

A wide-angle photograph of the Glen Canyon Dam, a large concrete structure spanning a deep, red-rock canyon. The river flows through the canyon below the dam. The sky is filled with white and grey clouds. The text is overlaid on the right side of the image.

Glen Canyon Dam Adaptive Management Program

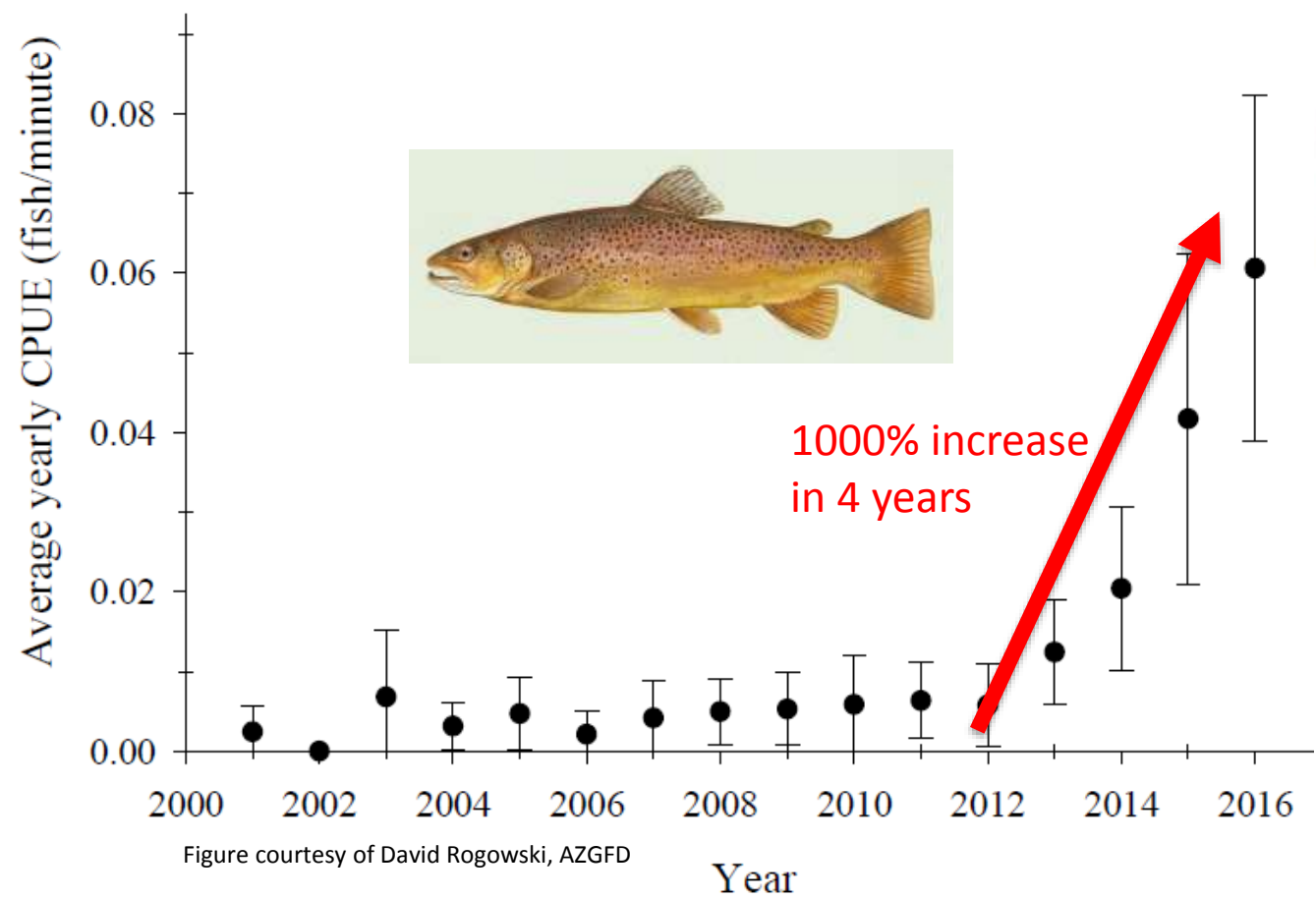
Brown Trout Workshop

**21-22 September 2017
Tempe, Arizona**

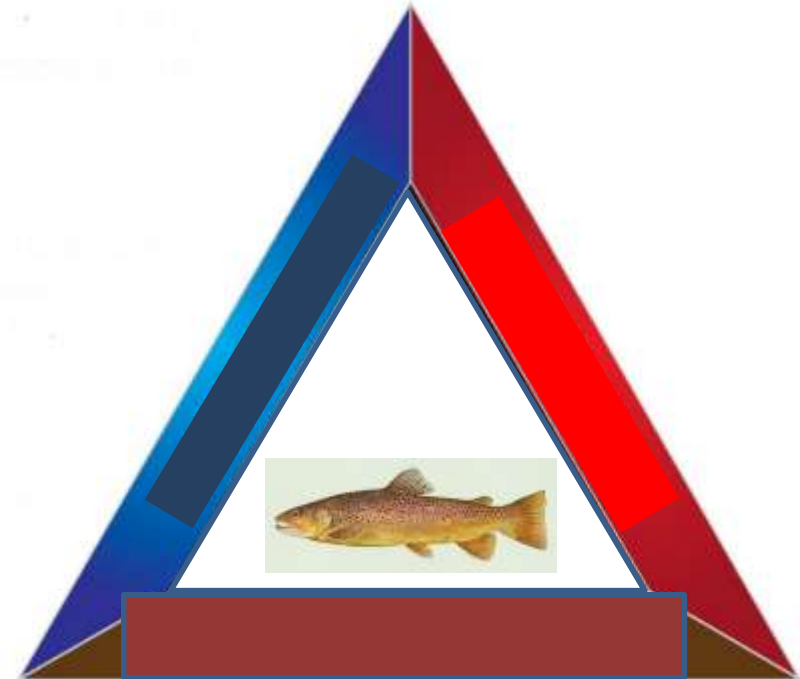
Root causes for the increase of brown trout in the Lees Ferry reach

Ted Kennedy-USGS
Jeff Kershner-USGS (retired)
Barry Nehring-Colorado Division of Wildlife (retired)
David Rogowski-AGFD
Robert Schelly-NPS
Melissa Trammell-NPS
Rich Valdez-SWCA
David Ward-USGS
Charles Yackulic-USGS
Mike Yard-USGS

What is driving this increase?



It wasn't just one thing



Expert elicitation

- Mike Runge and/or Jim Peterson sat-in on calls
 - Kept us honest/objective, did not rank hypotheses
- Two new outside experts that ranked hypotheses
 - Jeff Kershner (USGS-retired, worked on trout biology in Flaming Gorge Dam and non-native fish control in Snake River, etc.)
 - Barry Nehring (Colorado Division of Wildlife-retired, studied whirling disease and rainbow trout)
- Searched literature and available data for examples and evidence of proposed mechanisms
- 4 rounds of developing hypotheses and ranking
- Presenting final round today

What are the facts?

- 2013: more adults
- 2014: more adults, & hint of more juveniles
- 2015: new juveniles (successful spawn in 2014)
- 2016: new juveniles (successful spawn in 2015)



Figure courtesy of David Rogowski, AZGFD



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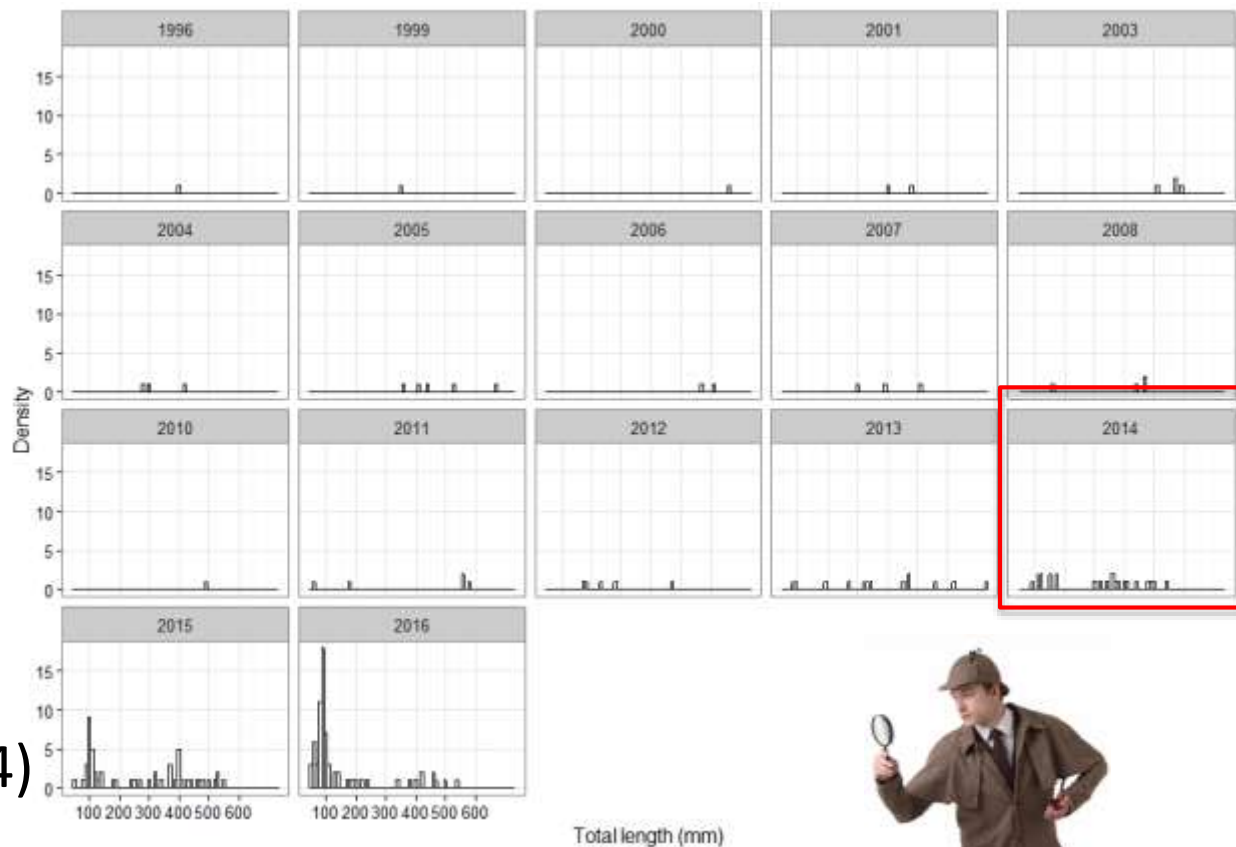


