Fine Sediment Impacts on Stream Ecology

Implications for wildfire-induced sediment loading within the Trinity Watershed

September 13, 2023

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Applied Ecohydraulics

Agenda

1. Background/Credentials
2. What is fine sediment and how is it transported in rivers?
3. What if there is too little or too much sediment in a river?
4. Turbidity and concentration: what is the difference?
5. Suspended sediment exposure-responses in fish
6. Ecological implications from wildfire-induced sediment loading
7. Management-related applications for suspended sediment loading

Background/Credentials

BSc. Civil and Environmental Engineering – University of Alberta

"How do we predict impacts to the environment from civil development? How do we mitigate its risk?"

MSc. Water Resources Engineering – University of Alberta

"How can we improve the development of remote aquatic habitat compensation projects to enhance ecological productivity?"

- Canadian Journal of Civil Engineering – 3 articles
- North American Journal of Fisheries Management – 1 article
- Transactions of the American Fisheries Society – 1 article
- Nationally recognized for best paper in environmental engineering (2014)

Background/Credentials

PhD Civil Engineering – University of British Columbia

"How can we improve environmental and economic outcomes from suspended sediment releases resulting from in-river construction activities?"

- River Research and Applications – 1 article
- Science of the Total Environment – 2 articles
- Developed statistical risk assessment methods for suspended sediment exposures on fish

Assistance with life history ecology models

- Bioenergetics derivation of growth models for an inland recreational fishery
- Cahill et al., 2020. A spatial-temporal approach to modeling somatic growth across inland recreational fisheries landscapes. Canadian Journal of Fisheries and Aquatic Sciences.

Background/Credentials

2013 Southern Alberta Floods - Lead River Engineer

- Over 40 flood response and planning projects in Southern Alberta
- Stream restoration, bank stabilization, triaging emergency response, technical advice and representation for municipal and non-profit organizations
- Large-scale aquatic and riparian habitat compensation projects

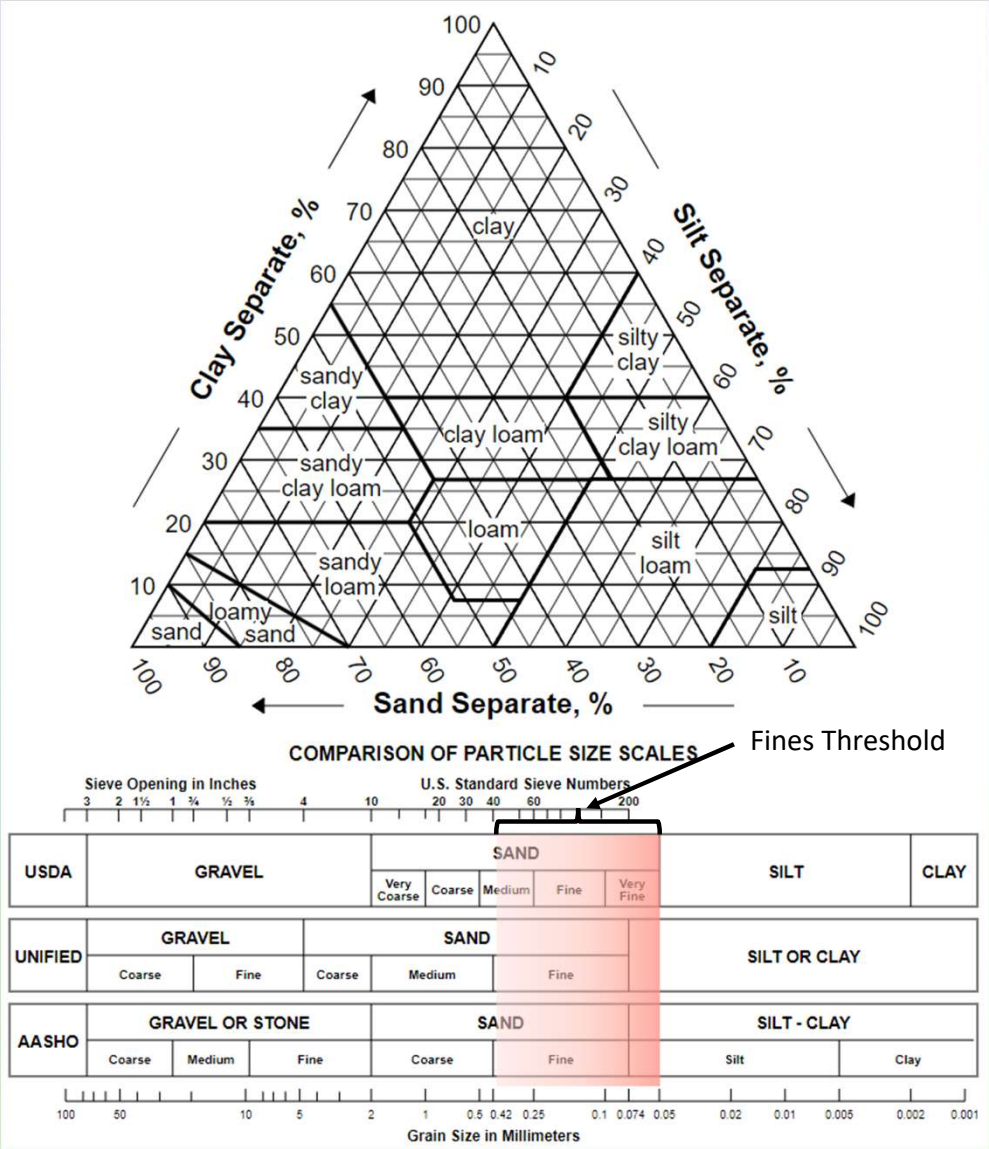
Certified Inspector of Erosion and Sediment Control

