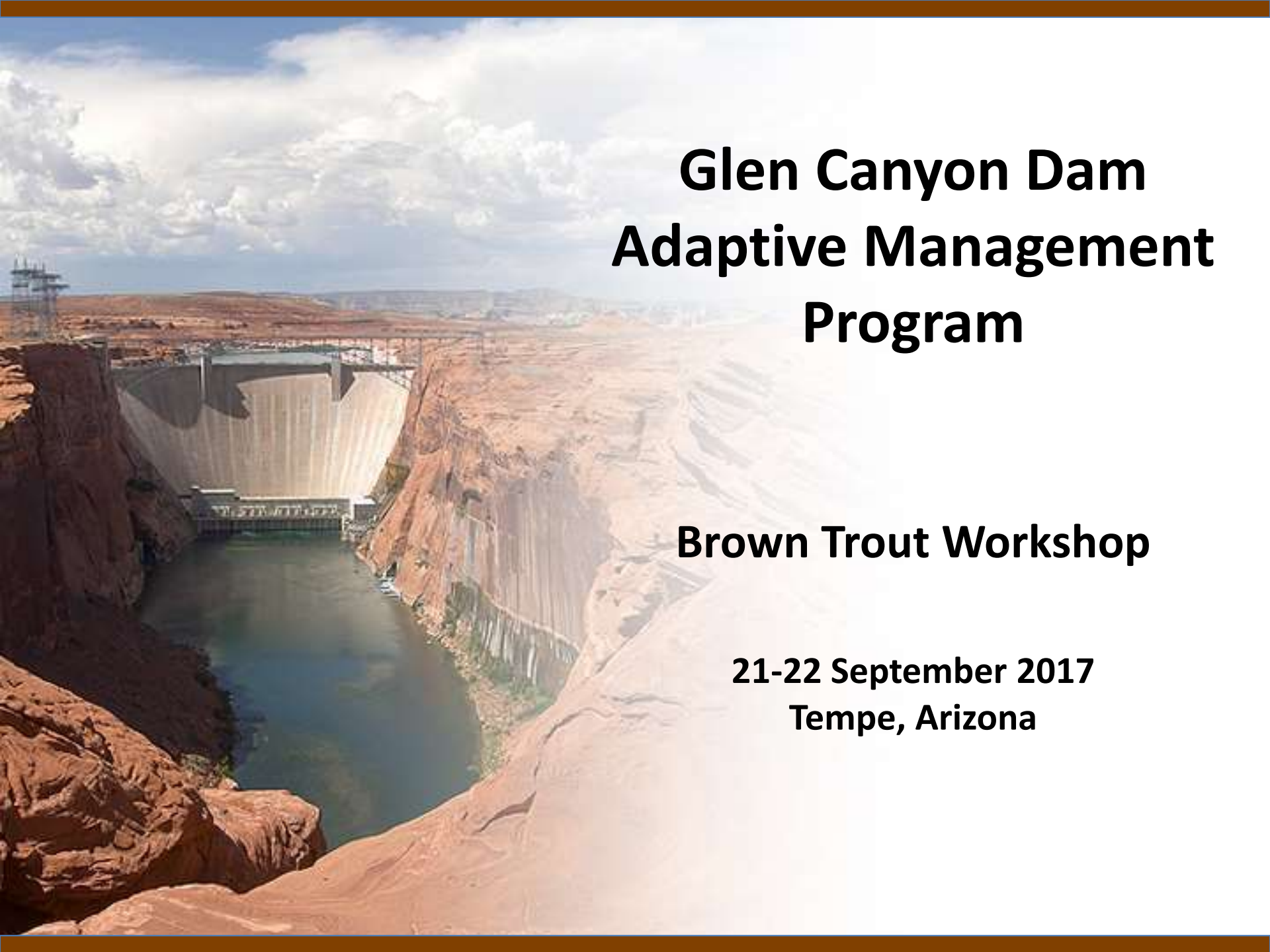


Glen Canyon Dam Adaptive Management Program

Brown Trout Workshop

21-22 September 2017
Tempe, Arizona

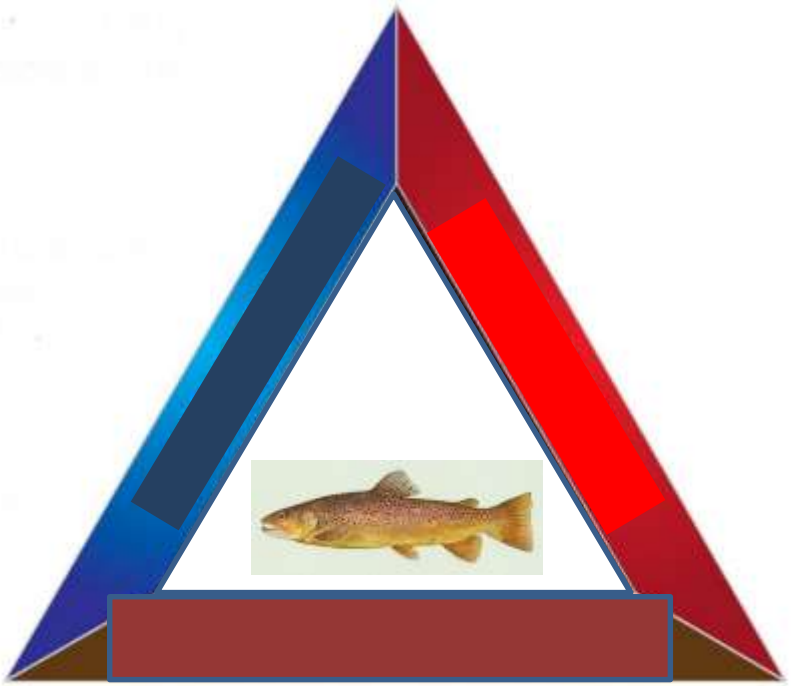
Root causes for the increase of brown trout in the Lees Ferry reach

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?

Figure courtesy of David Rogowski, AZGFD

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

USGS

What are the facts?

- 2013: more adults

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Figure courtesy of David Rogowski, AZGFD

USGS

What are the facts?

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(successful spawn in 2014)

Figure courtesy of David Rogowski, AZGFD

- 2016: new juveniles

(successful spawn in 2015)

USGS

What are the facts?

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- 2014: more adults,

& hint of more juveniles

- 2015: new juveniles

(successful spawn in 2014)

- 2016: new juveniles

(successful spawn in 2015)

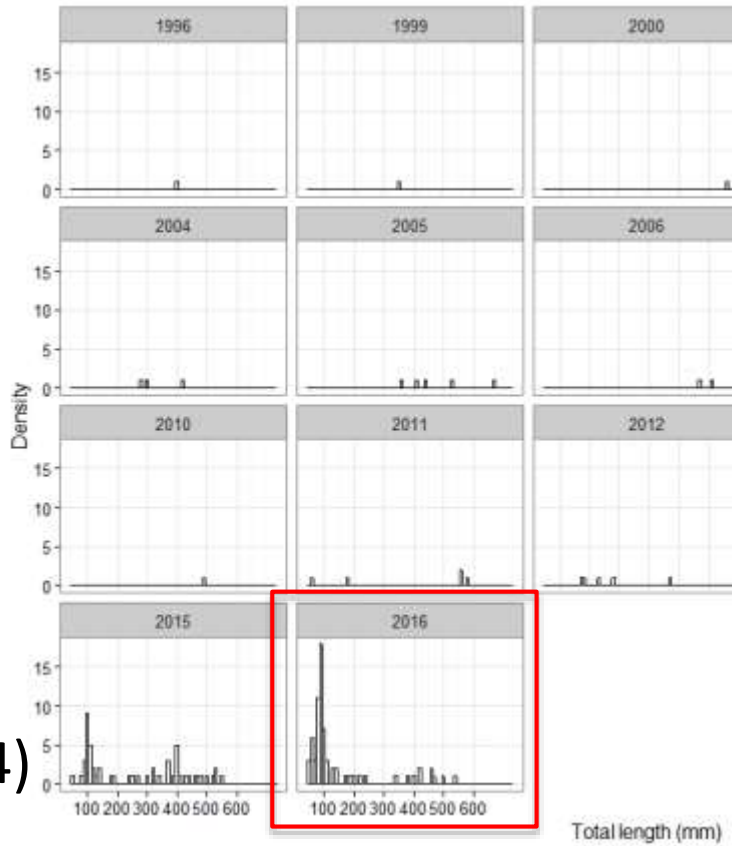


Figure courtesy of David Rogowski, AZGFD

USGS

Did you notice anything else unusual?

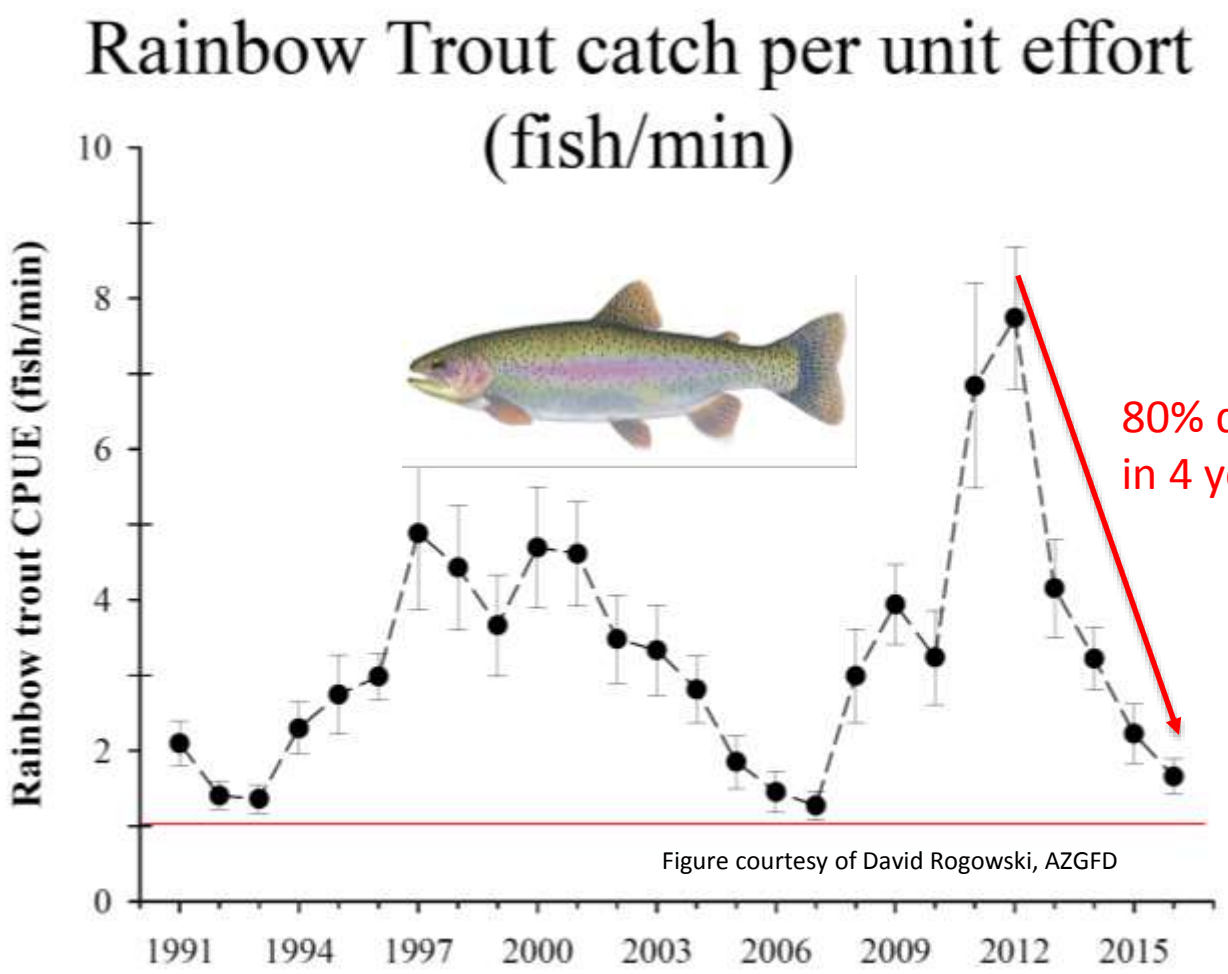
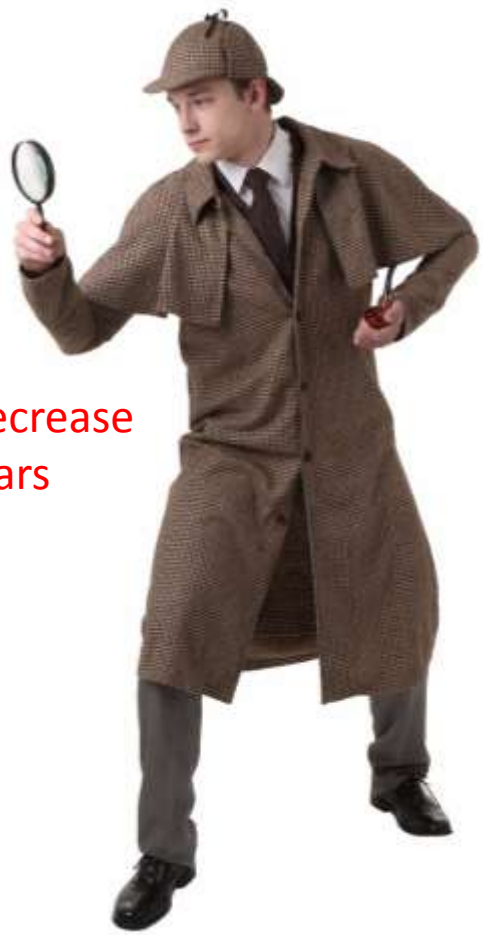


Figure courtesy of David Rogowski, AZGFD



USGS

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?

