Tradeoffs in resistance and resilience strategies in biomes to perturbation

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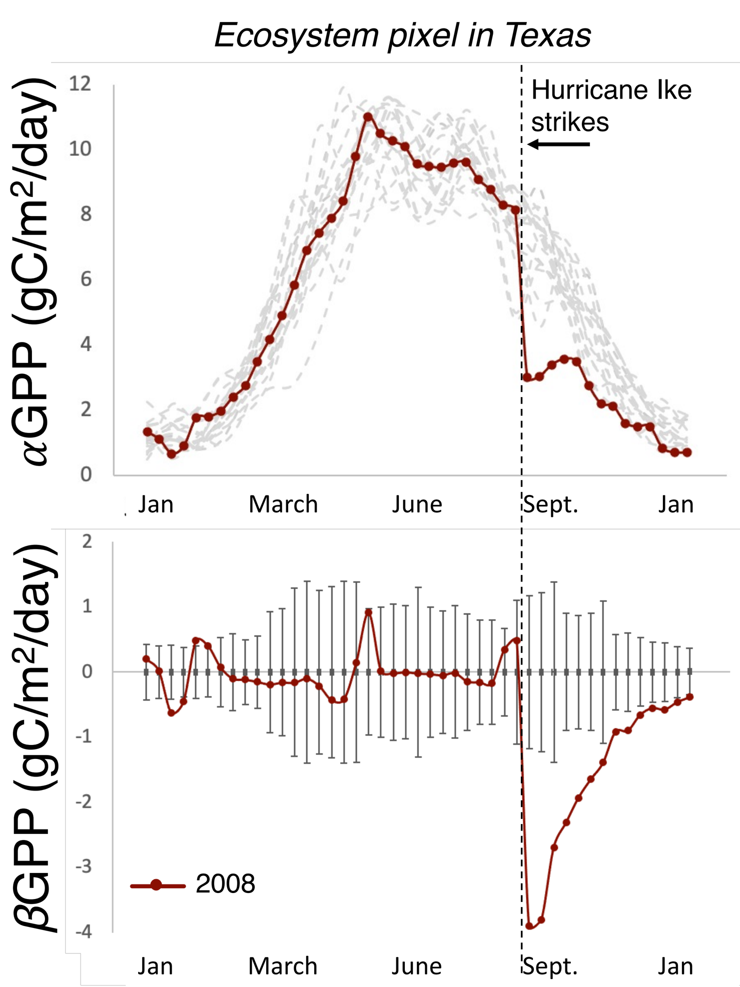
Introduction

- The photosynthetic processes that capture and input energy into the ecosystem (measured as gross primary productivity or GPP) are vulnerable to environmental stresses and disturbances.
- Perturbations in ecosystem GPP can be quantified in terms of their resistance and resilience. These metrics were calculated from long-term GPP remote sensing datasets, using the effect size *E* and the return time *R* of perturbation events.
- We predicted that the ecosystem responses *E* and *R* will vary by biome type because of differences in the mechanistic drivers of resistance and resilience, i.e., biodiversity, ecological succession, abiotic conditions, and the traits of the dominant organisms in the ecosystem.

Purpose

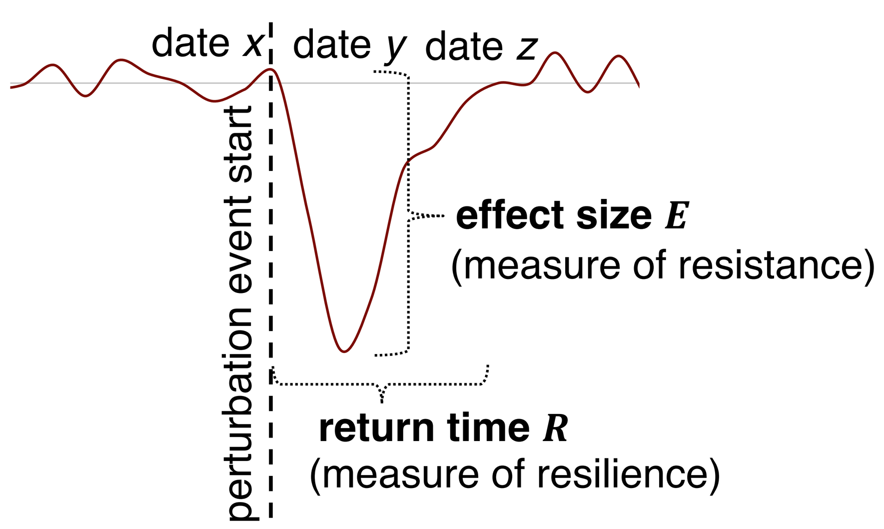
To compare the relative resistance and resilience of biomes across the globe, in terms of their productivity and carbon flux.