- CAN-CISEC #0881

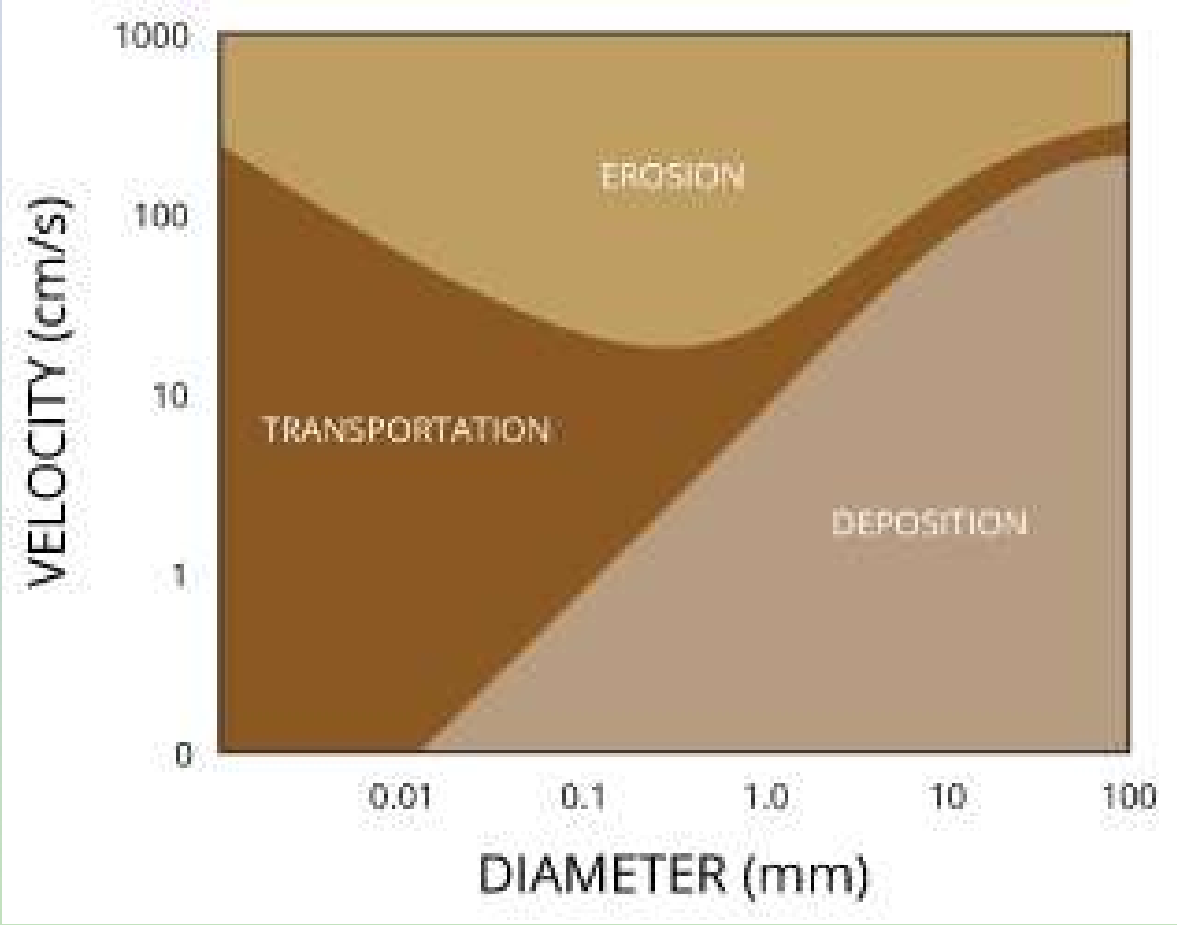
Influence on Regulatory Policy

- Cited in Fisheries and Oceans Canada “Pathways of Effects” for in-river construction
- Suspended sediment management advisor to the City of Calgary on several large-scale river gravel management projects
- “Duration-based” suspended sediment management framework for in-river construction projects: **approved by regulatory agencies**

What is fine sediment?



How does fine sediment move through a watershed?

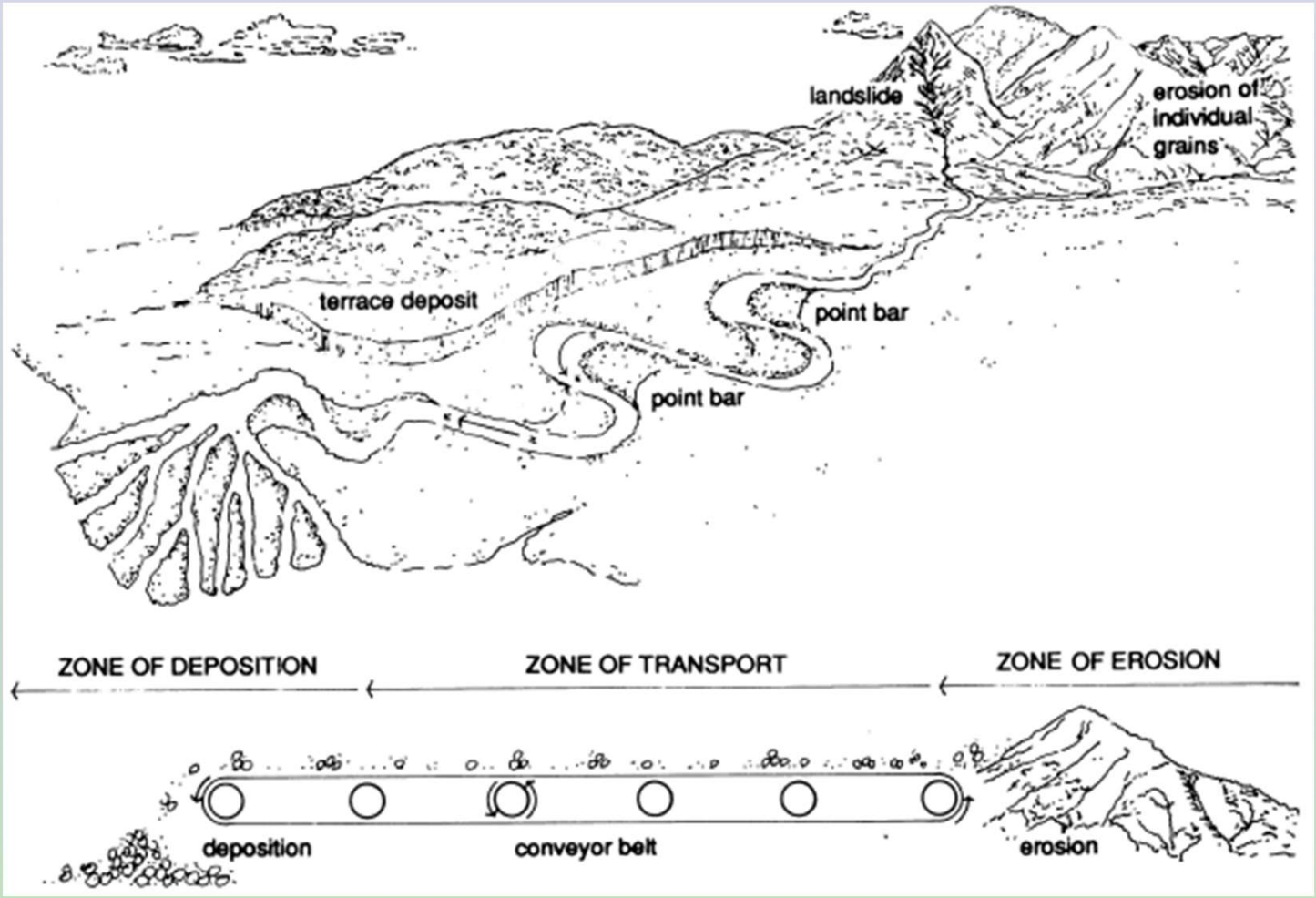


Fondriest Environmental, Inc. "Sediment Transport and Deposition." Fundamentals of Environmental Measurements. 5 Dec. 2014.

Erosion

Transportation

Deposition

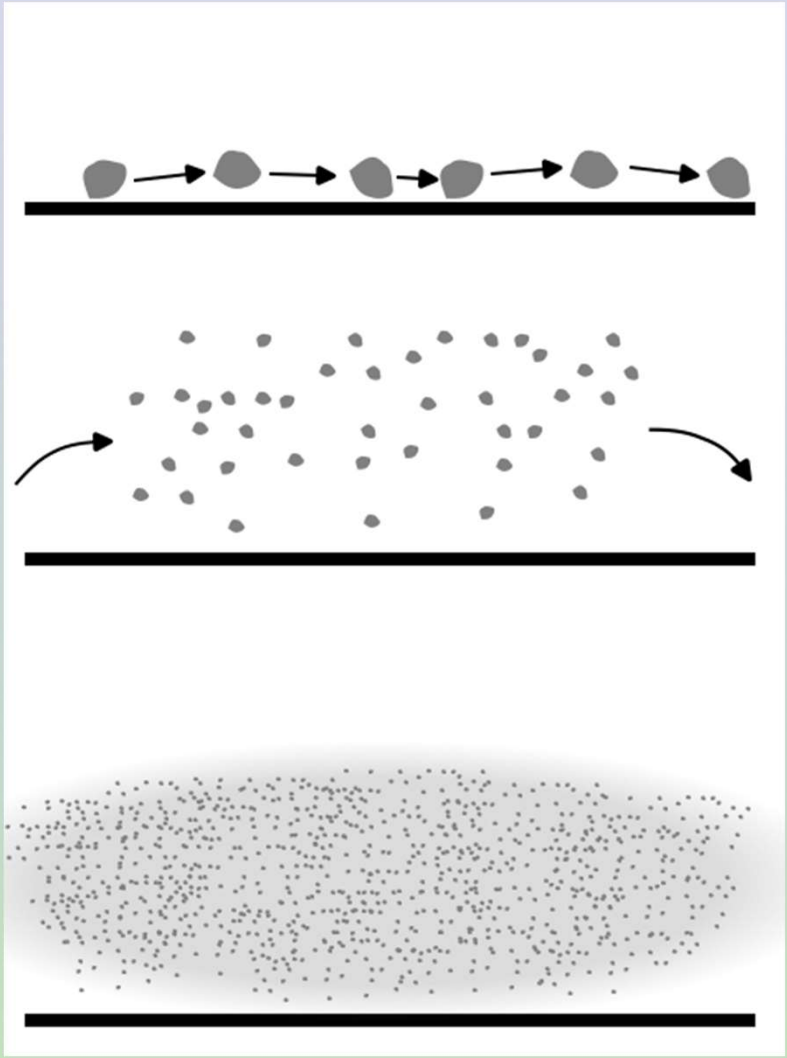


Kondolf, G. M. 1994. Geomorphic and environmental effects of instream gravel mining. Landscape and Urban Planning 28:225–243.

