Biodiversity under interacting pressures

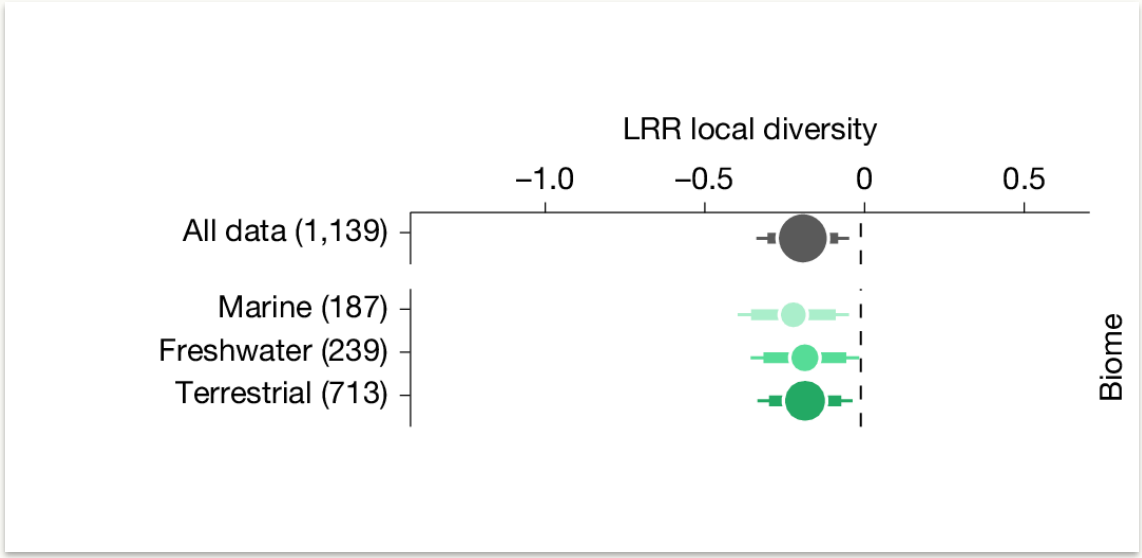
Multiple stressors across ecosystems and scales

What changes when environmental pressures act together?



The biodiversity crisis: loss and community change

LOCAL SPECIES RICHNESS



Negative values: fewer taxa in impacted communities

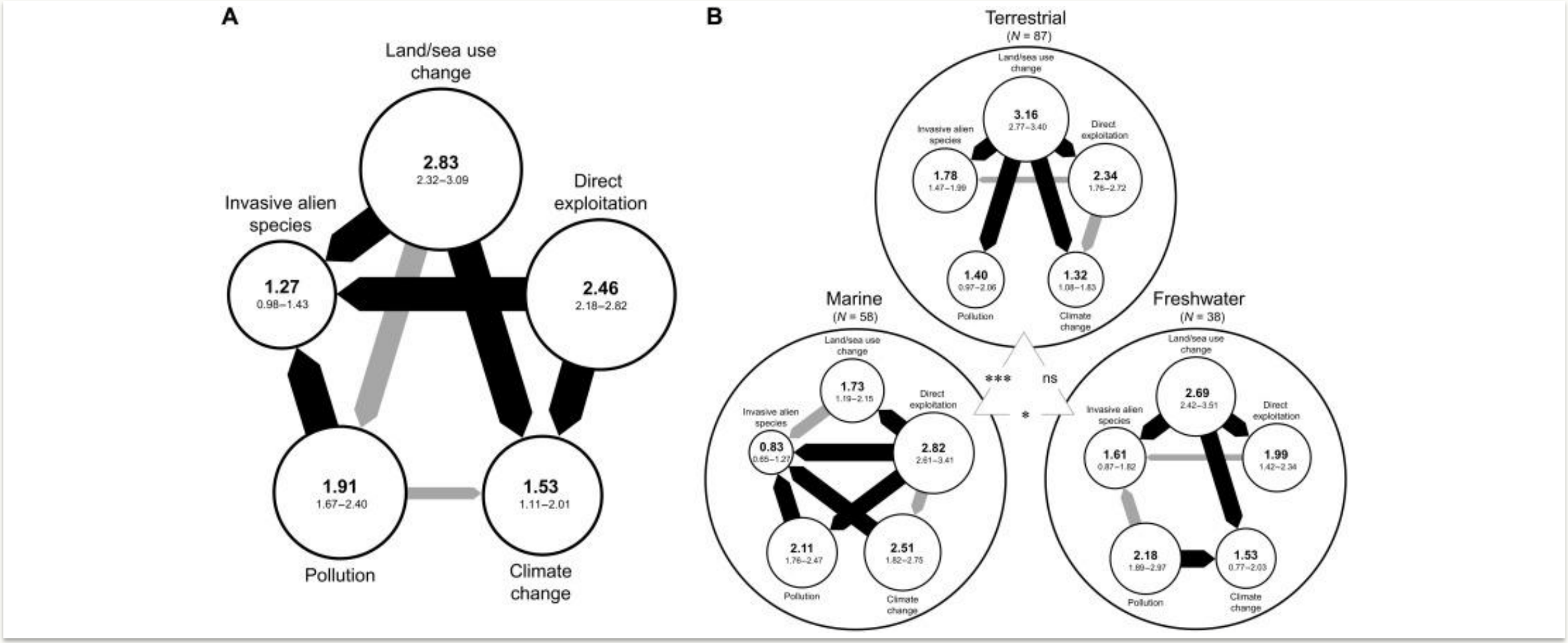
COMMUNITY COMPOSITION



Positive values: impacted and reference communities differ

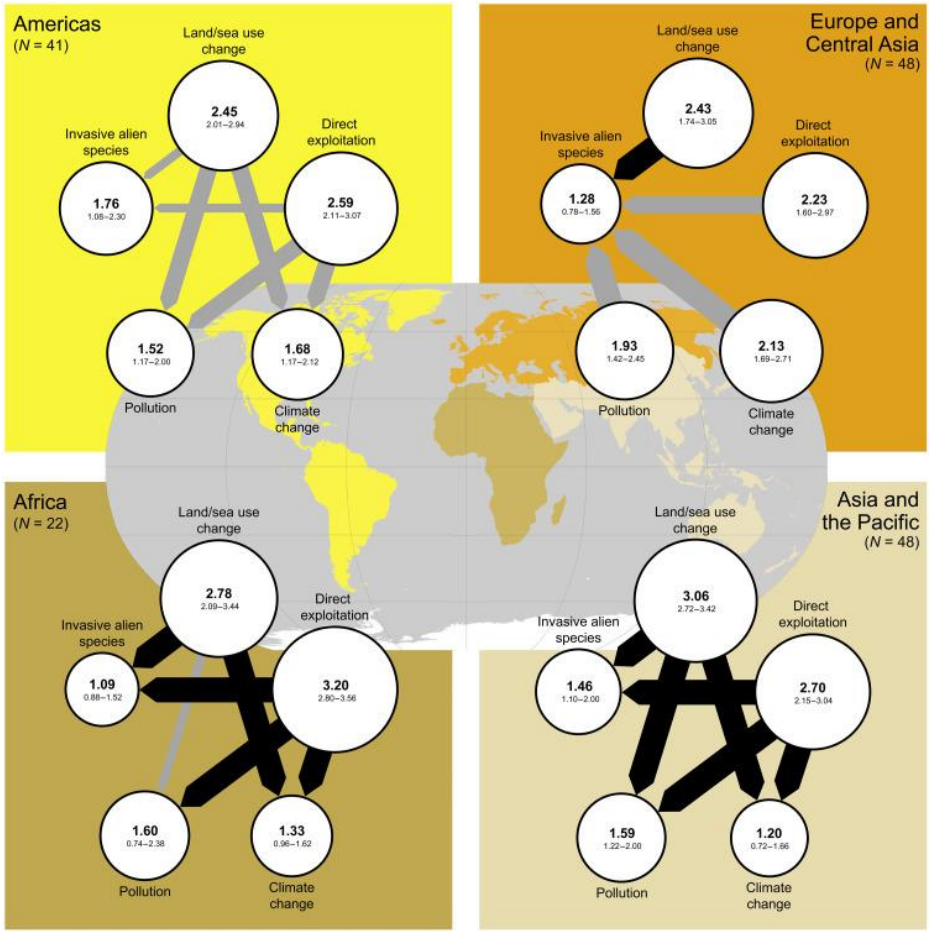
Keck et al. (2025) · Nature
https://doi.org/10.1038/s41586-025-08752-2

The leading pressures differ among ecosystems



Jaureguiberry et al. (2022) · Science Advances ·
https://doi.org/10.1126/sciadv.abm9982

