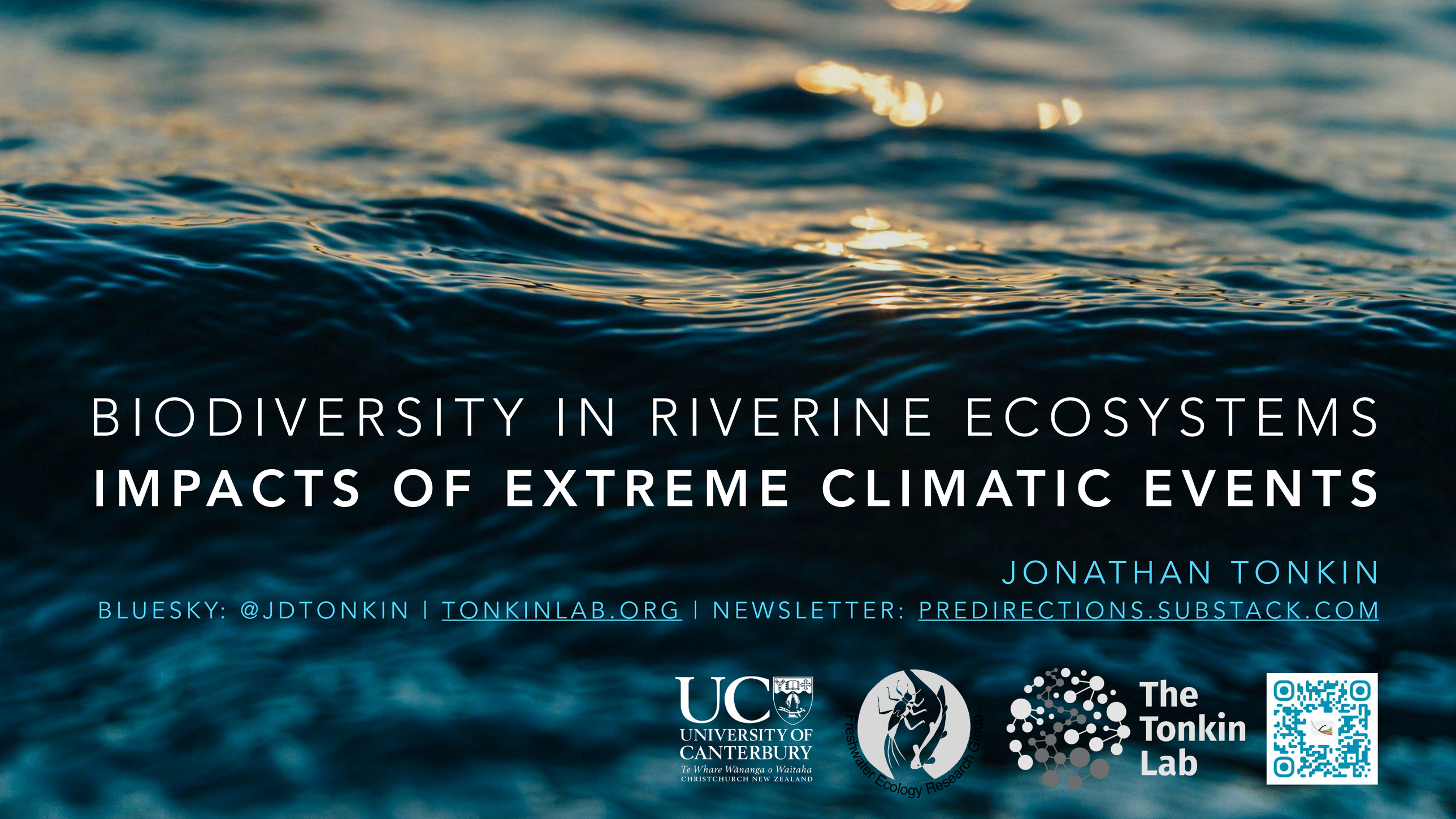


BIODIVERSITY IN RIVERINE ECOSYSTEMS
IMPACTS OF EXTREME CLIMATIC EVENTS

JONATHAN TONKIN

BLUESKY: @JDTONKIN | TONKINLAB.ORG | NEWSLETTER: PREDIRECTIONS.SUBSTACK.COM

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

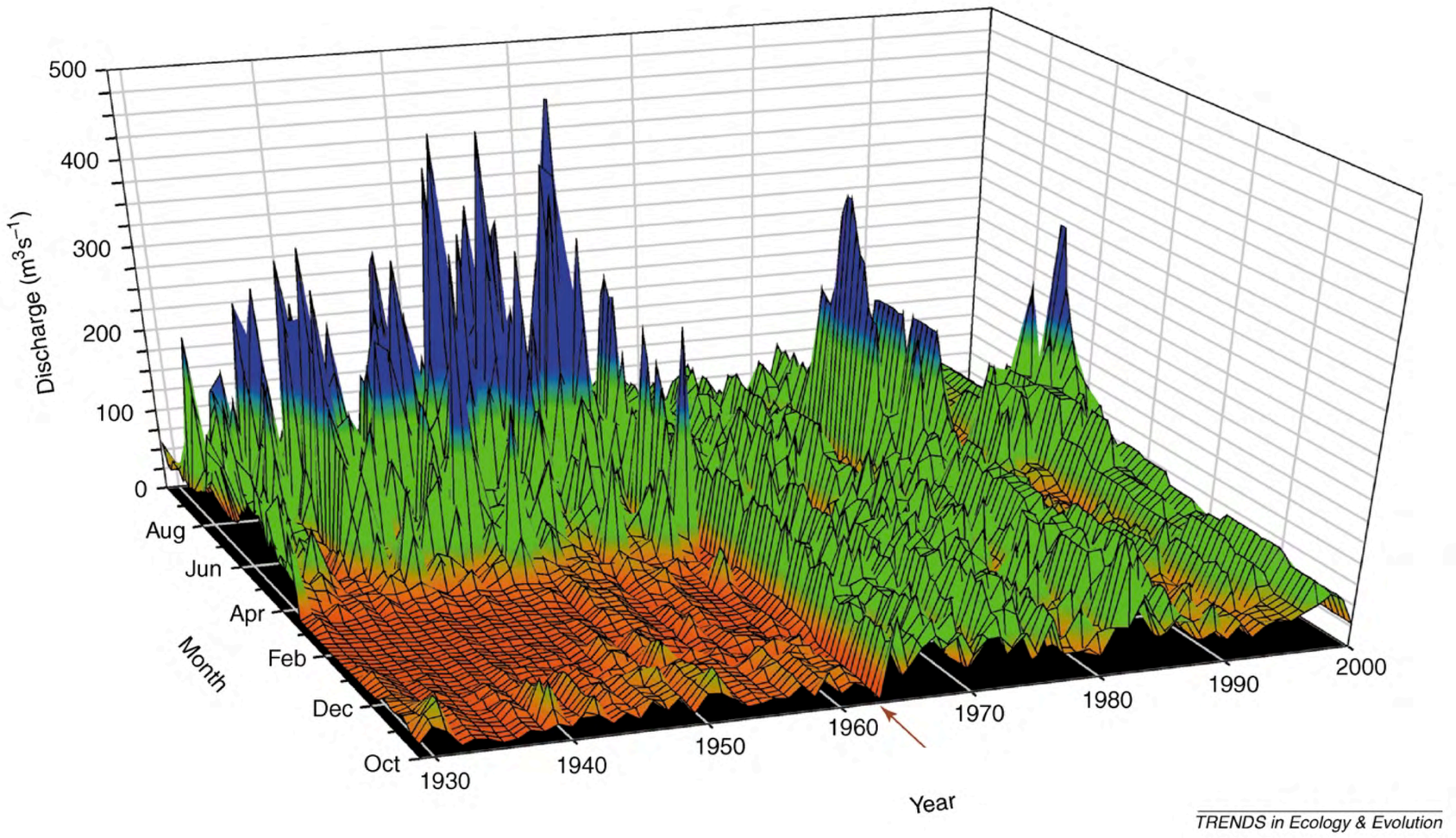
Freshwater Ecology Research Group

The Tonkin Lab

THE COLORADO RIVER HAS BEEN DAMMED AND DIVERTED SO MANY TIMES THAT IT NO LONGER FLOWS REGULARLY INTO THE GULF OF CALIFORNIA, LEAVING ITS ONCE-FERTILE DELTA DRY AND BARREN



Photograph by Blue Legacy/Oscar Durand

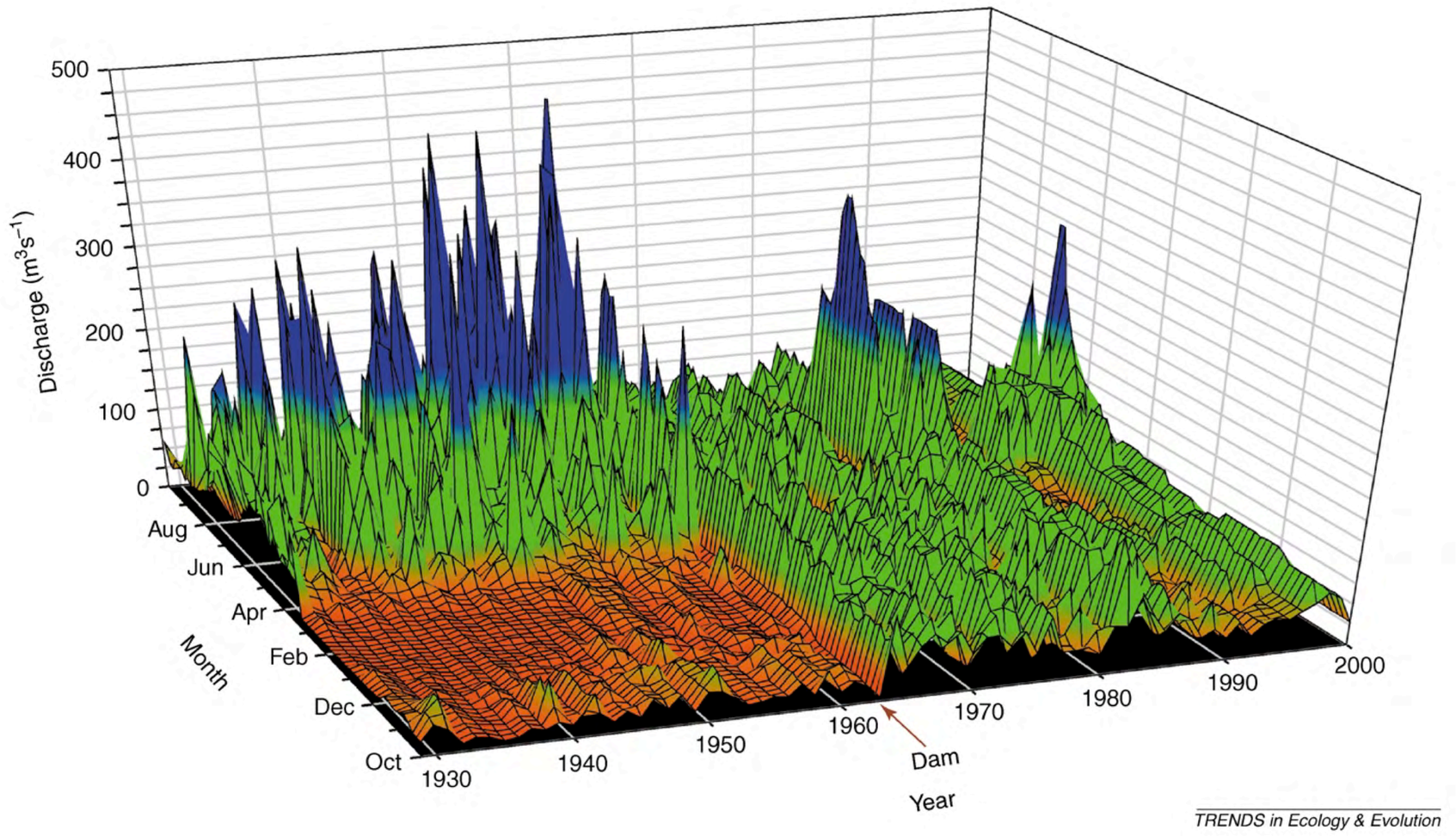


Lytle & Poff 2004 *TREE*

FLAMING GORGE DAM, 1963. GREEN RIVER, UTAH, USA



Christian Mehlführer



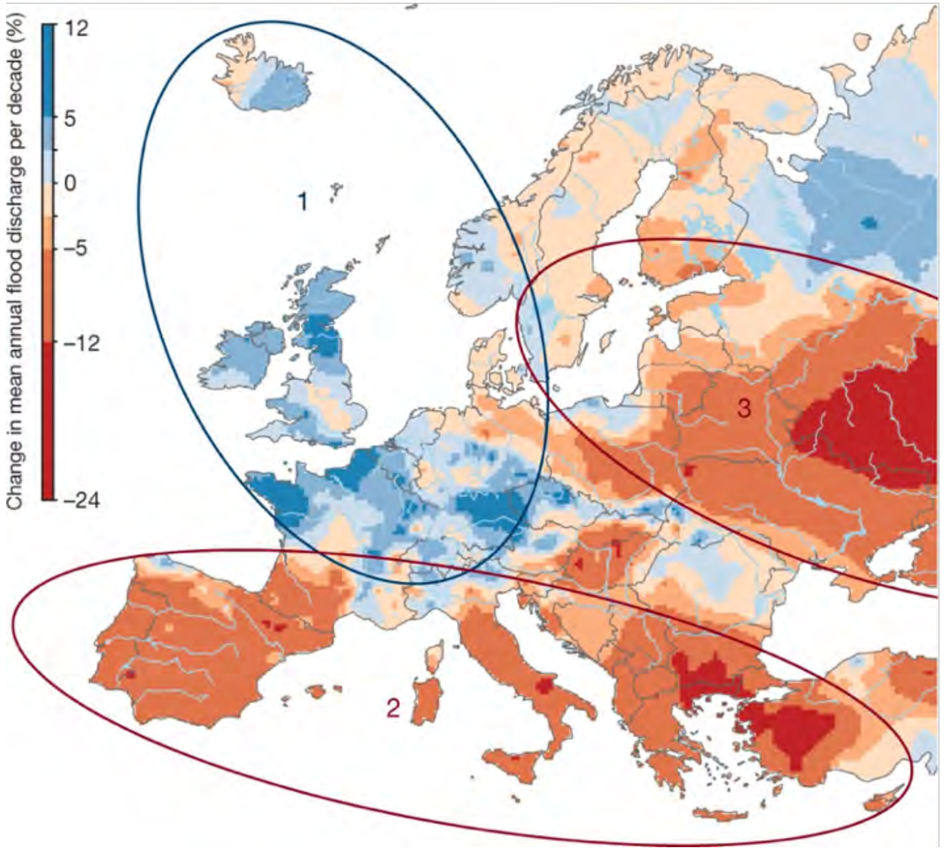
Lytle & Poff 2004 *TREE*

FLOWS HAVE BEEN MODIFIED FOR CENTURIES FOR HUMAN GAIN



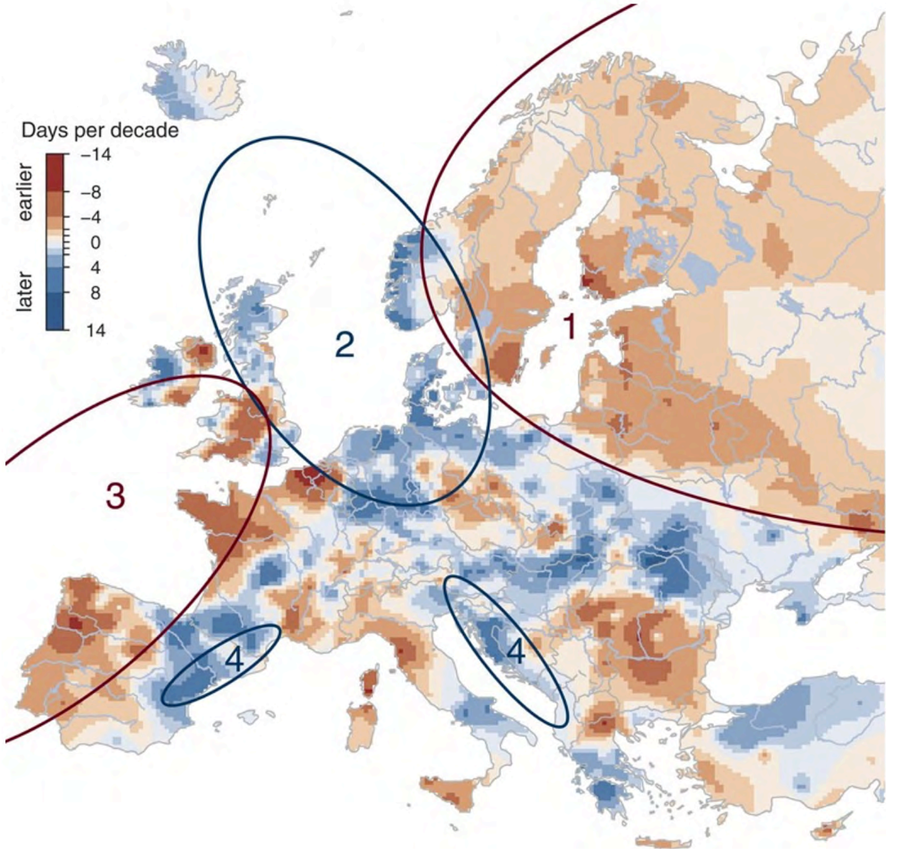
RIVER FLOWS ARE CHANGING VIA CLIMATE CHANGE

