nature portfolio

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Reporting Summary

Nature Portfolio wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Portfolio policies, see our Editorial Policies and the Editorial Policy Checklist.

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a	Confirmed	
☐	☒	The exact sample size (*n*) for each experimental group/condition, given as a discrete number and unit of measurement
☐	☒	A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
☐	☒	The statistical test(s) used AND whether they are one- or two-sided *Only common tests should be described solely by name; describe more complex techniques in the Methods section.*
☐	☒	A description of all covariates tested
☐	☒	A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons
☐	☒	A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals)
☐	☒	For null hypothesis testing, the test statistic (e.g. *F*, *t*, *r*) with confidence intervals, effect sizes, degrees of freedom and *P* value noted *Give P values as exact values whenever suitable.*
☒	☐	For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
☐	☒	For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
☐	☒	Estimates of effect sizes (e.g. Cohen's *d*, Pearson's *r*), indicating how they were calculated

Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	No software was used in data collection.
Data analysis	Data was analyzed and visualized with a custom code using R (4.2.0 and earlier) and the following R packages (mgcv 1.9-1, dagitty 0.3-1, ggplot2 3.4.4, FactoMineR 2.4 etc), as well as in ENVI 5.3 + IDL8.5, Matlab2018b. Geographical maps were processed in ArcGIS 10.6.1. Custom code for data processing for the figures, and for fitting the statistical models (GAM and DAG models) are deposited in a community repository (Code Ocean) according to Nature guidelines. Code for reproducing the modeling analysis and figures is posted on Code Ocean at https://codeocean.com/capsule/2432086/tree.

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our policy

All remote sensing data and products (vegetation/photosynthetic indices(https://lpdaac.usgs.gov/products/mcd19a3v006/, http://data.globalecology.unh.edu/data/GOSIF_v2), climate variables (https://disc2.gesdisc.eosdis.nasa.gov/data/TRMM_L3/TRMM_3B43.7/, https://goldsmr4.gesdisc.eosdisc.nasa.gov/data/MERRA2_MONTHLY/M2TMNXRAD.5.12.4/, https://airs.jpl.nasa.gov/data/get-data/standard-data/), land cover (https://lpdaac.usgs.gov/products/mcd12q1v006/, https://forobs.jrc.ec.europa.eu/TMF), tree characteristics (canopy height https://webmap.ornl.gov/ogc/dataset.jsp?dg_id=10023_1), soil texture (https://maps.isric.org/)) are publicly available at the website locations cited in the methods. The ground-based demographic validation data is publicly available in the method to Sousa et al. (2020; see References), and Brienen et al. (2015; see References). The ground-based hydraulic trait validation data is publicly available in the method to Tavares et al. (2023; see References). The HAND data are derived from digital elevation model-Shuttle Radar Topography Mission in Nobre et al. (2011; see References). The soil fertility data is available in Zuquim et al. (2019; see References).

Research involving human participants, their data, or biological material

Policy information about studies with human participants or human data. See also policy information about sex, gender (identity/presentation), and sexual orientation and race, ethnicity and racism.

Reporting on sex and gender	NA
Reporting on race, ethnicity, or other socially relevant groupings	NA
Population characteristics	NA
Recruitment	NA
Ethics oversight	NA

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☐ Behavioural & social sciences ☒ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Ecological, evolutionary & environmental sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	This study models forest responses to three 'once in a century' droughts using satellite vegetation indices and ground-based demographic data to go beyond climate-only explanations, to test three hypotheses for how climate interacts with different forest 'ecotypes' to explain the complexity of forest drought response at multiple scales. Two basic approaches taken in forest drought research have been: remote sensing explorations of drought-induced vegetation greening/browning patterns and how they correlate with climate across landscapes (but without much mechanistic biology); and ground- based studies of biological mechanisms of individual tree resilience or of plot-scale tree demography (but with limited connection to the heterogeneity of the broader landscape). Our study takes a novel approach that uniquely integrates both approaches, using remote sensing to test and then constrain region- to basin-scale implications of recent ecological hypotheses. The study shows how forest responses to drought are structured across landscapes, according to ecotype factors (water-table depth, soil fertility, and tree community characteristics) that are conducive (or not) to drought resilience. Our results provides new insight (and a warning) about which forests may be vulnerable, and which resilient, to future droughts.
Research sample	Well-validated satellite vegetation indices of photosynthetic capacity (the Enhanced Vegetation Index, EVI) and photosynthetic activity (the Global OCO-2 Solar Induced Fluorescence, GOSIF) were sampled over 19 hydrological years across the whole basin constrained by evergreen forests. The EVI is sampled as 8-day and aggregated to a monthly time step while GOSIF is sampled as monthly. Climate and ecotope observations were sampled to match the corresponding remotely sensed vegetation observations. The ground-based demographic forest tree samples from Brienen at al. (2015; see References) are as described in the reference individual trees > 10cm in diameter at breast height sampled and measured over 28 years from 321 tree plots of RAINFOR and other networks, which are distributed through regions of the Amazon basin). The mortality and recruitment demographic data from Sousa

	et al (2020; see References) are as described in the reference (observations of approximately 15,000 trees from two censuses during dry season in 2015 and 2016 with 25 1-ha plots). A pan-Amazon hydraulic trait dataset (hydraulic safety margins) from Tavares et al (2023; see References) are as described in the reference (sampled across 9 forest sites, including 108 species, distributed across western, central eastern and southern Amazon, sampling species representing between 14% and 70% of the total basal area).
Sampling strategy	We only sampled observations in evergreen forest type from non-flooded areas with cloud-free and low aerosol conditions. For statistical modeling we interpolated different datasets to common grid resolutions, according to the desired resolution of the model. This was typically 0.4°, the resolution needed to avoid inflation of statistical significance of drought responses in models by accounting for spatial autocorrelation among nearby pixels using variogram analysis.
Data collection	All remote sensing and ground-based demographic/hydraulic trait raw data and products are collected and processed by researchers at the website locations cited in the supplementary methods.
Timing and spatial scale	The remote sensed vegetation observations (1-km) are across 19 hydrological years of 2000-2020 (May 2000 to April 2020) at a monthly step across the whole basin constrained by drought region. The published demographic datasets from Brienen at al. (2015; see References) are over the period 1983-2011 from 321 tree plots of the RAINFOR and other networks, while the mortality and recruitment data from Sousa et al (2020; see References) are collected from two censuses during dry season in 2015 and 2016 with 25 1-ha plots distributed across eight research sites along the BR-319 road in the southern Amazon between Manaus and Porto Velho. A pan-Amazon hydraulic trait dataset (hydraulic safety margins) from Tavares et al (2023; see References) are sampled across 9 forest sites distributed across western, central eastern and southern Amazon over the period of 2014-2018.
Data exclusions	We excluded observations belonging to open water, deforested forests, and non-forest vegetation types, but only included evergreen forests. We also excluded floodplain from non-flooded forests, as well as excluded observations with cloud/aerosol contaminations. We conducted a sensitivity test by excluding majority or the entirety of degraded forests.
Reproducibility	The study is not based on experiments.
Randomization	This is not relevant to the study, as no experiments were performed.
Blinding	Blinding was not necessary as we did not perform any experiment containing groups and/or treatments, but analyzed long-term vegetation indices and demographic/hydraulic trait data for which blinding is not required.

Did the study involve field work? ☐ Yes ☒ No

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern
☒	☐ Plants

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Plants

Seed stocks	NA
Novel plant genotypes	NA
Authentication	NA