Figure courtesy of David Rogowski, AZGFD

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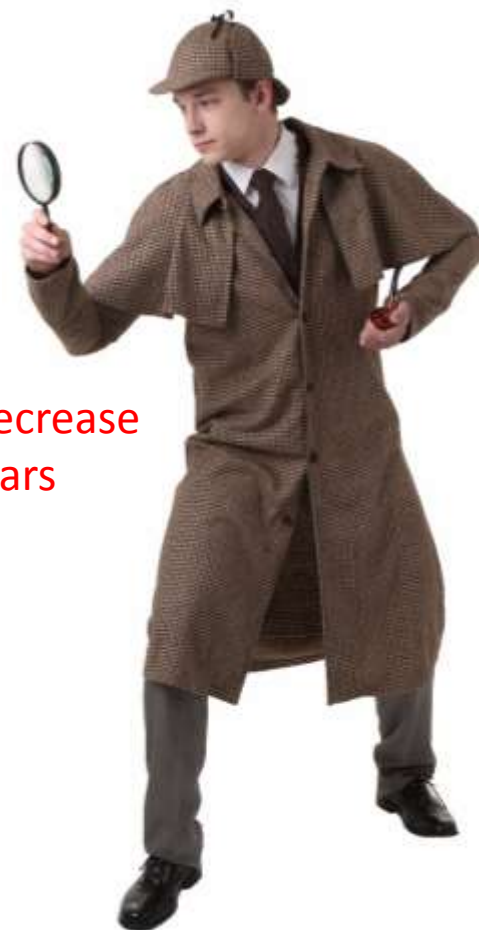
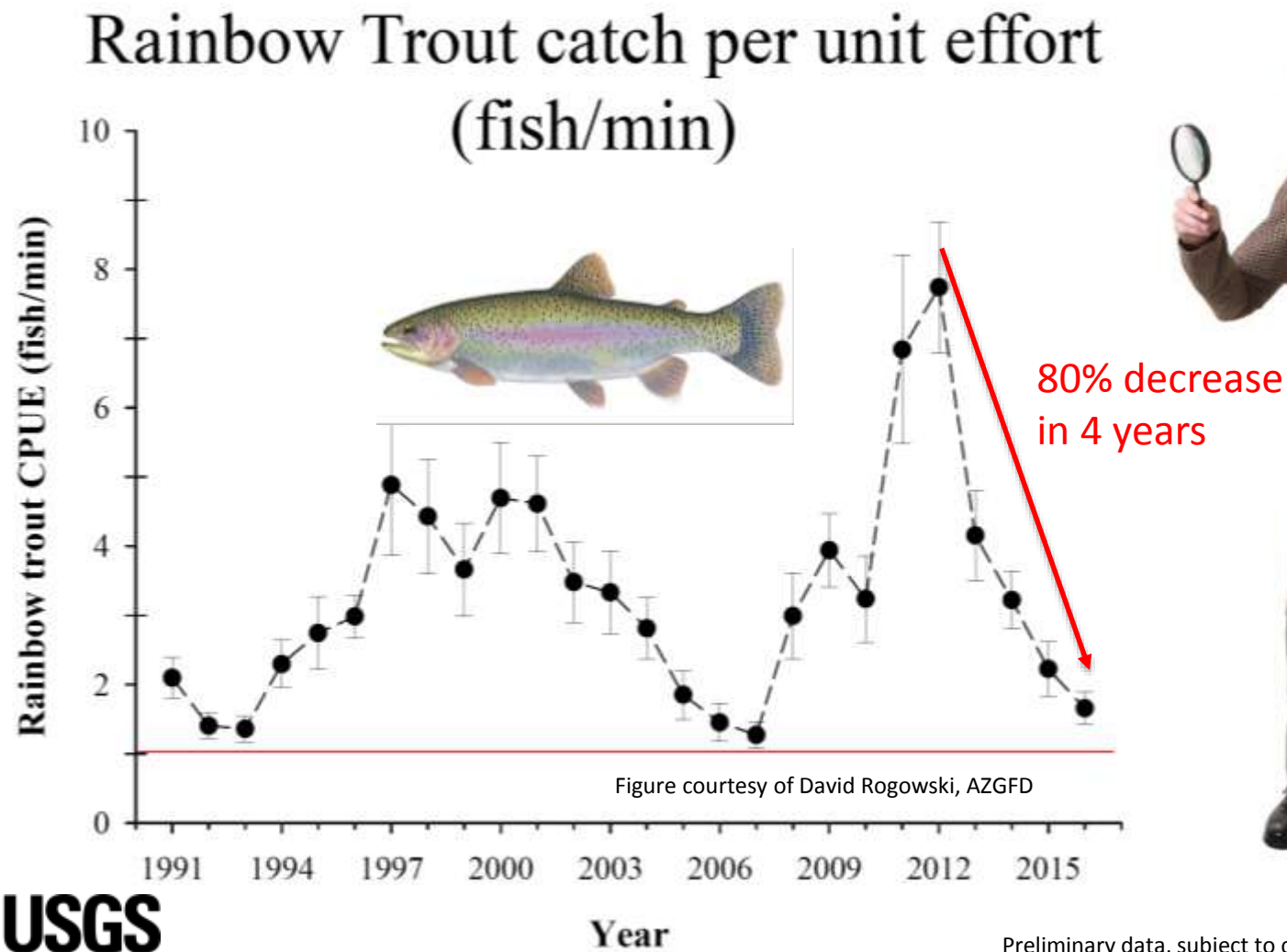
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Figure courtesy of David Rogowski, AZGFD



Did you notice anything else unusual?



Very interesting.....

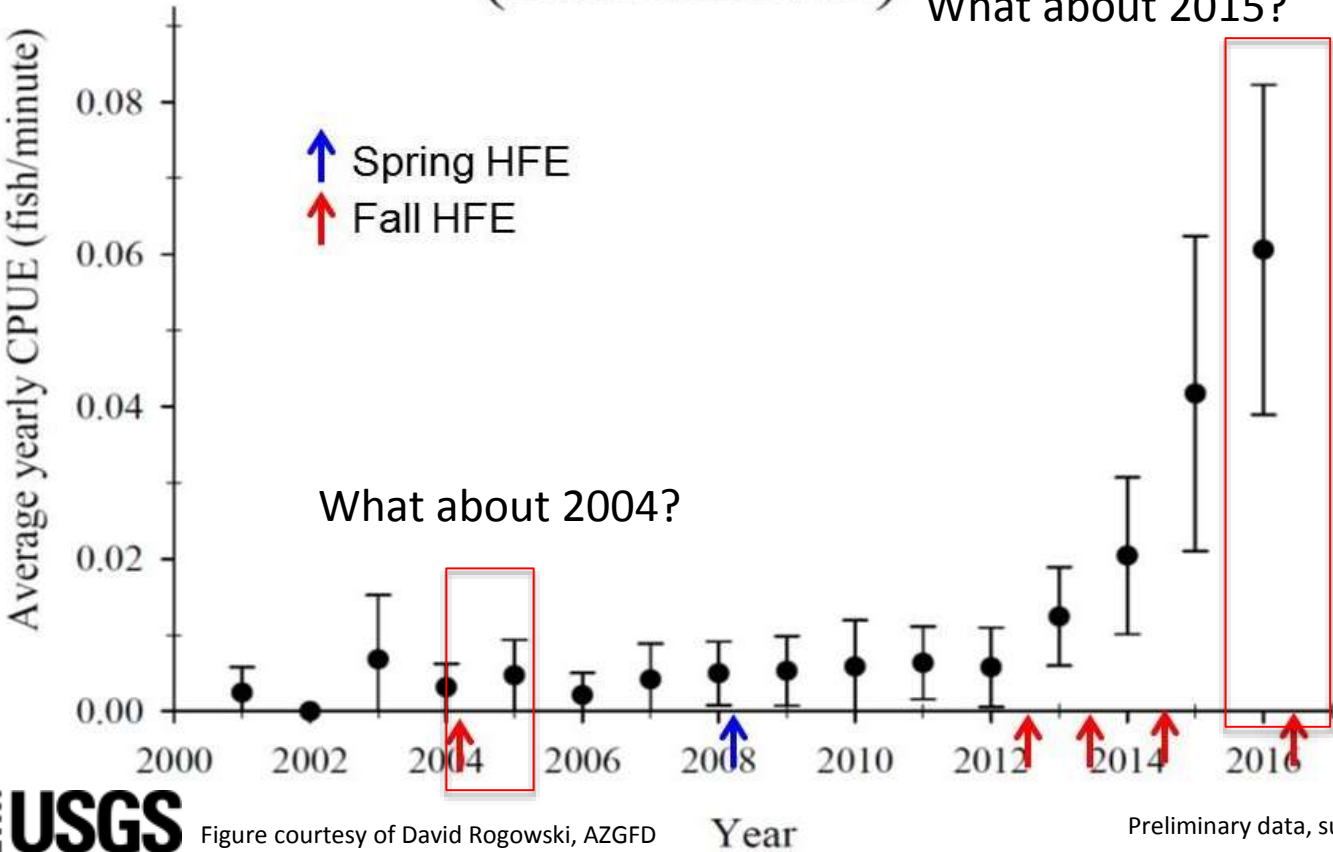


- So we're searching for mechanism that could have caused:
 - a) Initial increase in BNT adults ('13 & '14)
 - b) followed by successful BNT spawning ('15 & '16)
 - c) Concomitant crash in RBT populations (extra credit)



One more question, did dam operations recently change?

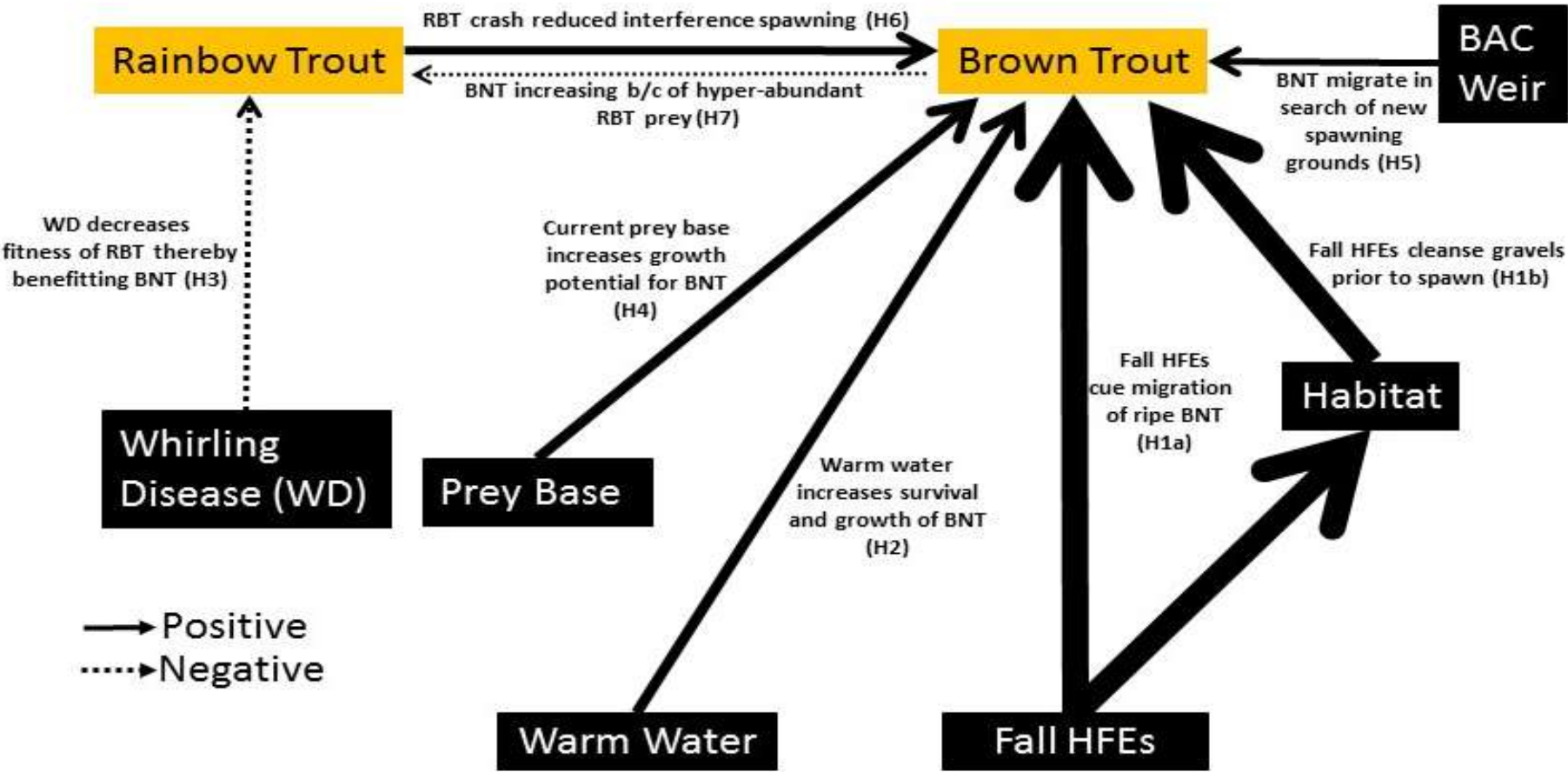
Brown Trout average electrofishing CPUE (fish/minute)



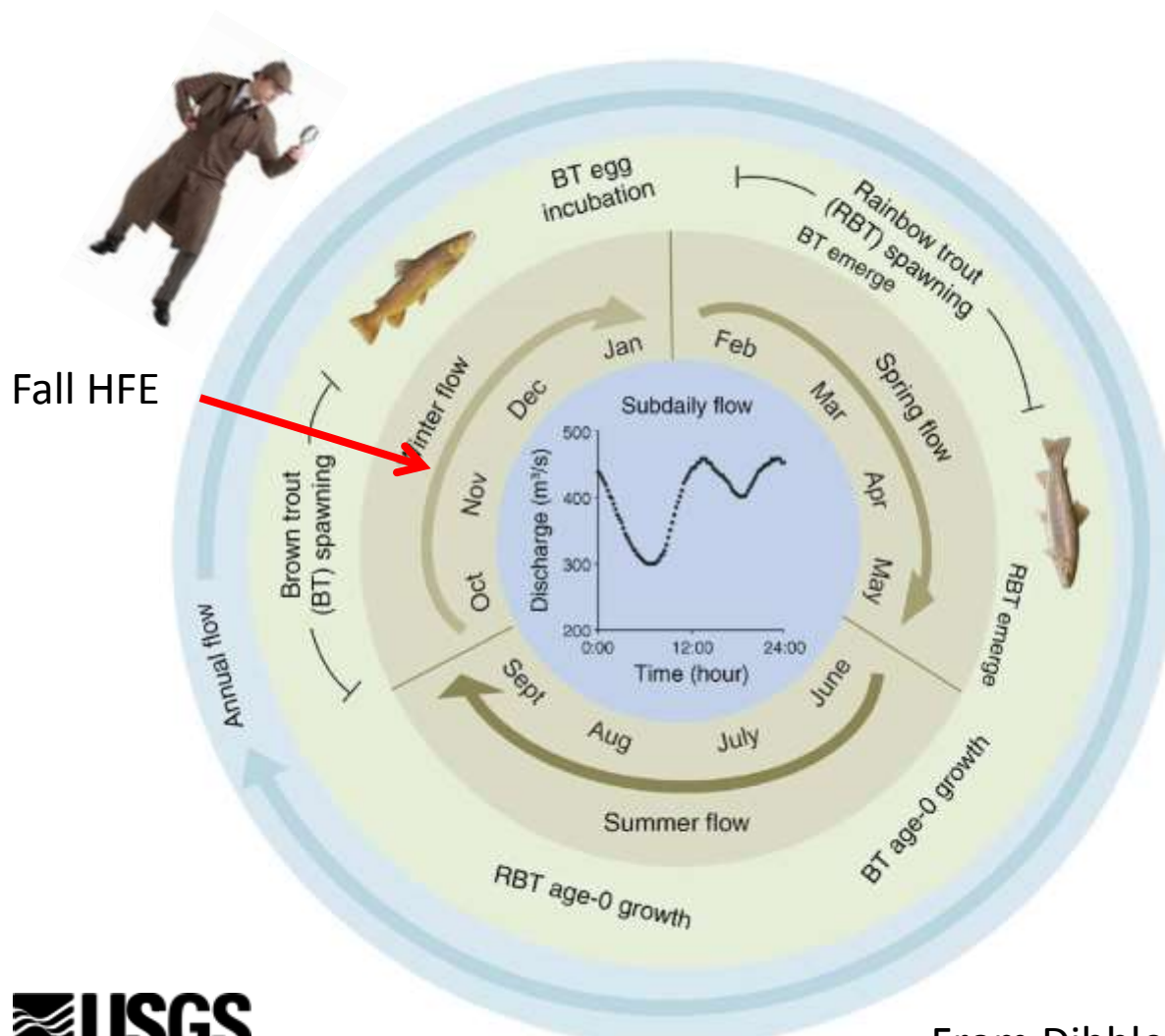
We considered 7 hypotheses

Hypothesis #	Type of hypothesis	Hypothesis	
H1	Physical driver	Fall HFEs	
H2	Physical driver	Warmer water	
H4	Biological driver	Prey base	
H6	Biological driver	Less interference spawning by RBT	
H5	Human driver	Weir at Bright Angel Creek	
H3	Physical driver	Whirling disease in Rainbow Trout	
H7	Biological driver	Abundant Rainbow Trout prey.	