Bed Load

Suspended Load

Wash Load



What happens when there is too little sediment?

- Channel armoring
- Changes to ground-surface water interaction
- Impacts to suitable spawning substrate and egg incubation
- Impacts to invertebrate habitat

Well Graded

Armored

https://blogs.scientificamerican.com/observations/the-fly-larva-that-thinks-it-s-a-stonemason/

Turbidity vs Suspended Sediment Concentration (SSC)

Turbidity

- Measured as “cloudiness” of water
- Nephelometric turbidity units (NTU)
- Qualitative measurement

Effects related to turbidity:

- Reduction in aquatic plant photosynthesis
- Impacts to predator/prey dynamics

SSC

- Measured as total suspended solid
- Milligrams per liter (mg/L)
- Quantitative measurement

Effects related to concentration:

- Fish physiological/lethal responses
- Habitat degradation (river hydraulics dependent)

Turbidity vs Suspended Sediment Concentration (SSC)

Turbidity

- Can be directly measured in the field using a nephelometer or other types of turbidity meters

SSC

- Cannot be easily measured in the field
- Require methods such as vacuum filtration

Turbidity can be used to estimate concentration by first establishing a (site specific) relationship between turbidity to concentration

Why should we make a distinction between turbidity and SSC?

Ping Pong Balls

Golf Balls

Each system has unique sediment mineralogy with unique light-scattering characteristics

Suspended Sediment (SS) Exposure-Response

Behavioural

- Alarm reaction
- Avoidance
- Feeding reduction
- Predator/prey dynamics impact

Physiological/Lethal

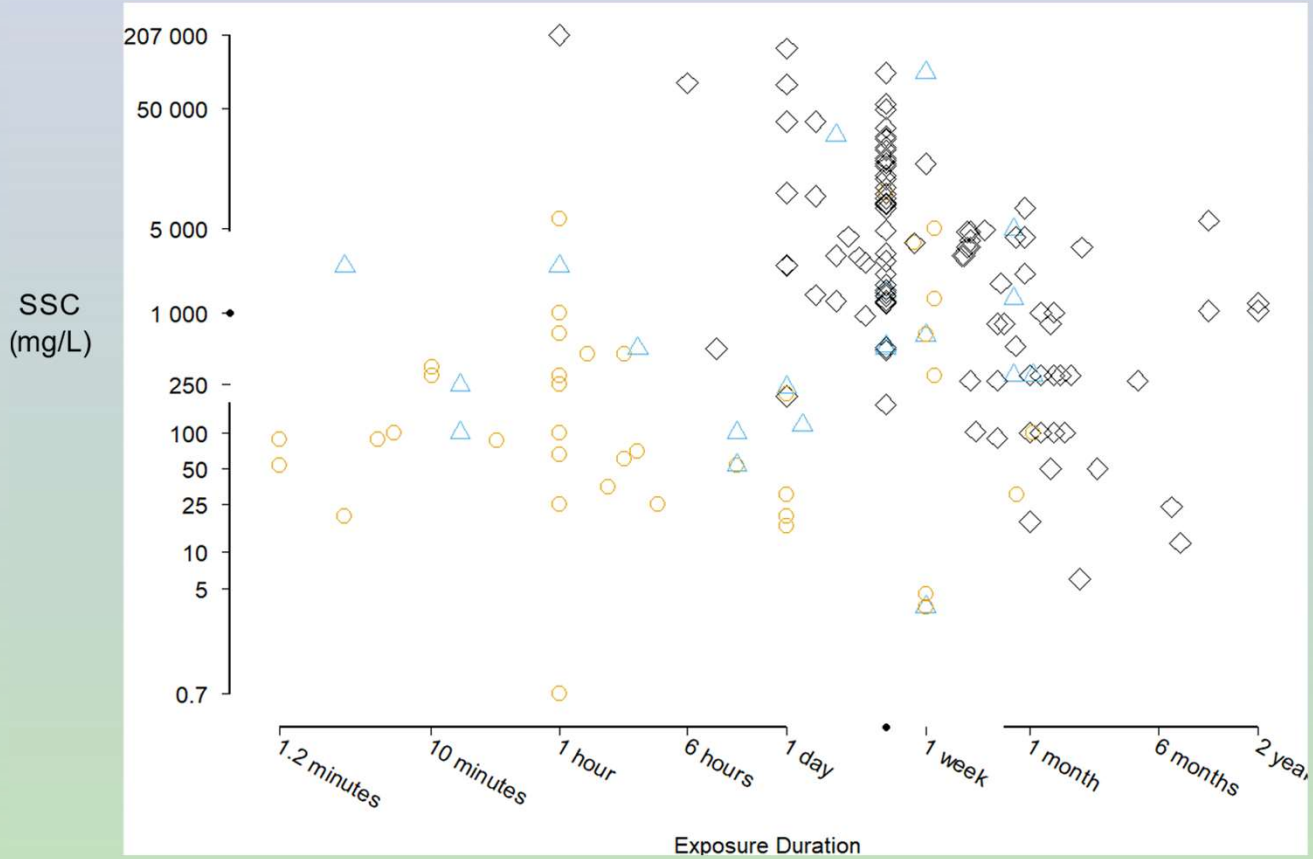
- Coughing
- Increased blood glucose and cortisol (stress)
- Gill tissue damage
- Reduced growth rate
- Mortality

Habitat Degradation

- Change in substrate composition
- Egg incubation impacts
- Highly dependent on river hydraulics

Does not include adverse effects derived from contaminated soils (varies widely)

