Equipping river ecosystem management for a highly uncertain future

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Dave Lytle, Julian Olden, Dave Merritt, Lindsay Reynolds, Jane Rogosch, LeRoy Poff, Albert Ruhi, Nick Bond, Avril Horne

$ Jason Tylianakis, Ian Dickie

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UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Oregon State University

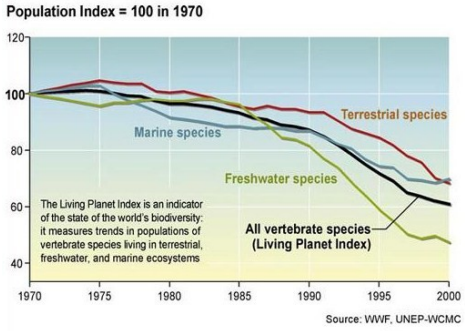
Bio-Protection
Bioprotection science for New Zealand

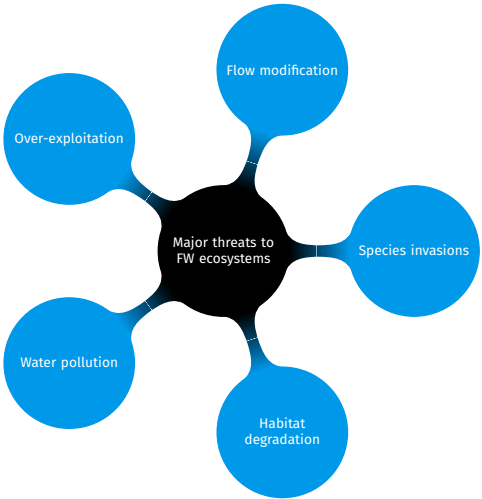
THE GREAT ACCELERATION

REFERENCE: Steffen, W., W. Broadgate, L. Deutsch, O. Gaffney and C. Ludwig. The Trajectory of the Anthropocene: the Great Acceleration, *The Anthropocene Review*, 16 January 2015.

MAP & DESIGN: Félix Pharand-Deschênes / Globaia

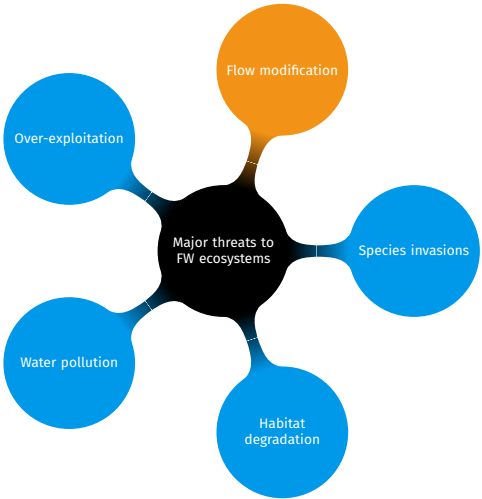
Freshwaters are under threat





S. Brown/National Geographic [B], U.S. Geological Survey [C], U.S. Department of Agriculture [E], Lancaster Online [G], National Park Service [H], A. Rehana [I], U.S. Fish and Wildlife Service [J], L. Craig/American Rivers [K], and National Weather Service [L].

Source left: Redrawn from Dudgeon et al. 2006 *Biol. Rev.*; right: Craig et al. 2017 *Elementa*.



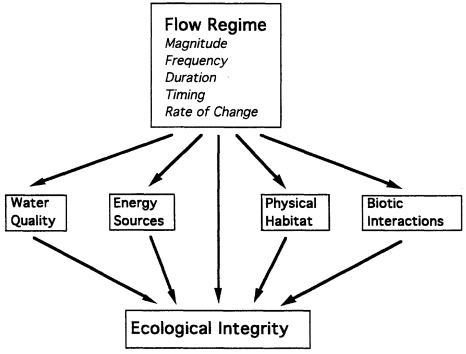
S. Brown/National Geographic [B], U.S. Geological Survey [C], U.S. Department of Agriculture [E], Lancaster Online [G], National Park Service [H], A. Rehana [I], U.S. Fish and Wildlife Service [J], L. Craig/American Rivers [K], and National Weather Service [L].

Source left: Redrawn from Dudgeon et al. 2006 *Biol. Rev.*; right: Craig et al. 2017 *Elementa*.

The Natural Flow Regime

A paradigm for river conservation and restoration

N. LeRoy Poff, J. David Allan, Mark B. Bain, James R. Karr, Karen L. Prestegaard, Brian D. Richter, Richard E. Sparks, and Julie C. Stromberg