Root Causes Hypotheses



Tailwater synthesis: Life cycle timing is key



“[Differences in brown vs. rainbow trout] response to flow management are likely attributable to differences in seasonal timing of key life history events such as spawning, egg hatching, and fry emergence.”

Spawning migration one example

- Ovidio and others, 1998
- Radio tagged brown trout in Belgian streams.
- Essentially no movement for weeks until....
- High variance in water temperature and discharge
- Which triggered spawning migrations and movement up to 5 km per night

Brown Trout

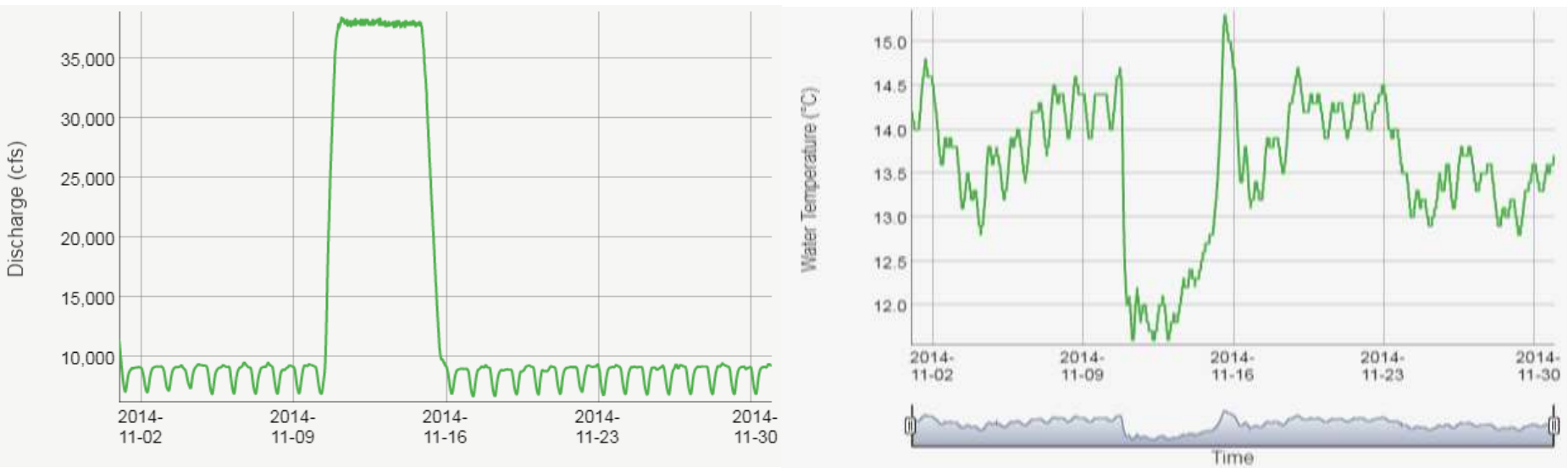


Fall HFEs
cue migration
of ripe BNT
(H1a)

Fall HFEs

- Ovidio, M., Baras, E., Goffaux, D., Birtles, C., and Philippart, J.C., 1998, Environmental unpredictability rules the autumn migration of brown trout (*Salmo trutta* L.) in the Belgian Ardennes: Hydrobiologia, v. 371, no. 0, p. 263-274, <https://doi.org/10.1023/A:1017068115183>.

HFEs drives variance in flow and temperature



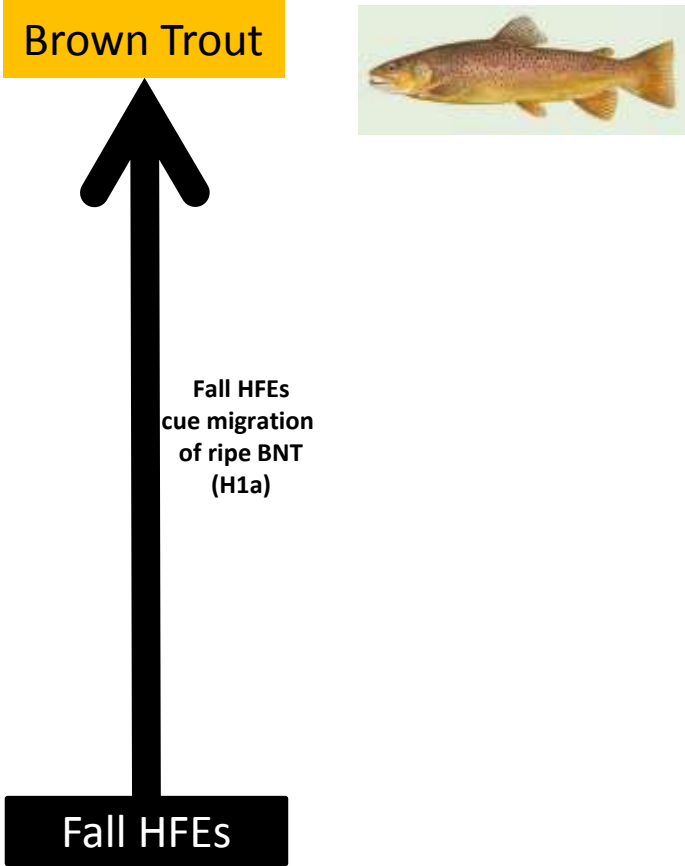
Figures drawn from https://www.gcmrc.gov/discharge_qw_sediment/station/GCDAMP/09380000



This hypothesis (mechanism) fits one of the facts

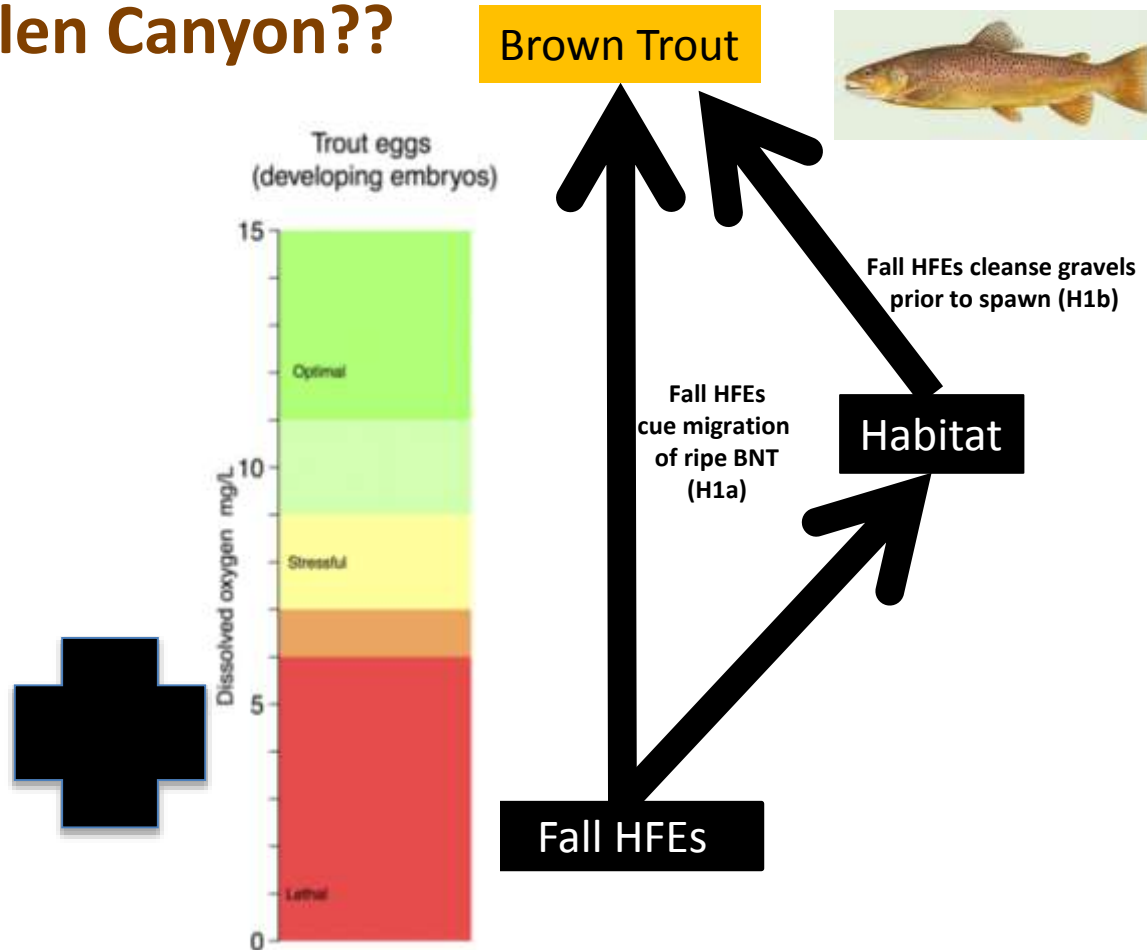


- Increase in adults 2013-2014
- Successful spawning 2015-2016
- Rainbow trout crash 2013-2016



But there's plenty of spawning habitat in Glen Canyon??

- Spawning habitat
 - Clean gravels
 - Good water quality

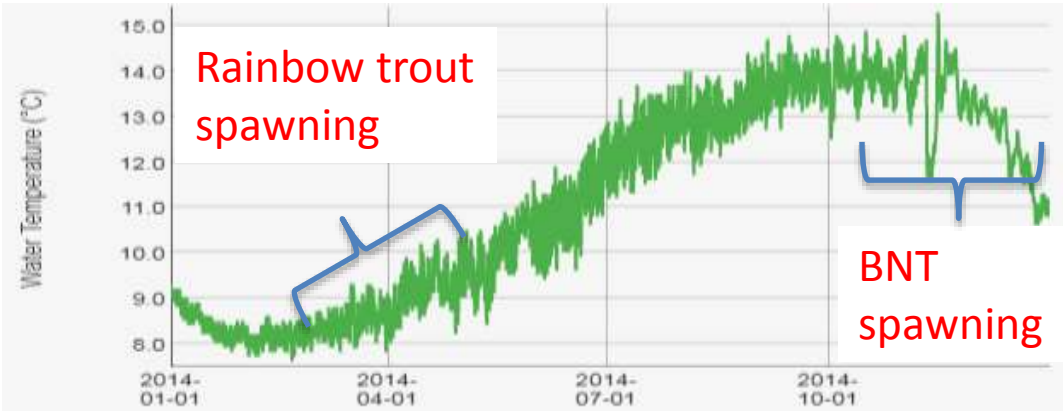
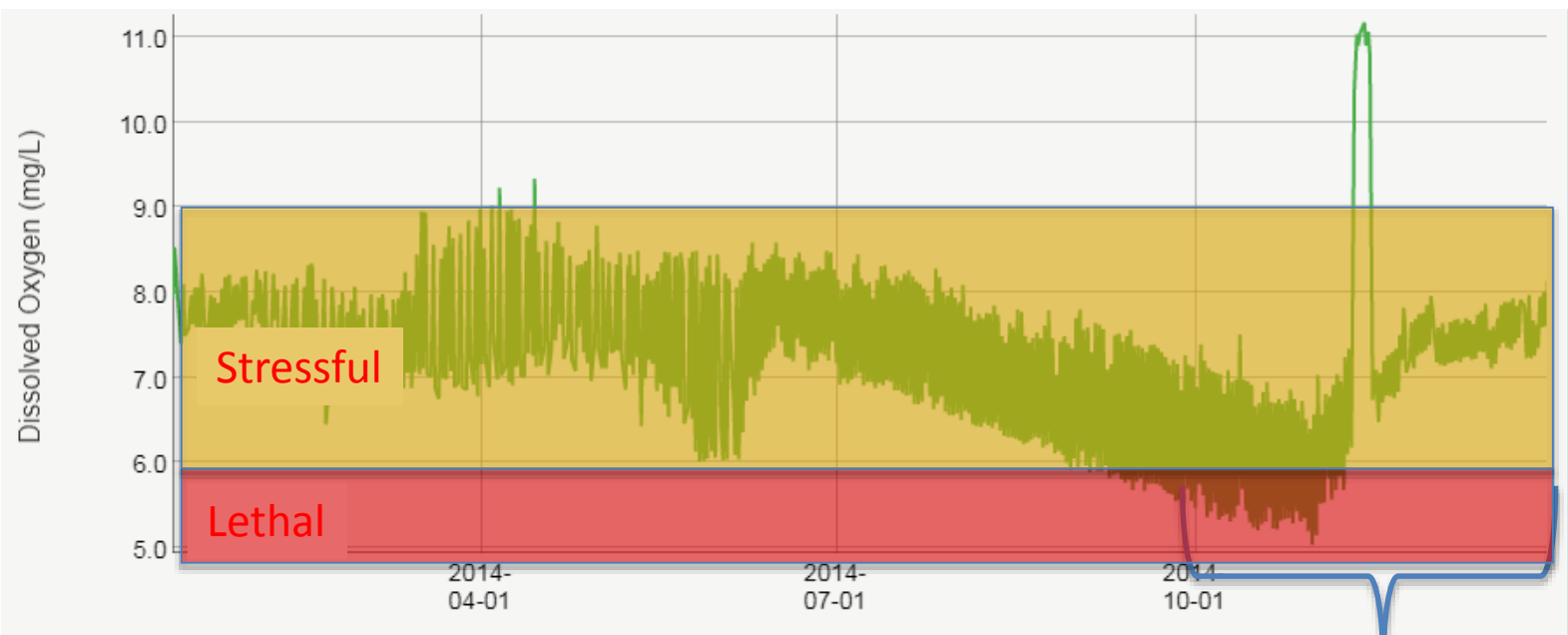


