Extreme Changes in Water Level and Nutrient Loading Can Shift Freshwater Coastal Wetlands from Nutrient Sinks to Sources

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Global change drivers, such as drastic alterations in water levels and nutrient loading, have the potential to transform coastal wetlands from nutrient sinks into nutrient sources. Elevated water levels in coastal systems can lead to wetland plant mortality, triggering increased nutrient mineralization and export. Additionally, flood-induced anaerobic conditions can enhance denitrification and promote phosphorus release via iron reduction. In the Laurentian Great Lakes of the USA, extreme lake level rises can interact with other change drivers, such as invasive species and increased nutrient inflow from the surrounding landscape, to significantly alter nutrient dynamics and ecosystem functions. Unraveling the complexities of these interactions is challenging, but simulation modeling offers a powerful approach to complement field observations. We utilized MONDRIAN, a process-based computational model, to simulate the interactions of individual plant species with environmental factors. Our in-silico experiment assessed the impact of water level fluctuations on coastal wetlands under six hydrological scenarios: a control (normal seasonal variation) and five disturbance treatments characterized by extreme flooding (reflecting observed Great Lakes conditions) lasting 1, 2, 3, 5, and 10 years, with water levels reaching thresholds that induced emergent plant mortality. Additionally, we simulated seven nutrient input levels, focusing on nitrogen (N) and phosphorus (P), ranging from low (4 g N m^{-2} yr^{-1}, 0.5 g P m^{-2} yr^{-1}) to extremely high (96 g N m^{-2} yr^{-1}, 24 g P m^{-2} yr^{-1}). Three plant community scenarios were also evaluated: native plants only, a Phragmites australis monoculture (a common invasive species), and P. australis invasion into a pre-established native community. This comprehensive experimental design resulted in over 1,000 MONDRIAN simulation runs fully crossing water levels, nutrient inputs, and plant community scenarios. Our results revealed that during extreme flooding, coastal wetlands shifted from nutrient sinks to sources, driven by reduced plant uptake, increased denitrification, and phosphorus desorption. The magnitude of this shift was influenced by both flood duration and nutrient input levels, with higher nutrient inputs amplifying nutrient release during extreme water levels. However, wetlands generally reverted to their nutrient sink state within one year after water levels returned to normal. While these patterns were broadly consistent across plant community scenarios, some community-specific trends emerged, particularly in the presence of P. australis. These findings underscore the critical role of hydrologic regimes in regulating nutrient dynamics within coastal wetlands and highlight the potential impacts of climate-driven changes in water levels, nutrient loading, and invasive species on shifting wetlands from nutrient sinks to sources.