Regional rankings: patterns and uncertainty



BROAD PATTERN

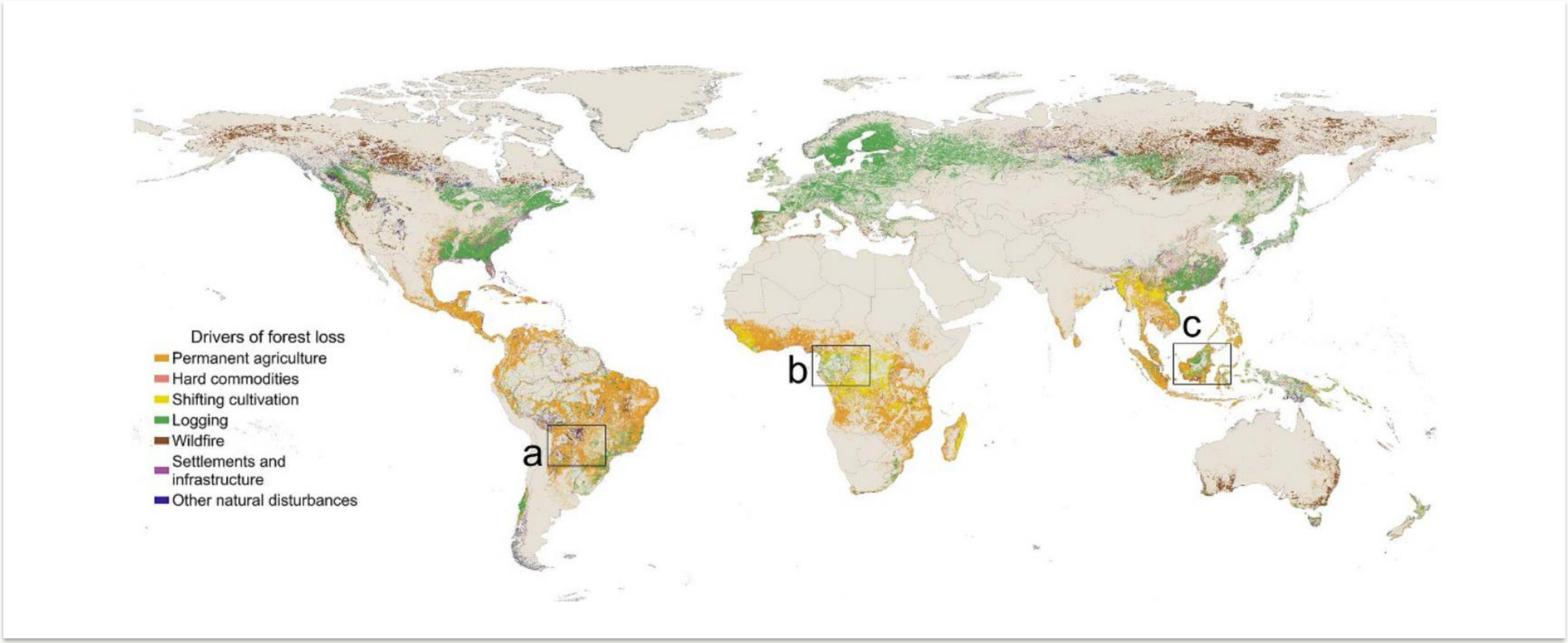
Land/sea-use change and exploitation lead

REGIONAL COMPARISON

Overall differences among regional hierarchies were not significant

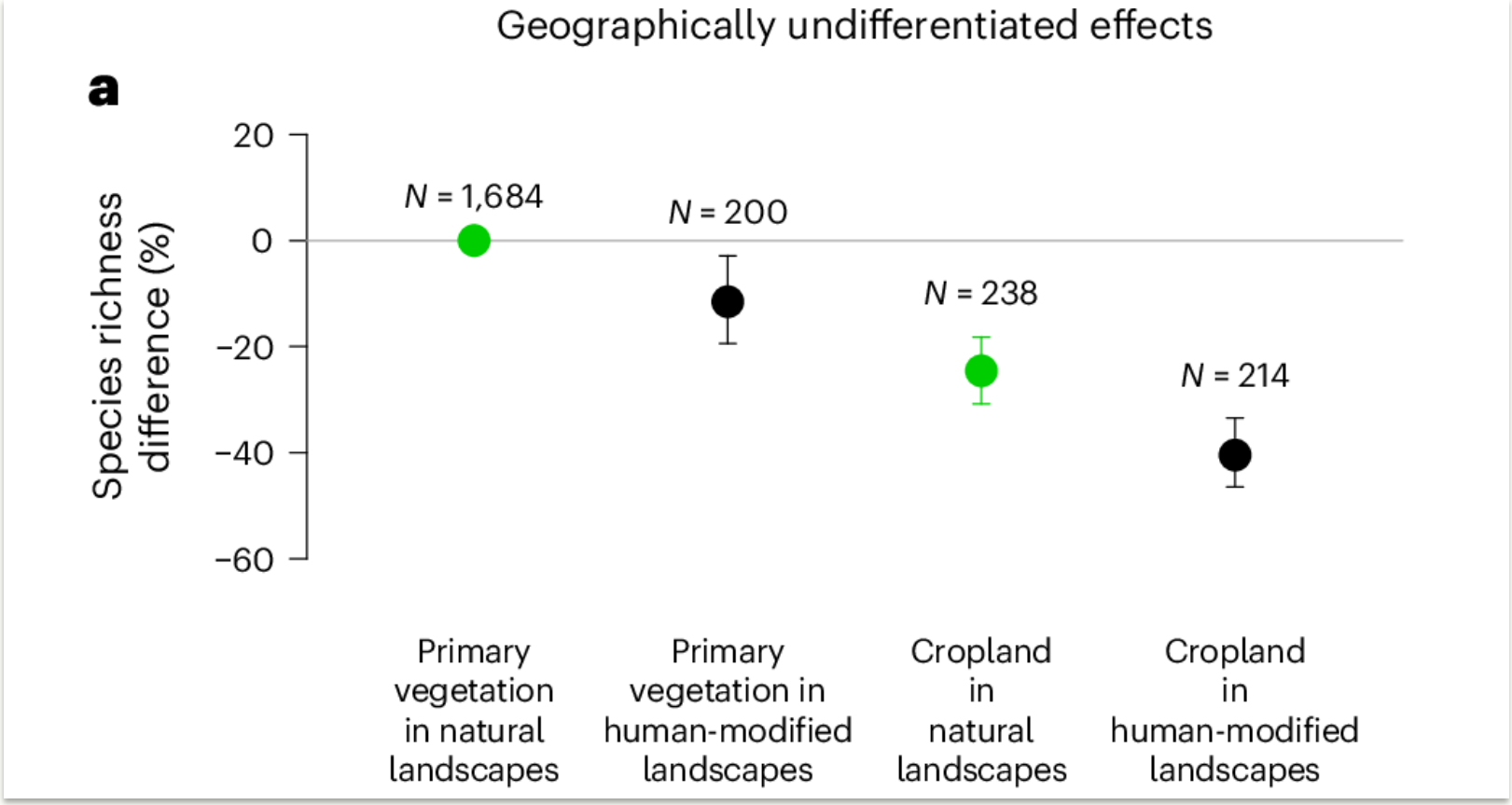
Jaureguiberry et al. (2022) · Science Advances
https://doi.org/10.1126/sciadv.abm9982

Deforestation: where forests become another land use



Sims et al. (2025) · Environmental Research Letters · Fig. 3 · global map and original legend; regional insets omitted
https://doi.org/10.1088/1748-9326/add606

Land conversion affects sites and their surrounding landscape



LANDSCAPE COVER

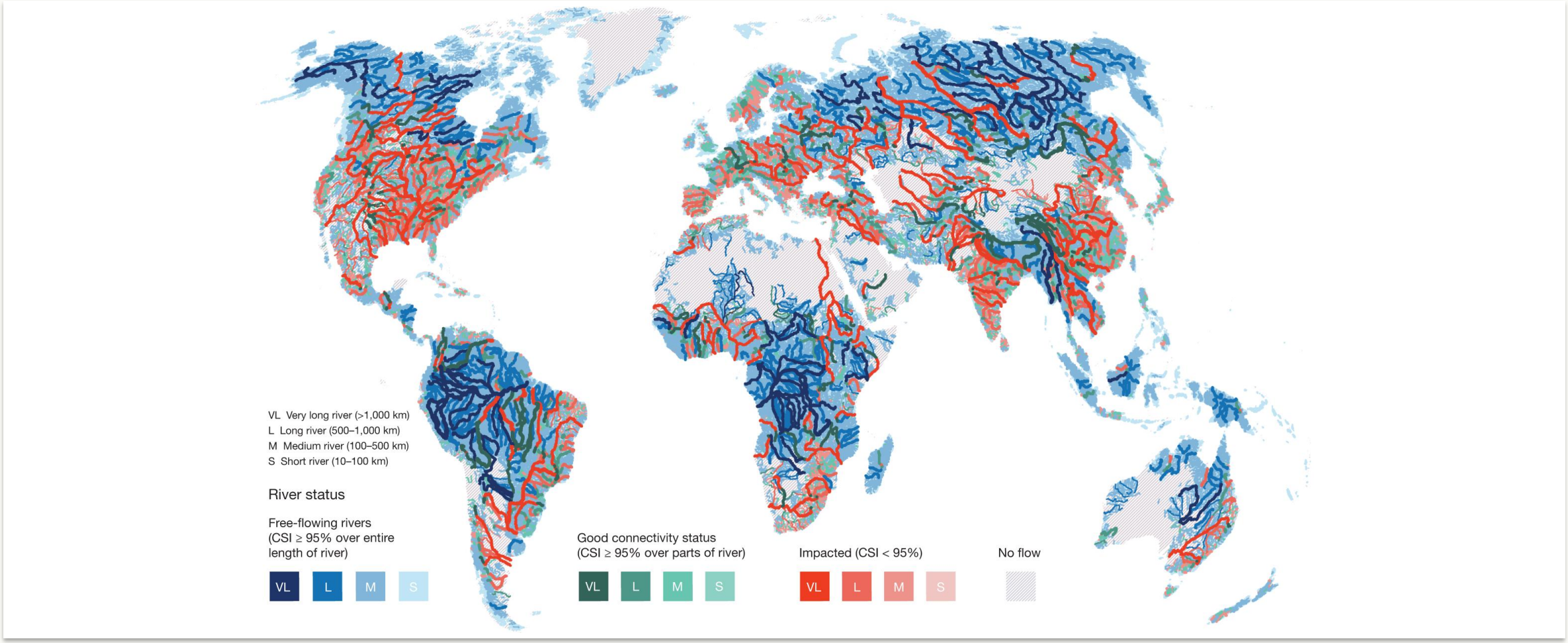
Green: >70% natural habitat
Black: <30% natural habitat

REFERENCE

Primary vegetation within a natural landscape

Ceauşu, Leclère & Newbold (2025) · Nature Ecology & Evolution
https://doi.org/10.1038/s41559-025-02691-x

River alteration has a strongly uneven geography



In this assessment, 37% of rivers longer than 1,000 km were free-flowing along their entire length.

Grill et al. (2019) · Nature · Fig. 3
https://doi.org/10.1038/s41586-019-1111-9

Freshwater taxa face different combinations of threats

a

Threat	Threatened freshwater species	Extinct freshwater species	Threatened decapods	Threatened fishes	Threatened odonates	Threatened tetrapods
Pollution	0.54	0.52	0.60	0.59	0.28	0.17
Dams and water management	0.39	0.63	0.19	0.46	0.23	0.09
Agriculture	0.37	0.06	0.33	0.32	0.61	0.74
Invasive species and disease	0.28	0.55	0.24	0.33	0.07	0.33

Threat records are not mutually exclusive: co-occurrence alone does not establish synergy.