Flood magnitude: Europe 1960–2010



Blöschl et al. 2019 *Nature*

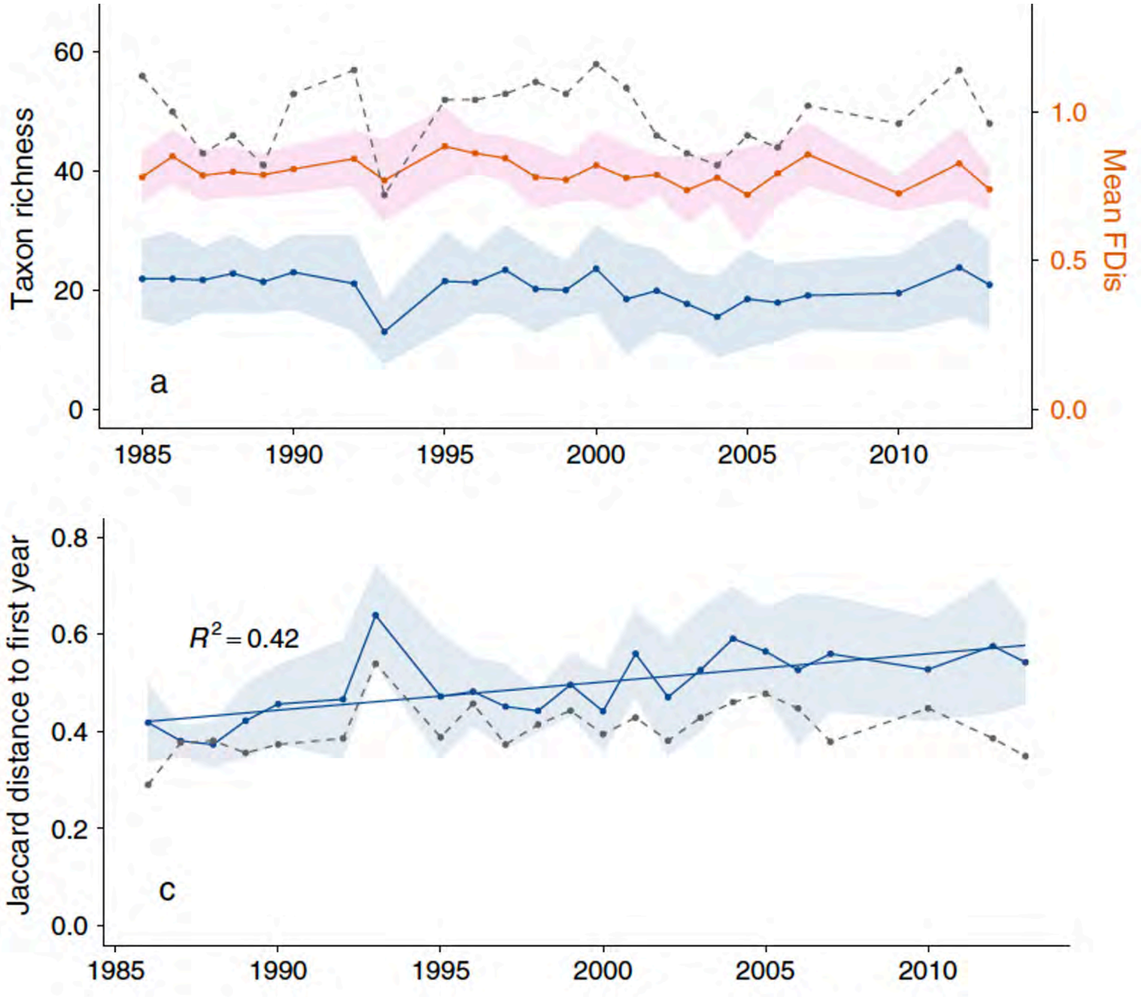
Flood timing: Europe 1960–2010



Blöschl et al. 2017 *Science*

IMPACTS ON BIODIVERSITY CAN BE SUBTLE

Richness may not change but species are being lost and replaced



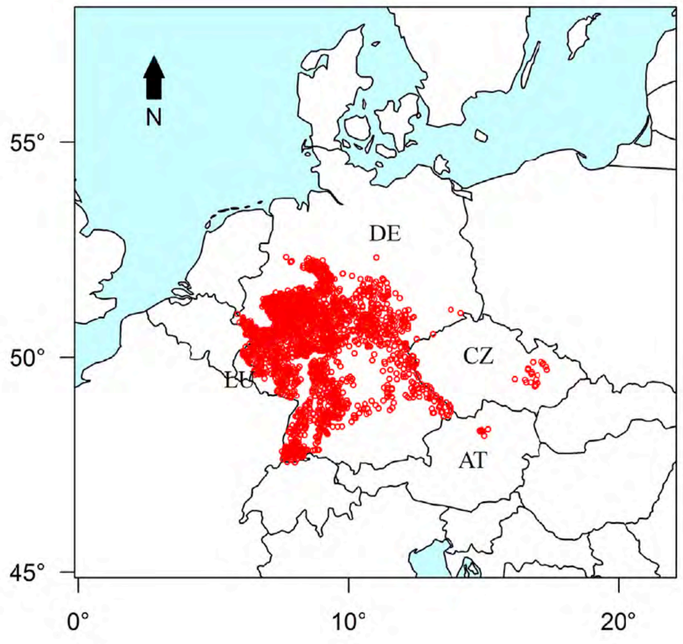
Larsen et al. 2018 *Ecology*

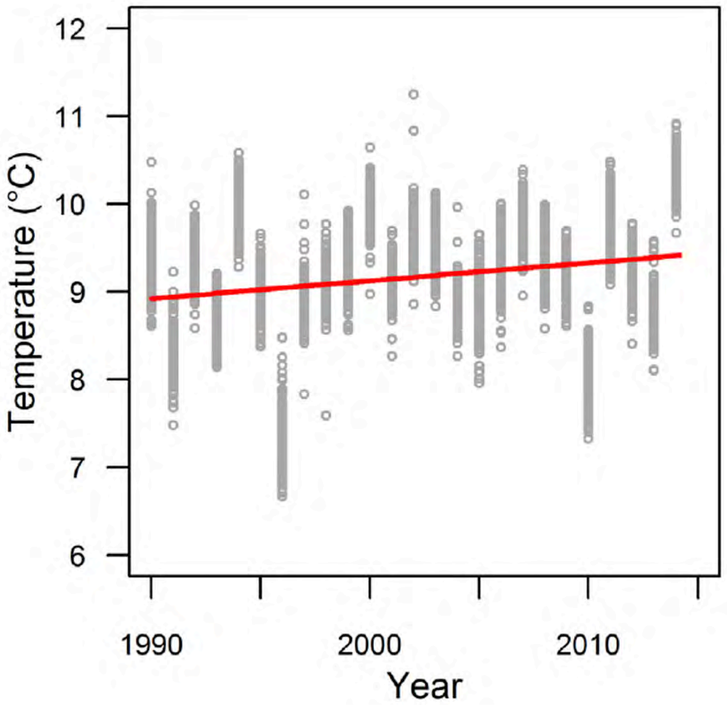
INVERTEBRATE COMMUNITIES ARE REORGANISING

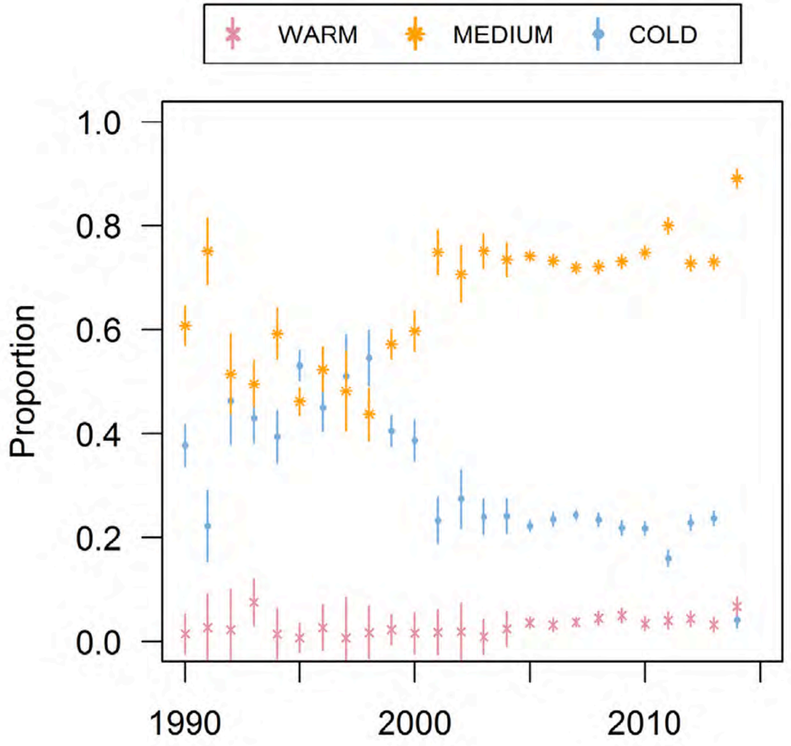
Cold-dwelling species are being replaced by warm in European rivers



Peter Haase







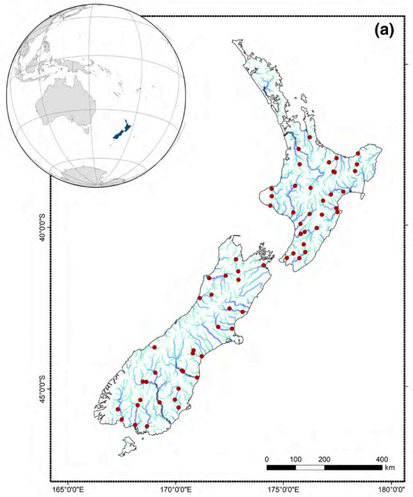
Haase et al. 2019 *Sci. Tot. Env.*

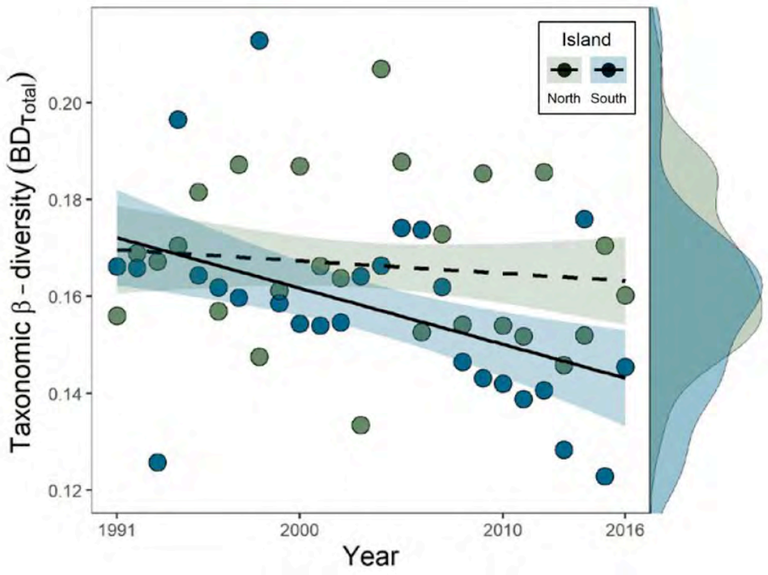
RIVER INVERTEBRATE COMMUNITIES ARE HOMOGENISING