<https://henrysfork.org/average-dissolved-oxygen-requirements-salmonids>

References: Chapman, G. 1986. Ambient water quality criteria for dissolved oxygen. U.S. EPA. EPA 440/5-86-003. 46 pp.
Raleigh, R.F., T. Hickman, R.C. Solomon, and P. C. Nelson. 1984. Habitat suitability information: Rainbow trout. U.S. Fish Wildl. Serv. FWS/OBS-82/10.60. 64 pp.
Raleigh, R.F., L. D. Zuckerman, and P. C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: Brown trout, revised. U.S. Fish Wildl. Serv. Biol. Rep. 82(10.124). 66 pp.

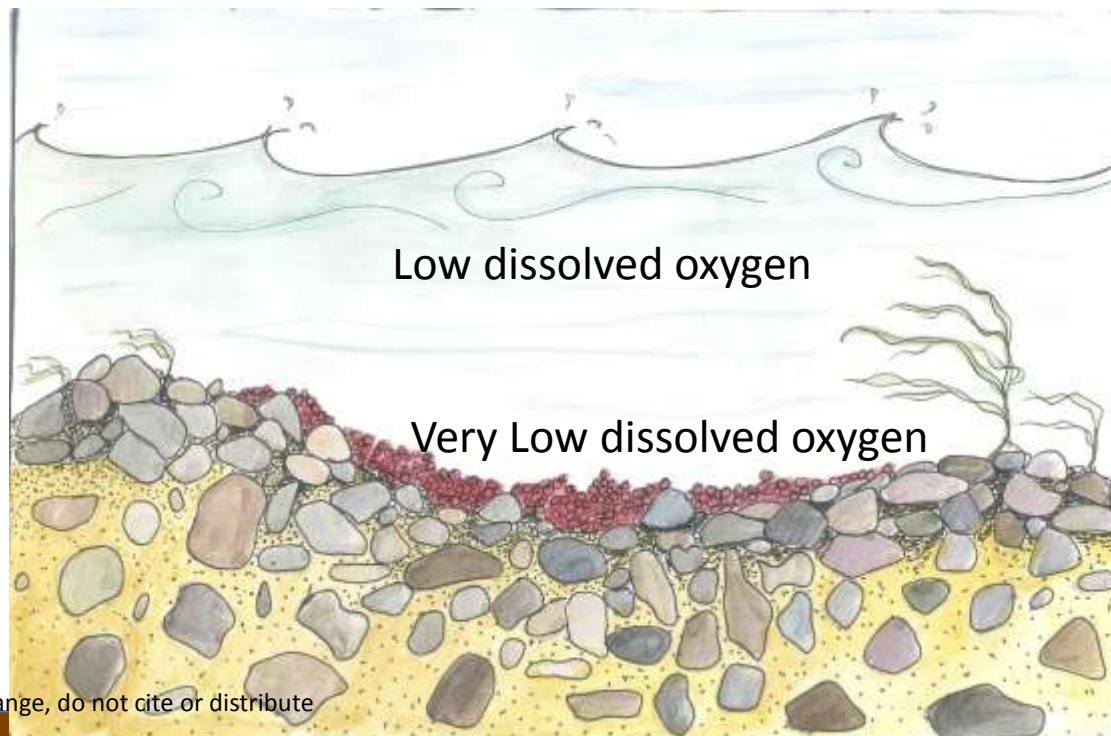
Preliminary data, subject to change, do not cite or distribute

Low dissolved oxygen during brown trout spawning

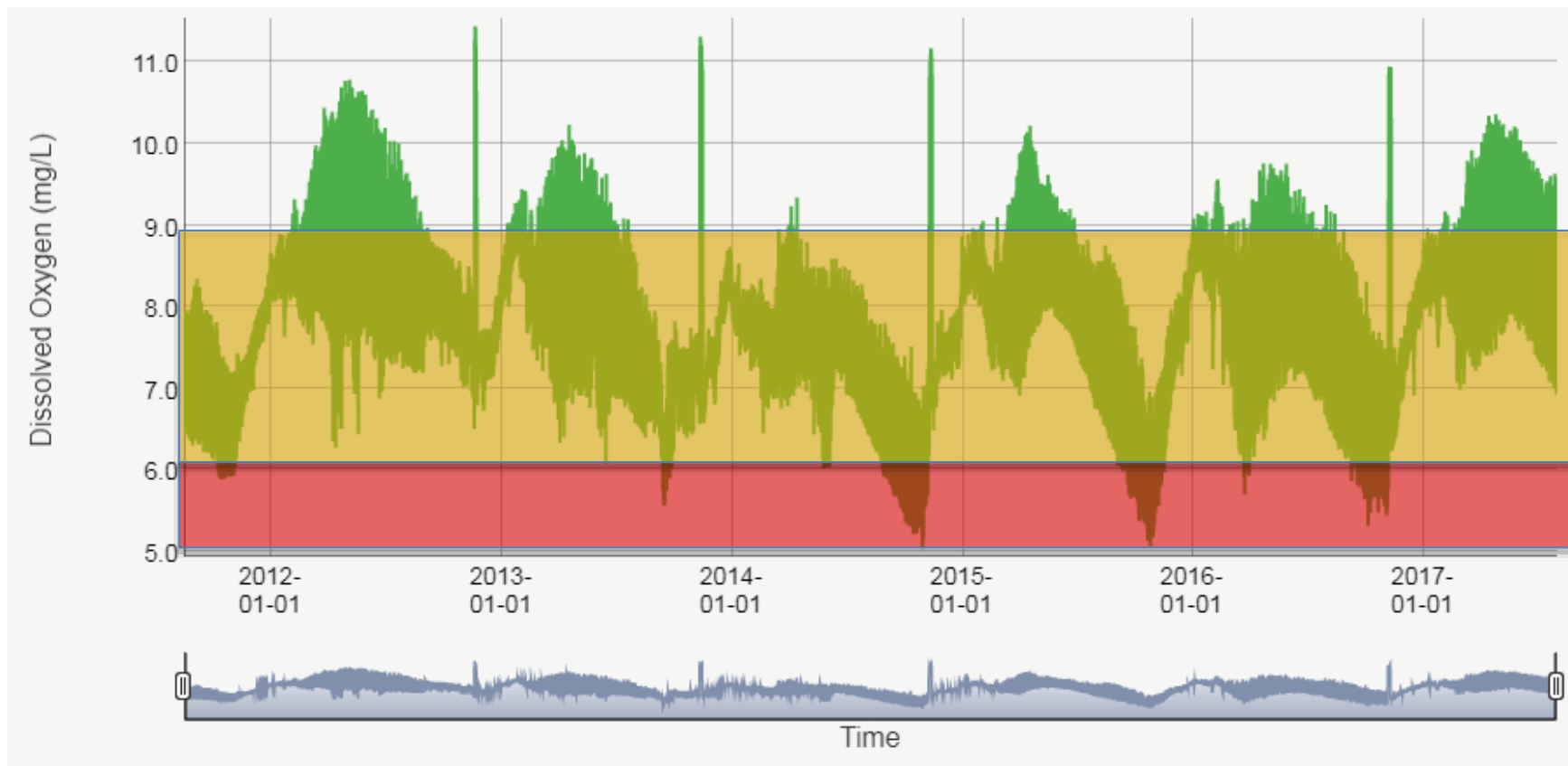


Sediment-water interface



- Very low dissolved oxygen on river bed b/c of biological oxygen demand (Larry Stevens pers. Comm.)
- Egg survival might be very low for brown trout
 - low DO and high temperatures at time of spawning

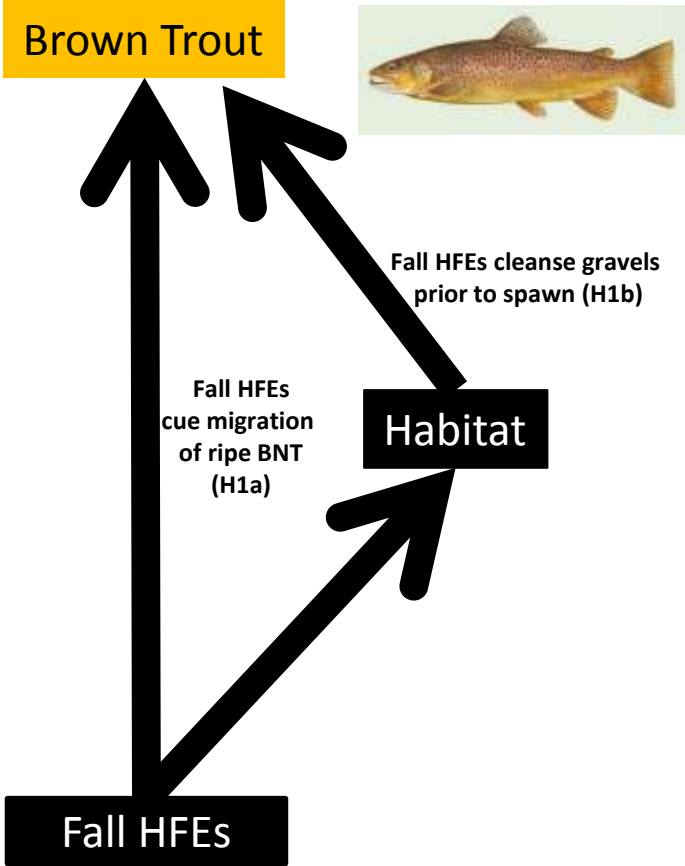
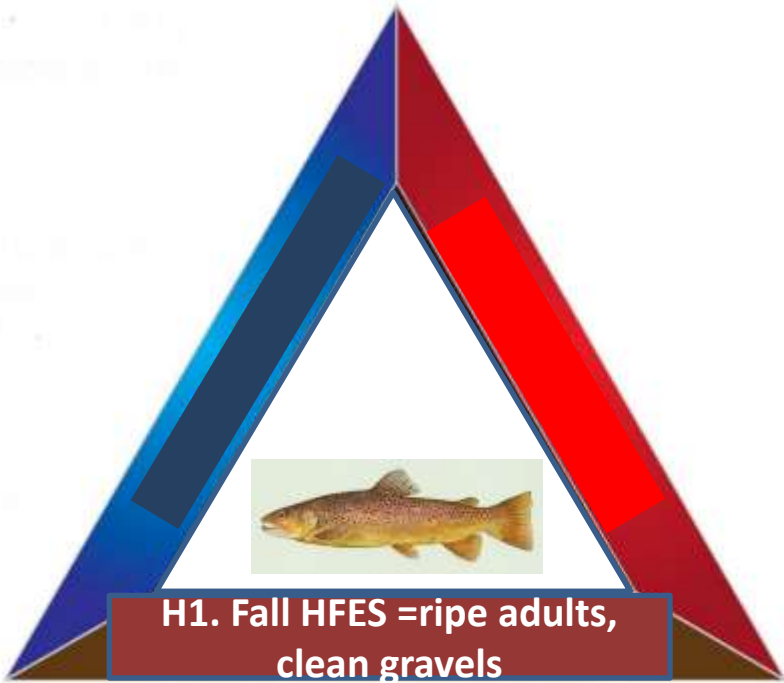