Sayer et al. (2025) · Nature ·
https://doi.org/10.1038/s41586-024-08375-z

Pollution changes biodiversity across ecosystems

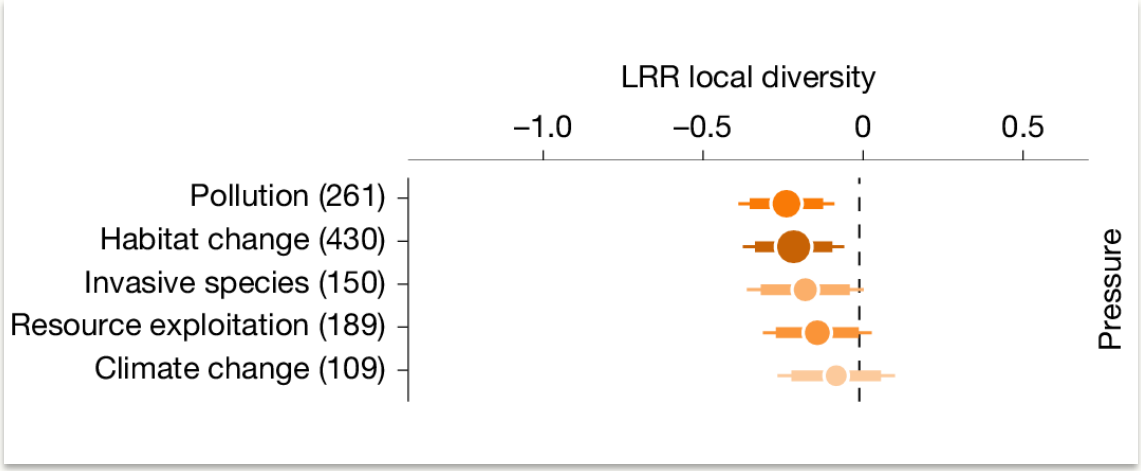
NUTRIENT ENRICHMENT

Changes in production and oxygen conditions

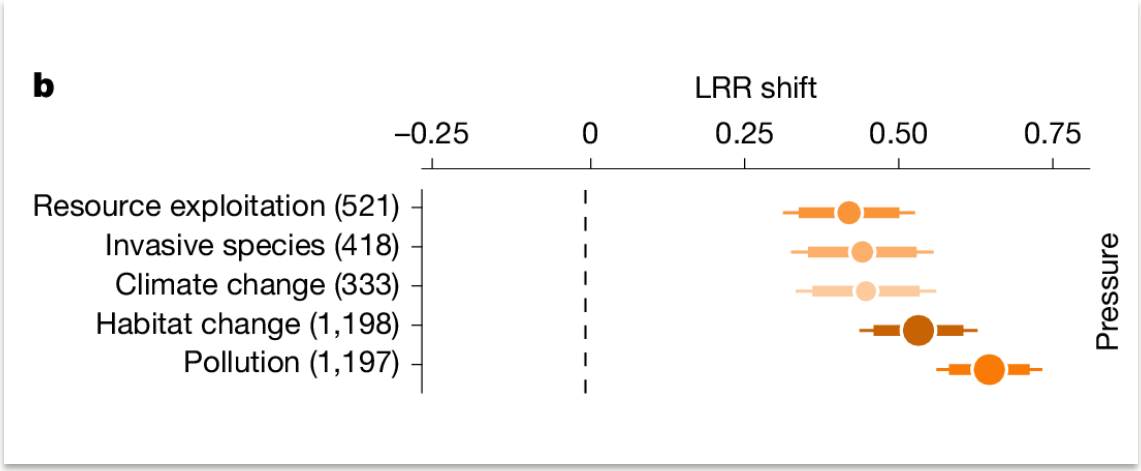
TOXIC EXPOSURE

Physiological damage and shifts in composition

LOCAL SPECIES RICHNESS



COMMUNITY COMPOSITION



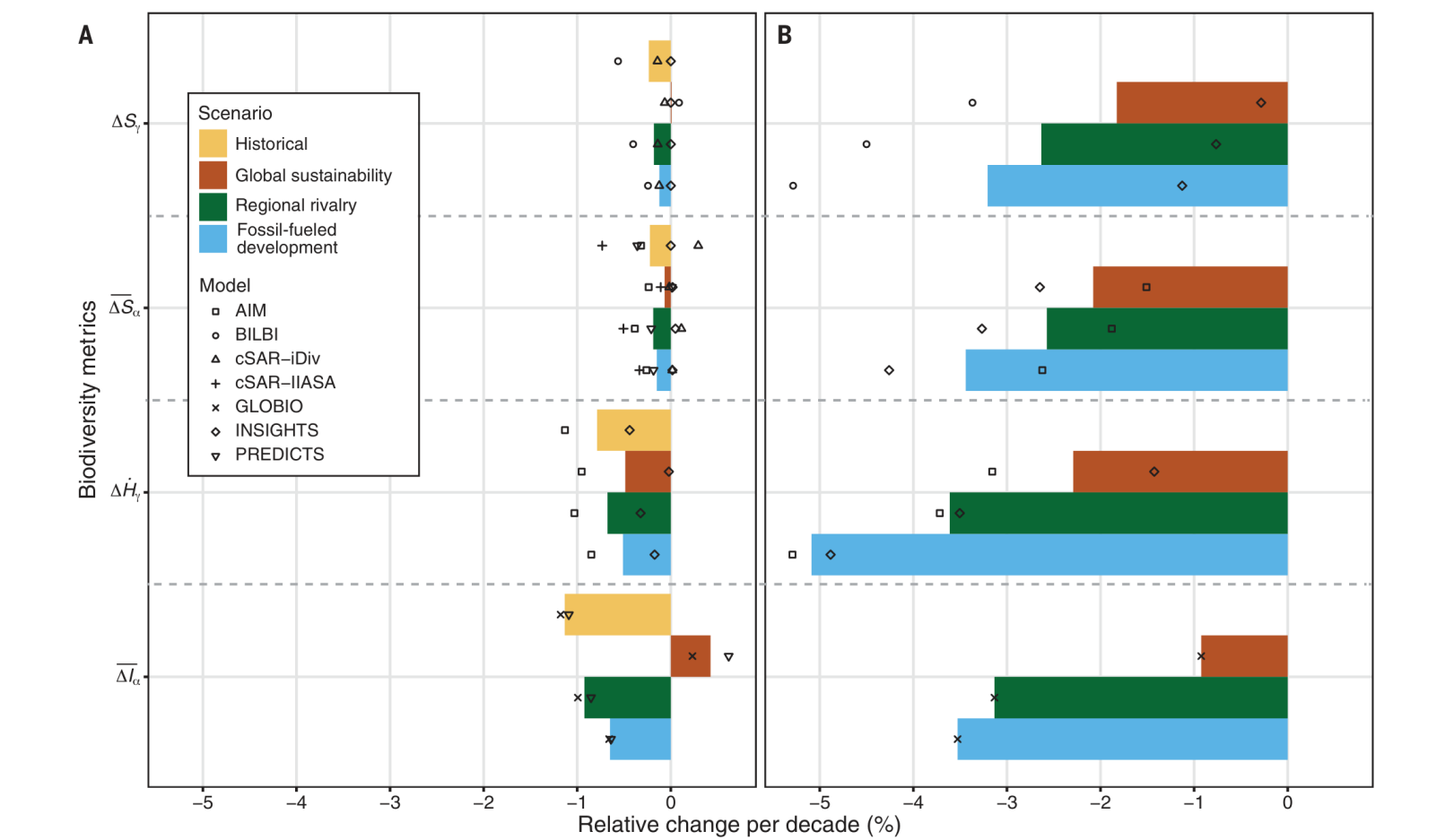
Negative values: lower local richness

Positive values: greater compositional change

Pressure groups from a global synthesis; effect sizes depend on exposure and study context.

