The influence of mountain streamflow on nearshore metabolism in a large, oligotrophic lake across dry and wet years

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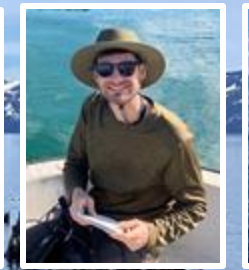
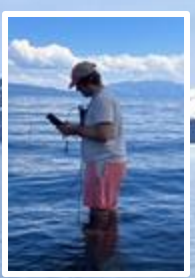
Thank you!

And thanks to the Blaszczak field and laboratory team members, Rob Miller, Meredith Brehob, Helen Lei, Taryn Elliott, Ian Halterman, Molly Ferro, Keenan Seto, Wubneh Belete Abebe, Rija Masroor, and Dillon Ragar, who helped collect and process the survey data; The University of Reno's Global Water Center and Chandra lab members, especially Emily Carlson, Erin Suenaga, Elizabeth Everest, and Zach Bess; Tahoe Regional Planning Agency, Kris Morehead, Tahoe National Forest; and the residents of Glenbrook Nevada, especially Gary and Susan Clemons.

NSF OIA-2019528, NSF GRFP, and Nevada Division of State Lands

Co-authors: Heili Lowman, Jasmine Krause, Leon Katona, Ramon Naranjo, Facundo Scordo, Adrian Harpold, Sudeep Chandra, and Joanna Blaszczak



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Solutions for sustainability

Recent changes to nearshore lake ecosystems:

Increased algae:

JOURNAL ARTICLE

Blue Waters, Green Bottoms: Benthic Filamentous Algal Blooms Are an Emerging Threat to Clear Lakes Worldwide

Yvonne Vadeboncoeur, Marianne V Moore, Simon D Stewart, Sudeep Chandra, Karen S Atkins, Jill S Baron, Keith Bouma-Gregson, Soren Brothers, Steven N Francoeur, Laurel Genzoli ... Show more

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Pub

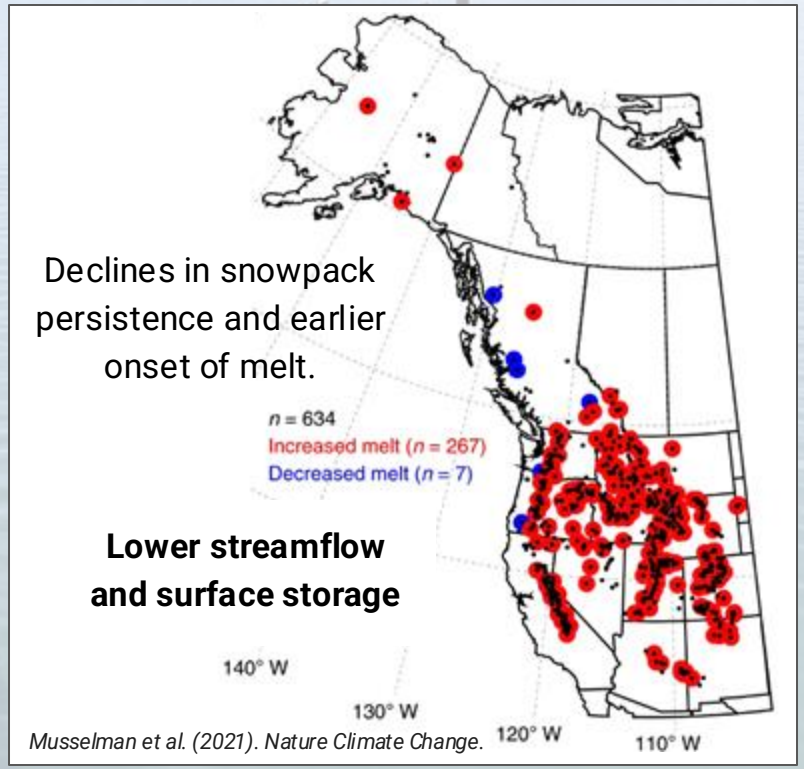
Nutrients and warming alter mountain lake benthic algal structure and function

Isabella A. Oleksy, Jill S. Baron, and Whitney S. Beck

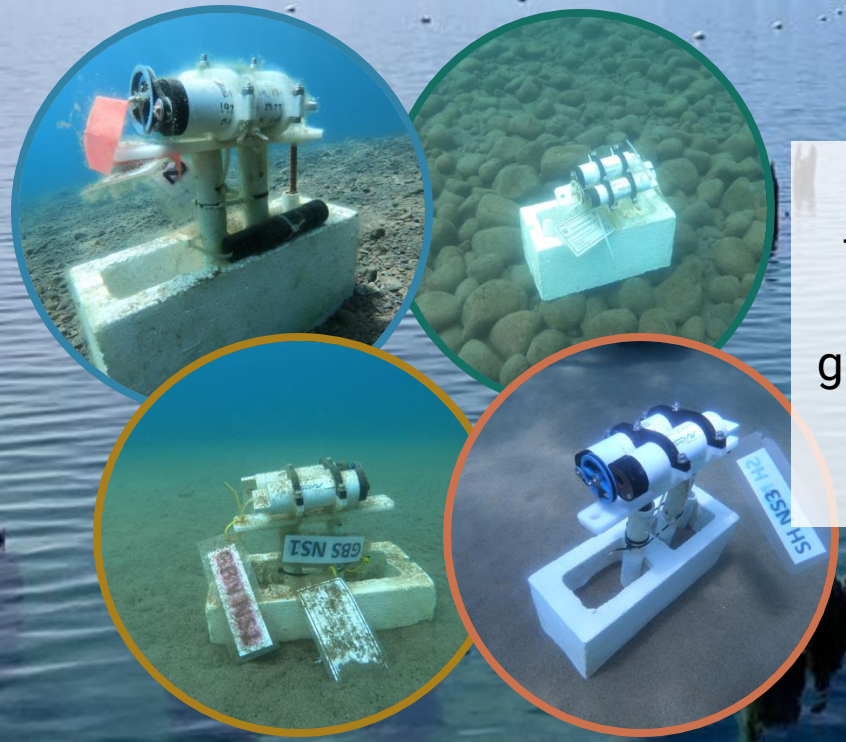
Corrections to this article

PDF | PDF PLUS | Abstract | Full Text | Supplemental Material

Decreased water storage:

