Rainbow Trout bioenergetics as a method to evaluate ecological risk of diversion rates

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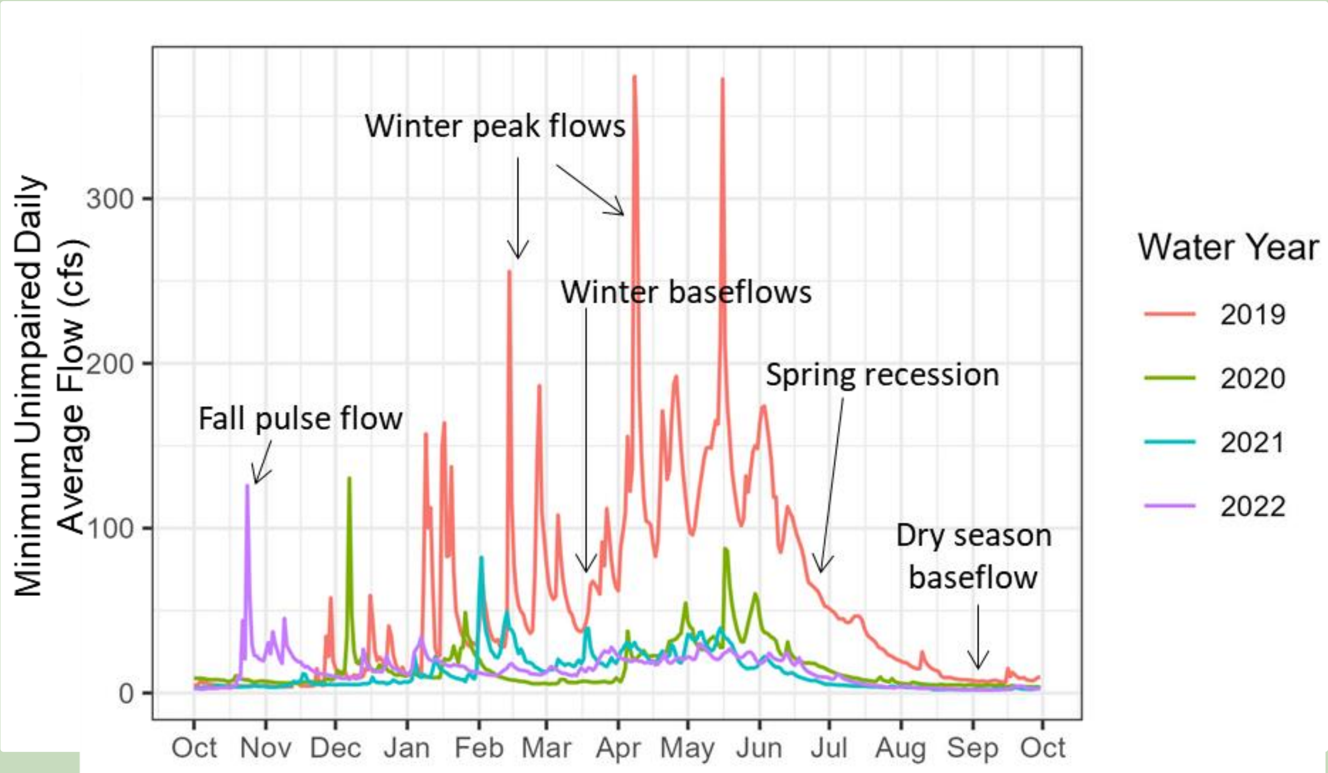
The natural flow regime

- “Flow regime is of **central importance** in sustaining the ecological integrity of flowing water systems”-Poff et al 1997
- Underlying principle: let the natural flow regime guide our instream flow assessments



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Two approaches to assessing instream flows

Bottom up:

- Every drop of water is justified for an ecological or geomorphic need
- *“How much water does a river need?”*

Top down:

- Any alteration to the natural flow regime has an ecological impact
- Tharme, 2003, recognized the need to determine an “acceptable level of departure” from the natural hydrograph
- *“How much can we alter the hydrograph?”*

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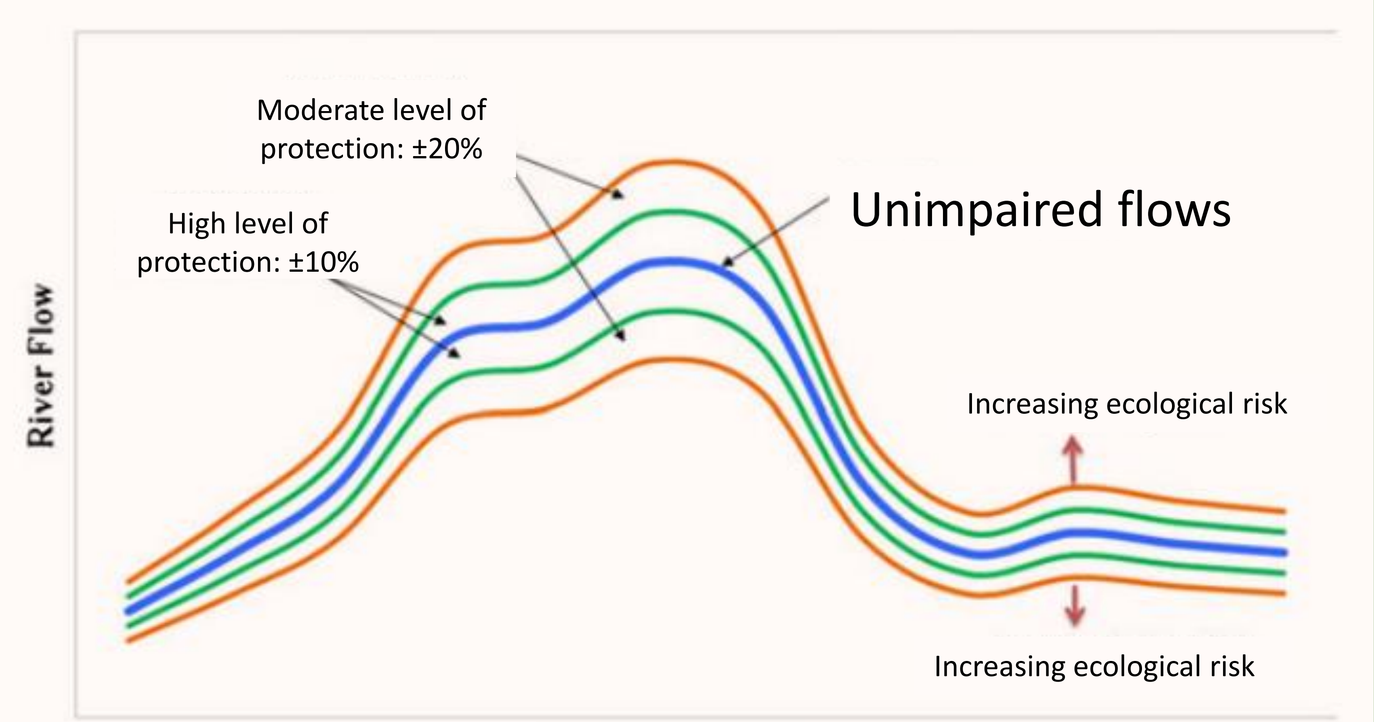
Percent-of-Flow (POF) Diversions

- POF diversions allow for the hydrograph to be altered within "sustainable boundaries" (Richter 2009, Richter et al 2012)
- POF diversions inherently maintain many functional flows and natural hydrologic variability



Modified from Richter et al. 2012

Instream flows for "fish in good condition"

- CF&G Code 5937 requires that fish are kept in good condition below dams and diversions
- Three tiers of fish in good condition have been defined by Moyle et al. 1998:

Tier 1: Individual Fish

- In reasonable health, disease and parasite free
- Have reasonable growth for region

Tier 2: Population

- Multiple age classes are present
- Life history stages have enough habitat and can move around
- Viable population size

Tier 3: Fish Community

- Dominated by native species
- Community is persistent through time
- Replicated geographically

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Instream flows for "fish in good condition"

- There is a need for flow-ecology relationships that directly relate to Tier 1, or individual condition
- Bioenergetics models can provide metrics for Tier 1

Tier 1: Individual Fish	Tier 2: Population	Tier 3: Fish Community
• In reasonable health, disease and parasite free • Have reasonable growth for region	• Multiple age classes are present • Viable population size • Life history stages have enough habitat and can move around	• Dominated by native species • Community is persistent through time • Replicated geographically

Bioenergetics models

Flow-habitat metrics (WUA curves, CRA)

