Environmental Disequilibrium in Freshwater Bioindicator Communities

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2025-09-29

Introduction

Freshwater ecosystems are under immense pressure worldwide (Reid *et al.* 2019). Anthropogenic land use and climate change are causing shifting water availability, widespread freshwater ecosystem degradation, and unprecedented freshwater biodiversity loss, threatening the ecosystem services and drinking water humans are dependent on for survival (Dudgeon *et al.* 2006) (Sterner *et al.* 2020) (Capon *et al.* 2021). Simultaneously, current freshwater management and monitoring efforts are insufficient to meet global needs, placing a projected 4.8 billion lives at risk by 2030 (United Nations Environment Programme 2024). Substantial improvements to both water quality and monitoring will be required in the coming years.

A key component of freshwater monitoring is the use of macroinvertebrate bioindicators, whose abundances are used as proxies for freshwater ecosystem health. For example, declines in the abundances of Ephemeroptera, Plecoptera, and Trichoptera (EPT) are widely considered indicators of poor water quality. The use of bioindicator species assumes that ecological communities are in equilibrium with their environment, meaning that species' abundances correspond 1:1 with environmental changes. However, extensive evidence has demonstrated that ecological communities frequently lag environmental changes, resulting in communities composed of species that are mismatched to their environment (hereafter environmental disequilibrium).

This work aims to investigate EPT communities across the Northern Hemisphere for environmental disequilibrium. In doing so, we will uncover insights into the reliability of bioindicator-based environmental assessments, a core component of freshwater monitoring.

Methods

To estimate total environmental disequilibrium, we used a community response diagram framework, where the environmental preferences of species are estimated. Then, for each site, we infer the environment based off of the species present. The inferred site is then compared against the known observed environment. Significant deviations from the known environment relative to null communities sampled from a regional pool of species are then considered environmental disequilibria. These disequilibrium states are unitless.