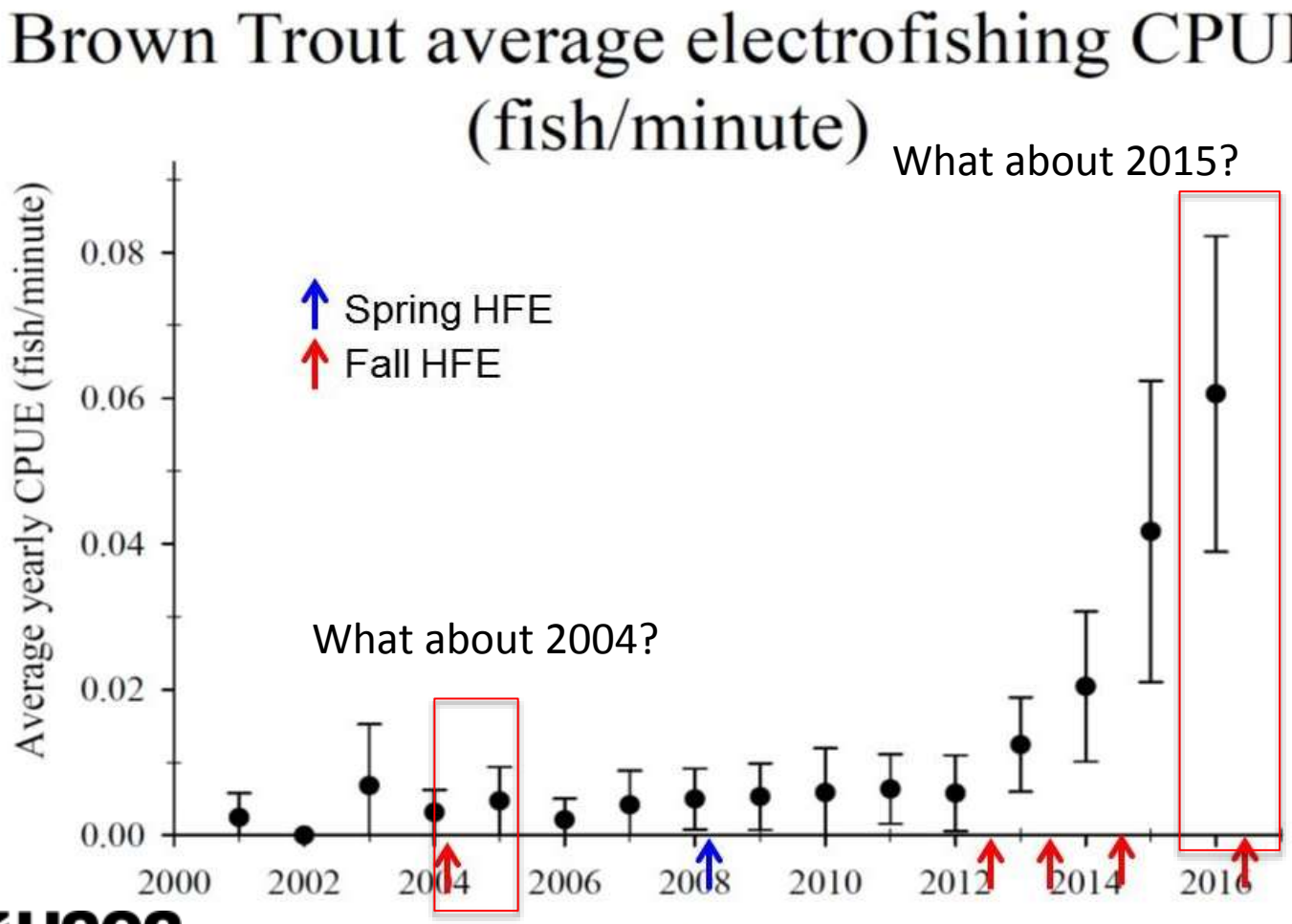
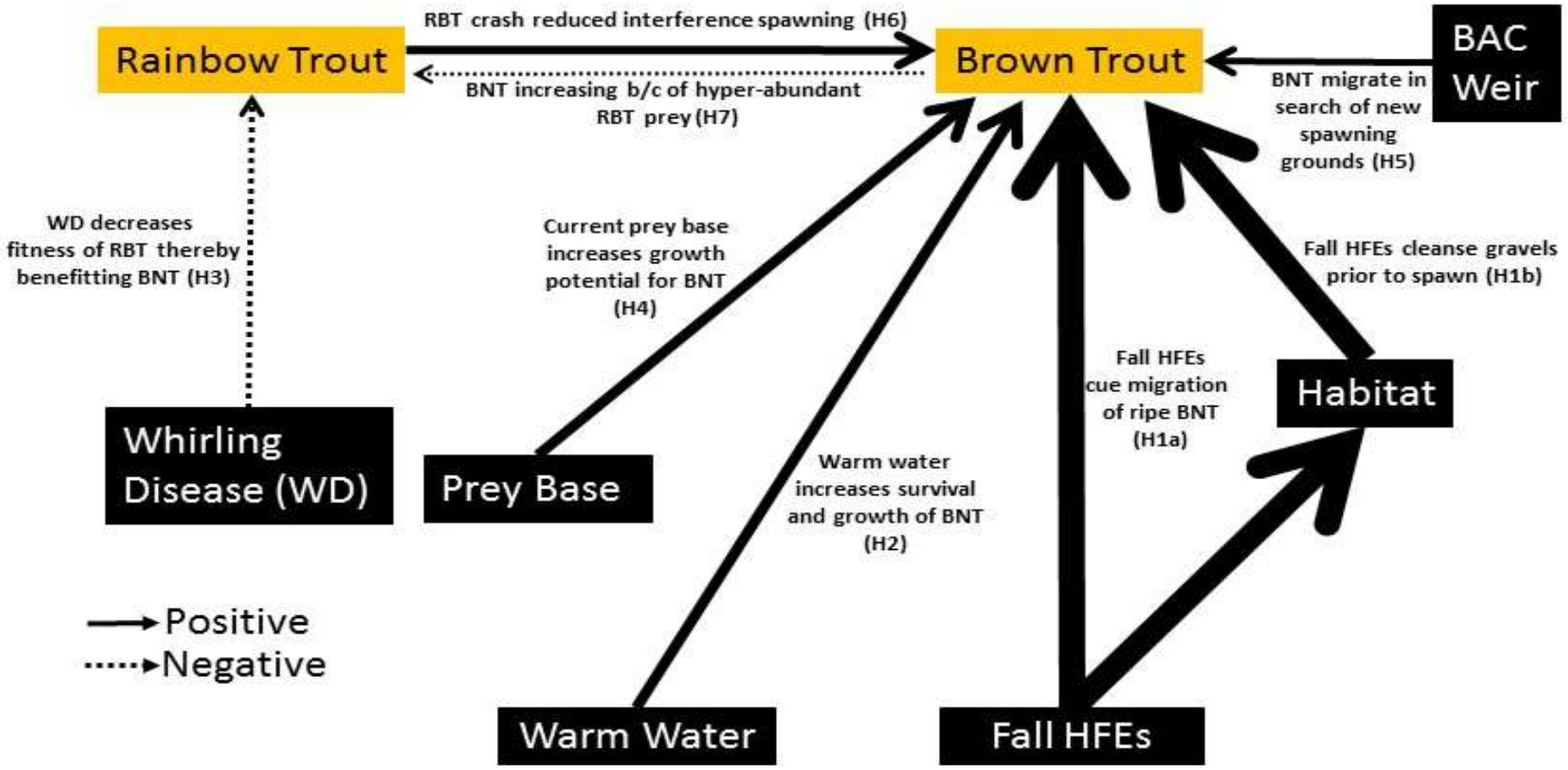


Figure courtesy of David Rogowski, AZGFD

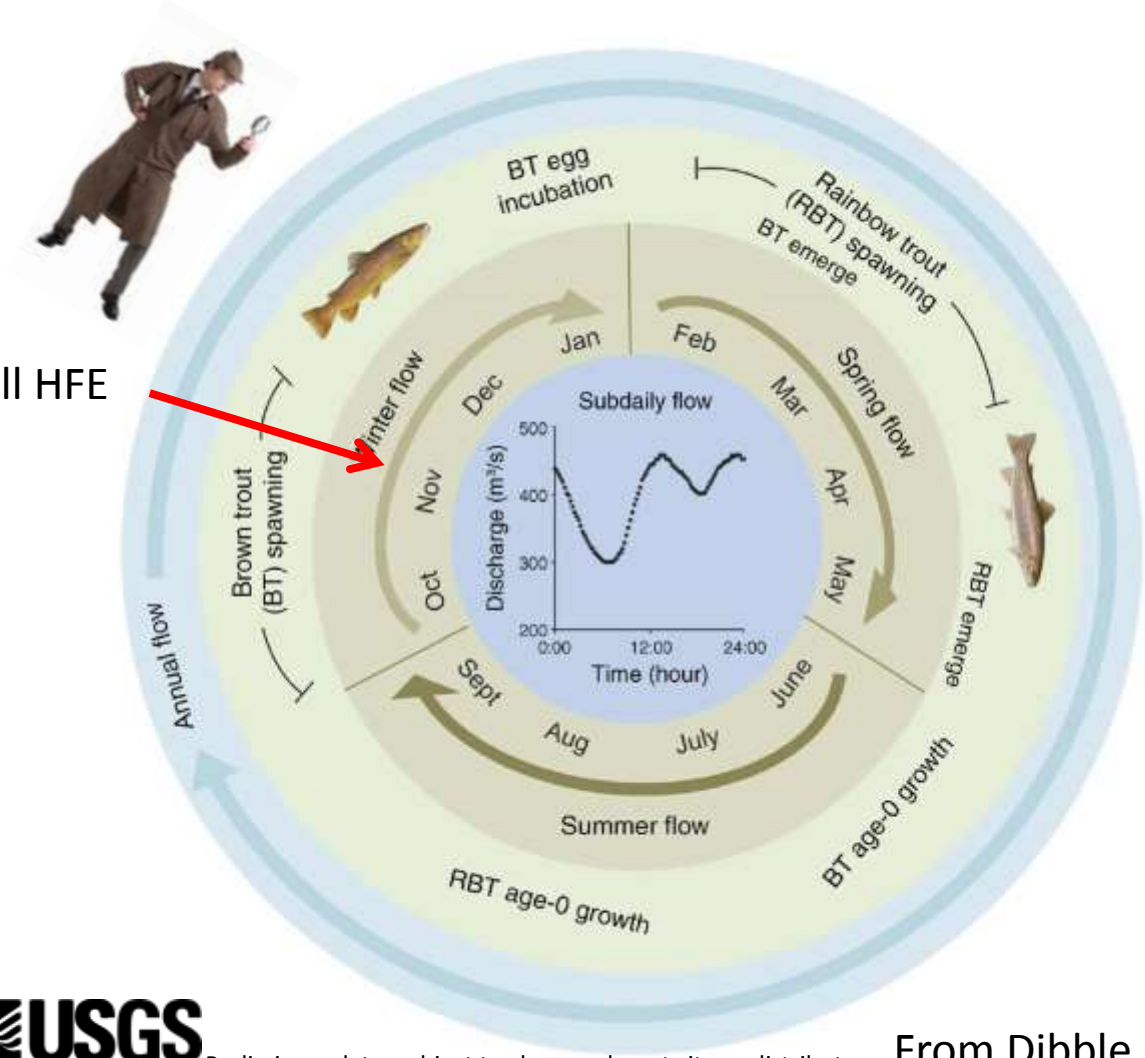
We considered 7 hypotheses

Hypothesis #	Type of hypothesis	Hypothesis
H1	Physical driver	Fall HFEs
H2	Physical driver	Warmer water
H4	Biological driver	Prey base
H6	Biological driver	Less interfence 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



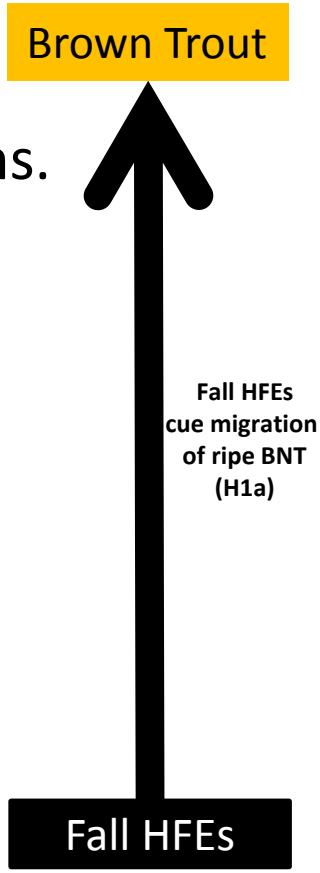
Fall HFE

"[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."