Moyle 1998

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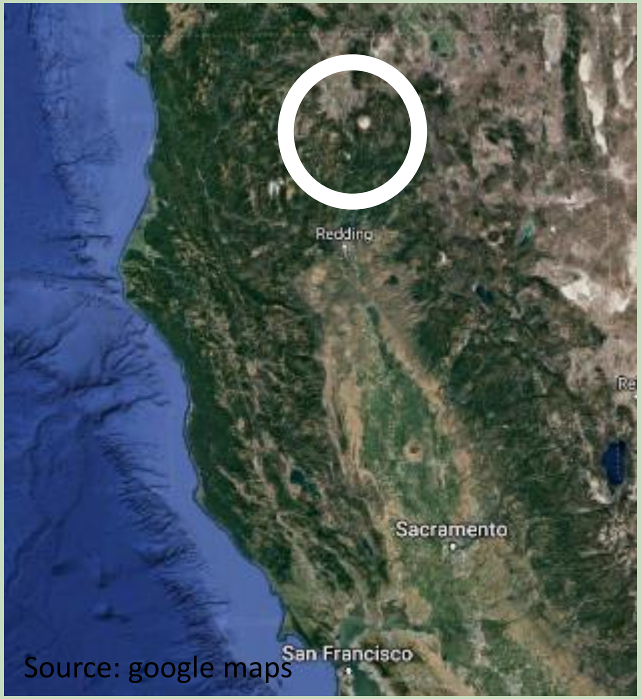
Case study in the Upper Shasta River

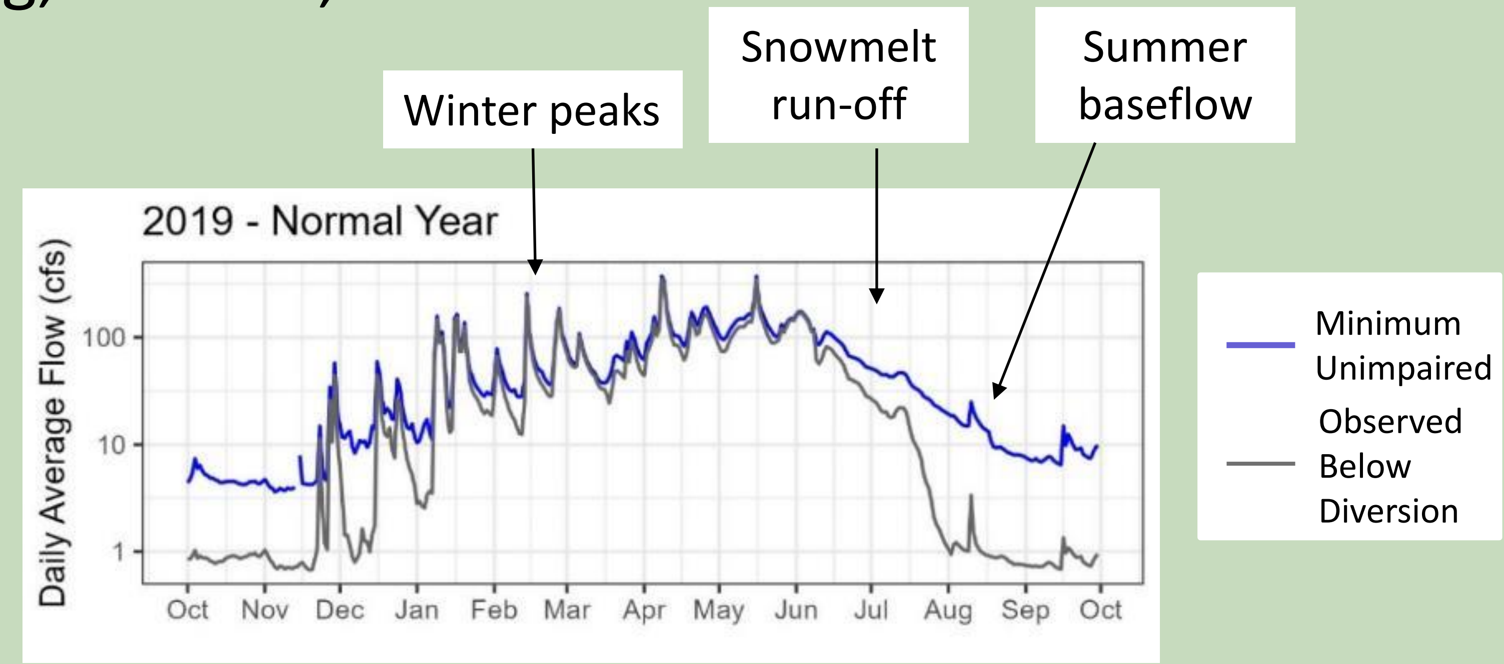


Source: google maps

- Hydrologic inputs from rainfall, snowmelt, springs
- Stream temperatures remain cool (<20°C) in the summer
- Rainbow Trout are native species of interest (above Dwinell dam)
- Up to 98% of stream flows are diverted in the summer months

Case Study in the Upper Shasta River

- Current alterations to the hydrograph are highest in the spring, summer, and fall months



- <u>Study question</u>: How much can we alter the hydrograph without risking change to condition of native Rainbow Trout?

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Project Elements

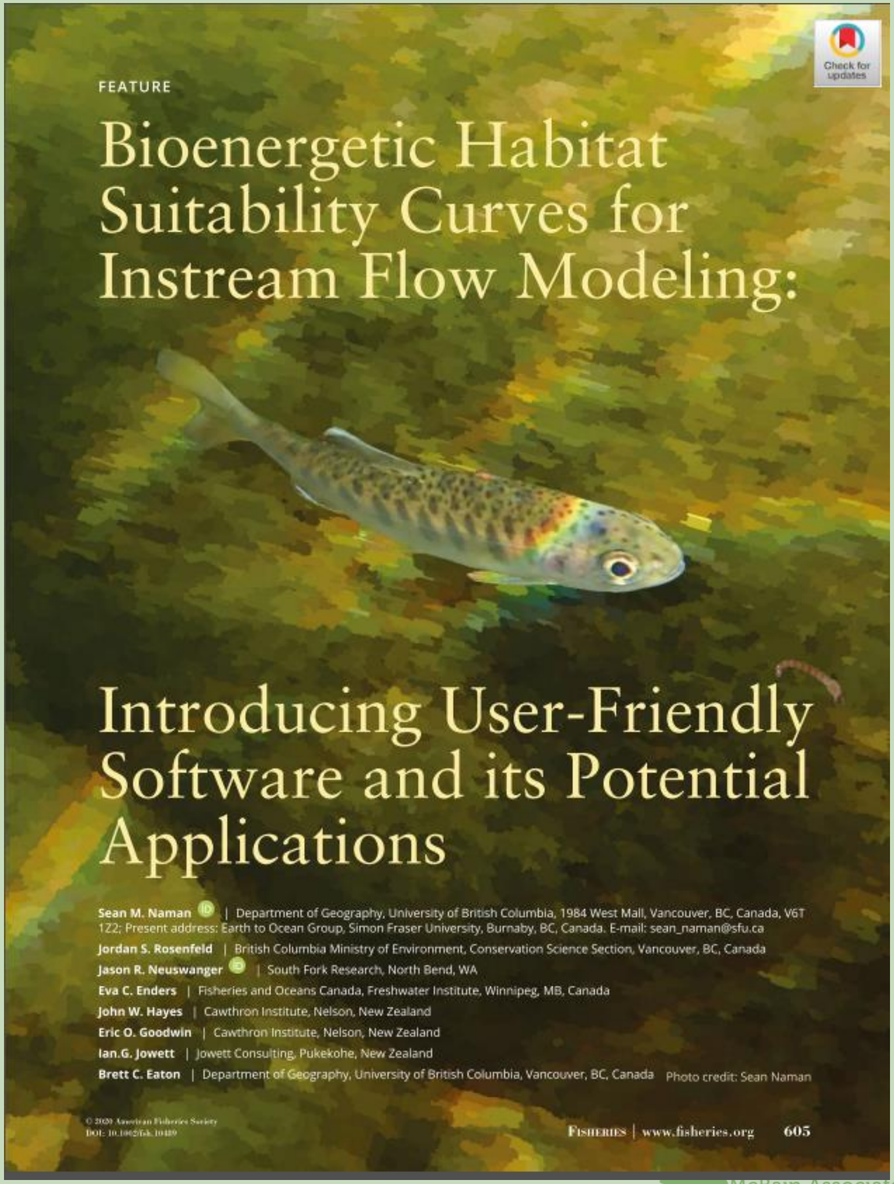
1. Estimate the impact of current large diversion on Rainbow Trout bioenergetic conditions
2. Validate Rainbow Trout bioenergetics with field data
3. Estimate maximum allowable diversion rate that minimizes risk of altering Rainbow Trout condition impacts using bioenergetics