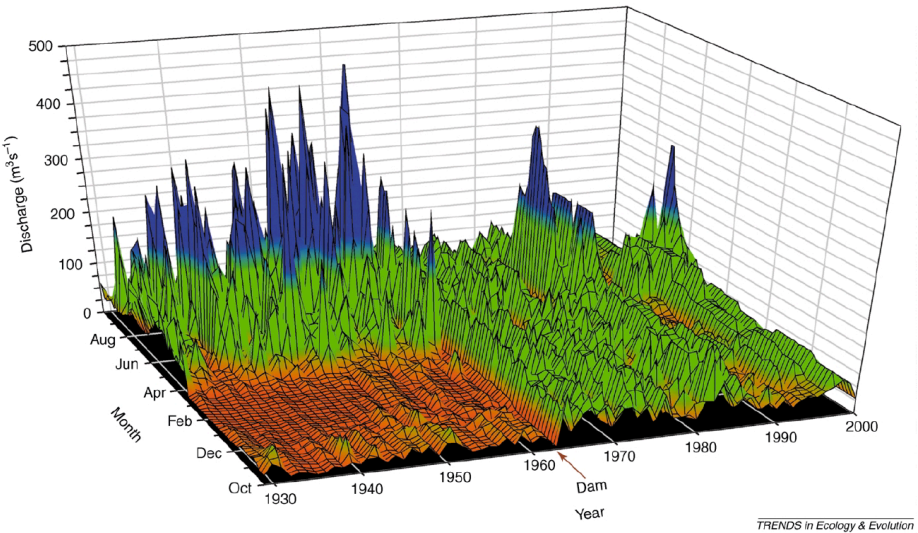


Source: Poff et al. 1998 *Bioscience*

River flow is a master variable

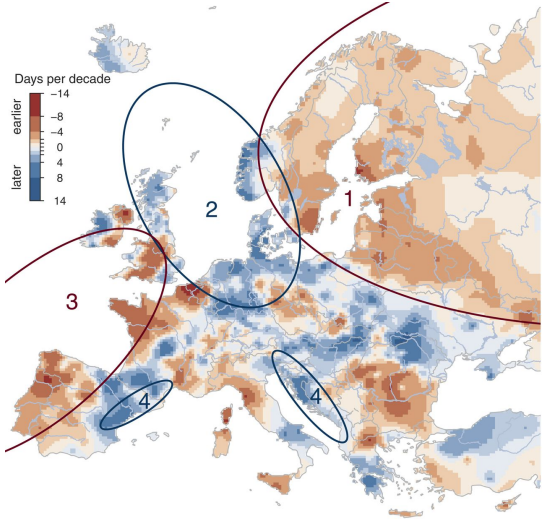
River flow is a master variable

But flow regimes are often heavily modified



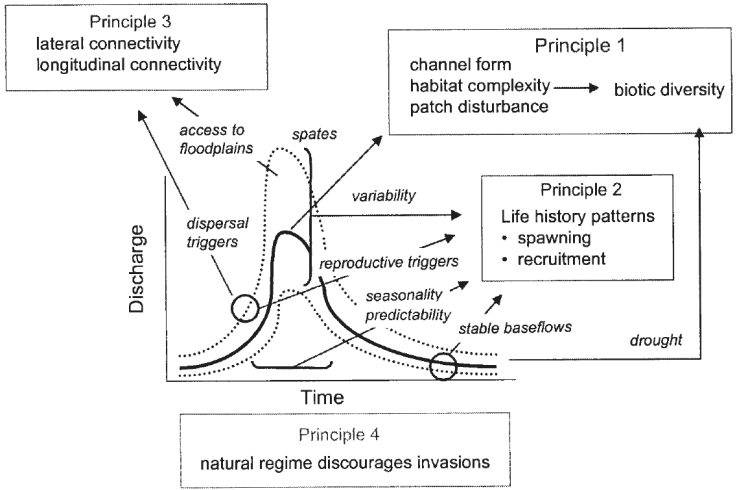
Source: Lytle & Poff 2004 *TREE*. Green River, Utah

Observed trends of river flood timing in Europe, 1960–2010



Source: Günter Blöeschel et al. 2017 *Science*

Aquatic biodiversity and natural flow regimes



Source: Bunn & Arthington 2002 *Eco. Apps.*

Altered river flows alter biodiversity

Flow Management for Hydropower Extirpates Aquatic Insects, Undermining River Food Webs

THEODORE A. KENNEDY, JEFFREY D. MUEHLBAUER, CHARLES B. YACKULIC, DAVID A. LYTLE, SCOTT W. MILLER, KIMBERLY L. DIBBLE, ERIC W. KORTENHOEVEN, ANYA N. METCALFE, AND COLDEN V. BAXTER

Declining streamflow induces collapse and replacement of native fish in the American Southwest

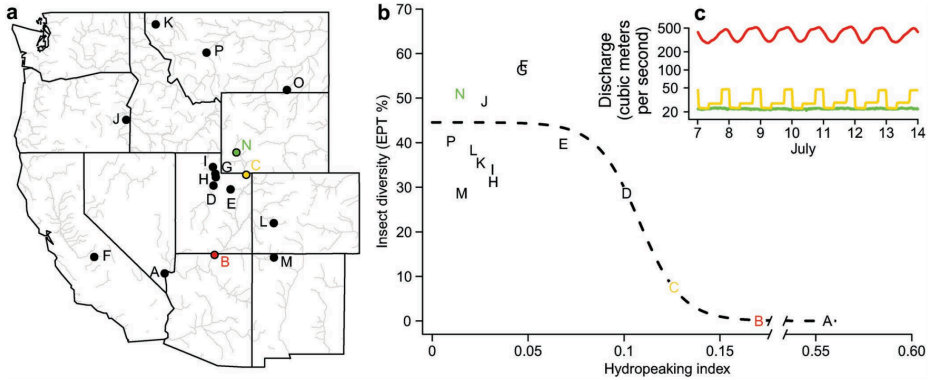
Albert Ruhi[1*], Julian D Olden[2], and John L Sabo[1,3]

ARTICLES
https://doi.org/10.1038/s41559-017-0379-0
nature ecology & evolution

Flow regime alteration degrades ecological networks in riparian ecosystems

Jonathan D. Tonkin[1*], David. M. Merritt[2], Julian D. Olden[3], Lindsay V. Reynolds[2] and David A. Lytle[1]

Altered river flows alter biodiversity



Source: Kennedy et al. 2016 *Bioscience*

Feedbacks

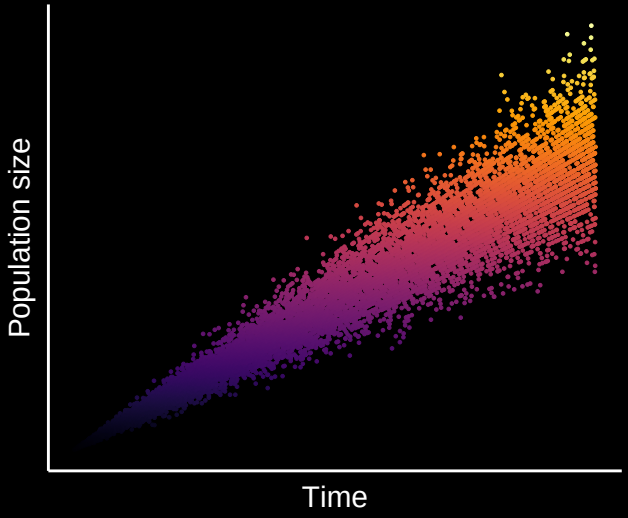
Flow regulation $\rightarrow$ Beaver $\rightarrow$ Geomorphic change $\rightarrow$ Ecological change

River flows are nonstationary

Nonstationarity

Nonstationarity

Natural systems no longer fluctuate within an unchanging envelope of variability


Population size
Time

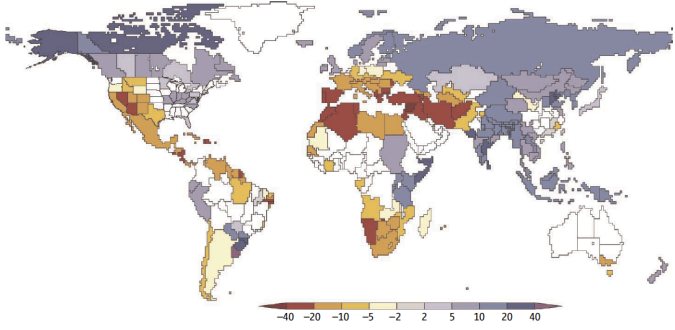
POLICYFORUM

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

P. C. D. Milly,[1]* Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]



% change in runoff by mid 21st century

Source: Milly et al. 2008 *Science*

> *... the reliance of management on historical benchmarks and the current practice of extrapolating future river ecosystem states from contemporary trends is destined to fail...*

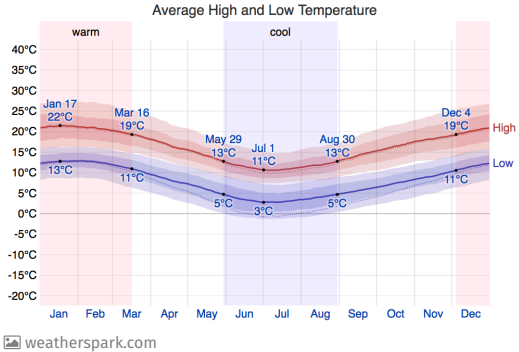
— Tonkin, Poff et al. *In review*

A solution to nonstationarity?