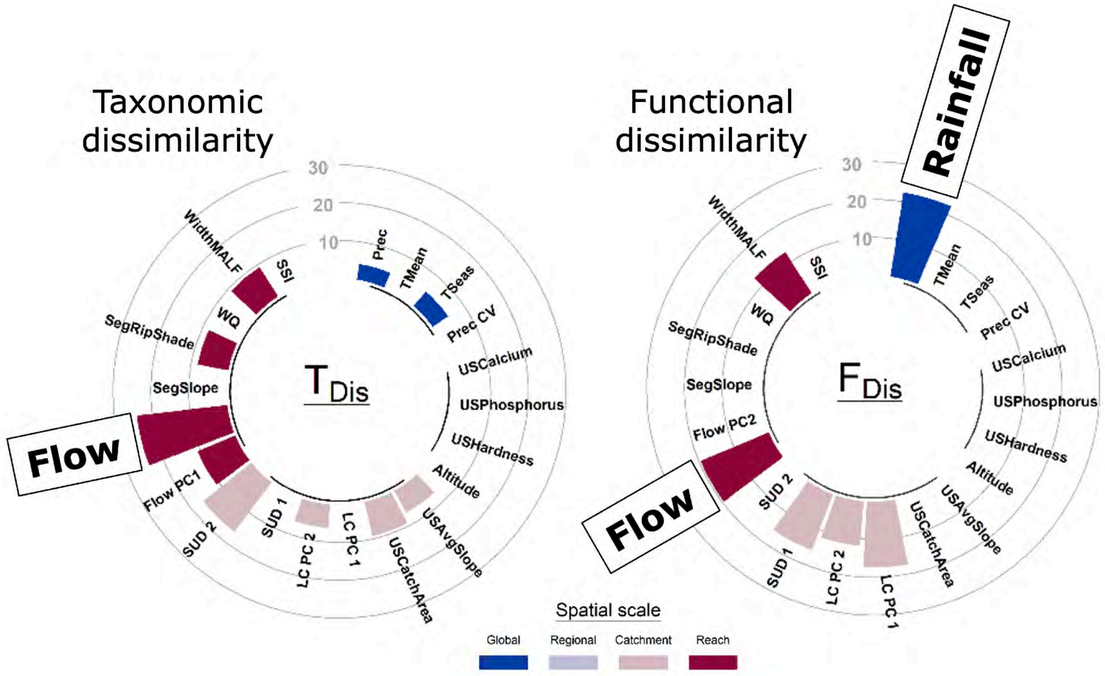
Changing flow regimes are a key player



Theo Mouton







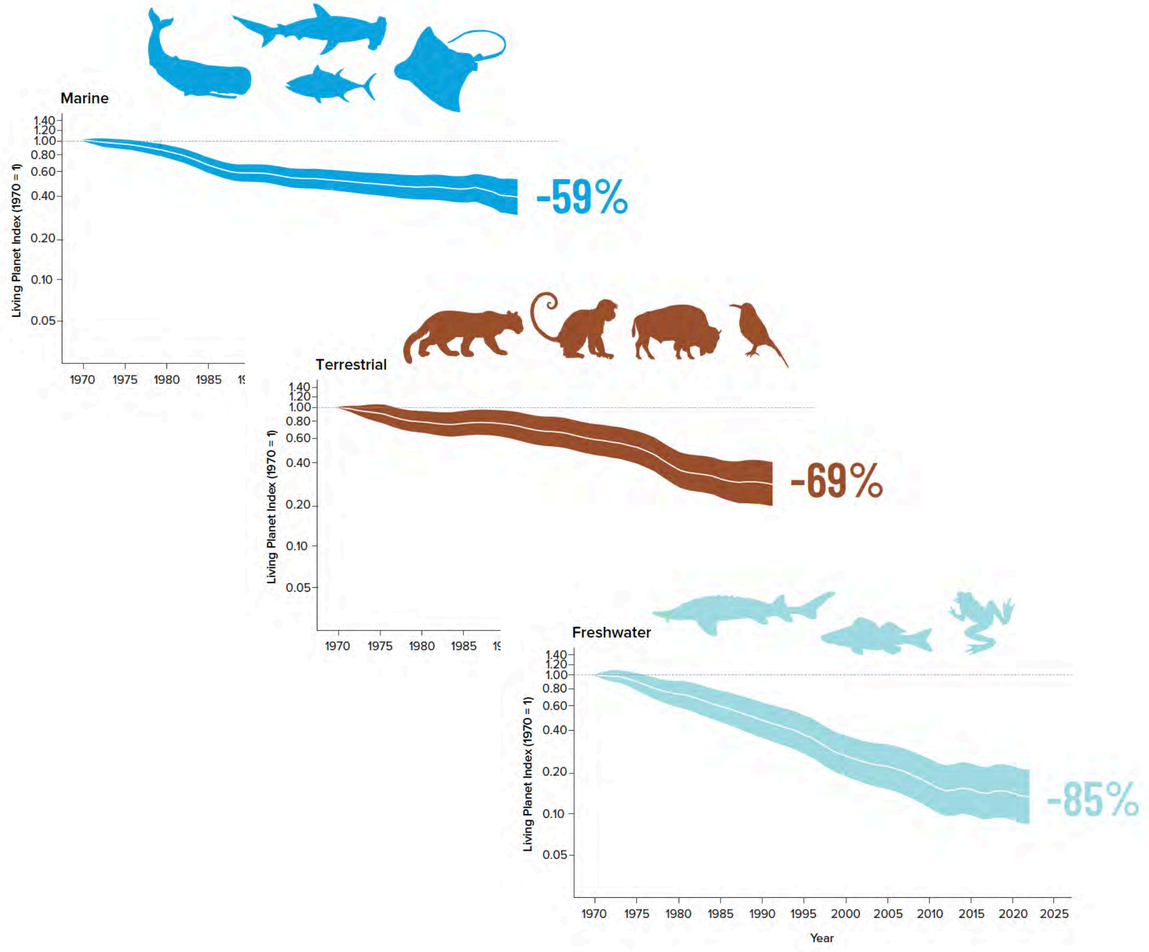
Mouton et al. 2022 *Ecography*

Mouton et al. 2020 *Glob. Chang. Biol.*

FRESHWATER IS DISPROPORTIONATELY THREATENED

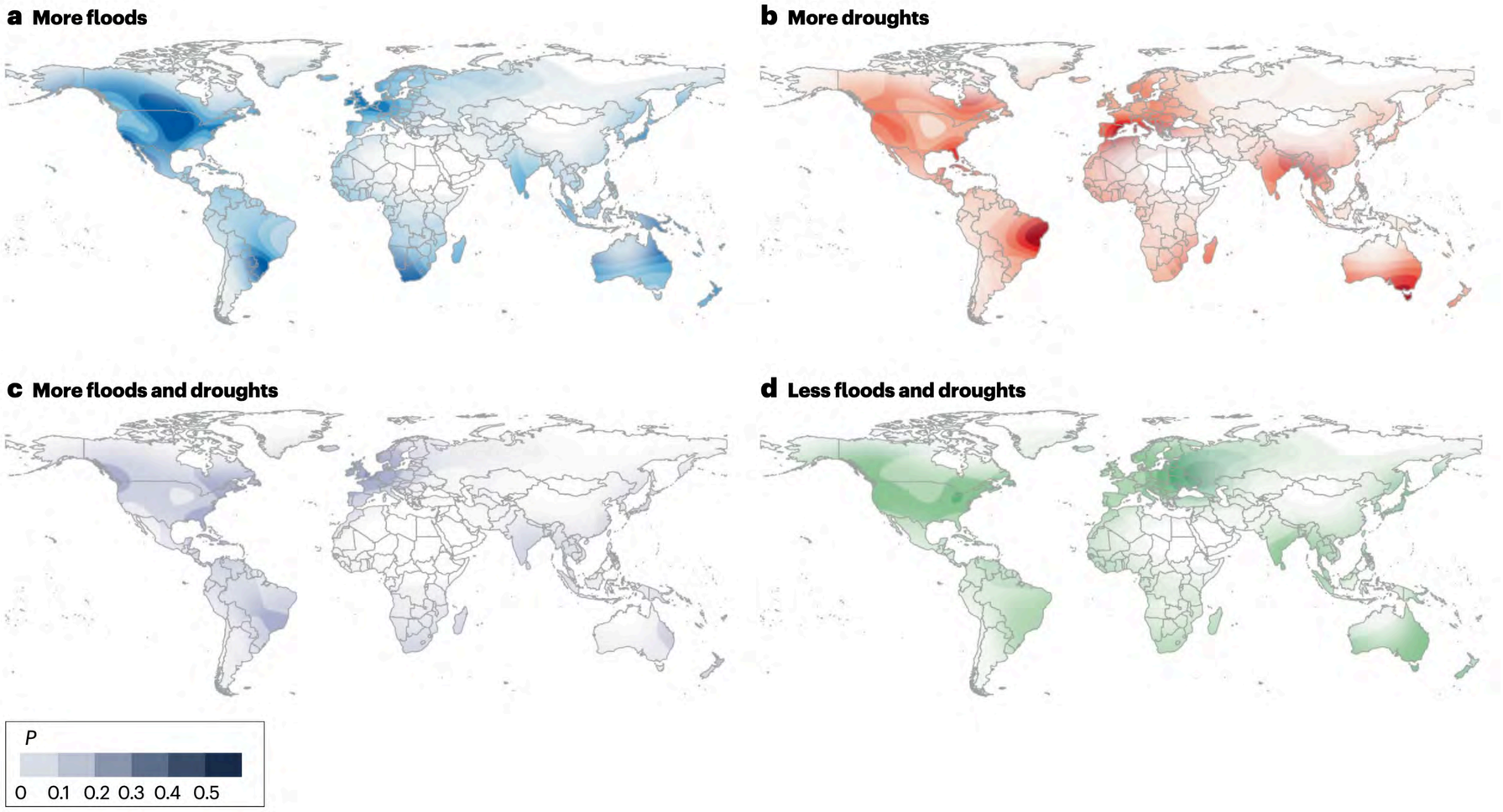


Craig et al. 2017, *Elementa*



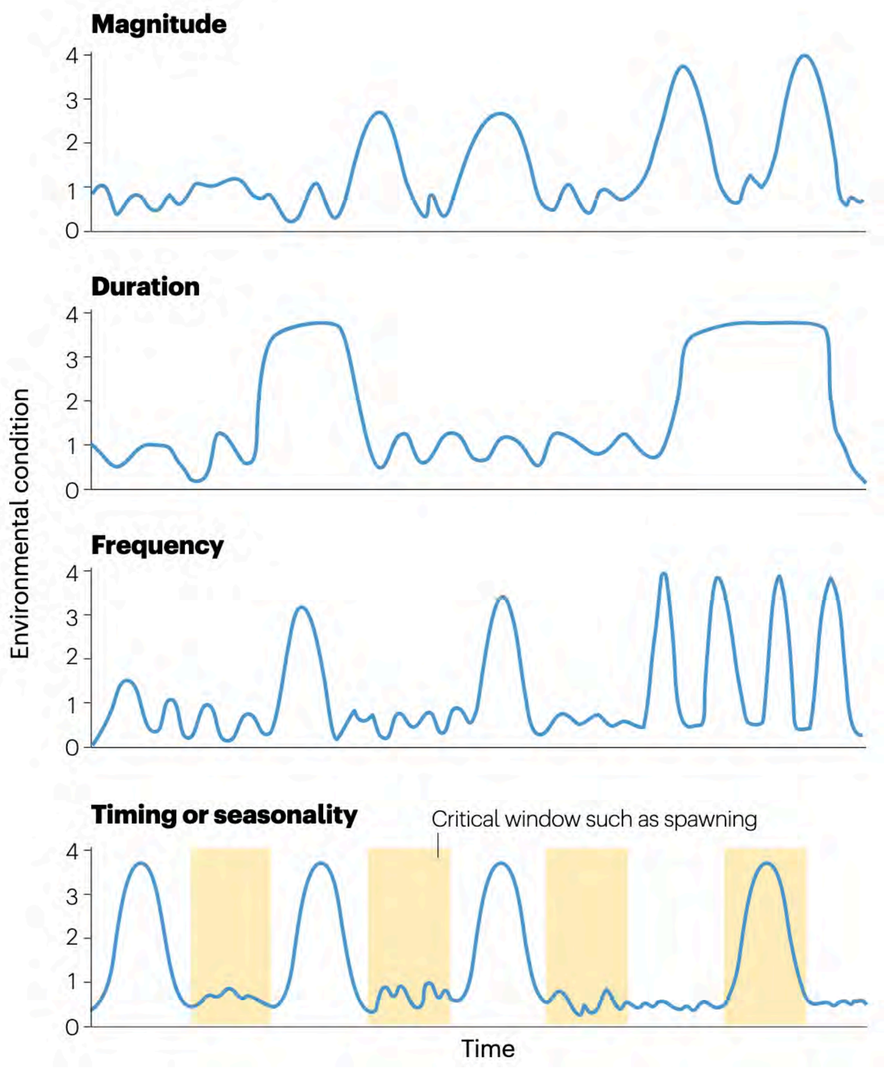
Living Planet Index, 2026

RIVER EXTREMES ARE CHANGING



Tonkin et al. (2026) *Nature Reviews Biodiversity*

RIVER EXTREMES ARE CHANGING

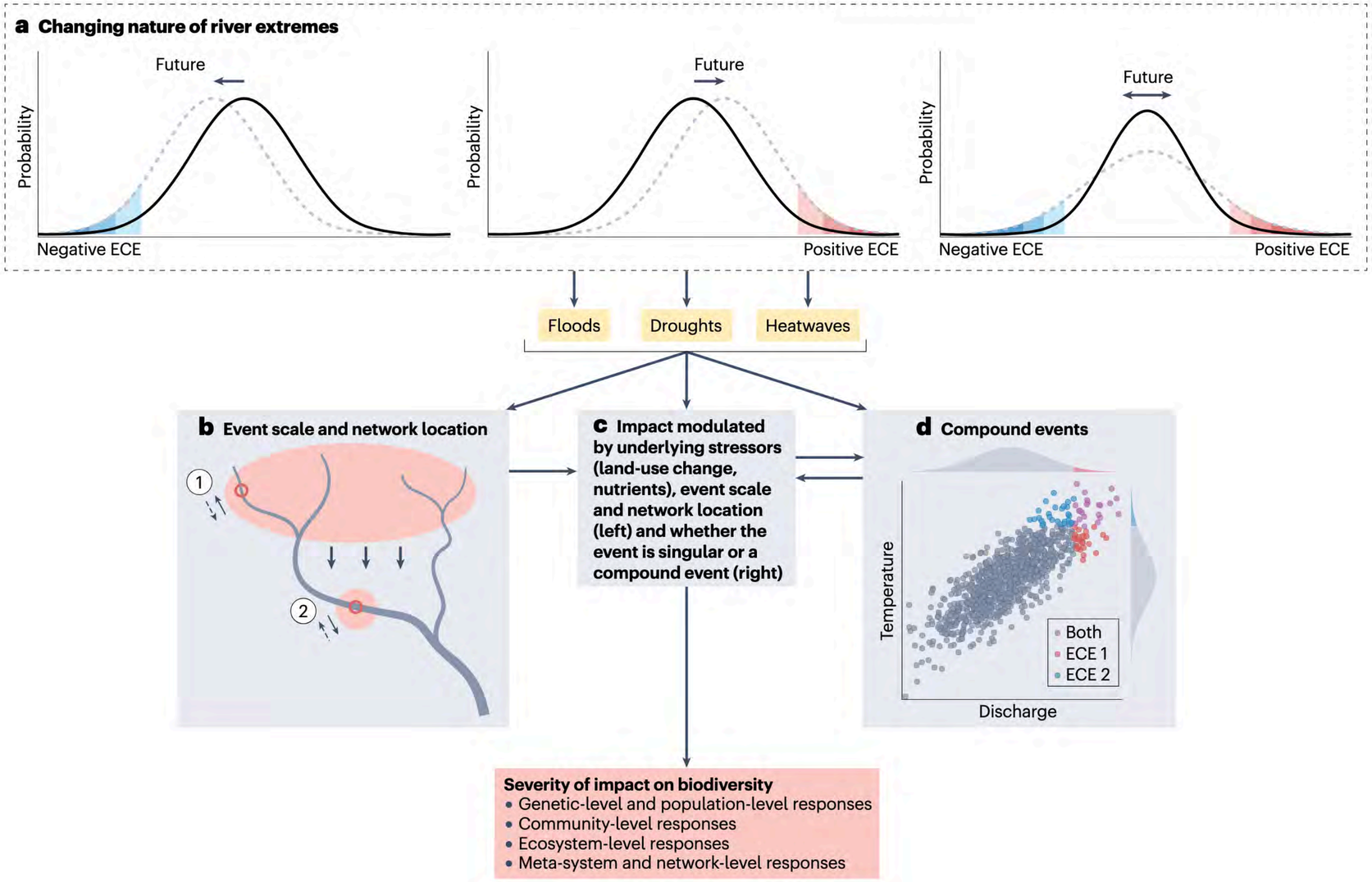


Tonkin et al. (2026) *Nature Reviews Biodiversity*

AND THE IMPACTS ARE WIDE RANGING AND CONTEXT-DEPENDENT

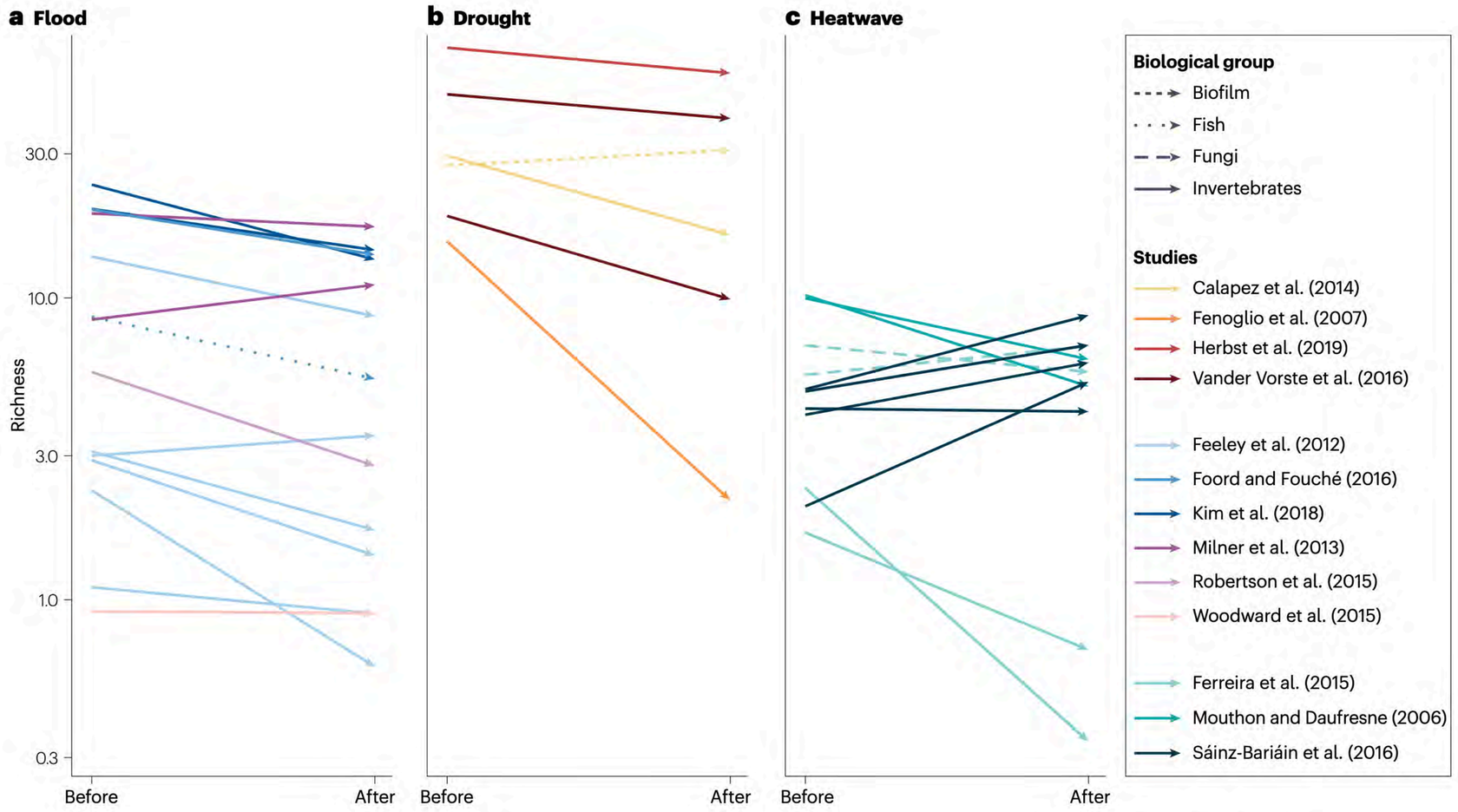
But they're hard to model!

- Rare so limited possibility to learn
- Nonlinear impacts
- Modulated by other things
  - Compound events, cumulative and lagged impacts, existing stressors
- Tail behaviour matters more than means



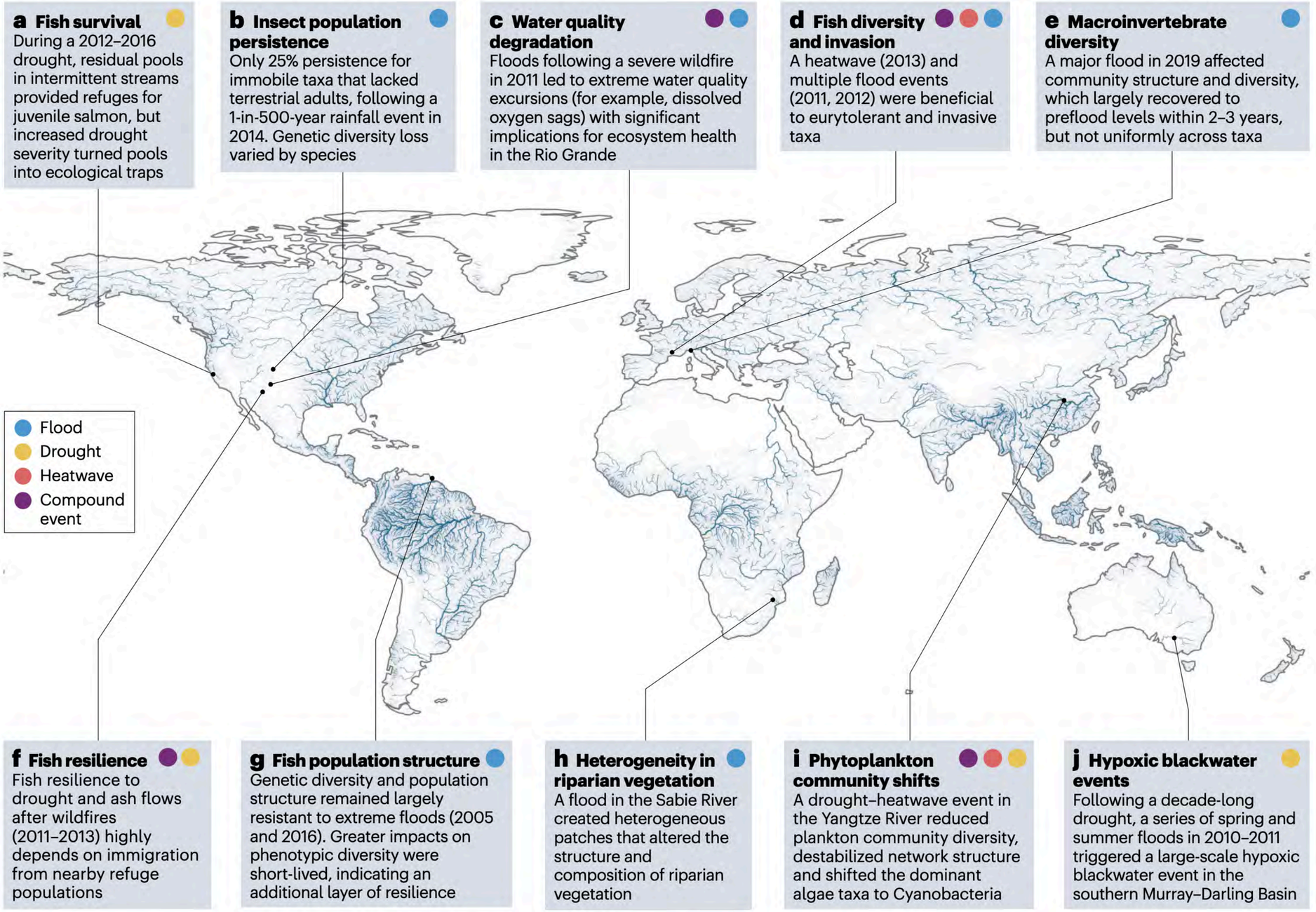
Tonkin et al. (2026) *Nature Reviews Biodiversity*

EXTREMES ALMOST ALWAYS COME WITH IMPACTS



Modified from Sabater et al. (2023) Biol. Rev.

Tonkin et al. (2026) *Nature Reviews Biodiversity*



Tonkin et al. (2026) *Nature Reviews Biodiversity*

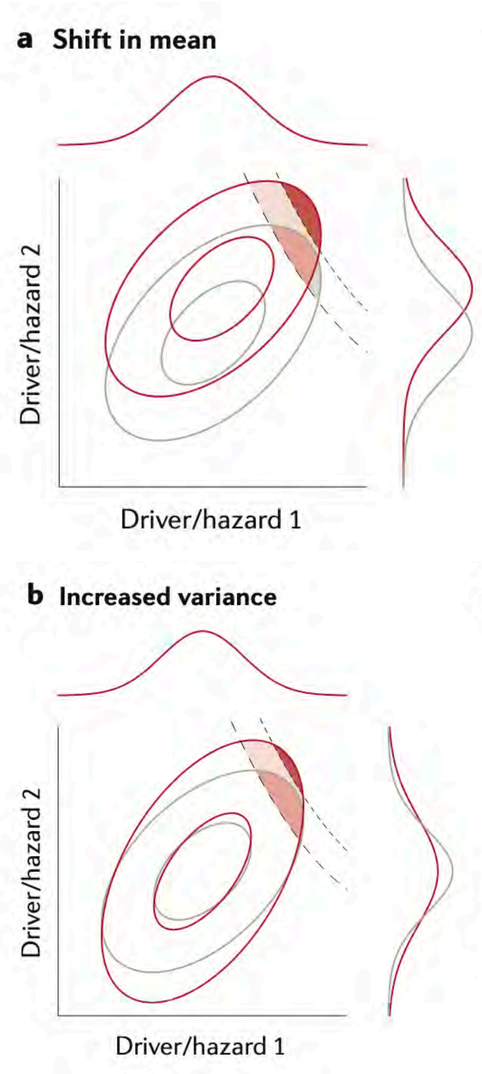
EXTREMES DO NOT ALWAYS OPERATE IN ISOLATION

Compound extremes come with compound risks

A typology:

- **Preconditioned** (where a pre-existing condition amplifies impacts, e.g., heavy rainfall on saturated soils)
- **Multivariate** (multiple hazards occur together, e.g., drought and heatwave)
- **Temporally compounding** (hazards occur in sequence, e.g., sequences of heatwaves)
- **Spatially compounding** (hazards occur simultaneously across regions, e.g., widespread floods)