Drift Foraging Bioenergetics

Drift-foraging bioenergetics models

- Process-based models that incorporate how changes in **depth**, **velocity**, and **food** resources influence profitability for trout
- Profitability is estimated as net rate of energetic intake, or **NREI**
- Models are mechanistic, or driven by predictions of how physical habitat and food alters foraging conditions

We implemented drift-foraging models in **Bioenergetics HSC**



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FEATURE

Bioenergetic Habitat Suitability Curves for Instream Flow Modeling: Introducing User-Friendly Software and its Potential Applications

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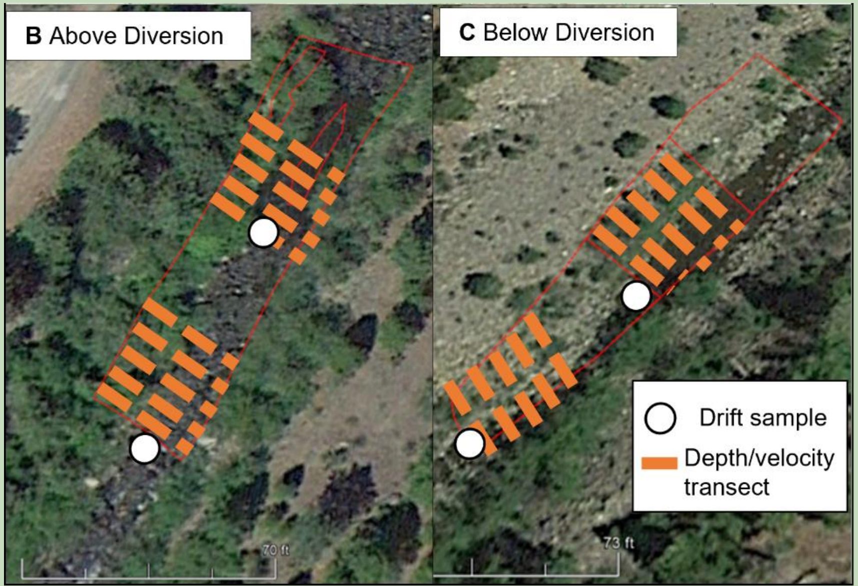
Photo credit: Sean Naman

Existing Bioenergetic Conditions

Inputs for bioenergetics models:
- Drift samples at three sites above and below the large diversion, including riffles and pools
- Depth-velocity transects, taken from 2-D hydraulic model
- Empirically measured water temperatures



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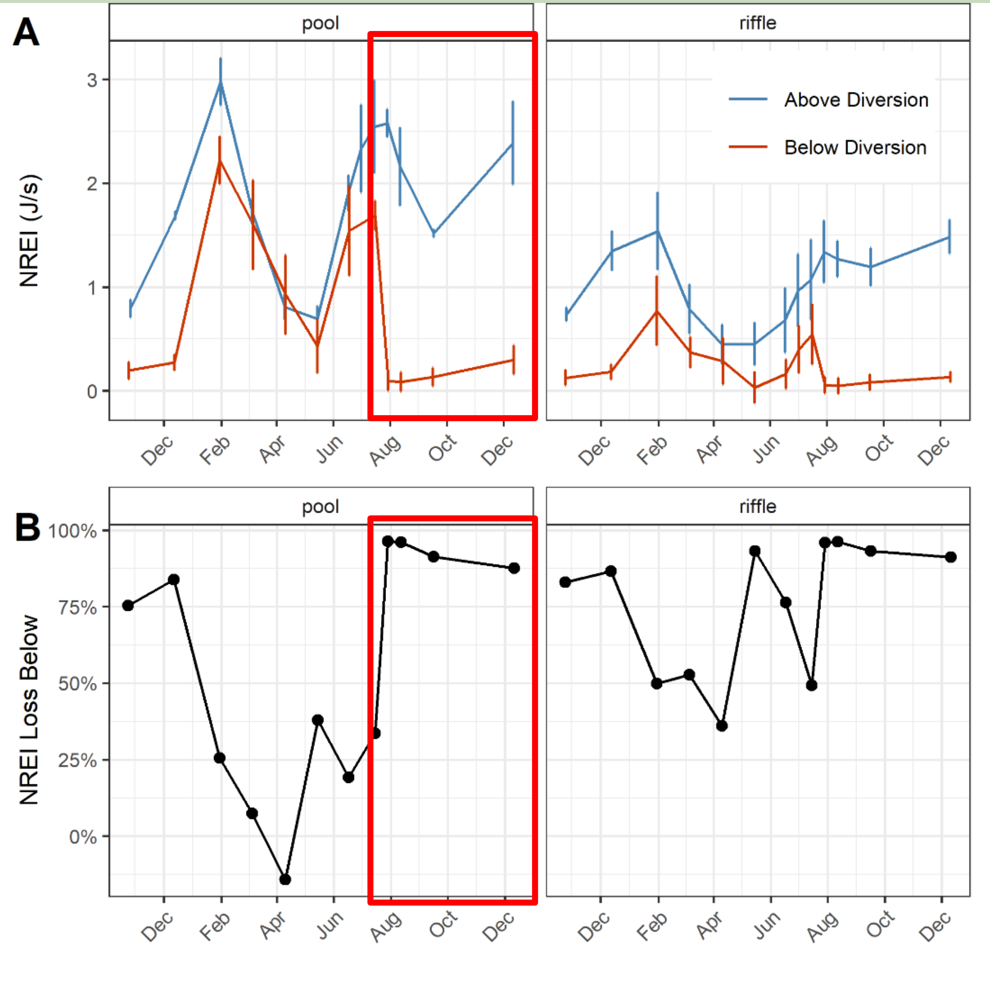
Rainbow trout energetics are greatly reduced below diversion

NREI is almost always lower below the large diversion

- Pools have a greater difference in NREI above vs. below the diversion than riffles
- NREI is most reduced in low-flow months

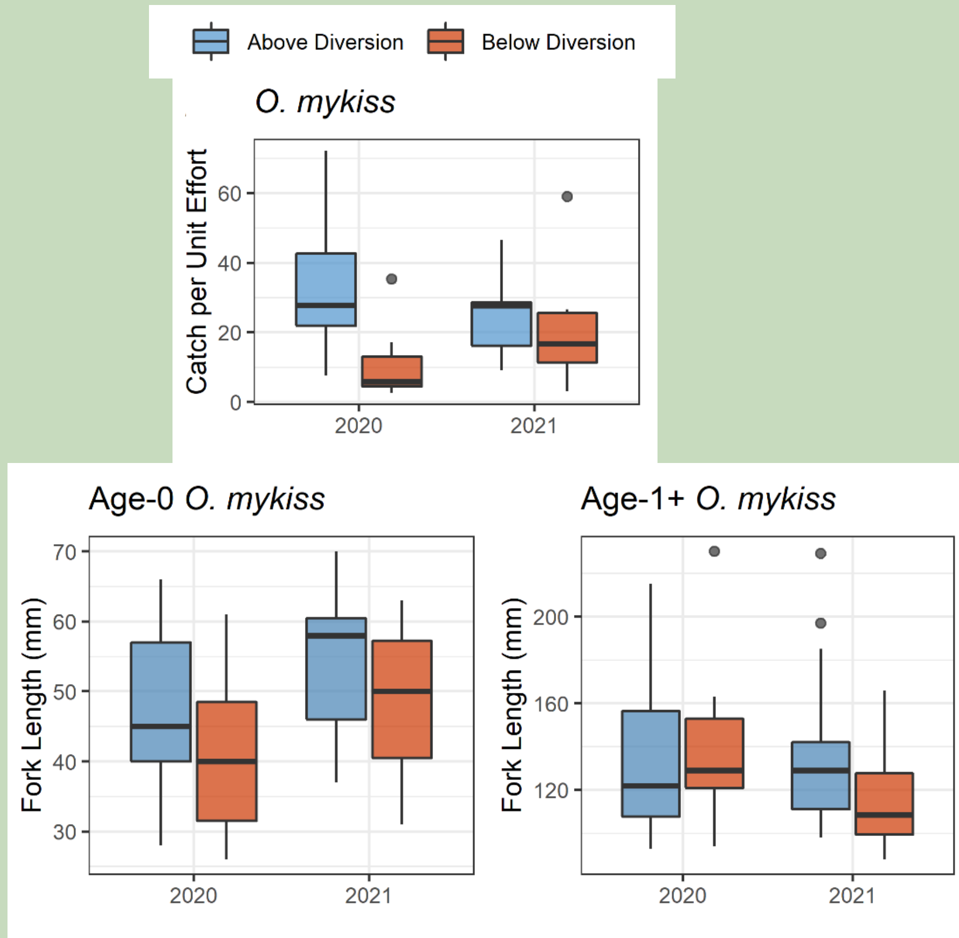


Validation of Bioenergetics models

- Field electrofishing surveys of density and size of Rainbow Trout and Brown Trout