Salmonid Exposure-Response Observations



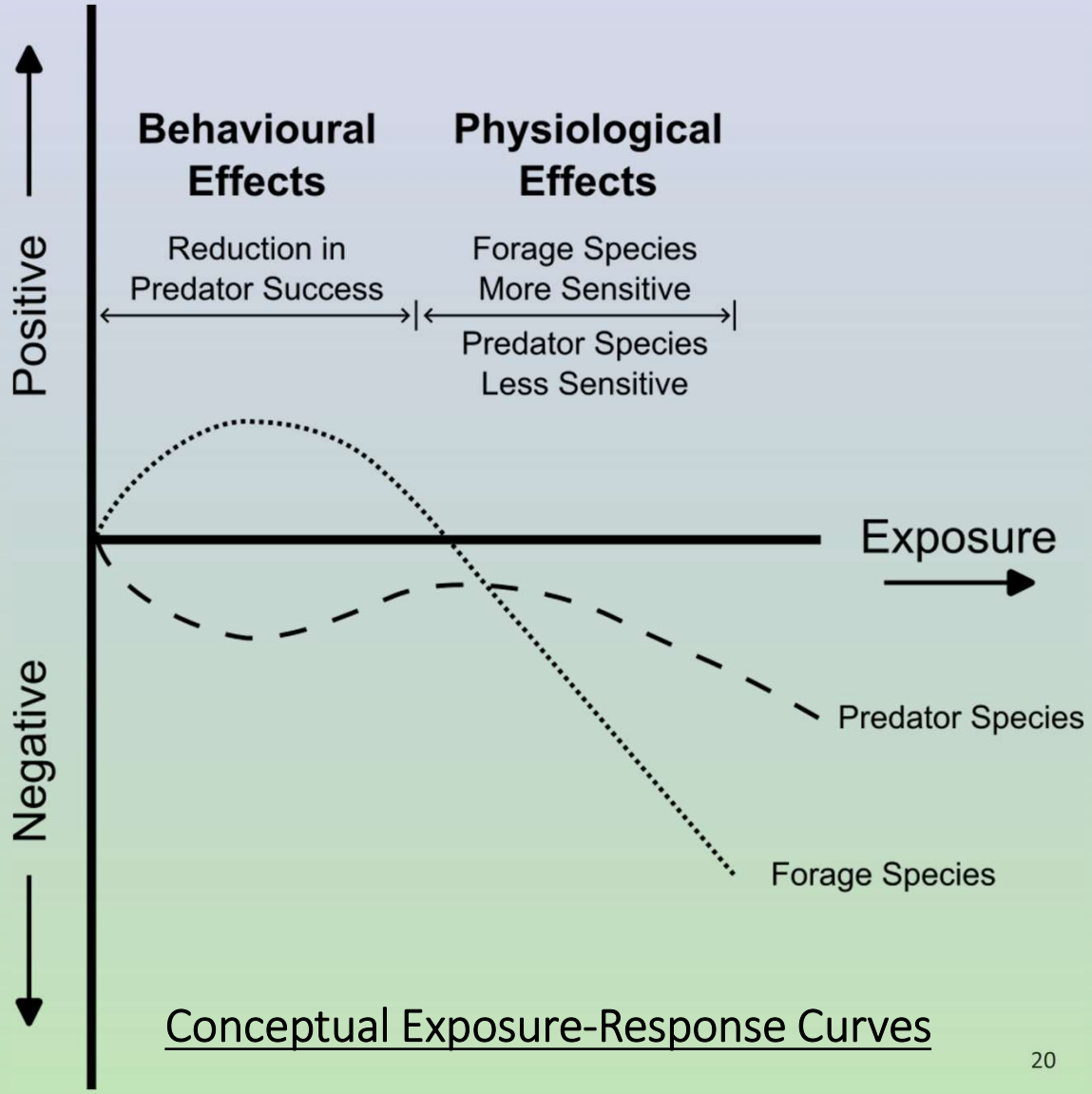
Circles:
Behavioral

Triangles:
Minor Physiological

Diamonds:
Major Physiological and Lethal

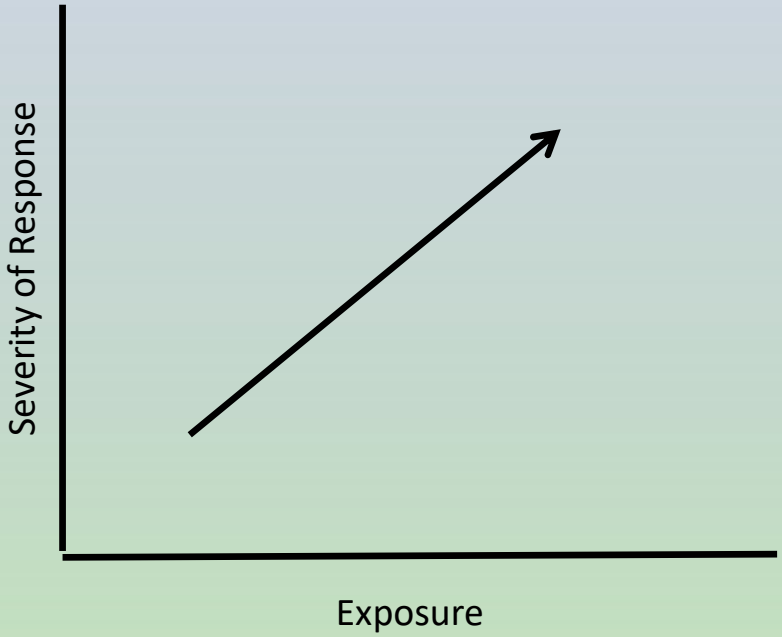
Courtice, G, et al., 2022. A categorical assessment of dose-response dynamics for managing suspended sediment effects on salmonids. Science of the Total Environment. 807(1).

A nuanced assessment…

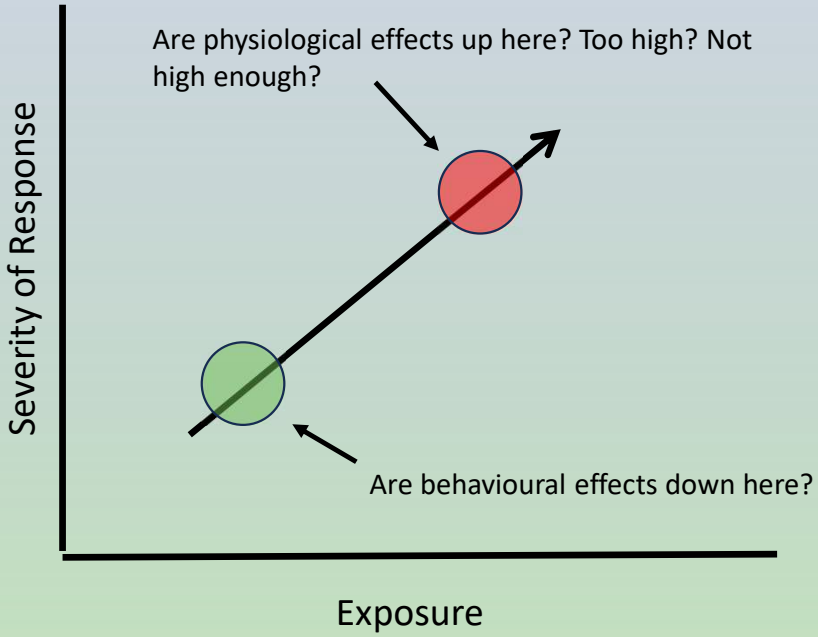


Conceptual Exposure-Response Curves

How do we explain SS exposure-response?



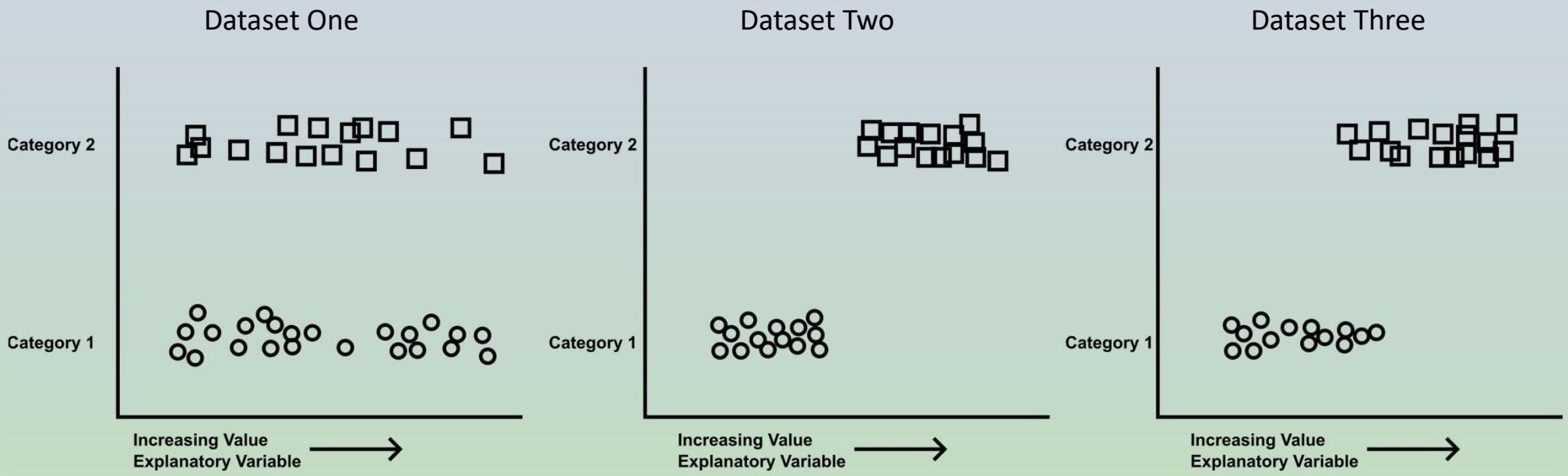
How do we explain SS exposure-response?