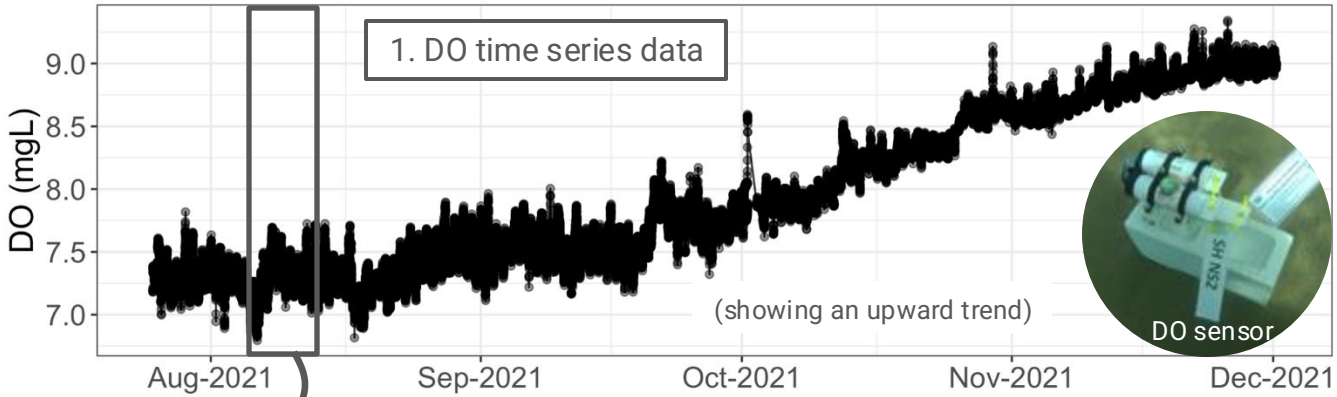


Musselman et al. (2021). Nature Climate Change.



We can assess lake ecosystem function by modeling daily rates of net ecosystem productivity (**NEP**), gross primary productivity (**GPP**) and ecosystem respiration (**ER**) using dissolved oxygen.

Assessing lake ecosystem function with dissolved oxygen and modeled lake metabolism



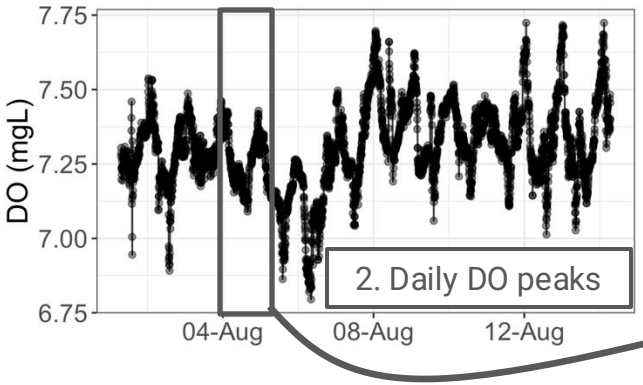
$$\Delta DO_t = \mathbf{GPP}_{t-1} + \mathbf{ER}_{t-1} + K$$

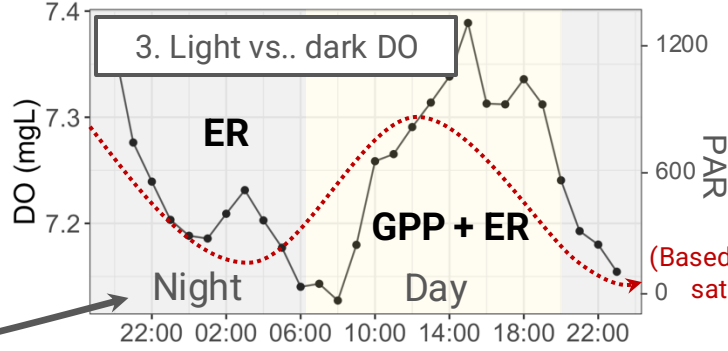
Gross primary productivity

Ecosystem respiration

$$\mathbf{NEP}_t = \mathbf{GPP}_t + \mathbf{ER}_t$$

Net ecosystem productivity





(Based on theoretical oxygen saturation conditions)

Spatial variation within lakes can drive patterns of GPP and ER

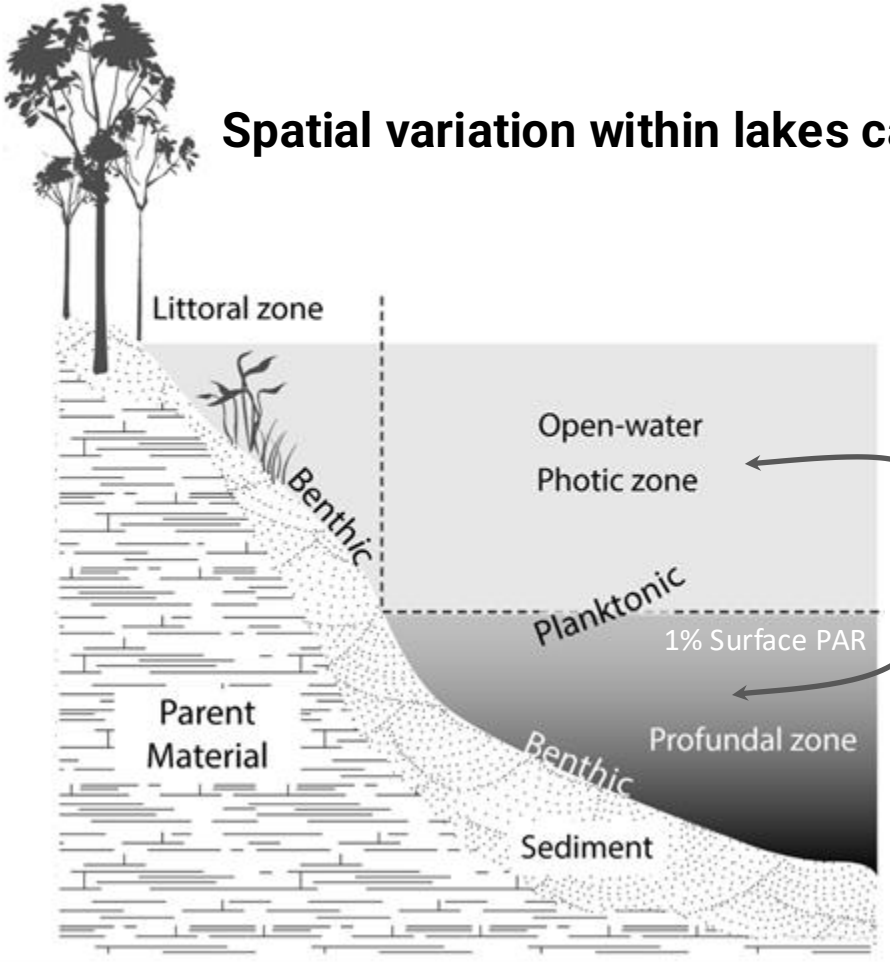
$\Delta DO_t = \mathbf{GPP}_{t-1} + \mathbf{ER}_{t-1} + K$

