



FROM INDICATORS TO GOVERNANCE: A PRESSURE- CONDITION-RESPONSE FRAMEWORK REVEALS NONLINEAR ECOLOGICAL RESPONSES TO MULTIPLE STRESSORS IN AN AGRICULTURAL-URBAN BASIN

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Abstract: Understanding how multiple interacting stressors modulate aquatic community dynamics is fundamental to forecasting ecosystem trajectories under accelerating global change. In subtropical basins, the concurrent influences of thermal regimes, ionic composition, and habitat structure generate nonlinear and often synergistic ecological responses that remain unresolved. In this study, we integrated community-level indicators with multivariate and threshold-detection analyses to identify principal environmental drivers and associated biological breakpoints across anthropogenic gradients. An adapted multicriteria index was employed to translate these ecological patterns into operational assessments applicable to regional water governance. Water temperature emerged as the dominant environmental filter regulating both macroinvertebrate and phytoplankton assemblages, exerting a stronger effect than ionic or geomorphological control. Community transitions were characterized by the replacement of thermosensitive taxa with tolerant and generalist groups, concomitant with pronounced reductions in taxonomic richness. Nonlinear responses included a peak in diversity at intermediate ionic concentrations and a critical dissolved oxygen window, beyond which biological integrity declined abruptly. Threshold analyses revealed consistent limits associated with temperature, conductivity, and substrate composition, whereas the multicriteria index effectively detected moderate disturbance but exhibited reduced sensitivity at the extremes, a compression pattern typical of linear scoring systems. Collectively, these results demonstrate that ecological vulnerability in subtropical streams arises from the interaction among thermal stress, oxygen limitation, and habitat simplification, rather than from isolated environmental gradients. By integrating multivariate and threshold-based diagnostics, this framework offers a scalable, mechanism-informed tool to anticipate ecological regime shifts and strengthen adaptive water governance under intensifying climatic and anthropogenic pressures.

Keywords: *Ecological thresholds; TITAN; Random Forest; Water security; Subtropical streams.*