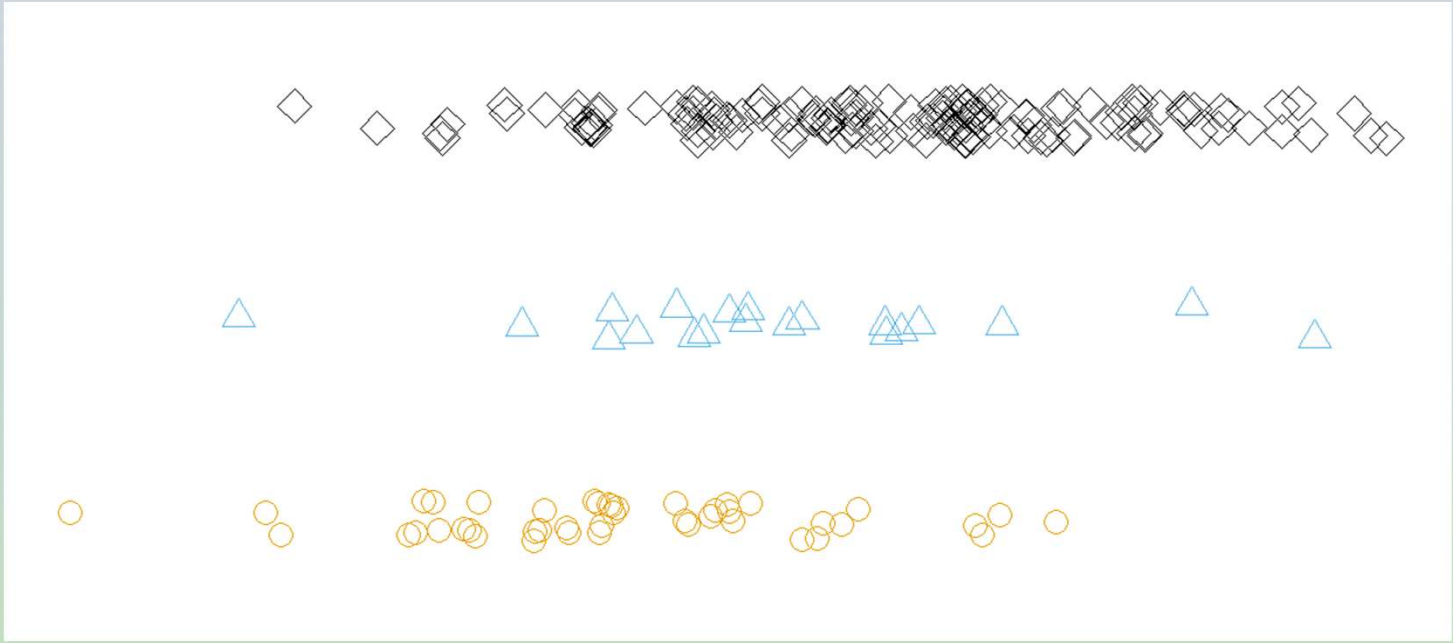
How much more severe is one effect from another?

We need to work with categorical responses.

How do we assess categorical responses?

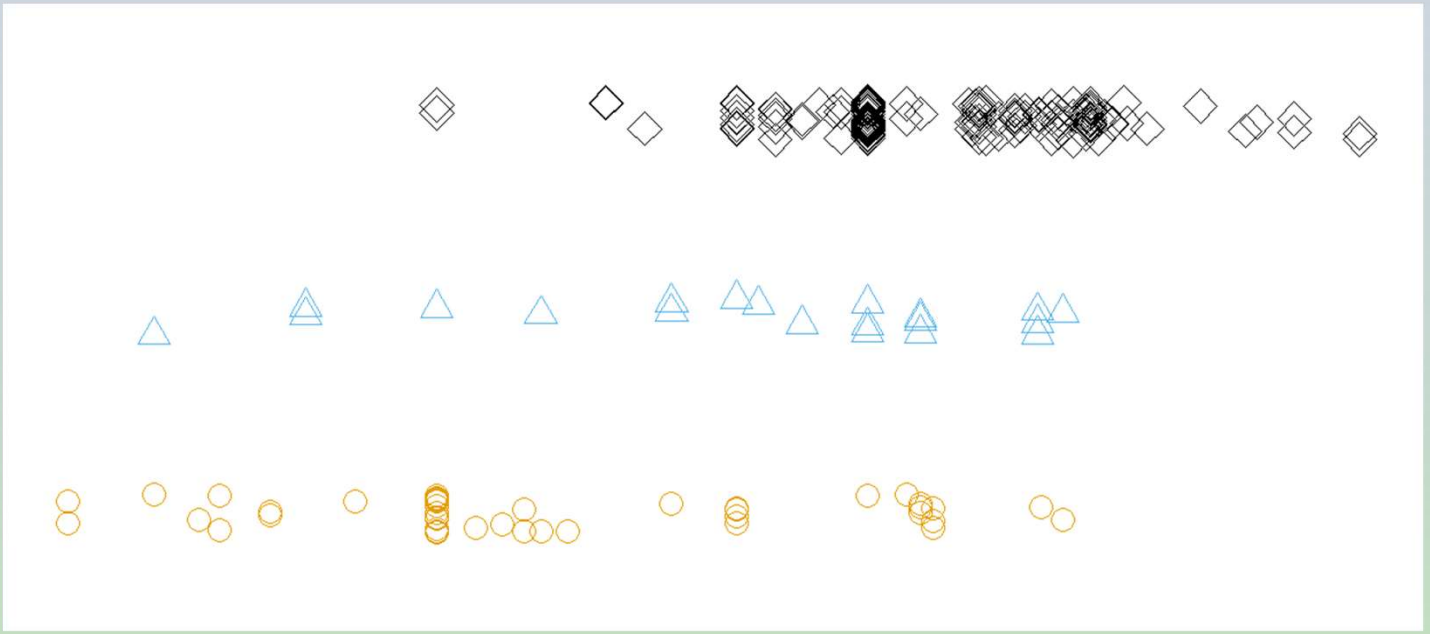


Classifying Exposure-Response Observations



What explanatory variable is being used to order the observations?
Is it providing a clear distinction of the response categories?

Classifying Exposure-Response Observations



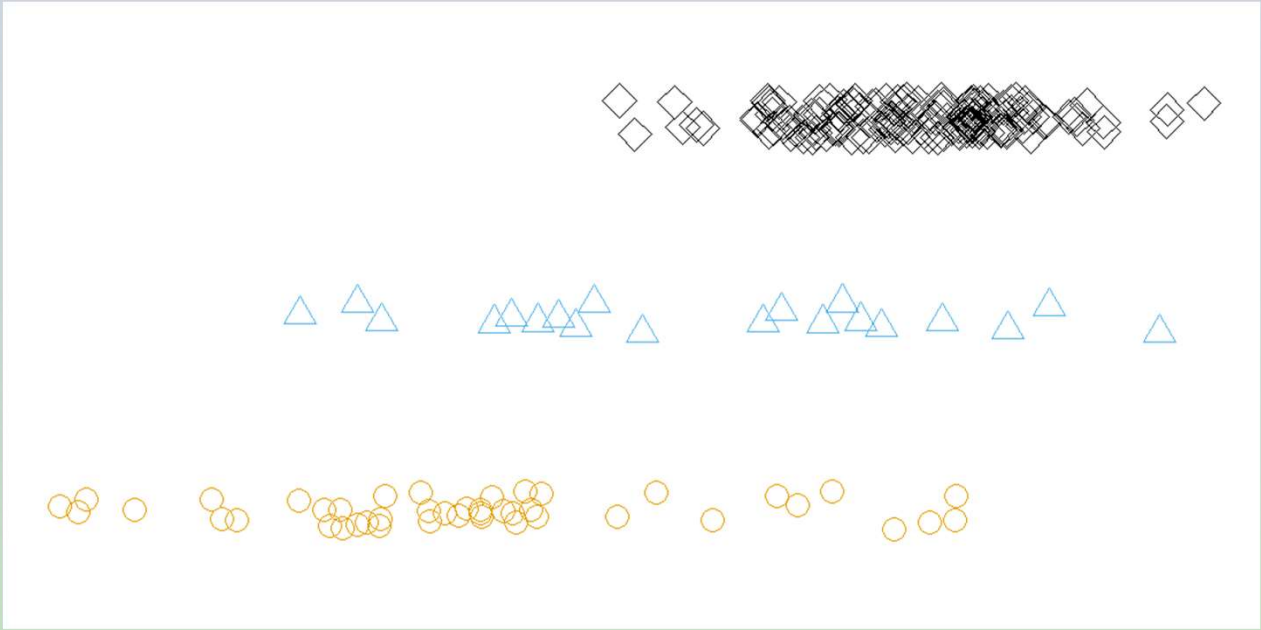
What explanatory variable is being used to order the observations?
Is it providing a clear distinction of the response categories?