Figures

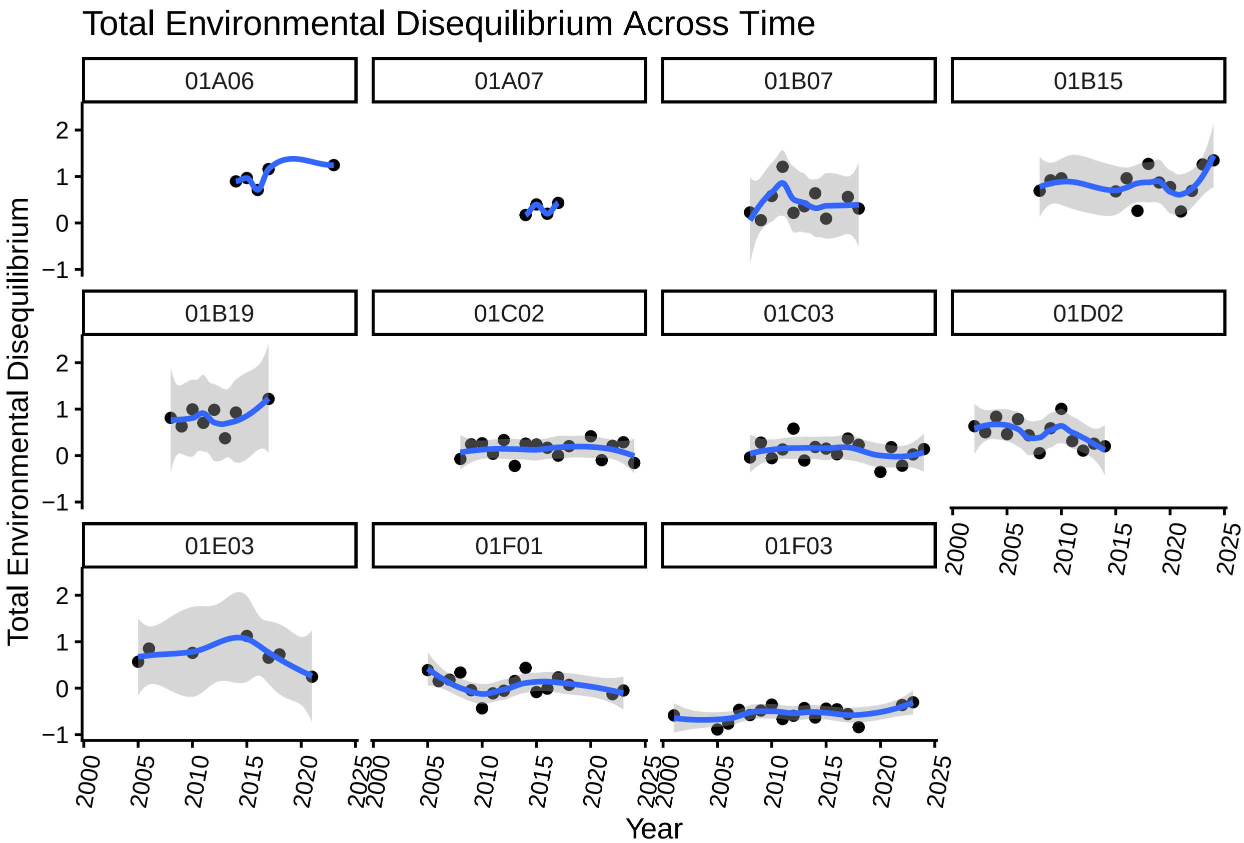

Figure 1: Time series of total environmental disequilibrium across sites.

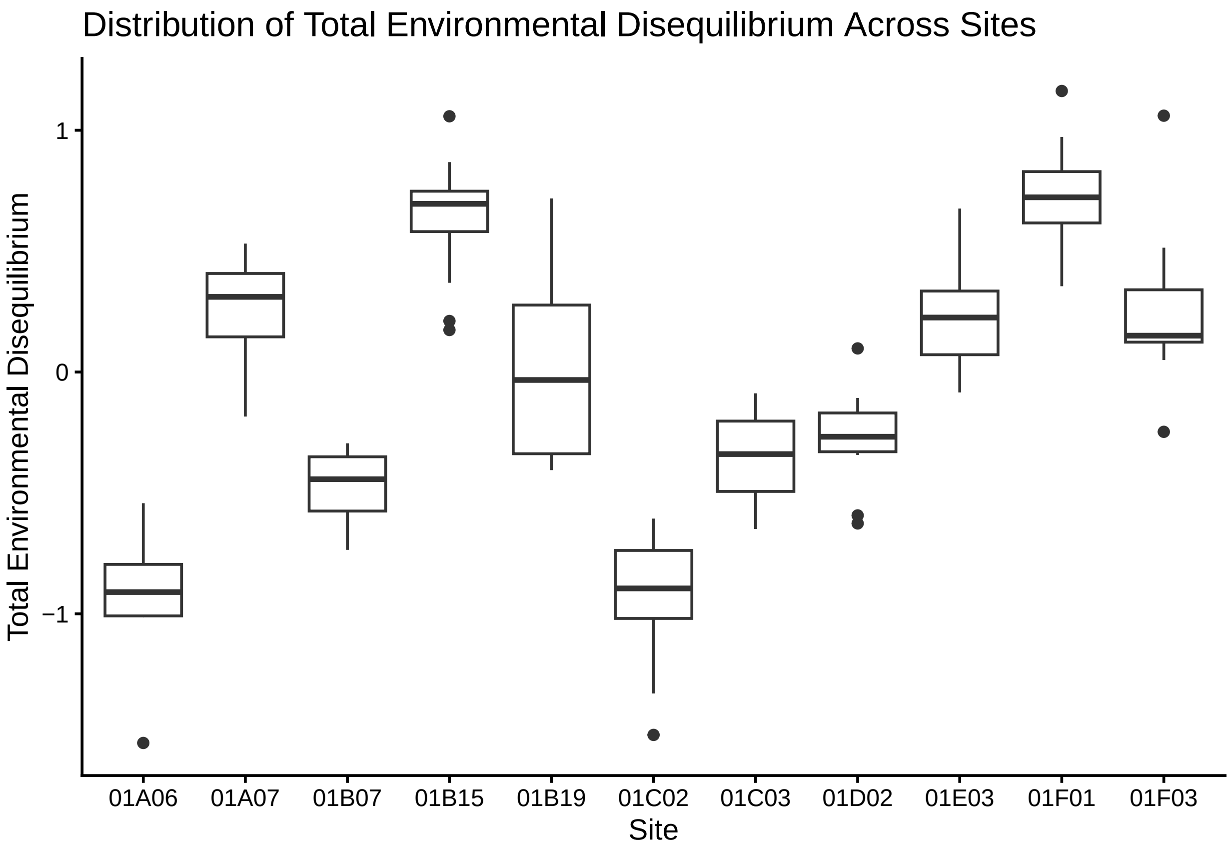

Figure 2: Comparison of total disequilibrium between sites.

Tables

Table 1: Mean environmental disequilibrium level across sites.

Site	Mean Environmental Disequilibrium
01A06	-0.9583717
01A07	0.2421923
01B07	-0.4795801
01B15	0.6340356
01B19	0.0375392
01C02	-0.9322636
01C03	-0.3506027
01D02	-0.2719545
01E03	0.2328760
01F01	0.7289795
01F03	0.2467063

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