AquaShift: Synchronized Chemical Equilibrium Convergence as a Leading Indicator of Phycocyanin-Threshold Cyanobacterial Bloom Onset Across Contrasting Freshwater Systems

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Cyanobacterial harmful algal blooms (HABs) pose threats to aquatic ecosystems and public health, yet existing prediction models rely on single-variable correlative thresholds that fail to capture the coupled biochemical dynamics driving bloom onset. Aquatic ecosystems are governed by interdependent chemical and biological reactions operating across multiple scales. When these reactions shift collectively toward a new equilibrium state, the system undergoes a phase transition, leading to sudden algal blooms. Detecting these transitions enables preparedness for such events. I developed Equilibrium-State Stoichiometry (ESS), a framework reconceptualizing bloom prediction as equilibrium-state analysis. ESS proceeds in four phases: (1) mapping key biochemical reactions to observable sensor parameters indicating reaction directionality, (2) connecting measured water chemistry to underlying reaction states through known chemical relationships, (3) detecting when multiple reactions simultaneously shift to favor rapid biomass production, and (4) comparing performance. The framework computes reaction quotient-to-equilibrium constant (Q/K) ratios across multiple coupled biochemical reactions. Validation used NOAA buoy data from areas such as Western Lake Erie (2016-2018) and the Columbia River, where ESS outperformed raw-sensor baselines across evaluated metrics (12.5% more accurate in the Columbia River and 26.2% in Lake Erie). Simultaneous Q/K convergence across multiple reactions preceded detectable bloom conditions, with multi-reaction convergence features emerging as top predictive indicators. These findings demonstrate that synchronized multi-equilibrium convergence, not individual variable thresholds, drives bloom onset with applications beyond HABs.

Awards Won:
Second Award of $2,400