Zscheischler et al. (2020) *Nature Rev. Earth. Env.*





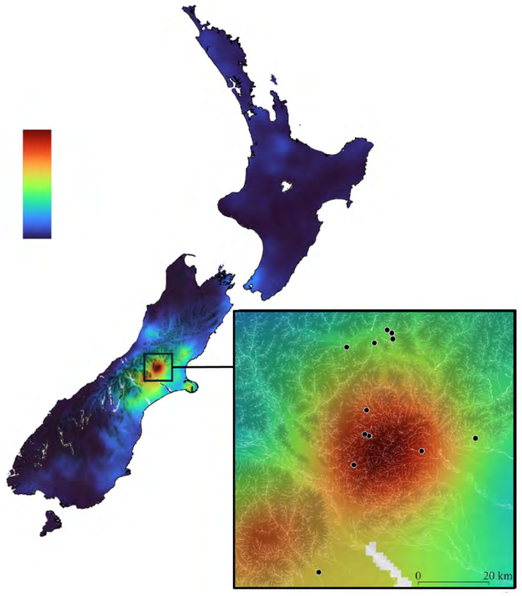
Dahm et al. (2015) *Freshwater Biology*

NUANCED IMPACTS: TROUT HINDER THE RECOVERY OF GALAXIIDS FROM EXTREME FLOODS

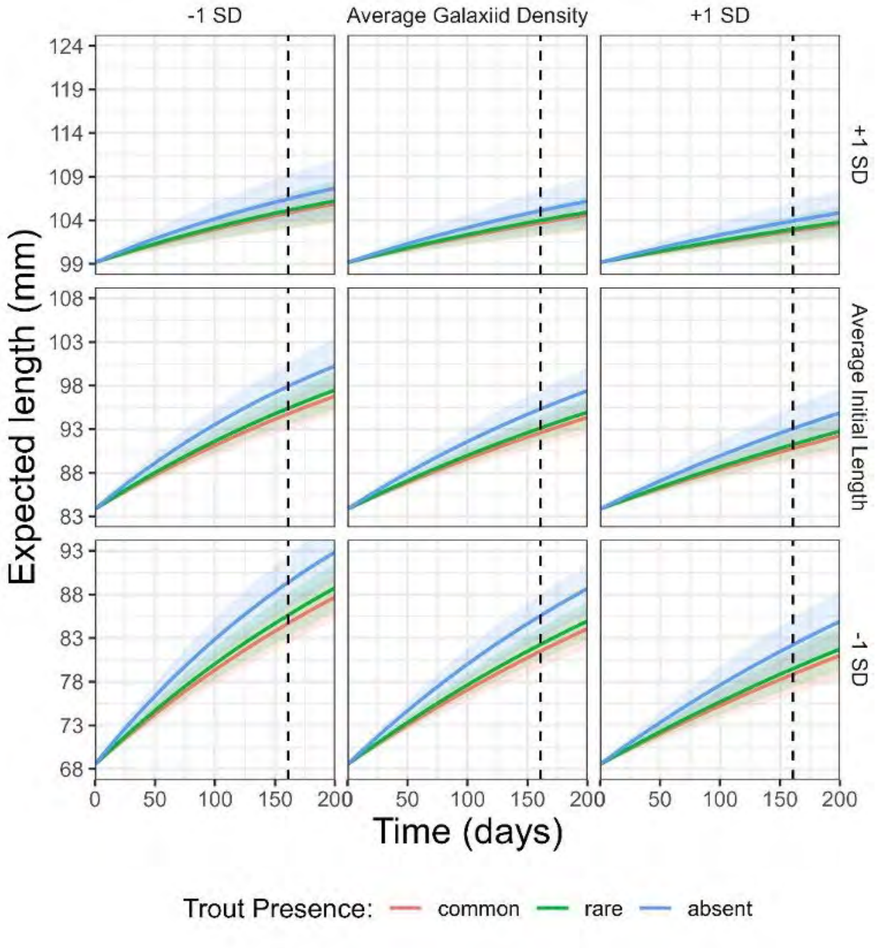
Galaxiids took longer to recover in the presence of trout



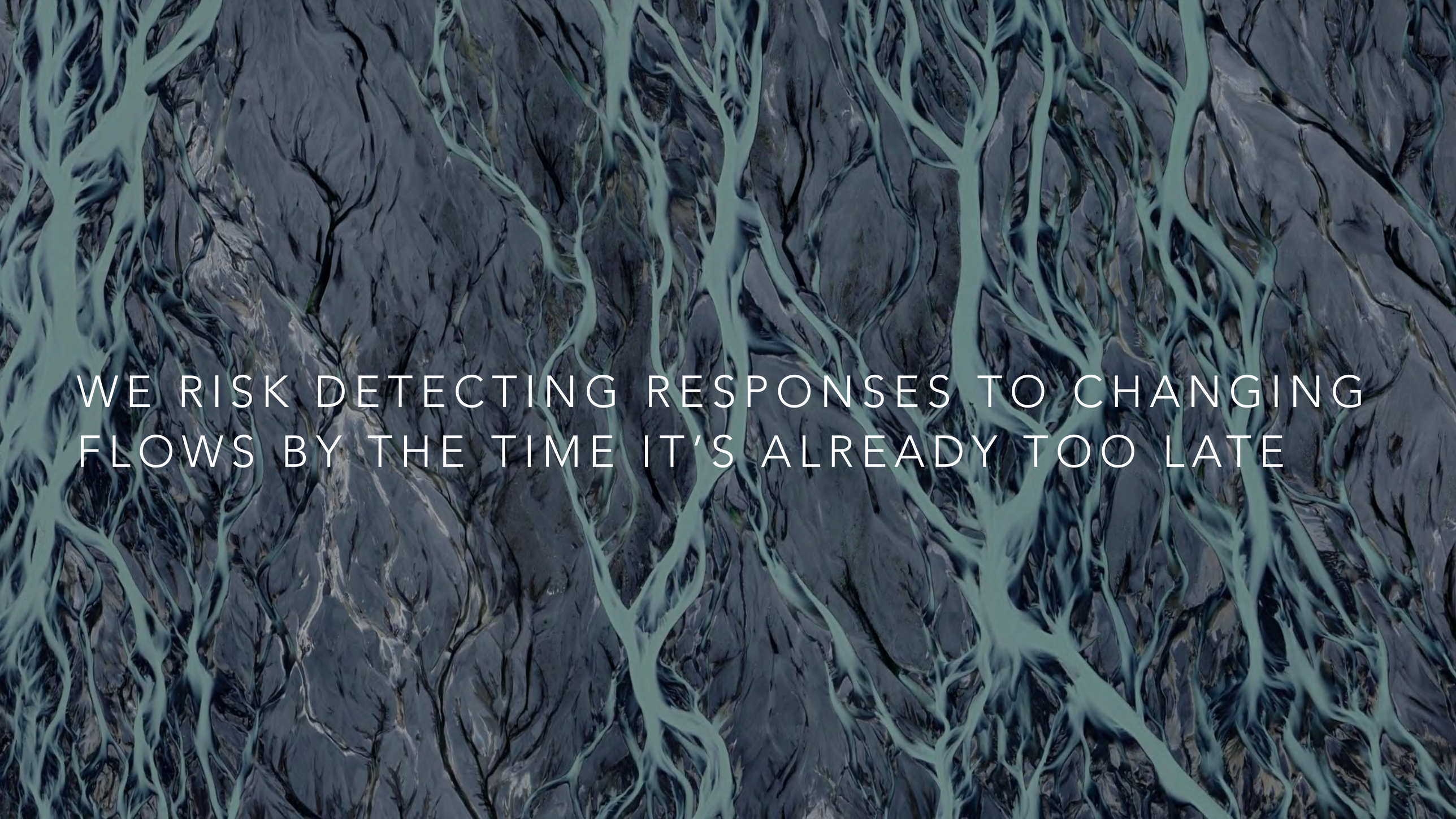
Rory Lennox







Lennox et al. *In review*


WE RISK DETECTING RESPONSES TO CHANGING
FLOWS BY THE TIME IT'S ALREADY TOO LATE

TWO TAKE HOMES

I. We need models to anticipate the full suite of potential impacts and interventions

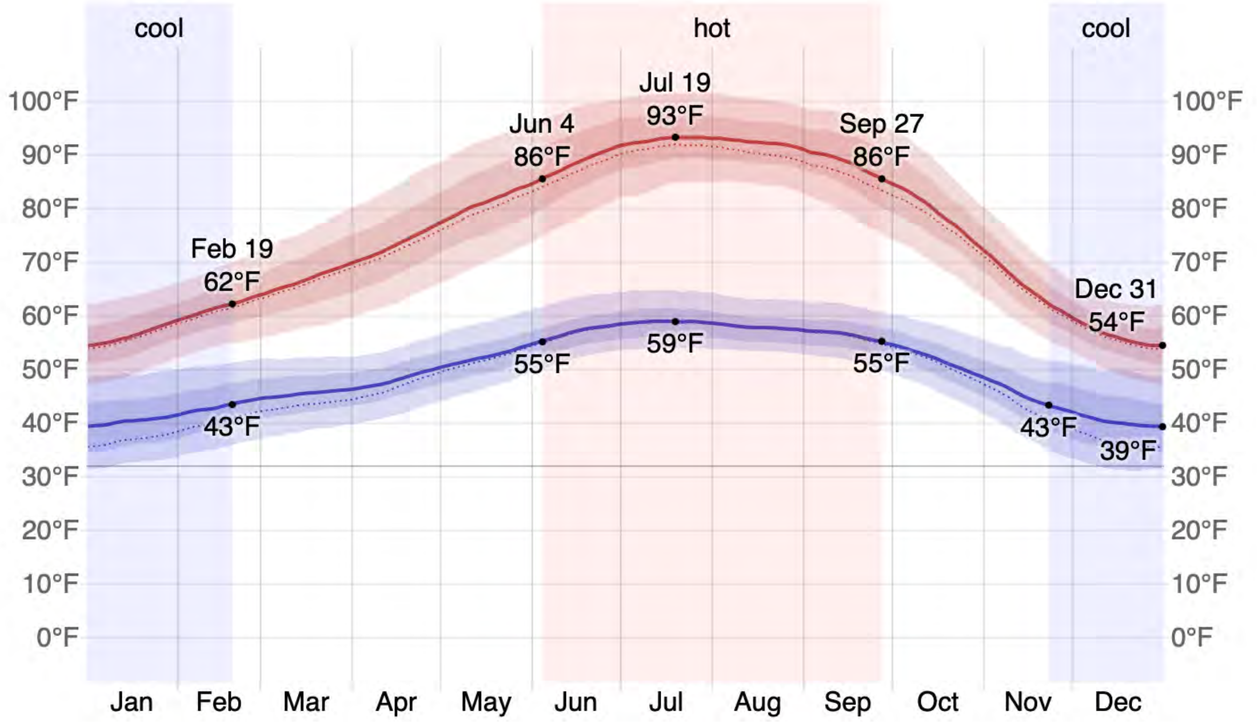
II. Rivers needed to be treated as living systems with space, heterogeneity, and connectivity

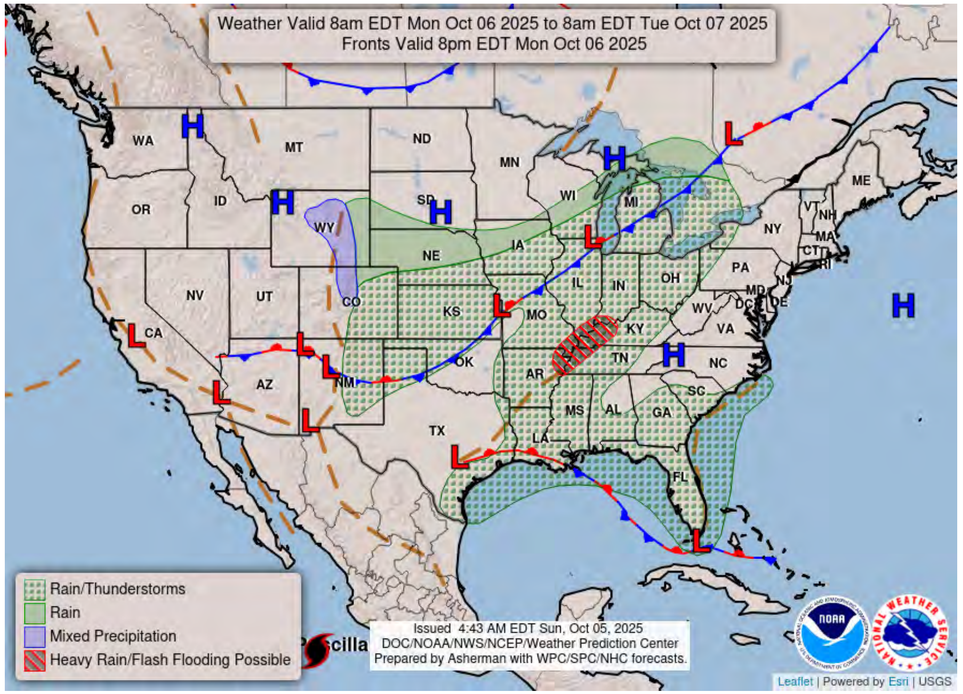


I. MODELS TO ANTICIPATE IMPACTS

PROCESS-BASED MODELS CAN PRODUCE PREDICTIONS THAT FORESHADOW THE NEED TO CHANGE MANAGEMENT LONG BEFORE TRENDS ARE DETECTED IN EMPIRICAL SURVEYS

EVERYDAY DECISIONS NEED FORECASTS…





… SO DO ENVIRONMENTAL DECISIONS

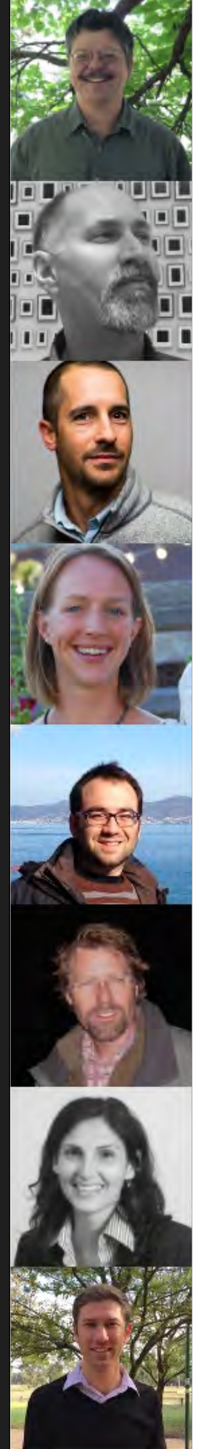
WHAT SORT OF PROCESSES ARE WE TALKING ABOUT?



Gabrielle Koerich



Koerich et al. 2023 *Trends Ecol. Evol.*



FOUR STEPS FOR RIVER SCIENTISTS AND MANAGERS

1. Collect data on mechanisms
2. Describe key processes in models
3. Focus management on bottlenecks
4. Pinpoint uncertainty

Tonkin et al. 2019 *Nature*



Dead fish on the banks of the Guadiaro River in southern Spain during severe drought.

Prepare river ecosystems for an uncertain future

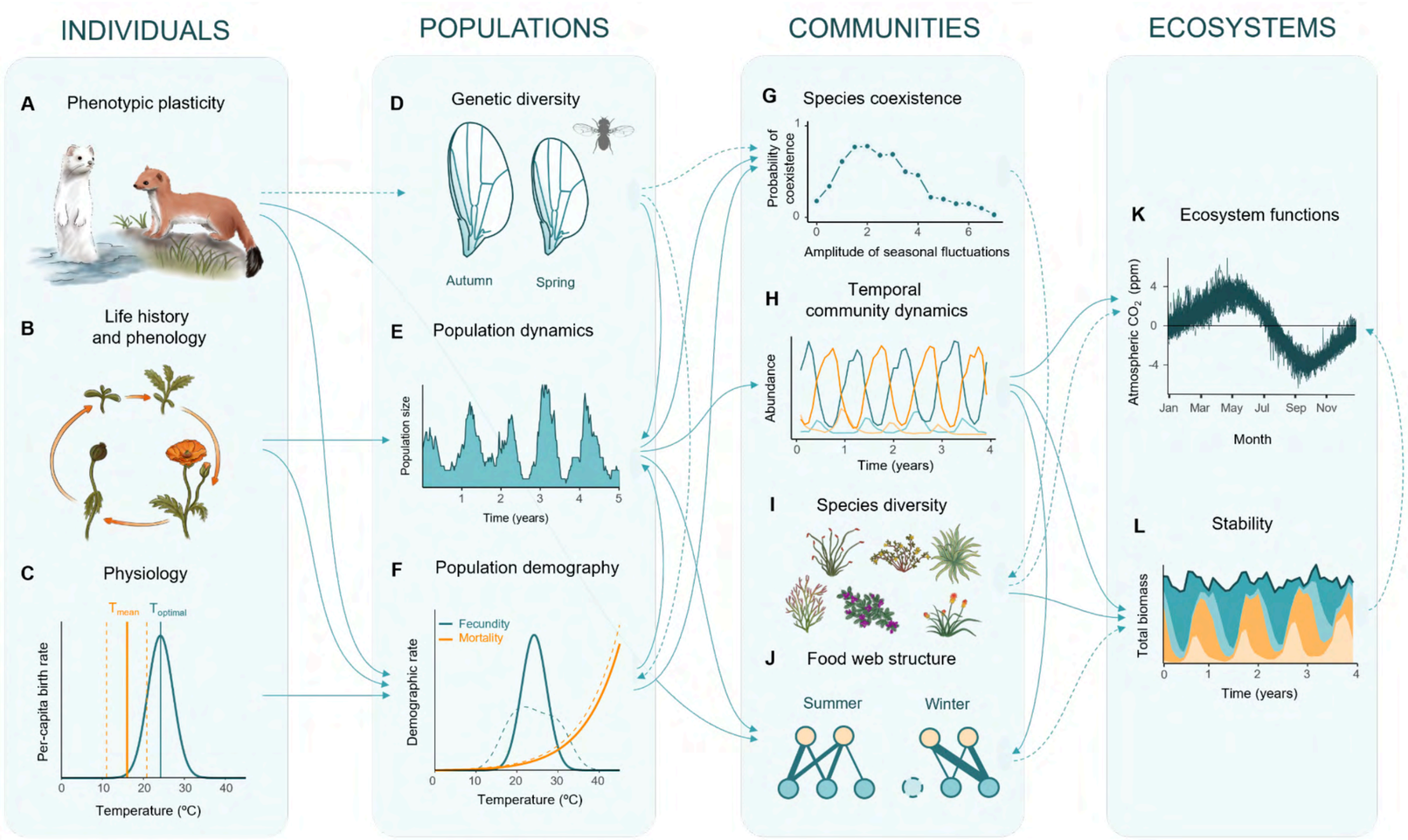
As the climate warms, we can't restore waterways to pristine condition, but models can predict potential changes, argue **Jonathan D. Tonkin**, **N. LeRoy Poff** and colleagues.