Gross primary productivity

Ecosystem respiration

$\mathbf{NEP}_t = \mathbf{GPP}_t + \mathbf{ER}_t$

Net ecosystem productivity

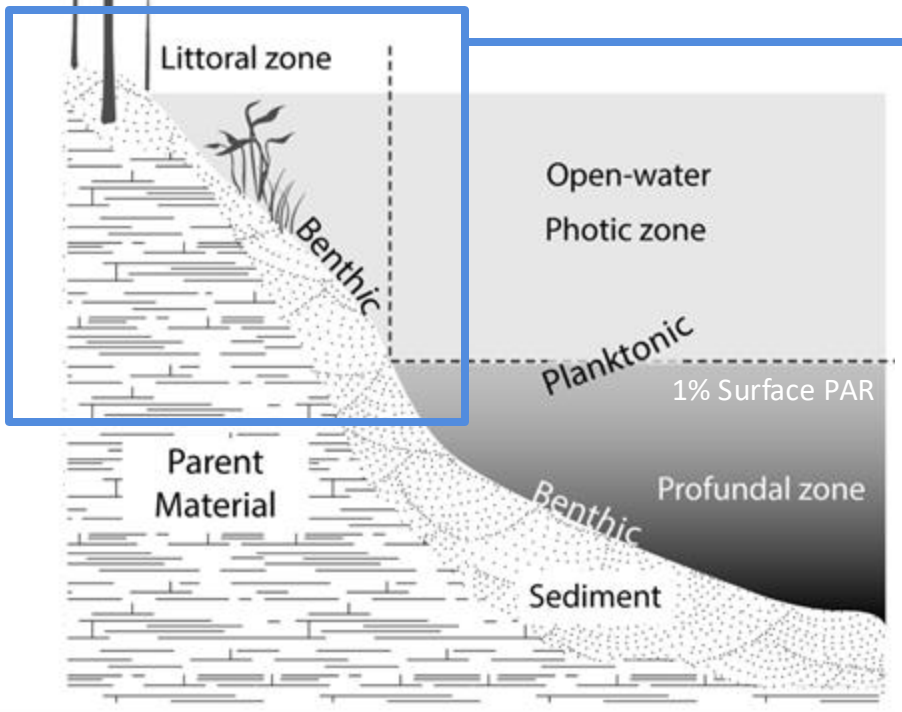


Variable access to **light**, and **nutrients**, and **substrates** suitable for growth for primary producers.

Vander Zanden, & Vadeboncoeur (2020). Inland Waters

Spatial variation within lakes:

Nearshore



Vander Zanden, & Vadeboncoeur (2020). Inland Waters

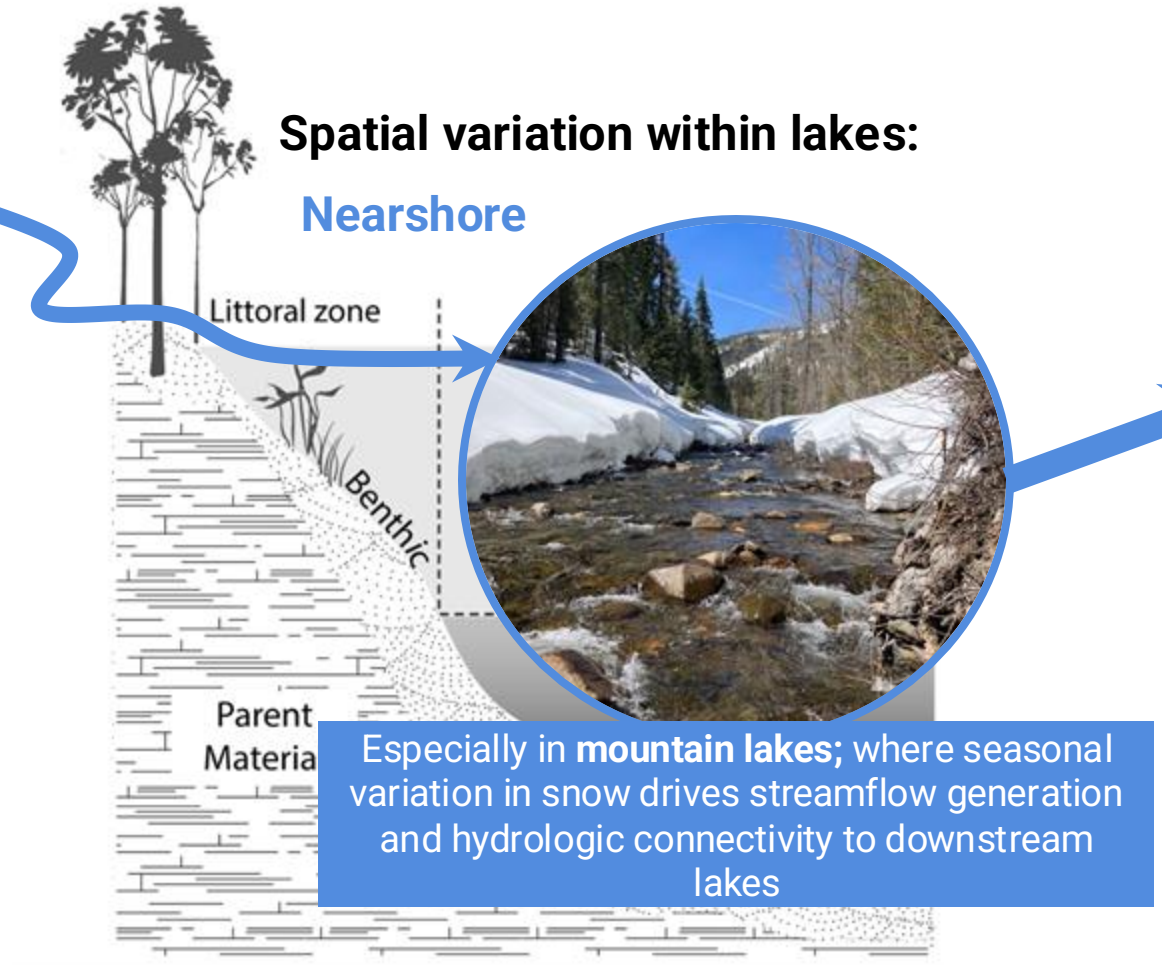
Nearshore dynamics

- Greater light availability
- Greater substrate-surface water interactions
  - Nutrients and carbon released from sediments
- First place of terrestrial deposition

Elevated ecological productivity

Spatial variation within lakes:

Nearshore



Especially in **mountain lakes;** where seasonal variation in snow drives streamflow generation and hydrologic connectivity to downstream lakes

Vander Zanden, & Vadeboncoeur (2020). Inland Waters

Stream to lake transition zones

- Deliver nutrients
- Disturb nearshore substrates
- Stimulate of biogeochemical activity

But, the timing and magnitude of material transport and transformation are dependent on streamflow velocity.