  - Rainbow were in **lower densities** below the diversion

  - Rainbow trout are **smaller** below the diversion within each age class



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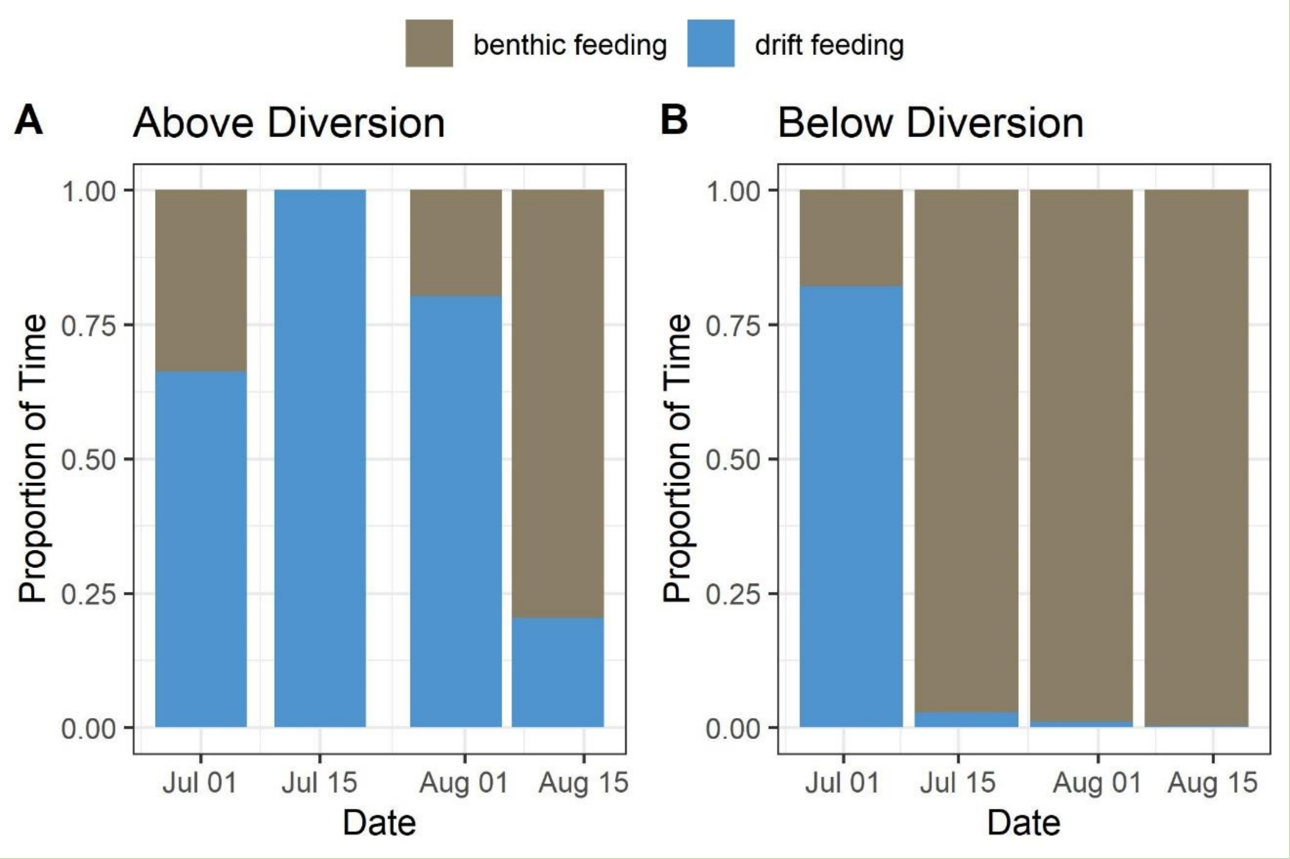
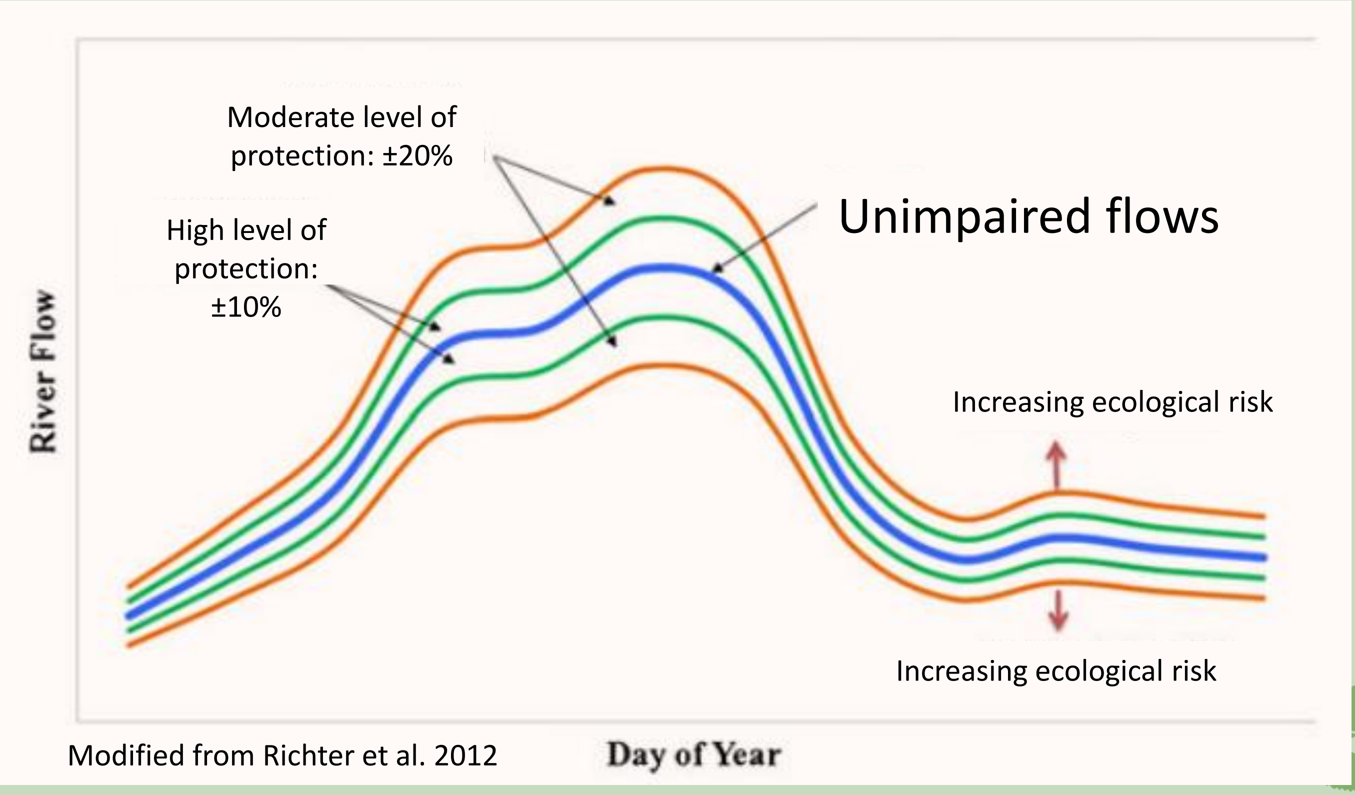
Validation of Bioenergetics Models

- Trout were observed drift feeding for longer above the large diversion in the summer of 2019 in underwater videos



