

# Tipping and its Consequences in Ecological Systems

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## **ABSTRACT**

Climate change and human activities significantly impact natural ecosystems, often leading to tipping phenomena: sudden, qualitative shifts in ecosystem dynamics, such as changes between stable states. These shifts occur when external disturbances lead to sudden, long-term changes in ecosystem behaviour. Our study reveals that ecosystems that have experienced environmental perturbation before may tip easily due to a second weak and inefficient pulse that does not even cross the bifurcation point. This means that consecutive small pulse-like environmental perturbations may have a catastrophic impact on system dynamics, although a single pulse does not cause such a change. We also explore various bifurcation tipping (B-tipping) phenomena in coupled ecological systems, highlighting three key patterns based on coupling strength: **tipping cascade**, where change spreads sequentially through the system; **cascade hopping**, where intermediate systems remain stable while others tip; and **indirect tipping**, where downstream subsystems tip without any preceding subsystems doing so. These findings underscore the importance of understanding both past stress exposure and interspecies coupling in predicting ecological tipping points.