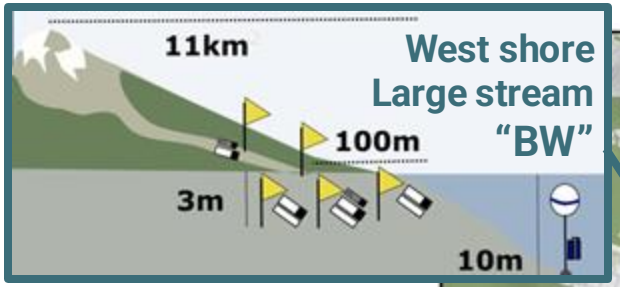
Uncertainty in how mountain streams may facilitate or suppress nearshore shore productivity in mountain lakes?

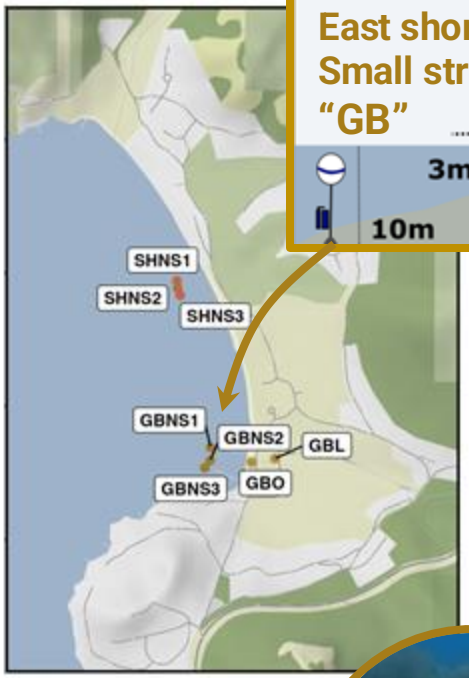
How does streamflow influence nearshore productivity in Lake Tahoe, across different stream to lake transition zones and through different hydroclimatic conditions?

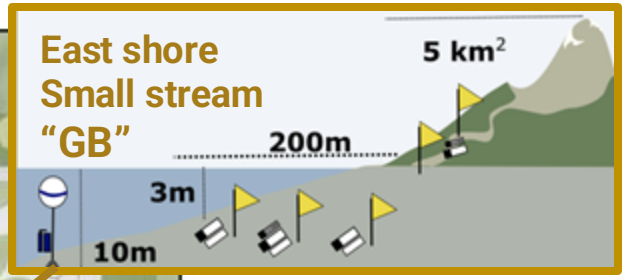
(1) How does streamflow regulate nearshore littoral water temperature and light availability to ultimately influence nearshore metabolism?

(2) How do environmental conditions in the nearshore change between a relatively wet verse dry year? And are those responses different based on the presence of inflowing streams?

Survey locations near streams







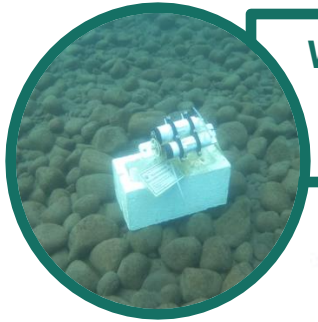
Large stream and large catchment:

- 11 km^2 watershed

Small stream and small catchment:

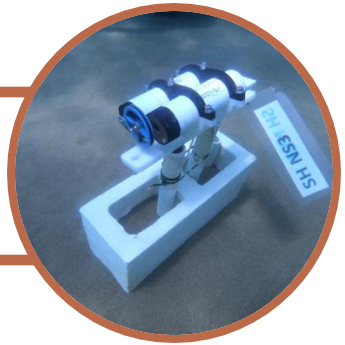
- 5 km^2 watershed

Survey locations away from streams



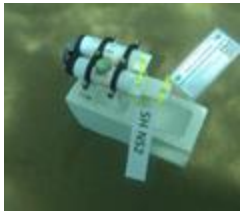
West shore
No stream
"SS"

East shore
No stream
"SH"



General survey methods

Nearshore instrumentation and lake sampling (~3 m)

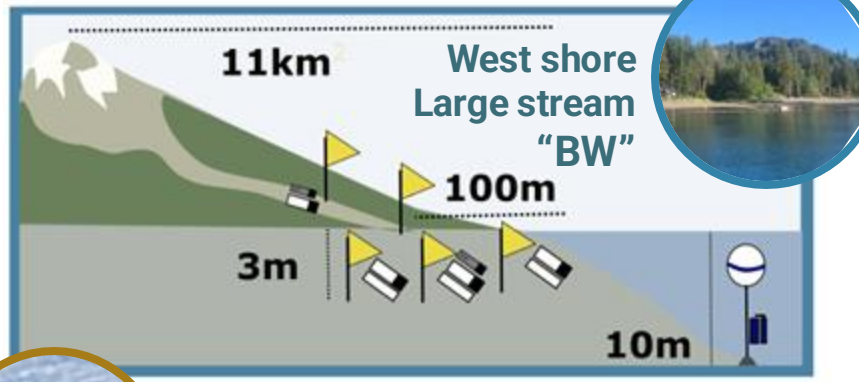


Lake covariates: Benthic light and lake temperature.

- miniDOTs
- PAR
- Temperature

Stream to lake interface monitoring

Upland covariates: catchment normalized streamflow



Key response - modeled lake metabolism:

$$\Delta DO_t = (GPP_t * P_I) + (ER_t) + (k_t * \Delta t * z_t^{-1}) * (O_{sat,t} - O_t)$$