Keck et al. (2025) · Nature
https://doi.org/10.1038/s41586-025-08752-2

Climate change increases projected biodiversity loss



A → B

Land-use change alone → land use + climate

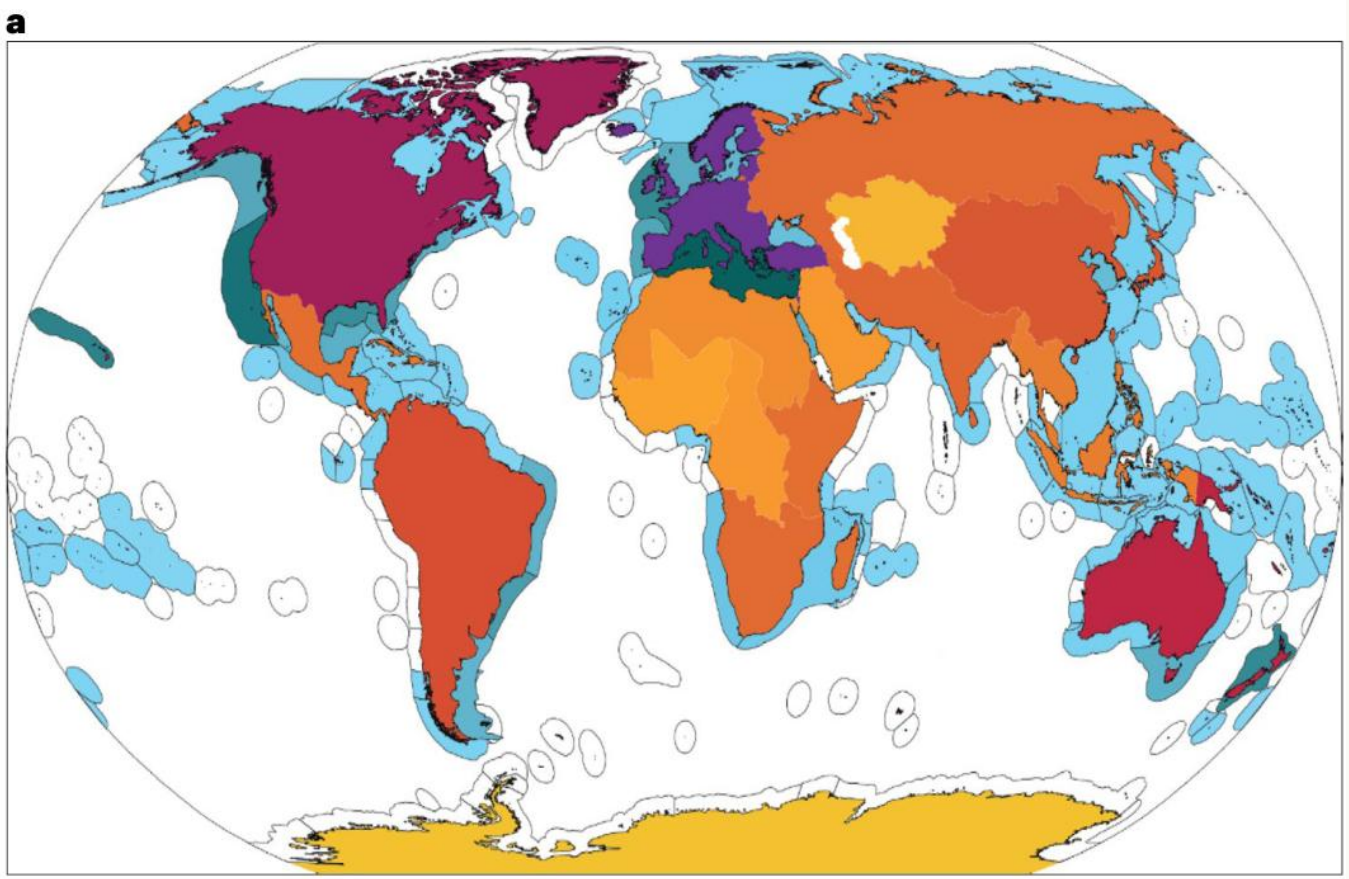
SECOND ROW

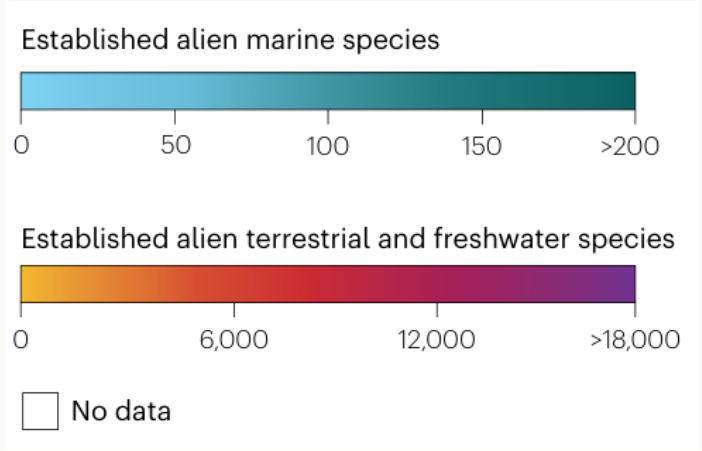
Mean local species richness

Future driver importance depends on the scenario, biodiversity metric and model assumptions.

Pereira et al. (2024) · Science
https://doi.org/10.1126/science.adn3441

Biological invasions change native communities





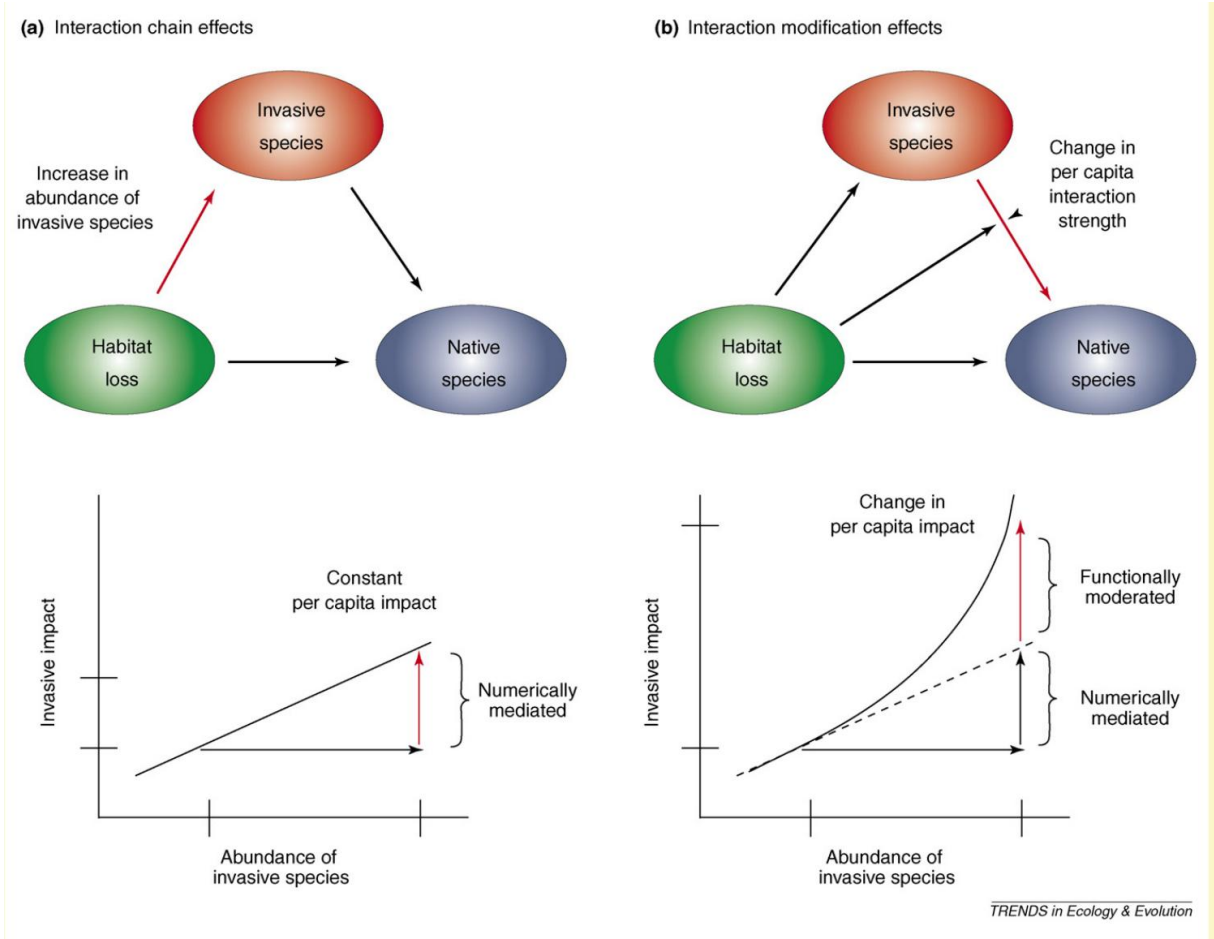
>3,500 invasive species

with documented negative impacts

Contributed to 60% of known global extinctions

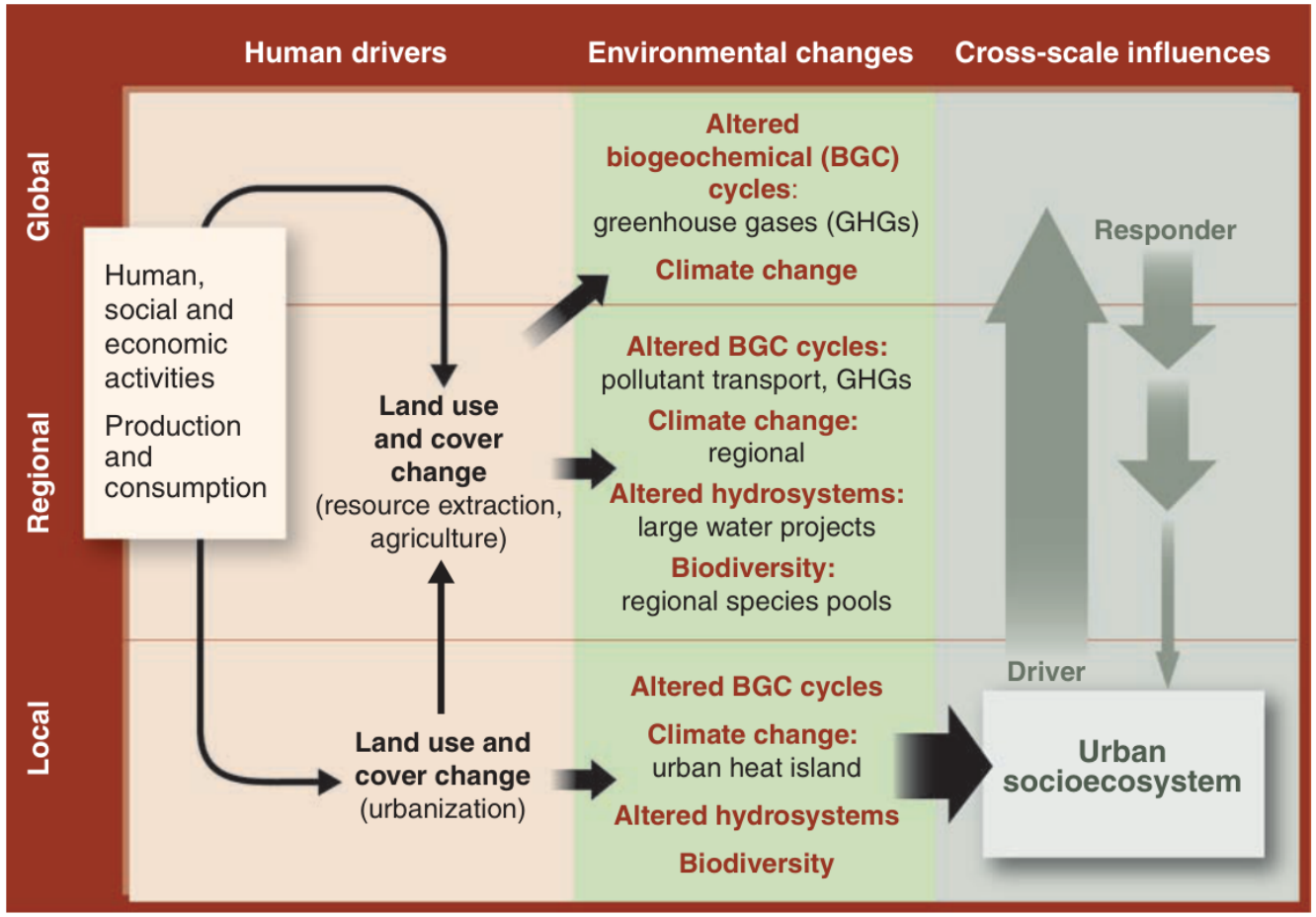
Roy et al. (2024) · Nature Ecology & Evolution ·
https://doi.org/10.1038/s41559-024-02412-w