CHANGING RHYTHMS

CONSEQUENCES OF CHANGING SEASONALITY



Daniel Hernandez



Hernandez et al. (2025) *Science*

EPT





OCH

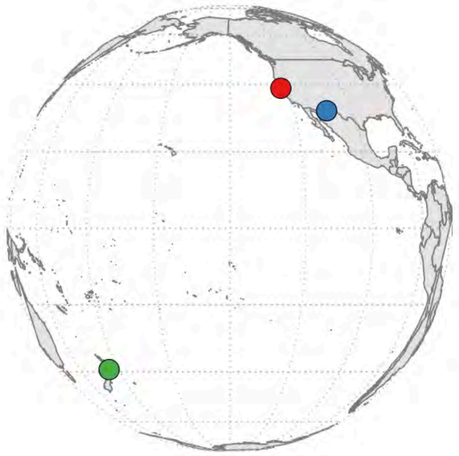




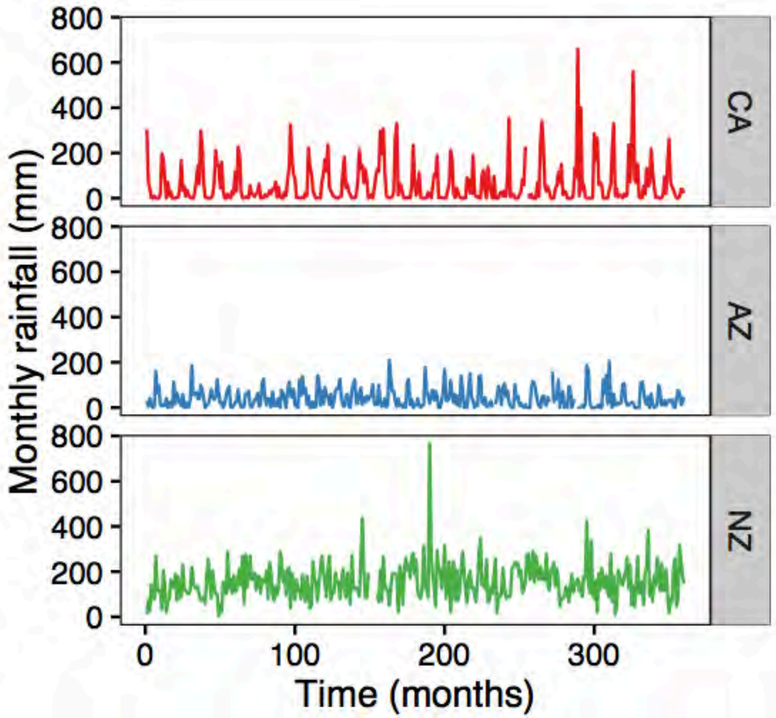


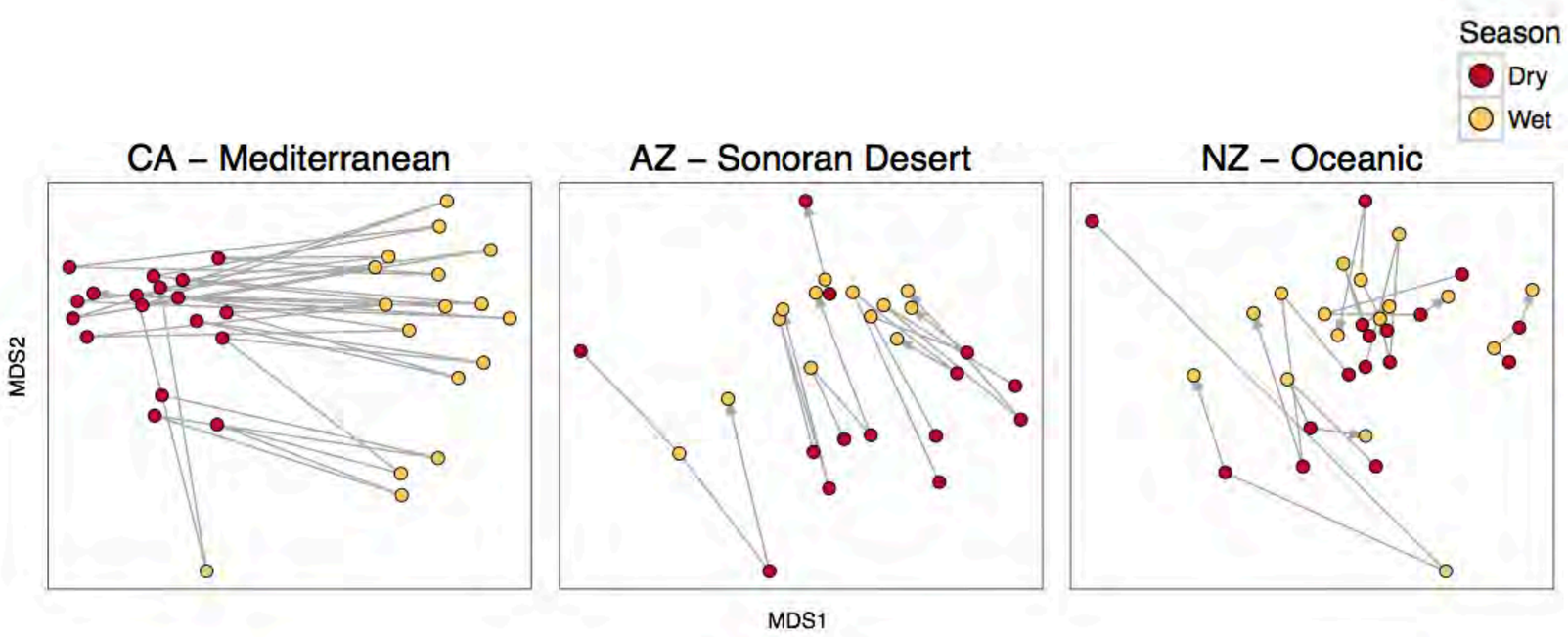


INVERTEBRATE COMMUNITIES BETWEEN SEASONS



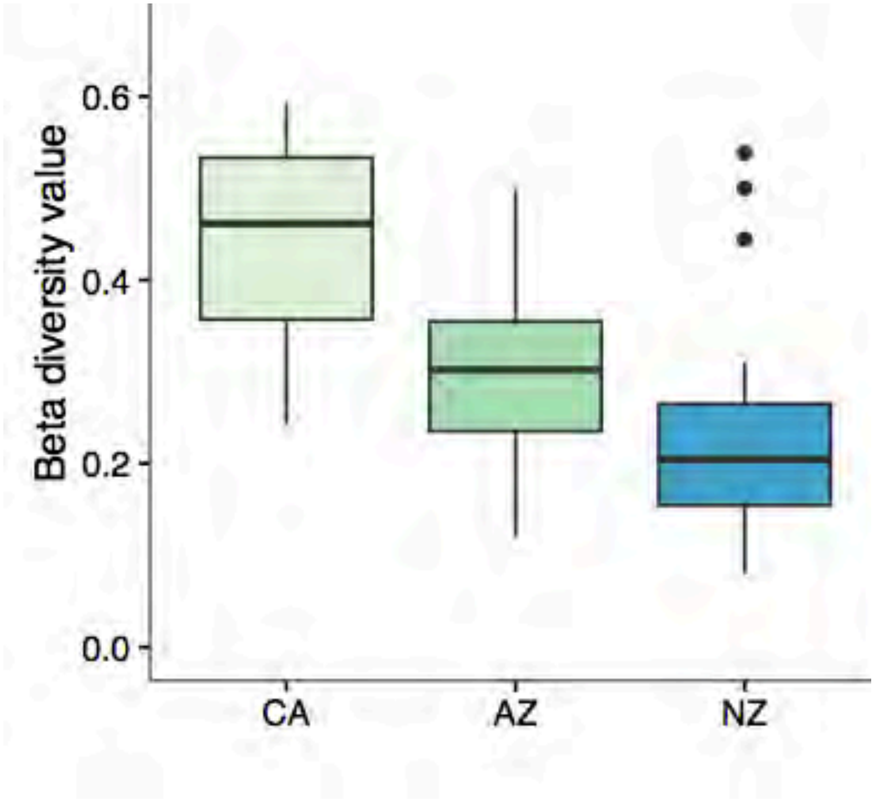
California: Mediterranean
Arizona: Sonoran Desert
New Zealand: Maritime

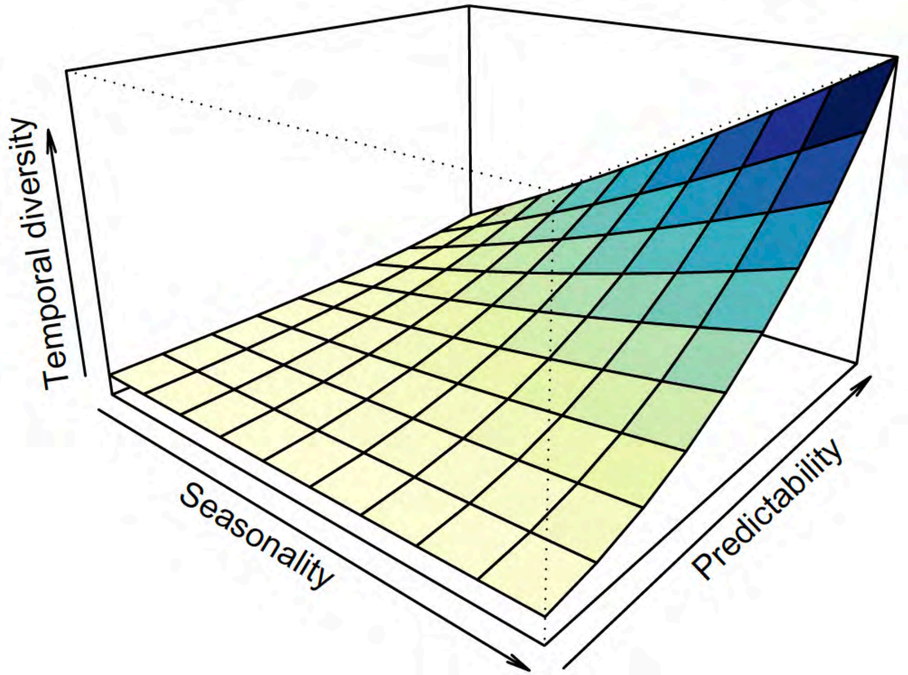




Tonkin et al. 2017 *Ecology*

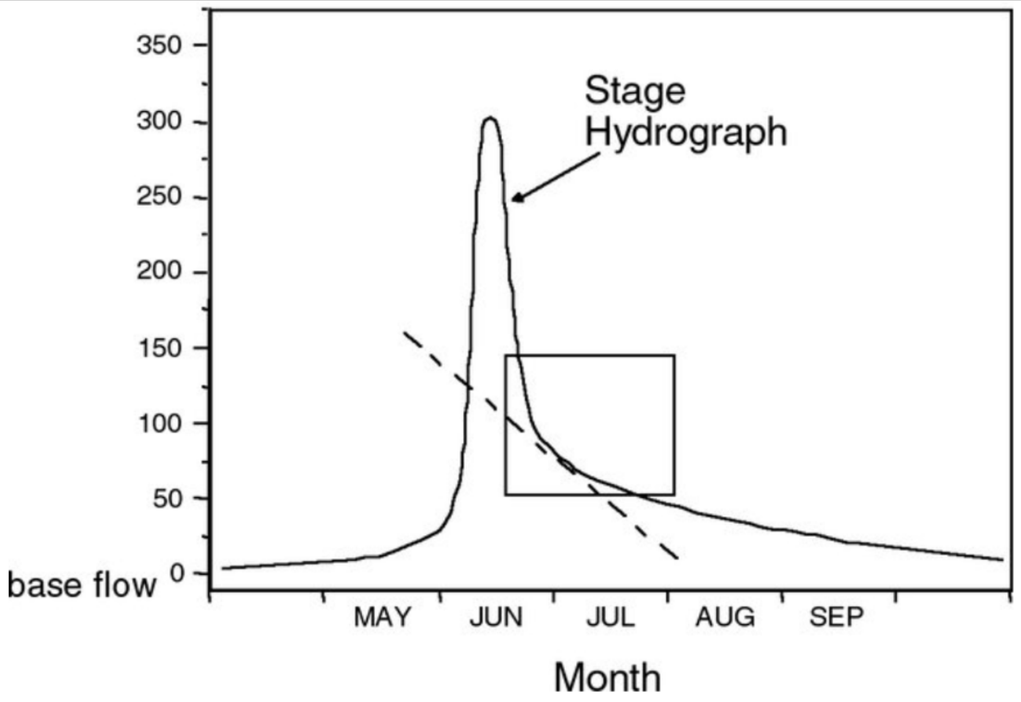
TEMPORAL DIVERSITY IS MAXIMISED IN **PREDICTABLY** SEASONAL ENVIRONMENTS





Tonkin et al. 2017 *Ecology*

RECRUITMENT BOX MODEL AS AN EXAMPLE



Mahoney & Rood (1998) *Wetlands*





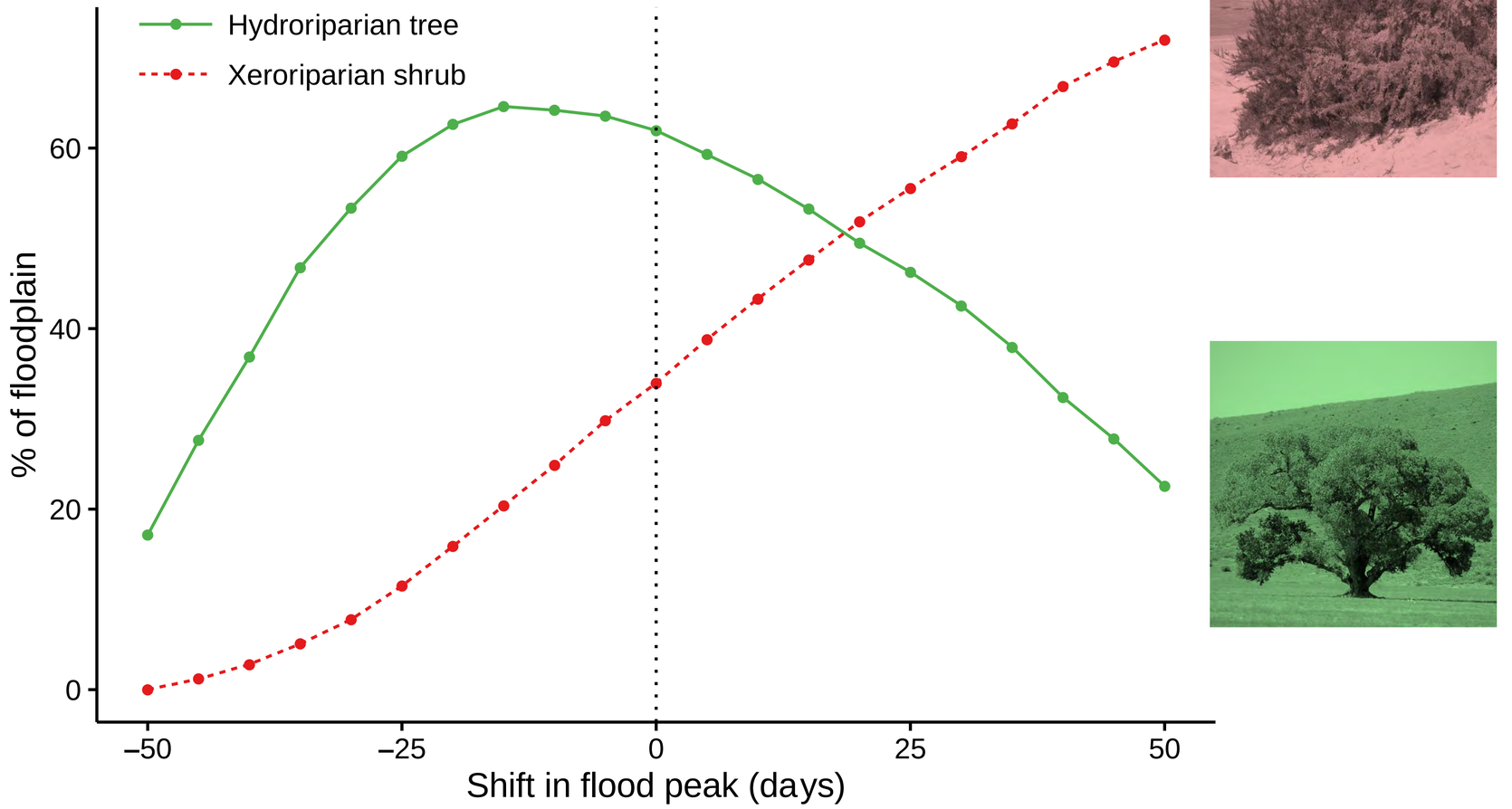
NATIVE COTTONWOODS BEING DISPLACED BY NON-NATIVE SALT CEDAR IN THE DOLORES RIVER, UTAH, OWING TO FLOW ALTERATION BY DAMMING