HFEs cleanse gravels at a critical time for brown trout

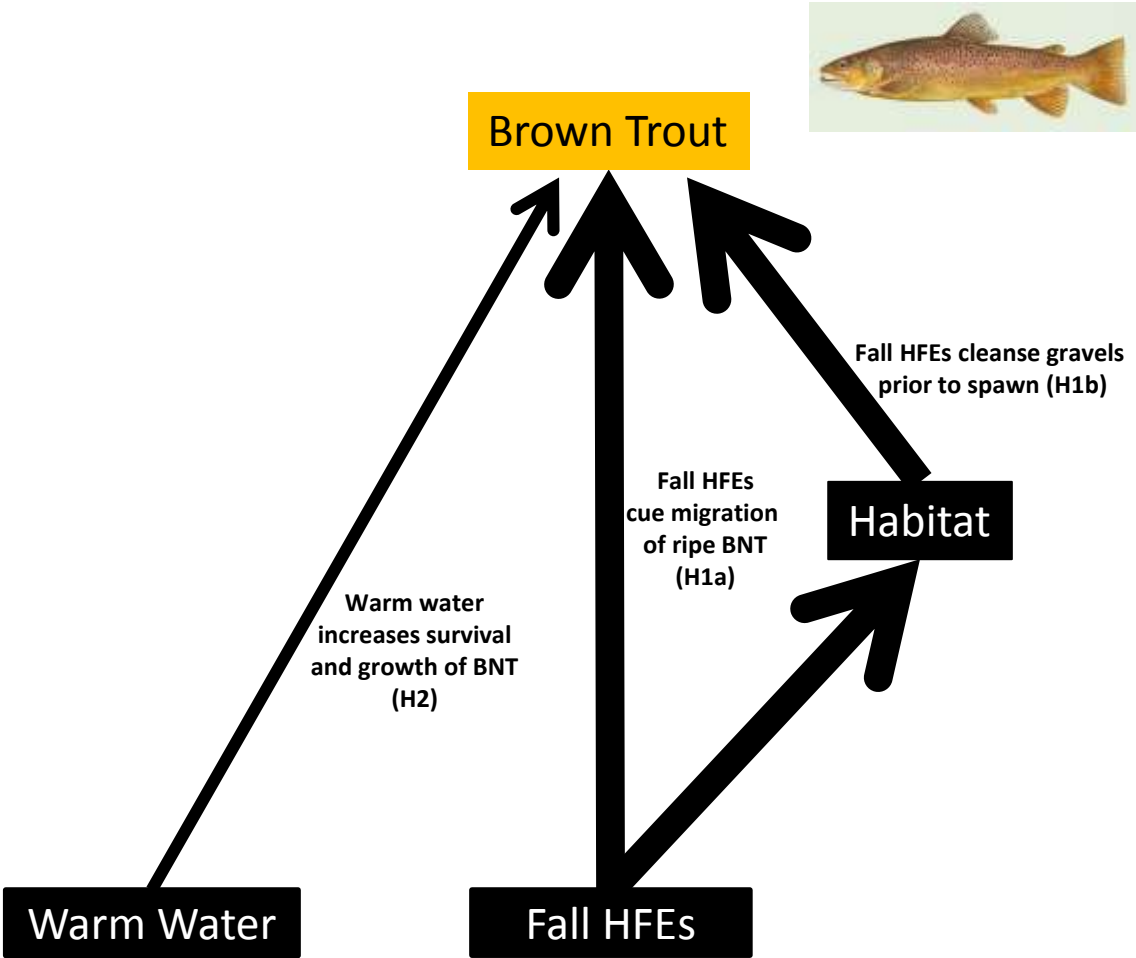


This mechanism fits another one of the facts

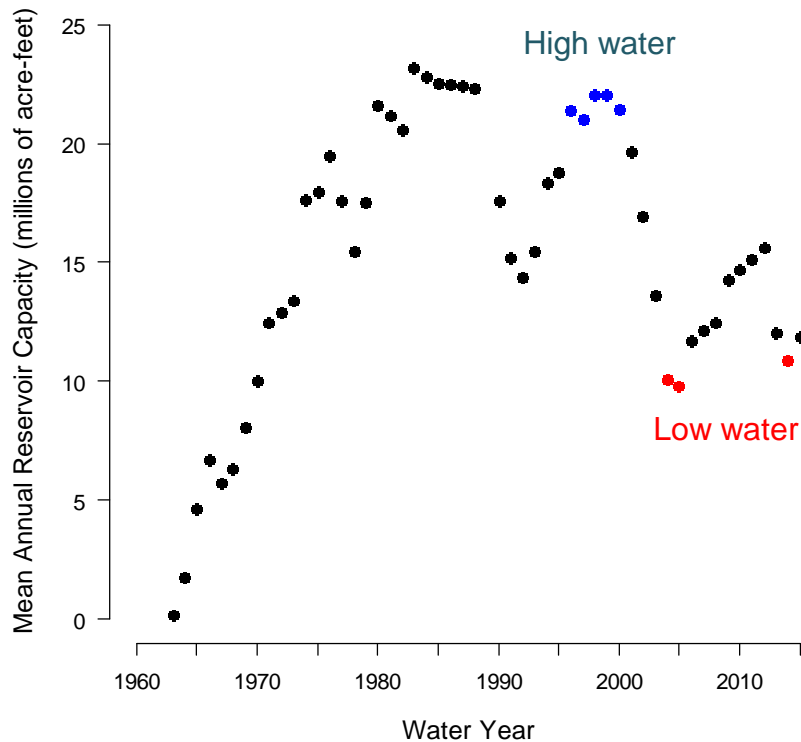
- 
 - Increase in adults 2013-2014
- 
 - Successful spawning 2015-2016
- Rainbow trout crash 2013-2016



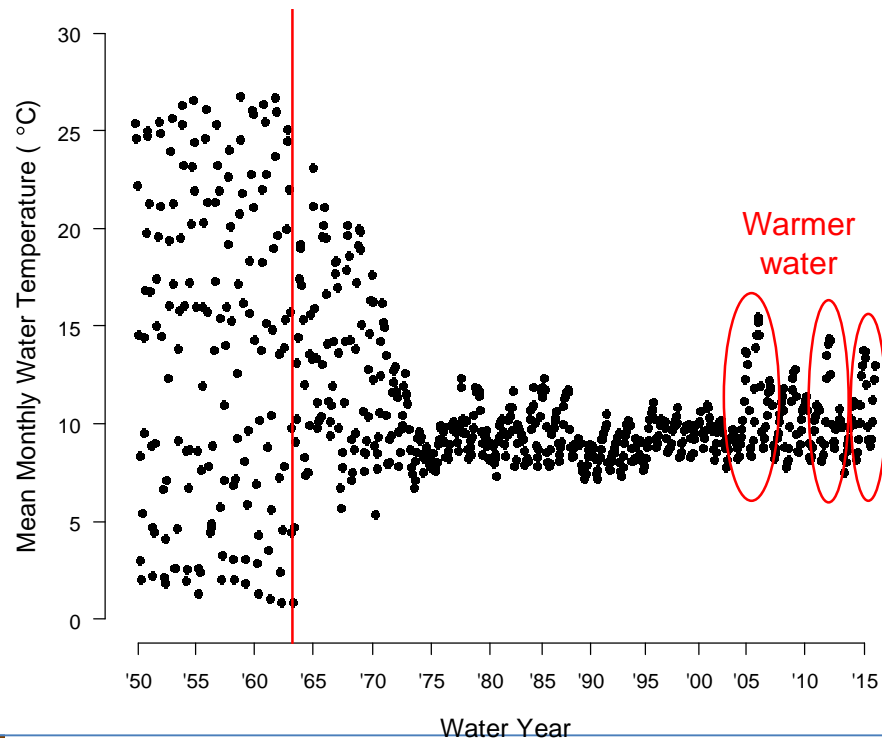
Water temperature



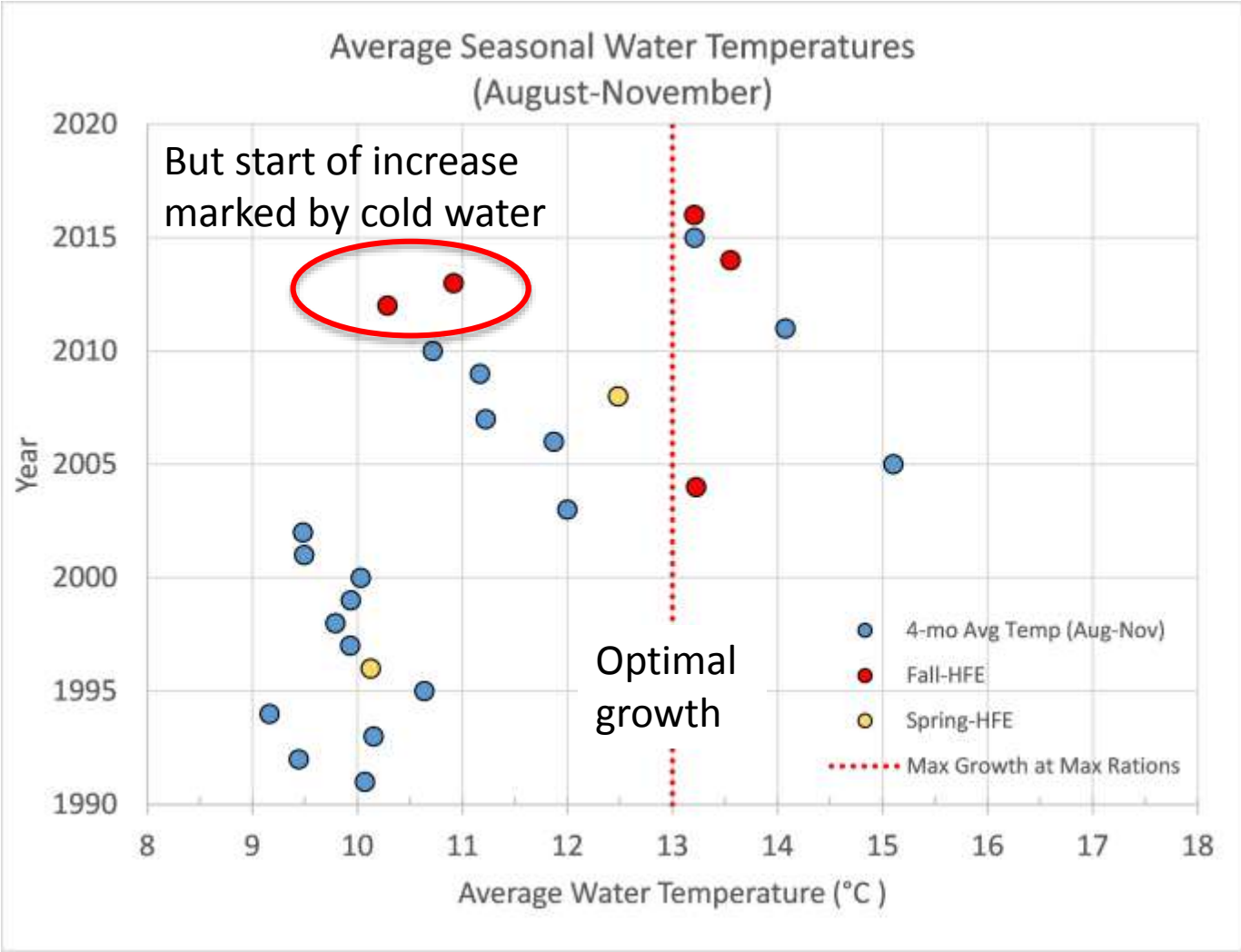
Water temperatures increase when Lake Powell levels are low



Figures courtesy of Kim Dibble, USGS



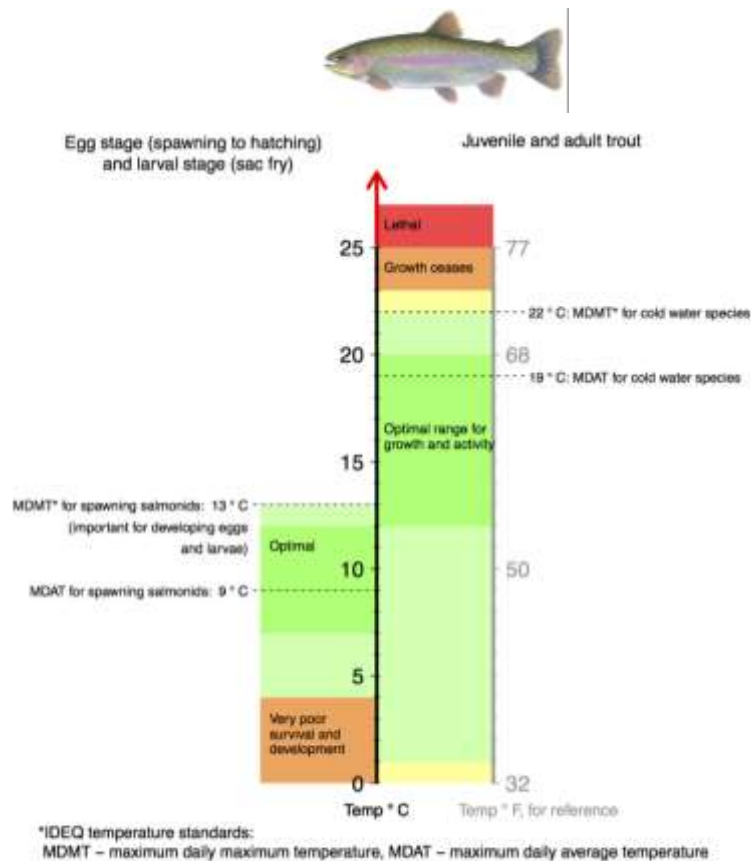
Water temperatures have been perfect for brown trout



