Evaluating the Role of Terrestrial Protected Areas in Maintaining Stream Ecological Integrity Using Benthic Macroinvertebrates in Selected Streams of Southern Luzon, Philippines

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Abstract

Terrestrial protected areas (PAs) are widely promoted as a foundation of biodiversity conservation; however, their effectiveness in safeguarding freshwater ecosystems remains poorly understood, particularly in tropical regions. This study evaluated the effectiveness of terrestrial protected areas in conserving stream ecosystem integrity in Southern Luzon, Philippines, using benthic macroinvertebrates as bioindicators. Streams within two protected landscapes, Mounts Palay-Palay–Mataas-na-Gulod Protected Landscape and Mounts Banahaw–San Cristobal Protected Landscape, were compared with streams in adjacent non-protected areas, namely the Palico River Watershed and the Mount Malepunyo Mountain Range. A Reference Condition Approach was applied alongside adjacent-site comparisons to reduce spatial confounding and strengthen inference. Stream condition was assessed using physicochemical parameters, taxonomic composition, biotic indices, and functional trait composition. Functional traits were analyzed using an integrated RLQ and fourth-corner framework linking environmental variables, macroinvertebrate assemblages, and fuzzy-coded trait data. Statistical significance of trait–environment relationships was evaluated using Monte Carlo permutation tests, with multiple testing controlled using false discovery rate (FDR) correction.

At the broader PA versus non-PA scale, RLQ analysis revealed significant trait–environment relationships, with nutrient enrichment (total dissolved solids and phosphate), dissolved oxygen, and other environmental variables contributing to functional organization. Fourth-corner analyses indicated non-random associations between traits (*e.g.*, attachment, respiration, dispersal, and life-history strategies) and environmental gradients, suggesting environmental filtering. Adjacent-site comparisons revealed contrasting patterns, with clearer functional differentiation between Site 1 and Site 4 and weaker relationships between Site 2 and Site 3.

Overall, protected streams supported higher proportions of pollution-sensitive taxa and exhibited better ecological condition based on biotic indices, while non-protected streams were characterized by elevated nutrients, lower dissolved oxygen, and dominance of tolerant taxa. Functional trait patterns further indicated that protection status influences community assembly through environmental filtering. However, some overlap in biological responses suggests that protected areas remain influenced by broader watershed pressures. The consistency of patterns across both broad and adjacent-site comparisons demonstrates that protection status, rather than geographic variation alone, is a key driver of stream ecological integrity.

Keywords: terrestrial protected areas; freshwater ecosystems; benthic macroinvertebrates; functional traits; RLQ analysis; fourth-corner analysis; environmental filtering; stream ecological integrity; Philippines