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Assessing the Sensitivity of Tropical Stream Ecosystems to Combined Warming and Reduced Water Flow

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Abstract: Warming and reduction in discharge might influence oxygen concentration and the decomposition of organic material in tropical streams; however, the impacts do not necessarily mean an analogous ecological response. This research attempts to understand the interaction between these two phenomena by applying a transparent process-based screening approach using twelve scientific papers in contemporary literature. The research design is described through a factorial analysis of nine scenarios of varying water temperature at 24, 26, and 28 °C and discharge at 1.00, 0.70, and 0.40. The first response variable is a simple oxygen balance that considers the temperature effect on oxygen consumption and the effect of discharge on reaeration. The second response variable is a function for litter decomposition influenced by temperature and discharge. Under the established central assumptions, the reference condition yields dissolved oxygen of 6.40 mg L^{-1} and a breakdown coefficient of 0.0200 d^{-1}. The warming scenario of 28 °C lowers the dissolved oxygen to 5.16 mg L^{-1} and raises the decomposition rate to 0.0234 d^{-1}. A combination of this warming with a 60% discharge reduction results in a concentration of oxygen of 3.63 mg L^{-1} and rate of degradation of 0.0159 d^{-1}. Sensitivity analysis demonstrates that the scale of these alterations depends very significantly upon assumed values of parameters related to reaeration and runoff responses. The model reveals the potential existence of such an inconsistency and not sets any threshold of tropical response in terms of measured indicators. This evaluation recommends simultaneous measurements of oxygen and organic matters transformation.

Keywords: Tropical Streams; Compound Stressors; Water Warming; Reduced Discharge; Dissolved Oxygen; Leaf Litter Decomposition.

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I. Introduction

Temperature and hydrological changes due to climate change could happen together in one stretch of a stream. A study on warming rivers in the United States and Central Europe shows the deoxygenation of streams and proves that flowing waters are not necessarily safe from oxygen depletion even though they are still connected. While the spatial extent of this study does not tell us about the extent of change in the tropical headwaters, it is a good motivation to look into oxygen when assessing warmer and drier streams (Zhi et al., 2023). The current paper will develop an exploratory model relating a chemical state variable to an ecosystem process. Streams can vary in terms of height, riparian shade, groundwater input, stream geometry, and rainfall in the tropics. Comparative studies done on insect populations living in both temperate and tropical streams show that regional and local temperatures need to be considered in sensitivity assessments (Dewenter et al., 2024).

Ecological sensitivity refers to the change in a specific response across a temperature or flow gradient that is imposed. Ecological sensitivity is not a measure of ecosystem health in the form of an index. Two streams may have the same change in oxygen concentration, but may have different decomposition responses depending on factors such as the availability of leaf litter, composition of the microbiota, hydrological characteristics, and consumer communities in each stream. The screening process must take this variation into consideration without reducing the variation in all the responses to just one category of vulnerability. The change in the functional aspect must be evaluated properly. Research on fungal and leaf litter in Neotropical streams has shown that higher rates of decomposition occur despite a lower species richness and spore concentration with warming (Gentilin-Avanci et al., 2022).

Objectives and Scope

Three questions are answered by this research. Firstly, how does a reduced oxygen balance react to individual and simultaneous variations in temperature and flow rate? Secondly, does it become possible for litter decomposition to vary in a reverse direction from dissolved oxygen? Finally, which assumptions impact the scenario comparison results most? The research applies a three-by-three factorial design for separating the individual stressors and their combined effect, and further applies a parameter test for several selected variables around the core specification. The contribution is a framework that reproduces itself on the basis of assumptions stated both physically and functionally. All results depend upon its equations.

II. Evidence and Ecological Context

A study of tropical non-perennial streams in Brazil's Caatinga revealed different community responses in the phases of flowing streams and disconnected pools. Some lotic macroinvertebrates went extinct, but other taxa invaded the pools that remained, while fish responded differently. This shows that both community replacement and resistance can take place simultaneously, and that hydrological shrinkage does not mean an equivalent loss for all groups of organisms (Oliveira et al., 2024). The difference between reduction in flow and complete cessation of flow is crucial to the current model. A positive discharge fraction means the presence of flow. Zero discharge will cause a mathematical singularity and overlooks the ecological shift to disconnected habitat.