Estimating allowable diversions using bioenergetics

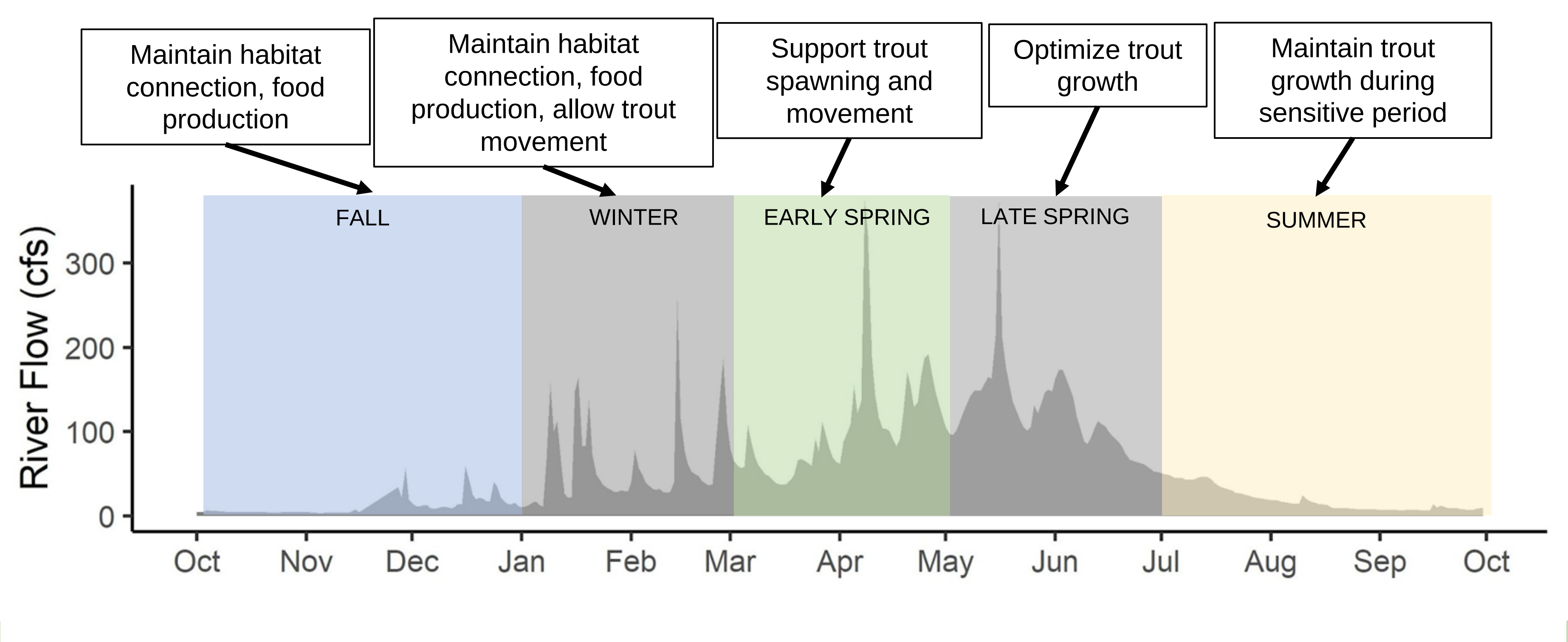
- How much can we alter the hydrograph without risk to Rainbow Trout condition?
- Can we evaluate risk by estimating when altered NREI falls outside the natural range of NREI?



Modified from Richter et al. 2012

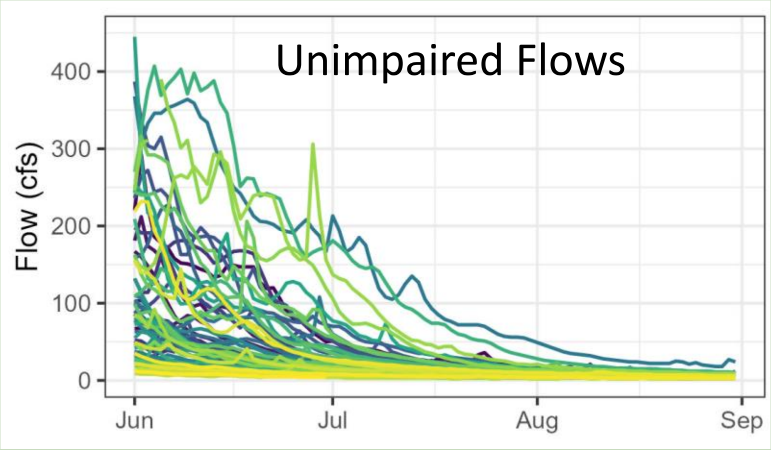
Estimating allowable diversions using bioenergetics

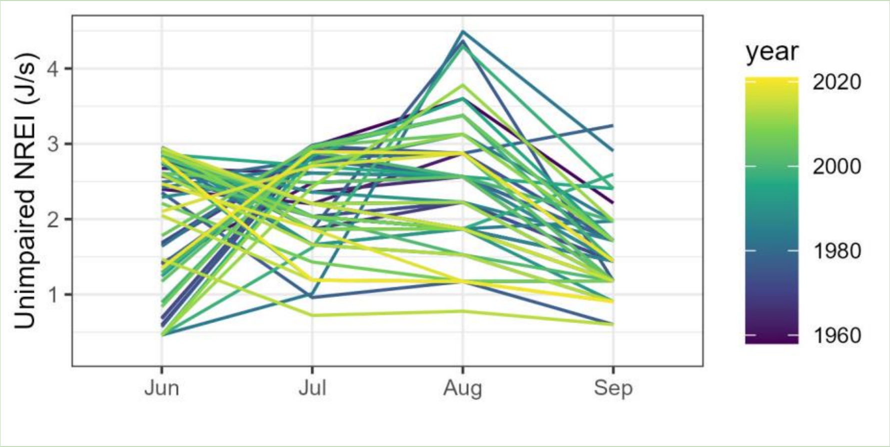
- Focus on spring and summer months
- These are ecologically productive months with increasing food and warming stream temperatures



Estimating allowable diversions using bioenergetics

- How much can we alter the hydrograph so that the altered range of NREI falls within the natural range of NREI?





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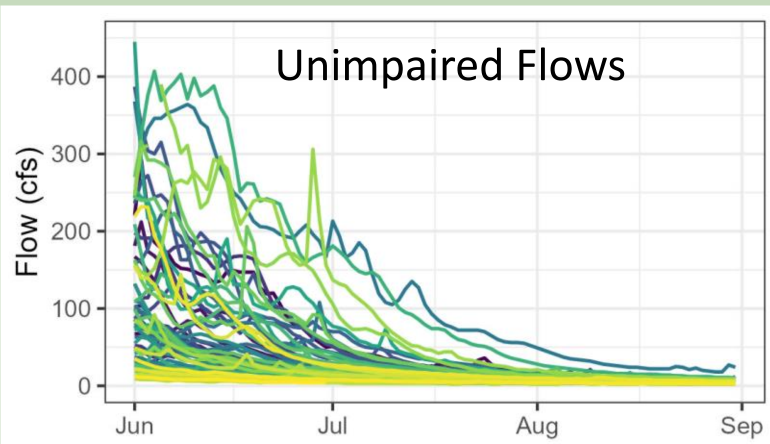
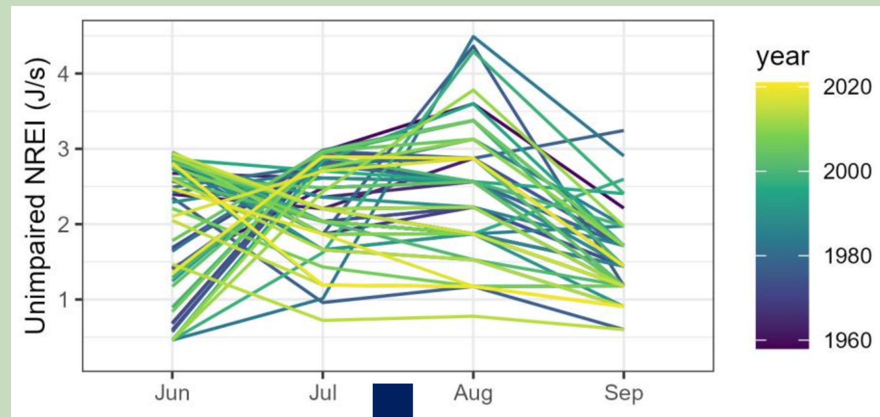
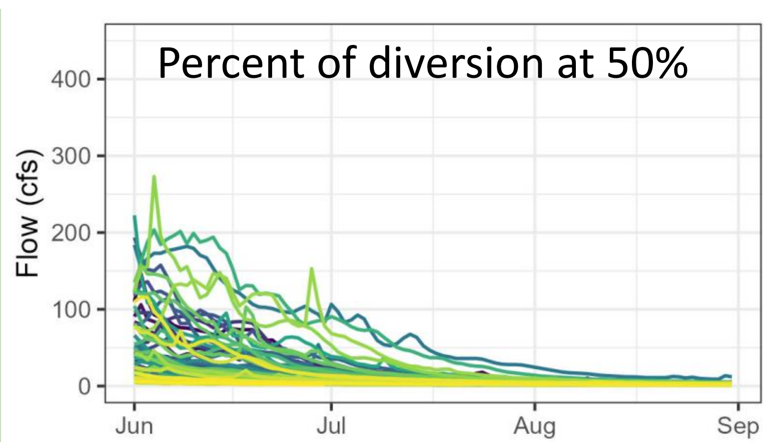
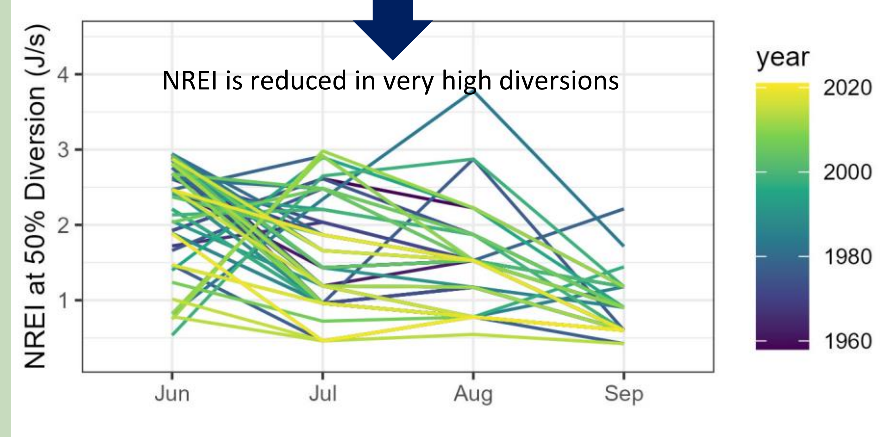
Estimating allowable diversions using bioenergetics