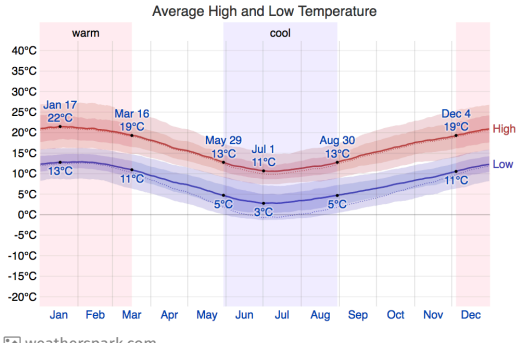
A solution to nonstationarity?

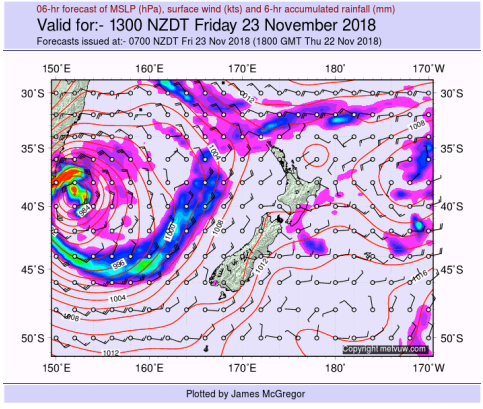
Process-based models

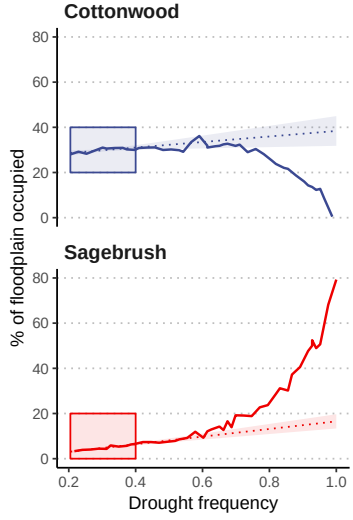
Phenomenological vs. process-based



Phenomenological vs. process-based







Tonkin, Poff et al. *In review*

PBMs can provide input for...

Decision support tools

nature climate change

PERSPECTIVE

PUBLISHED ONLINE: 14 SEPTEMBER 2015 | DOI: 10.1038/NCLIMATE2765

Sustainable water management under future uncertainty with eco-engineering decision scaling

N. LeRoy Poff[1]*, Casey M. Brown[2], Theodore E. Grantham[3], John H. Matthews[4], Margaret A. Palmer[5], Caitlin M. Spence[2], Robert L. Wilby[6], Marjolijn Haasnoot[7,8], Guillermo F. Mendoza[9], Kathleen C. Dominique[10] and Andres Baeza[11]

PBMs can provide input for...

Decision support tools

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Adaptive management

PBMs can provide input for...

Decision support tools

Sustainable water management under future uncertainty with eco-engineering decision scaling

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Adaptive management

SUSTAINABILITY

Prediction, precaution, and policy under global change

Emphasize robustness, monitoring, and flexibility

By **Daniel E. Schindler*** *and* **Ray Hilborn**

> *Produce predictions that may foreshadow the need to change management practices long before trends are detected in empirical surveys.*

Key challenge

Informing river managers with predictions robust to nonstationarity

Process-based models for a nonstationary world

Process-based models for a nonstationary world

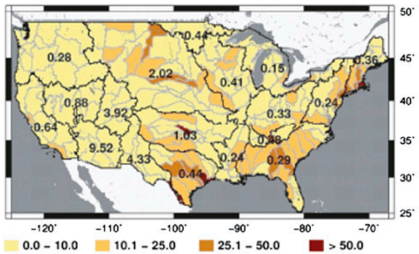
Demonstrating their utility for river flow management

Dryland river ecosystems

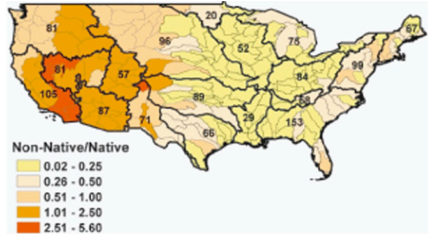
- Rivers dominated by cycles of floods and droughts
- Often highly predictable flow regimes
- Organisms highly attuned to natural flow events
- Hydrology = master variable

Western rivers are highly modified

Dams per 100km of river length



Nonnative:native fish species



Sabo et al. 2010 *PNAS*

Environmental flows...

> *... describe the quantity, timing, and quality of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, sustainable livelihoods, and well-being.*

— Arthington et al. 2018 *Front. Env. Sci.*

River flow is a master variable

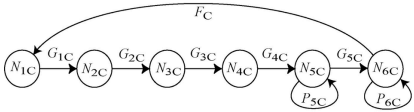
River flow is a master variable

Models that link flow regimes with population dynamics

Riparian plants

The model

- Flow interacts with vital rates: growth, survival, recruitment, reproduction
- Coupled, stochastic matrix population models
- Finite amount of space available for recruitment

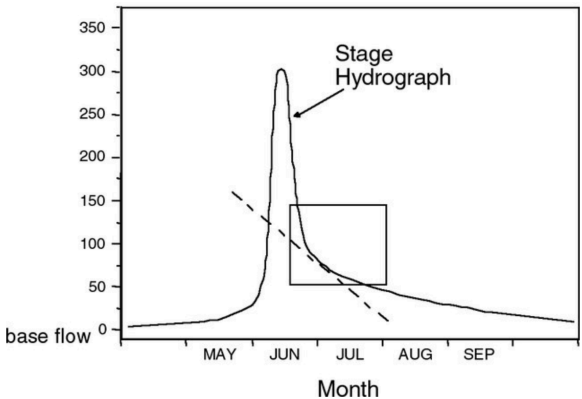






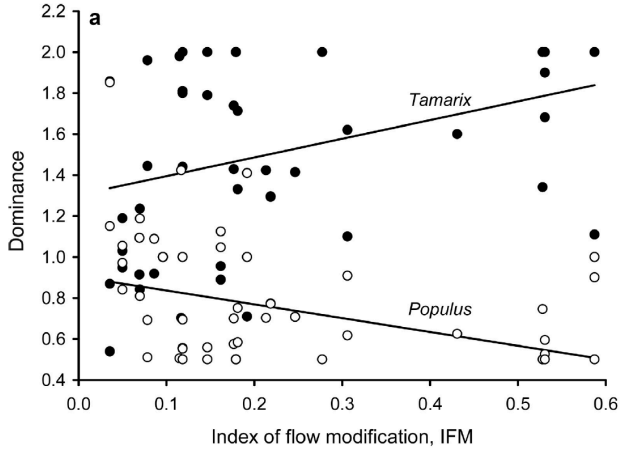
Lytle et al. 2017 *Ecol. Apps.*. Photos: delange.org, M. Bloem, S. Hammonds, USGS, Wikipedia-Beemus.