From Dibble et al. 2015, *Ecological Applications*.

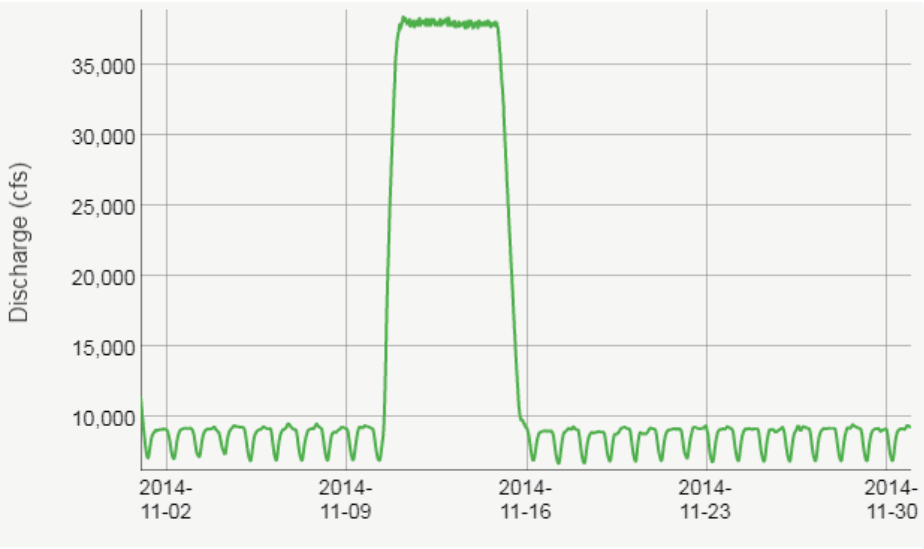
Spawning migration one example

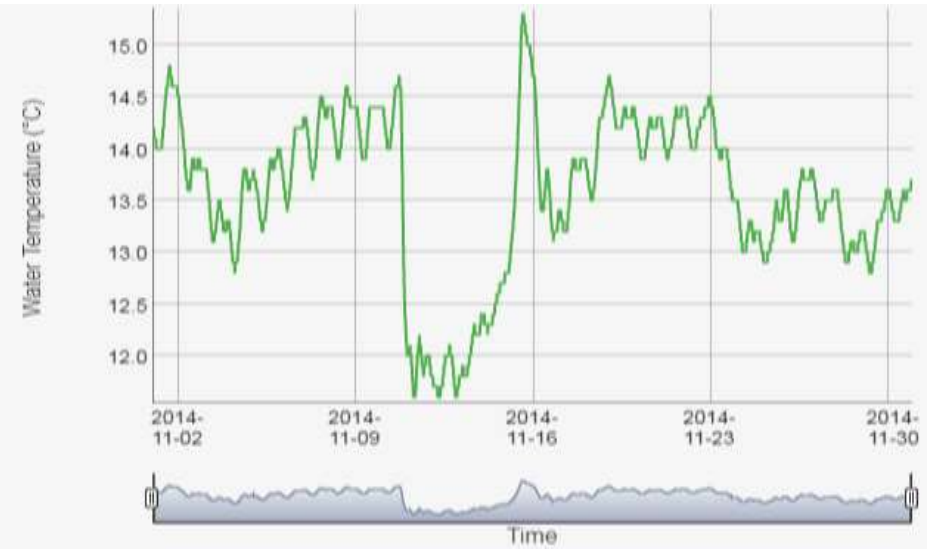
- Ovidio and others, 1998
- Radio tagged brown trout in Belgian streams.
- Essentially no movement for weeks until….
- High variance in water temperature and discharge
- Which triggered spawning migrations and movement up to 5 km per night



- 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

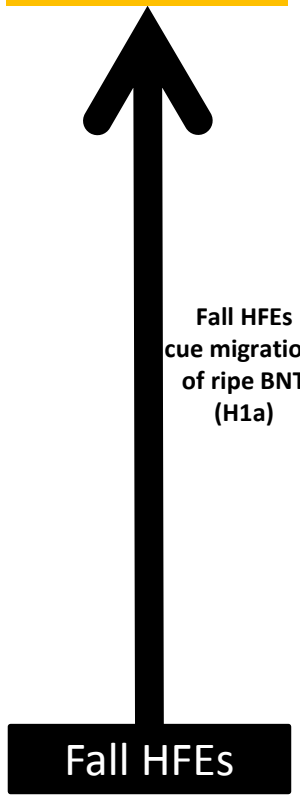




Figures drawn from https://www.gcmrc.gov/discharge_qw_sediment/station/GCDAMP/09380000

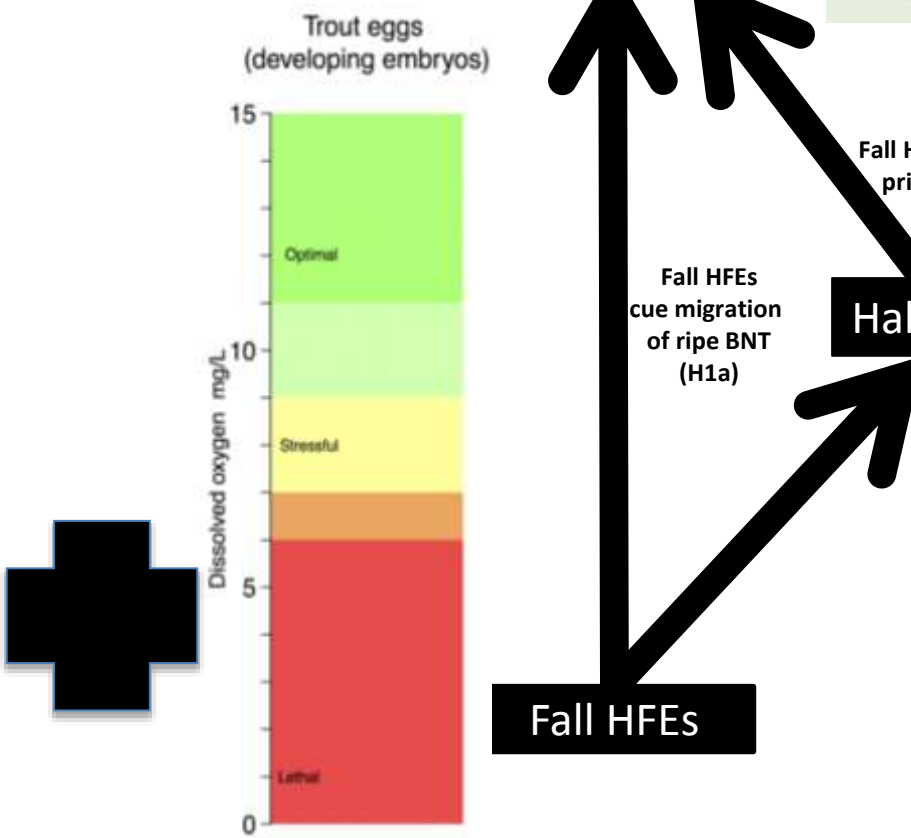
This hypothesis (mechanism) fits one of the facts

- 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



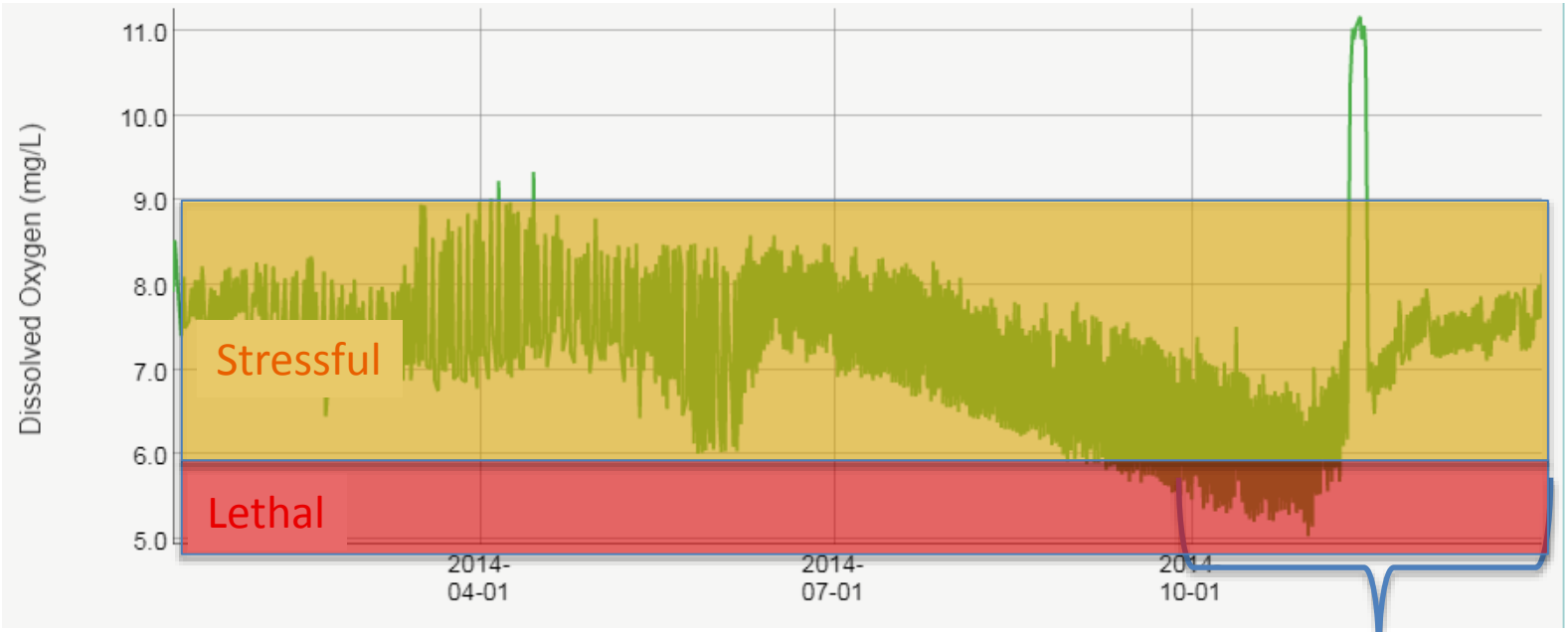
https://henrysfork.org/average-dissolved-oxygen-requirements-salmonids

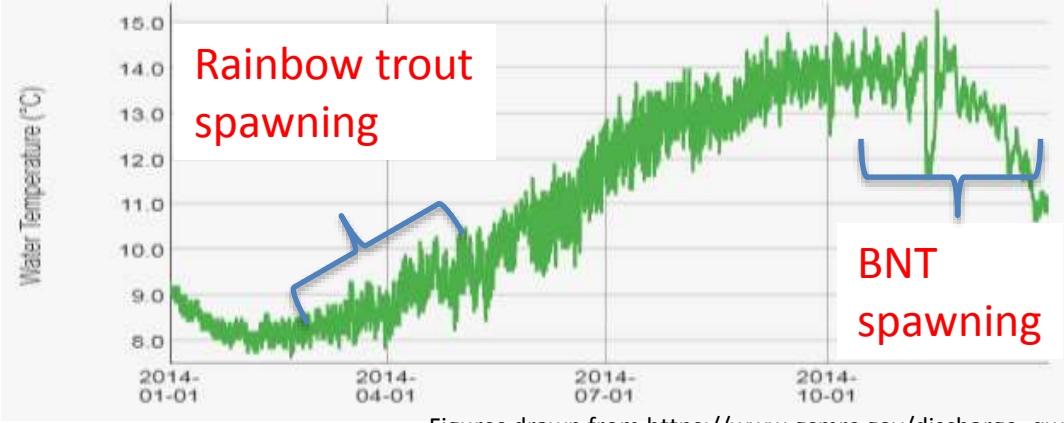
References: Chapman, G. 1986. Ambient water quality criteria for dissolved oxygen. U.S. E.P.A. EPA 440/5–86–003. 46 pp
Raleigh, R.F., T. Hickman, R.C. Solomon, and P. C.Nelson. 1984. Habitat suitability information: Rainbow trout. U.S. Fish Wildl. Serv. FWS/OBS–82/10.60. 64 pp
Raleigh, R.F., L. D. Zuckerman, and P. C.Nelson. 1986. Habitat suitability index models and instrem flow suitability curves: Brown trout, revised. U.S. Fish Wildl. Serv. Biol. Rep. 82(10.124). 65 pp.