Invasion impact depends on habitat context



Didham et al. (2007) · Trends in Ecology & Evolution
https://doi.org/10.1016/j.tree.2007.07.001

Urbanisation concentrates and exports pressures



LOCAL

Land cover, heat, water and biogeochemistry

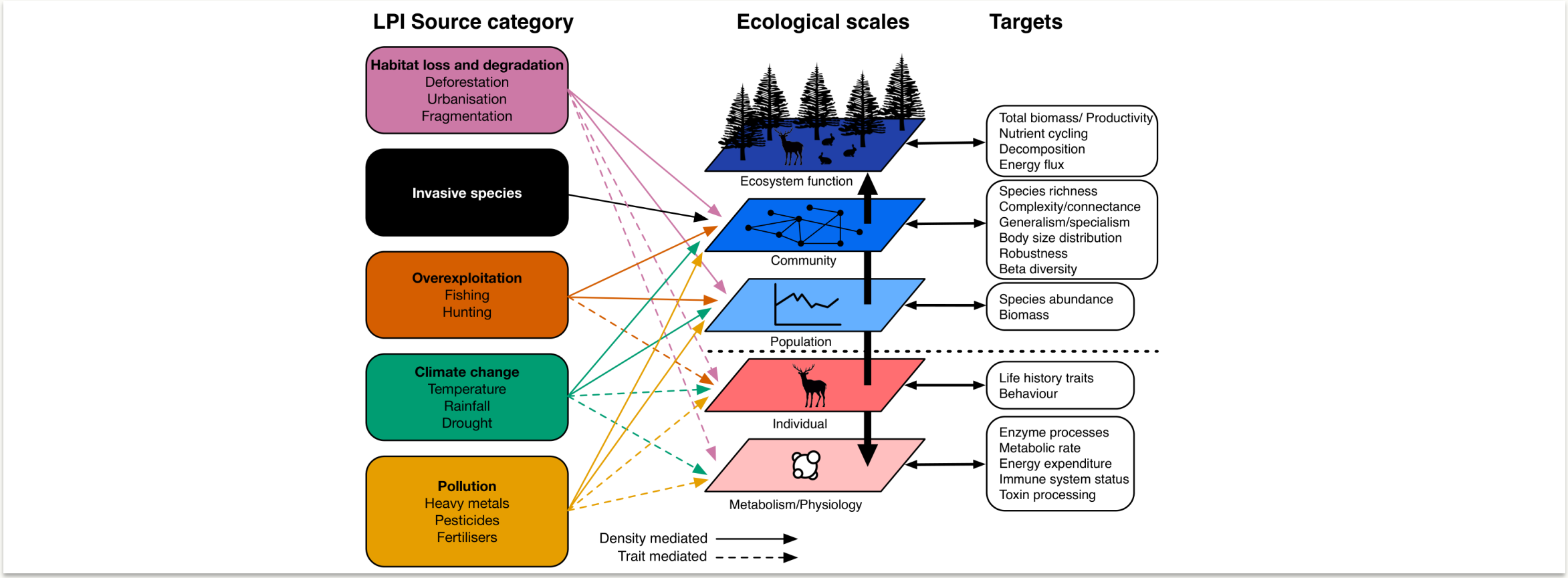
REGIONAL / GLOBAL

Inputs and effects cross the city boundary

One land-use process can generate several exposures at once.

Grimm et al. (2008) · Science · Fig. 2
https://doi.org/10.1126/science.1150195

Multiple pressures: define the response before the interaction



Simmons et al. (2021) · Nature Ecology & Evolution ·
https://doi.org/10.1038/s41559-021-01547-4

Metabolic responses depend on the consumer's presence

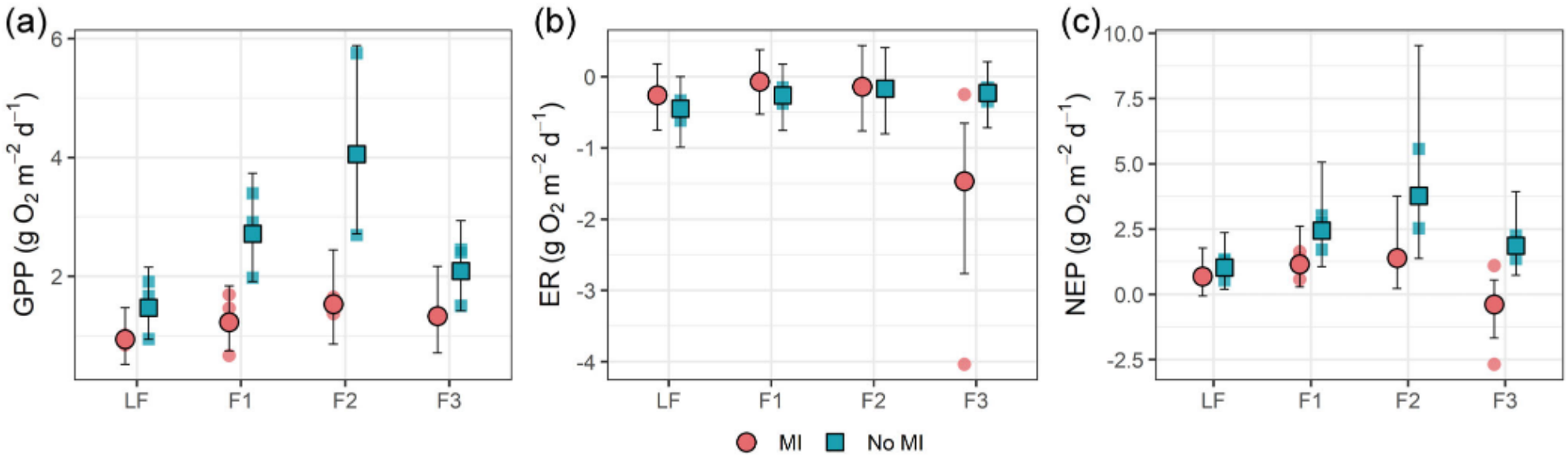
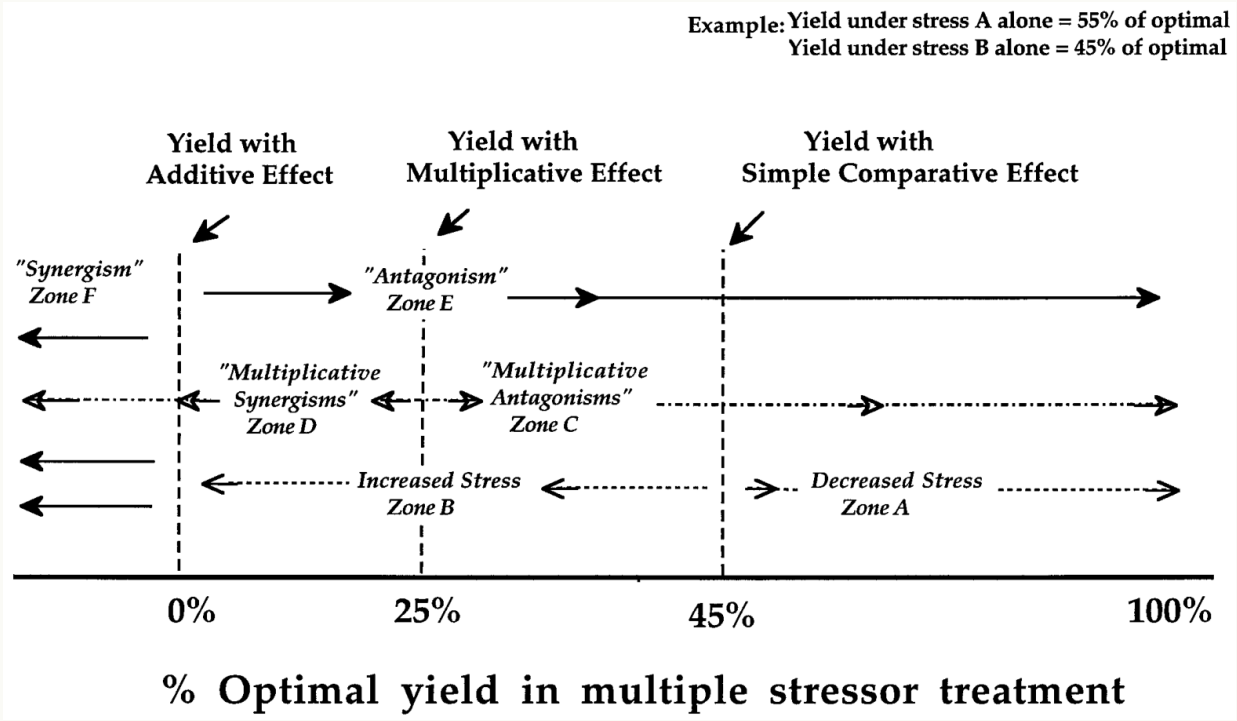


Fig. 5. Gross primary production (GPP), ecosystem respiration (ER), and net ecosystem production (NEP) (g O_2 m^{-2} d^{-1}) from chamber-scale measurements under different flow velocity treatments. Red circles represent mesocosms with macroinvertebrates (MI) and blue squares represent mesocosms without macroinvertebrates (No MI). Flow treatments include Low Flow (LF) and three flushing events of increasing frequency (F1, F2, F3). Symbols indicate mean values and error bars represent 95% confidence intervals of the mixed-effects model estimates from the chamber measurements ($n = 3$ per treatment).