Recruitment box model for cottonwood

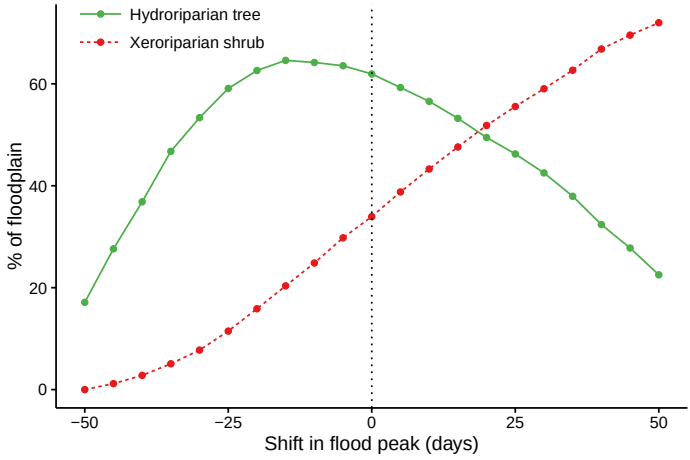


Source: Mahoney and Rood 1998 *Wetlands*

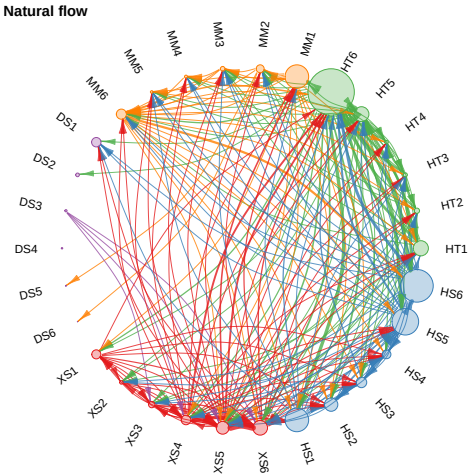
Dave Merritt

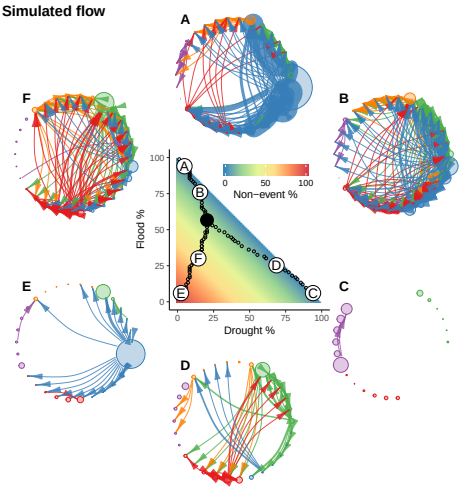


Merritt & Poff 2010 *Ecol. Apps.*



Lytle et al. 2017 *Ecol. Apps.*





Tonkin et al. 2018 *Nature Ecology and Evolution*

Benthic invertebrates

$$\frac{\mathrm{d}N}{\mathrm{d}t} = rN\left(1 - \frac{N}{K}\right)$$

McMullen et al. 2017 *Ecol. Letters*

$$\frac{\mathrm{d}N}{\mathrm{d}t} = rN\left(1 - \frac{N}{K}\right)$$

McMullen et al. 2017 *Ecol. Letters*

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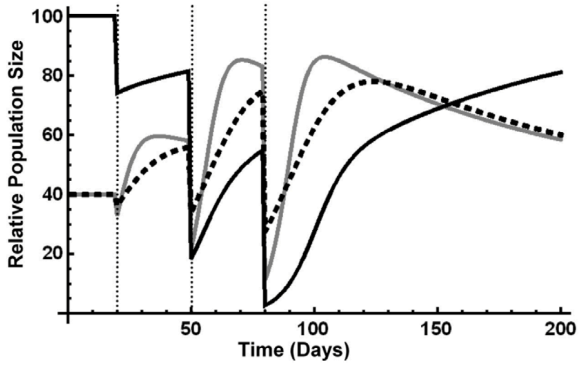
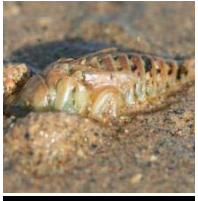
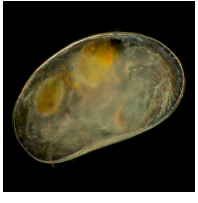


Dave Lytle



Laura McMullen



Antonio Guillen

McMullen et al. 2017 *Ecol. Letters*

Flood-adapted (gray and dashed lines), flood-averse (solid lines)

Applying to whole ecosystems

Applying to whole ecosystems

Designer environmental flows

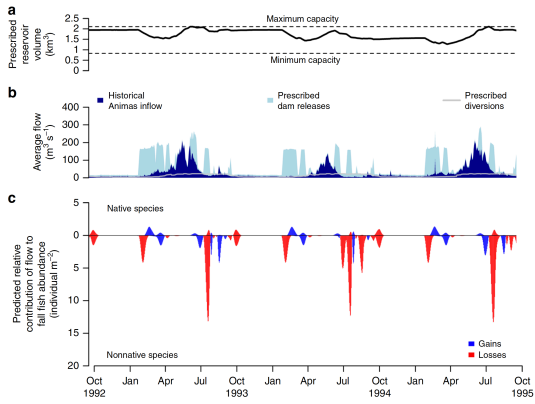
nature COMMUNICATIONS

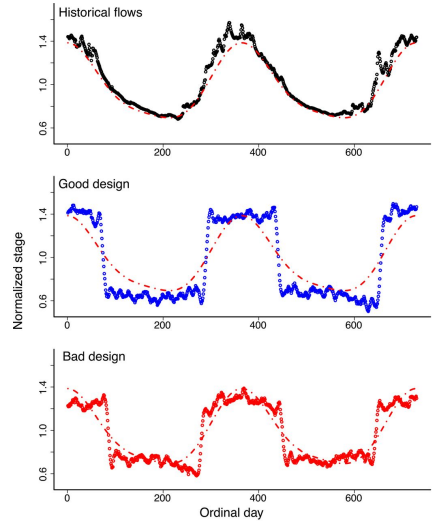
ARTICLE

DOI: 10.1038/s41467-017-02226-4 OPEN

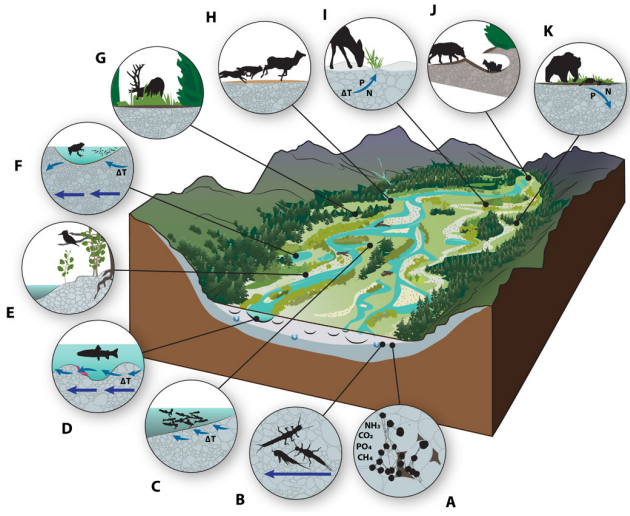
Designing flows to resolve human and environmental water needs in a dam-regulated river

