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A Bayesian hierarchical model of channel network dynamics reveals the impact of stream dynamics and connectivity on metapopulation

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The active portion of river networks varies in time thanks to event-based and seasonal cycles of expansion-retraction, mimicking the unsteadyness of the underlying climatic conditions. These rivers constitute a major fraction of the global river network, and are usually referred to as temporary streams.
Channel network dynamics have significant implications in catchment hydrology an beyond, including ecological dispersion, stream metabolism and greenhouse gas emissions. Moreover, temporary streams provide a unique contribution to riverine ecosystems, as they host unique habitats that are capable of promoting biodiversity. Nonetheless, to date the complex ways in which the temporal dynamics of the active portion of a stream network affect ecological processes and ecosystem services are not fully understood. In this contribution, we present a stochastic framework for the coupled simulation temporary stream dynamics and the related occupancy of a metapopulation. The framework combines a stochastic model for the generation of synthetic streamflow time series with the hierarchical structuring of river network dynamics, to enable the simulation of the full spatio-temporal dynamics of the active portion of the stream network under a wide range of climatic settings on the basis of a limited number of physically meaningful parameters. The hierarchical nature of stream dynamics - which postulates that during wetting nodes are activated sequentially from the most to the least persistent, and deactivated in reverse order during drying - represents a key feature of the approach, as it enables a clear separation between the spatial and temporal dimensions of the problem. The framework is complemented with a stochastic dynamic metapopulation model that simulates the occupancy of a metapopulation on the simulated stream. Our results show that stream intermittency negatively impacts the average occupancy and the probability of extinction of the focus metapopulation. Likewise, the spatial correlation of flow persistency along the network also bears a significant impact on the mean network connectivity and occupancy. This effect is particularly important in drier climates, where most of the network undergoes sporadic and flashy activations, and species dispersal is therefore inhibited by river fragmentation most of the time. The approach offers a robust but parsimonious mathematical framework for the synthetic simulation of the spatio-temporal dynamics of the active stream network under a broad range of climatic and morphological conditions, providing useful insights on stream expansion and retraction and its ecological significance.