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

USGS

Low dissolved oxygen during brown trout spawning





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

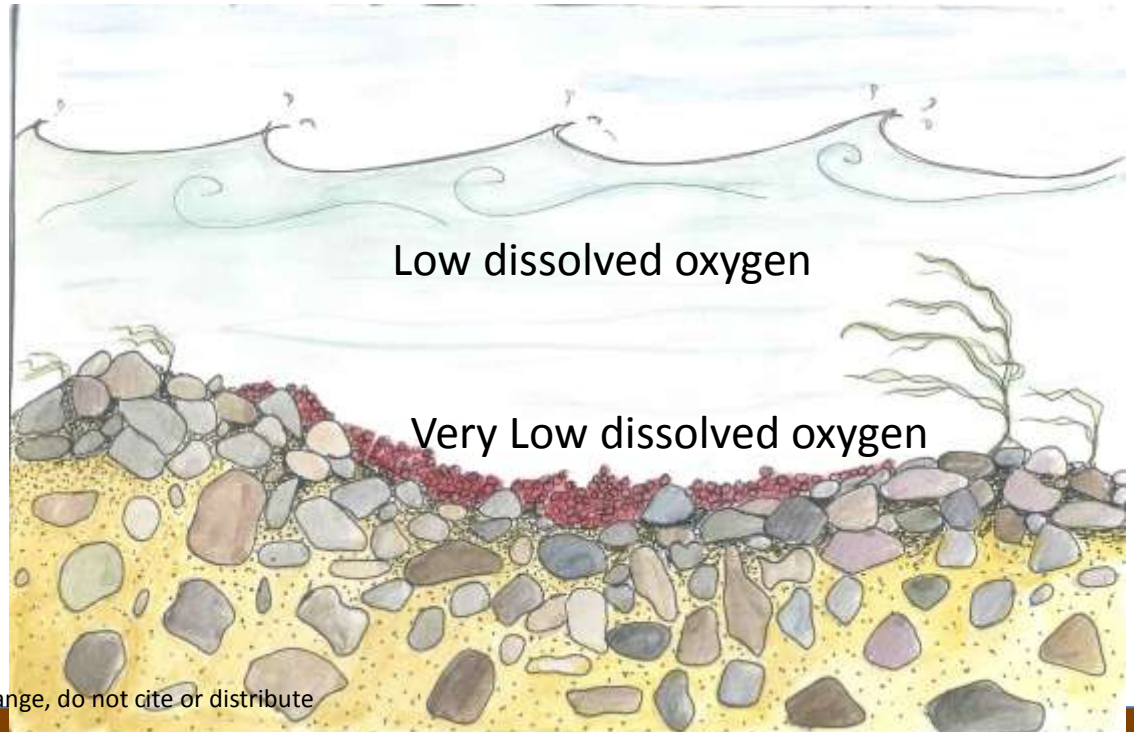
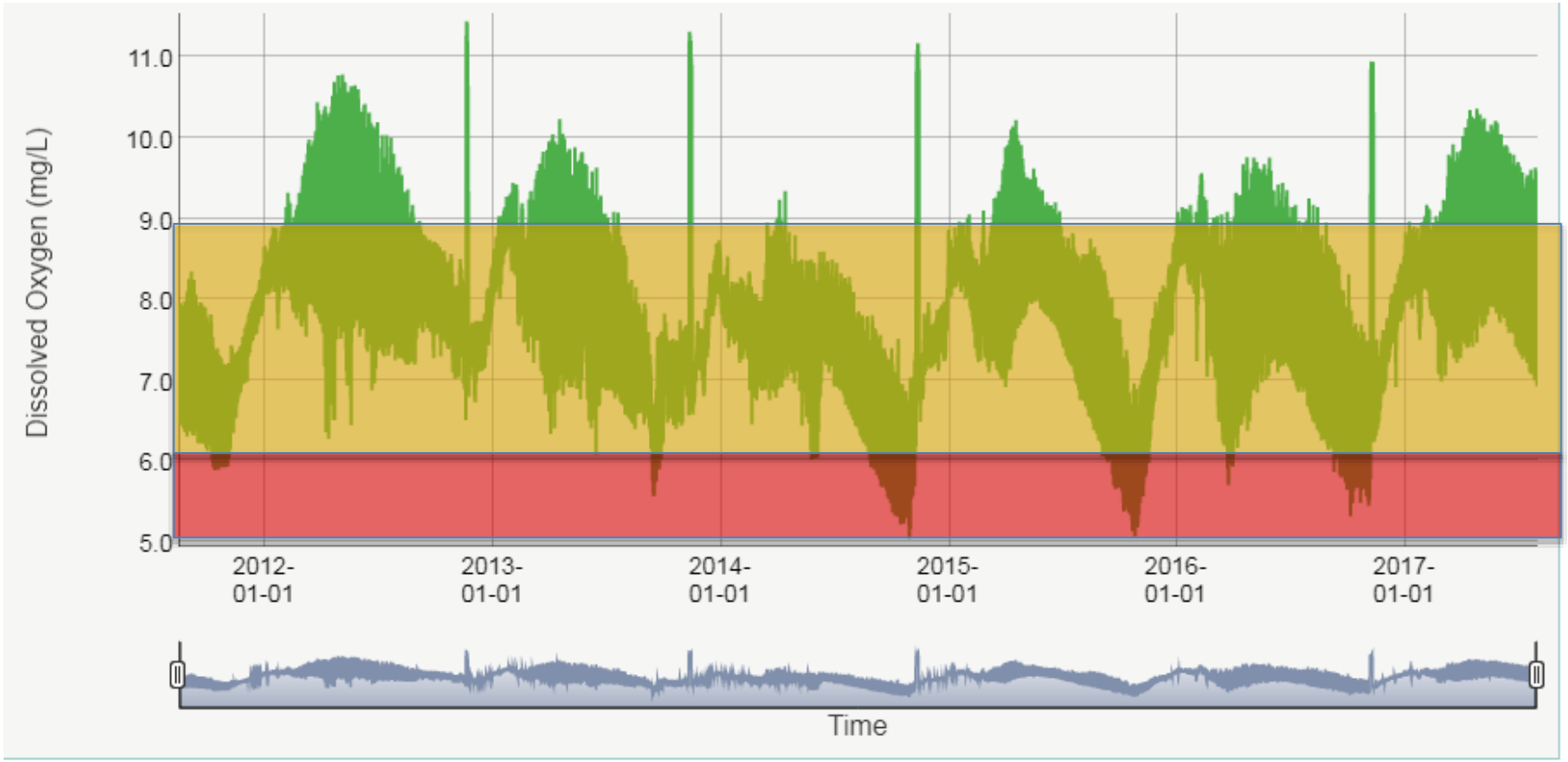


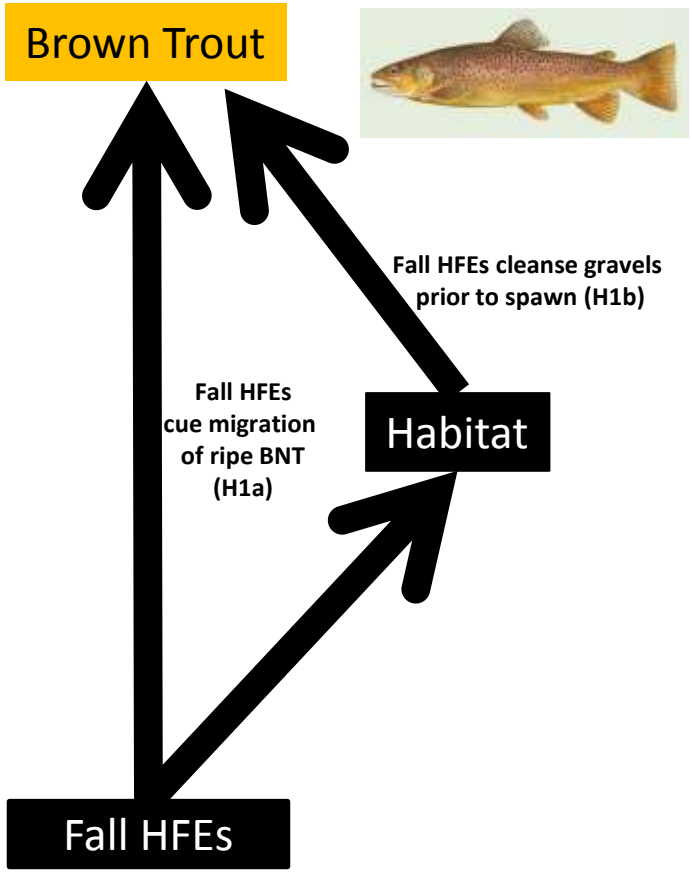
Figure taken from https://trouttanktales.com/lifecycle/

HFEs cleanse gravels at a critical time for brown trout

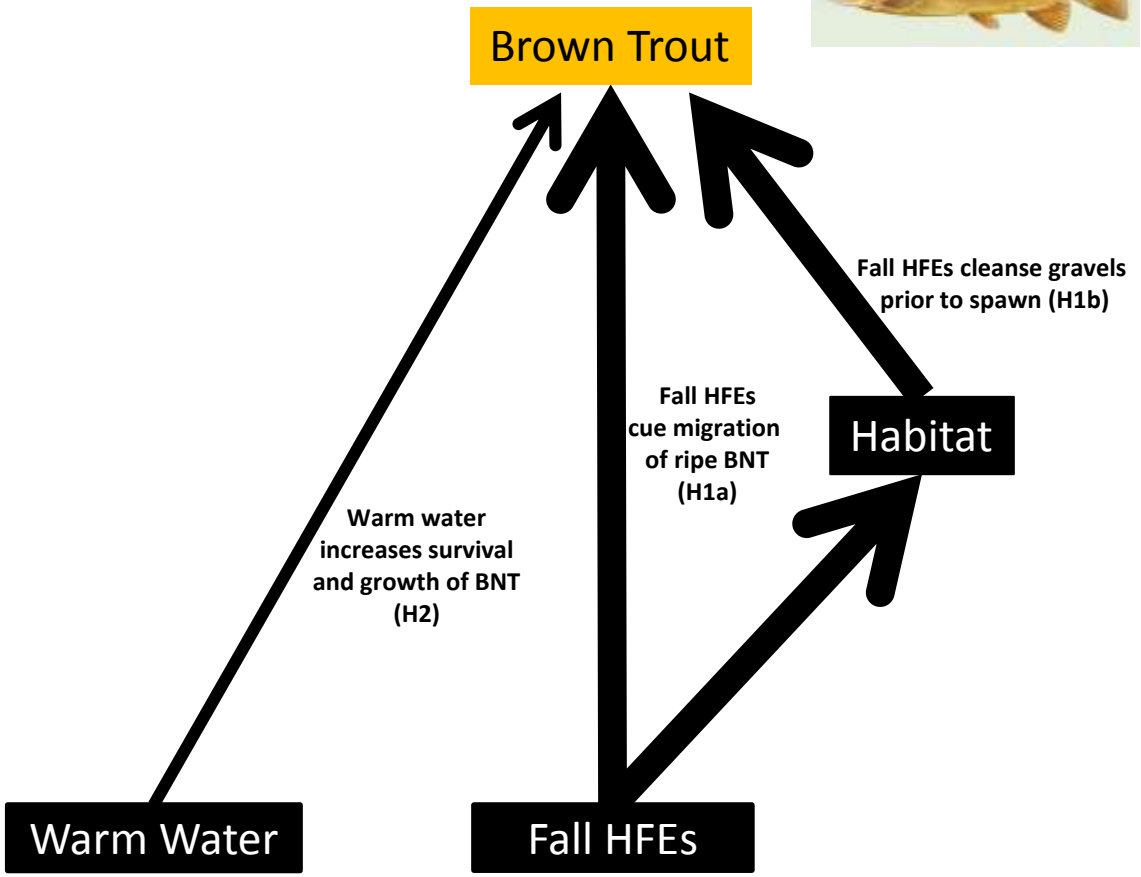


This mechanism fits another one of the facts

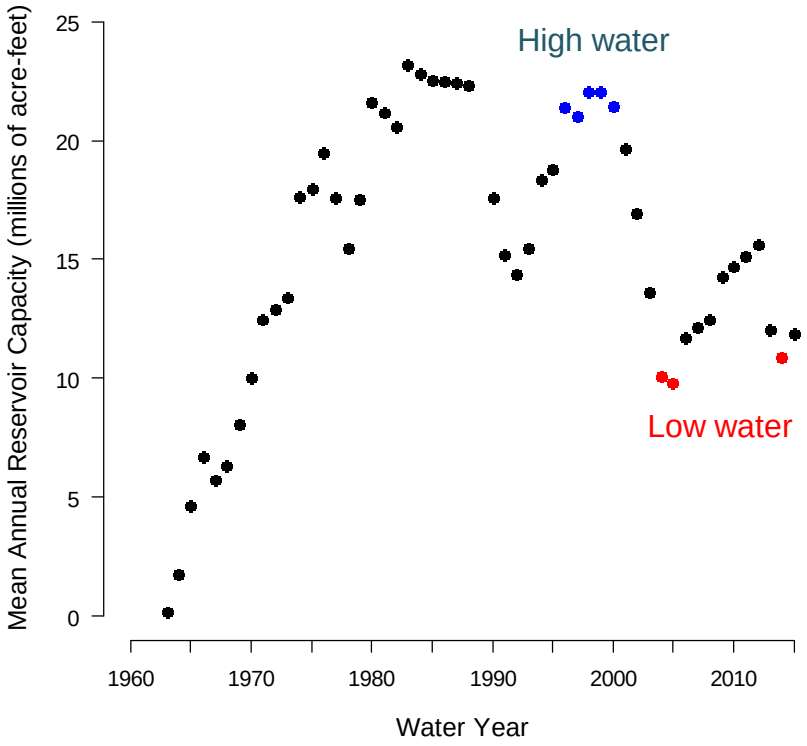
- Increase in adults 2013-2014
- Successful spawning 2015-2016
- Rainbow trout crash 2013-2016

