FREE FLOWING RIVERS

Mapping the world's free-flowing rivers using the Connectivity Status Index (CSI)

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Image: Dao Van Hoang

State of freshwater systems in decline globally

Past and current dam building, water-related megaprojects and pollution led to rapid loss of freshwater biodiversity and ecosystem services

Goals of this study

- Develop common framework for the identification of free-flowing rivers at multiple scales, and
- create a global inventory of rivers that remain free-flowing today
- Inform research and conservation planning
- provide a new global indicator for monitoring purposes, river health assessments, and river impact studies.

Overview of FFR methodology

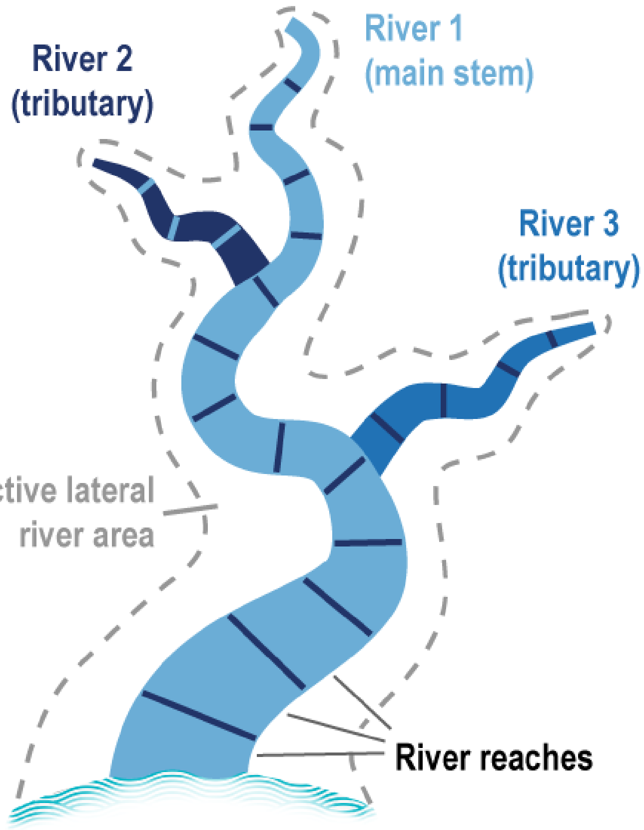
Global datasets and models

- Integrating global datasets into HydroSHEDS framework (Lehner et al., 2008).
- Using river routing model HydroROUT (Grill et al., 2015)

Combining multiple pressures

- 6 pressure indicators are combined
- using weighted overlay technique to produce Connectivity Status Index (CSI).
- classification of Free-flowing river status based on CSI.

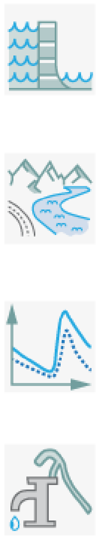
a) Hydrographic framework



River reach: Smallest element in the river network and unit for calculation of Connectivity Status Index (CSI)

River: Linear feature that consists of multiple river reaches. Tributaries form new rivers. Free-flowing status is determined at scale of entire river.

b) Four dimensions are considered to determine the Connectivity Status Index (CSI) of river reaches



longitudinal (connectivity between up- and downstream)

lateral (connectivity to floodplain and riparian areas)

temporal (connectivity based on seasonality of flows)

vertical (connectivity to ground-water and atmosphere)