Methods



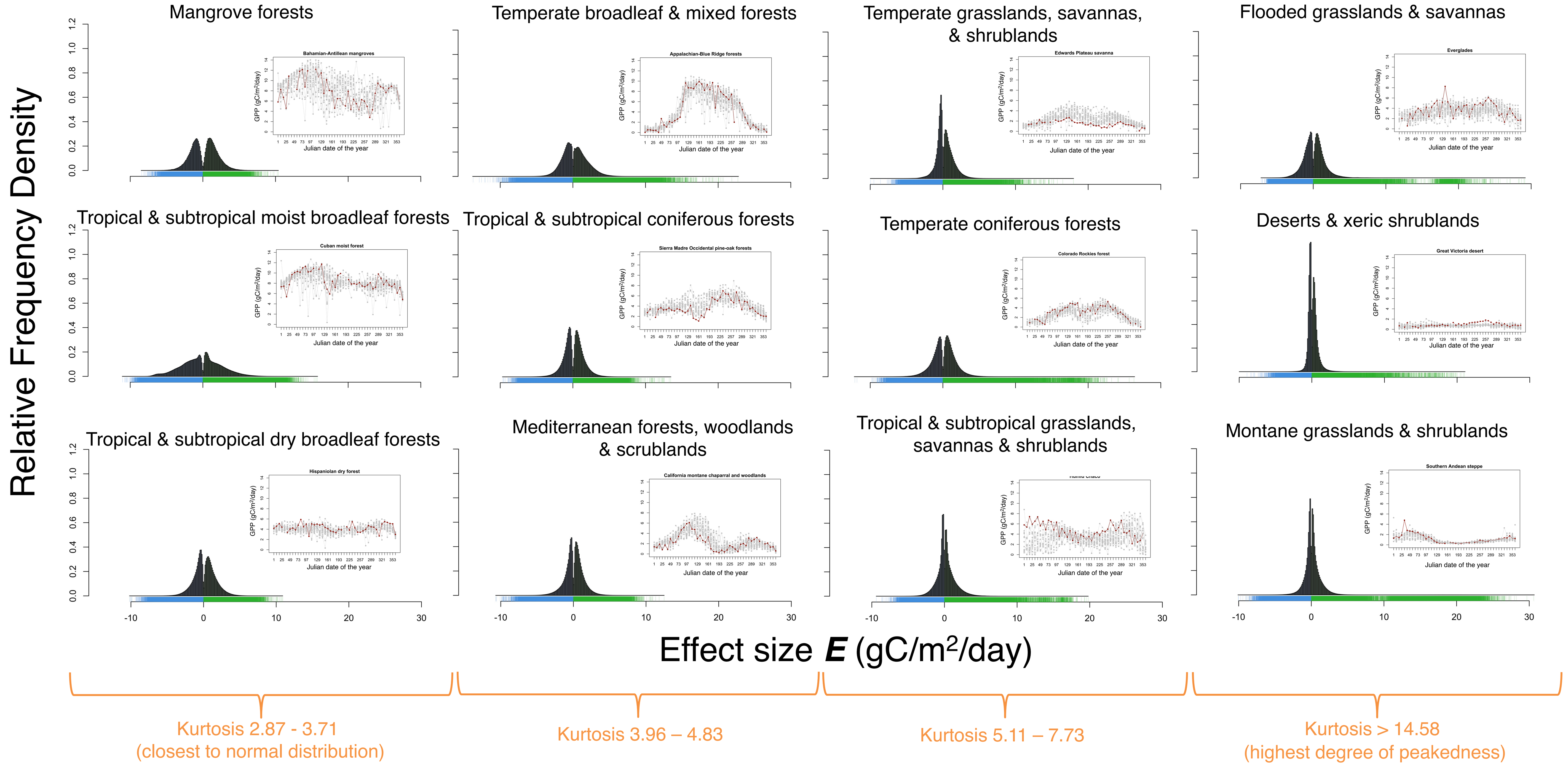
1) We used the MOD17A2 Gross Primary Productivity (GPP) data product from the NASA Oak Ridge National Laboratory (ORNL) to analyze the global productivity of 14 terrestrial biomes, at 500 m resolution, every 8 days from 2000-2022.

2) We standardized the data across locations and time by computing the anomaly of GPP from each location's 8-day epoch mean. The GPP anomaly, β_x, was quantified as the GPP product value, α_x, minus the mean (μ) GPP for all similar date *x* epochs at that location.



