Trophic Cascade Attenuation vs. Keystone Species Reintroduction: A Comparative Evaluation of Top-Down Regulation Strategies in Fragmented Temperate Riparian Ecosystems

Jesse Clark
Professor
Technische Universität Dresden
Helmholtzstraße 10, 01069 Dresden, Saxony, Germany

Morgan Hernandez
Associate Professor
Kyoto University
Yoshida-Honmachi, Sakyo-ku, Kyoto 606-8501, Japan

Dana Davis
PhD
University of British Columbia
2329 West Mall, Vancouver, British Columbia V6T 1Z4, Canada

Riley Gonzalez
D.Sc
Adam Mickiewicz University in Poznań
ul. Wieniawskiego 1, 61-712 Poznań, Wielkopolska, Poland

Abstract. Restoring ecological balance in fragmented riparian corridors remains a central challenge in contemporary conservation biology. This study comparatively evaluates two prevailing top-down regulation paradigms—trophic cascade attenuation (TCA) via mesopredator suppression and active keystone species reintroduction (KSR)—across twelve temperate riparian watersheds in Central Europe and East Asia. Using a combination of stable isotope analysis ($\delta^{13}C$, $\delta^{15}N$), guild-level biodiversity indexing, and structural equation modelling of species interaction networks, we quantified biomass flux redistribution, riparian vegetation recovery rates, and macroinvertebrate assemblage resilience under each strategy. KSR demonstrated statistically superior outcomes in riparian canopy regeneration ($p < 0.001$) and benthic biodiversity recovery, while TCA exhibited greater cost-efficiency in highly fragmented landscapes. These findings provide empirically grounded decision frameworks for adaptive watershed management and policy-level biodiversity offsetting schemes.

Keywords: trophic cascade attenuation, keystone species reintroduction, riparian ecosystem restoration, mesopredator release hypothesis, stable isotope trophic analysis, species interaction networks, benthic macroinvertebrate assemblages, top-down trophic regulation, fragmented watershed management

Introduction

Anthropogenic landscape fragmentation has emerged as one of the most pervasive and ecologically disruptive forces governing freshwater and riparian biodiversity loss in the twenty-first century. By 2025, it is estimated that more than 60% of the world's temperate riparian corridors have been structurally disconnected from their native upland habitats through agricultural encroachment, impoundment infrastructure, and expanding peri-urban development (IPBES, 2024). The consequences of this fragmentation extend well beyond simple habitat reduction: they fundamentally reconfigure trophic interaction webs, destabilize energy flux pathways, and precipitate cascading extinctions that disproportionately affect apex predators, obligate riparian specialists, and stenotopic macroinvertebrate taxa. Within this context, restoration ecologists and environmental policy architects have increasingly converged on two competing theoretical and applied frameworks for reinstating functional ecological integrity in degraded riparian systems. The first framework, trophic cascade attenuation (TCA), proceeds from the mesopredator release hypothesis, first systematized by Soulé et al. (1988) and subsequently validated across a range of guild structures. Under this paradigm, the suppression or managed removal of opportunistic mesopredators—including corvids, generalist mustelids, and mid-tier piscivores—is hypothesized to restore regulatory pressure on herbivore and primary consumer guilds, thereby indirectly facilitating riparian vegetation recovery and sediment stabilization. The second framework, keystone species reintroduction (KSR), draws on the foundational work of Paine (1969) and the more recent rewilding ecology literature, positioning the deliberate reintroduction of ecologically disproportionate predators—most notably Eurasian lynx (Lynx lynx), Eurasian beaver (Castor fiber), and native salmonid apex predators—as the principal vector of ecosystem reassembly. Despite a substantial and growing body of empirical literature supporting elements of both approaches, no rigorously controlled, multi-watershed comparative study has yet benchmarked these strategies under equivalent fragmentation pressure regimes and hydrological disturbance gradients. This gap is particularly consequential given the accelerating urgency of post-2020 Global Biodiversity Framework (GBF) commitments, which mandate measurable ecosystem integrity improvements across 30% of degraded land and freshwater areas by 2030. Management agencies face acute pressure to allocate finite restoration budgets between approaches whose relative effectiveness remains contested in fragmented versus continuous landscape matrices. Furthermore, the role of climatic nonstationarity—manifested as increased precipitation variability and thermal regime shifts in northern temperate systems—introduces additional uncertainty regarding the long-term structural resilience of restored trophic networks under either paradigm. This paper is structured as follows: Section 2 describes the study watersheds, sampling design, and analytical methods, including isotopic fractionation protocols and network modularity metrics. Section 3 presents comparative results across biodiversity, vegetation, and hydromorphological indicators. Section 4 engages in a critical synthesis of the two frameworks, incorporating cost-efficiency analysis and scalability considerations. Section 5 offers management recommendations and outlines priority directions for future longitudinal monitoring.

This is a preliminary version. To read the full version of the article, please purchase a subscription.

References

1. Fang, Z., & Wu, W. (2025). Inter-event creep of rock fractures during fluid injection: laboratory investigation and implications for injection-induced moment release. Rock Mechanics and Rock Engineering, 58(8), 9147-9162.
2. Mavuri, M., Chakrabarty, S., Rathod, U., & Sarda, D. (2025, December). Geospatial Analysis Using Transformer on TOAR and Meteorological Data for Early Warning of Particulate Matter Exceedance. In 2025 IEEE International Conference on Bioinformatics and Biomedicine (BIBM) (pp. 7036-7043). IEEE.
3. Mavuri, M., & Chakrabarty, S. (2024, December). Geospatial Analysis of Socioeconomic Equity and Environmental Factors Influencing Lung Cancer Prevalence in US. In 2024 IEEE International Conference on Bioinformatics and Biomedicine (BIBM) (pp. 6597-6604). IEEE.