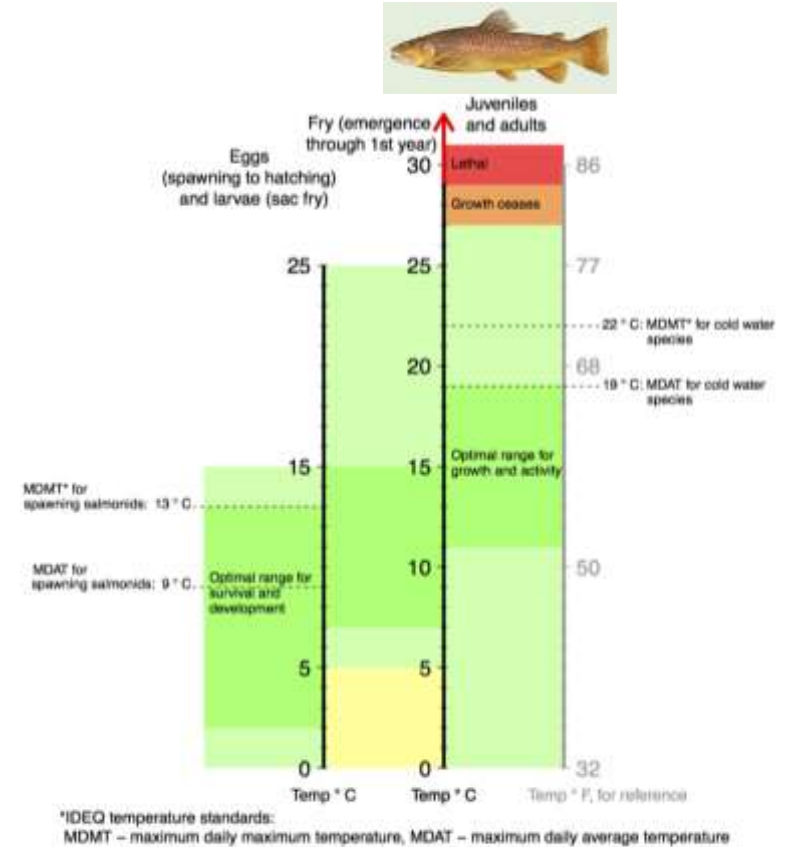
Glen Canyon Dam Adaptive Management Program

Brown Trout Workshop 2017

But temperatures also perfect for rainbow trout?



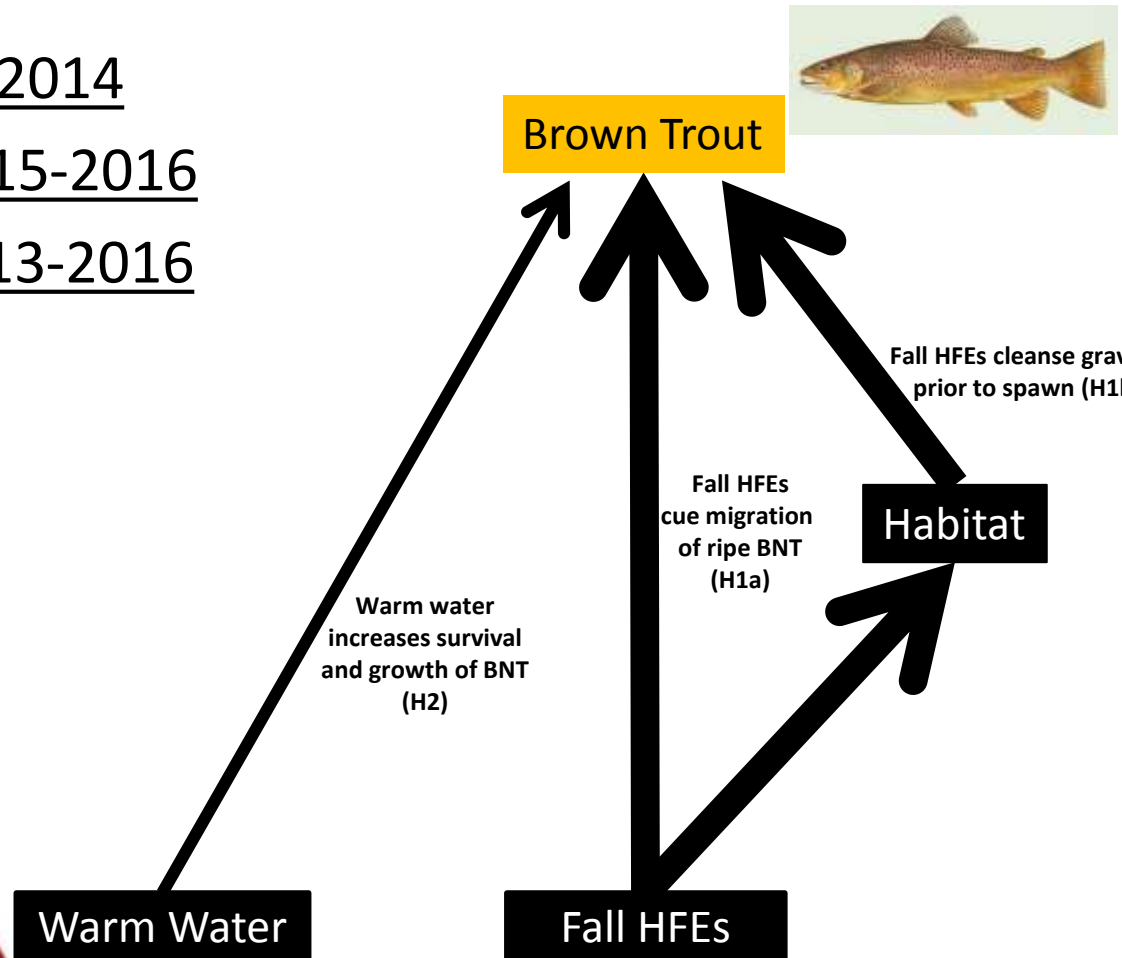
References: Raleigh, R.F., T. Hopman, R.C. Solomon, and P. C. Nelson. 1984. Habitat suitability information: Rainbow trout. U.S. Fish Wild. Serv. FWS/OBS-82/10.60. 64 pp.
Idaho D.E.Q. (2015, October). Stream Temperature Standards. Retrieved from <http://ideq.idaho.gov/water-quality/surface-water/temperature.aspx>



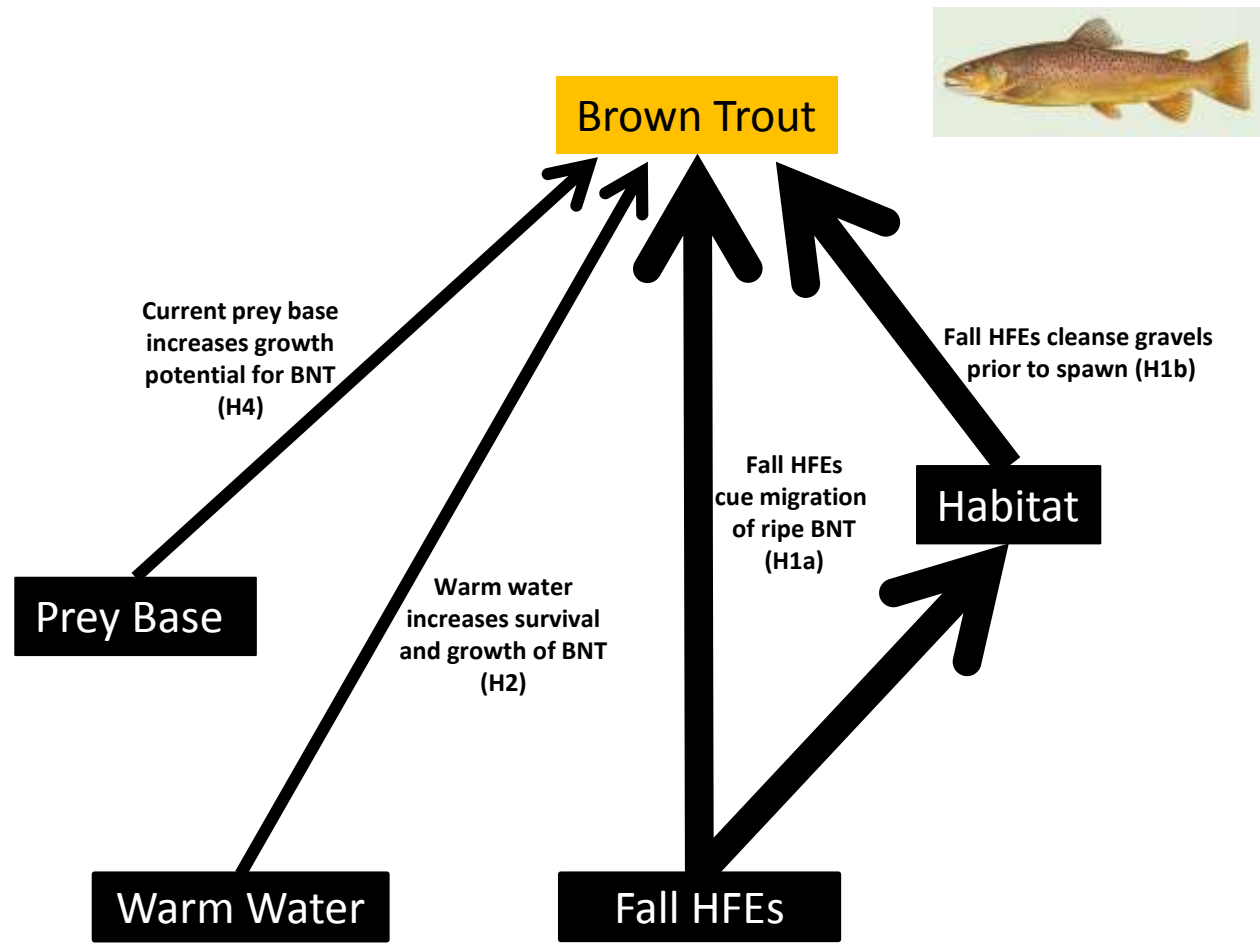
References: Raleigh, R.F., T. Hopman, R.C. Solomon, and P. C. Nelson. 1984. Habitat suitability information: Rainbow trout. U.S. Fish Wild. Serv. FWS/OBS-82/10.60. 64 pp.
Idaho D.E.Q. (2015, October). Stream Temperature Standards. Retrieved from <http://ideq.idaho.gov/water-quality/surface-water/temperature.aspx>

Temperature aligned with spawning opportunities

- ✓ Increase in adults 2013-2014
- ✓ Successful spawning 2015-2016
- Rainbow trout crash 2013-2016