- How much can we alter the hydrograph so that the altered range of NREI falls within the natural range of NREI?







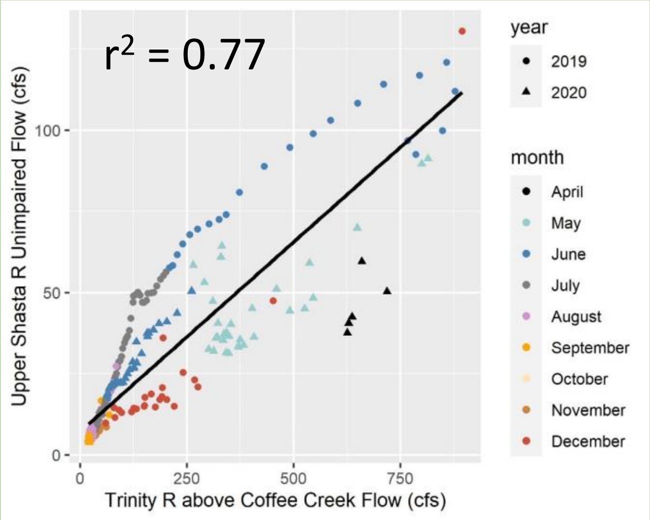


Estimating allowable diversions using bioenergetics

Ingredients:

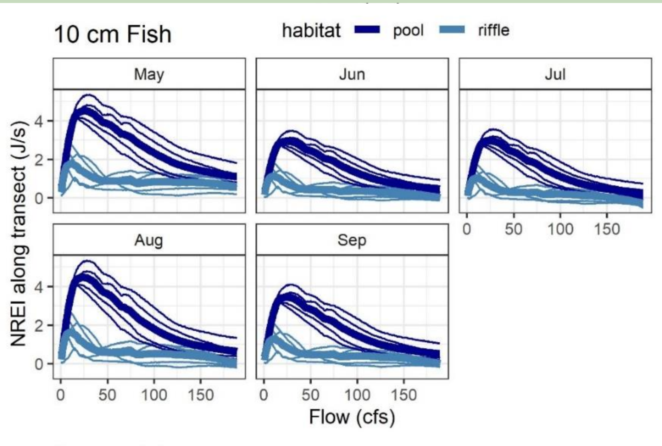
Time series of unimpaired flow data

- On-site flow gaging data was regressed with USGS gage data for the Trinity River above Coffee Creek (1962 – ongoing)



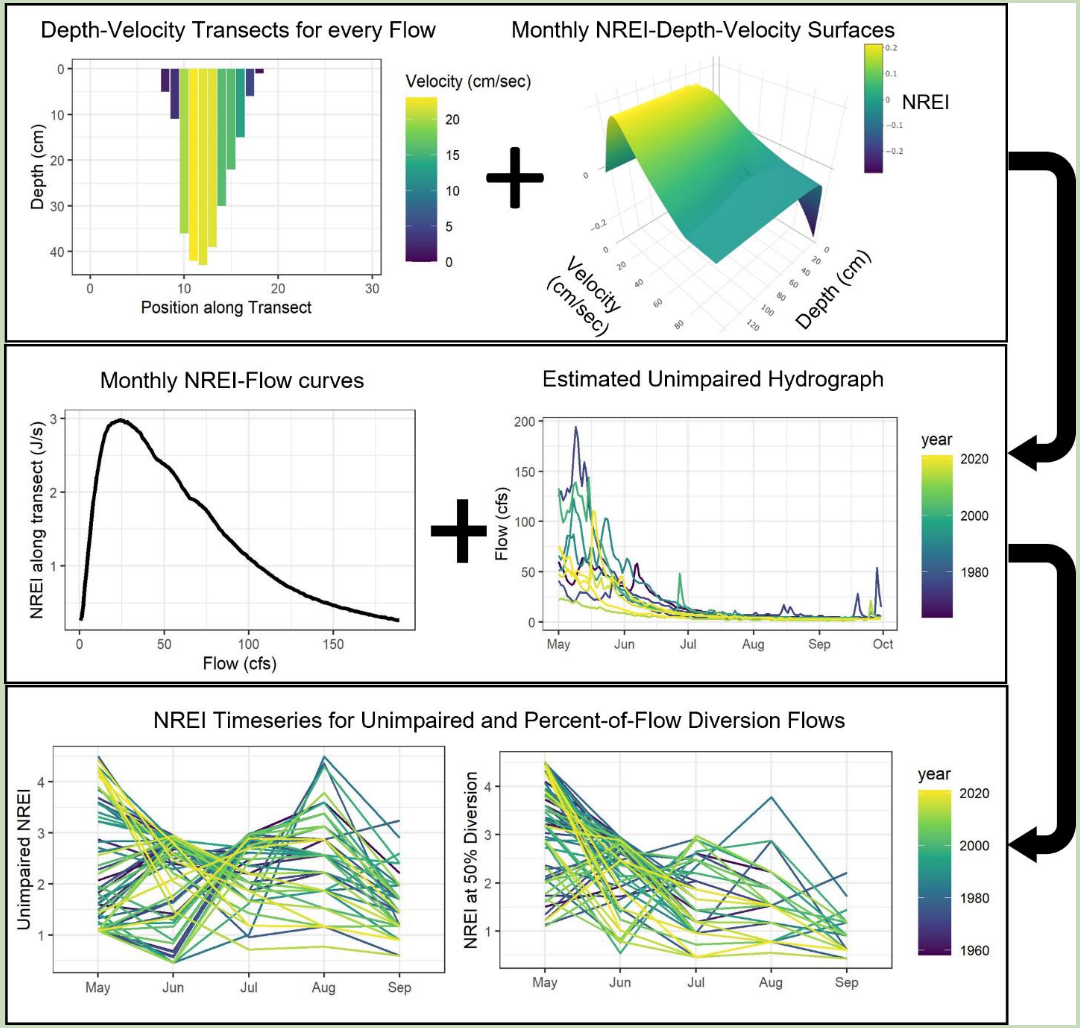
NREI-flow curves

- NREI was estimated across a range of flows
- Depth and velocity was extracted from a 2D hydraulic model
- Monthly drift concentration input files were estimated from field studies