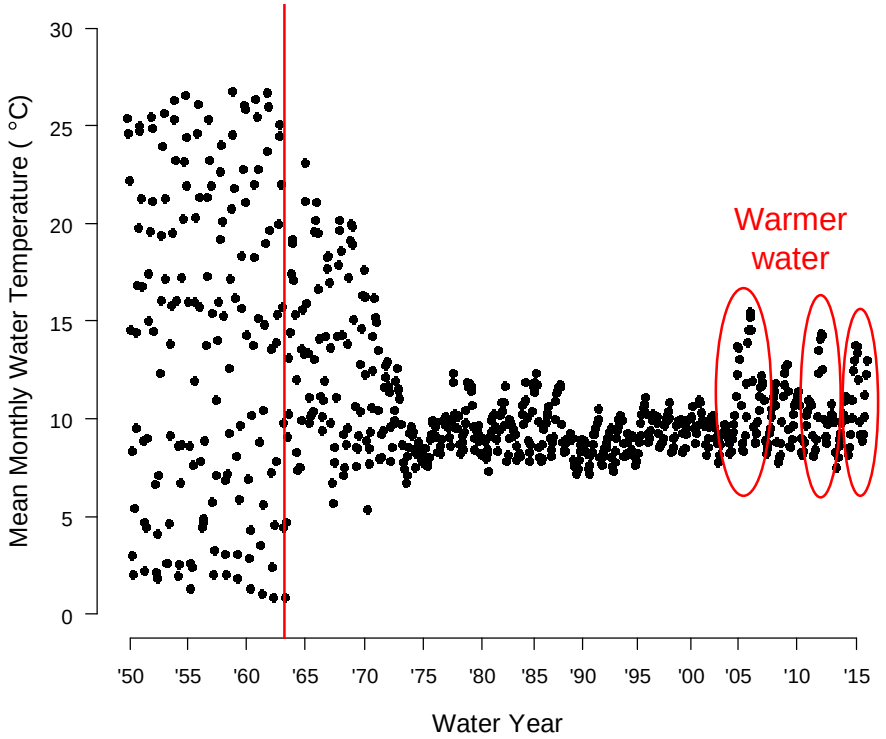


Water temperature



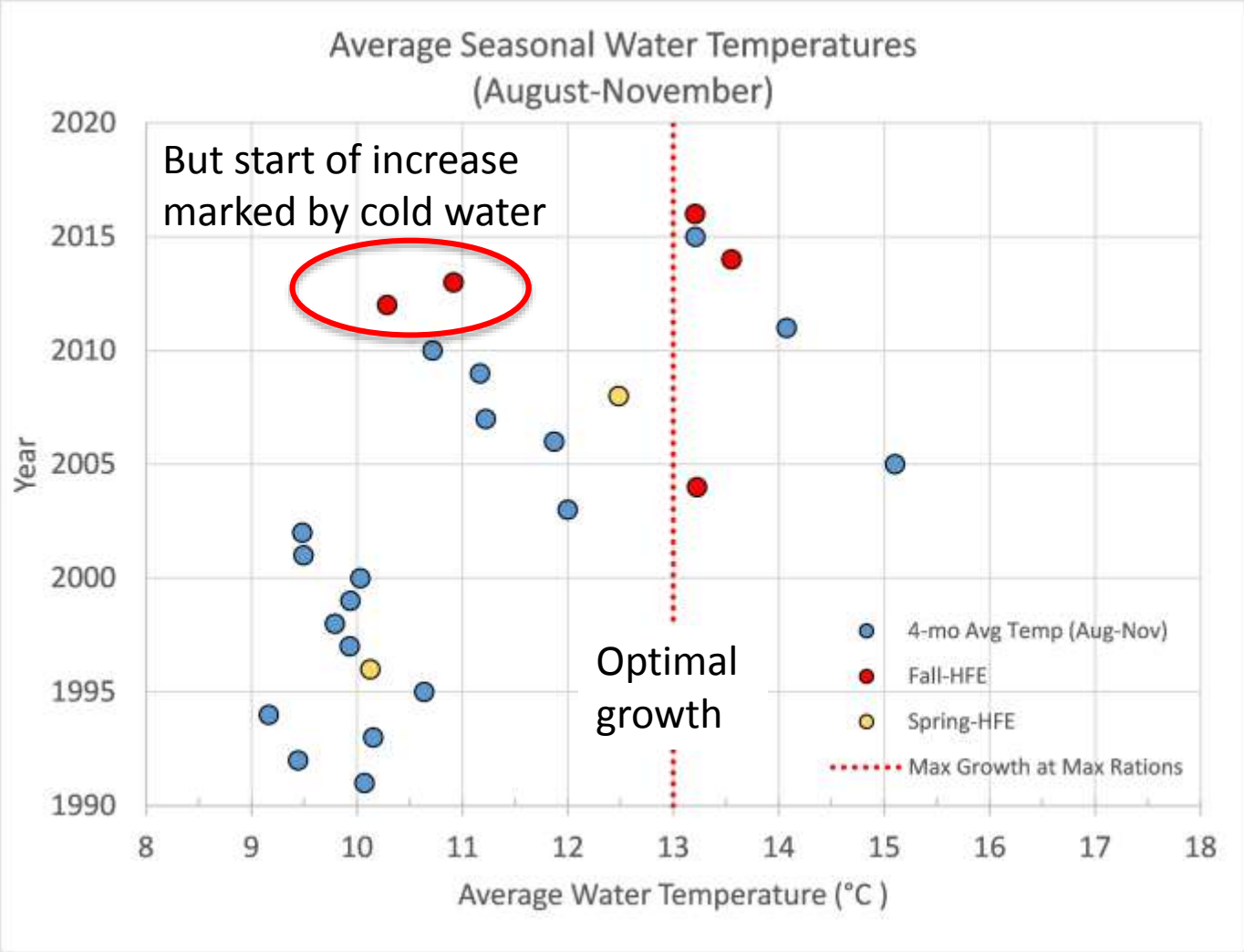
Water temperatures increase when Lake Powell levels are low





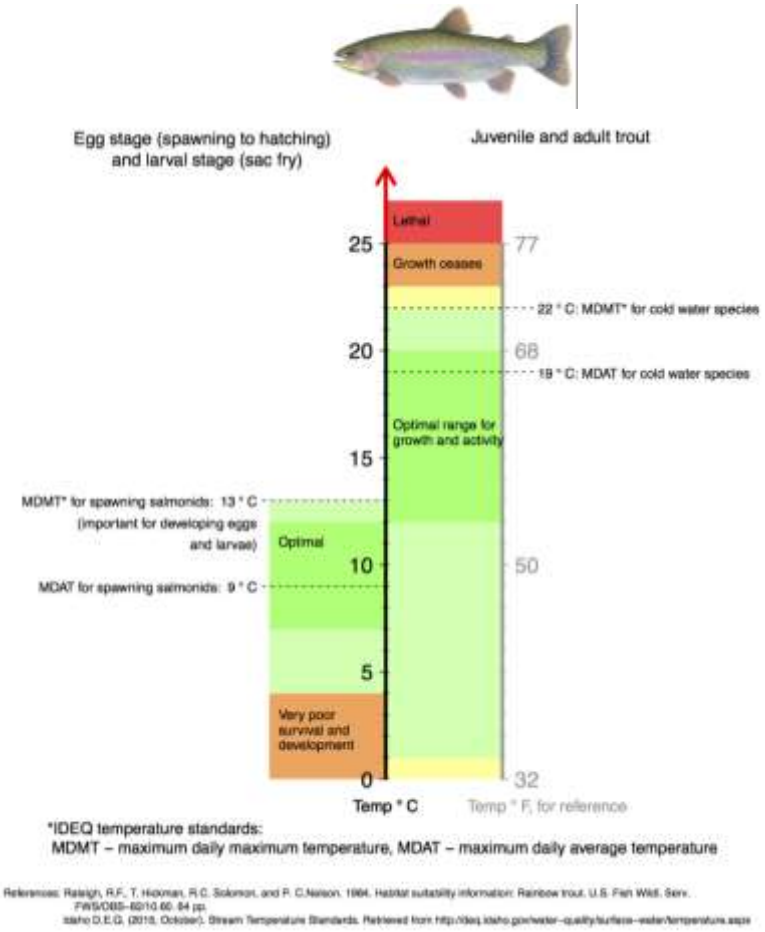
Figures courtesy of Kim Dibble, USGS

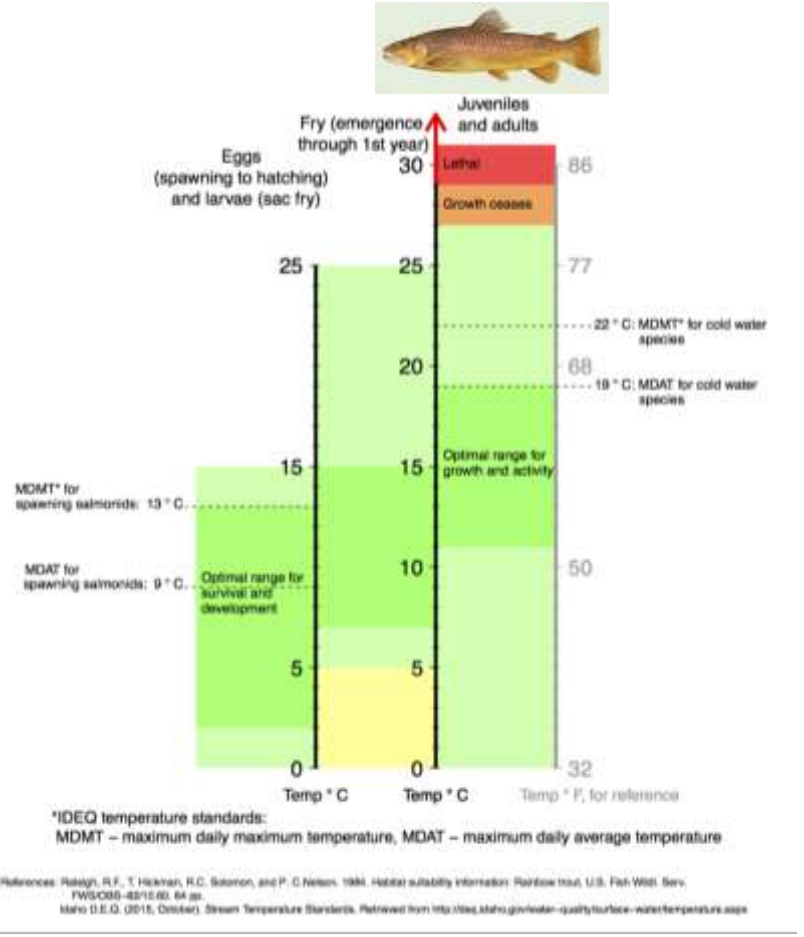
Water temperatures have been perfect for brown trout



Figures courtesy of Mike Yard, USGS

But temperatures also perfect for rainbow trout?