The tropical microcosm study in Panama uses warming and salinization to test the roles of microbes and detritivores in leaf breakdown. This study highlights the need for testing both warming and discharge and distinguishing the different decomposer groups, but provides no warming-discharge calibration (García et al., 2024). The restored urban stream mesocosms subjected to warming, reduced velocity, and salinization have shown little impact on various microbial decomposer metrics. Therefore, strong impacts do not always occur and the degree of exposure, history of the community, and duration of the experiment should be considered (David et al., 2024). Large stream mesocosm experiment investigating warming, low flow, and sedimentation indicates the difference in decomposition response in benthic and hyporheic zones. Hyporheic zone may act as a refuge and sediment accumulation changes exchange and habitat quality. Single water column oxygen measurement cannot account for these subsurface dynamics, which makes it necessary to consider this model as a reach screening tool (Wild & Geist, 2025).

Experiments conducted in Brazil reveal that low flow, sedimentation, and nutrient loading influence macroinvertebrate communities in varying ways. Low flows therefore cannot be considered equivalent to nutrient or sediment stress. These stresses have been kept constant in the current experiment for the sake of focusing on the stated warming-flow pathways and not due to lack of importance in agricultural catchments (Almeida et al., 2025). Stream algal experiments examine temporal dynamics under climate change and land use stressors. This is important due to the possibility of time-dependency in photosynthetic response which can result in different oxygen conditions for other organisms. The current oxygen calculations deliberately omit the diel photosynthetic term and should not be interpreted as a prediction of diurnal oxygen maxima or nocturnal minima (Penk et al., 2024). Experiments that have been conducted on heatwaves, variable flow velocity, carbon dioxide, and fine sediments reveal that variability and low flow treatments are not the same. A positive response to the variable velocity treatment cannot therefore be expected under low flow conditions. The current scenarios assume constant exposure conditions and not repeated heatwaves or flow variability (Hunn et al., 2024).

A study on an Atlantic stream system showed significant non-interacting contributions from multiple stressors to macroinvertebrate diversity. Another study on a flume experiment that included flow reduction and light showed no interaction from light for some responses. These results highlight the importance of defining a comparison model before characterizing the combined effect as synergistic or antagonistic (Lourenço et al., 2023; Lourenço et al., 2023). This supports the use of paired chemical and functional assessment. The response coefficient is still an assumption and undergoes sensitivity analysis.

III. Materials and Methods

Twelve research papers published from 2019 to 2023 have been selected through targeted searches on publishers' websites, database entries, and institutional repositories. The keywords used in the searches include tropical stream, warming, reduced flow, dissolved oxygen, litter decomposition, and multiple stressors. The records were checked. Selection criteria included preference for experiments or observations that investigated a model pathway or a limitation to evidence transferability across regions. The evidence base used in this study is not a comprehensive systematic review. The numerical experiment includes three different temperatures, T = 24, 26, and 28 °C, and three additional discharge fractions, $f = Q/Q_0 = 1.00$, 0.70, and 0.40. In the equation above, Q_0 stands for reference discharge, and f = 0.40 indicates a 60% decrease in flow rate. Temperature and discharge are varied independently in order to distinguish their analytical contributions.

The reference condition is an imaginary shaded, low-elevation flowing tropical stretch at 24 °C. Neither a specific stream, drainage area, time of sampling, nor discharge level is assigned to it. The litter, organic content of the water, nutrients, salinity, and composition of the biological community all stay the same between the central conditions. The chosen temperature range and level of flow reduction constitute experimental contrasts.

