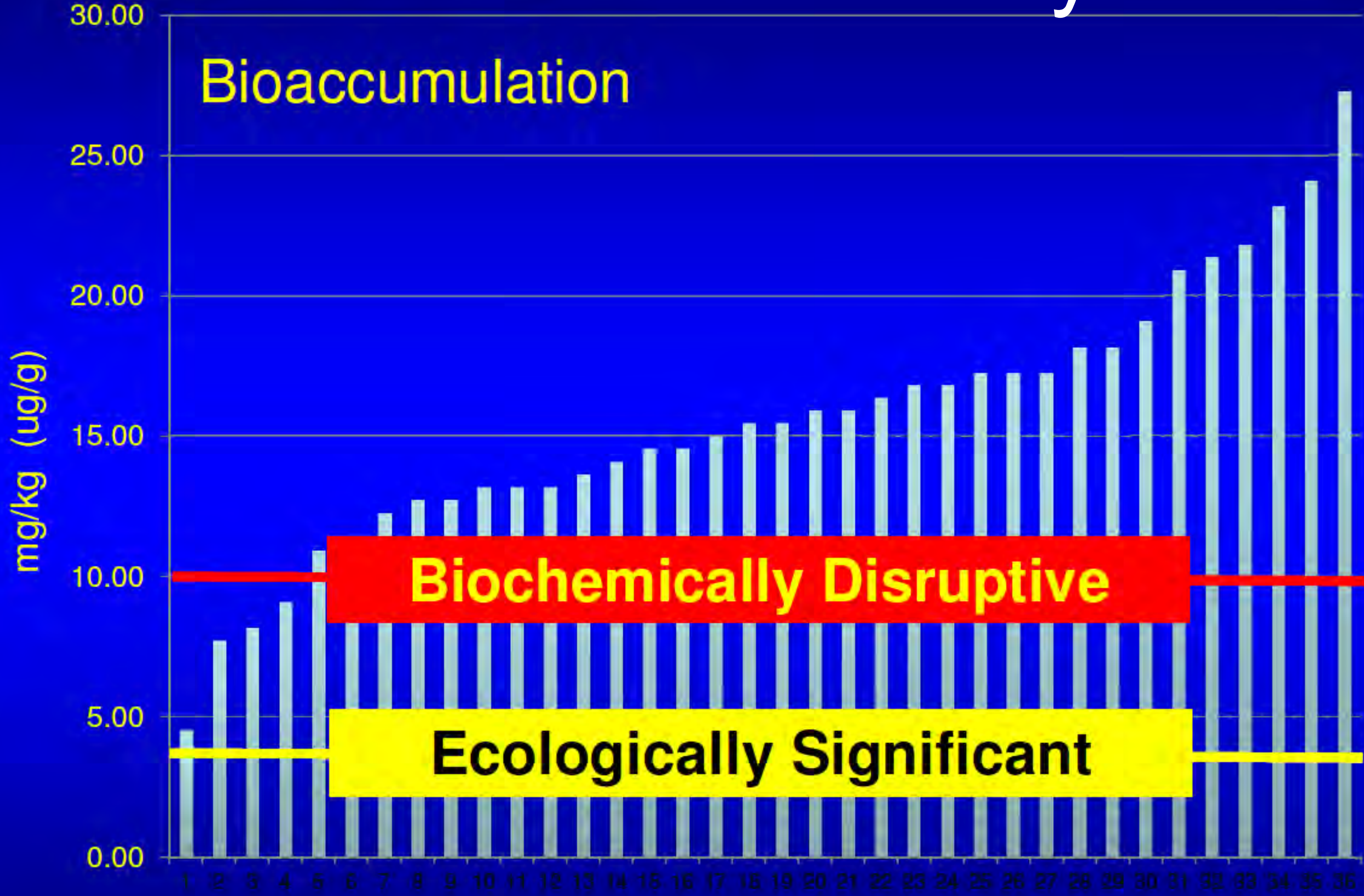


Composition of the Order Trichoptera
Total Abundance (per m2)
4000
3500
3000
2500
2000
1500
1000
500
0
Flathead
Elk
Misc. Pupae
Rhyacophila
Parapsyche elsis
Micrasema
Lepidostomatidae
Hydroptila
Dicosmoecus gilvipes
Brachycentrus americanus
Arctopsyche grandis

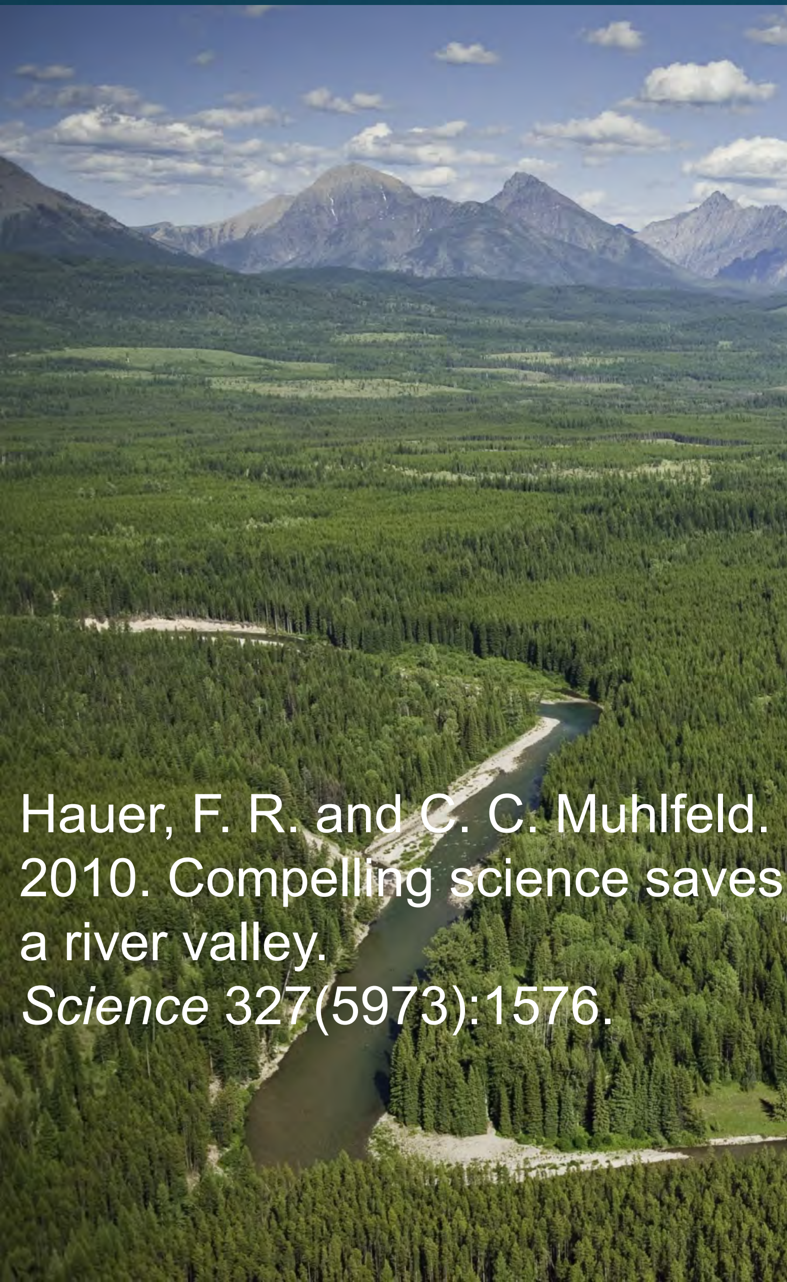

Composition of the Order Ephemeroptera
Total Abundance (per m2)
8000
7000
6000
5000
4000
3000
2000
1000
0
Flathead
Elk
Pollution Tolerant - Grazers
Serratella
Rhithrogena
Heptageniidae
Ephemerellidae
Ephemerella
Epeorus
Drunella spinifera
Drunella doddsii
Drunella coloradensis
Cinygmula
Caudatella hystrix
Baetis tricaudatus
Baetis bicaudatus
Baetis
Baetidae
Ameletus
Acentrella

Selenium Toxicity

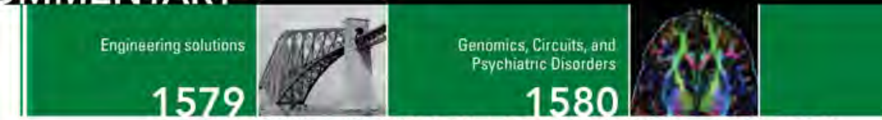
Selenium Toxicity



MDFWP with permission



Hauer, F. R. and C. C. Muhlfeld. 2010. Compelling science saves a river valley. *Science* 327(5973):1576.



LETTERS

edited by Jennifer Sills

Compelling Science Saves a River Valley

Flathead River

THE FLATHEAD RIVER, WHICH originates in British Columbia and flows into Montana, is considered one of America's wildest rivers. Its water quality is pristine, it harbors abundant and diverse aquatic life, and it sustains the full complement of mid- to large carnivores that have lived there since the 1800s. Time and time again since the mid-1970s, the river has been threatened by British Columbia's plans to strip mine for coal. In 2007, British Petroleum announced plans for coal-bed methane development in the basin (*1*). The swift response, which successfully prevented these plans from coming to fruition, included three elements: a careful scientific analysis, a fact-finding mission that respected the scientific input, and a productive diplomatic relationship that resulted in policy changes.

First, the United States responded by developing a science team to conduct a comprehensive environmental assessment of water quality, aquatic food webs, habitat, native fish, and wildlife. The science was compelling. A comparison between data collected from the Flathead and from the neighboring Elk River, the site of more than 50 years of open-pit coal mining, showed that waters of the Elk basin were significantly more polluted than those of the Flathead: Elk basin had more than 1000 times the nitrates, 100 times the sulfates, and 10 times the selenium concentrations. Similarly, aquatic food webs in coal mine–affected waters lost biodiversity as many pollution-sensitive species disappeared (*2*). In contrast, the pristine water and aquatic habitats in the Flathead support migratory populations of endangered species such as bull trout and nonhybridized westslope cutthroat trout (*3*).

In September 2009, a joint United Nations Educational, Scientific, and Cultural Organization (UNESCO)/International Union for Conservation of Nature fact-finding mission visited the Flathead in Montana and British Columbia to investigate whether the proposed mining was a threat to Waterton-Glacier International Peace Park, a UNESCO-designated World Heritage Site and Biosphere Reserve. The UNESCO mission listened carefully to the scientists' results. Their report concluded that mining in the Flathead would be "incompatible" with Waterton-Glacier as a World Heritage Site (*4*).

Finally, diplomacy at the state/provincial level and at the federal level between the United States and Canada was developed through personal relationships and mutual interest. Policy-makers in both countries respected the scientific and fact-finding analyses. As a result, on 18 February 2010, Premier Gordon Campbell of British Columbia and Governor Brian Schweitzer of Montana signed an accord to prohibit coal mining, coal-bed methane extraction, and gas and oil exploration and development in the transboundary North Fork of the Flathead River Basin.

Throughout this process, scientific results played a central role in providing the backbone for resolute policy and the case for relentless political pressure. This healthy precedent will allow science to continue to inform policy as Canadian and U.S. officials work together to develop a natural-resource policy that protects this remarkable, shared ecosystem. We believe that this case will stand as an international model in which the natural goods and services provided by a World Heritage Site and Biosphere Reserve were ultimately valued over the commodities of natural-resource extraction.

F. RICHARD HAUER[1]* AND CLINT C. MUHLFELD[2]

[1]Flathead Lake Biological Station, The University of Montana, Polson, MT 59860, USA. [2]U.S. Geological Survey–Northern Rocky Mountain Science Center, Glacier Field Office, Glacier National Park, West Glacier, MT 59936, USA.

*To whom correspondence should be addressed. E-mail: ric.hauer@umontana.edu

References

1. J. Mann, "Coal-bed permits sought," *The Daily Inter Lake*, 9 August 2007; www.dailyinterlake.com/news/local_montana/article_a58f4503-95e5-5b93-a73e-06319bc91e47.html.
2. F. R. Hauer, E. K. Sexton, "Transboundary flathead water quality and aquatic life: Biennial report" (Flathead Basin Commission, Kalispell, MT, 2010).
3. C. C. Muhlfeld, T. E. McMahon, D. Belcer, J. Kershner, *Can. J. Fish Aquat. Sci.* **66**, 1153 (2009).
4. P. R. Dingwall, K. Rao, "Report of the reactive monitoring mission" (UNESCO World Heritage Centre, International Union for Conservation of Nature, Waterton-Glacier International Peace Park, 2009).