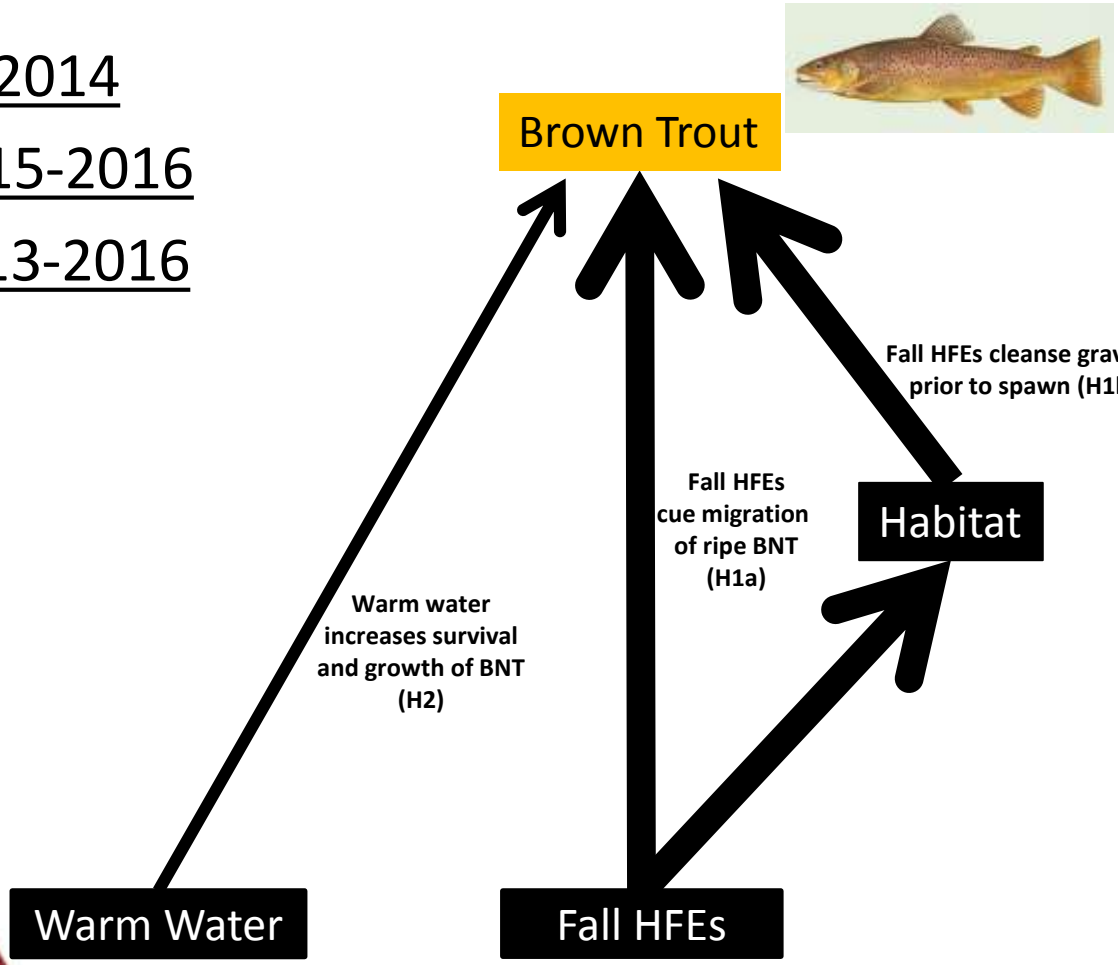




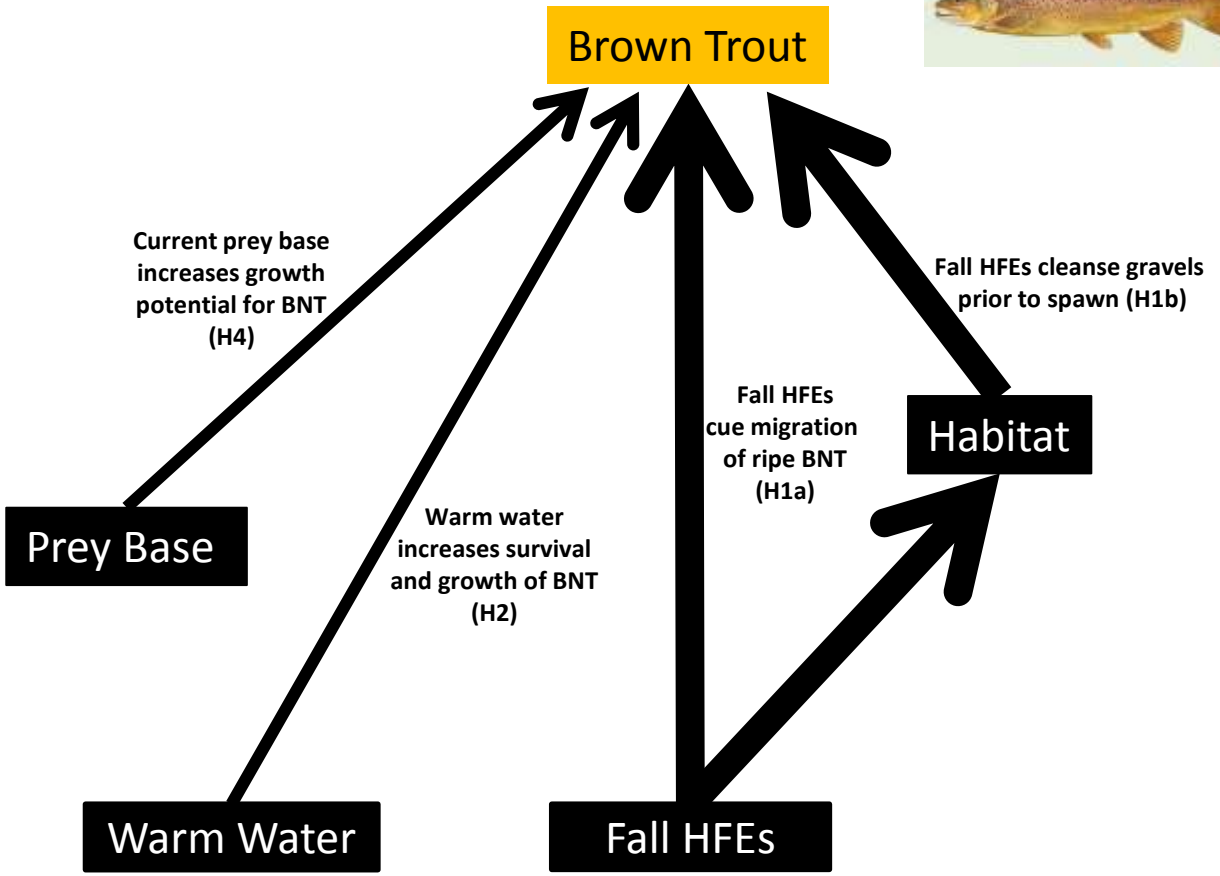
Figures from
https://henrysfork.org/average-dissolved-oxygen-requirements-salmonids

Temperature aligned with spawning opportunities

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



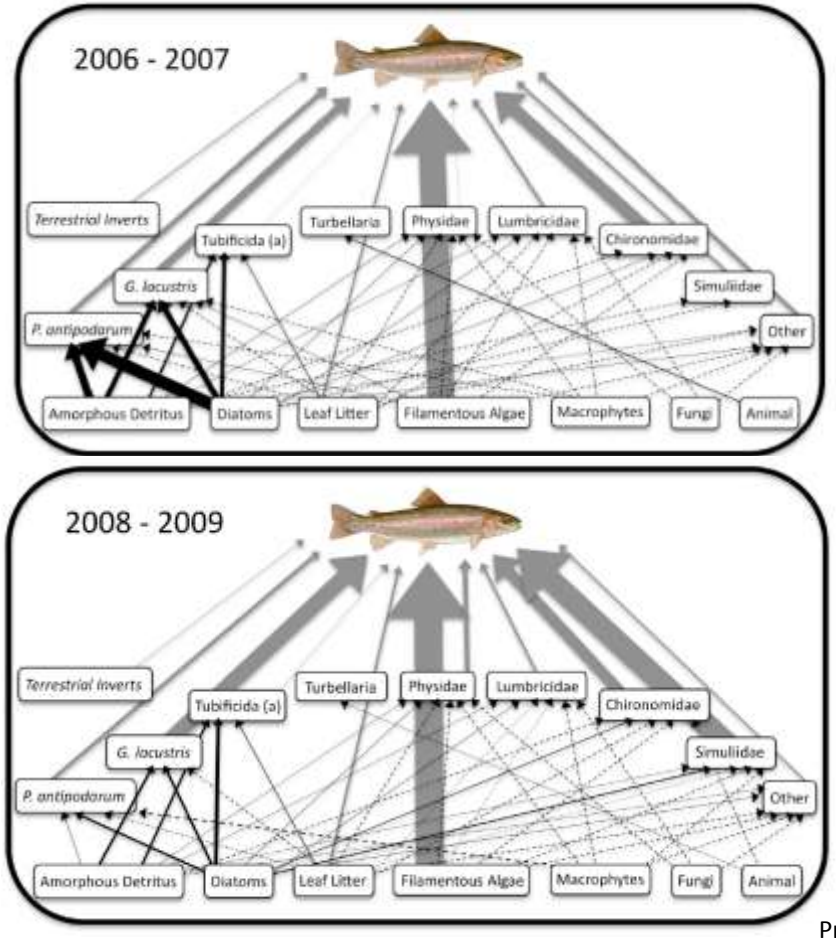
Prey base


Brown Trout
Current prey base increases growth potential for BNT (H4)
Fall HFEs cleanse gravels prior to spawn (H1b)
Fall HFEs cue migration of ripe BNT (H1a)
Habitat
Prey Base
Warm water increases survival and growth of BNT (H2)
Warm Water
Fall HFEs

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

No HFE

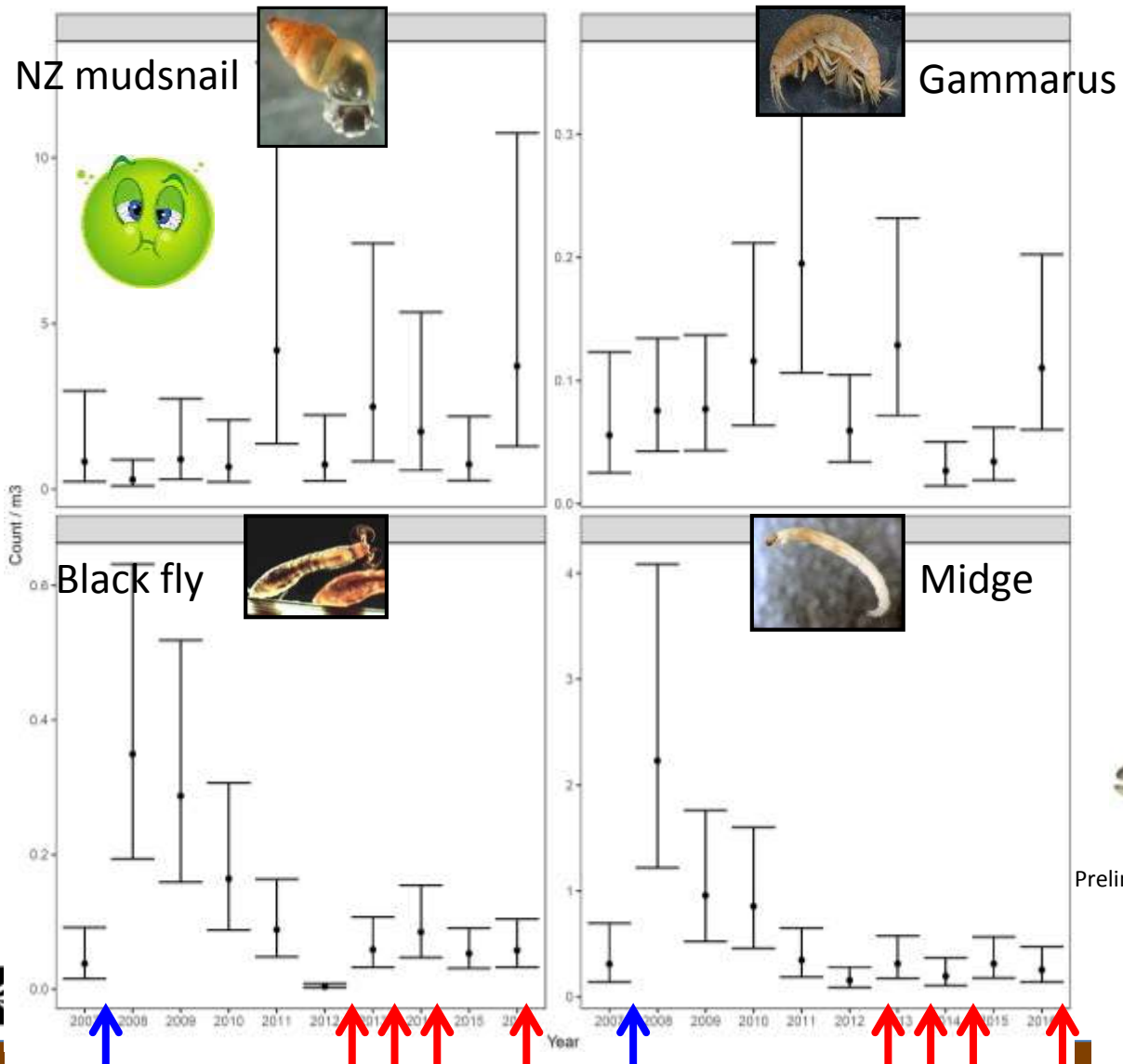
2008 Spring HFE



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

Taken from: Cross, Wyatt F., Colden V. Baxter, Kevin C. Donner, Emma J. Rosi-Marshall, Theodore A. Kennedy, Robert O. Hall, Holly A. Wellard Kelly, and R. Scott Rogers. "Ecosystem ecology meets adaptive management: food web response to a controlled flood on the Colorado River, Glen Canyon." *Ecological Applications* 21, no. 6 (2011): 2016-2033.

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.

