Inferring fluvial metabolism from CO_2–O_2 paired measurements across contrasting hydrological conditions

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Funded by the European Union NextGenerationEU

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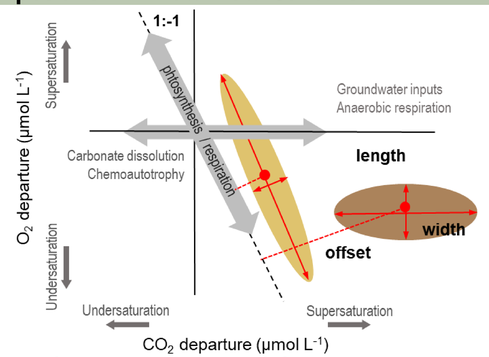
Objective

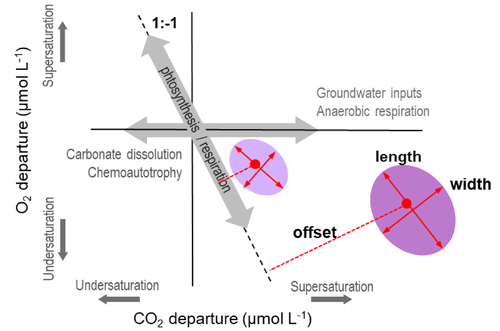
Identify the main drivers of CO_2 and O_2 concentrations in an intermittent Mediterranean headwater stream and assess how their relative importance shifts under contrasting hydrological conditions.

Expectation 1 - Low-Flow Conditions



- **Main driver: stream aerobic metabolism.** Long and stretch CO_2–O_2 ellipses close to 1:-1 (yellow ellipse)
- **Main driver: stream anaerobic metabolism.** Long and wide CO_2–O_2 ellipses, far from 1:-1 (brown ellipse)

Expectation 2 - High-Flow Conditions

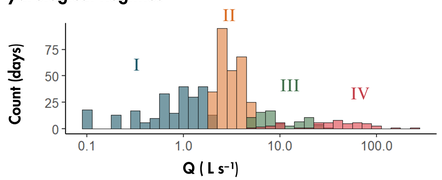


- **Main driver: groundwater inputs.** Short and wide CO2-O2 ellipse, far from both 1:-1 and 0:0 (atmospheric equilibrium) (dark purple ellipse)
- **Main driver: reaeration.** Short and stretched CO2-O2 ellipses, close to both 1:-1 and 0:0 (light purple ellipse)

Study Site & Methodology

- **Study site:** Fuirosos, an intermittent, Mediterranean headwater stream
- **Sampling period:** May 2021- Feb 2024
- **Measures:** 10-min O_2 and CO_2 concentrations, discharge, and daily gross primary productivity (GPP), ecosystem respiration (ER), and net primary production (NEP = GPP-ER)