Firstly, there is the dissolved oxygen level C which can be expressed in units of mg/L. This is assessed using an oxygen balance that takes into account the reaeration term which restores the oxygen to its specified saturation value and the oxygen demand term, which is dependent on the water temperature. These are the only terms used in the model and other factors would require further measurement.

$$dC/dt = a(f)[C_s(T) - C] - R(T) \quad (1)$$

$$C_s(T) = 8.40 - 0.15(T - 24); \quad a(f) = a_0 f^b \quad (2)$$

$$R(T) = R_0 \times (q^R)(T - 24)/10 \quad (3)$$

The local saturation approximation is an arbitrary linear equation for 24–28 °C, where the concentration is expressed in mg L^{-1} and the slope is in mg L^{-1} $°C^{-1}$. This equation is not a derived solubility equation and is only applicable to 24–28 °C, but is not used at any other temperature, altitude or salinity. The key parameters are $a_0 = 2.0$ d^{-1}, b = 0.50, $R_0 = 4.0$ mg L^{-1} d^{-1}, and $q^R = 2.0$. They are all arbitrary parameters which have been selected to guarantee positivity of oxygen concentrations throughout the central grid and are not derived from the literature that has been referred to in this document. Equating equation (1-3) to zero results in $C^* = C_s(T) - R(T)/a(f)$. If this value turns out to be negative, then the assumption of oxygen independent demand must be disproved by revising the oxygen dependent equation.

The second parameter is the first order leaf litter decomposition rate constant k measured in d^{-1} units. It denotes the rate of mass loss in relation to a defined leaf litter pool. The formula used to describe this is: $M(t) = M_0 \exp(-kt)$, where M_0 and M(t) are the initial and final litter mass, respectively. The real-life determination of this parameter would take several readings to account for physical loss. However, in the present situation, the parameter was generated from the provided response equation (4-5).

$$k(T, f) = k_0 \times (q^L)(T - 24)/10 \times f^e \times [g(C*)/g(C_0)] \quad (4)$$

$$g(C) = C/(C + H); \quad C_0 = 6.40\, mg\, L^{-1} \quad (5)$$

The key parameters are $k_0 = 0.0200$ d^{-1}, $q^L = 1.70$, e = 0.30, and H = 2.0 mg L^{-1}. The ratio of $g(C^*)/g(C_0)$ normalizes the oxygen dependence to one with respect to the reference condition. The thermal multiplier represents a formula of the potential amplification of the decomposition reaction rate. The discharge multiplier represents a formula of the potential limiting factor for the transport and decomposition reactions. It is a phenomenological assumption and does not imply that a 60% reduction in discharge will result in a specific change in microbial respiration. The sensitivity to temperature is different for the oxygen demand and litter decomposition since these are two different aggregated processes represented by the model.

Oxygen background demand is imposed independently of the litter pool. The litter equation responds to the calculated oxygen demand but does not affect R. One-way coupling prevents the assertion of a closed carbon-oxygen budget and should be modified if litter respiration is a significant part of the reach demand.

Each single parameter was changed with respect to the central case of T = 28 °C and f = 0.40. Reaeration exponent b was varied from 0.30 to 0.70; reference reaeration a_0 from 1.5 to 2.5 d^{-1}; and decomposition flow exponent e from 0.10 to 0.50. If a_0 changes, then reference concentration C_0 is computed anew as $8.40 - R_0/a_0$ to ensure that k_0 will be equal to the basic value for this parameter combination. The extremal cases are assumption sensitivity indicators, not confidence intervals. With regard to oxygen, the combined concentration changes are measured against the sums of warming and flow changes separately based on mg/L scale. The residual value is $C^*(T,f) - C^*(T,1) - C^*(24, f) + C^*(24,1)$. In the case of litter breakdown, the reference additive expectation as well as reference multiplicative expectation are taken into account since interaction terms will be defined by the choice of scale of response. Significance tests do not apply to deterministic solutions. Full precision calculations are applied. Oxygen is presented with two decimal points while k is with four decimal points. The same output was used for the heatmap and table. The central grid point was compared against reference normalization, oxygen derivative and closed-form equilibrium solution. The analysis included nine scenario states instead of nine independent field observations.