William Chen [1,2] & Julian D. Olden [2]



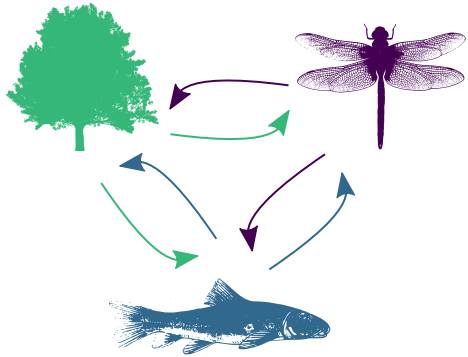


Source: Sabo et al. 2017 Science (DOI: 10.1126/science.aao1053)



Source: Hauer et al. 2016 Sci. Advances (DOI: 10.1126/sciadv.1600026)

What are the ecosystem-wide consequences of targeted flow management?



Invertebrates: Time-varying logistic growth model. McMullen et al. 2017 *Ecology Letters*
Plants: Stage-structured matrix model. Lytle et al. 2017 *Ecological Applications*
Fish: Stage-structured matrix model. Rogosch et al. *In review*

Cottonwood

Tamarisk

Willow

Meadow

Desert shrub

Cottonwood

Tamarisk

Willow

Meadow

Desert shrub

Desert sucker

Sonora sucker

Roundtail chub

Green sunfish

Red shiner

Smallmouth bass

Yellow bullhead

Cottonwood

Tamarisk

Willow

Meadow

Desert shrub

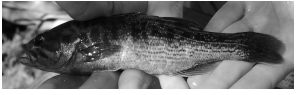
Desert sucker

Sonora sucker

Roundtail chub

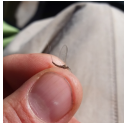
Green sunfish

Red shiner



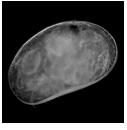
Smallmouth bass

Yellow bullhead

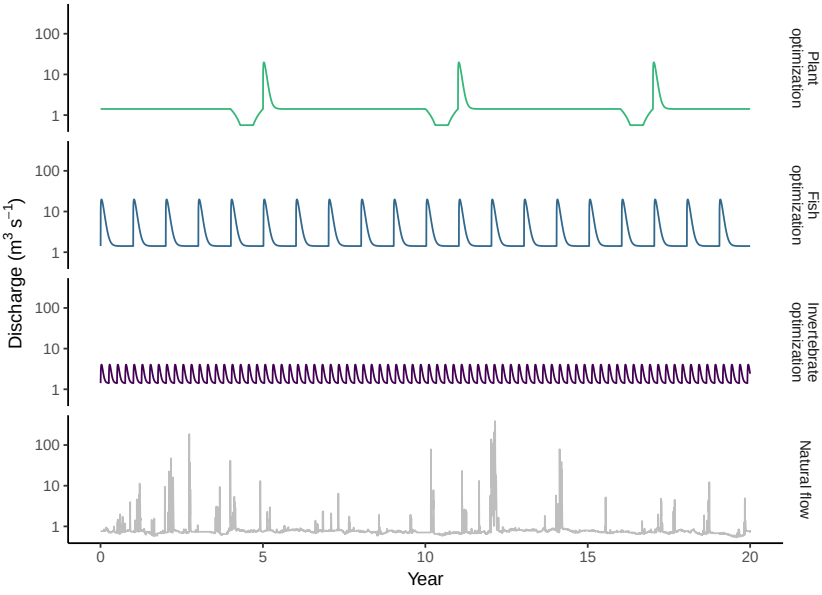


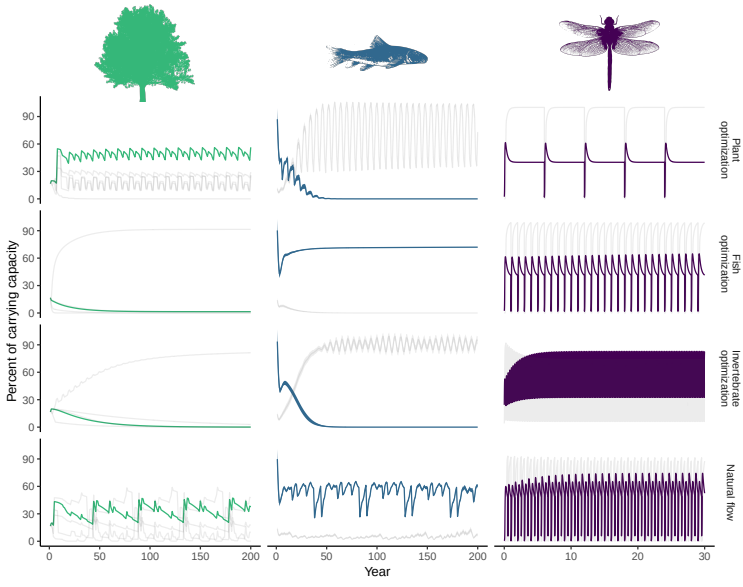
Fallceon

Progomphus



Ostracod

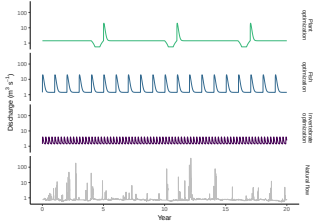

Discharge (m3 s−1)
100
10
1
Plant optimization
Fish optimization
Invertebrate optimization
Natural flow
0
5
10
15
20
Year


Percent of carrying capacity
Year
Plant optimization
Fish optimization
Invertebrate optimization
Natural flow
0
30
60
90
0
50
100
150
200
0
10
20
30


Invertebrates
Natural flow
Fish
Plants
0
20%
40%
60%
80%
100%
0.55
0.28
0
0.36
0.71
0.73
0.24
0.49

Conclusions

Organisms respond to different frequencies



Conclusions

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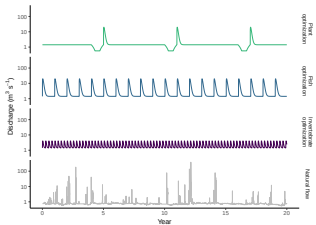
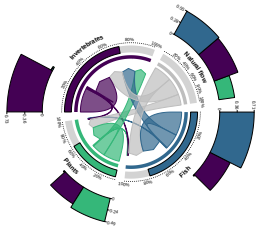


Designer flows have ecosystem-wide consequences



Conclusions

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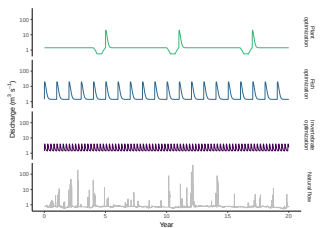

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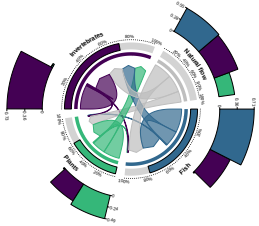
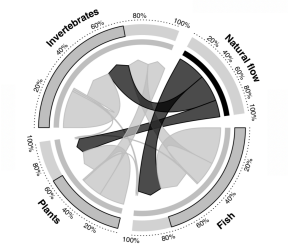


The natural flow regime meets multiple needs



Returning to natural flow regime may no longer be viable, but...