Hydrological Regimes

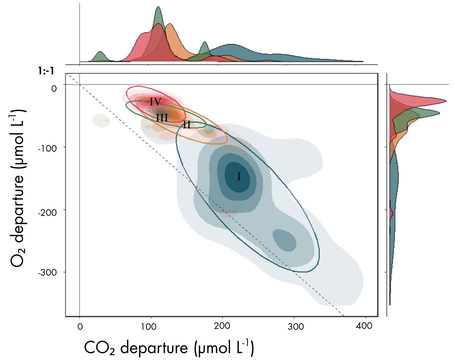


Colors represent days under different hydrological conditions

→ **Regime I:** 0.1 – 1.8 L s^{-1} → **Regime II:** 1.9 – 5.1 L s^{-1}

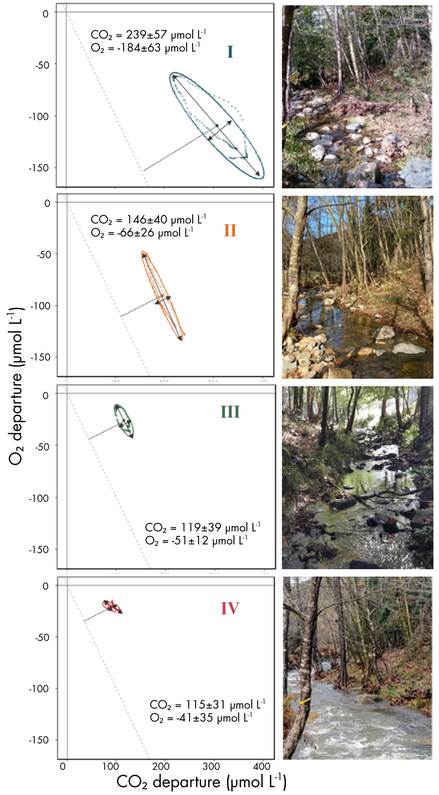
→ **Regime III:** 5.2 – 29 L s^{-1} → **Regime IV:** 5.6 – 268 L s^{-1}

Daily CO_2:O_2 departure

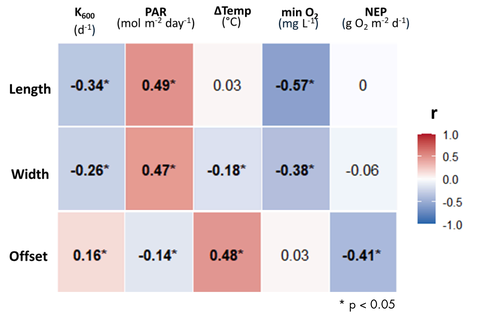


Examples of subdaily CO_2 and O_2 ellipses

Data of one representative CO_2–O_2 ellipse and mean CO_2 and O_2 concentrations for each hydrological regime

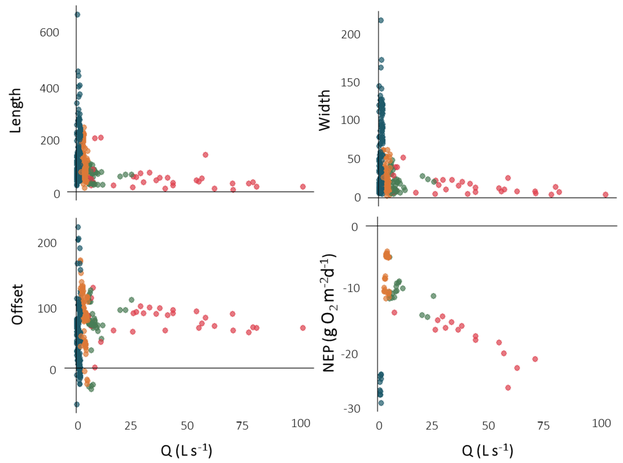


Results



CO_2-O_2 Drivers

- **Length:** Increases with light inputs and decreases with minimum daily O_2 concentrations, suggesting strong GPP influence on CO_2–O_2 dynamics.
- **Width:** Increases with light inputs and decreases with minimum daily O_2 concentrations, suggesting anaerobic CO_2 production coupled to GPP.
- **Offset:** Increases with diel variations in temperature and ecosystem respiration (negative NEP), suggesting aerobic CO_2 production.



CO_2-O_2 and NEP Patterns

- **Length and Width:** Lower and more stable as discharge increases, reflecting lower influence of the stream metabolic fingerprint at high flows
- **Offset:** More stable as discharge increases, reflecting the importance of external groundwater inputs at high flows.
- **NEP:** Declines with discharge, driven by increased ecosystem respiration. At very low flows, NEP sharply diverges from the trend, becoming highly negative.

Conclusions

- At extreme low flows (Regime I and II), in-stream processes drive CO_2-O_2 dynamics: long ellipses suggest influence of GPP, and wide ellipses suggest influence of anaerobic metabolism
- At high flows (Regimes III and IV), physical processes drive CO_2-O_2 dynamics: short and stretched ellipses suggest strong air-water exchange rates. Yet, relatively large offsets suggest CO_2 inputs and high respiration rates.