IV. Results and Discussion

Table 1 shows the full central scenario grid. The oxygen concentration decreases monotonically with increase in temperature and decreases in discharge. The reference value of 6.40 mg/L reduces to 5.16 mg/L in case of warming only and 5.24 mg/L in case of discharge reduction only at the highest levels tested. In the combination of both, the value is 3.63 mg/L, which is a reduction of 2.77 mg/L or 43.32%.

Table 1: Modelled Dissolved Oxygen and Litter Breakdown Under Warming and Reduced Discharge

Temperature (°C)	Remaining discharge (% of reference)	Dissolved oxygen (mg L^{-1})	Breakdown k (d^{-1})
24	100	6.40	0.0200
24	70	6.01	0.0177
24	40	5.24	0.0144
26	100	5.80	0.0217
26	70	5.35	0.0191
26	40	4.47	0.0153
28	100	5.16	0.0234
28	70	4.65	0.0204
28	40	3.63	0.0159

The litter decomposition dynamics have a distinct characteristic. Warming of 28 °C at reference discharge increases the rate constant k from 0.0200 to 0.0234 d^{-1}, which corresponds to an increase of 16.96%. Decreasing the discharge to 40% at 24 °C decreases k to 0.0144 d^{-1}. The combination of the extremes yields 0.0159 d^{-1}, which is 20.53% less than the reference value but more than the flow only value. Hence, thermal stimulation partially counteracts reduced decomposition under low discharge in this equation. At 28 °C and 70% of remaining discharge, the value of k is 0.0204 d^{-1}, nearly equal to the reference value, and the oxygen concentration is 4.65 mg L^{-1}. Therefore, near reference dynamics may occur in the presence of a significant chemical transformation.

Figure 1 shows both metrics using the same temperature-discharge coordinates. Oxygen levels go down in the warmest, lowest discharge corner. Breakdown levels are highest in the warmest reference flow condition and lowest in the coolest low flow condition. The varying response surfaces show why one metric cannot capture all impacts of compound exposure.

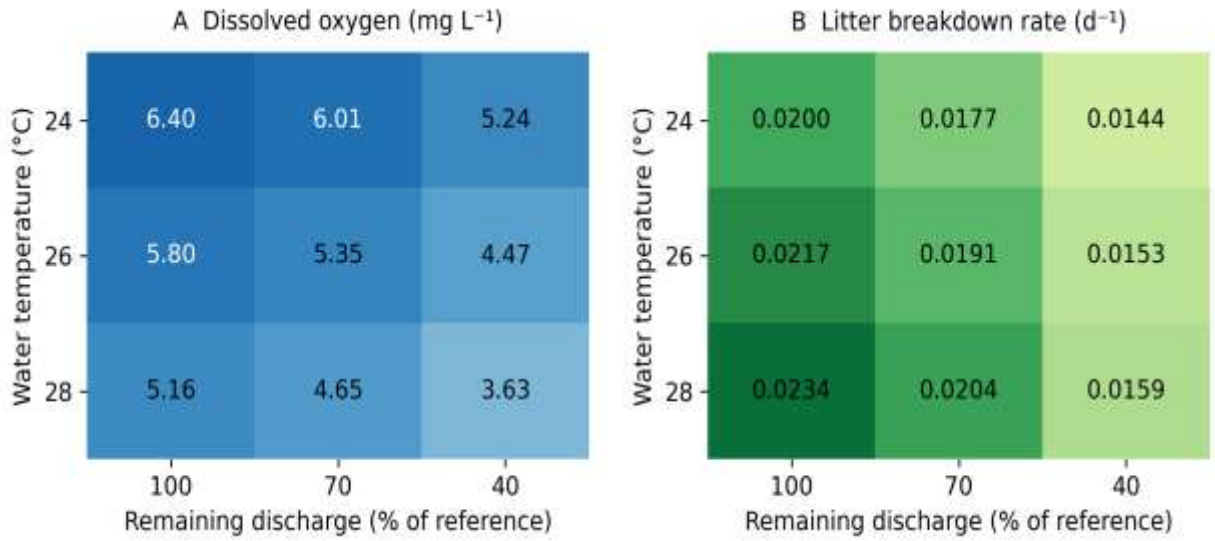


Figure 1: Sensitivity Surfaces of Two Metrics for Artificial Tropical Streams. A) Equilibrium Dissolved Oxygen; B) Daily Litter Breakdown Rate Coefficients