Asian Test-Score Culture Thwarts Creativity

ASIA HAS BEEN HAILED AS THE NEXT GLOBAL SCIence player as fast-growing Asian economies invest heavily in science and technology to drive further growth. However, Asian science will continue lagging behind the West because the Asian education system does not nurture

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Published by AAAS

G. Lenz

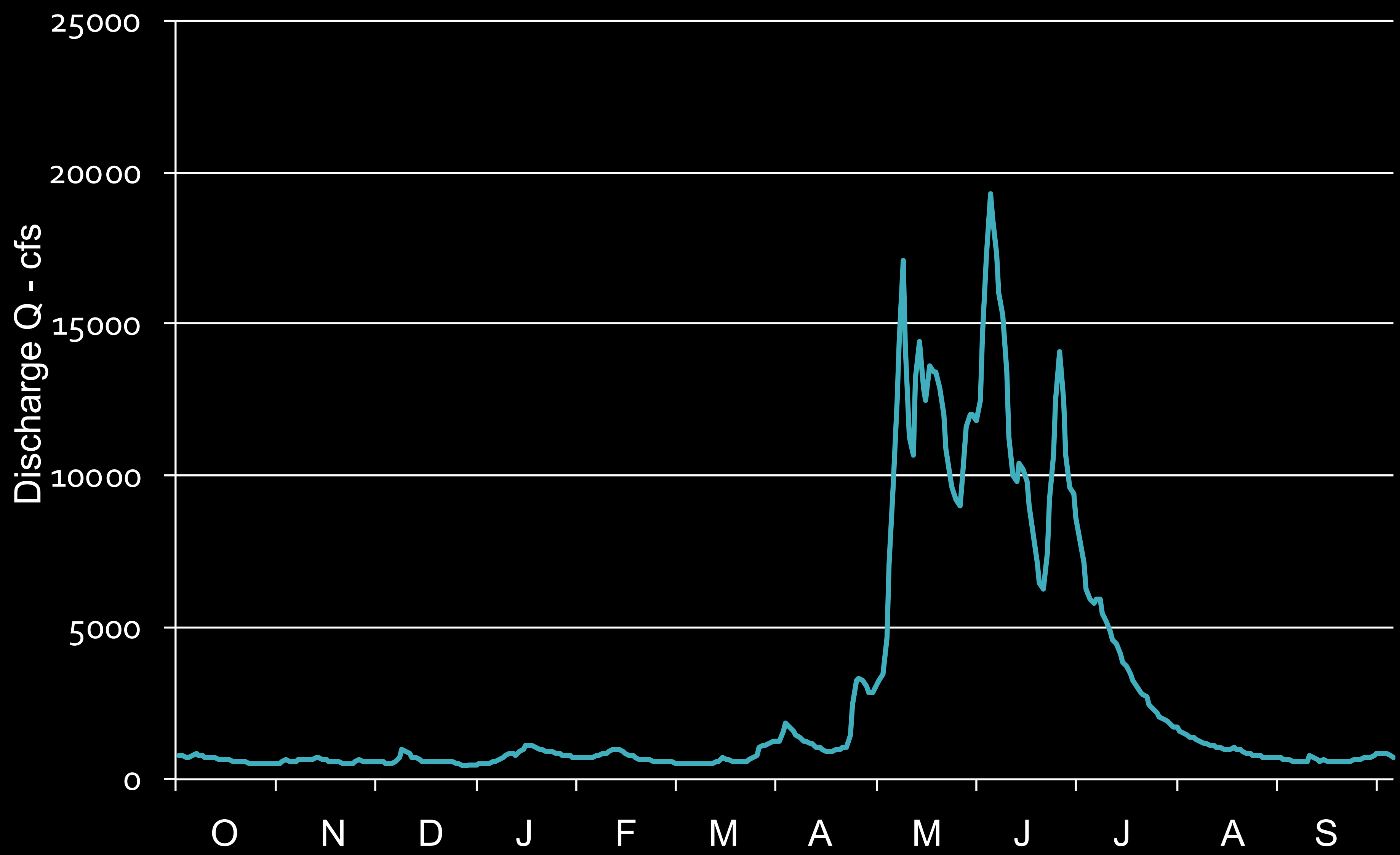
Gravel-Bed River

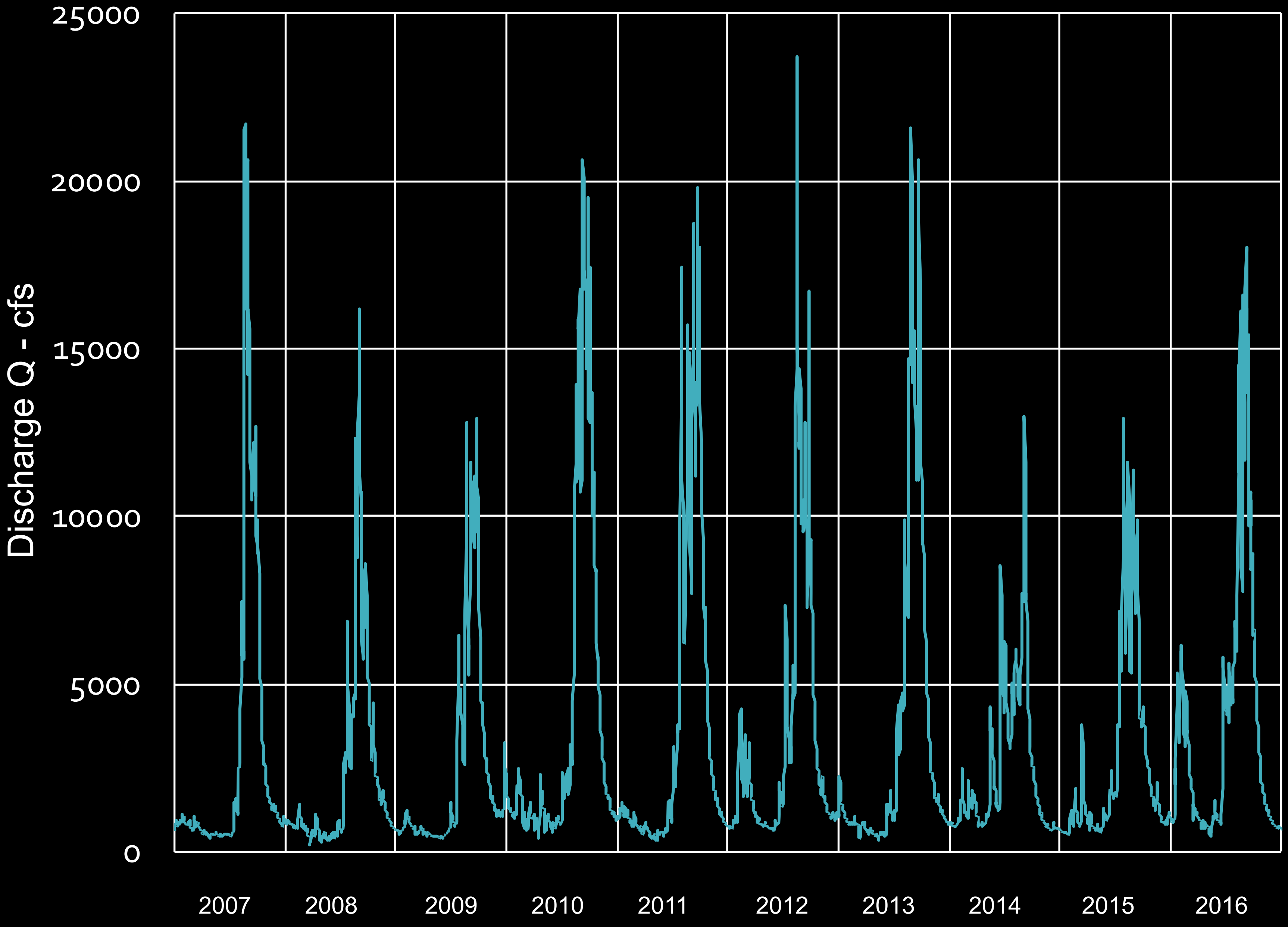
BioStation Faculty, Staff
and Students

Photo- Harvey Locke

Geo-Physical Basis of Gravel-bed River Floodplains

Hydrograph – Discharge as Power to perform Cut and Fill Alluviation





25000
20000
15000
10000
5000
0
Discharge Q - cfs
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

River/Floodplain hydro-geomorphic and vegetative structures of the Shifting Habitat Mosaic

River/Floodplain hydro-geomorphic and vegetative structures of the Shifting Habitat Mosaic

River/Floodplain hydro-geomorphic and vegetative structures of the Shifting Habitat Mosaic

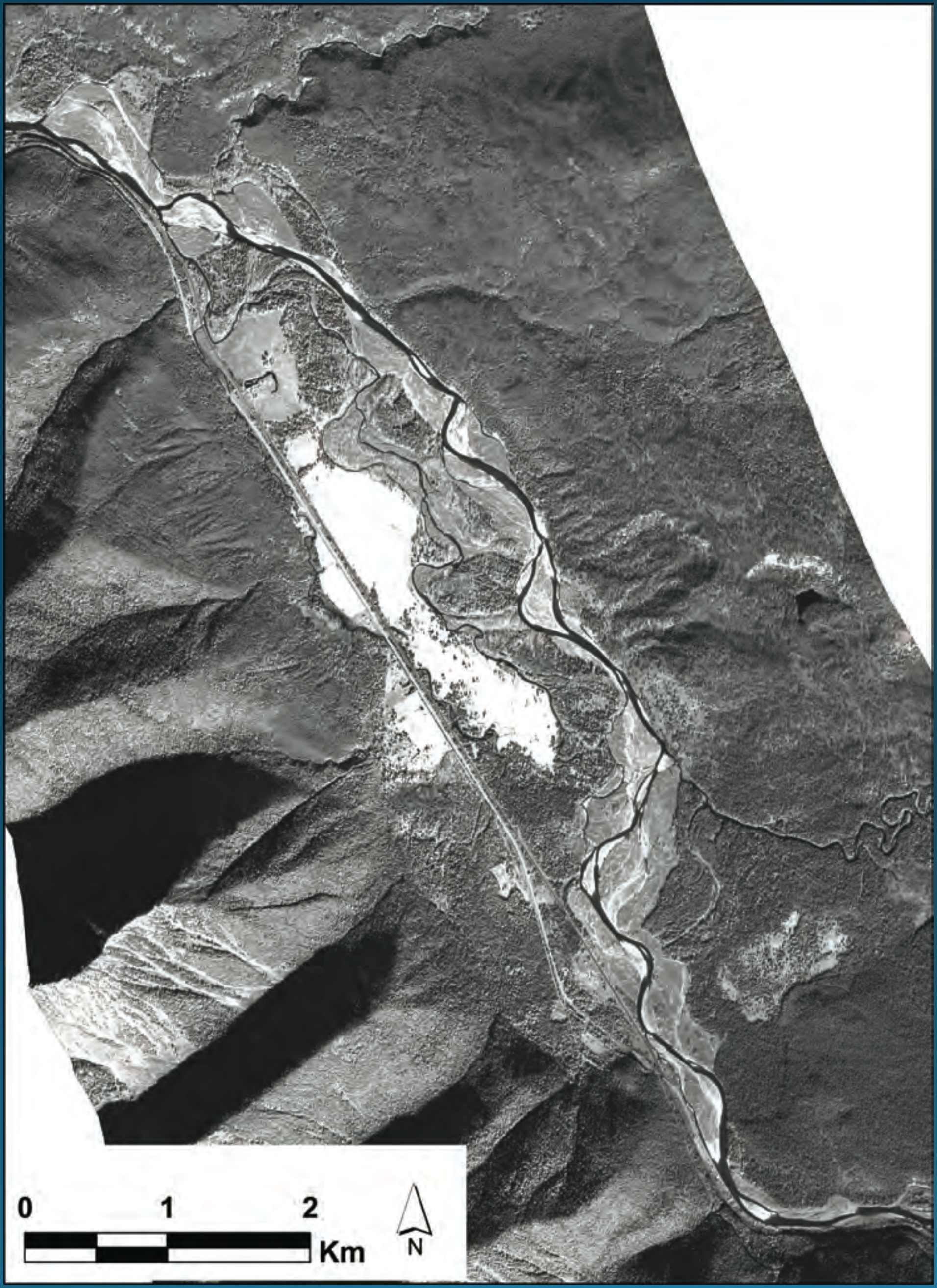
River/Floodplain hydro-geomorphic and vegetative structures of the Shifting Habitat Mosaic