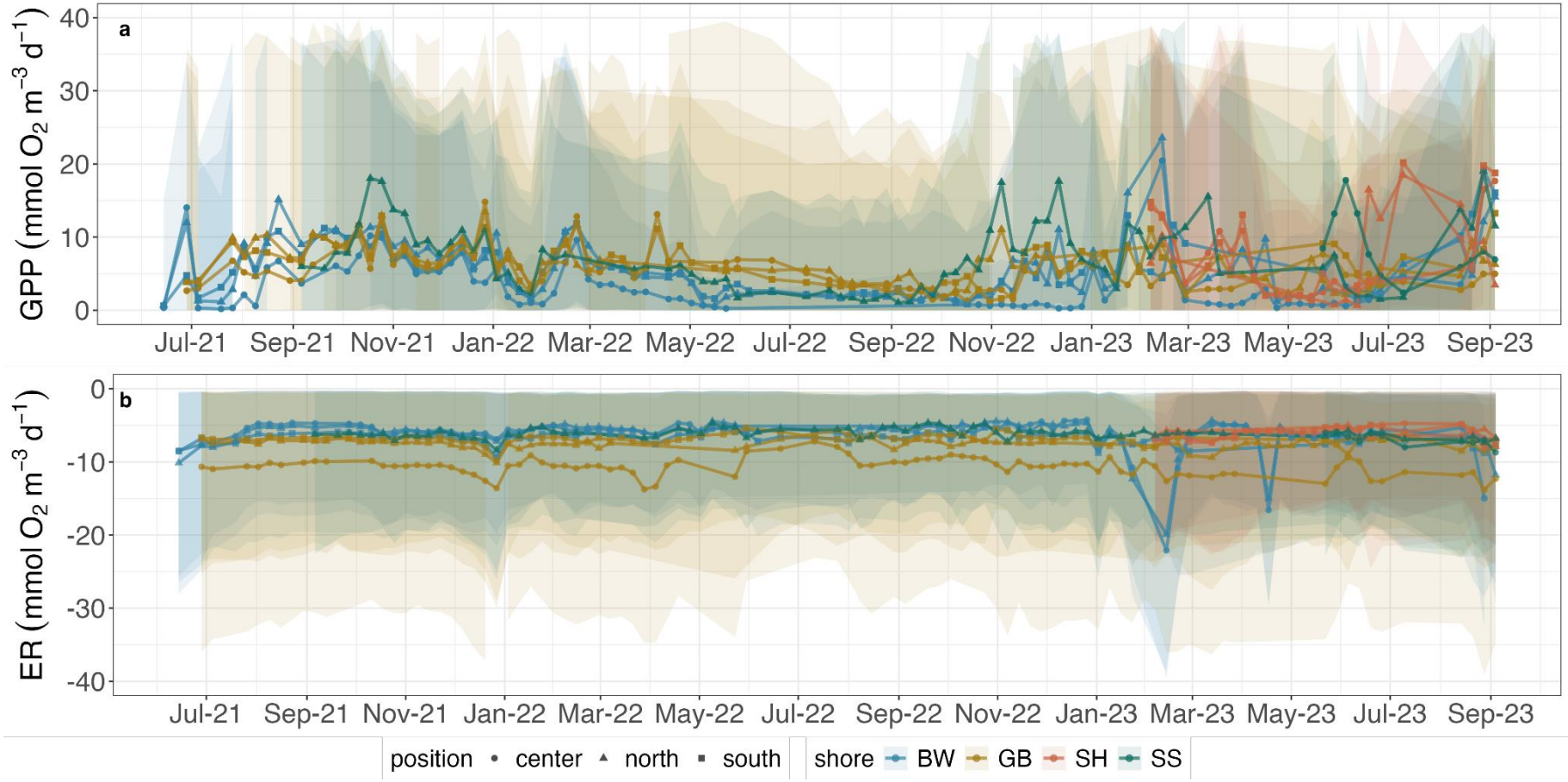
(Winslow et al. 2016; Lotting et al. 2021)

Other data: USGS stream gage, lake level stage, PRISM, and NLDAS/ GLDAS (incoming solar radiation, windspeed, and barometric pressure)

Temporal resolution:

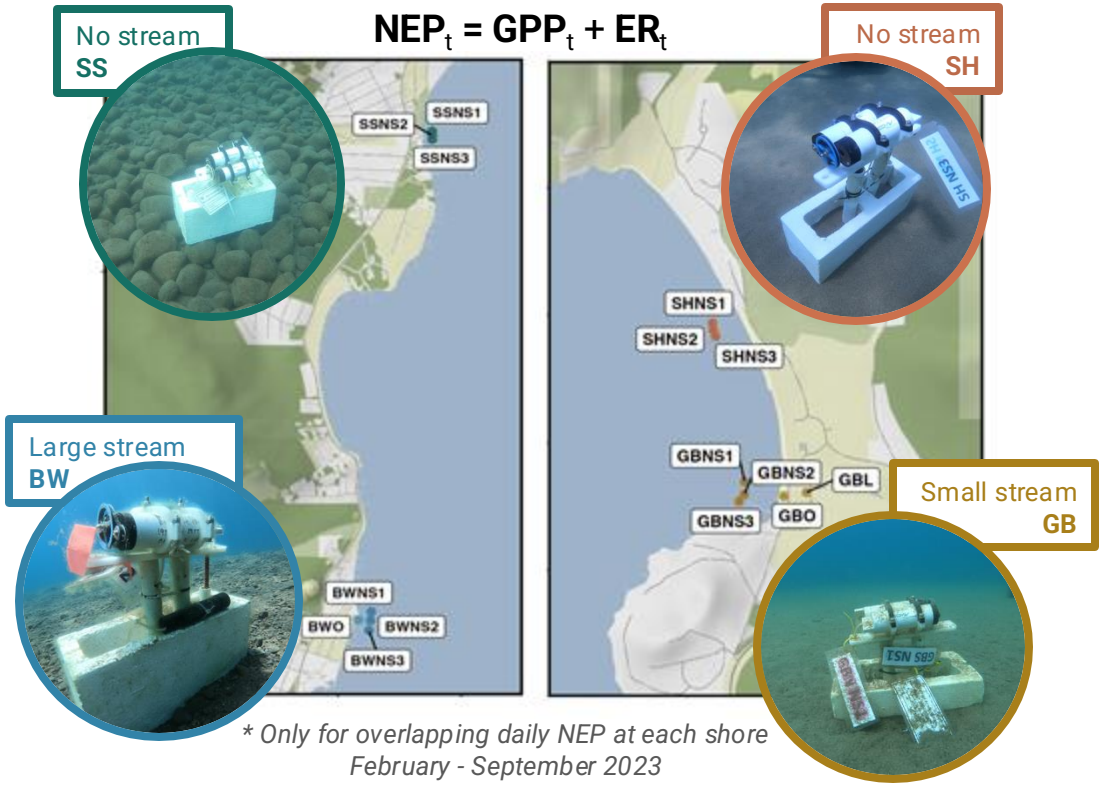
	2021	2022	2023
Near shore metabolism	Daily		
Nearshore sampling		Monthly	
Interface sampling		Bi-Weekly	
Stream sampling		Bi-Weekly (summer weekly)	