For oxygen, adding the warming only and flow only extremes predict 4.00 mg L^{-1} using an additive reference. Multiplication of the coefficients yields 3.63 mg L^{-1}, which is 0.37 mg L^{-1} lower than that value. This occurs mathematically due to higher oxygen depletion divided by a lower reaeration rate. It represents a non-additivity in the concentration domain of this model, not statistical proof of biological synergy. The additive expectation for breakdown is 0.0178 d^{-1}, whereas the multiplicative expectation is 0.0169 d^{-1}. The calculated multiplicative value for the combination of 0.0159 d^{-1} is lower than expected values. But the value is higher compared to the flow only coefficient; therefore, referring to this as an amplification of damage does not take into account any possible compensation effect. The chosen expectation, measurement, and units relate to any interaction type description. This conditional interpretation corresponds to modern scientific researches with different results. High impact does not have to occur at low exposure, and zones within the stream can shift the process. Direct extrapolation of the current coefficient values to tropical streams would depend on confirmation of hydraulic effects and biological oxygen effects (David et al., 2024; Wild & Geist, 2025).

The difference between the range of calculated oxygen of 4.33 to 2.79 mg L^{-1} is produced by changing b between 0.30 and 0.70 at 28 °C and 40% of remaining discharge. The change of the reference reaeration a_0 between 1.5 and 2.5 d^{-1} results in 2.24 and 4.46 mg L^{-1}, correspondingly. Thus, channel exchange assumptions have significant influence on the combined situation. It is impossible to make any statement on oxygen decrease related to a smaller flow proportion without the presence of hydraulic data. Litter flow exponent variation from 0.10 to 0.50 gives the total breakdown coefficients of 0.0191 and 0.0132 day^{-1}, respectively. This sensitivity underscores the need for calibration of the discharge vs. processing relationship. The model does not give a likelihood of the accuracy of a certain coefficient. The application requires data on temperatures and oxygen concentration along with discharge and retention time of litters. The estimates of reaeration, pressure correction, and repetitive oxygen determinations are essential in separating the exchange from biological demand component. The standardization of litter types and mesh size can discriminate substrates, microbes, and consumers. Habitat and assemblage data need to accompany function measures since decomposition alone is insufficient for determining the state of biodiversity (Gentilin-Avanci et al., 2022; Almeida et al., 2025).

The assumptions behind the model include those of equilibrium as well as a lack of consideration for diel variation, oxygen-dependent uptake, organic loading variations, thermal acclimation, mortality, and habitat fragmentation. The flow multipliers included in the model are unable to address the conflicting influence of low velocities and low depths on gas exchange. Changes in temperature with regard to

reaeration are also disregarded in the model. The sensitivity of a few coefficients is not an uncertainty analysis, and there is no threshold value for a tropical environment.

V. Conclusion

The combination of warming and decreased discharge could result in the creation of different chemical and functional responses within a transparent tropical stream screening model. In nine different simulated scenarios, the most intense exposure results in a decrease in the dissolved oxygen content from 6.40 to 3.63 mg L^{-1} and in litter breakdown from 0.0200 to 0.0159 d^{-1}. It is shown that warming causes increased breakdown rates together with decreased oxygen, which demonstrates the reason why higher rates of an ecosystem process do not mean better ecological state. Reaeration and discharge response assumptions significantly affect the extent of change. The main result of the research is the development of a testable framework for paired oxygen and litter measurements rather than the evaluation of observed ecosystem sensitivity.

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