Classifying Exposure-Response Observations

Lethal and
Major Physiological

Minor Physiological

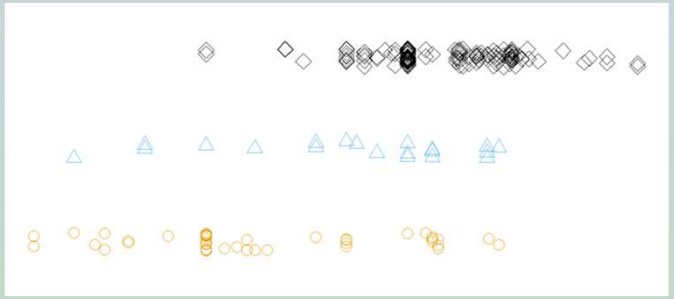
Behavioral



What explanatory variable is being used to order the observations?
Is it providing a clear distinction of the response categories?

Classifying Exposure-Response Observations

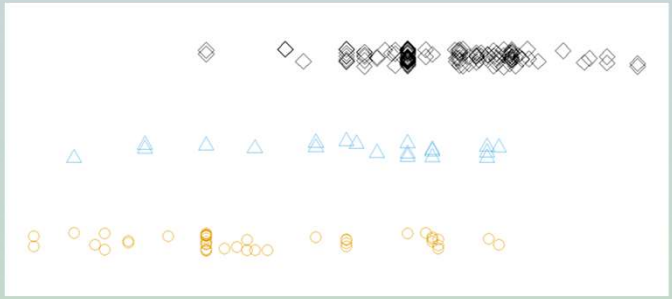
Can we rank them worst (1) to best (3)?



Classifying Exposure-Response Observations

Can we rank them worst (1) to best (3)?

1



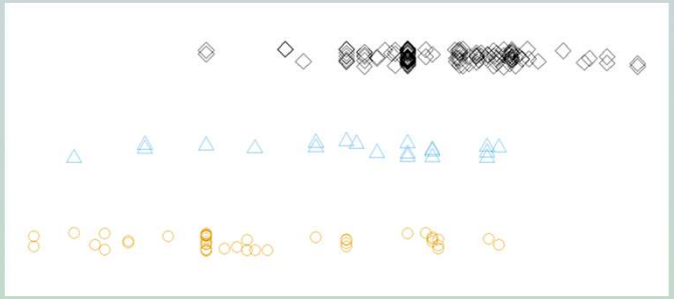
2

3

Classifying Exposure-Response Observations

Can we rank them worst (1) to best (3)?

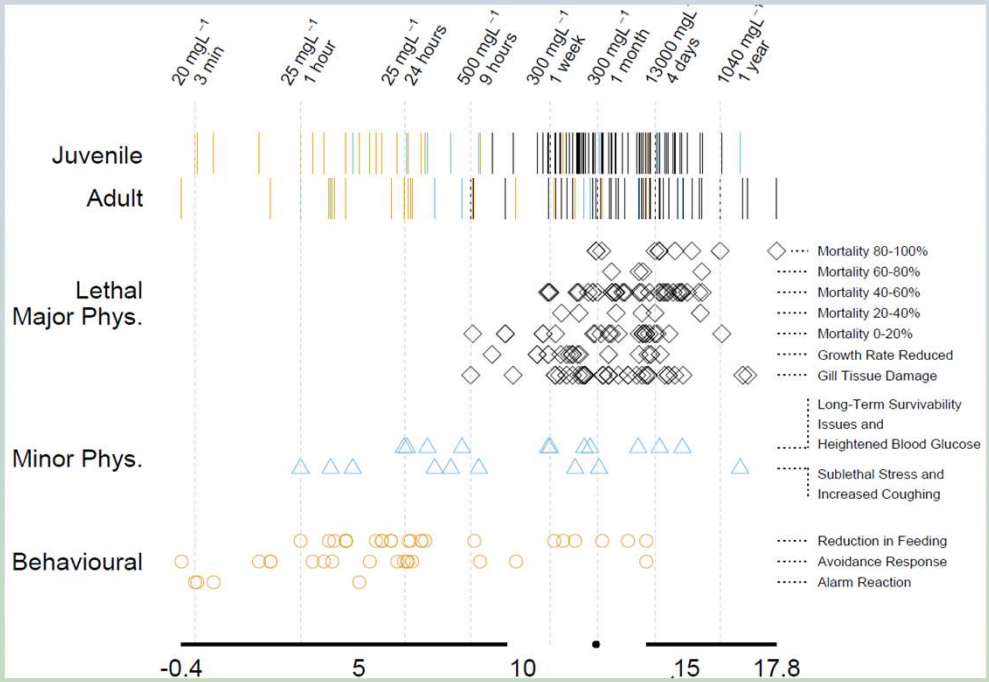
SS Concentration
(SSC)



Duration of Exposure
(DoE)

SS Dose
(SSD = SSC x DoE)

Classifying Exposure-Response Observations



Natural Logarithm of SSD

Courtice, G, et al., 2022. A categorical assessment of dose-response dynamics for managing suspended sediment effects on salmonids. Science of the Total Environment. 807(1).

Ecological implications from wildfire-induced sediment loading

Reduced vegetation and combustion of soils lead to

- Water-repellent soils
- Decreased hillslope roughness
- Reduce soil permeability
- Increase readily-erodible soils

For a given precipitation event:

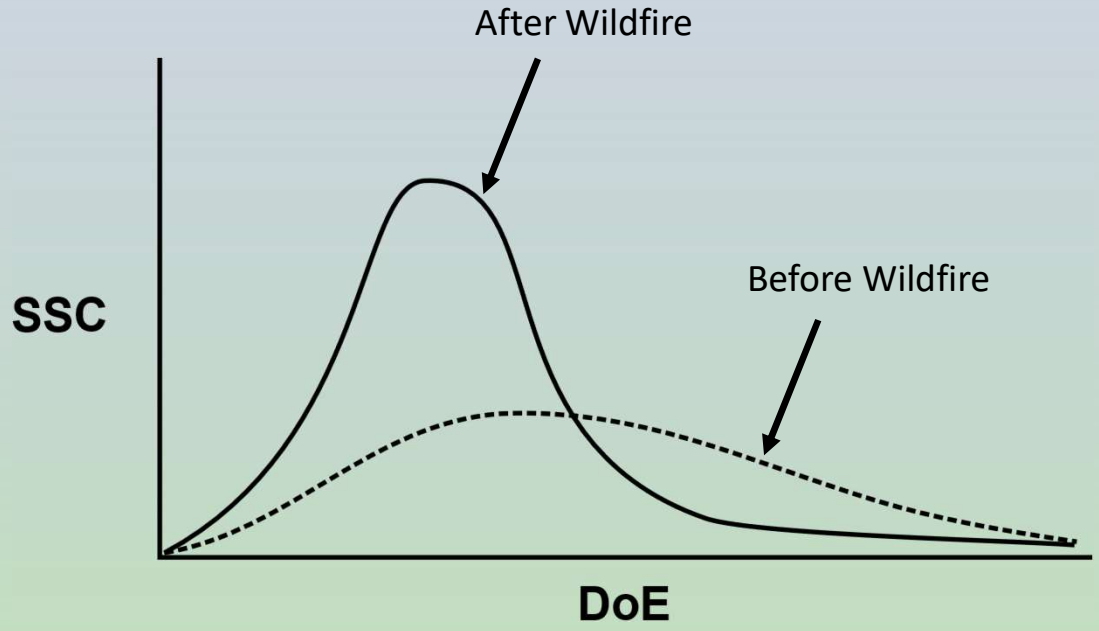
- More sediment in the water
- More water in the river

Storm events following wildfires can <u>increase sediment transport by two orders of magnitude.</u>