NON-NATIVE WINS WITH LATER FLOODS

Once we know the mechanisms in a multi-species model, we can tailor regimes



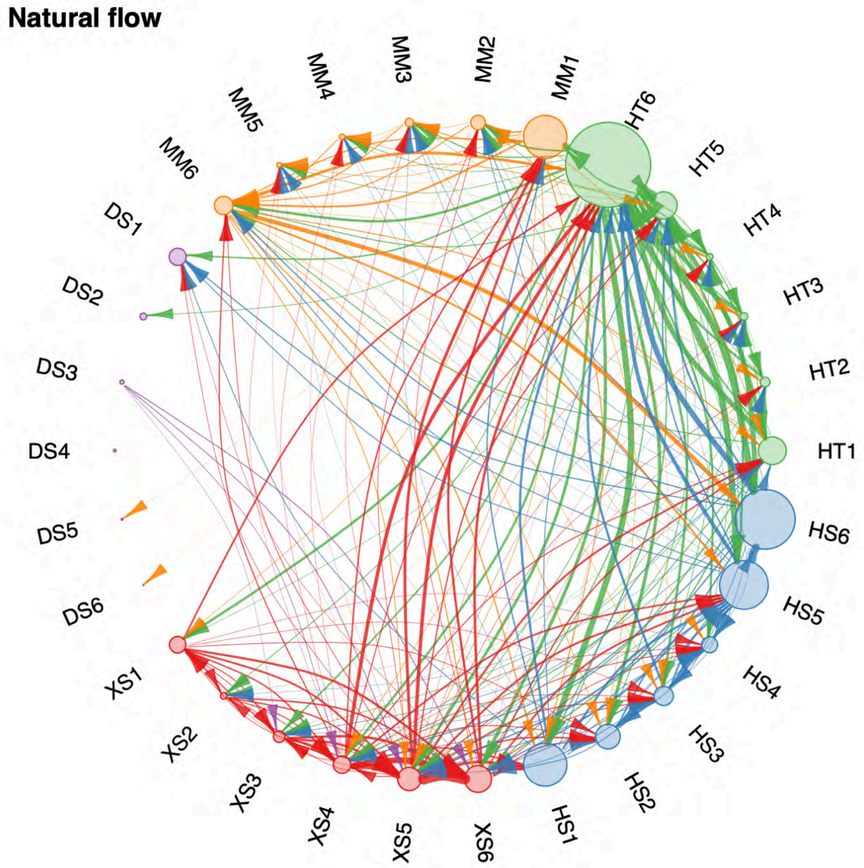
Dave Lytle

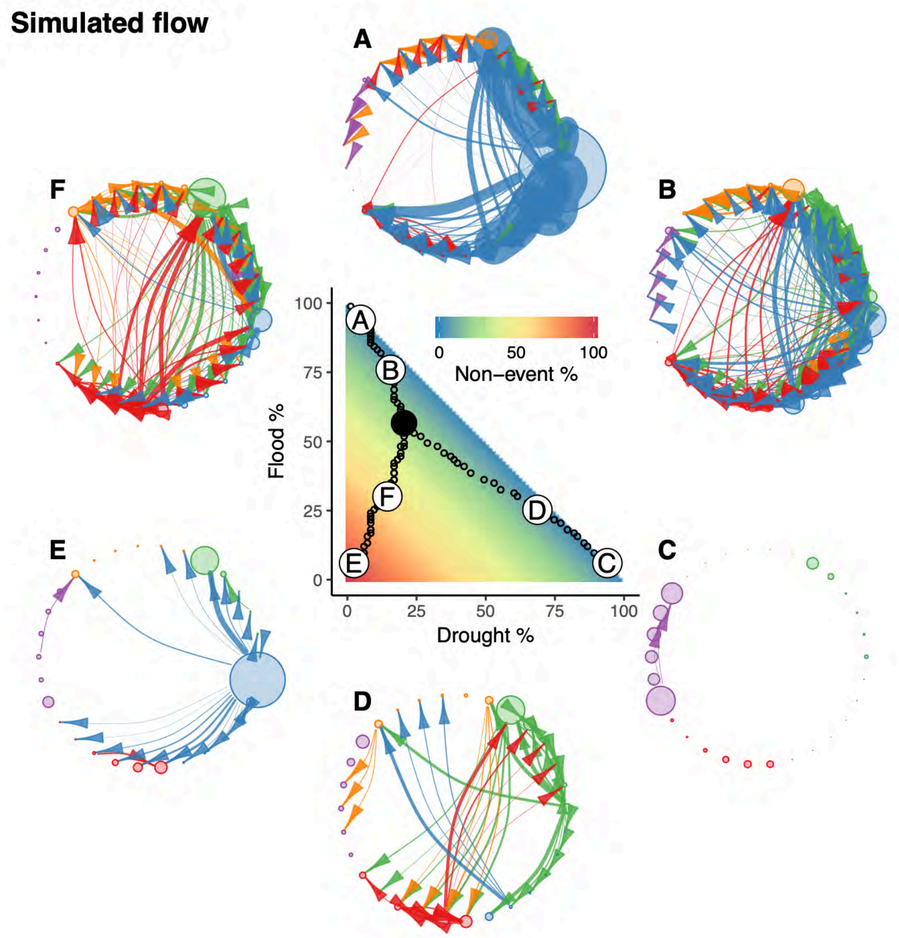


Lytle et al. 2017 *Ecol. Appl.*

NETWORKS UNRAVEL WITH FLOW CHANGE

Predicting the full consequences





1 = seedlings … 6 = adults







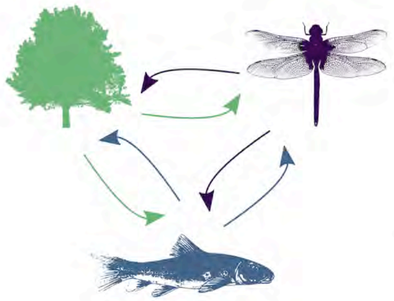




Tonkin et al. 2018 *Nature Eco. Evo.*

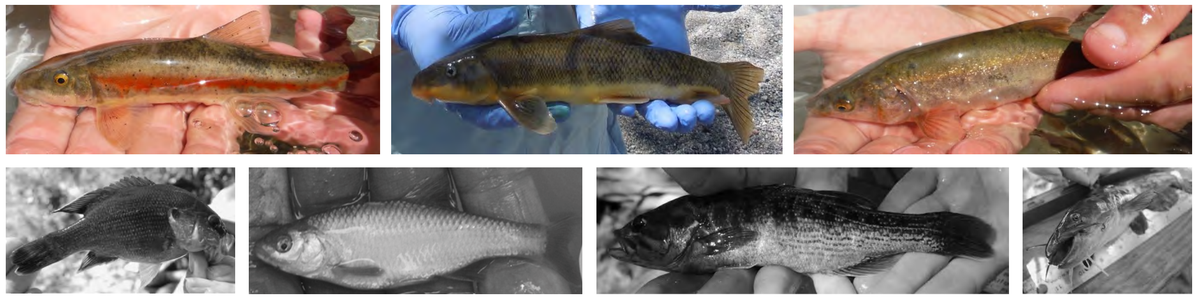
SPECIES EXPERIENCE THE SAME RIVER DIFFERENTLY

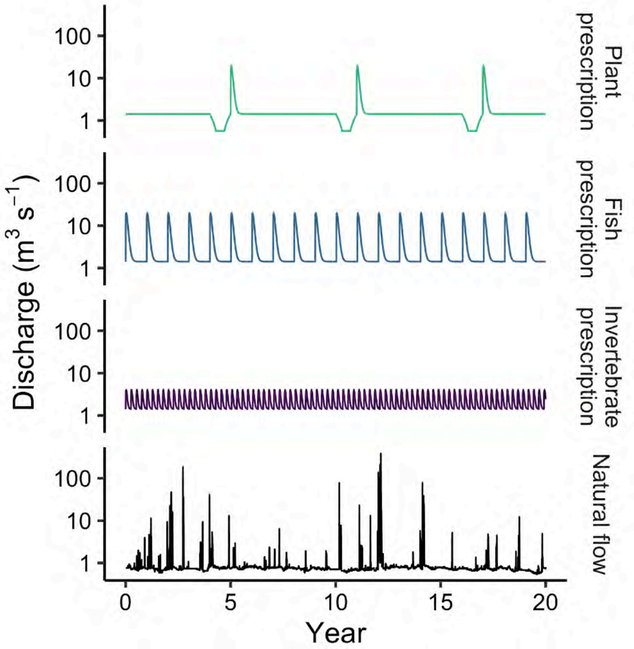
Ecosystem-wide consequences of targeted flow management

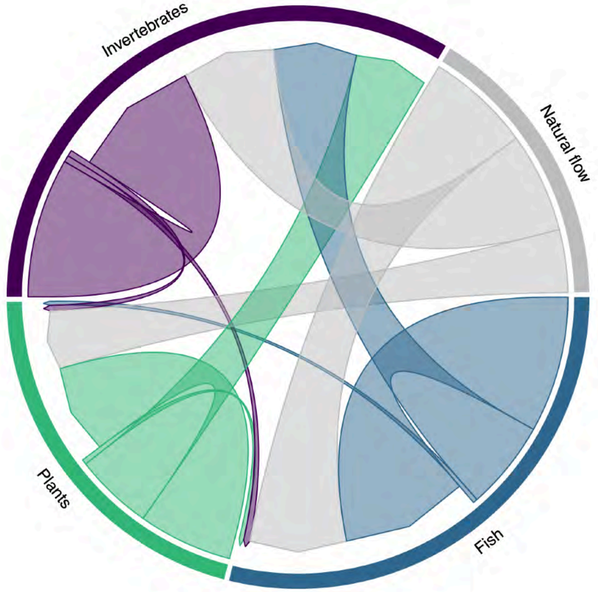










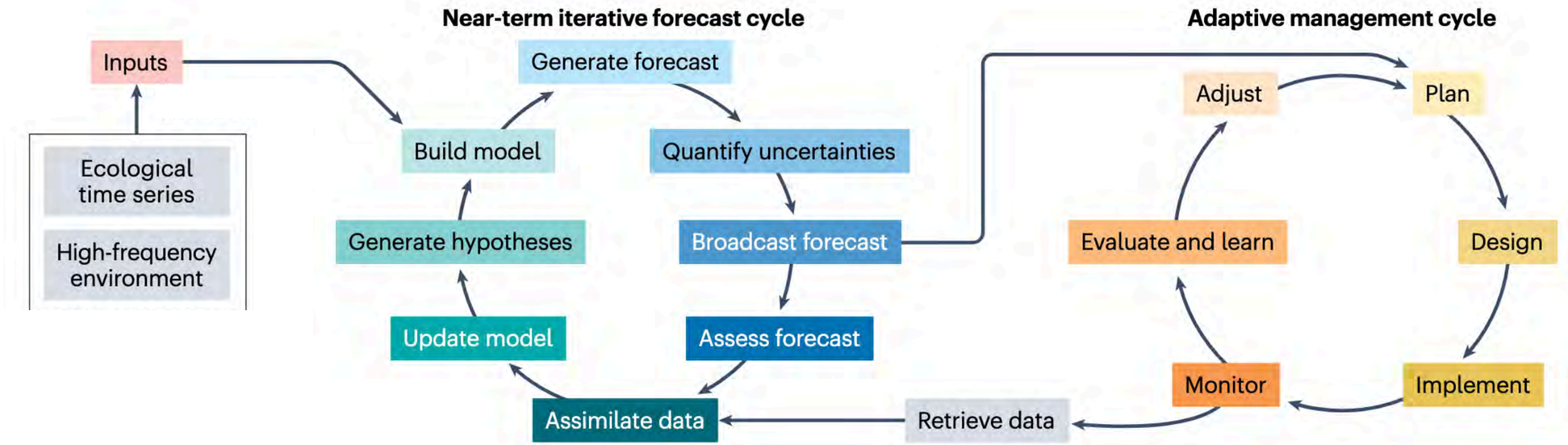


Based on processes collected from basic natural history work

— allows looking beyond the past

Tonkin et al. 2021 *Fron. Ecol. Environ.*

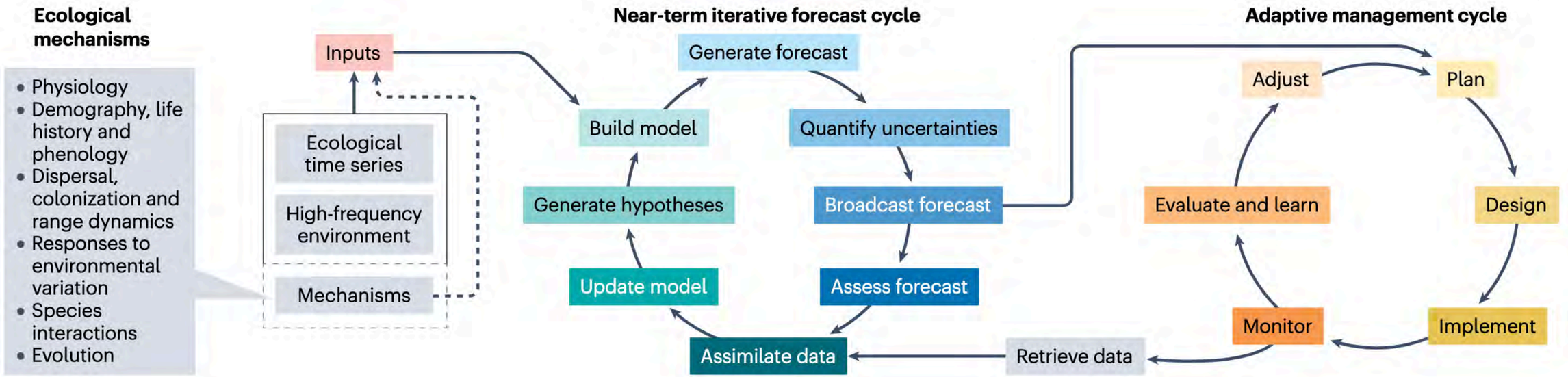
PUTTING IT ALL TOGETHER IN A COUPLED CYCLE



Tonkin et al. (2026) *Nature Reviews Biodiversity*

PUTTING IT ALL TOGETHER IN A COUPLED CYCLE

Iterative approaches are key for understanding and managing extremes, but embedding mechanisms will improve accuracy, given the rarity of extremes



Tonkin et al. (2026) *Nature Reviews Biodiversity*



BUILDING RESILIENCE



II. RIVERS NEED ROOM TO MOVE



DEATH BY A THOUSAND CUTS


WAIMAKARIRI RIVER, 1950s


TODAY

WE'VE OCCUPIED PLACES WHERE RIVERS FLOOD



WE'RE SEEING A PATTERN

Latest Local News Live Shows ... CBS NEWS

WORLD

Spain's worst floods in a century hit Valencia region, killing at and leaving others missing

By Chris Livesay, Tucker Reals
Updated on: October 31, 2024 / 2:43 PM EDT / CBS News



newsroom.

ENVIRONMENT

NZ on the cusp of a rivers revolution

We've been fighting nature for years. Given climate change, it's high time to let rivers roam. David Williams reports.

"Jonathan Tonkin [...] says from an ecological standpoint, the more space you give a braided river, the more naturally it functions."

cals fed up with nstant storms

Share this

nt hammering of bad weather - with at least five storms in the g off communities.



"COMMAND-AND-CONTROL" IS BEGINNING TO MAKE WAY FOR GIVING RIVERS ROOM FOR FLOOD RISK MANAGEMENT...

...BUT WE'VE OVERLOOKED THE ECOLOGICAL CO-BENEFITS

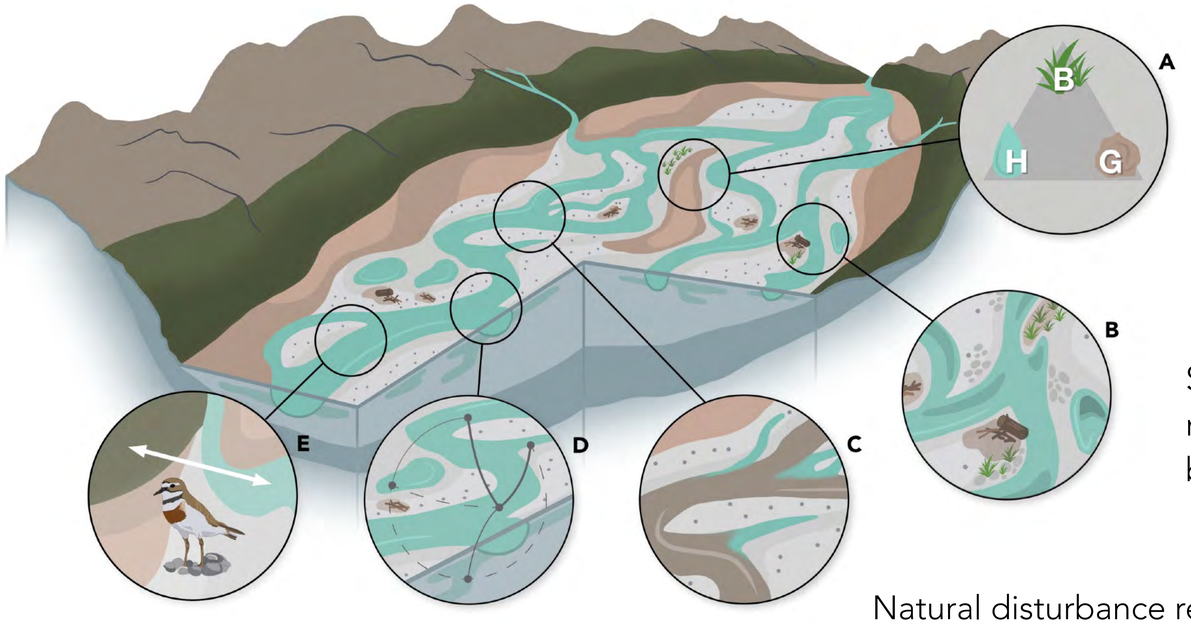


ECOLOGICAL BENEFITS OF GIVING RIVERS ROOM

Naturally functioning rivers are variable in space and time



Christina McCabe



Dynamic balance between the drivers of channel morphology (B: biology, G: geology, and H: hydrology)

Spatiotemporally variable habitat mosaic promotes regional biodiversity

Natural disturbance regime maintains a complex habitat mosaic and affects habitats asynchronously

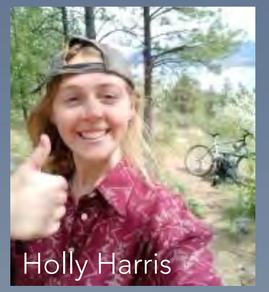
Functioning aquatic-terrestrial interface connects river to a wider meta-ecosystem

Variable hydrologic connectivity between patches modulates community assembly & maintains movement through the system

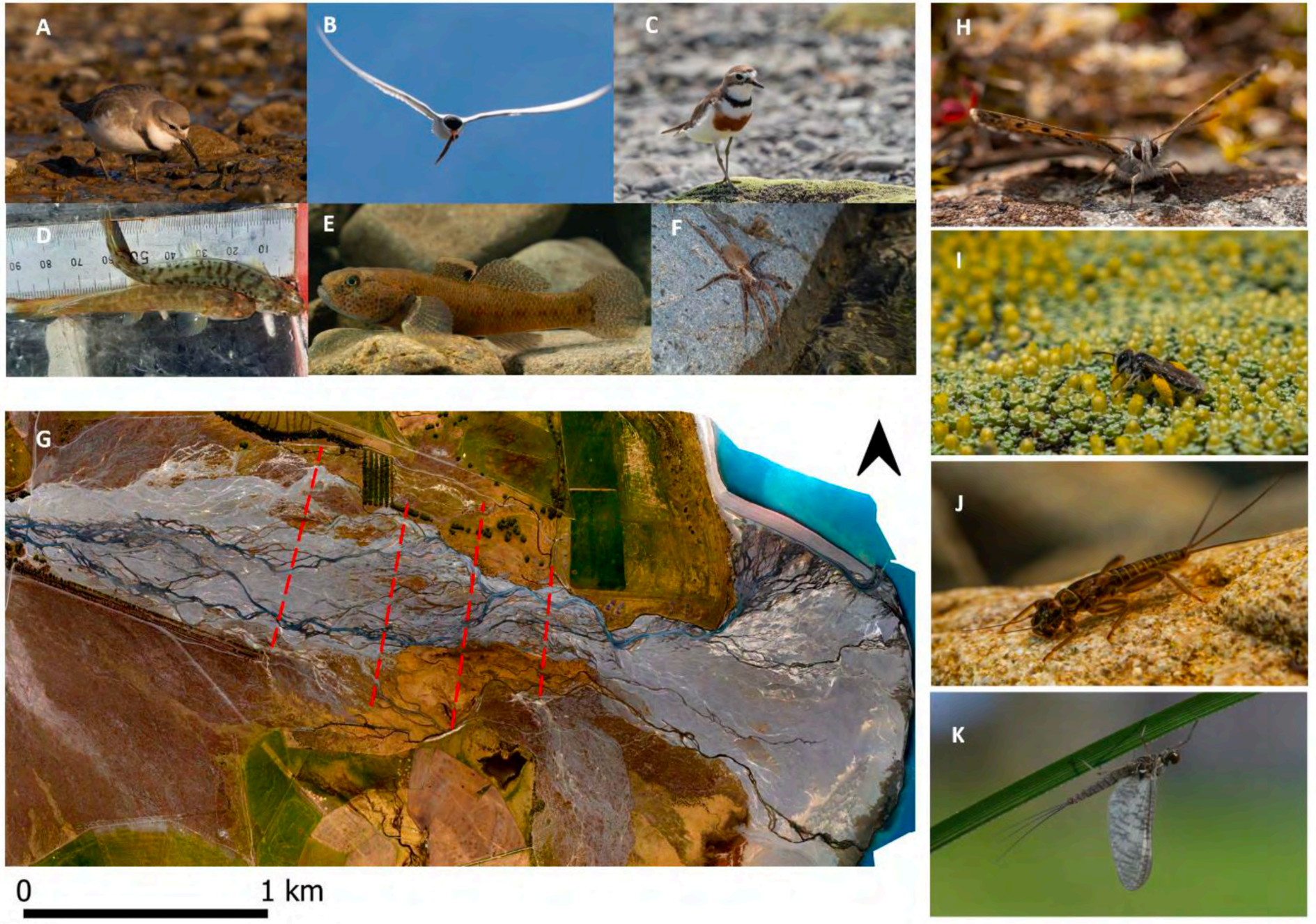
McCabe et al. (2025) *Nature Water*

WHAT A NATURALLY FUNCTIONING RIVER LOOKS LIKE

Trophic connections and food-web structure in the Cass River, Tekapo







Harris et al. (2025) *NZ J. Ecology*

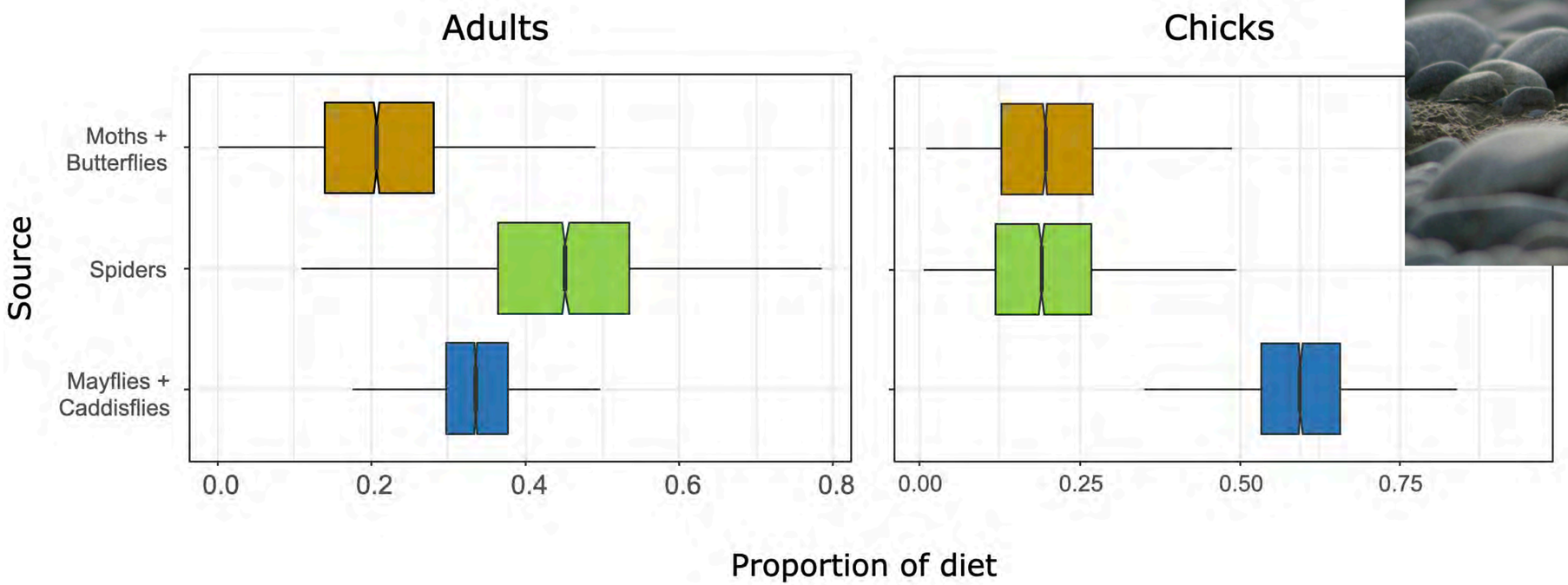
AQUATIC AND TERRESTRIAL DIETARY PROPORTIONS OF BANDED DOTTEREL VARY BETWEEN ADULTS AND CHICKS