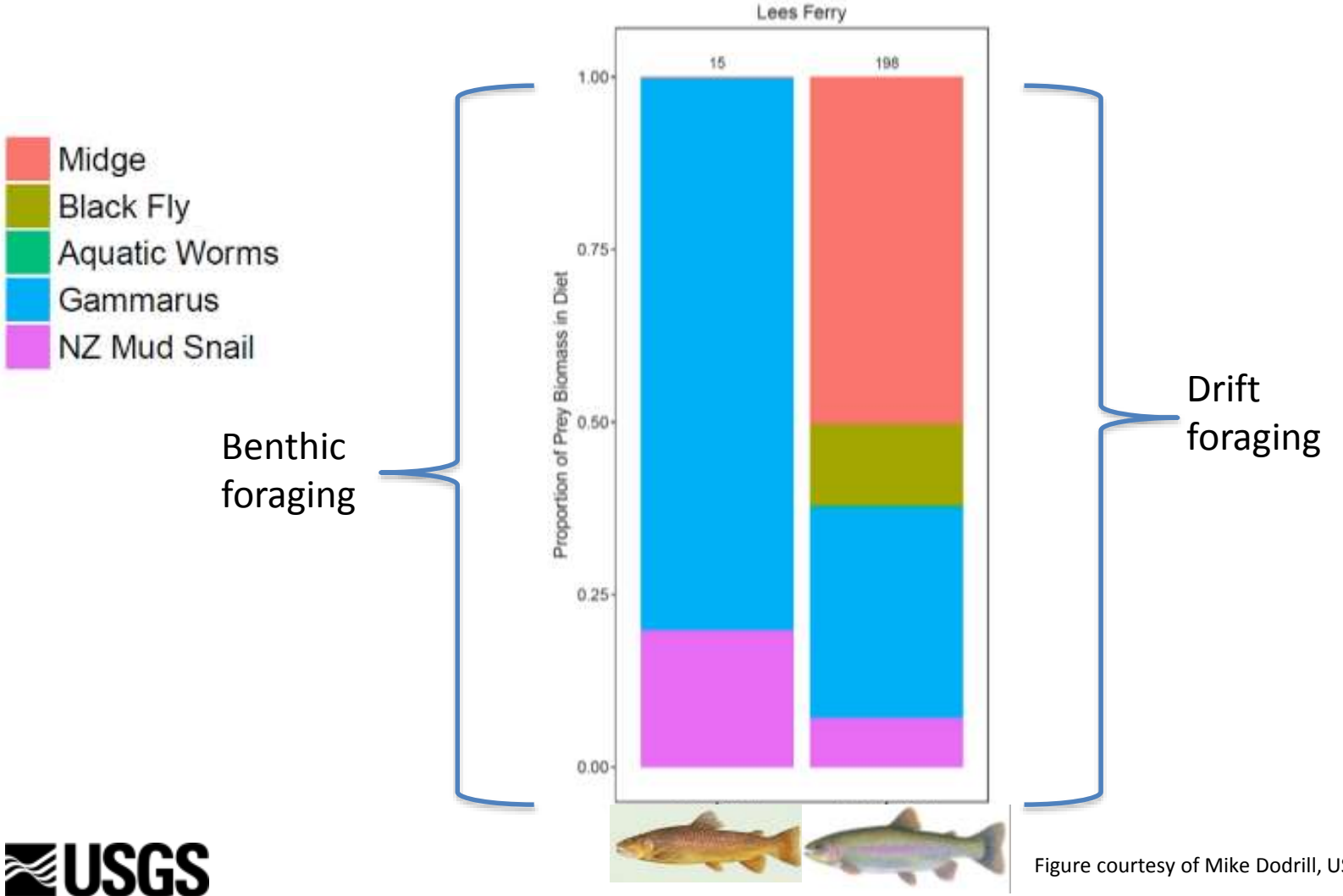
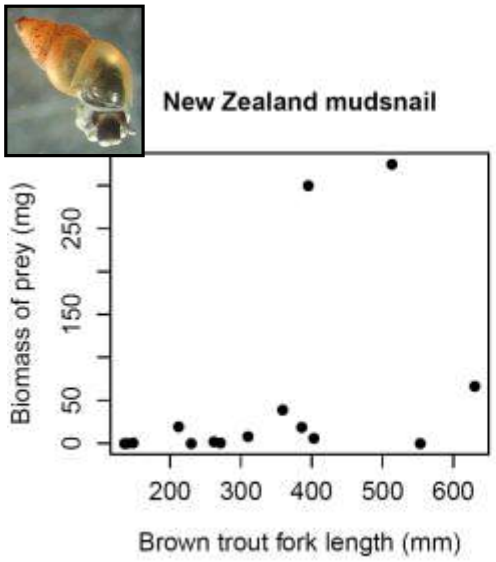
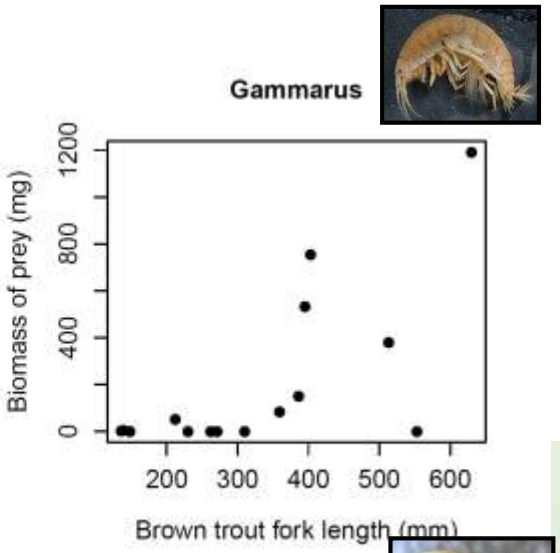
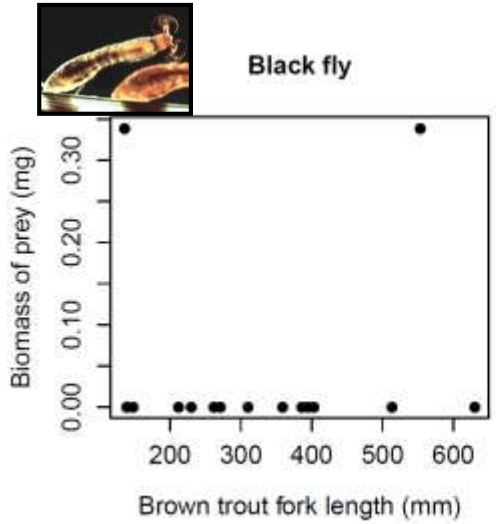


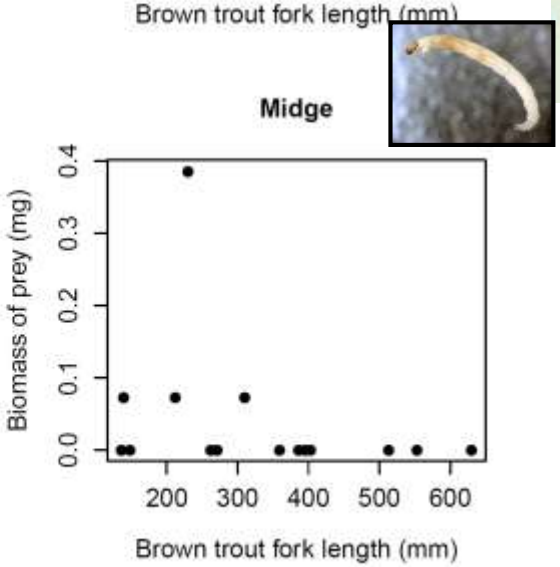
Figure courtesy of Mike Dodrill, USGS

Large brown trout eating Gammarus and mudsnails









Gill raker spacing makes benthic foraging possible.

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

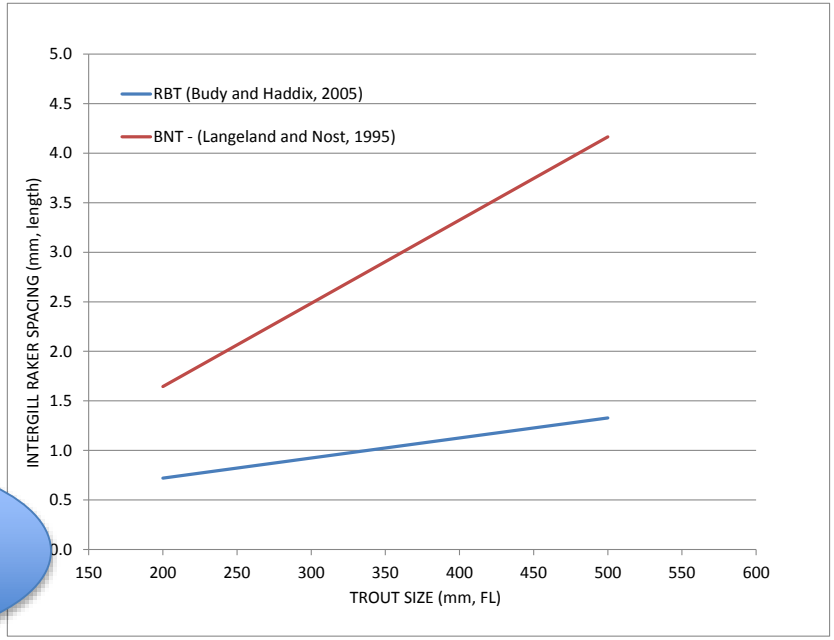
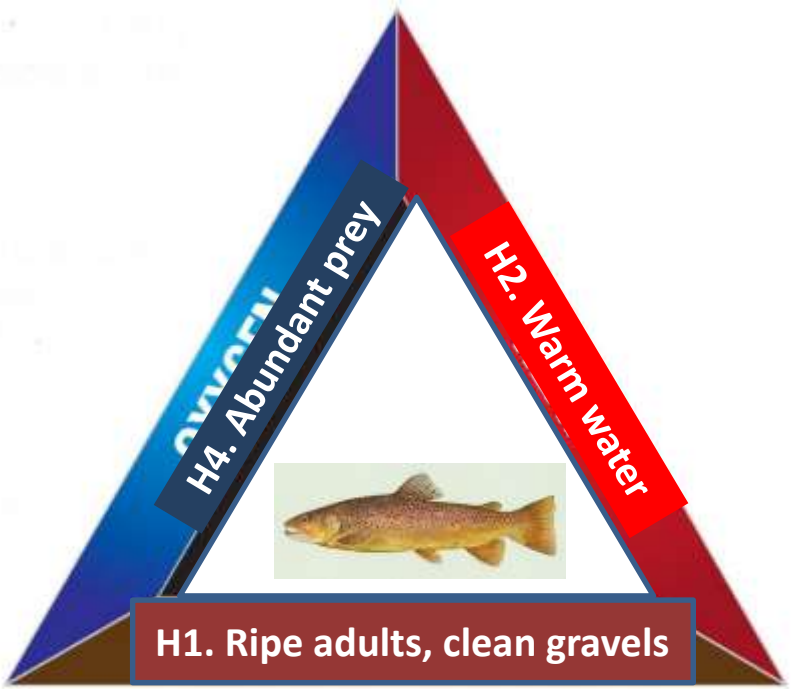


Figure courtesy of Mike Yard, USGS

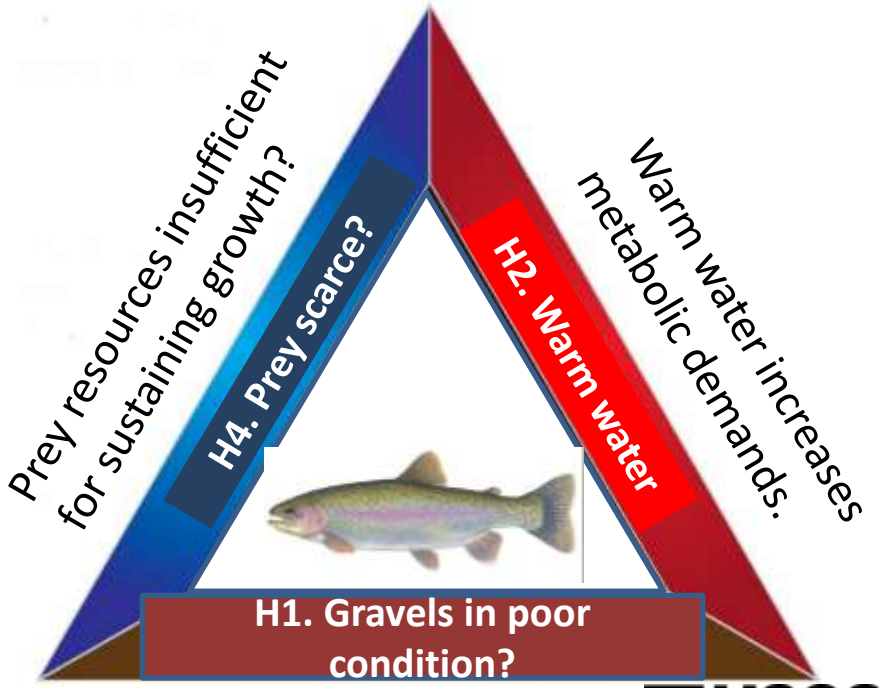
This combination of hypotheses fits all the facts

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

Brown trout



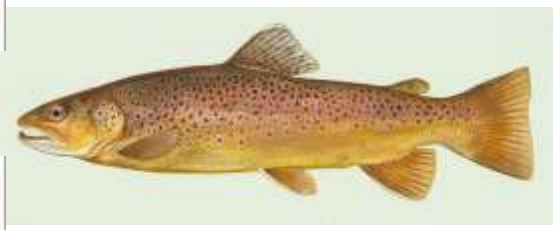
Rainbow trout



H7: Brown Trout have i… because of hyper-abundant Rainbow…

- Evidence for: The… of rainbo… prey
- Evidence again… …BT are ra… …re are >100,000

Conclusion: Falsified



USGS

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

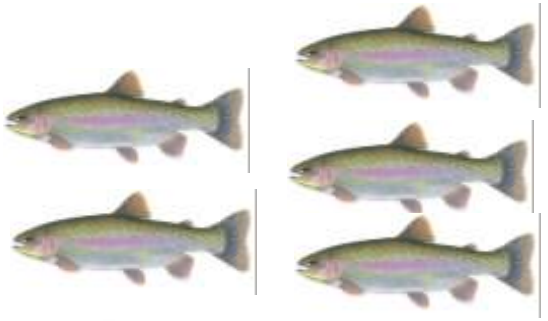
- Evidence for: WD is present in Lees Ferry. WD has caused declines in RBT and increases in BNT in many streams and rivers.
- Evidence against: Infection rate in Lees Ferry is low (deformities, whirling swimming are rare).