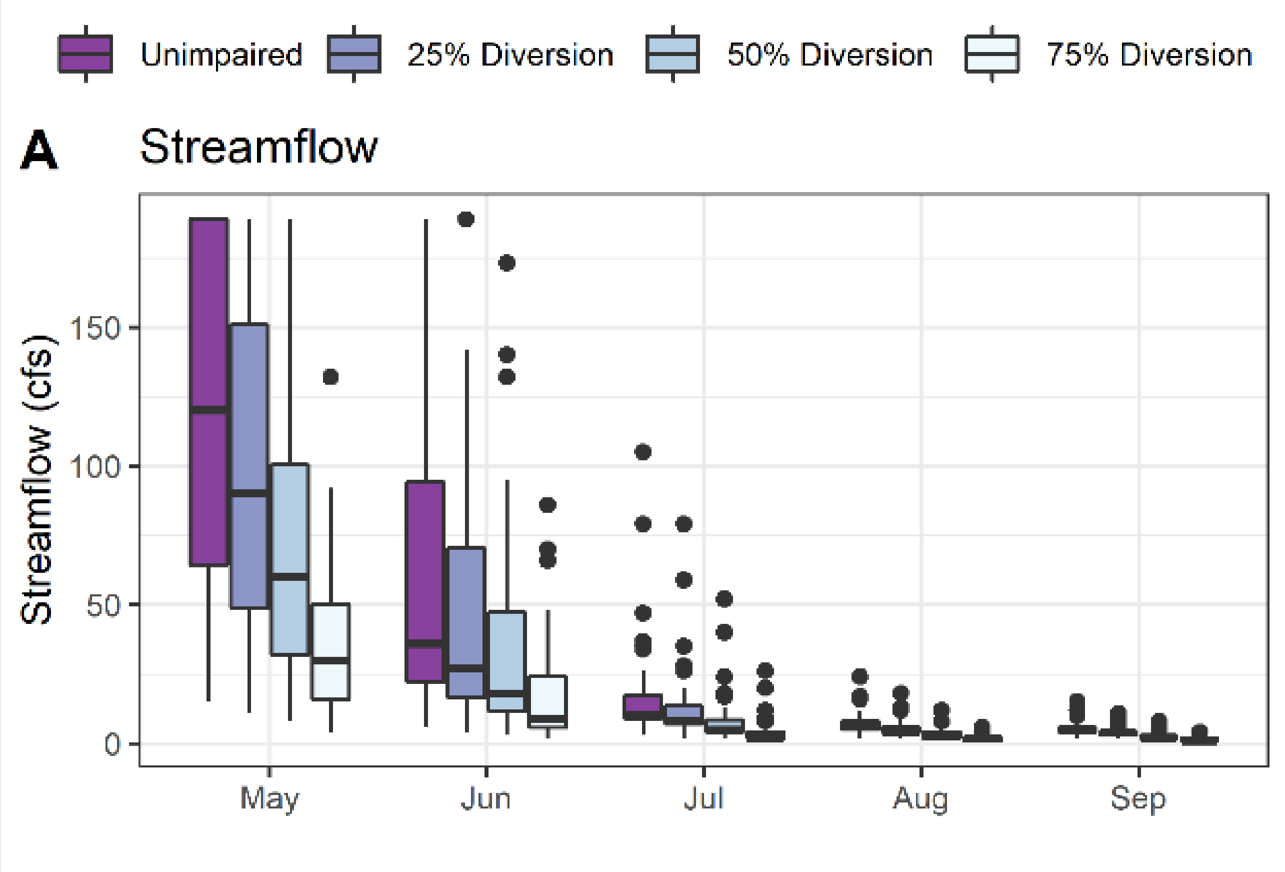
Estimating allowable diversions using bioenergetics

Workflow for estimating NREI under different POF diversion rates



Estimating allowable diversions using bioenergetics

- We estimated instantaneous NREI during spring and summer months over a set of POF diversion scenarios
  - We initially evaluated 75%, 50% and 25% POF diversions



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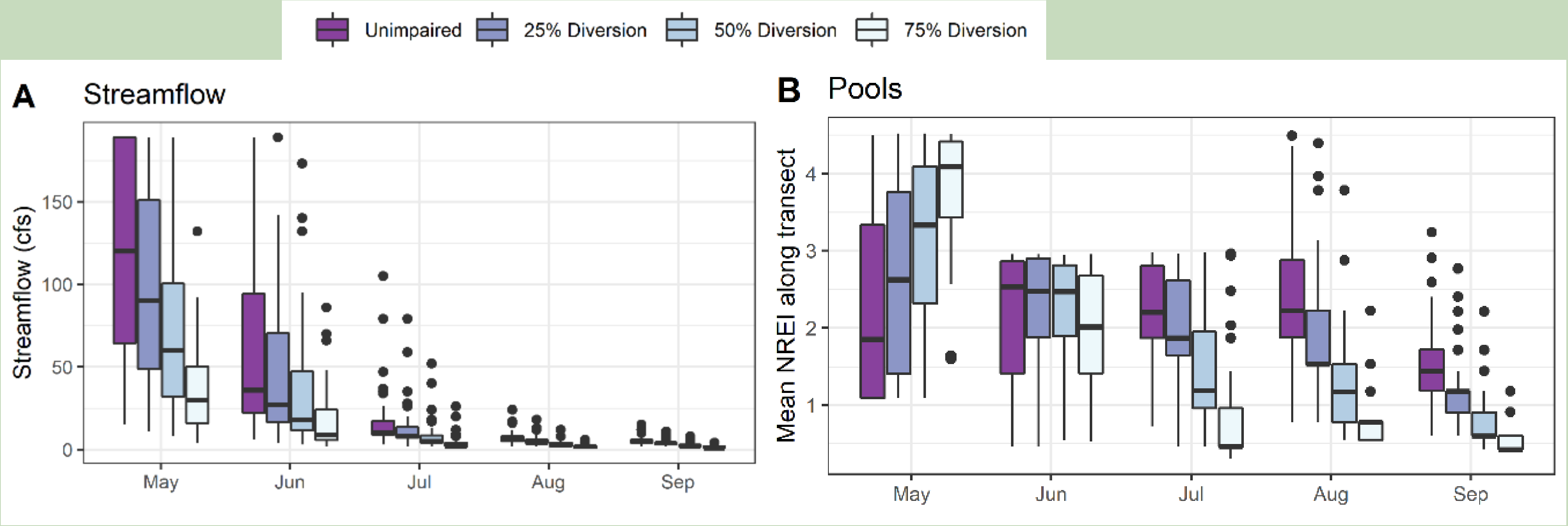
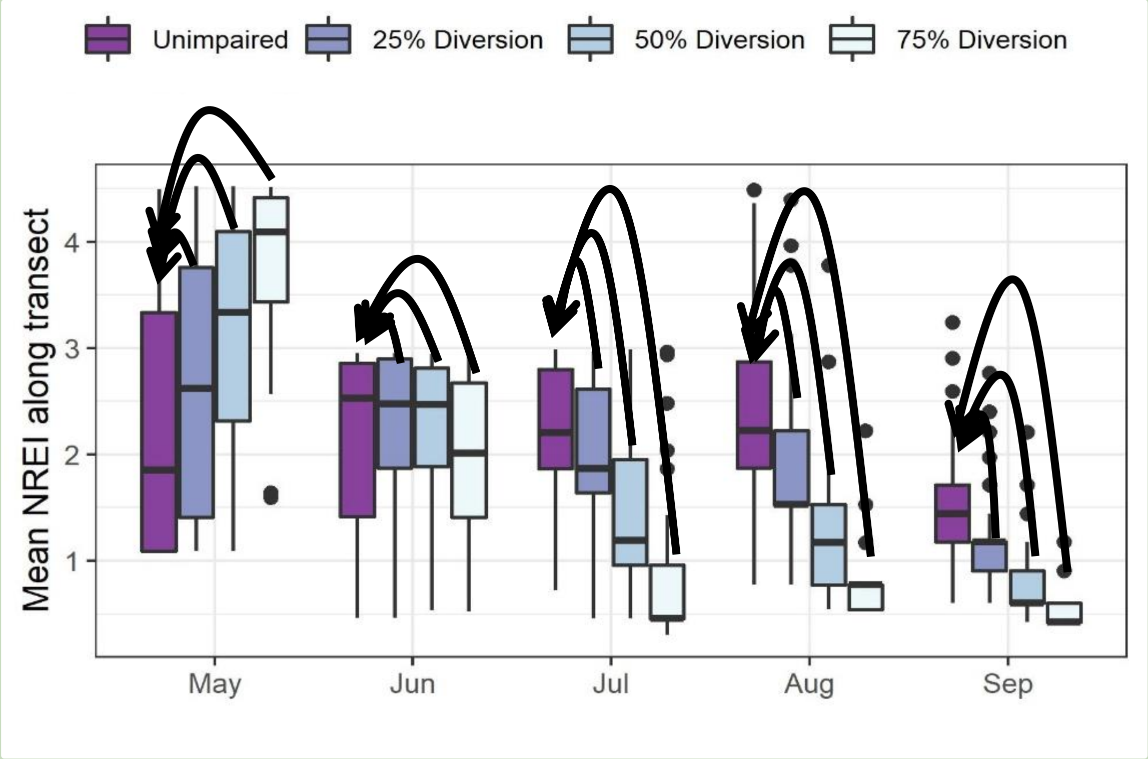
Results: Estimating allowable diversions using bioenergetics

- In low-flow months, a higher POF decreases NREI
- In high-flow months, NREI is similar or even higher under increasing POF scenarios



Results: Estimating allowable diversions using bioenergetics

- For low-flow months, what is the highest allowable POF rate that will maintain NREI within the natural range?
- We conducted "ratcheting", where we compared NREI under POF diversion scenarios in 1% increments to the unimpaired NREI, until we found that NREI was significantly reduced



Results: Estimating allowable diversions using bioenergetics

- The highest allowable POF varied by month and habitat type
- Recommended max POF rates are <16% in July and <9% in August – September

TABLE 2 The maximum percent-of-flow (POF) diversion rate that maintains NREI within the range of NREI under unimpaired flow scenarios for 5, 10, and 15 cm fish in pools. The most limiting size class, or the size class that requires the lowest diversion, is in bold.