Synergy requires an explicit reference model



Δ = observed − expected

Two decreases: Δ < 0 → synergy

ADDITIVE EXPECTATION

$$E(AB) = R(A) + R(B) - R(C)$$

Combines absolute changes

MULTIPLICATIVE EXPECTATION

$$E(AB) = R(A) \times R(B) / R(C)$$

Combines proportional changes

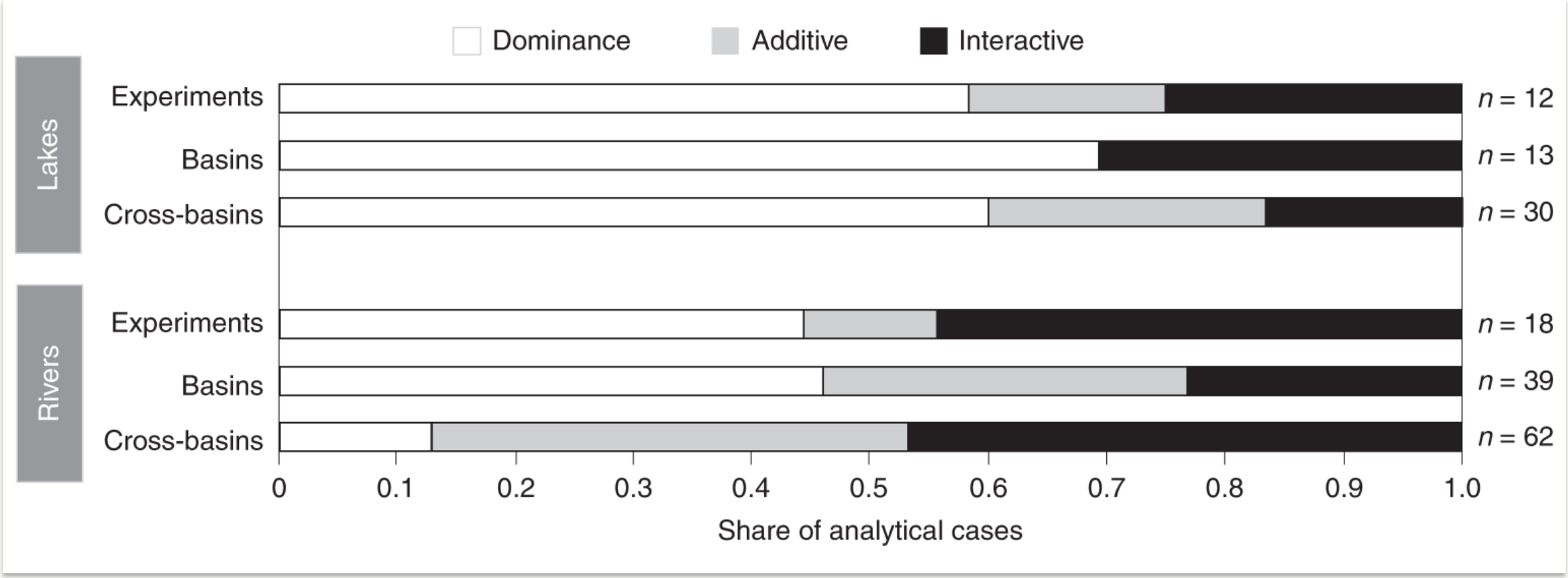
R(C): control; R(A), R(B): single-stressor responses

Two increases: Δ > 0 → synergy

Compatibility ≠ proof of exact additivity

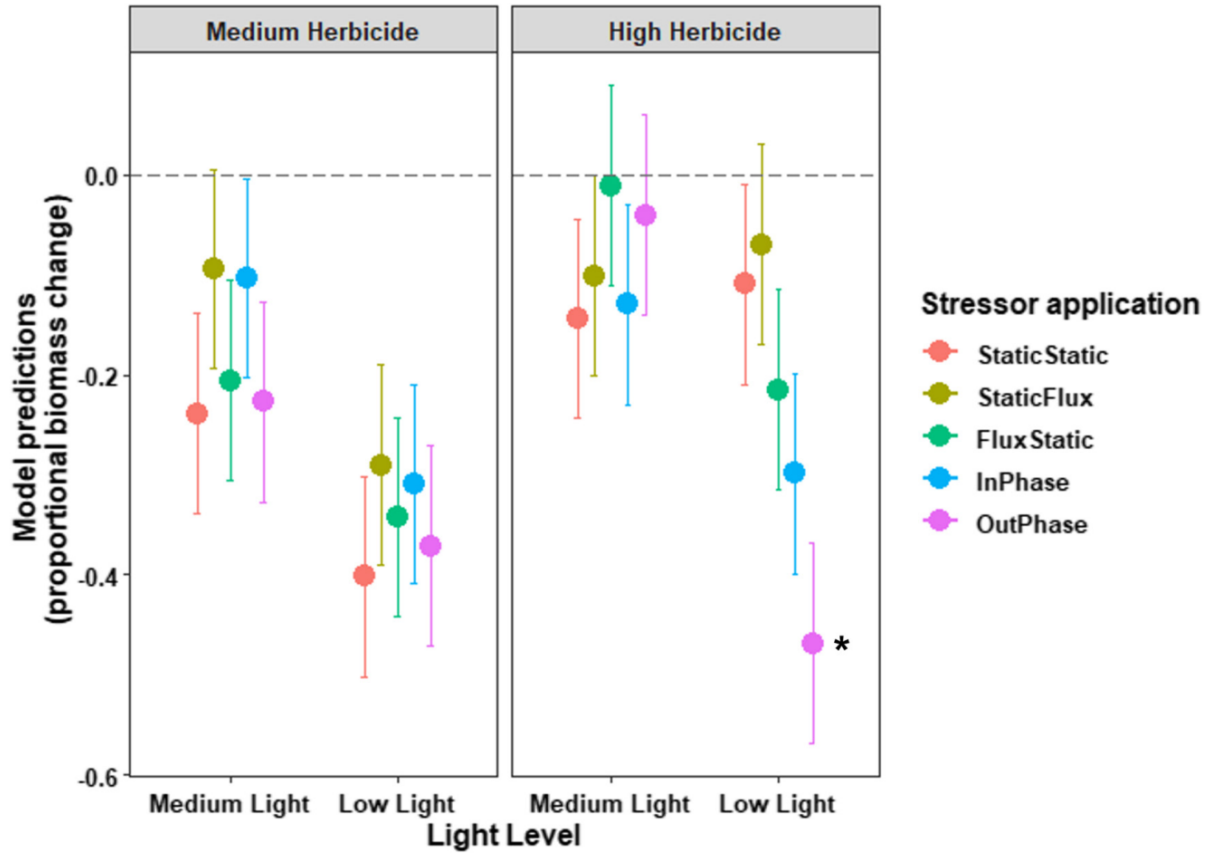
Folt et al. (1999) · Limnology and Oceanography · | Schäfer & Piggott (2018) · Global Change Biology
https://doi.org/10.1111/gcb.14073

Two stressors do not always produce a non-additive response



Birk et al. (2020) · Nature Ecology & Evolution ·
https://doi.org/10.1038/s41559-020-1216-4

Timing changes the impact of multiple stressors



Modelled means ± SE; * p < 0.05 versus constant exposure.

THE EXPERIMENT

Halophila ovalis
12 replicates per treatment.
Constant or fluctuating pressures; same mean exposure.

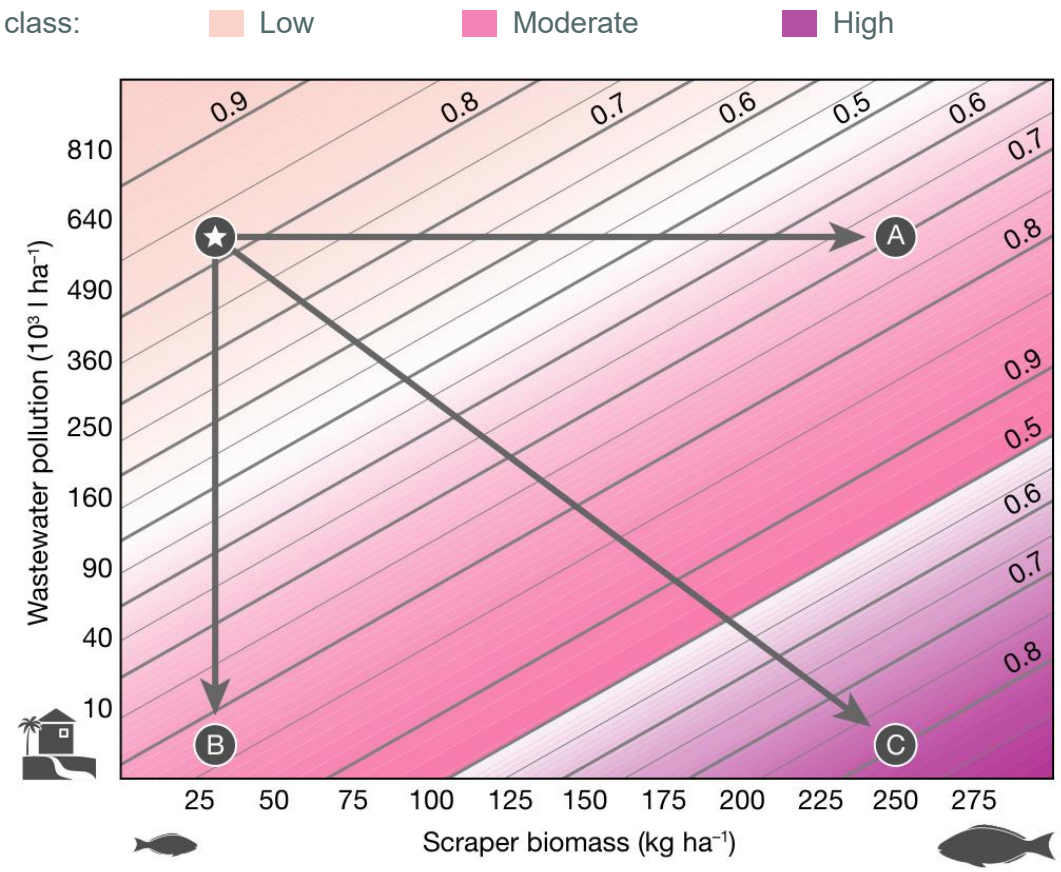
THE RESULT

At high herbicide and low light, asynchronous exposure caused greater biomass loss than constant exposure.