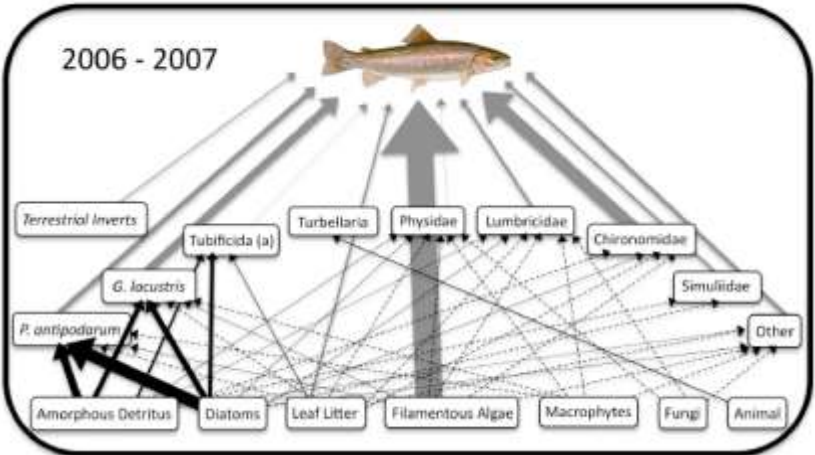


Prey base

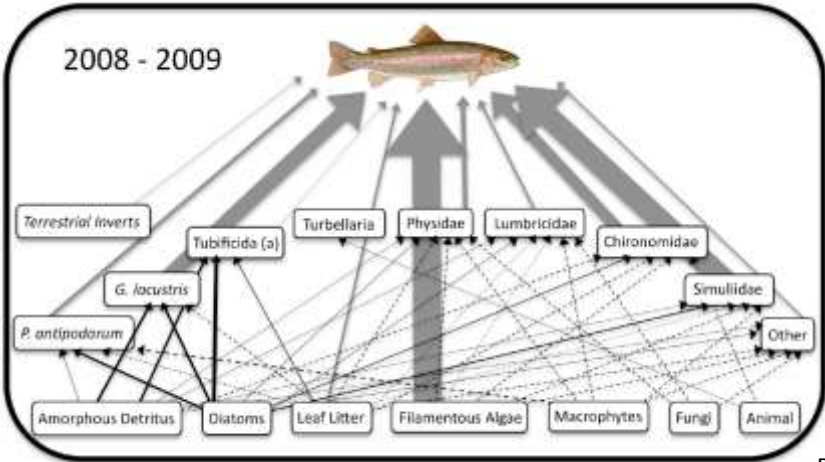


2008 Spring HFE stimulated rainbow trout prey base (midges and black flies)

No HFE

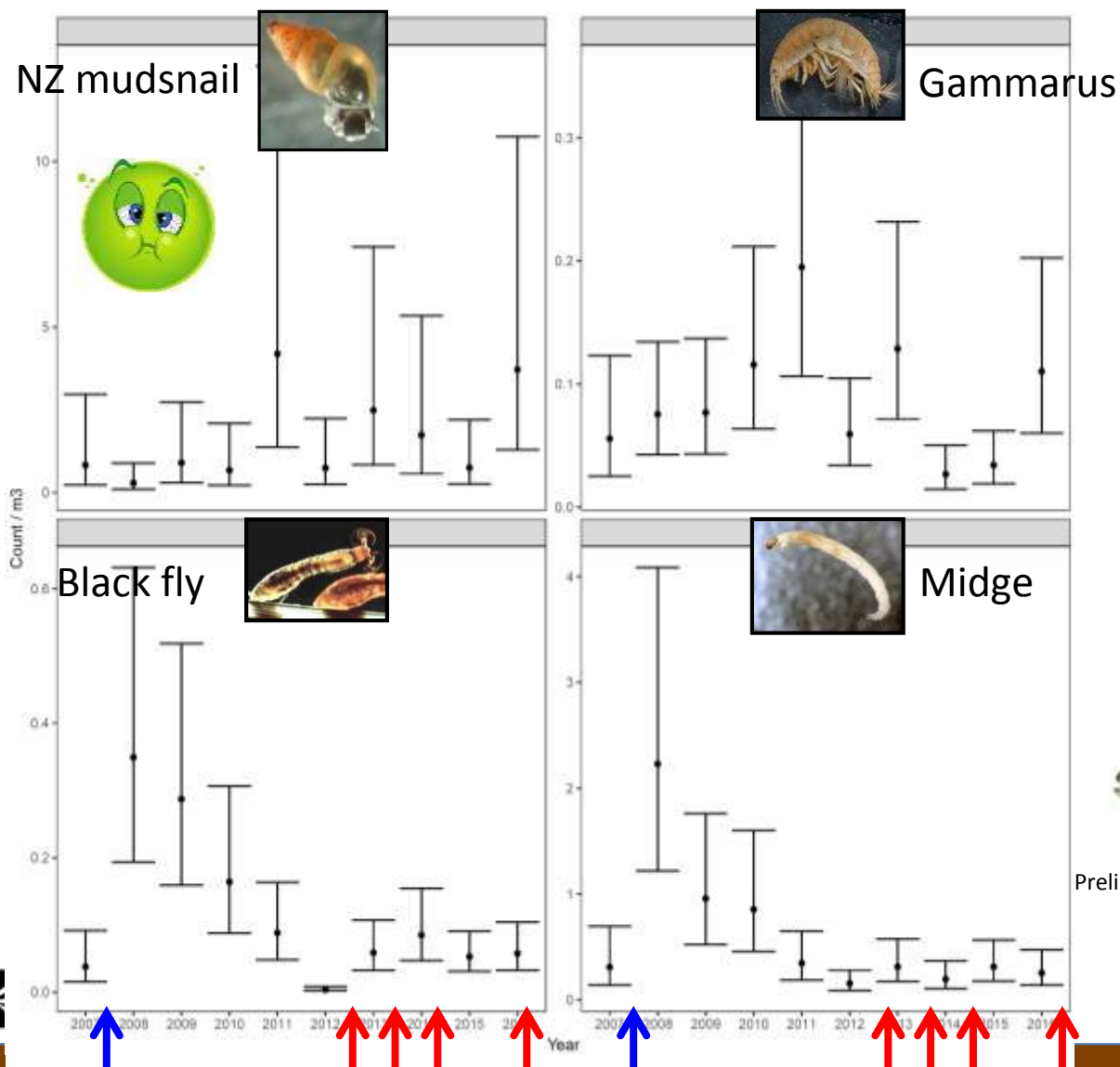


2008 Spring HFE



Preliminary data, subject to change, do not cite or distribute

Drift monitoring in Lees Ferry

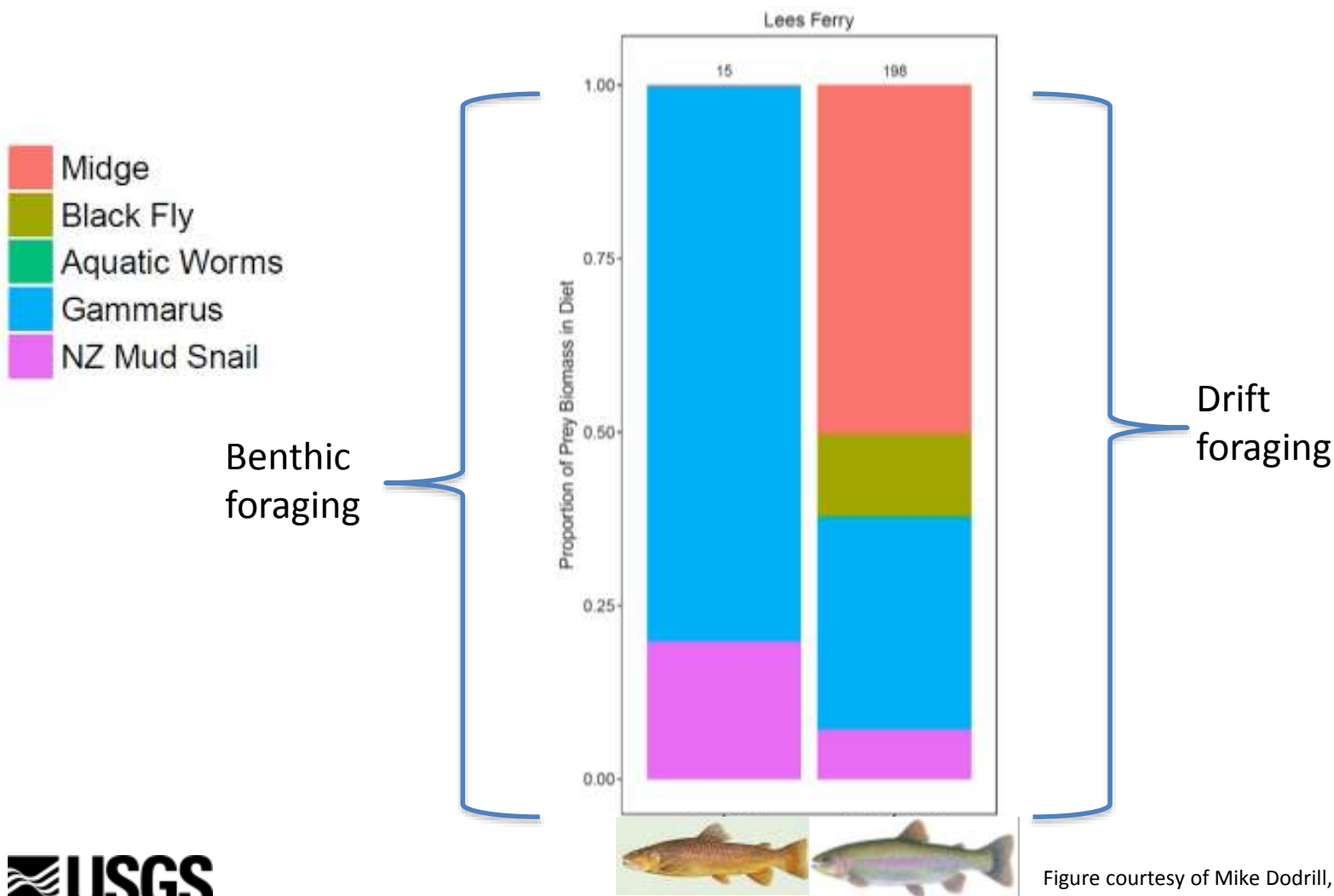


Preliminary data, subject to change, do not cite or distribute

↑ Spring HFE

↑ Fall HFE

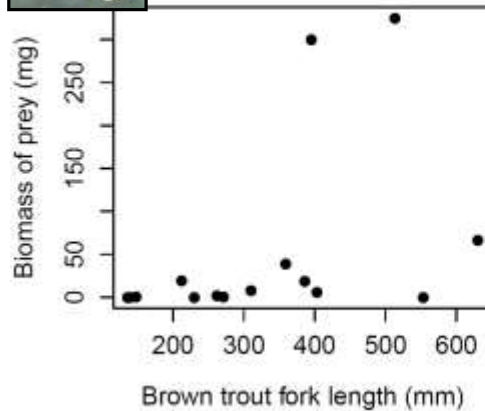
Feeding habits of brown trout ≠ rainbow trout.



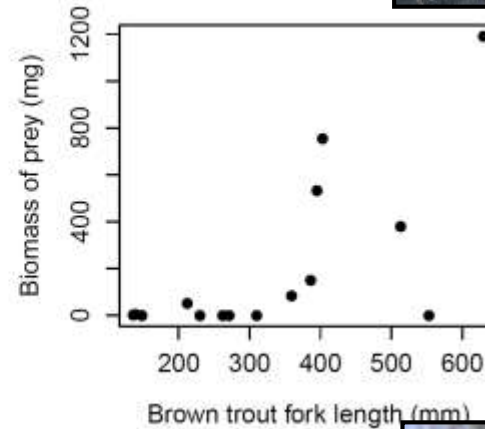
Large brown trout eating Gammarus and mudsnails



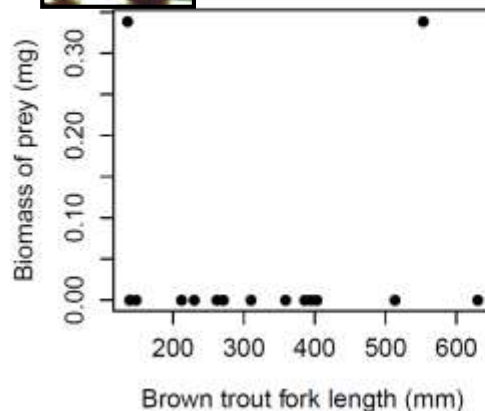
New Zealand mudsnail



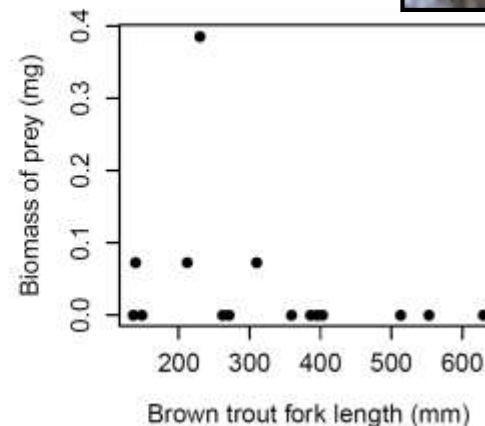
Gammarus



Black fly



Midge



Gill raker spacing makes benthic foraging possible.

