Humpback chub growth becomes resource dependent when released from temperature limitation

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BACKGROUND

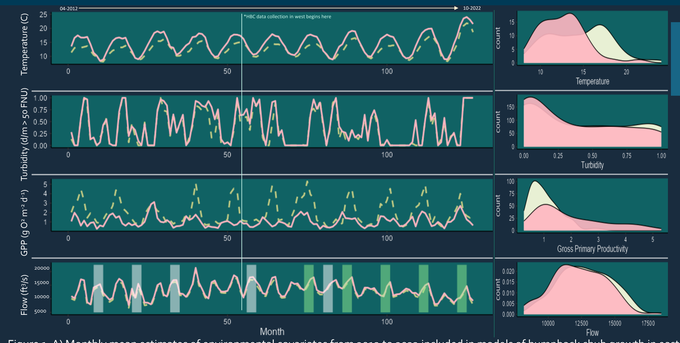


Figure 1. A) Monthly mean estimates of environmental covariates from 2012 to 2022 included in models of humpback chub growth in eastern (pink line) and western (orange line) Grand Canyon. From the top, plots show mean monthly water temperature, mean monthly gross primary productivity, proportion of days per month with turbidity greater than 50 FNU, and mean monthly flow with months with high flow experiments marked with vertical gray bars and months with bug flow experiments marked with vertical green bars. B) Frequency estimates of covariates in the eastern reach (pink) and western reach (orange) from April 2012 to November 2022.

- Organismal growth is constrained by species-specific resource requirements.
- Resources that often determine somatic growth rates in ectotherms include temperature, food availability, and habitat conditions.
- Liebig's Law of the Minimum: growth is dictated not by total resources available, but by the scarcest resource (limiting factor)

METHODS

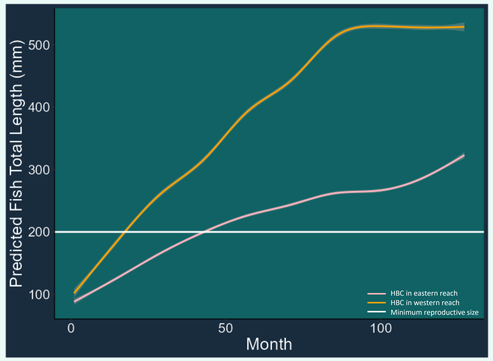
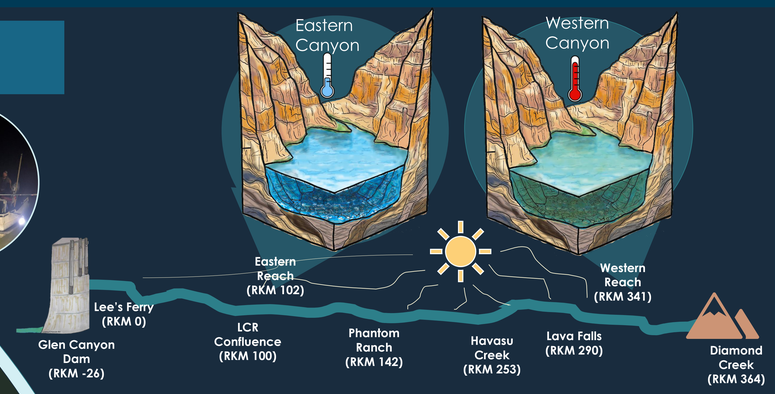


Fig 5. Predicted size of an 80-mm humpback chub throughout the 10 year study period if that individual was located in the eastern (pink line) or western (orange line) reach. Gray band around each line signifies the 95% credible interval. Horizontal white line represents the minimum spawning size for a humpback chub in Grand Canyon (USGS 2021). An 80-mm individual would reach reproductive age ~1.5 years earlier in the western reach than it would in the eastern reach



- Humpback chub data collected between April 2012 – November 2022 at JCM East (RKM 102) and JCM West (RKM 341)
- Environmental covariate data collected from USGS Stream Gages. High frequency GPP data modeled using StreamMetabolizer (Deemer et al. 2022).
- We fit Bayesian state-space growth models to data collected from two groups of humpback chub (*Gila cypha*) located ~240 river kilometers apart in the Colorado River within the Grand Canyon, Arizona.
- We selected relevant variables for our models via inclusion tests (Yackulic et al. 2018). Variables with small posterior estimates are less influential than variables with high values.
- As the river travels through the Grand Canyon the thermal and sediment regimes remain modified but progress in the direction of more natural conditions.