Returning to natural flow regime may no longer be viable, but... designing river flows to support entire ecosystems must begin from natural flow regime principles.

Conclusions

1. Nonstationarity major challenge for river ecosystem management

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Conclusions

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2. Need tools that can provide managers with robust predictions
3. PBMs are one solution that are well established in other fields
4. Growing capacity to mechanistically forecast ecosystem responses by explicitly linking biological processes to stochastic hydrologic variability
5. Broader adoption of PBMs needed to advance river management aimed at ecological resilience, even if implementation is challenging

> *A new science-based framework that incorporates process-based, causal hydro-ecological understanding is necessary to proactively manage river ecosystems under intensifying hydrologic uncertainty.*

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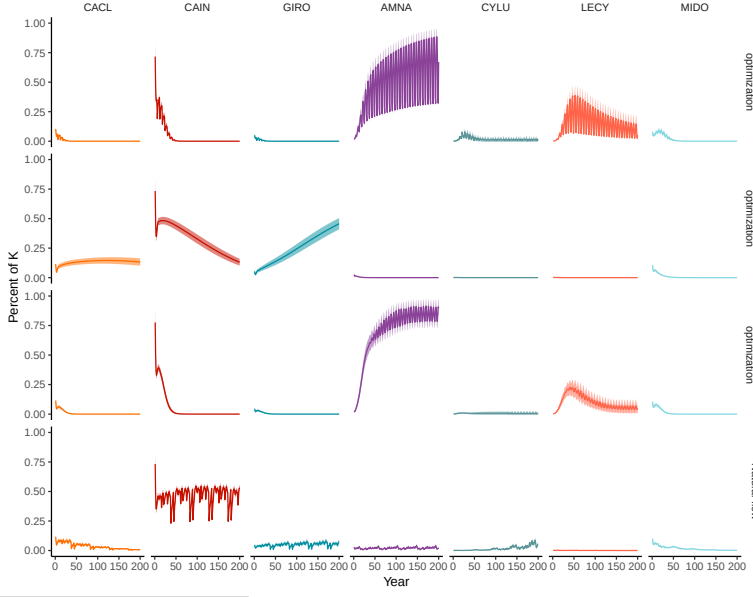
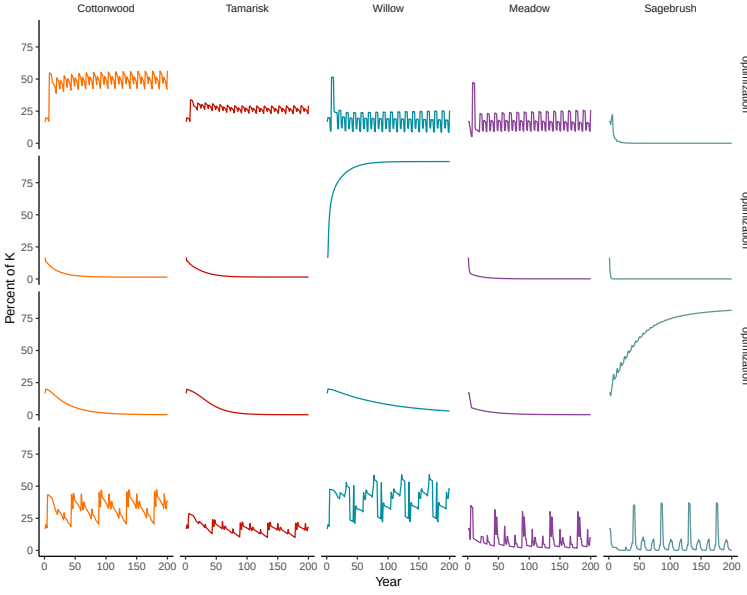
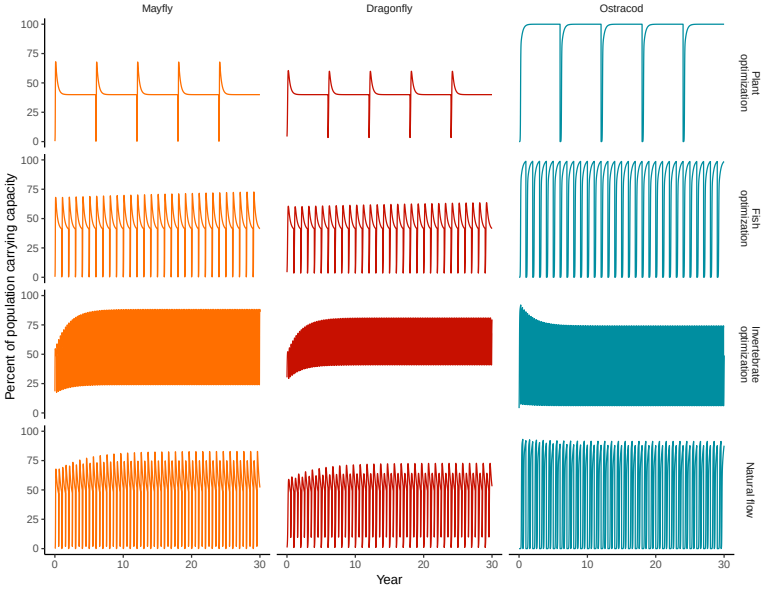
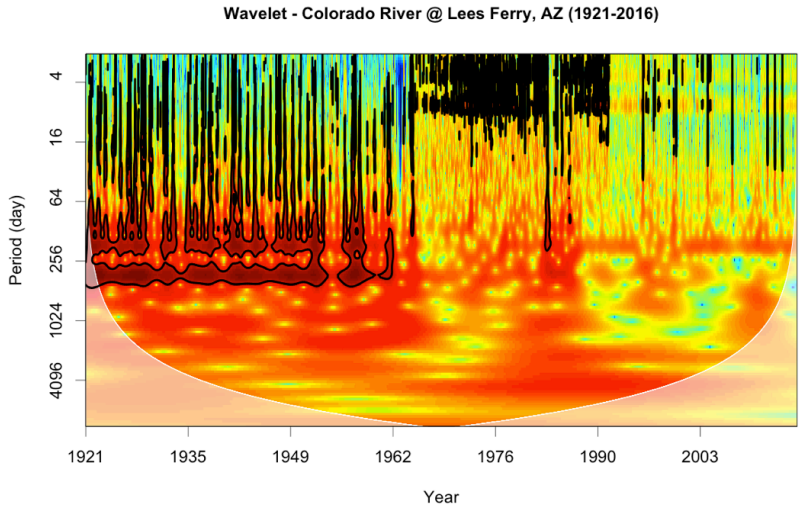


Native. CACL: desert sucker. CAIN: sonora sucker. GIRO: roundtail chub.
Non-native. AMNA: yellow bullhead. CYLU: red shiner. LECY: green sunfish. MIDO: smallmouth bass.