Stable isotope analysis of diet



Holly Harris





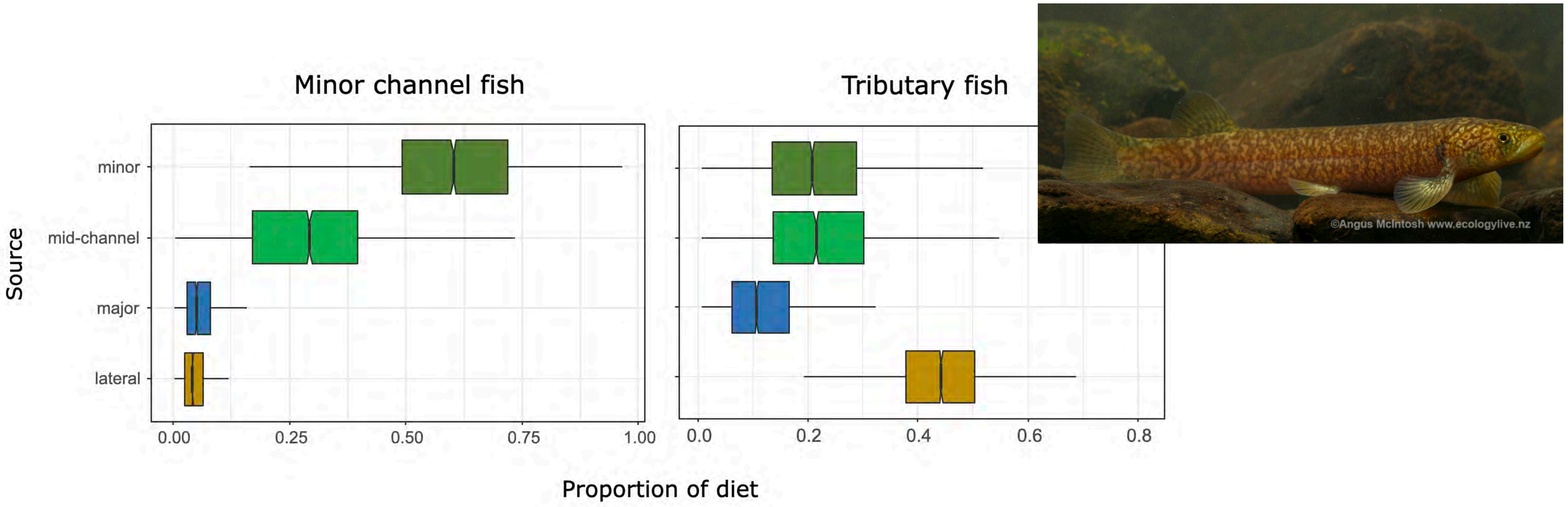
Harris et al. 2026 *Ecology*

DIETARY PROPORTIONS OF KŌARO VARY SPATIALLY

Very little sustenance from major braids



Holly Harris



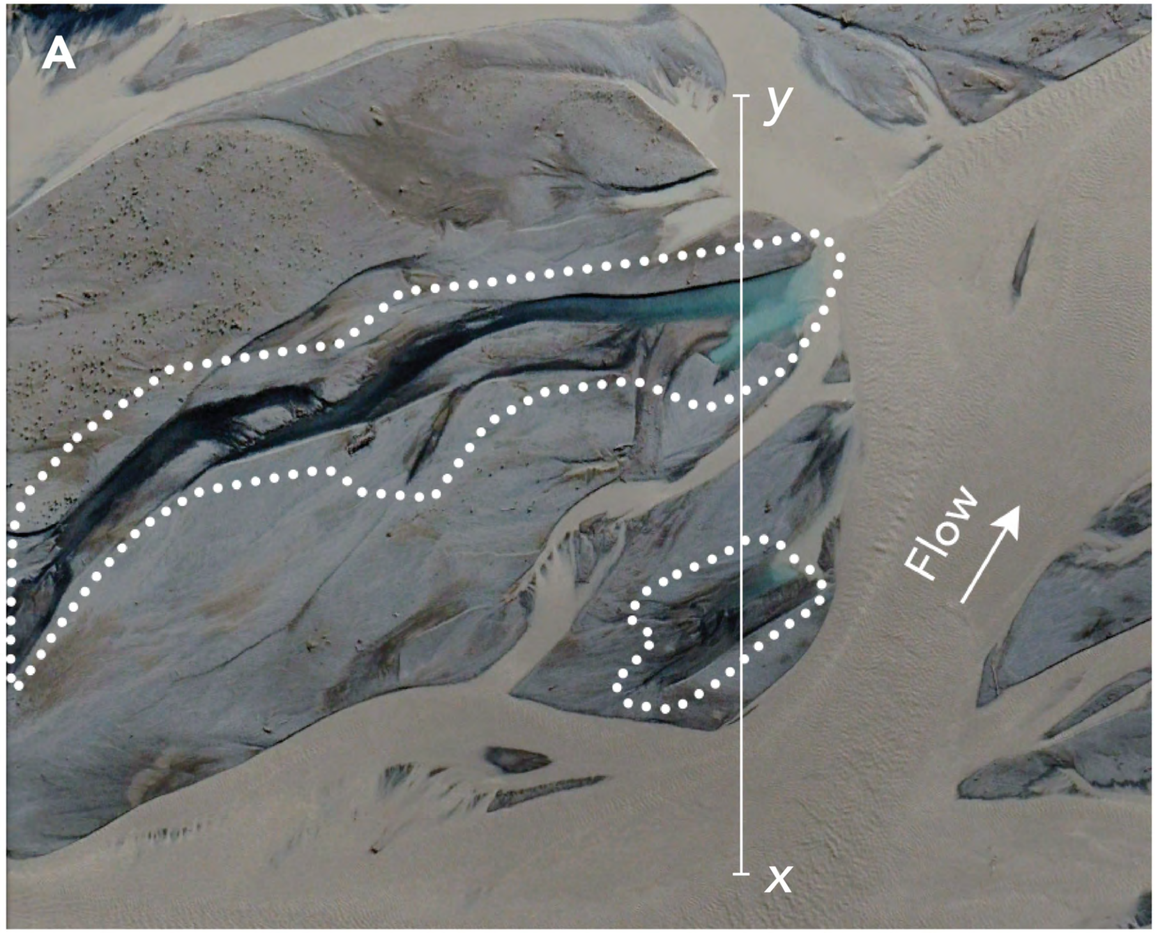
Harris et al. 2026 *Ecology*

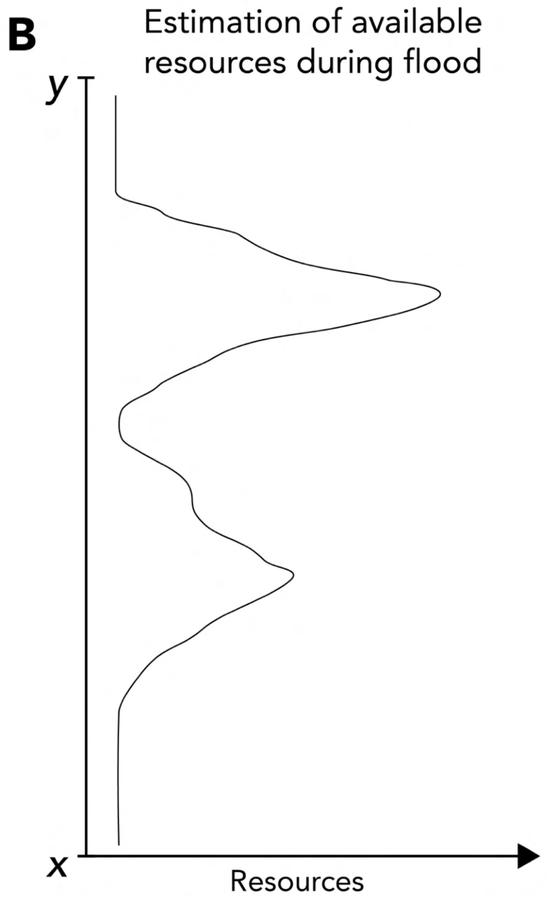
HETEROGENEOUS HABITATS ARE MORE LIKELY TO INCLUDE REFUGES

Providing resistance from and resources during disturbances



Christina McCabe





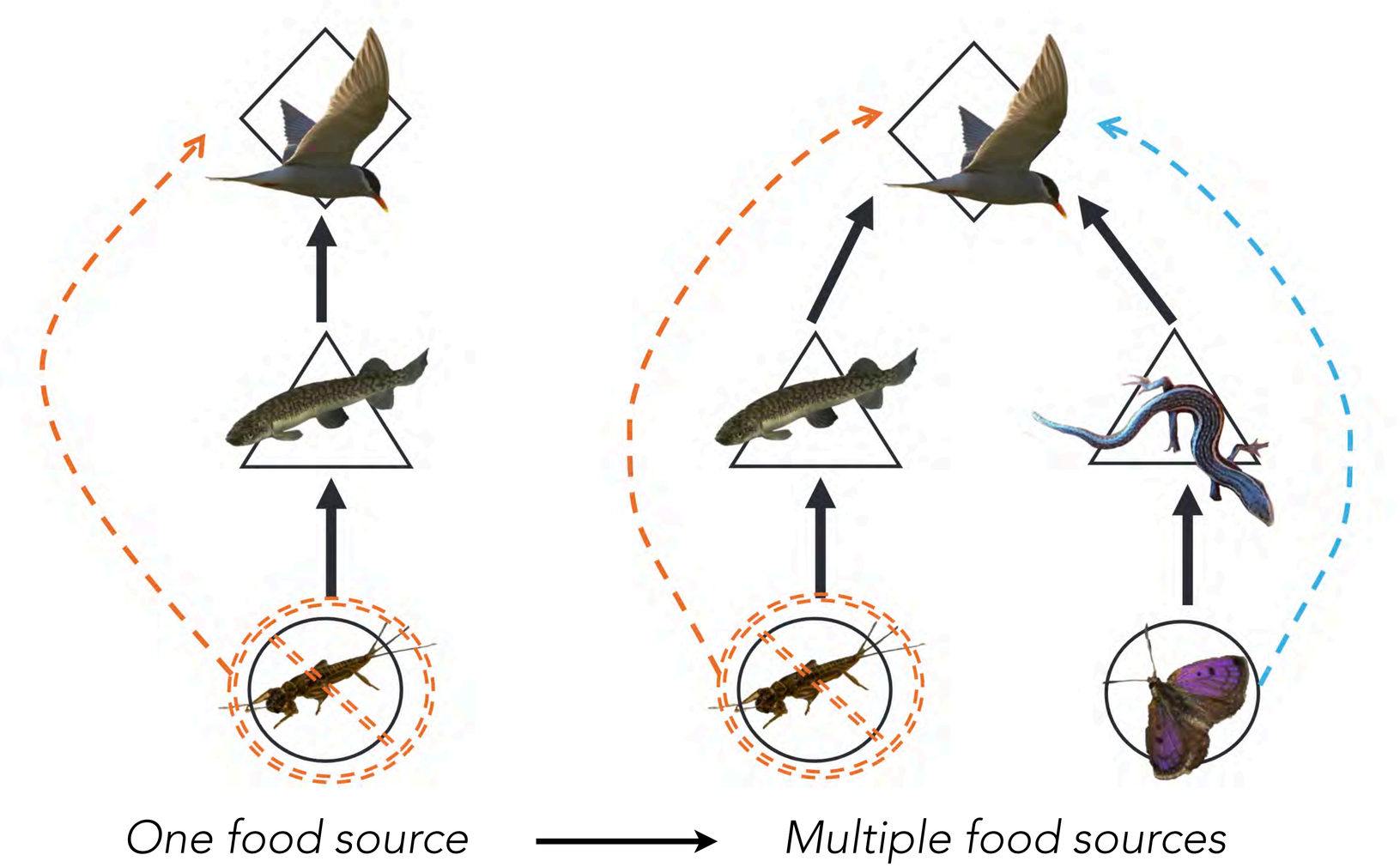
McCabe et al. (2025) *Nature Water*

ROOM TO MOVE PROVIDES RESILIENCE

Predators have access to multiple food sources



Holly Harris



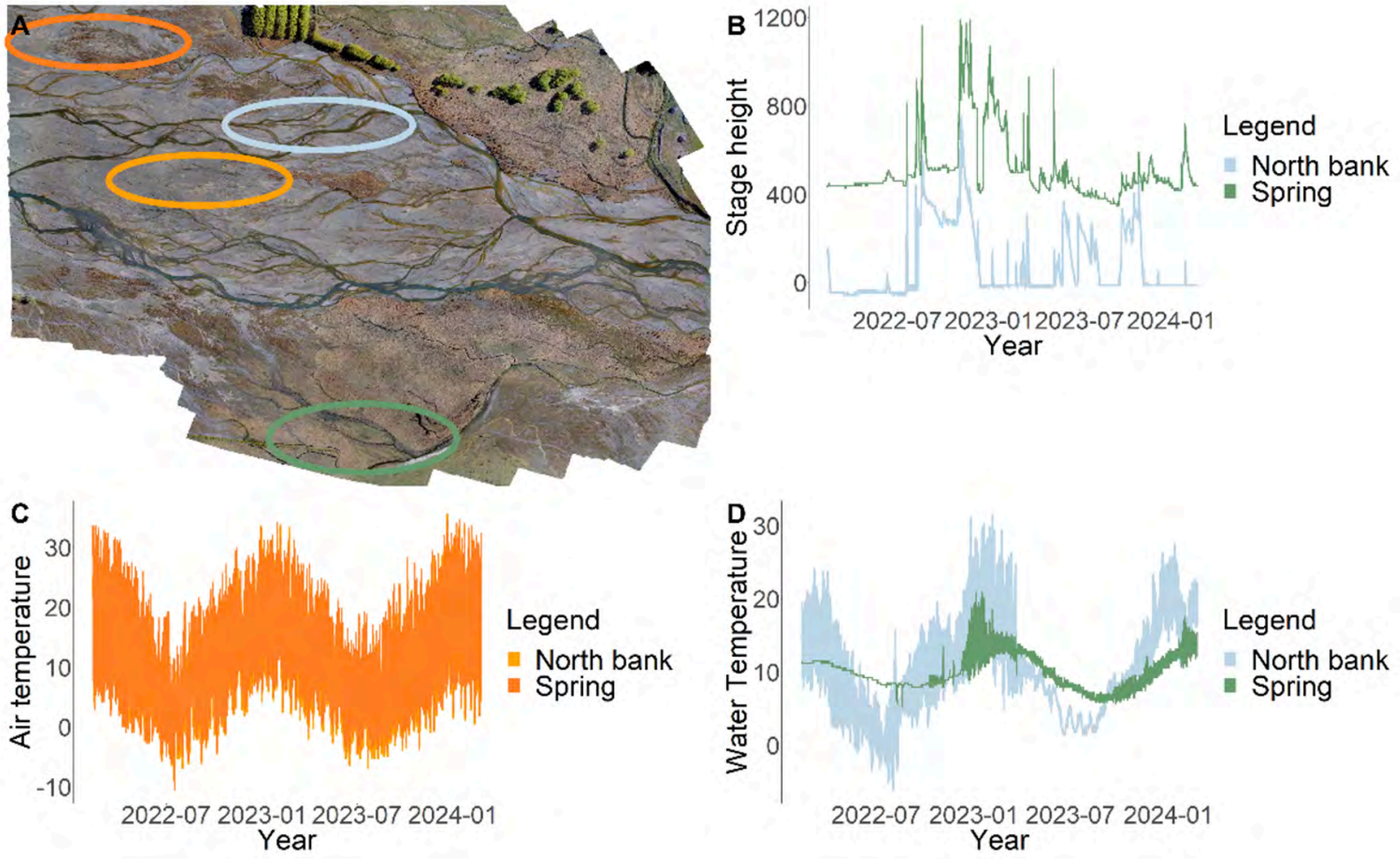
Harris et al. (2025) *NZ J. Ecology*

ROOM TO MOVE DAMPENS TEMPORAL VARIABILITY

Physical heterogeneity sets the stage



Holly Harris



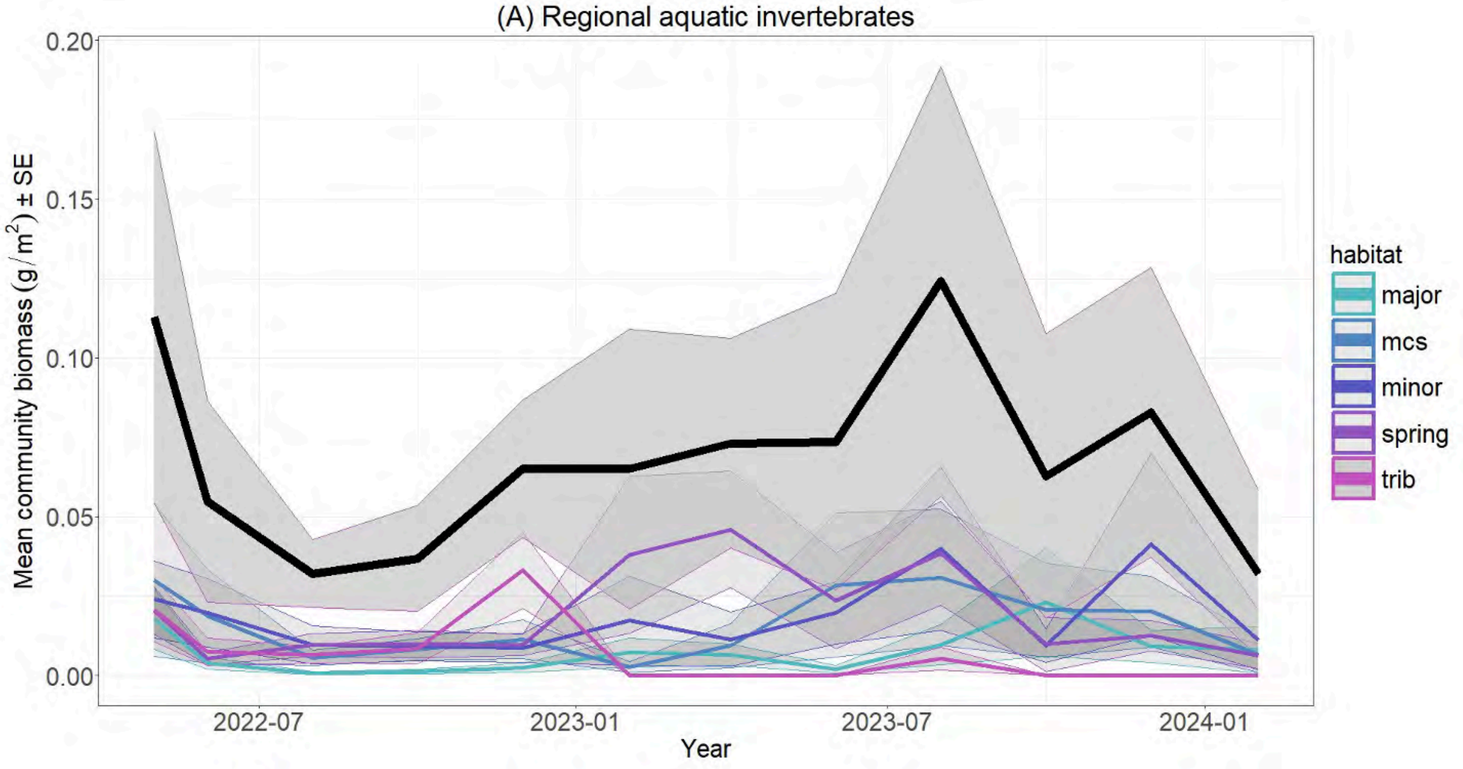
Harris et al. 2026 *Oikos*

ROOM TO MOVE DAMPENS TEMPORAL VARIABILITY

Metacommunity variability is dampened by patch asynchrony



Holly Harris



Similar results for fish and terrestrial invertebrates

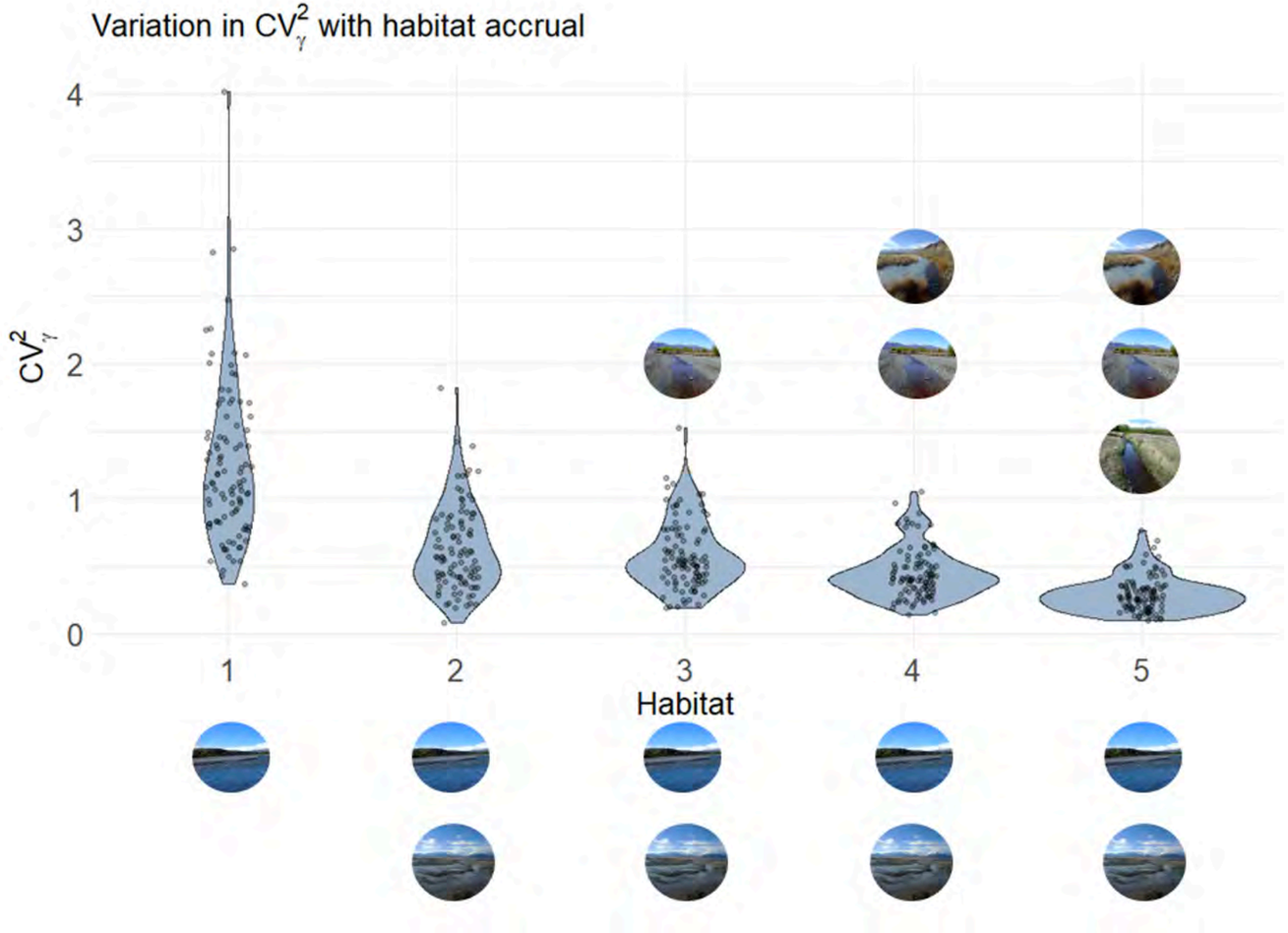
Harris et al. 2026 *Oikos*

ROOM TO MOVE DAMPENS TEMPORAL VARIABILITY

Simply adding different habitats dampens regional variability



Holly Harris



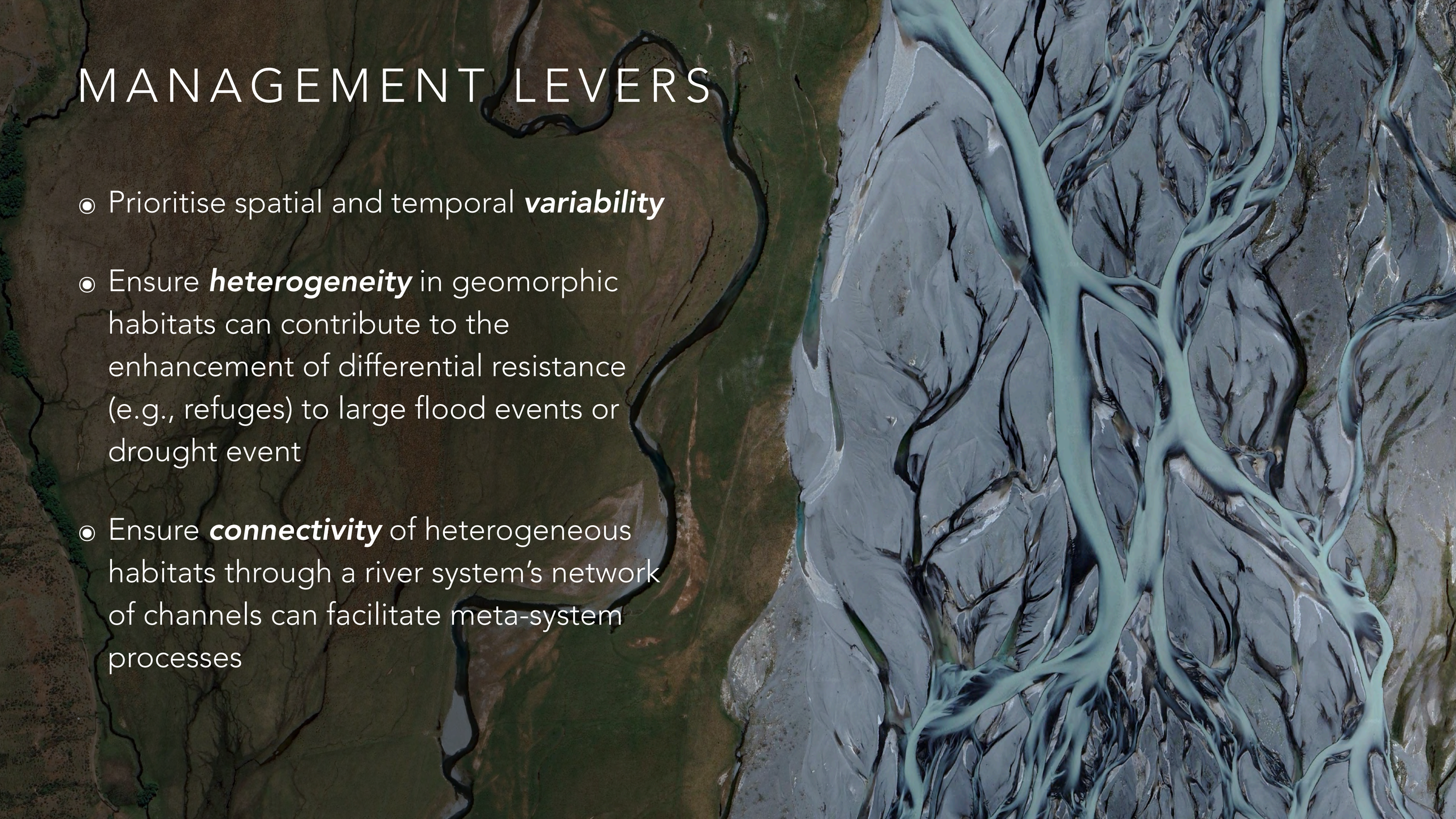
Harris et al. 2026 *Oikos*

RIVERS WITH ROOM ARE RESILIENT

- Rivers with space to roam support diverse assemblages and resilience to extremes
- Encroaching on rivers threatens resilience
- To support full life cycle, all habitats are required
- Heterogeneity is stabilising

MANAGEMENT LEVERS

- Prioritise spatial and temporal ***variability***
- Ensure ***heterogeneity*** in geomorphic habitats can contribute to the enhancement of differential resistance (e.g., refuges) to large flood events or drought event
- Ensure ***connectivity*** of heterogeneous habitats through a river system's network of channels can facilitate meta-system processes



PROVIDING CATCHMENT RESILIENCE TO EXTREMES

A typology of river settings that differ in the potential to provide catchment resilience to extreme climatic events

River setting	Context	Native biodiversity potential	Feature	Management action (RAD)	Outcome
Free-flowing stream or river	Connected to larger free-flowing river	High	Well-connected catchment with presumably high resilience (variability and heterogeneity)	Resist changes in land cover management at the catchment scale to maintain natural flow (discharge), sediment, temperature processes and connectivity	Maintains catchment resilience and high beta and gamma diversity
Tributary to stream or river impounded downstream	Tributaries to a river that itself is impounded by a nearby downstream dam	Medium	Limited connectivity in catchment interrupted by a downstream dam. Might not help migratory species that cannot pass dam and impounded river	Resist degradation of free-flowing tributaries in catchment, assist in re-establishing connectivity above impounded river. High priority catchments might hold unique biodiversity	Maintains high beta and gamma diversity and supports system resilience through variability, heterogeneity and connectivity