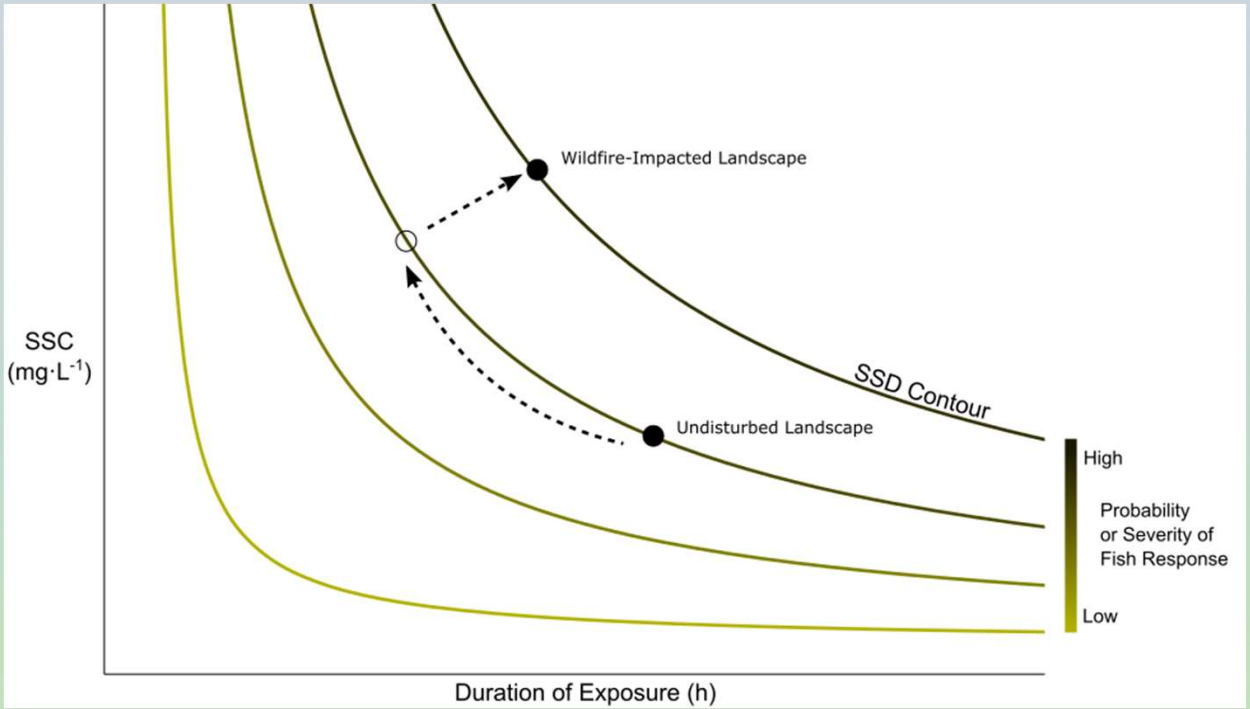
Recent publication:
Jumps, N., Gray, A.B., Guilinger, J.J., and Cowger, W.C. (2022). Wildfire impacts on the persistent suspended sediment dynamics of the Ventura River, California. Journal of Hydrology: Regional Studies.

Ecological implications from wildfire-induced sediment loading

- Ecological responses aren't just about intensity
- How do both concentration and duration play a role?
- Wildfire landscapes may lead to more intense but shorter duration runoff events that have greater sediment loading



How can a change in sediment loading characteristics impact responses?



SSD: Suspended Sediment Dose

SSD = SSC x DoE

Quicker, more intense event:

- Moves along contour to upper left (similar risk)

Increased sediment loading:

- Jumps across contours (increased risk)

How can a change in sediment loading characteristics impact responses?

Circles: Behavioral

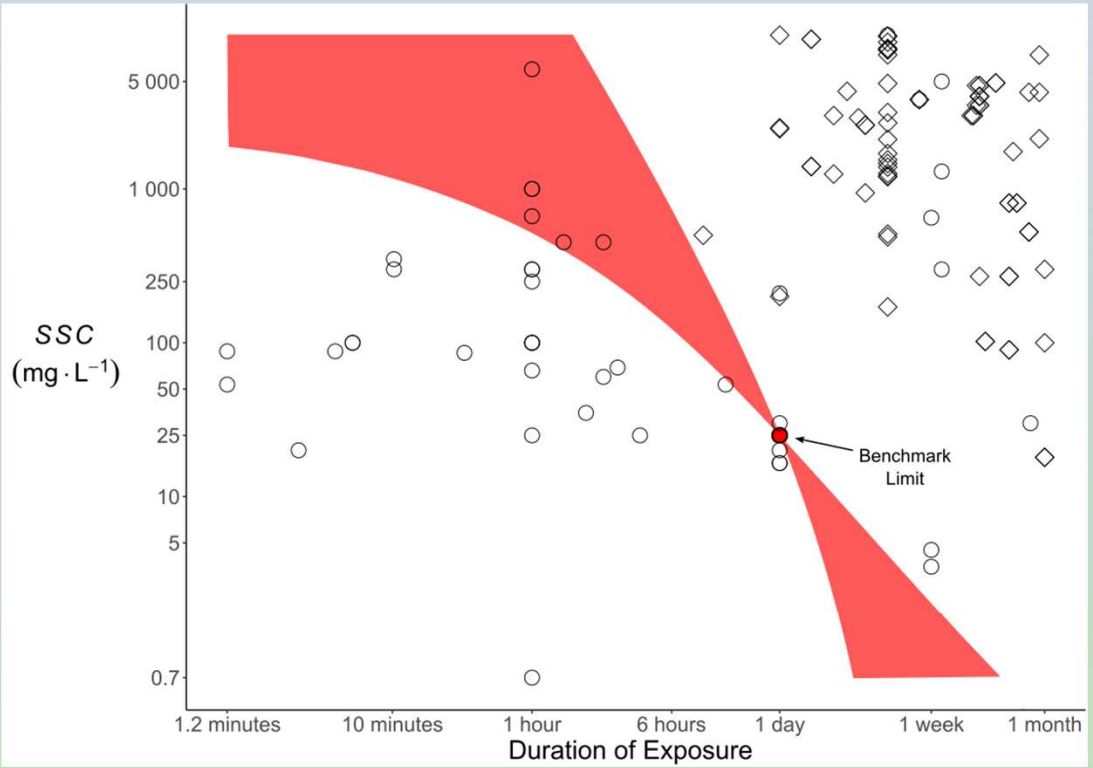
Diamonds: Major Phys. and Lethal

Benchmark limit

- Risk tolerance used in Canada and elsewhere
- 25 mg/L over 24 hours

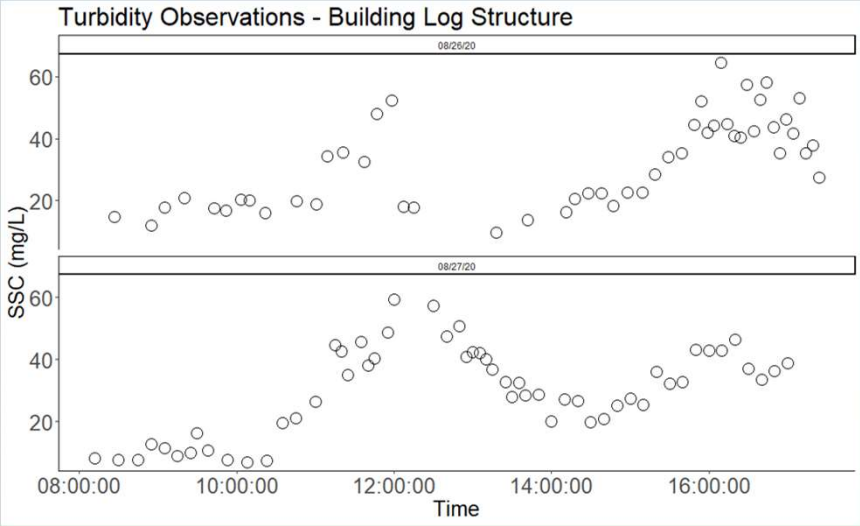
Red shaded region

- 90% chance similar risk present to benchmark limit, given data



Courtice, G. et al., 2022. Suspended sediment releases in rivers: Toward establishing a safe sediment dose for construction projects. Science of the Total Environment. 848.

