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# Balancing trade-offs among aquatic ecosystem services while navigating through regime shifts

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## **Abstract:**

Eutrophication can cause shallow lakes to experience regime shifts from the clear to the turbid state which impairs multiple dependent ecosystem services (such as drinking water or sites for recreational activities). While in most cases the clear state is seen as favorable, once it shifted to the turbid, its restoration is difficult and the costs often outweigh the expected benefits. While in some places costly restorations are under way, e.g. through biomanipulation and wetland construction, it remains challenging to implement measures that are able to support multiple ecosystem services simultaneously without compromising other connected services. More precisely, lake managers need to consider the temporal and spatial decoupling between lake use activities by beneficiaries and the activities from distant actors eventually polluting the lake.

Here, we present a simulation model to demonstrate how understanding of underlying feedbacks that support either the desired or undesired state can give a much more promising picture for restoring desired ecosystem states and services. To achieve this more holistic view about restoring ecosystem services, we assume a coupled social-ecological system where ecosystem beneficiaries respond to deteriorating ecosystem indicators and regulate their impacts accordingly. As an example, we explore simulations of shallow lake restoration, prone to regime shifts, with three alternative scenarios of social reinforcement for adopting more effective sewage treatment technology. By analyzing the emerging response time lags from different levels of decision making, we go beyond traditional single driver analyses and provide management perspectives for intentionally navigating through a regime shift to restore the desired ecosystem state and its dependent services.

**Keywords:** social-ecological interaction; regime shifts; shallow lake restoration; co-production; ecosystem services