Ecosystem resistance of a perturbation event was estimated in terms of the effect size, ***E***, in GPP, quantified using: $E = \beta_y - \beta_x$

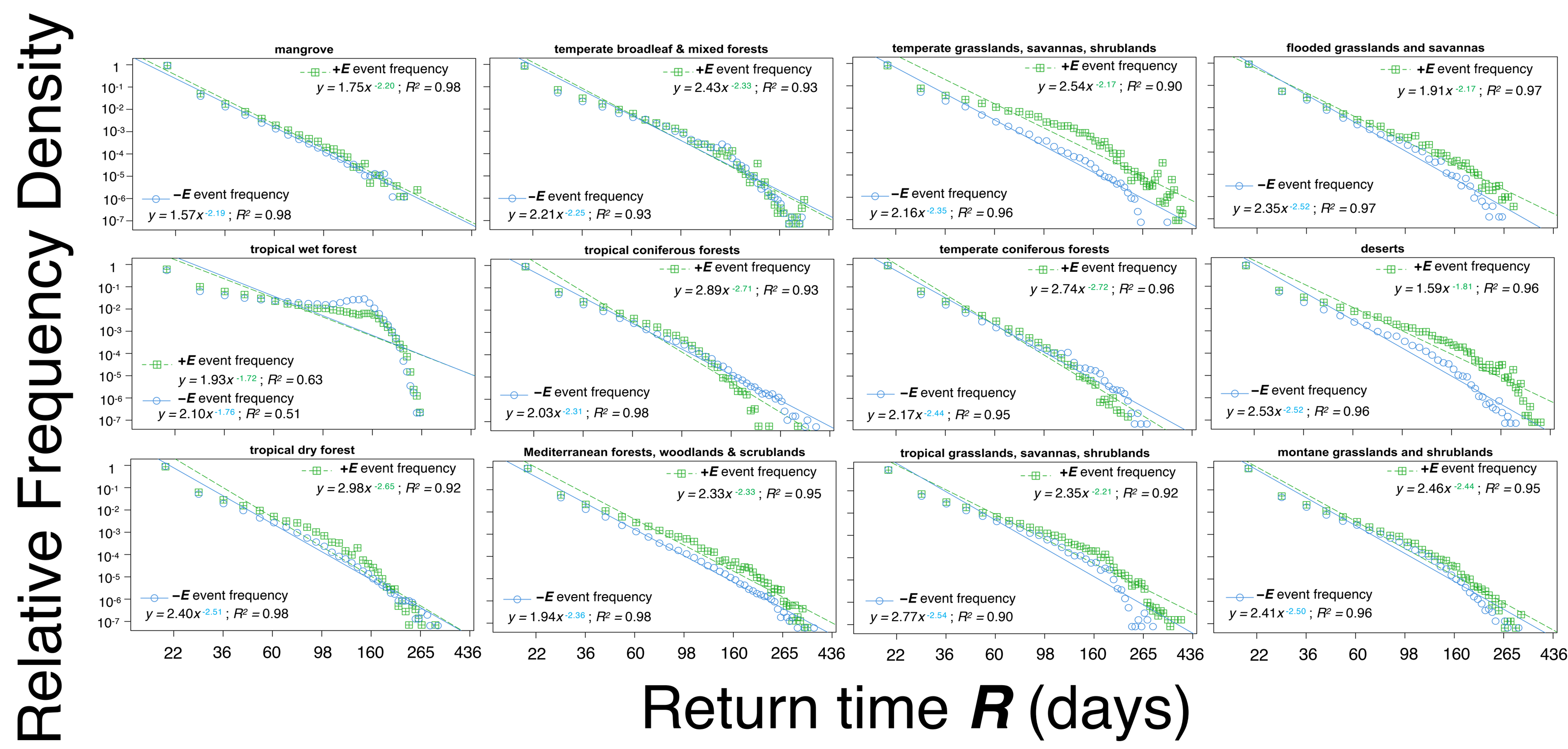
Ecosystem resilience of a perturbation event was estimated as the return time, ***R***, or the length of the GPP perturbation event. The return tolerance was set between $\mu_{z,L} \pm \sigma_{z,L}$ (the standard deviation from the mean GPP for values that composed epoch *z* for location *L*).



For resistance, or the effect size *E* of the ecosystem-level GPP perturbations, we found that large magnitude events were less frequent than small-sized events, and this scaling relation exhibited exponential decay.