River/Floodplain hydro-geomorphic and vegetative structures of the Shifting Habitat Mosaic

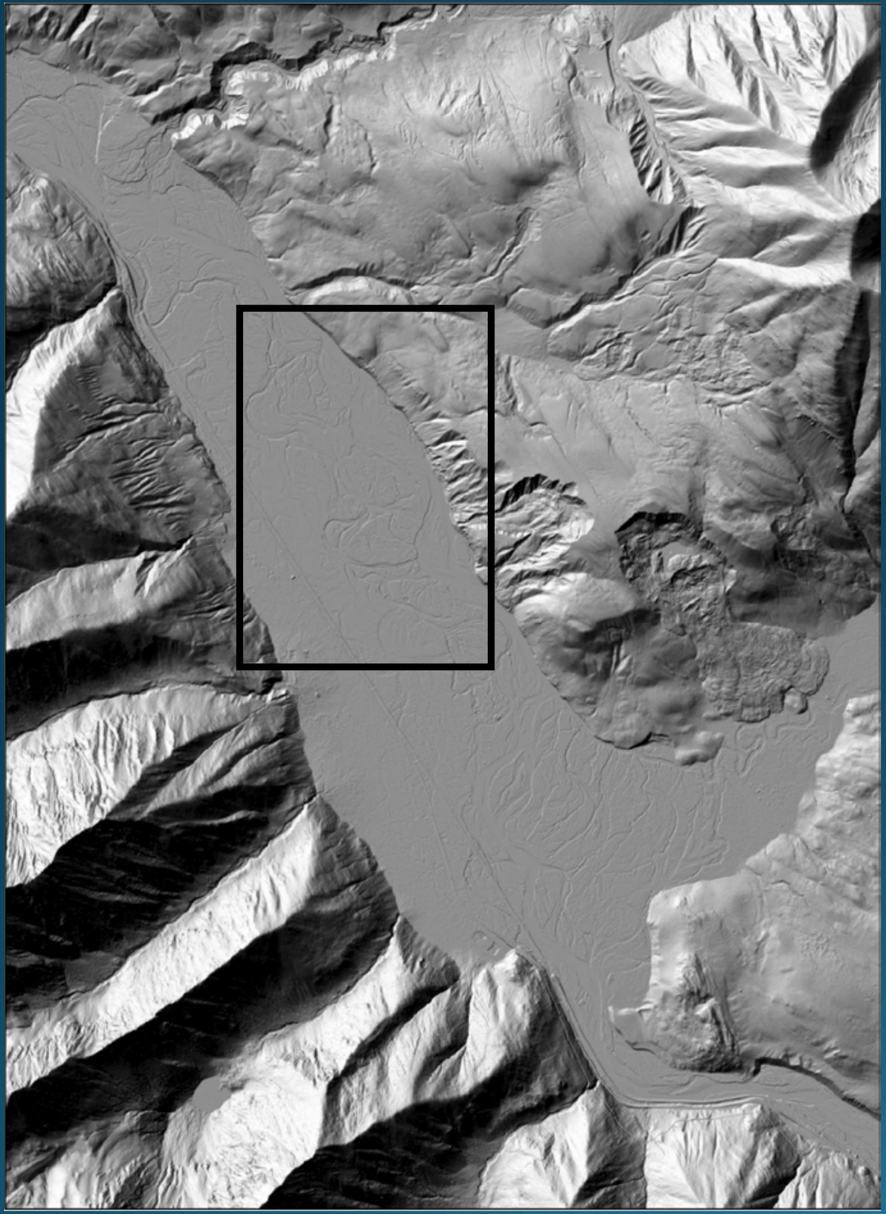

Photo: Tom Gonser

Nyack Floodplain

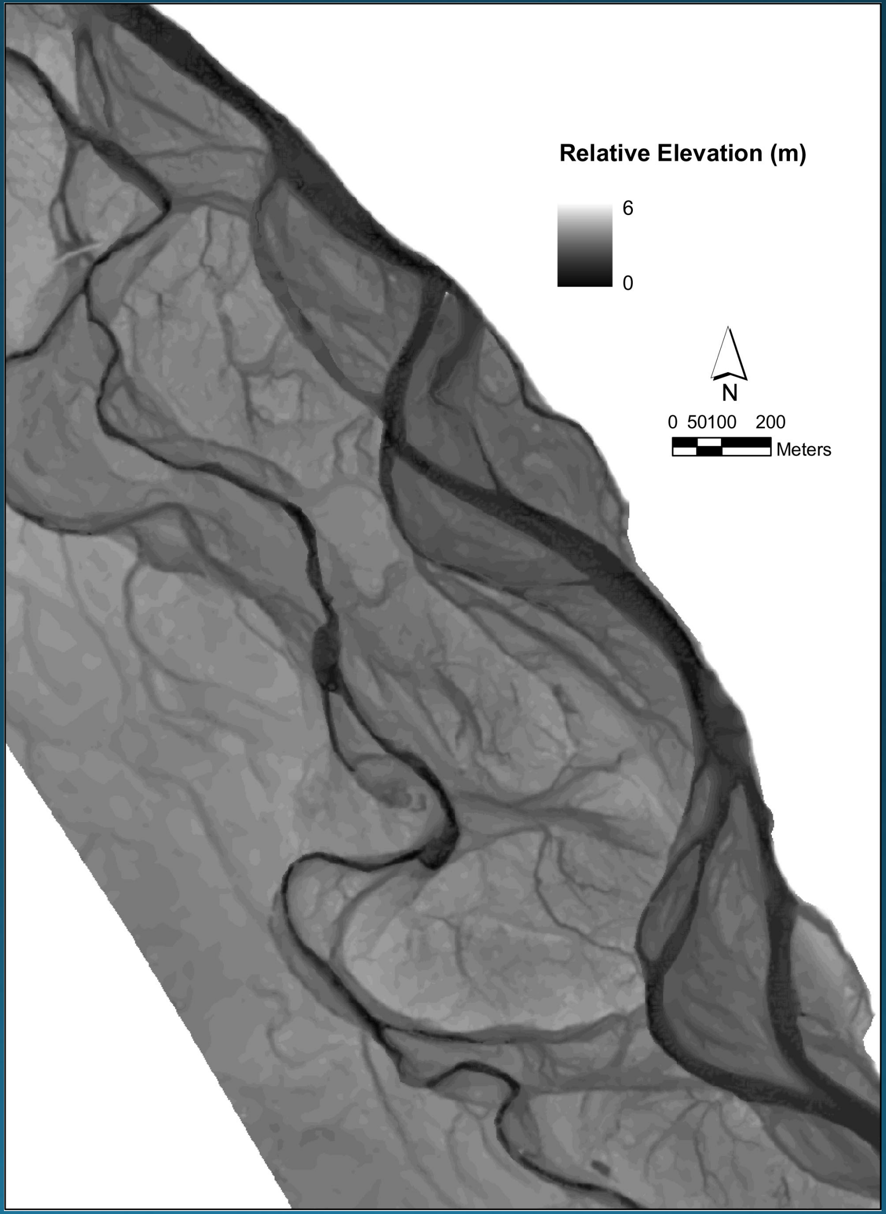
Middle Fork Flathead

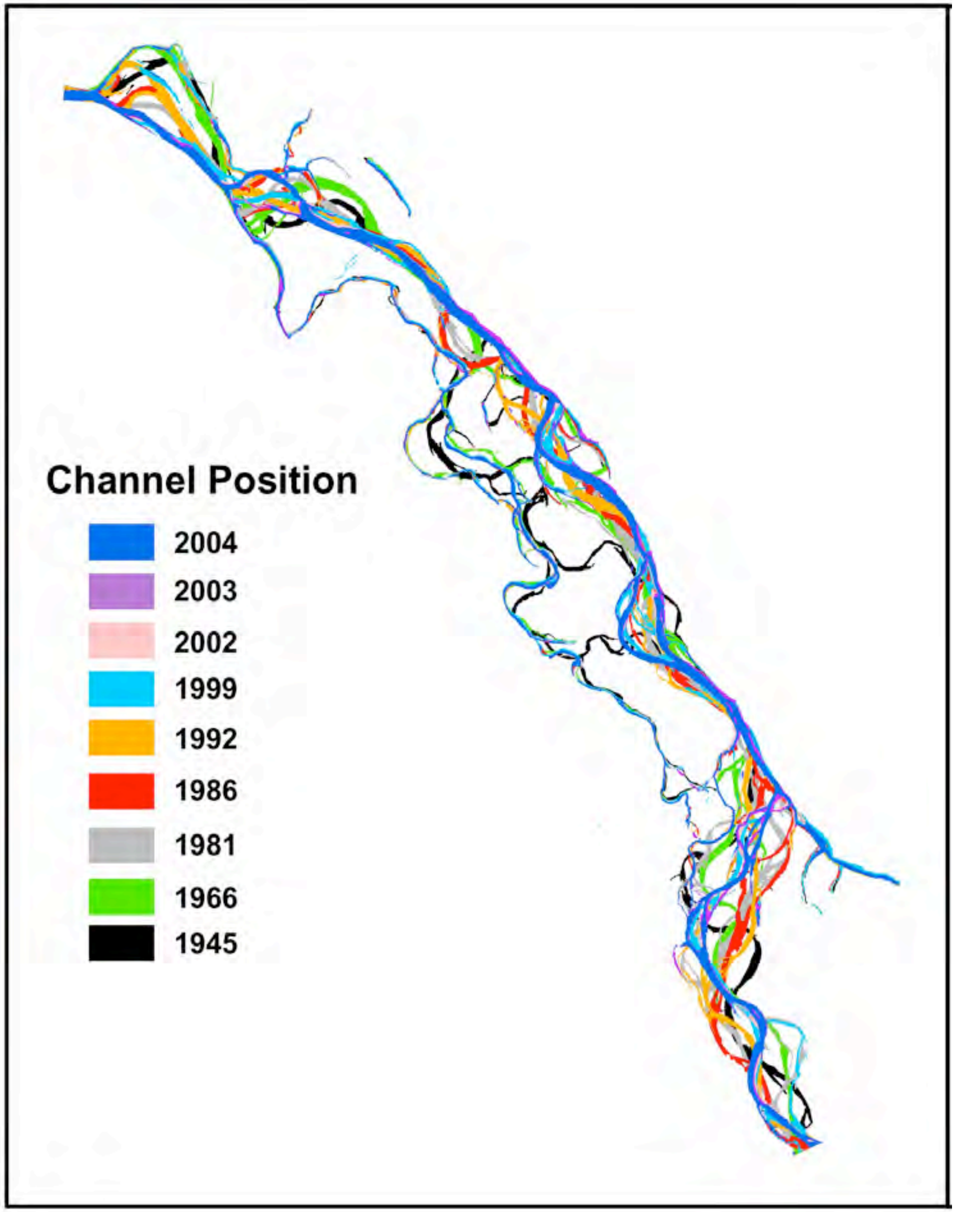


LiDAR Image



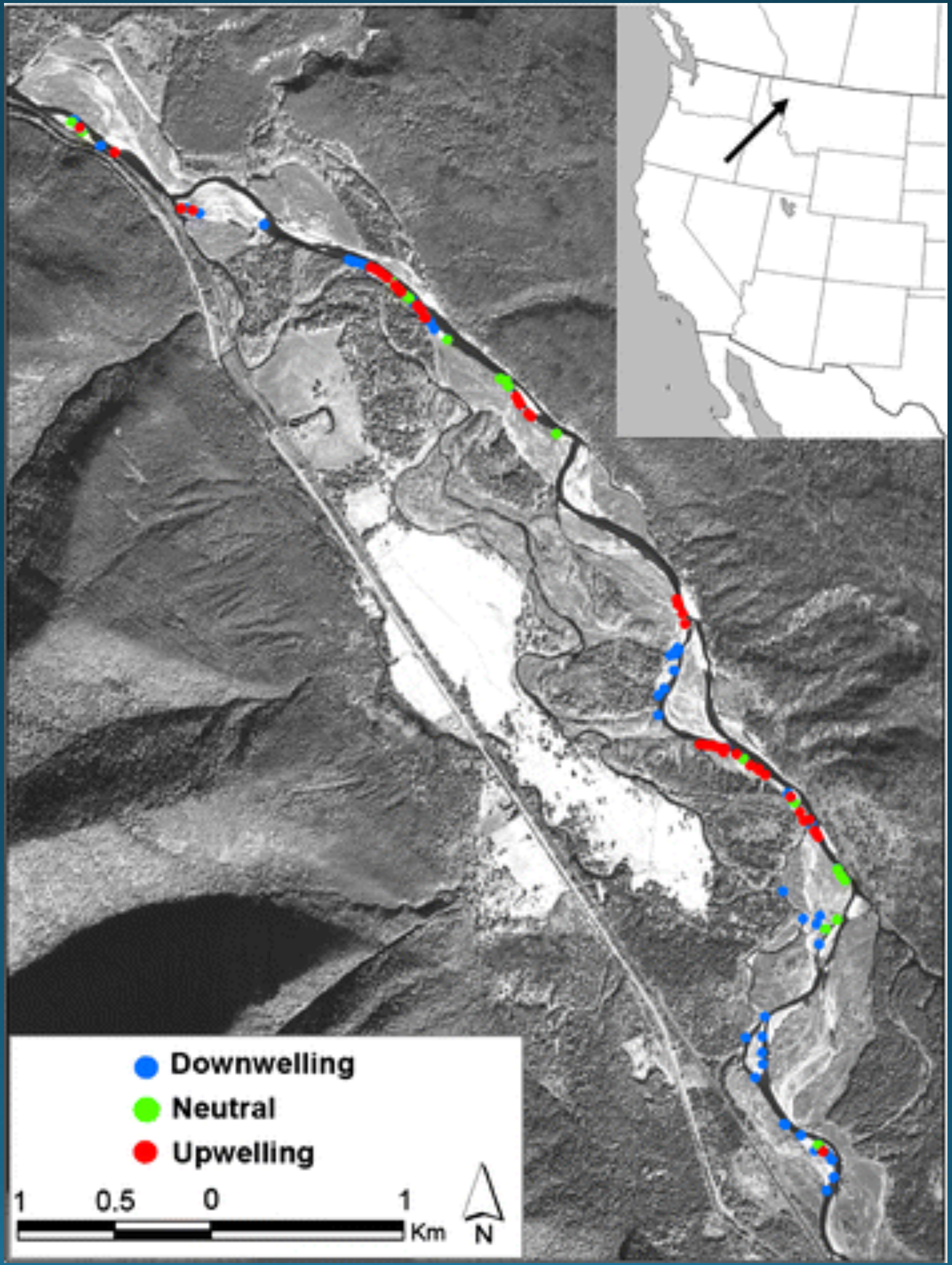
LiDAR Image Normalized to Water Surface

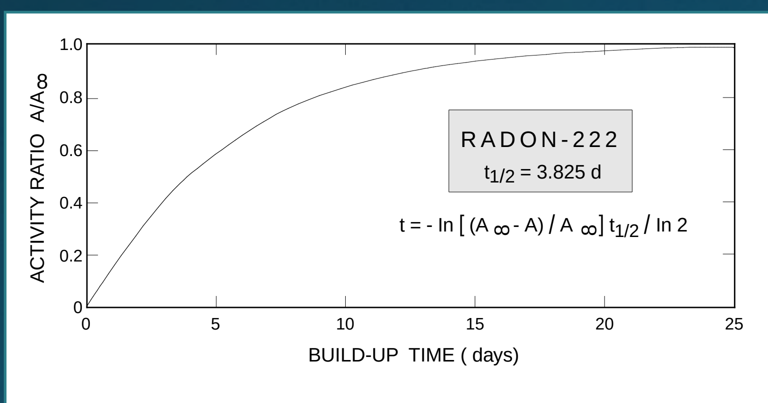


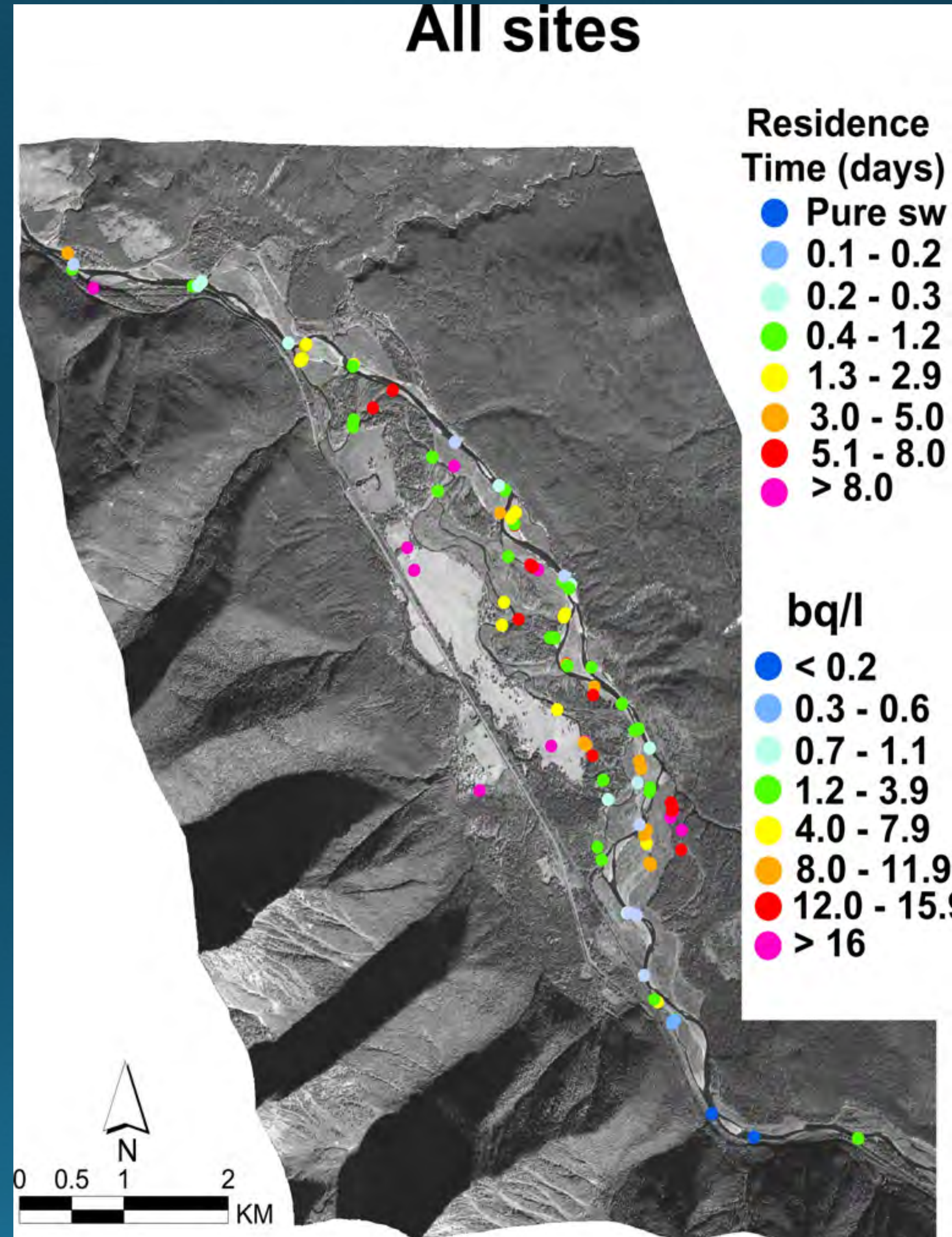


Whited et al. 2007 *Ecology*

Groundwater / Surface Water Exchange between the Channel and Hyporheic Zone

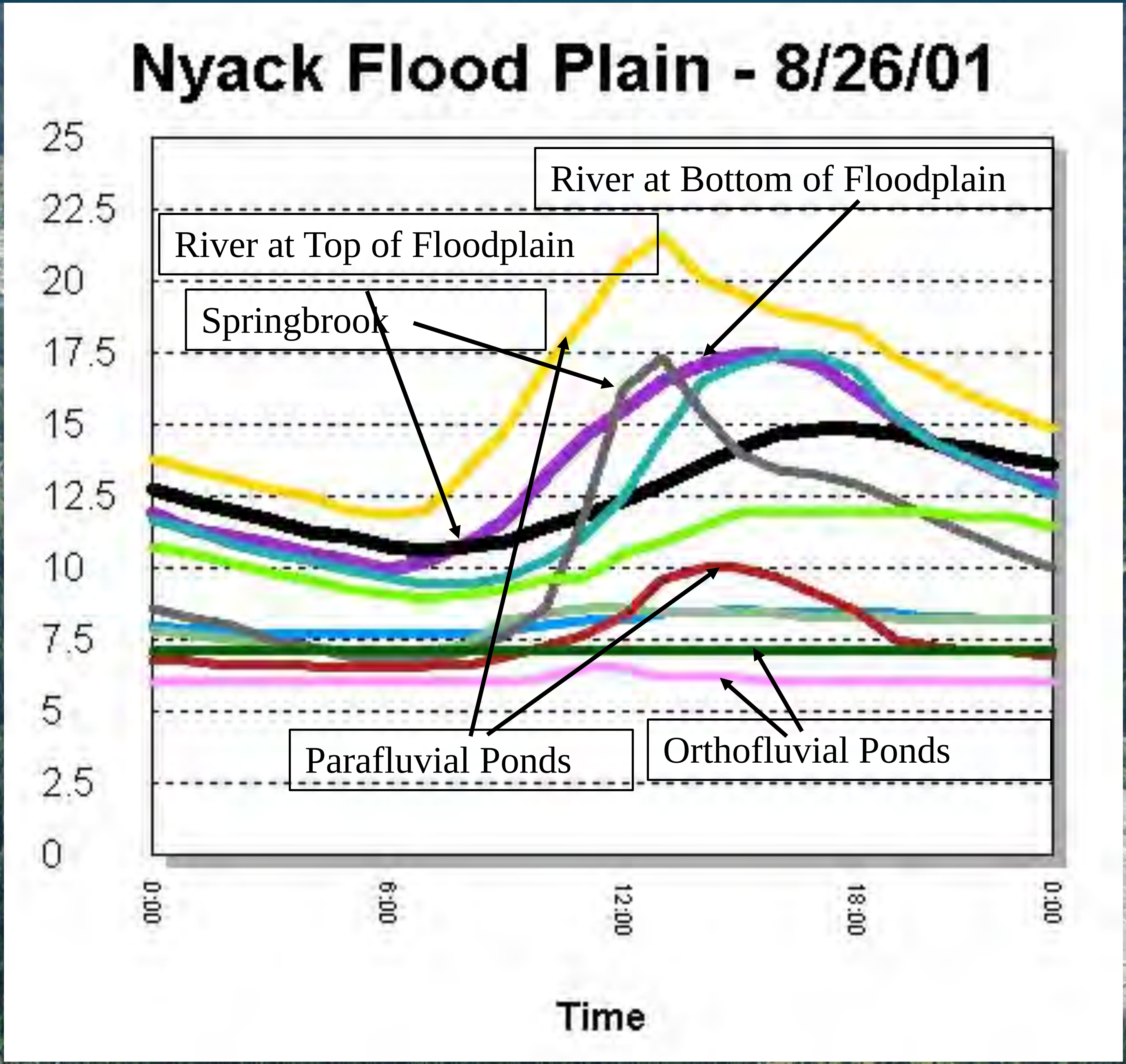




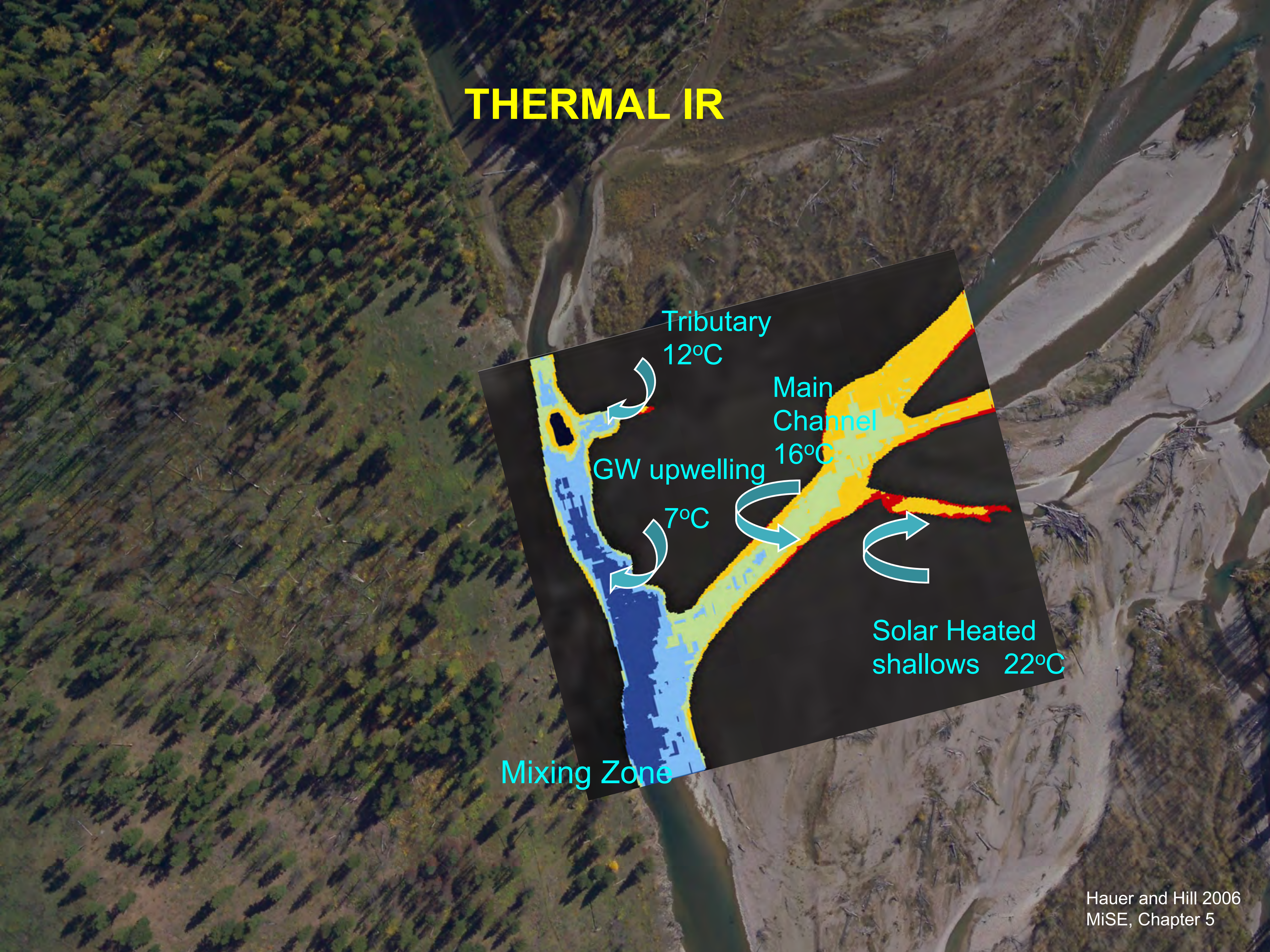


Unpublished data: T. Gonser with permission

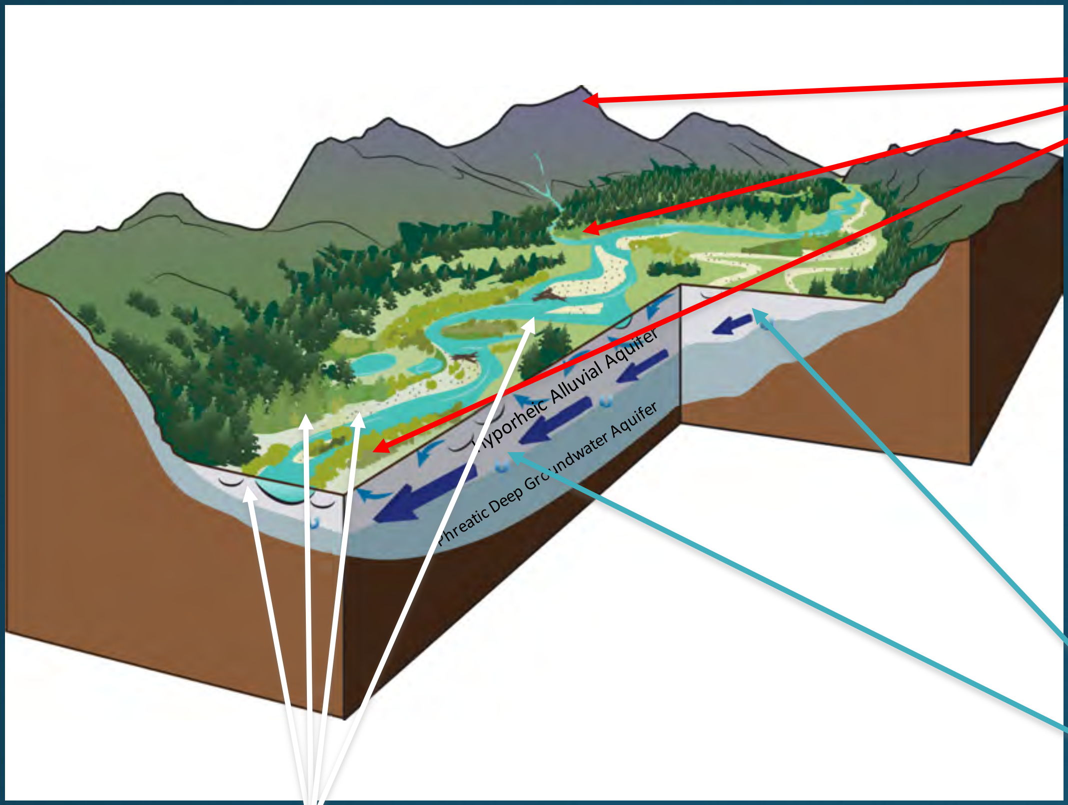