Maximum percent of diversion	May	June	July	August	September
Pools—NREI					
5 cm	>50%	>50%	18%	9%	9%
10 cm	>50%	>50%	16%	9%	9%
15 cm	>50%	>50%	16%	12%	10%
Riffles—NREI					
5 cm	>50%	>50%	>50%	30%	12%
10 cm	>50%	>50%	>50%	9%	9%
15 cm	>50%	>50%	38%	9%	9%

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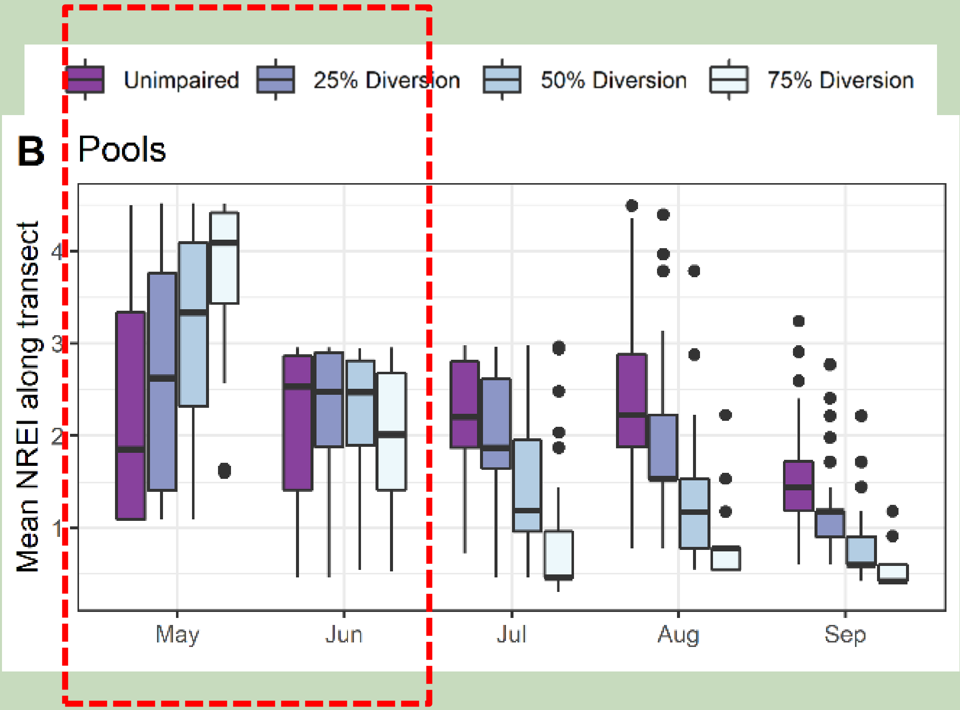
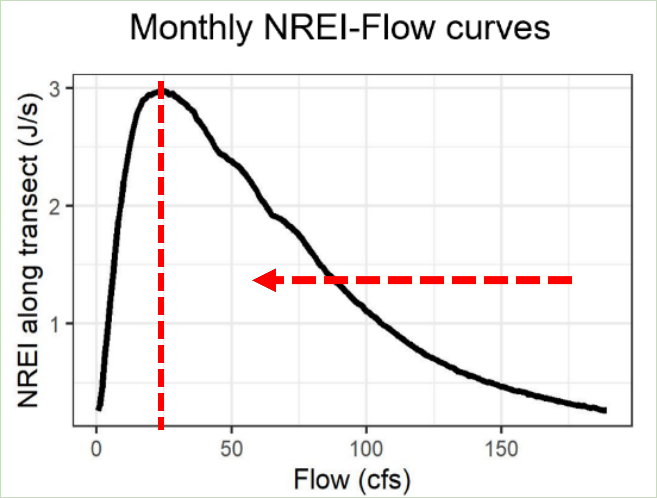
Results: Estimating allowable diversions using bioenergetics

- What's happening in high-flow months?



In high-flow months, diverting water brings flows closer to the optimum NREI value



Other flow-ecology variables could complement an assessment in this time of the year, like flows needed for:

- Riparian vegetation maintenance
- Floodplain connectivity
- Spawning habitat

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Summary

- Bioenergetics models predicted that the current diversion is impacting Rainbow Trout energetic condition
- Field studies (size and density) corroborated that Rainbow Trout are smaller, in lower densities, and practicing less drift-foraging below the diversion
- In dry months, we predicted that diversions <16%-9% would maintain Rainbow Trout energetic conditions within the natural range
    - This is near the Richter et al. (2012) presumptive standard that 10% diversions would provide "high protection" for natural function

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Conclusions

- Bioenergetics models are tools that can integrate changes in biological and physical responses into one metric that varies with flow
  - These models directly address Tier 1 of "fish in good condition"
- Unimpaired conditions provide a reference to develop ecological risk thresholds
  - POF diversion rates are inherently holistic in protecting functional flows
- Risk-based framework could be used for many flow-ecology or flow-geomorphology relationships
  - CEFF metrics can help guide instream flows and predictions
  - But don't forget about your conceptual model!

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Burden of Proof

- Technical studies can identify thresholds for ecological risk
- They do not answer the question about how much risk we are willing to take

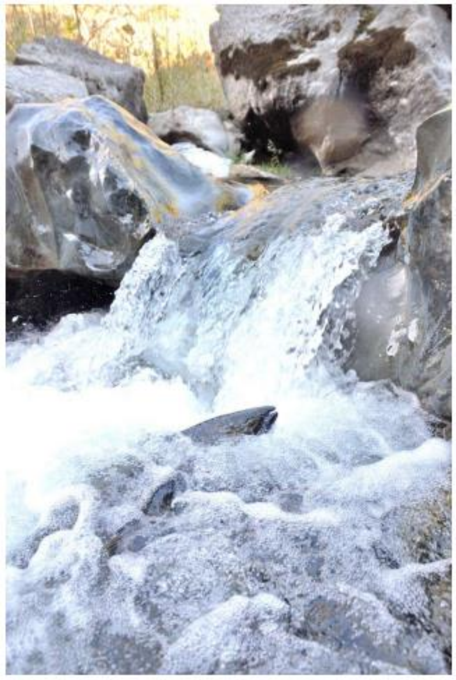

Photo: CDFW 2017

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AMERICAN WATER RESOURCES ASSOCIATION JAWRA

RESEARCH ARTICLE

Trout bioenergetics as a process-based tool to estimate ecological risk in a regulated river

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Marin Community Foundation; National Fish and Wildlife Foundation

Abstract
Bioenergetics models produce quantitative flow-ecology relationships that summarize changes in habitat and food resources from altered flows. We used a drift-foraging bioenergetics model to quantify the net rate of energetic intake (NREI) for trout above and below a water diversion. NREI is reduced by >95% below the water diversion in July–September, when up to 98% of unimpaired flows are diverted. We then used a risk-based approach to estimate the maximum diversion rate, expressed as a percentage of unimpaired flow, that would produce NREI values that are not significantly lower than values under unimpaired flows throughout a 62-year period. NREI decreased with increased percent-of-flow diversion rates in low-flow months (July–September). Diversion rates of 16% in July and 9% in August and September would maintain NREI within the range of unimpaired flow conditions. In higher flow months, May–June, increasing diversions brought estimated instream flows closer to the peak NREI flow, leading to the assessment that increased diversions would increase NREI. Bioenergetic models can be used to develop protective flow rates at times of the year when fish growth and production would be high under unimpaired flows, which often coincides with when water is diverted. Our study is the first to develop protective percent-of-flow diversion rates for holistic flow management using a quantitative process-based and fish-centric ecological metric.

KEYWORDS
percent-of-flow, holistic flow management, natural flow regime, salmonid, foraging behavior, drift-feeding

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