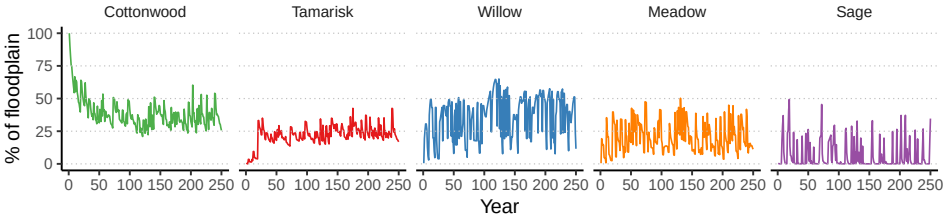

Cottonwood
Tamarisk
Willow
Meadow
Sagebrush
Plant optimization
Fish optimization
Invertebrate optimization
Natural flow
Percent of K
0
25
50
75
0
50
100
150
200
Year


Mayfly
Dragonfly
Ostracod
Plant optimization
Fish optimization
Invertebrate optimization
Natural flow
Percent of population carrying capacity
Year
0
25
50
75
100
0
10
20
30

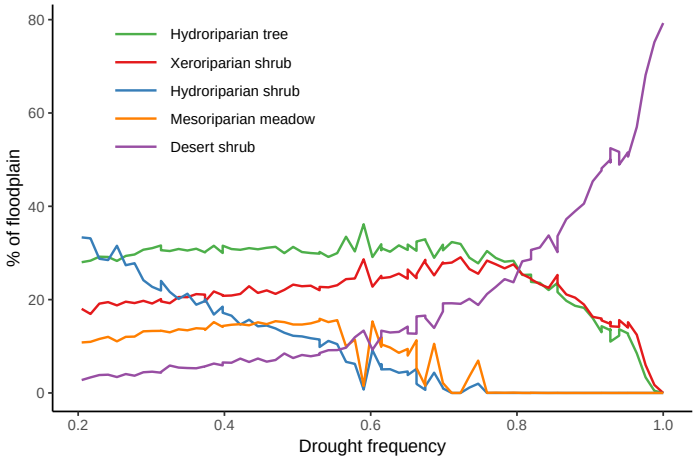
Altered flow periodicities



Source: Albert Ruhi

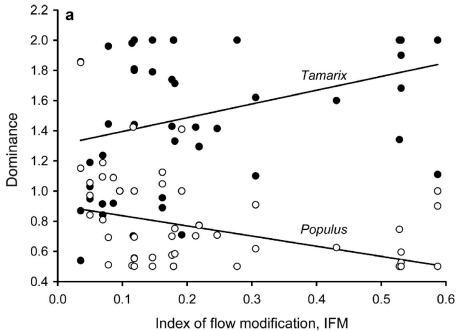


Lytle et al. 2017 *Ecol. Apps.*

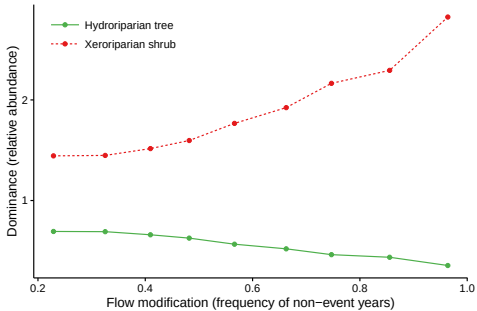


Lytle et al. 2017 *Ecol. Apps.*

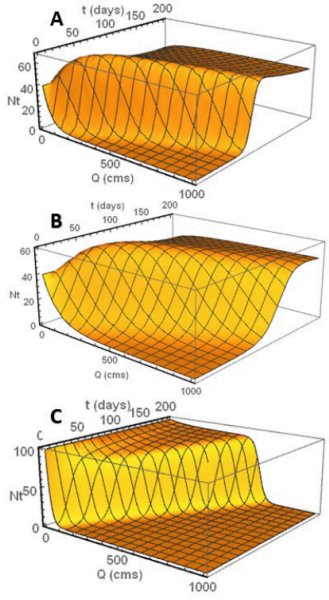
Merritt & Poff (2010): 13 western US rivers



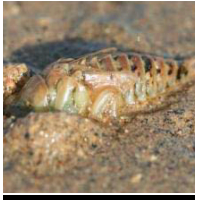
Simulating flow homogenization



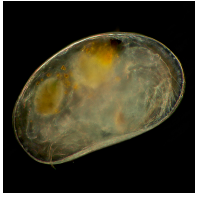
Lytle et al. 2017 *Ecol. Apps.*



Dave Lytle

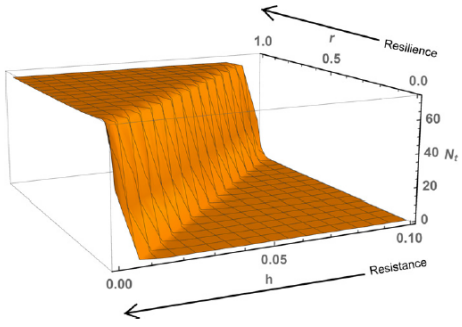


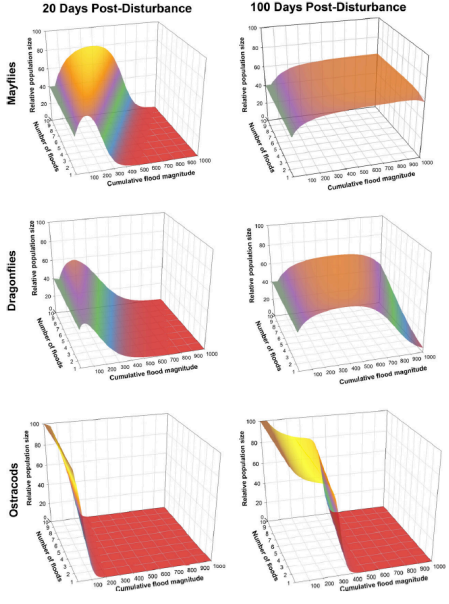
Laura McMullen



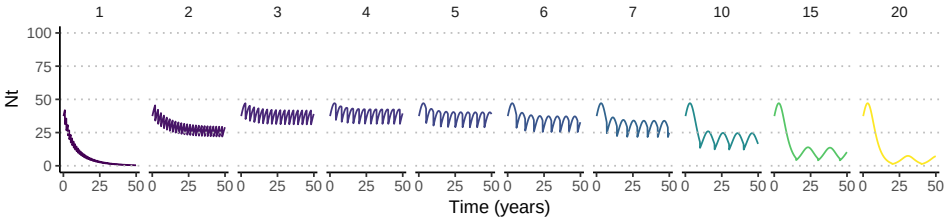
Antonio Guillen

McMullen et al. 2017 *Ecol. Letters*


r
Resilience
1.0
0.5
0.0
60
40
N_t
20
0
0.10
0.05
0.00
h
Resistance



Source: McMullen et al. 2017 *Ecol. Letters*


1
2
3
4
5
6
7
10
15
20
Nt
100
75
50
25
0
0
25
50
Time (years)