Photo: Tom Gonser



Data M. Lorang


THERMAL IR
Tributary
12oC
Main
Channel
16oC
GW upwelling
7oC
Solar Heated
shallows 22oC
Mixing Zone
Hauer and Hill 2006
MiSE, Chapter 5

The 4-dimensional structure of the gravel-bed river.

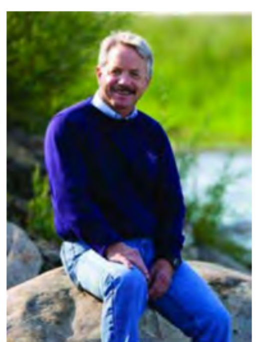


The floodplain landscape is created and maintained by biophysical processes that lead to a complex and dynamic habitat mosaic.

A legacy of cut-and-fill alluviation, characterized by highly sorted open-network cobble substrata with interstitial flow pathways are left behind as the river channel moves laterally on the floodplain surface.

The hyporheic alluvial aquifer, is characterized by river-origin water flowing through the gravel subsurface, from floodplain-edge to floodplain-edge (often valley wall to valley wall).

Hauer et al. 2016. *Science Advances*
[illustration credit: Emily Harrington].



Gravel-bed River Floodplains are the Ecological Nexus of Glaciated Mountain Landscapes

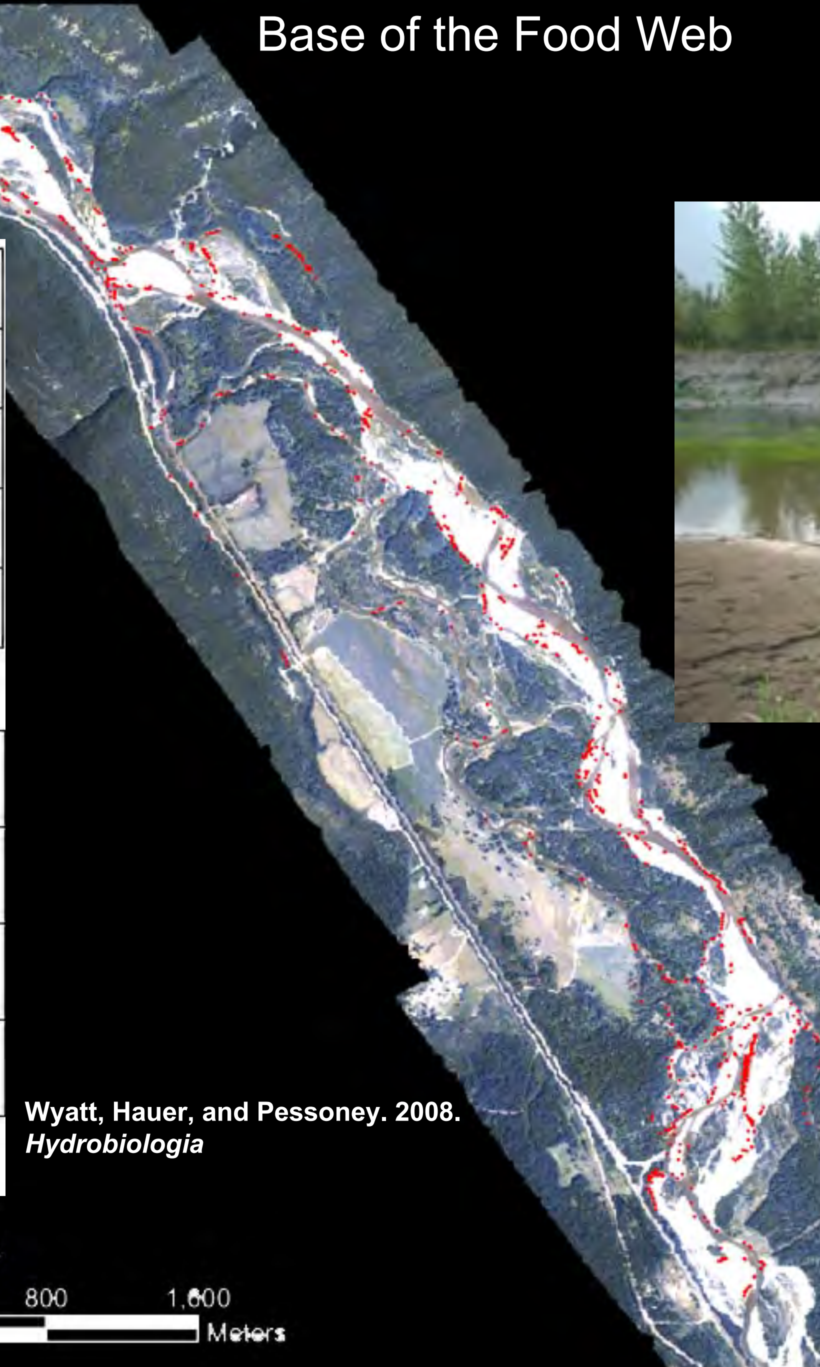
F. Richard Hauer, Harvey Locke, Victoria J. Dreitz, Mark Hebblewhite, Winsor H. Lowe, Clint C. Muhlfeld, Cara R. Nelson, Michael F. Proctor, Stewart B. Rood

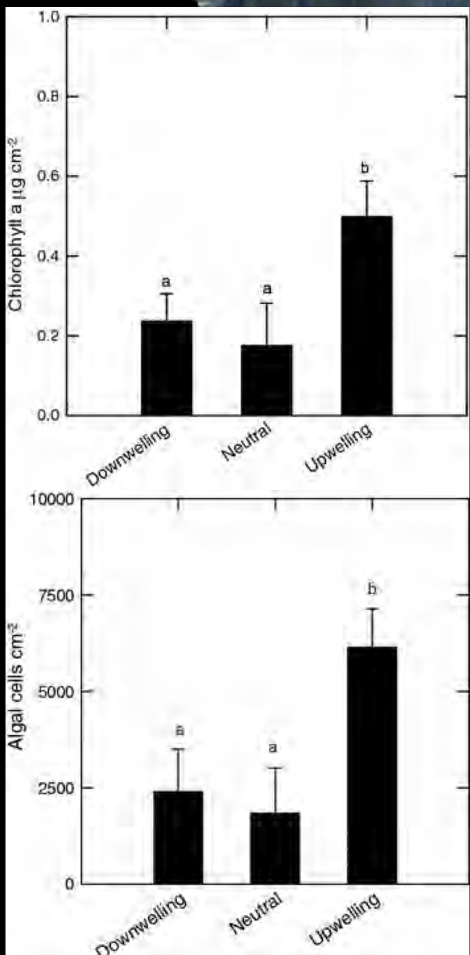
Science Advances:
advances.sciencemag.org/content/2/6/e1600026

Why You Should Care

Gravel-bed river floodplains in mountain landscapes disproportionately concentrate diverse habitats, nutrient cycling, productivity of biota, and species interactions.