The same mean exposure can produce different outcomes when stressor timing changes.

Ostrowski et al. (2022) · Ecology Letters 25:2611–2623 ·
https://doi.org/10.1111/ele.14120

Heat stress does not act on reefs in isolation



MODELLED PROBABILITY OF HIGH COVER

A	Higher scraper biomass	**14%**
B	Less wastewater	**26%**
C	**Both changes**	**80%**

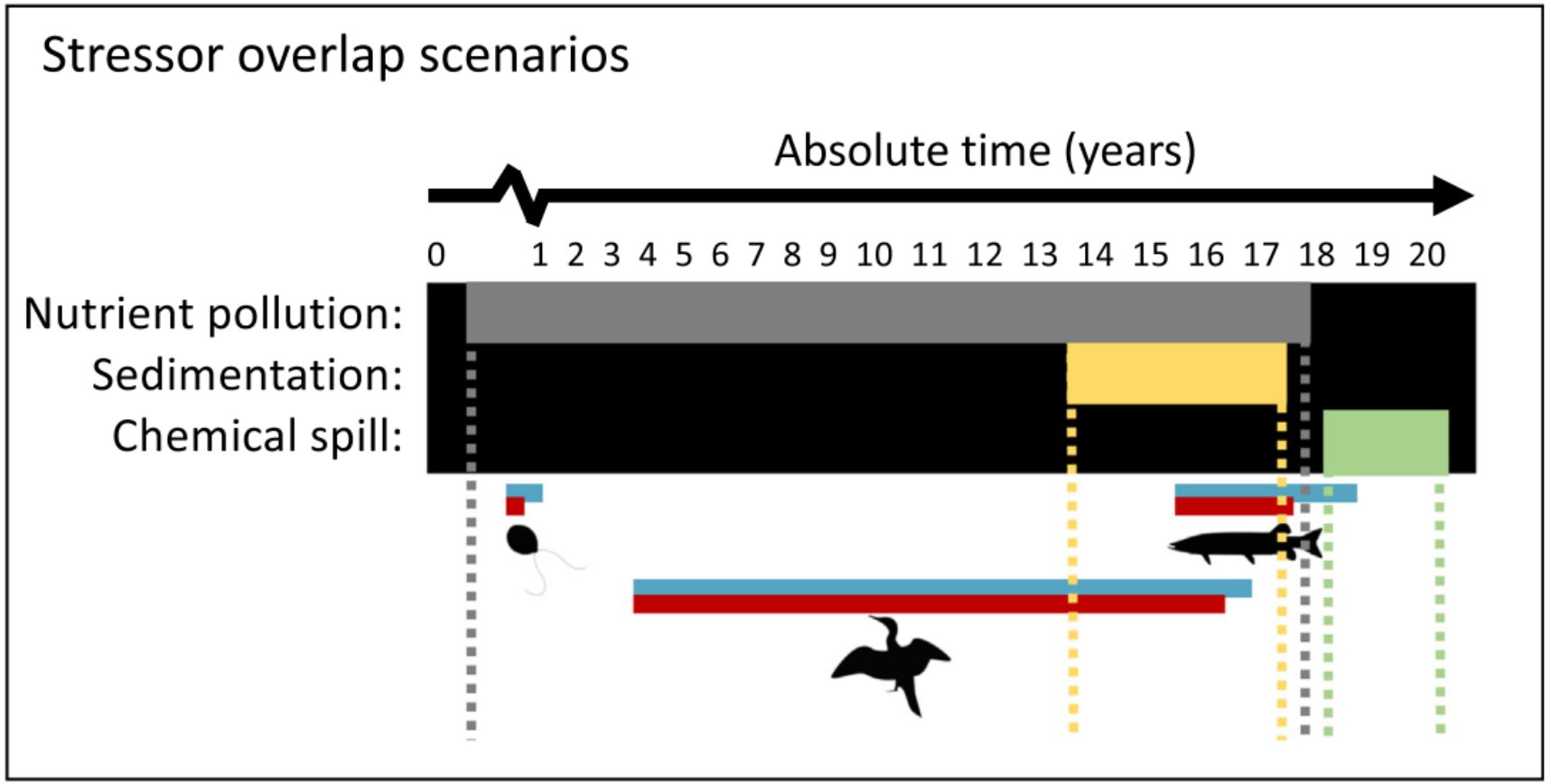
High = top quartile of reef-builder cover in the survey.

Reef builders: hard corals + crustose coralline algae.

The model predicts the best outcome when land and sea conditions improve together.

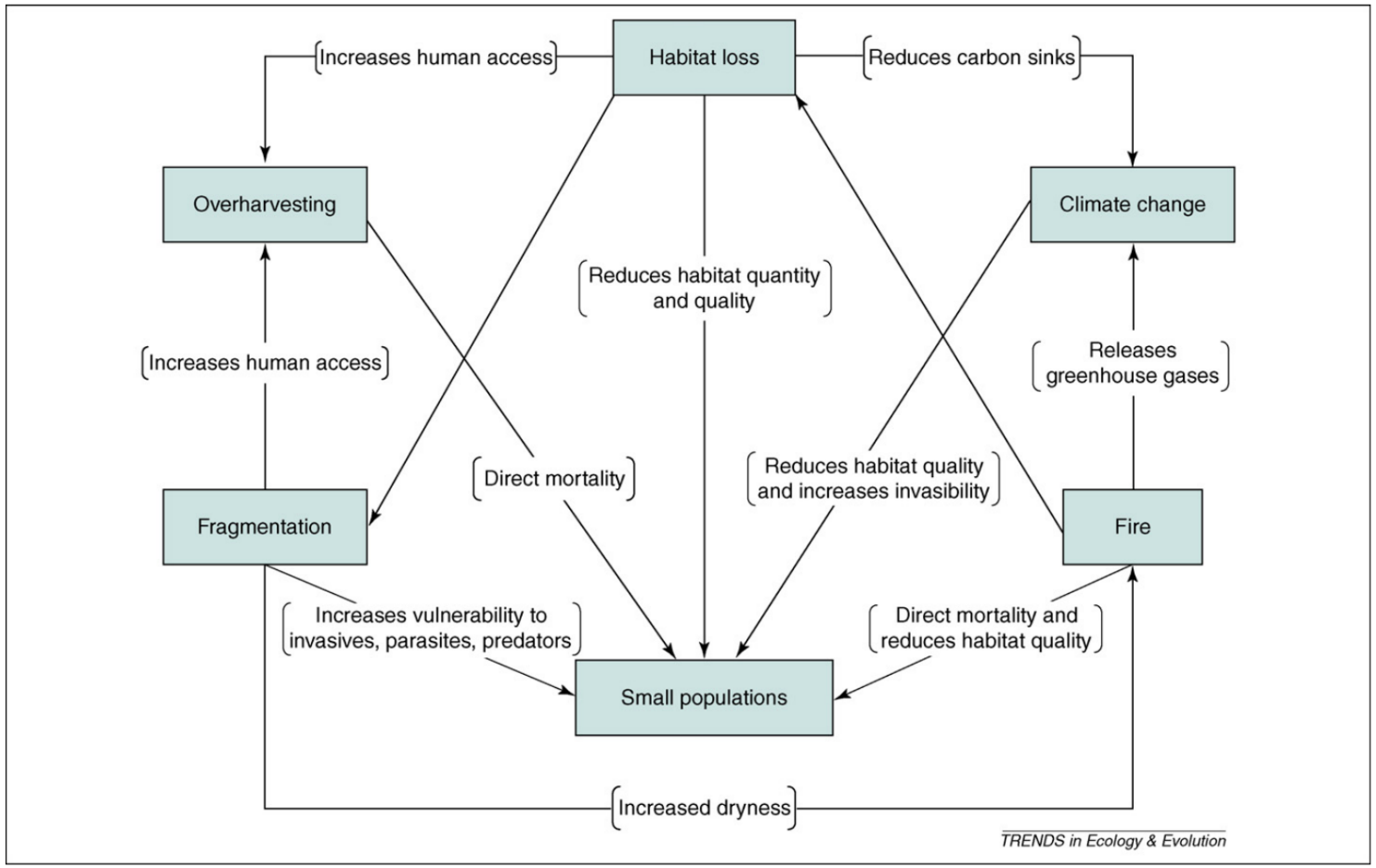
Gove et al. (2023) · Nature 621:536–542
https://doi.org/10.1038/s41586-023-06394-w

Exposure timing and biological timescales



Jackson, Pawar & Woodward (2021) · Trends in Ecology & Evolution · Fig. 2
https://doi.org/10.1016/j.tree.2021.01.005