DATA COLLECTION

Flow response guilds

- 5 guilds
- 6 stage classes
- HT, XS, HS, MM, DS

Vital rates

- Transition prob.
- Self thinning rate
- Flood tolerance
- Drought tolerance

Flow data

- 83 years
- Maybell Gauge
- Yampa River, USA

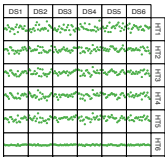
CORE MODEL

Structured population model

- Vital rates a function of flow regime
- Guilds compete for space (K)

Sensitivity analysis

- Alter vital rates in minute increments
- Measures degree of competition betweeen classes



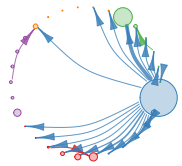
NETWORK ANALYSIS

Network compilation

- Form network from results of sensitivity analysis

Network analysis

- N. edges, nodes, connectance, reciprocity
- Degree of nodes



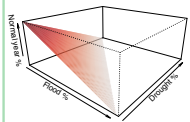
PROJECTION

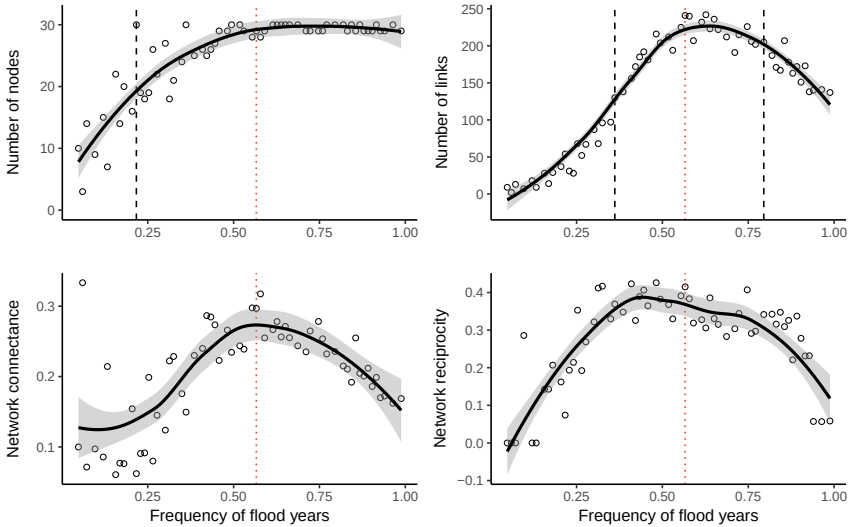
Simulations of flow

- Natural > 100% flood years, drought years, non-event years

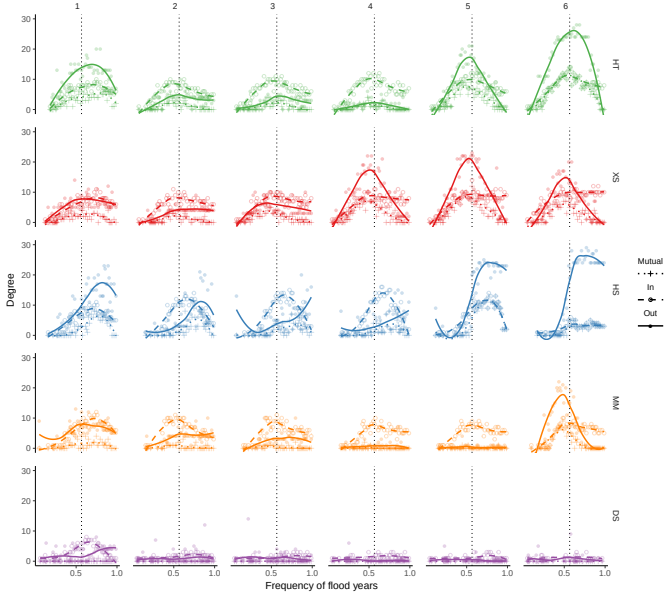
Changepoint analysis of network properties

- Single changepoint either side of natural

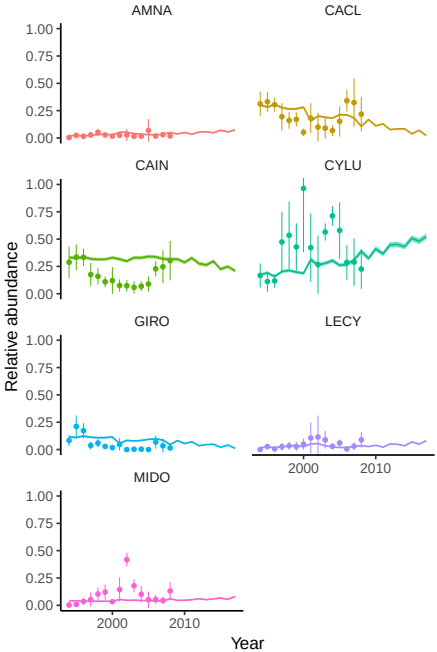


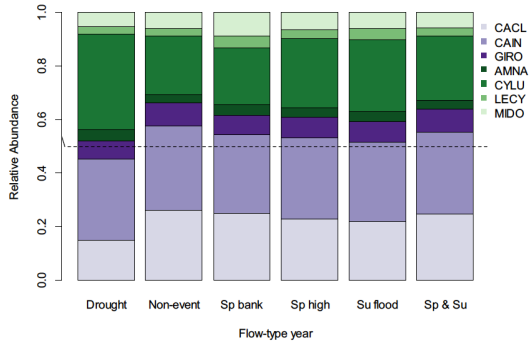


Tonkin et al. 2018 *Nature Ecology and Evolution*



Tonkin et al. 2018 *Nature Ecology and Evolution*


AMNA
CACL
CAIN
CYLU
GIRO
LECY
MIDO
Relative abundance
1.00
0.75
0.50
0.25
0.00
2000
2010
Year


Relative Abundance
0.0
0.2
0.4
0.6
0.8
1.0
Drought
Non-event
Sp bank
Sp high
Su flood
Sp & Su
Flow-type year
CACL
CAIN
GIRO
AMNA
CYLU
LECY
MIDO