RESULTS

Temperature is the most limiting factor on humpback chub growth with growth being minimal to non-existent at temperature below 12° C.

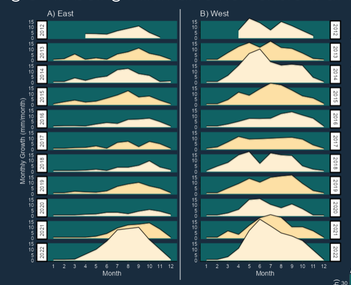


Figure 2. Predicted mean monthly growth rate of an 80-mm total length humpback chub in eastern and western Grand Canyon by year and month. 2022 was very warm, which led to a spike in growth in both reaches.

Effects of turbidity and gross primary productivity are positive and relatively strong, while high flow disturbance and bug flow have a small but negative effect on chub growth.

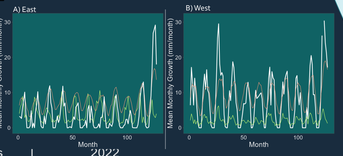


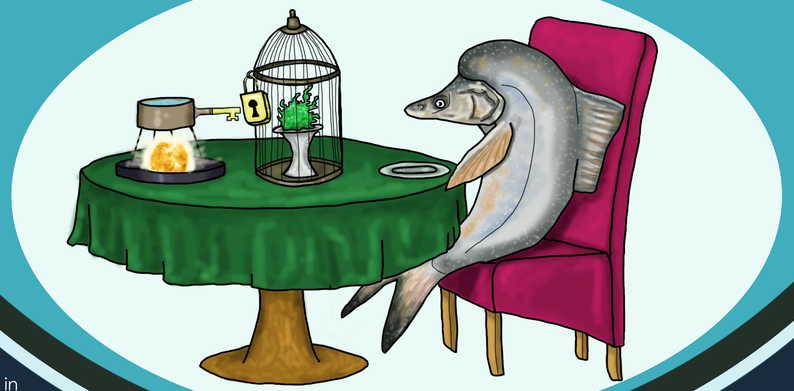
Figure 3. Predicted mean monthly growth (white lines) and 95% credible interval (gray ribbons) with random effects for an 80-mm chub across the duration of our study in the A) East and B) West. Red line represents temperature and green line represents GPP. Models suggest higher temperatures release growth, so we see a closer connection between GPP and growth in the western data.

Figure 4. Predicted mean monthly growth rates (white points) and standard deviations (whiskers) in the A) eastern reach and B) western reach under mean temperature conditions (pink line) across three decadal eras. The 2022 panel reflects river temperatures as they were in 2022. During the 21st century drought conditions led to warming river temperatures and subsequent release of the cold water limitation on growth.

Covariate	Inclusion Estimate East	Inclusion Estimate West
Temperature	**1.00**	**0.99**
Turbidity	**0.87**	0.51
GPP	0.17	**0.85**
Flow	0.27	0.35
High Flow Event	0.51	0.39
Bug Flow	0.23	0.54

Table 1. Results from inclusion tests for environmental covariates used in humpback chub growth models for humpback chubs in the eastern and western reaches. Covariates with strong support for inclusion (inclusion estimate > 0.7) are bold black. Covariates with moderate support for inclusion (inclusion estimate > 0.5 and < 0.7) are shaded in black, while covariates below the threshold are blue.

Warm water in the west releases temperature limitation of chub growth, allowing models to 'see' other environmental factors that influence growth in chubs, such as gross primary productivity (GPP).



Low reservoir Elevations in Lake Powell contributed to high river-wide water temperatures in 2022 that led to a steep increase in humpback chub growth.

CONCLUSIONS

- When the limitation of cold temperature is relieved, the role of other factors including turbidity (a proxy for allochthonous food), gross primary productivity a (proxy for autochthonous food) and bug flows become more pronounced.
- Effect of GPP is 1.5 times higher than temperature in the western reach, where temperature limitation is released.
- While many studies have related fish growth to temperature and flow, this study is part of an emerging literature that highlights the bioenergetic constraints on fish populations when temperatures warm.

ACKNOWLEDGEMENTS & SOURCES

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