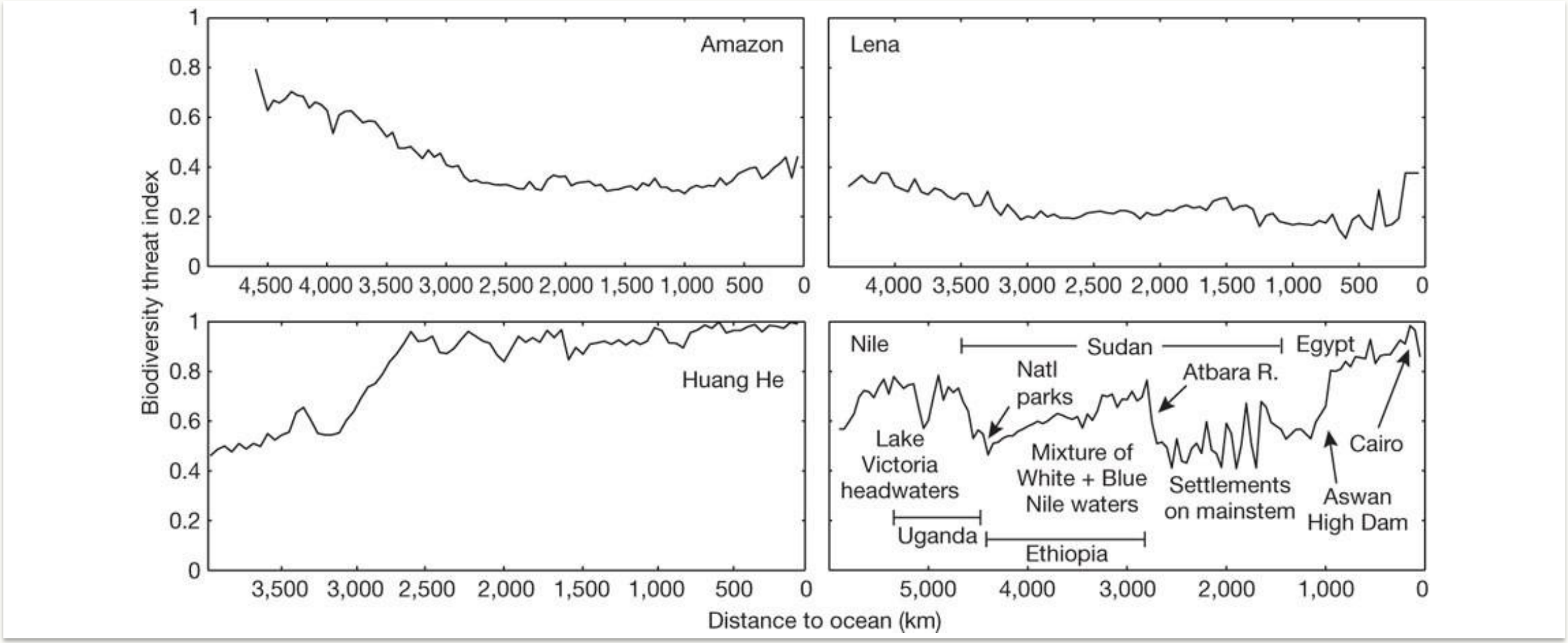
Causal pathways can include reinforcing feedbacks



Access → exploitation; canopy opening → drying → fire → further habitat loss.

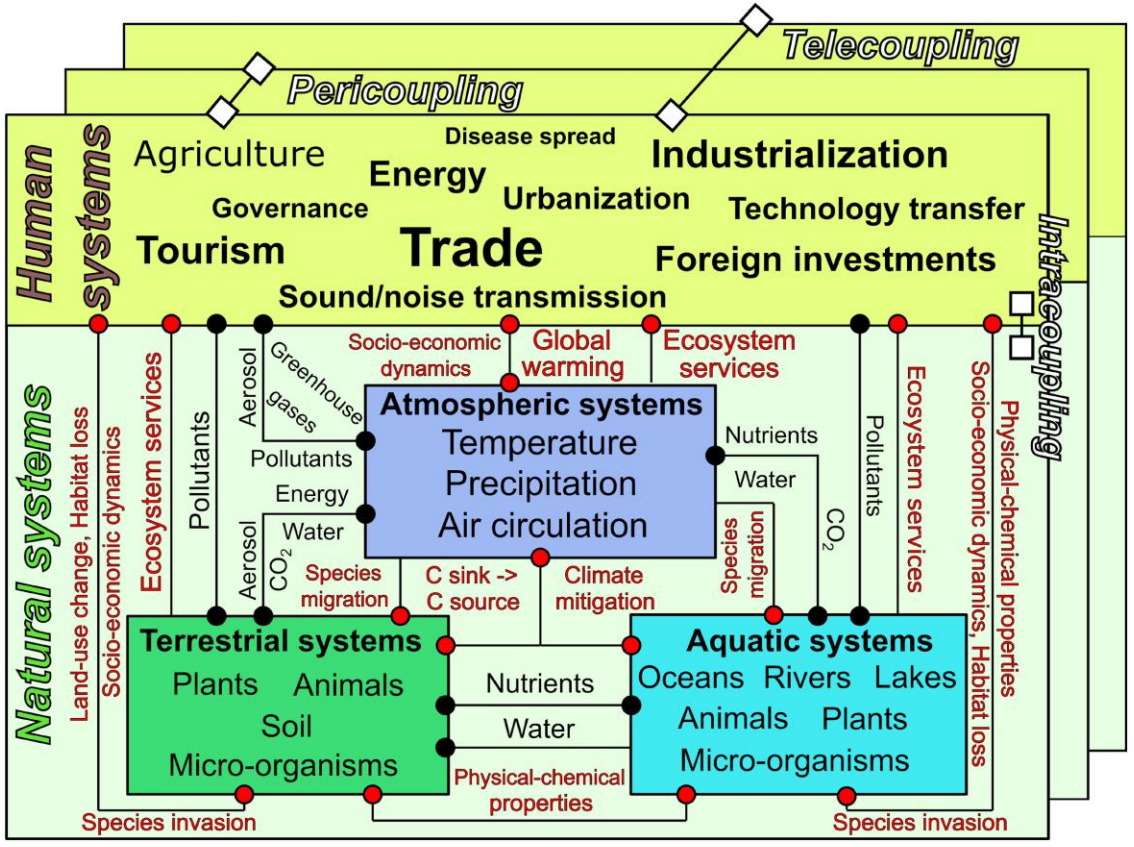
Brook, Sodhi & Bradshaw (2008) · Trends in Ecology & Evolution · Fig. 3
https://doi.org/10.1016/j.tree.2008.03.011

River networks transmit and redistribute pressures



Vörösmarty et al. (2010) · Nature · Fig. 2
https://doi.org/10.1038/nature09440

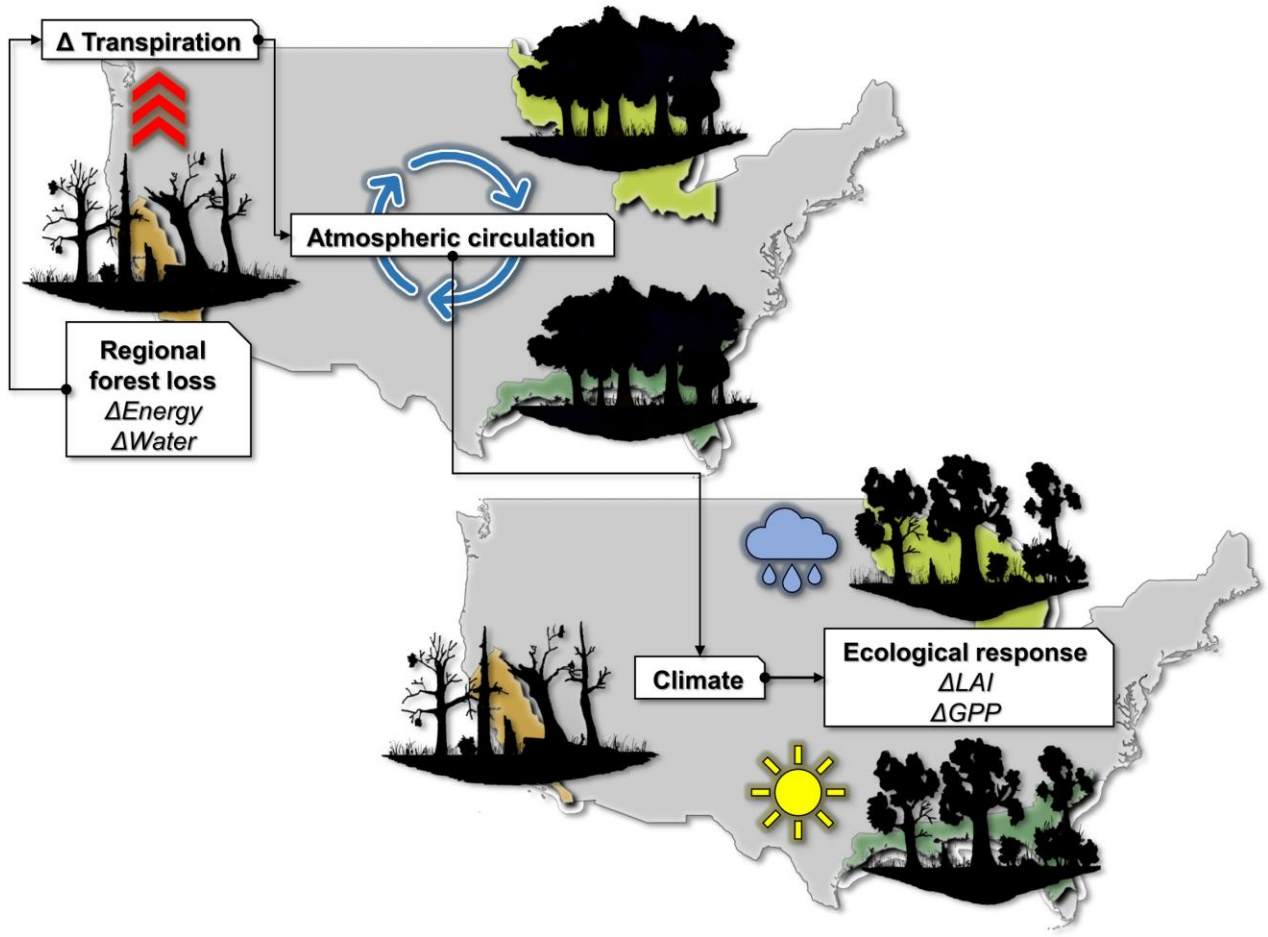
Ecological effects can propagate across ecosystem boundaries



Sources and impacts can occur in different ecosystems, linked by flows and feedbacks.

Tromboni et al. (2021) · Frontiers in Ecology and the Environment ·
https://doi.org/10.1002/fee.2289

Forest loss can alter ecological conditions far away



Regional forest loss → surface fluxes → atmospheric circulation → distant ecological responses.

Tromboni et al. (2021) · Frontiers in Ecology and the Environment
https://doi.org/10.1002/fee.2289

Valle Averto: follow the water

PUBLISHED STUDY MAP · OUR FIELD-VISIT SITE



HABITAT MOSAIC

Fresh and brackish waters, reedbeds and wet woodland