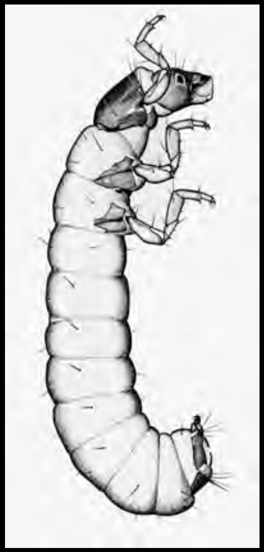
Base of the Food Web



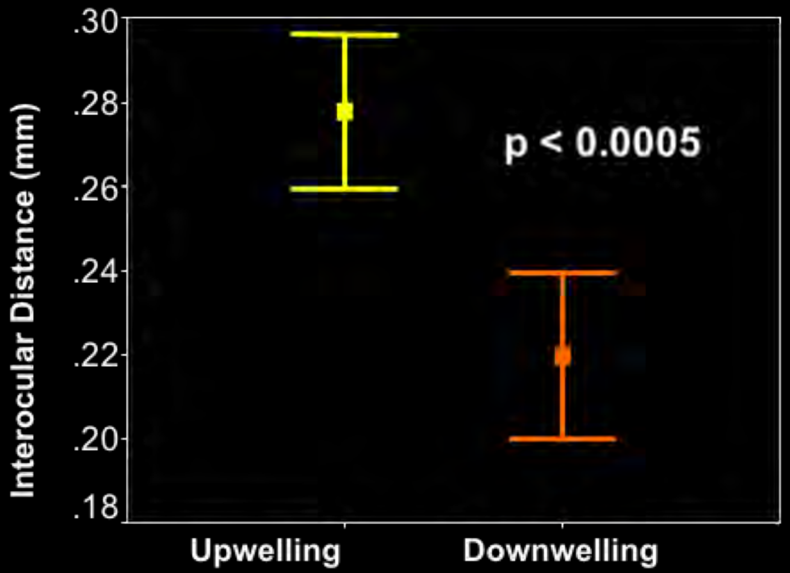


Wyatt, Hauer, and Pessoney. 2008.
Hydrobiologia

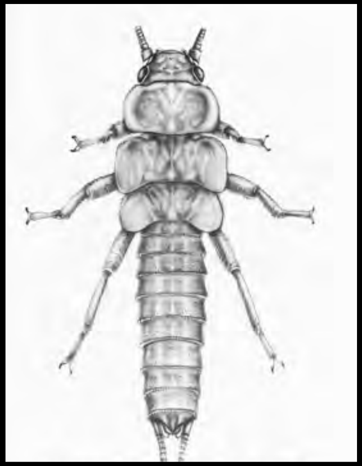
Trophic Dynamics, Growth and Secondary Production



Glossosoma spp.
Size Comparison

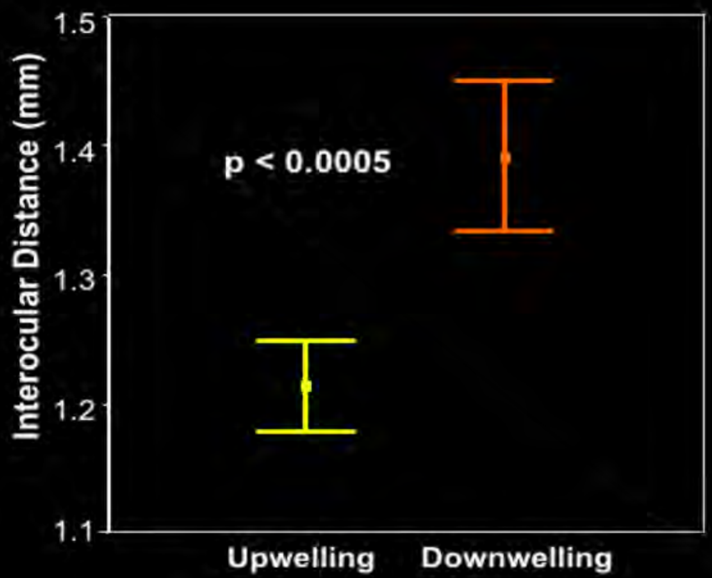


Pepin and Hauer. 2002
JNABS

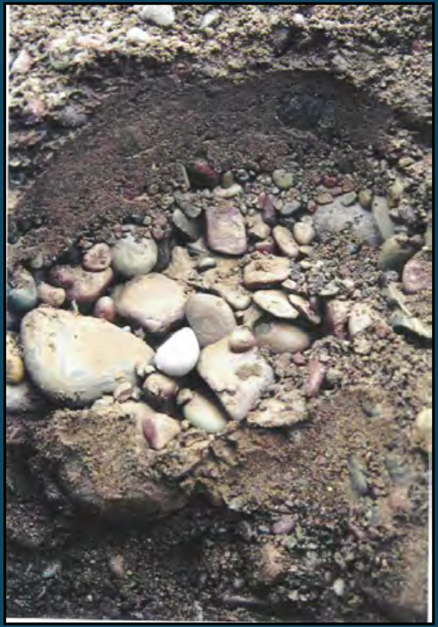


Pteronarcella badia

Size Comparison



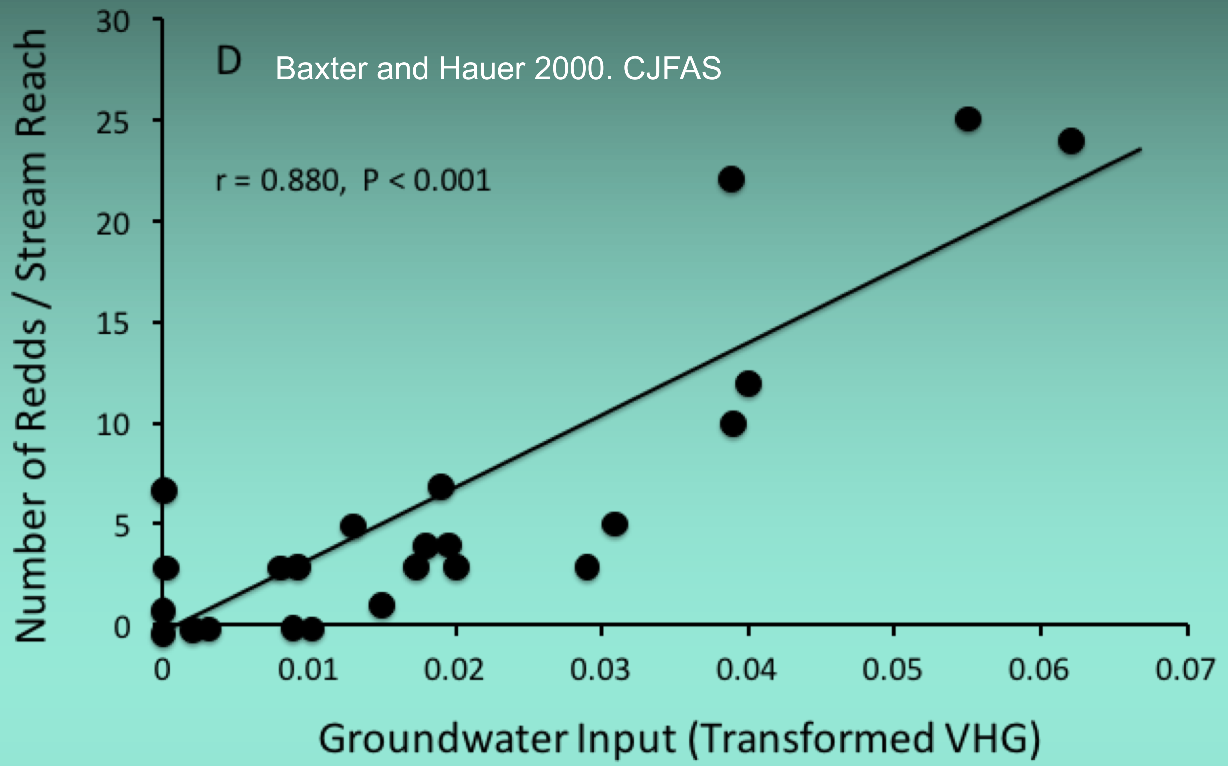
Preferential Flow Path as Habitat



Open – sorted sediments facilitate both high hydraulic conductivity (water flow), but also the movement of hyporheic organisms

Photo: Jack Stanford

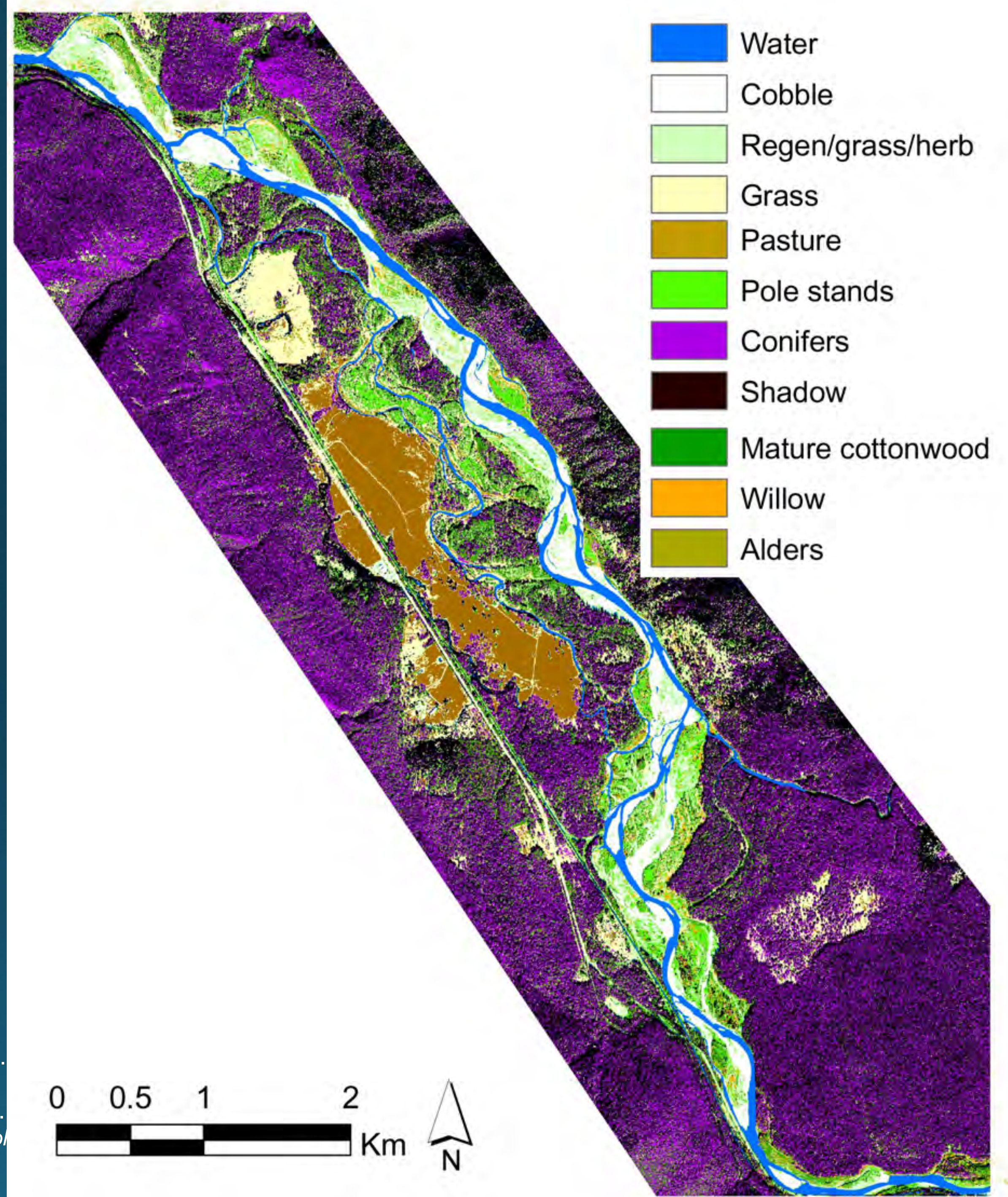
Fish



Bull Trout

Salmonid spawning habitat selection is directly associated with GW/SW interaction