GPP and ER June 2021- September 2023

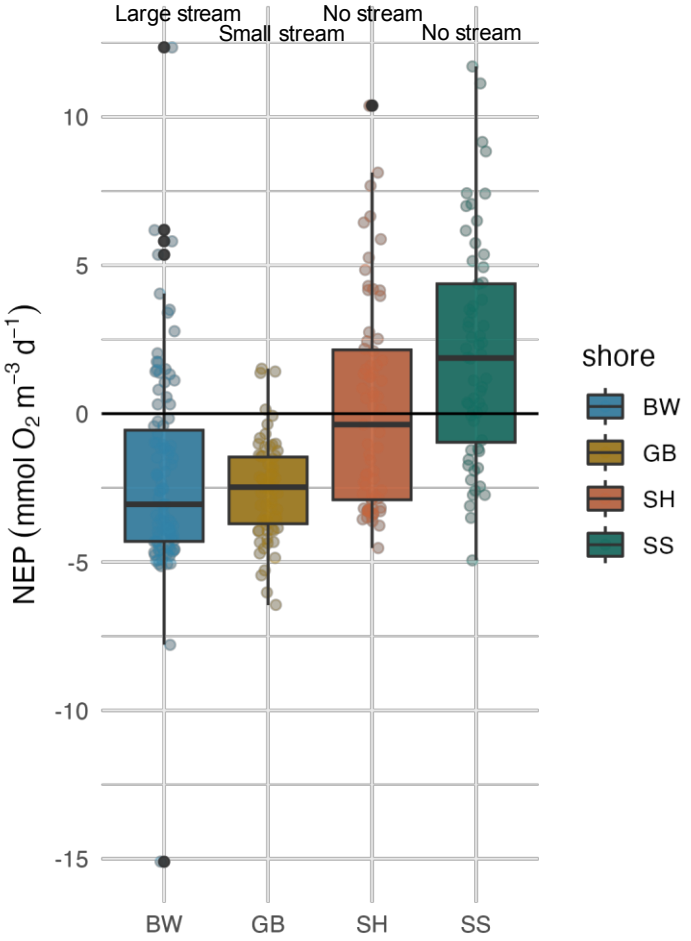


Areas **away from streams** tend to be more **autotrophic.**
Areas **near streams** tend to be more **heterotrophic**.

$$NEP_t = GPP_t + ER_t$$



** Only for overlapping daily NEP at each shore*
February - September 2023



1. How does streamflow regulate nearshore water temperature and light availability to ultimately influence nearshore productivity?

Evaluating effects of streamflow on metabolism using Bayesian piecewise structural equation models (SEM)

$$log(\mathbf{GPP}_{t\,i}+1) = \beta_0 + \beta_1 x\ log(\mathbf{GPP}_{\mathbf{t\text{-}1}\,i}+1) + \beta_2 x\ \mathbf{littoral\ light}_{t\,i} + \beta_3 x\ \mathbf{lake\ temp.}_{t\,i} + \beta_4 x\ log(\mathbf{streamflow})_{t\,i} + \mu_{t\,i} + \epsilon_{t\,i}$$

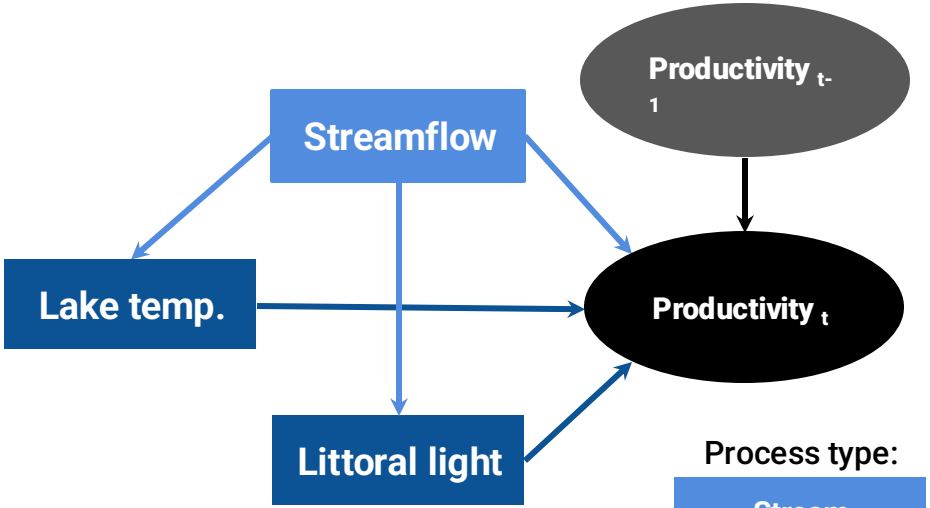
$$\mu_i \sim N(0, \sigma^2_{\mu}) \text{ and } \epsilon_{t\,i} \sim N(0, \sigma^2)$$

$$\mathbf{lake\ temp.}_{t\,i} = \gamma_0 + \gamma_1 x\ log(\mathbf{streamflow})_{t\,i} + \mu'_{t\,i} + \epsilon'_{t\,i}$$

$$\mu'_i \sim N(0, \sigma^2_{\mu'}) \text{ and } \epsilon'_{t\,i} \sim N(0, \sigma'^2)$$

$$\mathbf{littoral\ light}_{t\,i} = \delta_0 + \delta_1 x\ log(\mathbf{streamflow})_{t\,i} + \mu''_{t\,i} + \epsilon''_{t\,i}$$

$$\mu''_i \sim N(0, \sigma^2_{\mu''}) \text{ and } \epsilon''_{t\,i} \sim N(0, \sigma''^2)$$



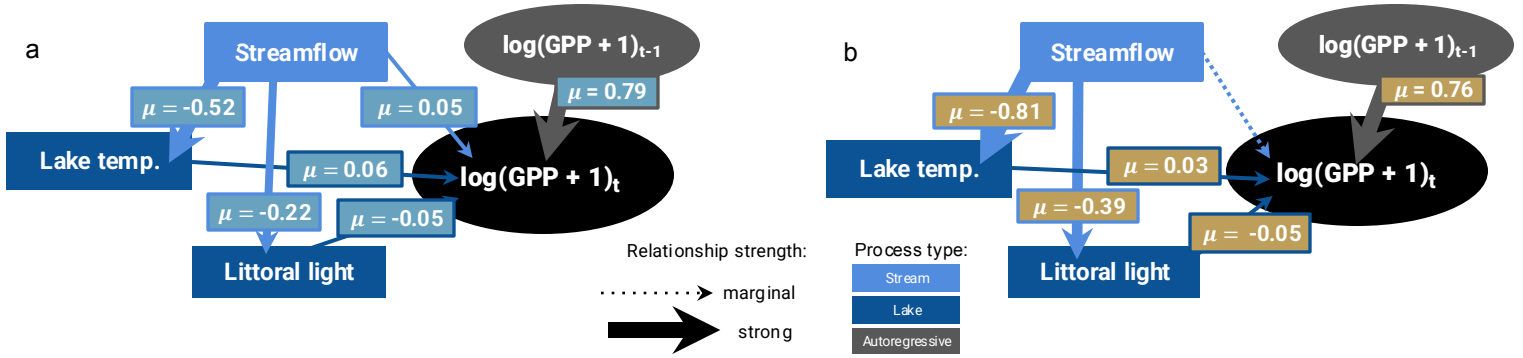
Process type:

- Stream
- Lake
- Autoregressive

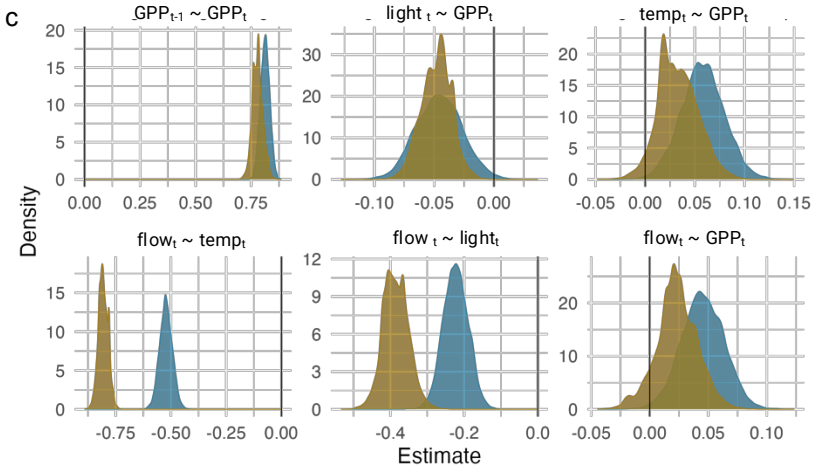
Not considered here:

- Weather
- Grazing
- Nutrients
- OM

Both shores have a strong signal of temporal autocorrelation.



West shore
Large stream
"BW"



*Analysis for just stream sites (BW and GB)
On overlapping days June 2021 – September 2023

East shore
Small stream
"GB"

How does streamflow influence nearshore productivity in Lake Tahoe, across different stream to lake transition zones and through different hydroclimatic conditions?

(1) How does streamflow regulate nearshore littoral water temperature and light availability to ultimately influence nearshore metabolism?

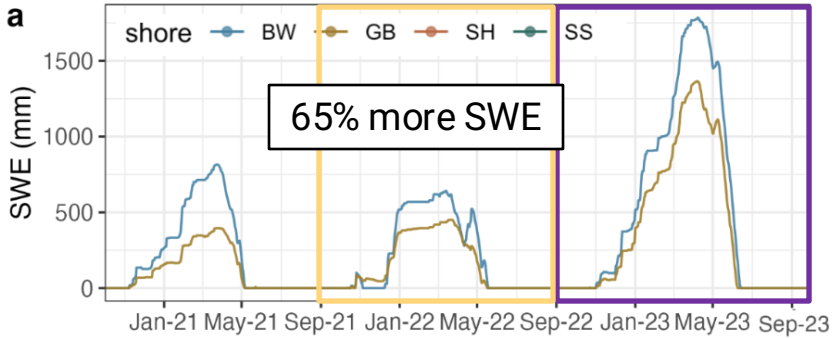
Indirectly

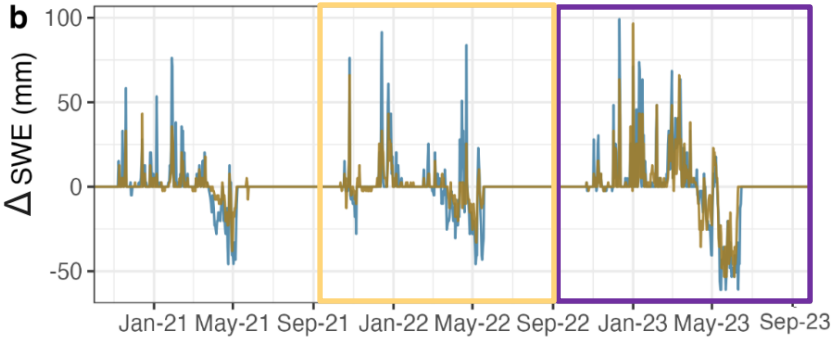
- **Streamflow** had a small positive impact on nearshore GPP.
- **Streamflow** can decrease **lake water temperature**
- **Streamflow** can decrease **littoral light**

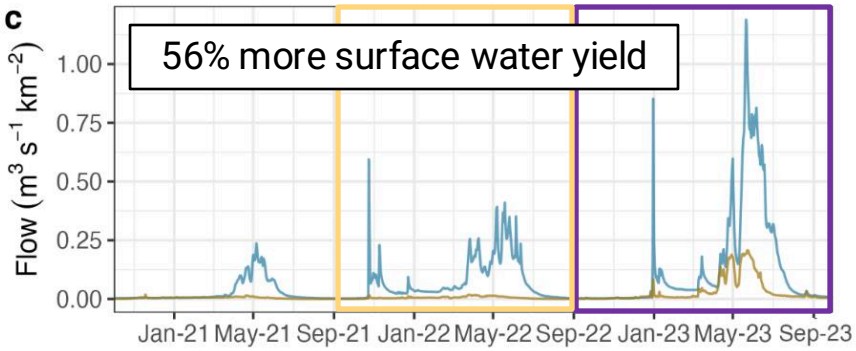
How does streamflow influence nearshore productivity in Lake Tahoe, across different stream to lake transition zones and through different hydroclimatic conditions?

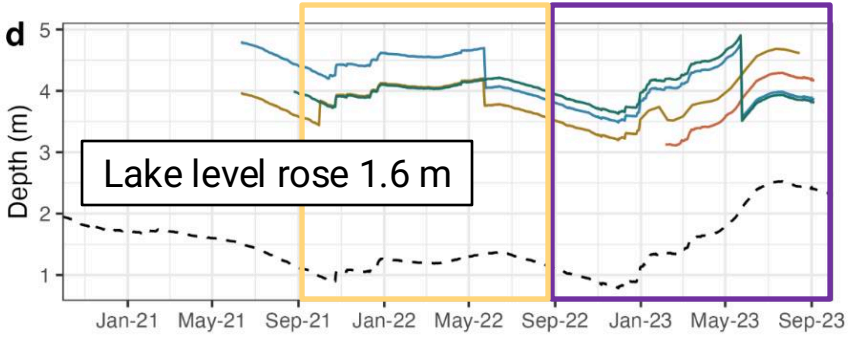
(2) How do environmental conditions in the nearshore change between a relatively wet verse dry year? And are those responses different based on the presence of inflowing streams?