- Rainbow trout
 - drift feed
- Brown trout
 - can drift feed or benthic

I'm hungry



Mmm, gammarus, my favorite

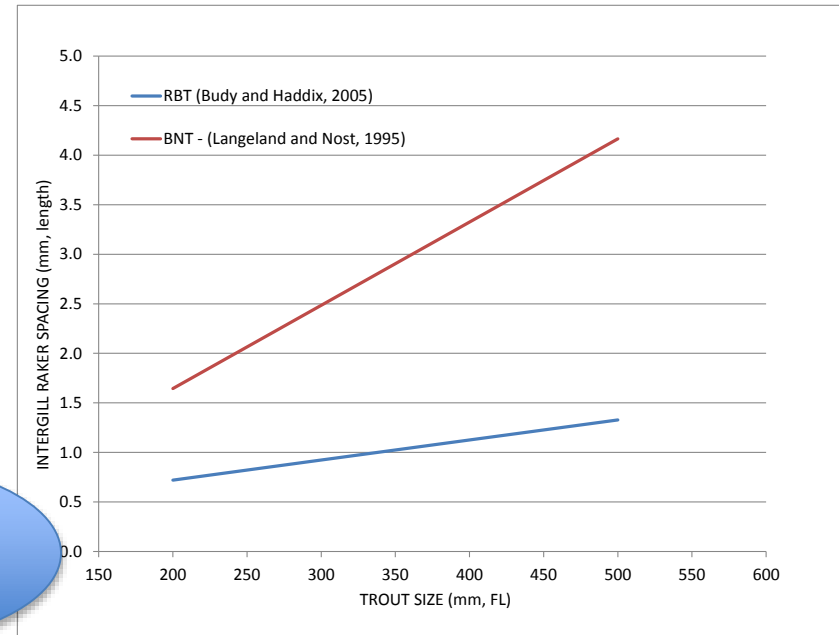
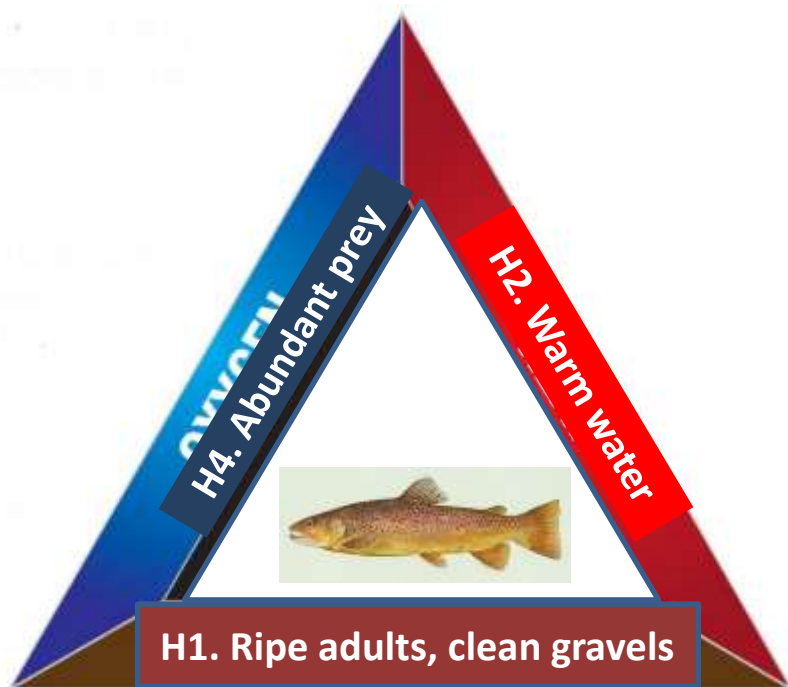


Figure courtesy of Mike Yard, USGS

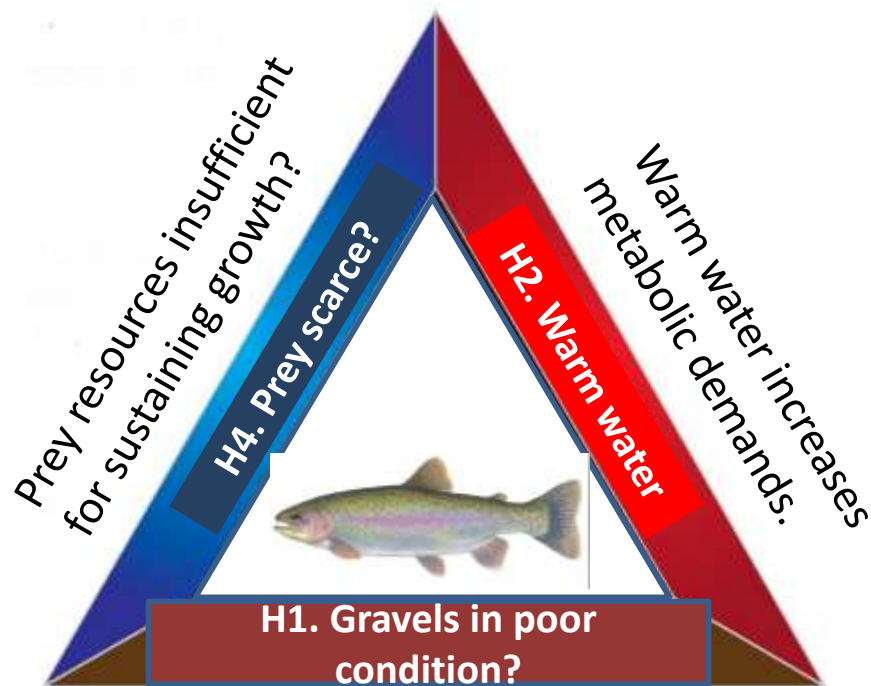
This combination of hypotheses fits all the facts

- ✓ Increase in adults 2013-2014
- ✓ Successful spawning 2015-2016
- ✓ Rainbow trout crash 2013-2016

Brown trout



Rainbow trout



H7: Brown Trout have increased because of hyper-abundant Rainbow Trout

- Evidence for: The diets of rainbow trout are prey
- Evidence against: Brown Trout are rare where there are >100,000



Conclusion: Falsified



H3: Whirling disease (WD) affected Rainbow Trout provide abundant prey for Brown Trout.

- Evidence for: WD is present in Lees Ferry. WD has caused declines in RBT and increases in BNT in many streams and rivers.
- Evidence against: Infection rate in Lees Ferry is low (deformities, whirling swimming are rare).

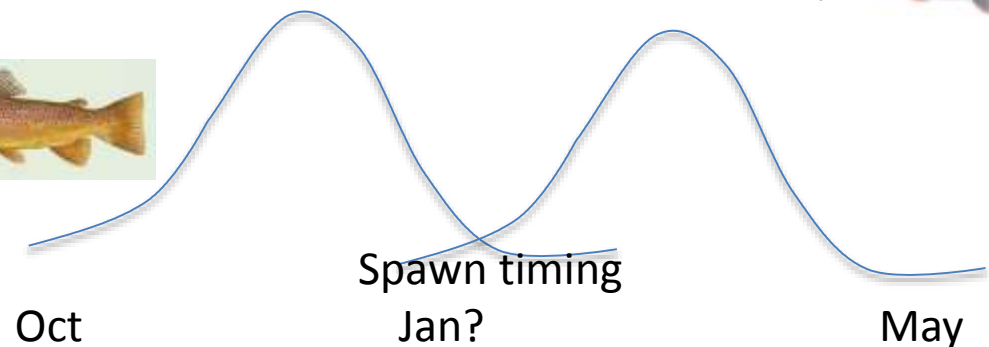
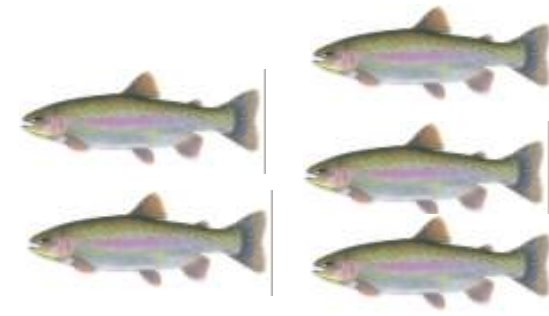
Conclusion: Weak hypothesis, but can't falsify without better info on WD (batch testing coarse method of monitoring)



H6. Brown trout have increased because of declines in Rainbow Trout and less interference spawning.

- Evidence for: Examples in literature of RBT superimposing eggs on top of BNT reducing egg survival.
- Evidence against: No increase in BNT from 2003-2007 when RBT abundance was low and declining.

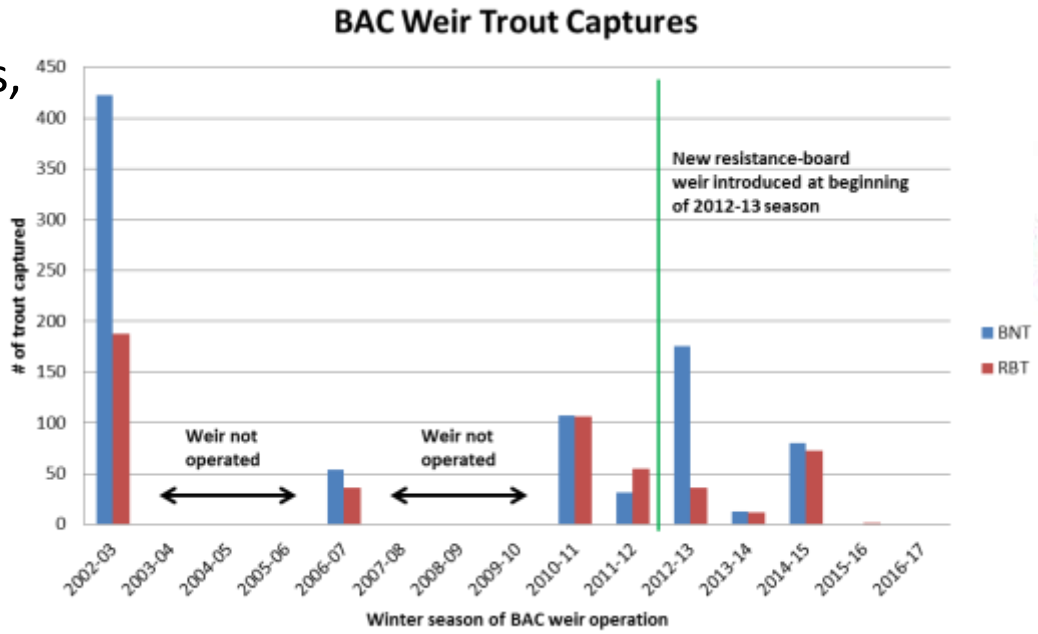
Conclusion: Weak hypothesis, but can't falsify without more details on BNT spawning (never studied).

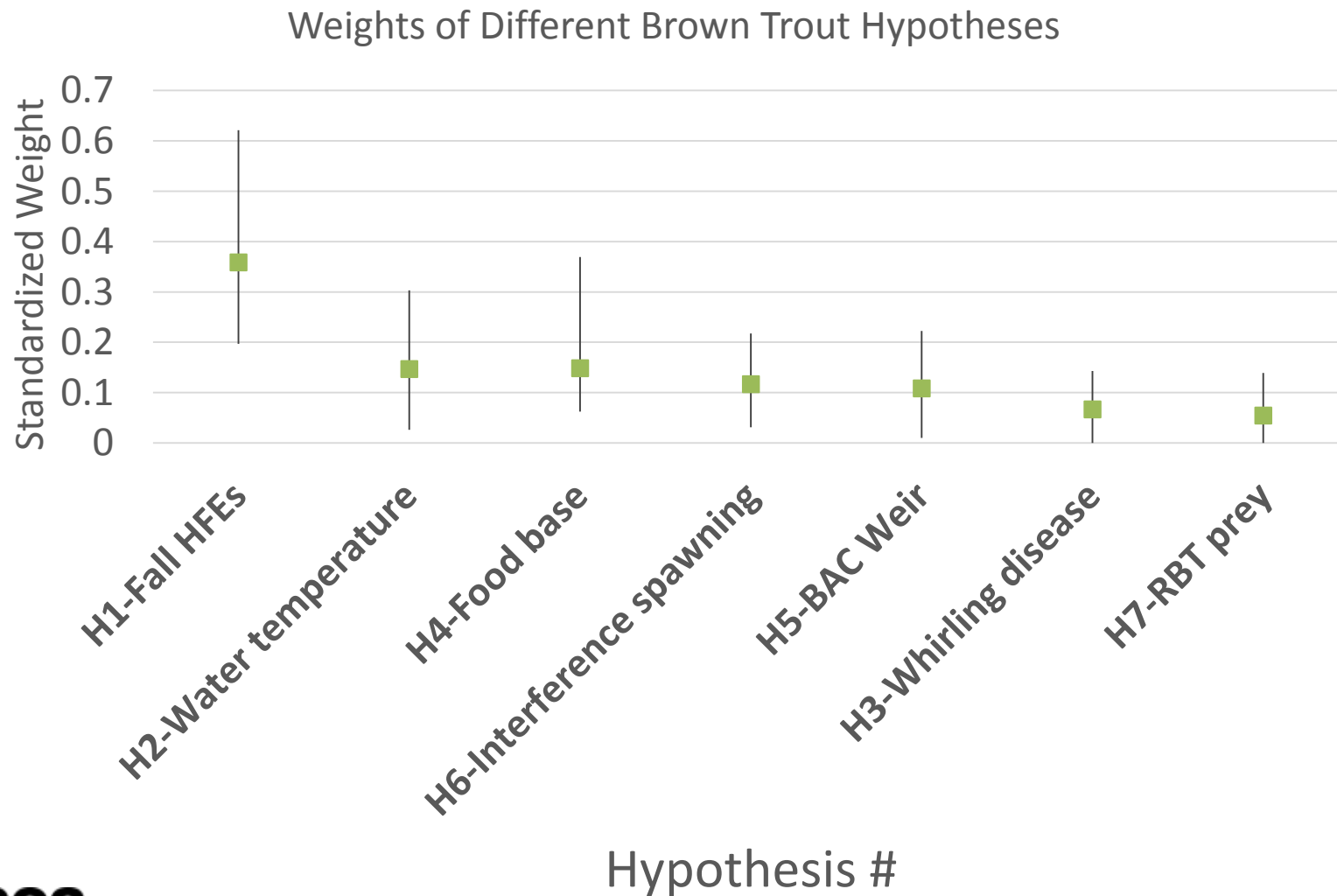


H5: Weir at Bright Angel Creek forced Brown Trout to migrate in search of new spawning grounds.

- Evidence for: Hell hath no fury like a brown trout...
- Evidence against: First four seasons of weir operation not correlated with increases in brown trout at Lees Ferry.

Conclusion: Weak hypothesis, but can't falsify without e.g., otolith microchemistry.





Life cycle timing is key