Example with Trinity River Construction Data



Date	Activity	Ave SSC (mg/L)	Exposure Duration (h)
August 26, 2020	Building Log Structure	32	8.95
August 27, 2020	Building Log Structure	30	8.80

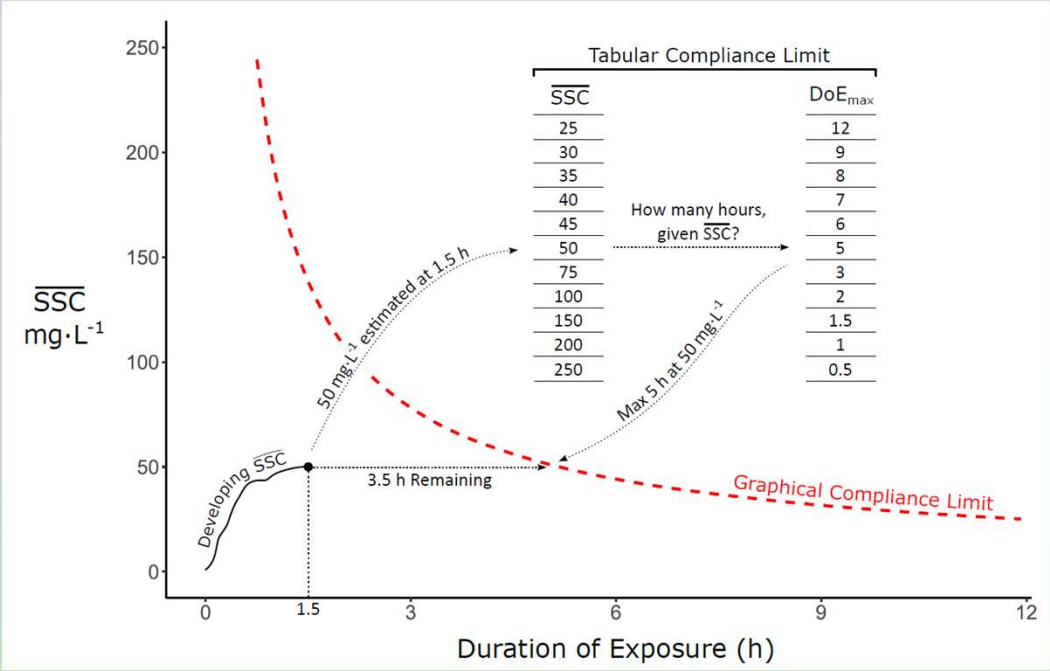
Function developed in R to compare exposure risk…

How do we use Suspended Sediment Dose for management applications?

Duration-Based Management

"Given monitored concentration, how many hours can we work in the day?"

1) Set SSD limit (300 used in the figure)
2) Use monitoring data to estimate average SSC ($\overline{SSC}$)
3) Max daily duration of exposure, DoE_{max} = SSD/ $\overline{SSC}$



Courtice, G. and Bauer B. *(in review).* Balancing environmental and economic objectives for in-stream construction projects: A case study on sediment management. Journal of Water Resources Planning and Management.

Gravel Berm Construction: April 4, 2022

SS Management Strategy: **Prioritize *SSC***

Total volume of gravel placed: **650 m^3**
Mean SS concentration: **36.2 mg/L**
Duration of exposure: **6.75 h**

Gravel Berm Construction: April 5, 2022

SS Management Strategy: **Prioritize Efficiency**

Daily volume of gravel placed: **1800 m^3**
Mean SS concentration: **67.5 mg/L**
Duration of exposure: **3.25 h**

Which approach was better?

April 4, 2022

- Prioritized managing SSC
- Longer release
- Less intense
- Less work completed

April 5, 2022

- Prioritized efficient construction
- Shorter release
- More intense
- More work completed

The second day increased productivity by ~500% (an economic benefit).

The second day also had less sediment loading (an environmental benefit).

How do these two days really compare?

Date	Activity	Ave SSC (mg/L)	Exposure Duration (h)	Gravel Placed (m^3)
August 26, 2020	Gravel Berm	36.2	6.75	650
August 27, 2020	Gravel Berm	67.5	3.25	1800

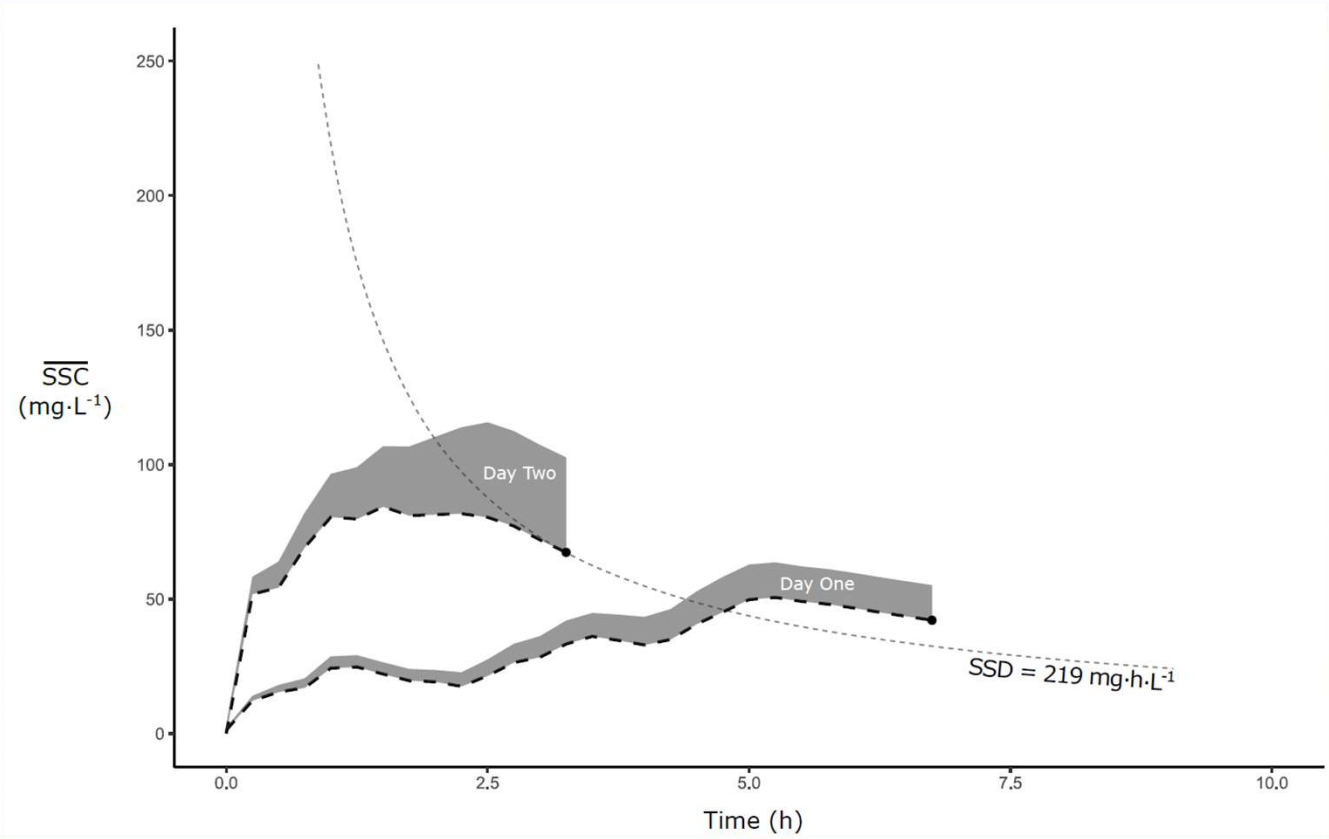
Let's take a look at the risk comparison function…

Graphical Summary of Results

Dashed line is the trend of average SSC over time

Shaded ribbon is the relative amount of gravel placed over time

Dotted curve represents SSD and equivalent sediment loading



Courtice, G. and Bauer B. *(in review).* Balancing environmental and economic objectives for in-stream construction projects: A case study on sediment management. Journal of Water Resources Planning and Management.

Prioritizing efficiency, facilitated by duration-based management, led to improved economic and environmental outcomes

Conclusions

- Sediment is an important component of fluvial systems and their ecology, but too much can be harmful
- Concentration on its own is not a reliable indicator of ecological effects
- Wildfire-induced impacts to sediment loading may increase ecological risk
  - Due to overall sediment loading, increased intensity may not be a risk factor

Conclusions

- Need to consider both concentration and duration in risk assessments

- Past construction-induced sediment releases likely fall within a relatively low risk tolerance
  - Relaxing concentration to allow for more efficient construction may be valuable to consider from both economic and environmental perspectives

Recommendations

- Inferences on ecological risk are taken from averages
- It would be valuable to study system-specific ecological sensitivities

"What is an acceptable threshold for this system?"

- Findings from such studies can help inform strategic management objectives

"What objectives will target the most sensitive parts of the ecosystem, and where do we have more resilience?"

Thank You!

Applied Ecohydraulics

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