Tributary to stream or river impounded upstream	Tributaries that flow into regulated river (that is, one impounded by a nearby upstream dam)	Medium	Set of potentially unconnected tributaries, but habitat potentially accessible to downstream migratory species. Natural flow regime entering modified mainstem	Protect undammed tributaries to dammed river (that is, those flowing into regulated river)	Helps to support beta diversity of system, and protects native species and resilience through supporting colonists
Isolated stream or river	Regulated river (that is, one downstream of dam that modifies flow, sediment, temperature and connectivity)	Medium-low	Single, linear habitat that is disconnected from catchment-scale meta-processes	Direct management of environmental flow and/or thermal (for example, cold water) releases from reservoir for key species	Provides improved flow and temperature regimes that support alpha diversity in regulated river
Isolated stream or river hydrologically disconnected from other streams	Affected river (that is, one that flows through a highly urbanized catchment)	Low	Disconnected from meta-processes and thus low resilience	Accept that system cannot be managed towards a more resilient state to support biodiversity	May offer limited opportunities to support biodiversity

RAD, resist–accept–direct.

Tonkin et al. (2026) *Nature Reviews Biodiversity*



NEW HORIZONS

In addition to anticipatory approaches

High-resolution, high-frequency monitoring programmes

Continued and coordinated long-term research programmes

Broaden understanding of compound events

Enhance knowledge of legacy effects

Study biophysical feedbacks

Tonkin et al. (2026) *Nature Reviews Biodiversity*

SUMMARY

Extreme events are reshaping river biodiversity

- from populations to ecosystems

The impacts are often indirect and context dependent

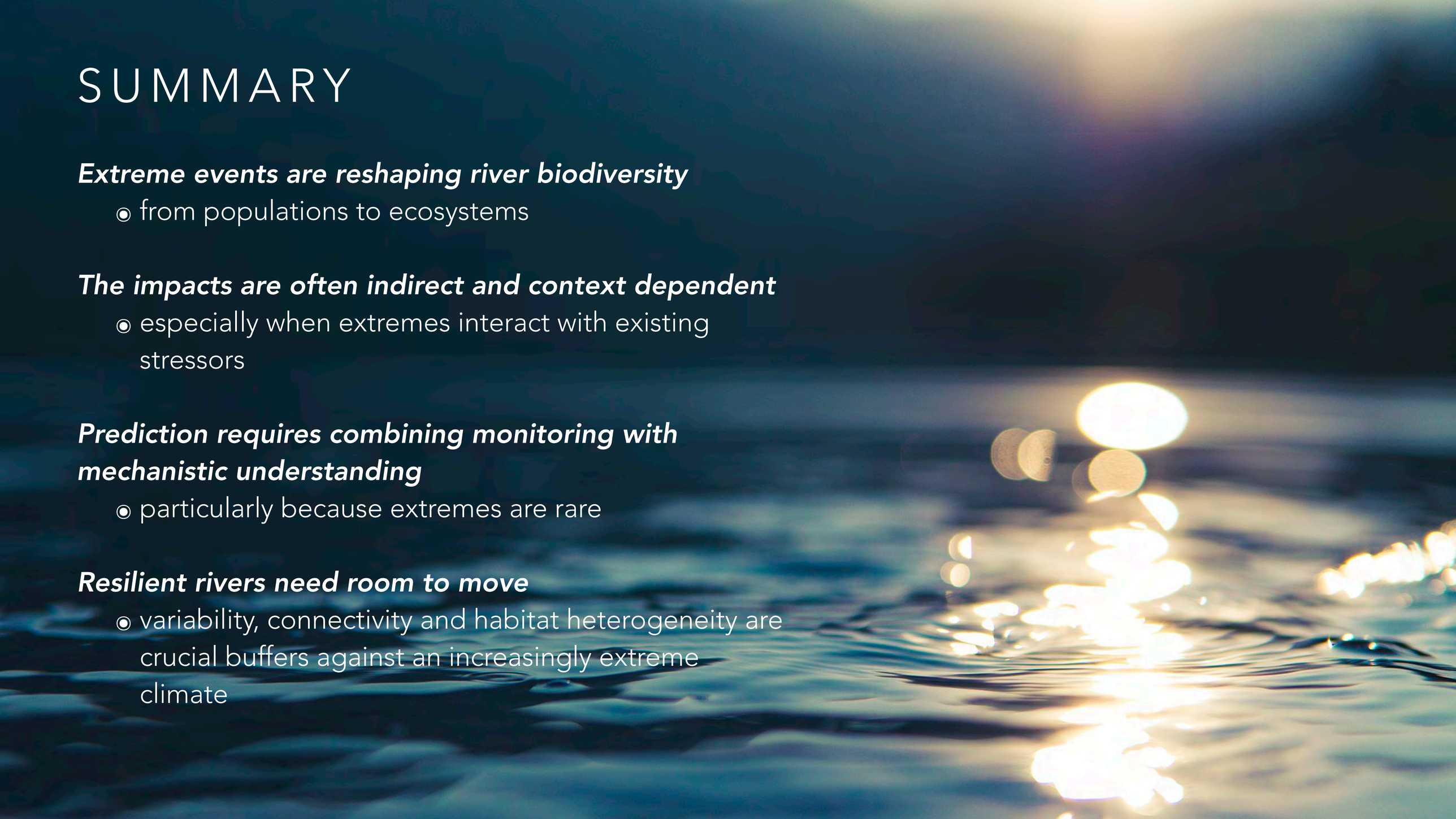
- especially when extremes interact with existing stressors

Prediction requires combining monitoring with mechanistic understanding

- particularly because extremes are rare

Resilient rivers need room to move

- variability, connectivity and habitat heterogeneity are crucial buffers against an increasingly extreme climate



TWO TAKE HOMES

I. **Extreme events don't act in isolation**

We need models to anticipate the full suite of potential impacts and interventions

II. **Resilient rivers need room to move**

Rivers needed to be treated as living systems with space, heterogeneity, and connectivity





ONWARDS!

Tonkin Lab members involved in this work: Gabrielle Koerich, Christina McCabe, Dani Hernandez, Rory Lennox, Holly Harris, Julian Merder, Anne McLeod, Hao Ran Lai, Ignacio Reyes, AJ Gillis, Naomi Heller, Li Wang, Ilya Shabanov

Other collaborators involved: Dave Lytle, Julian Olden, Dave Merritt, Lindsay Reynolds, Jane Rogosch, LeRoy Poff, Albert Ruhi, Nick Bond, Avril Horne, Mike Bogan, Nuria Bonada, Blanca Rios Touma, Theo Mouton, Erin Abernethy, Angus McIntosh, Julia Talbot-Jones, Thibault Datry, Tadeu Siqueira

PREDIRECTIONS

predirections.substack.com

I cover a lot of these topics in my newsletter

BLUESKY: @JDTONKIN

TONKINLAB.ORG

Freshwater Ecology Research Group

Te Pūnaha Matatini
Complexity is at our heart

RUTHERFORD DISCOVERY FELLOWSHIPS

ROYAL SOCIETY TE APĀRANGI

WAIMAKARIRI DISTRICT COUNCIL

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The Tonkin Lab

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