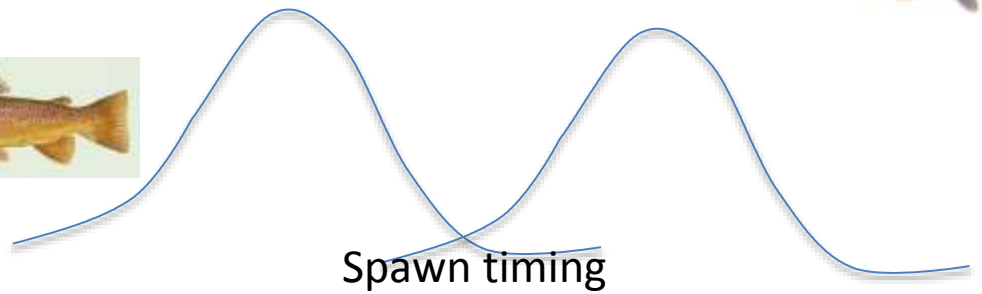
Conclusion: Weak hypothesis, but can't falsify without better info on WD (batch testing coarse method of monitoring)

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.

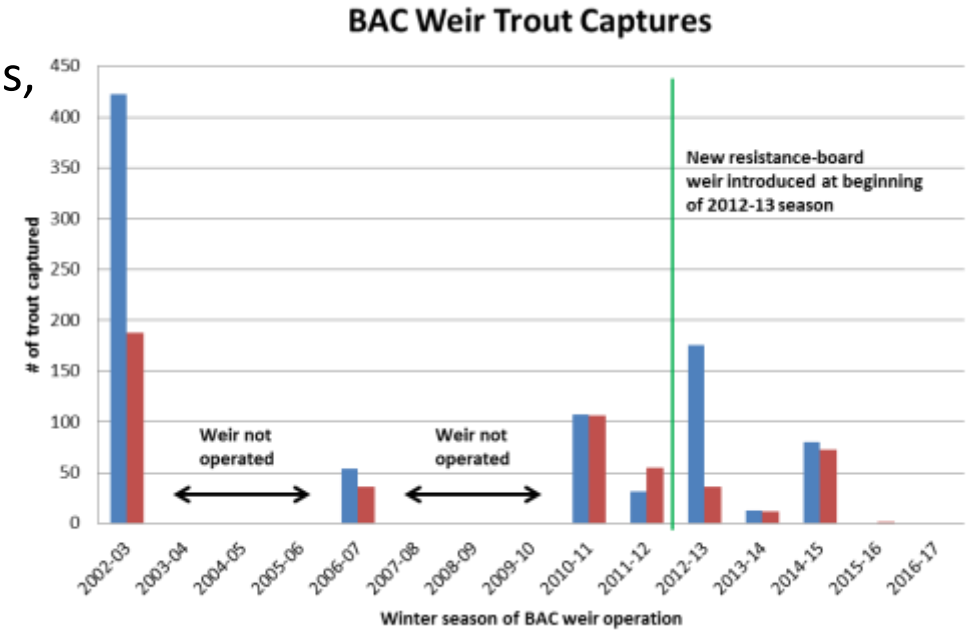
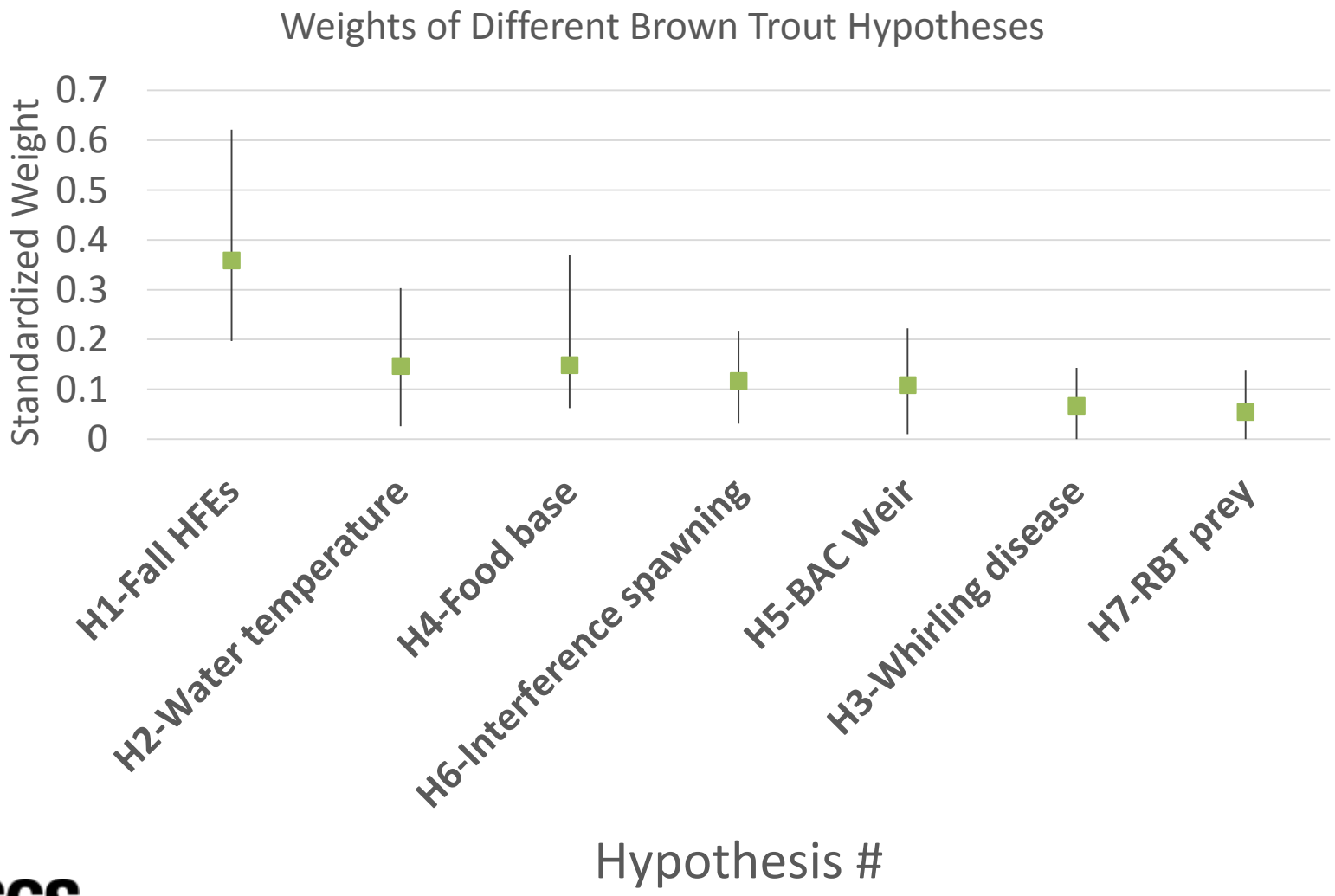
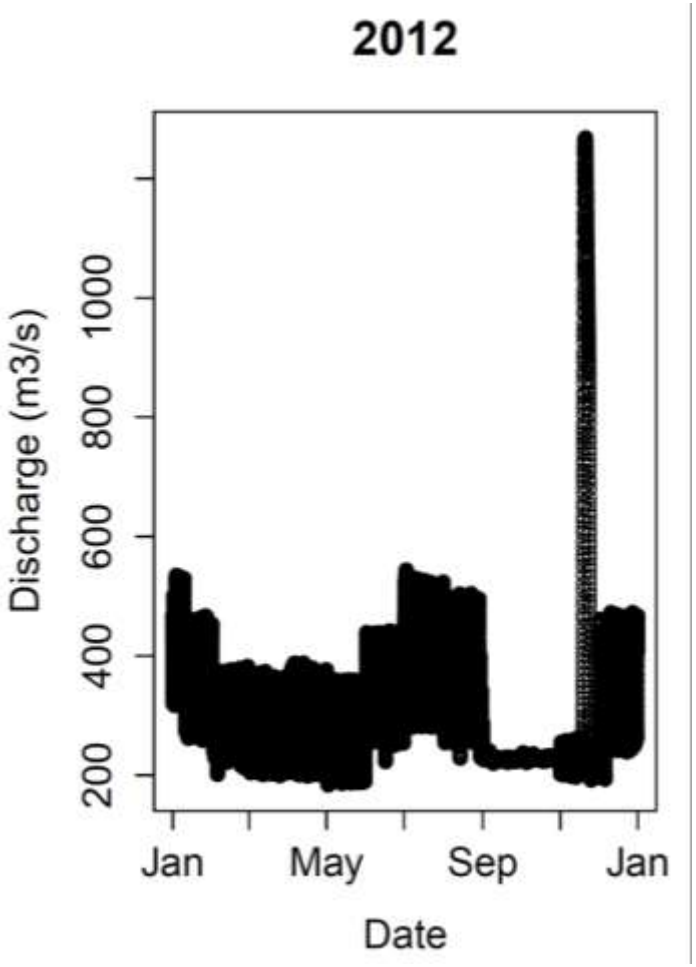
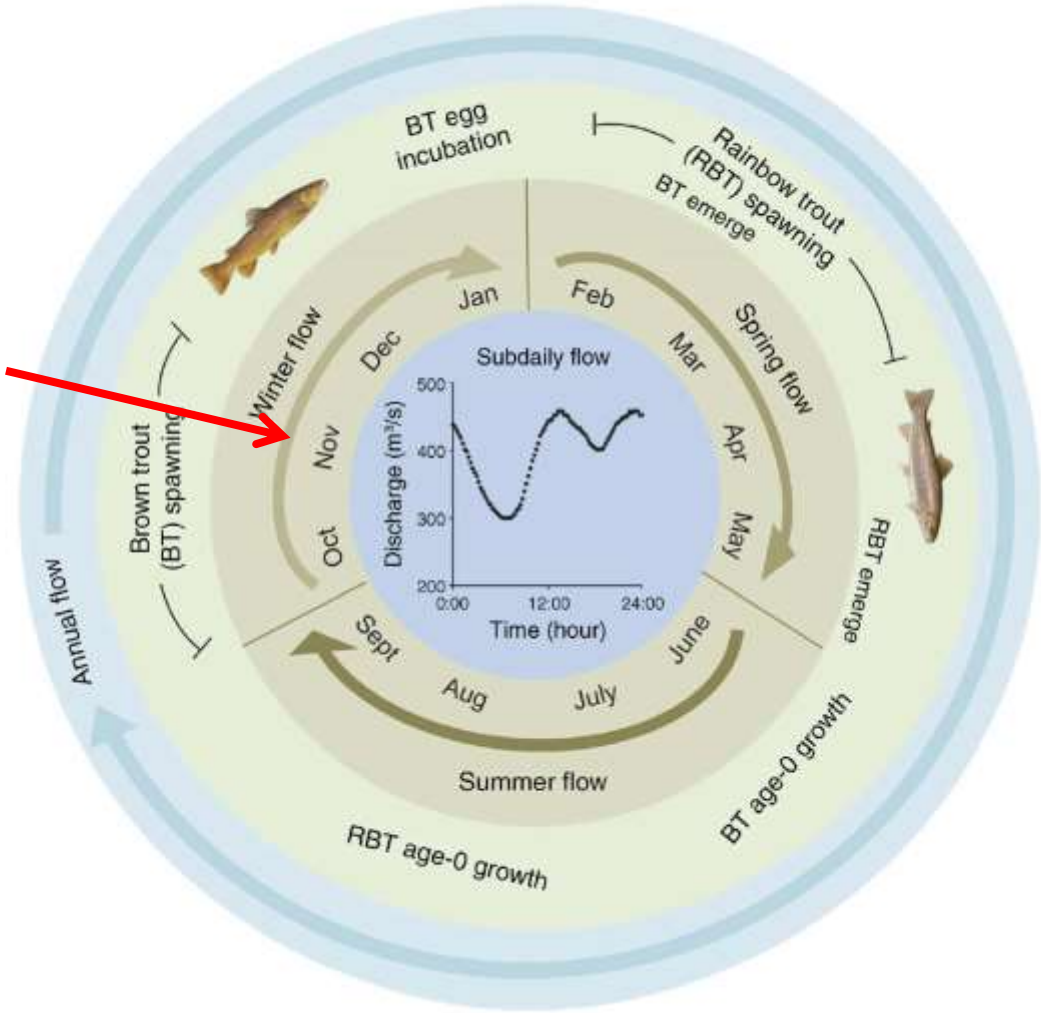


Figure courtesy of Robert Schelly, NPS


Weights of Different Brown Trout Hypotheses
Standardized Weight
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
H1-Fall HFEs
H2-Water temperature
H4-Food base
H6-Interference spawning
H5-BAC Weir
H3-Whirling disease
H7-RBT prey
Hypothesis #

Life cycle timing is key





From Dibble et al. 2015, *Ecological Applications*.