Shifting Habitat Mosaic

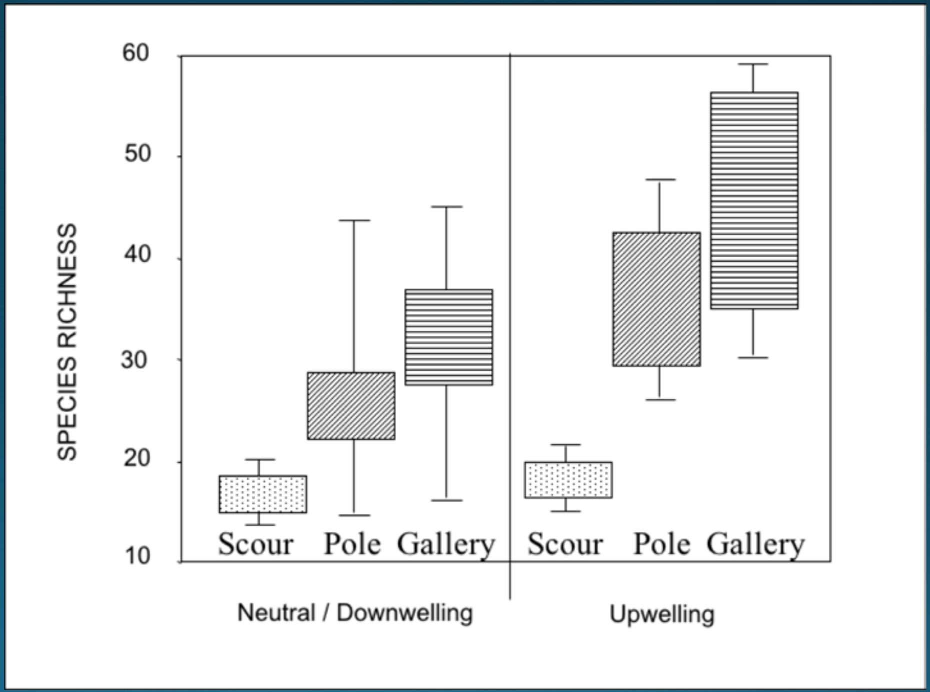


Stanford, Lorang, and Hauer. 2005. The Shifting Habitat Mosaic of River Ecosystems. *Verh. Internat. Verein. Limnol* 29:123-136.

Vegetation Species Diversity

Highest diversity of vegetation regionally is found on floodplains

Especially old-growth gallery forest stands have significantly higher species diversity in up-welling compared to down-welling regions on floodplains.



Mouw and Alabeck 2003. *J. Biogeography*.

BIRDS

Western Montana, Western Alberta and Eastern BC

- 235+ known breeding bird species
  (Montana Bird Distribution Committee 1996)

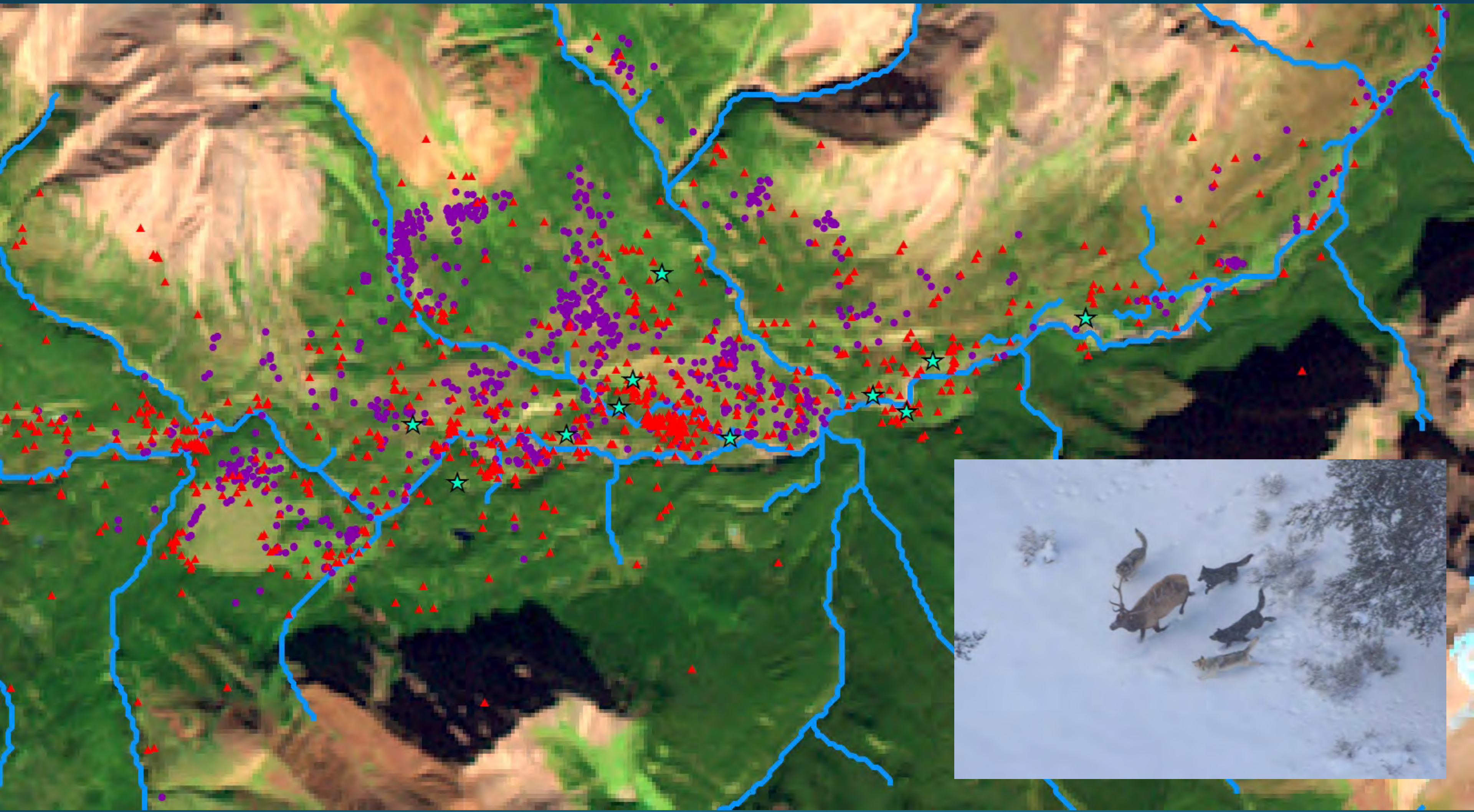
- 90% (210+ species) use floodplain habitat for significant portions of their life histories (Mosconi and Hutto 1982)

- Of these >200 species about 105 species (45% of all bird species) are restricted to floodplain/riparian habitats during the nesting season (Mosconi and Hutto 1982)