Hydroclimatic differences between wet (2023) and dry (2022) years





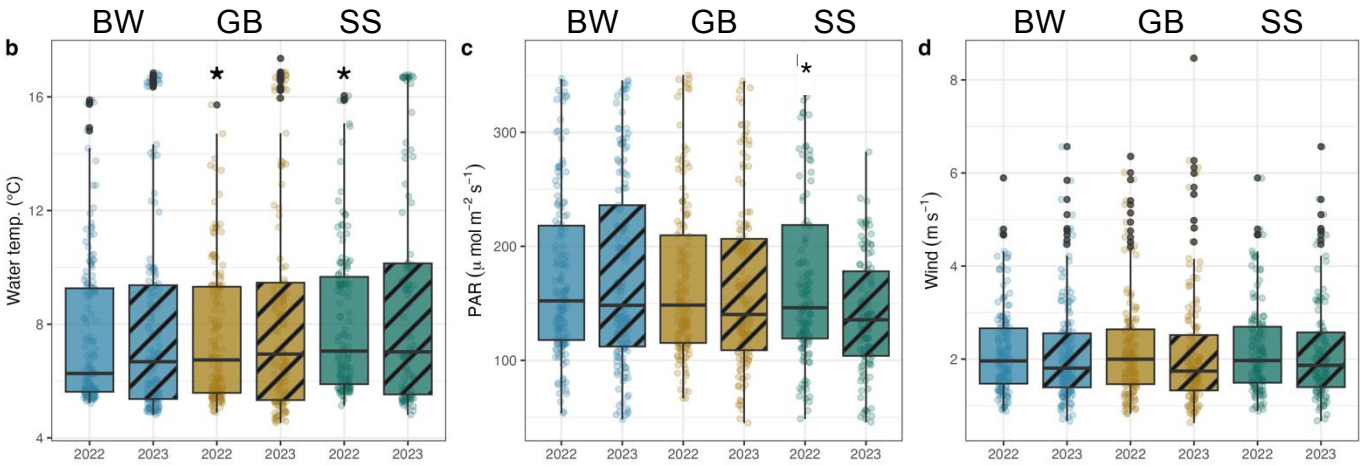




Snowpack melted 12 and 27 days later

(2) How do conditions in the nearshore change between relatively wet verse dry years?

Analysis for just sites BW, GB, and SS with data from water years 2022 and 2023



Warmer water

7% at BW, 12% at GB, and 10% at SS

** GB F: 5.05, p = 0.03;*
** SS F:3.79, p = 0.05*

Less light

20% less at SS

** SS F: 14.6, p < 0.001*

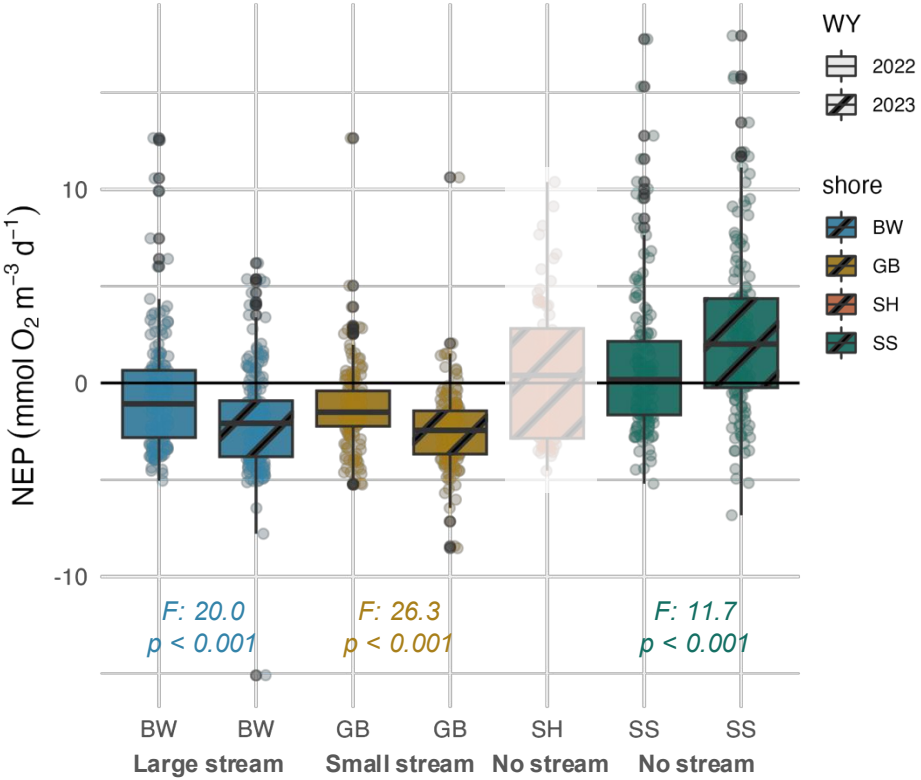
No change in wind

WY
2022 dry
2023 wet
* = p < 0.05

shore
BW
GB
SH
SS

(2) How do conditions in the nearshore change between relatively wet verse dry years?

And are those responses different based on the presence of inflowing streams?



**Analysis for sites with data from water years 2022 and 2023 (BW, GB, and SS)*

Areas **away from streams** were more **autotrophic in the wet year** (WY 2023).

- SS: 1.62 mm O_2 m^{-3} d^{-1} NEP increase

Areas **near streams** were more **heterotrophic in the wet year** (WY 2023).

- BW: 1.30 mm O_2 m^{-3} d^{-1} NEP decrease
- GB: 1.22 mm O_2 m^{-3} d^{-1} NEP decrease

How does streamflow influence nearshore productivity in Lake Tahoe, across different stream to lake transition zones and through different hydroclimatic conditions?

(2) How do environmental conditions in the nearshore change between a relatively wet verse dry year? And are those responses different based on the presence of inflowing streams?

- Twice as much precipitation
- Warmer littoral water temperature
- Decreased light for areas away from streams

- Wet years were more autotrophic for areas away from streams and more heterotrophic for areas near streams.

Main take aways

1. Inflowing streams influence productivity along the nearshore.
2. This influence changes with stream size and across dry and wet years.
3. Where areas around streams tend to be more heterotrophic while areas away from streams tend to be more autotrophic.
4. Where wet conditions were associated with warmer water, slightly less benthic light, and greater heterotrophy in areas near streams inflows, but greater autotrophy in areas away from inflowing streams.

Questions?

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Thank you.

The Blaszczak field and laboratory team members, Rob Miller, Meredith Brehob, Helen Lei, Taryn Elliott, Ian Halterman, Molly Ferro, Keenan Seto, Wubneh Belete Abebe, Rija Masroor, and Dillon Ragar, who helped collect and process the survey data; The University of Reno's Global Water Center and Chandra lab members, especially Emily Carlson, Erin Suenaga, Elizabeth Everest, and Zach Bess; Tahoe Regional Planning Agency, Kris Morehead, Tahoe National Forest; and the residents of Glenbrook Nevada, especially Gary and Susan Clemons.

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