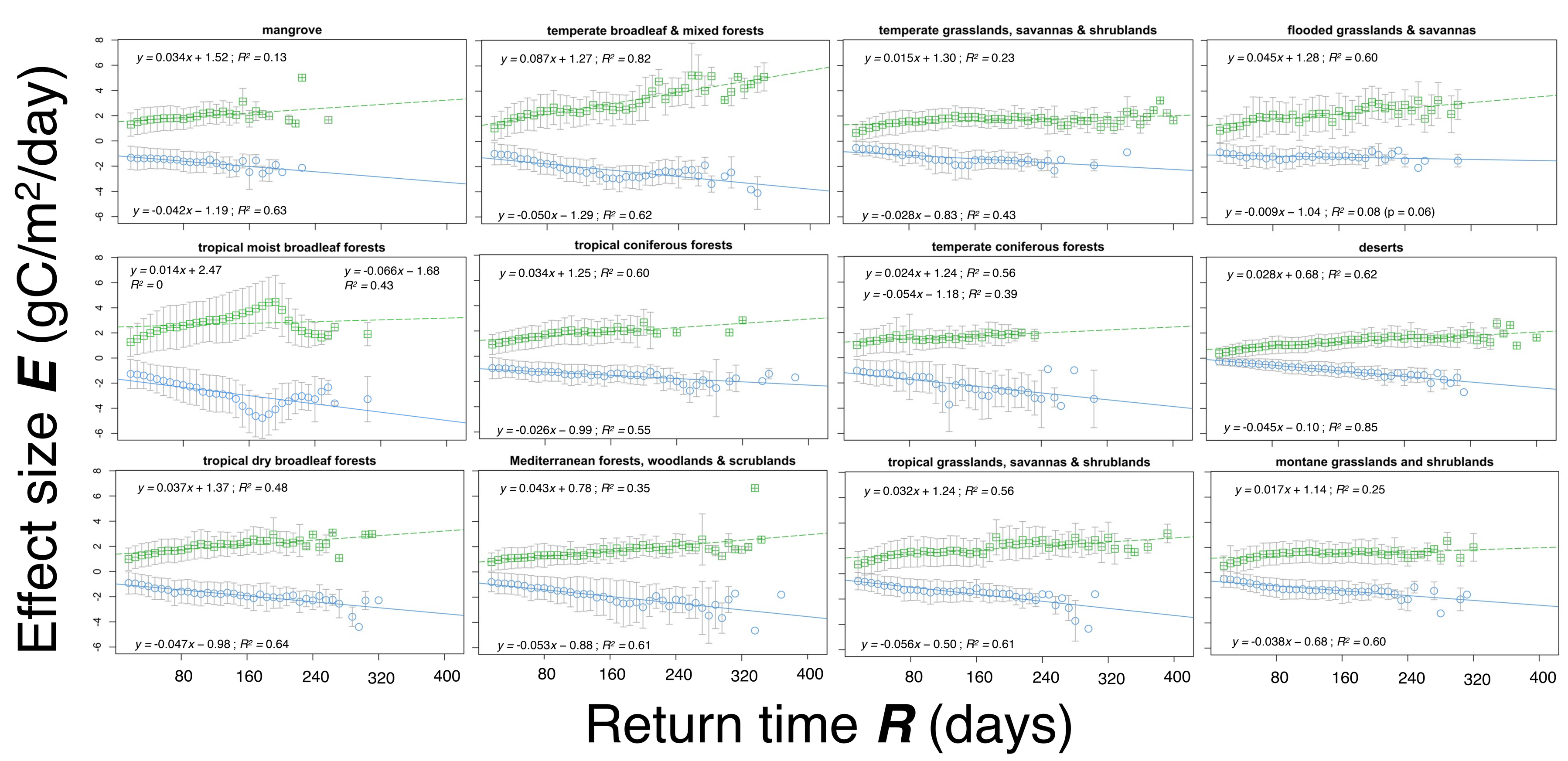
Overall, biomes experienced more positive than negative perturbation events, but the negative events were more extreme in their magnitude.

This fundamental relationship between the size and frequency of ecosystem-level carbon fluxes resembles the Gutenberg-Richter exponential scaling law for earthquake frequency and magnitude. GPP for one characteristic biome pixel is shown.



For ecosystem resilience, or the return time *R*, we found that long return times were less frequent than short return times, and the scaling very closely followed an inverse power law function (Pareto distribution).

The majority of return times were about 1 month in duration and in comparison to the effect size distributions, their distributions were heavier-tailed, i.e., outcomes far from the mean were much less rare, since *R* was not bounded by the same physical constraints on ecosystem productivity as *E*. Thus a greater range of variation in return times is possible and long-tailed frequency distributions were generated.



Effect size (*E*) and return time (*R*) are correlated metrics. The negative covariation between resistance and resilience suggests these key metrics of ecosystem stability functionally tradeoff. Mangroves and temperate coniferous forests are highly tuned towards larger negative events, a stability strategy we call *redundancy*, where ecosystems have more network connections, and despite undergoing substantial reorganization, can rapidly recover their function. Flooded grasslands and savannas and temperate broadleaf and mixed forests are better adapted to larger positive perturbations, a stability strategy we call *efficiency*, where ecosystems have fewer, but stronger network connections, which allows the system to amplify its dynamics to maximize productivity when resources are available.

Conclusions/Broader Impacts

Our standardized metrics for measuring resistance and resilience in time series datasets can operationalize these terms across all disciplines, facilitating the discovery of universal patterns and tradeoffs in these two strategies.