Ungulates and Wolves

Mark Hebblewhite and students

Elk – Wolf Interactions

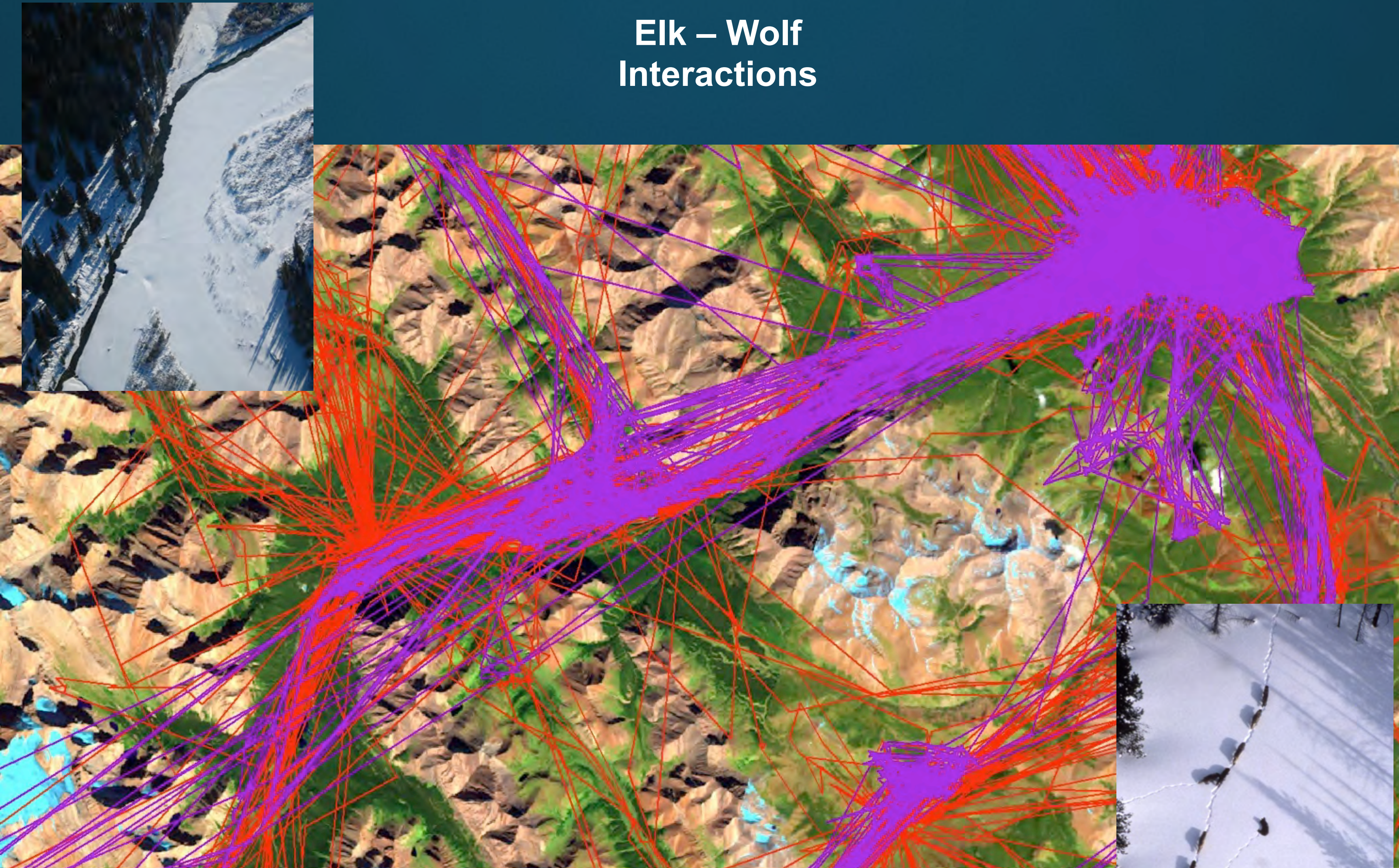


Elk spatial frequency
Wolf spatial frequency

Mark Hebblewhite and students

Hauer et al. 2016. *Science Advances*

Elk – Wolf Interactions



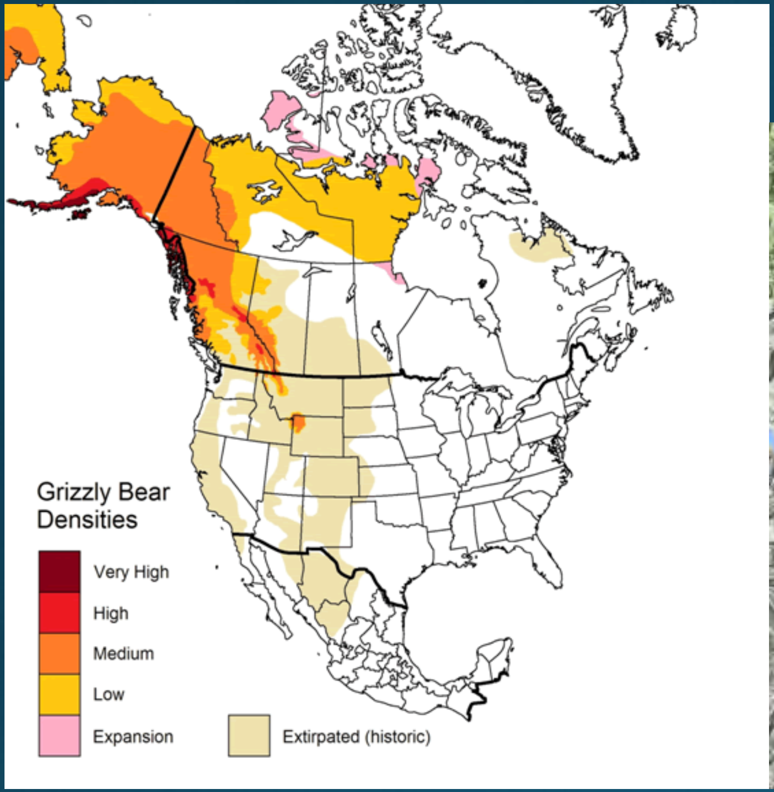
● Elk spatial frequency

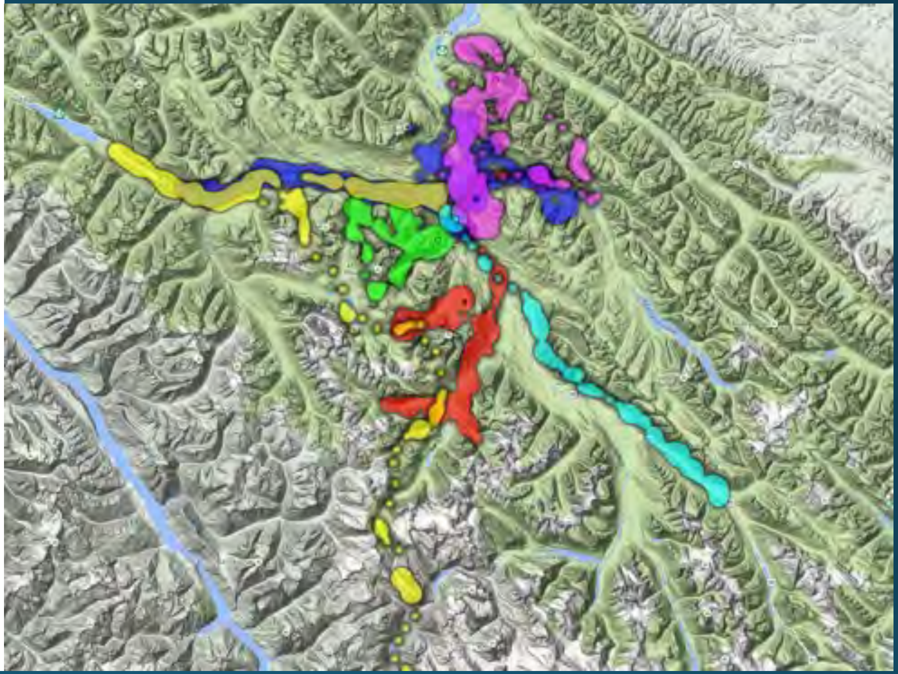
▲ Wolf spatial frequency

Critical Grizzly Bear Habitat

Photo – Peter Mather

Grizzly Bears – a primary user of floodplains



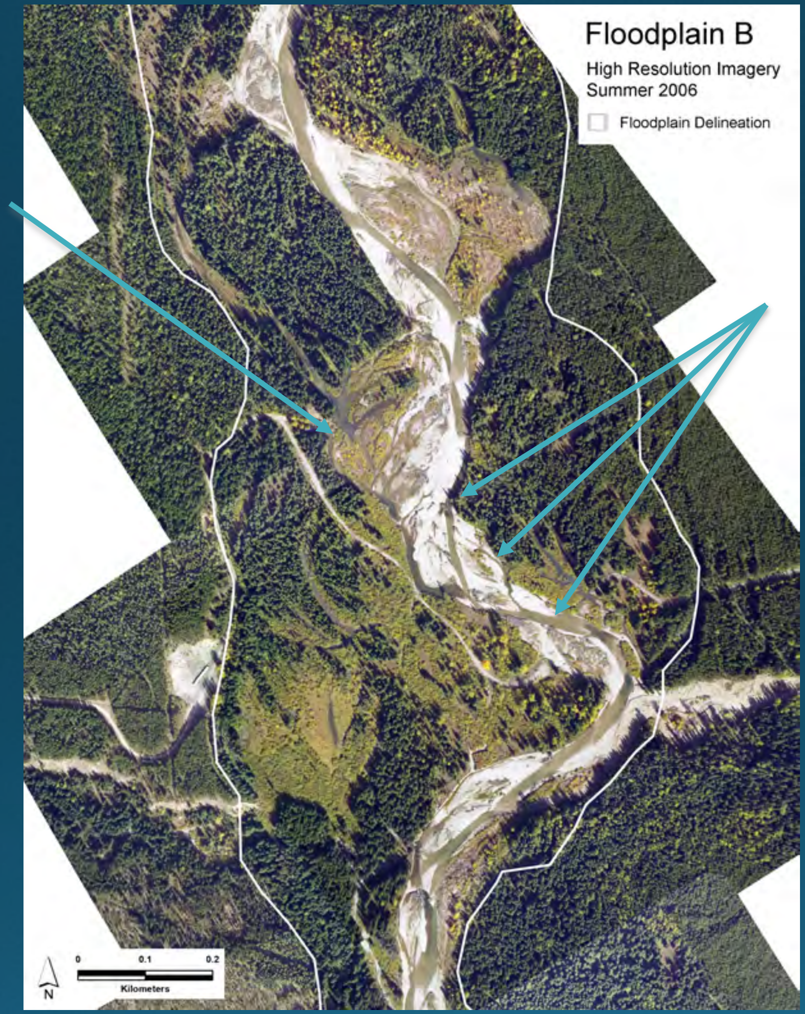


“Heat Map” of six grizzly bear locations over a month

Clayton D. Apps, Bruce N. McLellean, Michael F. Proctor, Gordon B. Stenhouse. (2016). **Predicting spatial variation in grizzly bear abundance to inform conservation.** The Journal of Wildlife Management.

North Fork Flathead River BC

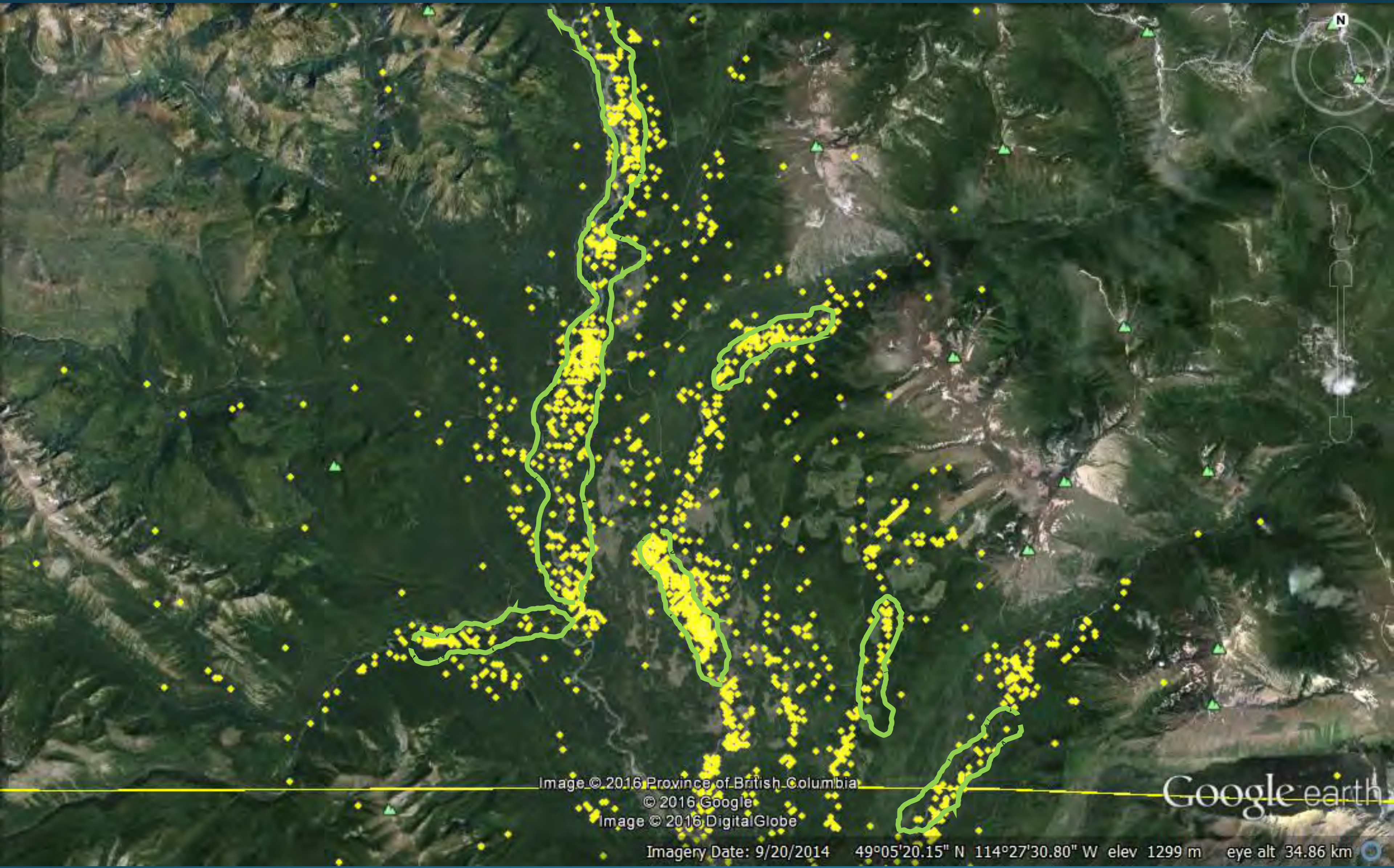
Alluvial Floodplain – Flathead River bull trout spawning reach



Locations of alluvial GW upwelling

Alluvial Floodplain – Flathead River bull trout spawning reach

Grizzly Bear GPS Spatial Frequency Distribution



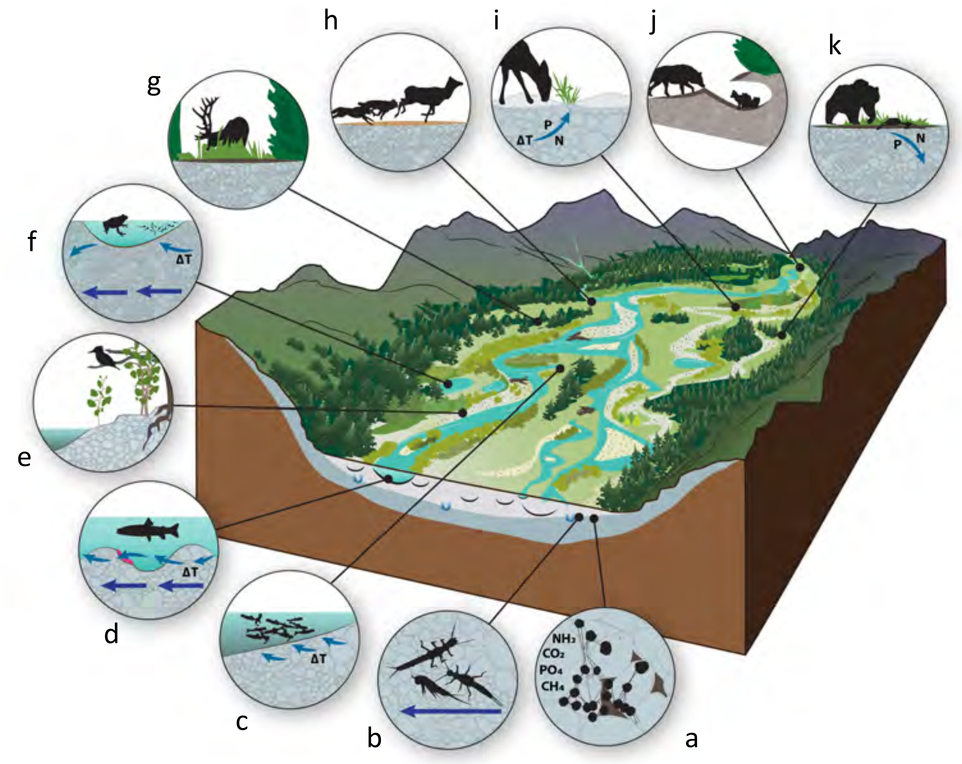
Unpublished Data: Michael Proctor and Bruce McLellan with permission

In a Nutshell

- Although occupying < 3% of the area within the region, gravel-bed river floodplains account for > 60% of vegetation diversity, > 70% of aquatic food web diversity and productivity, >80% of bird diversity
- The primary "arena" where competition, predation, and critical life history events occur for a wide variety of aquatic and terrestrial species, from microbes to grizzly bears.
- Disproportionately concentrate diverse habitats, nutrient cycling, productivity of biota, species interactions, and connectivity corridors between populations

from: Hauer et al 2016 *Science Advances*

WRAP



Hauer et al. 2016. ***Science Advances***
[illustration credit: Emily Harrington].