c) Free-flowing river status is determined based on CSI

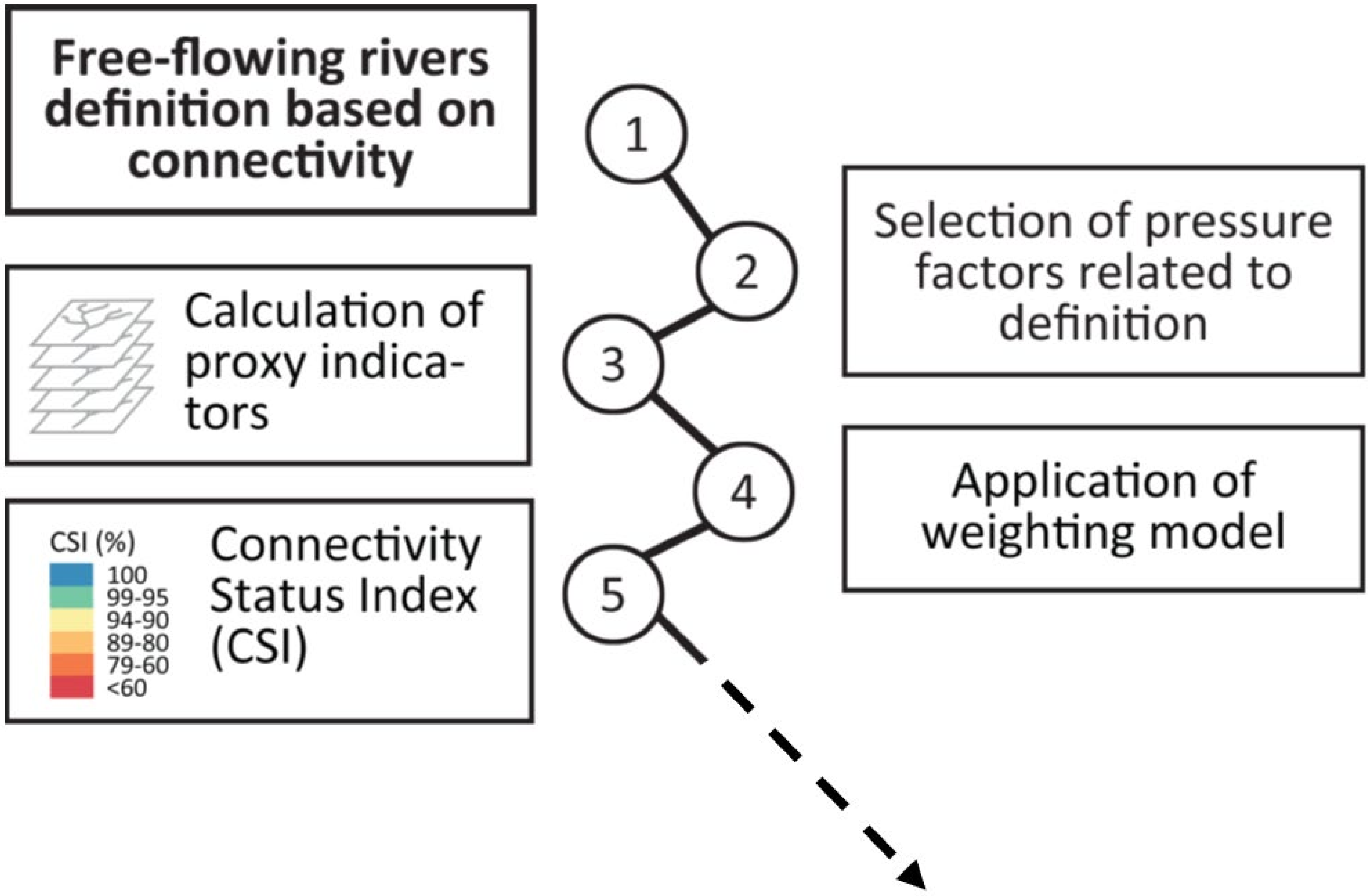
Only rivers with high levels of connectivity (CSI ≥ 95%) throughout entire length are considered free-flowing rivers.

d) "A free-flowing river is a river where natural aquatic ecosystem functions and services are largely unaffected by changes to the fluvial connectivity allowing an unobstructed exchange of material, species and energy within the river system and surrounding landscapes.

Fluvial connectivity encompasses **longitudinal** (river channel), **lateral** (floodplains), **vertical** (groundwater and atmosphere) and **temporal** (intermittency) components and can be compromised by:

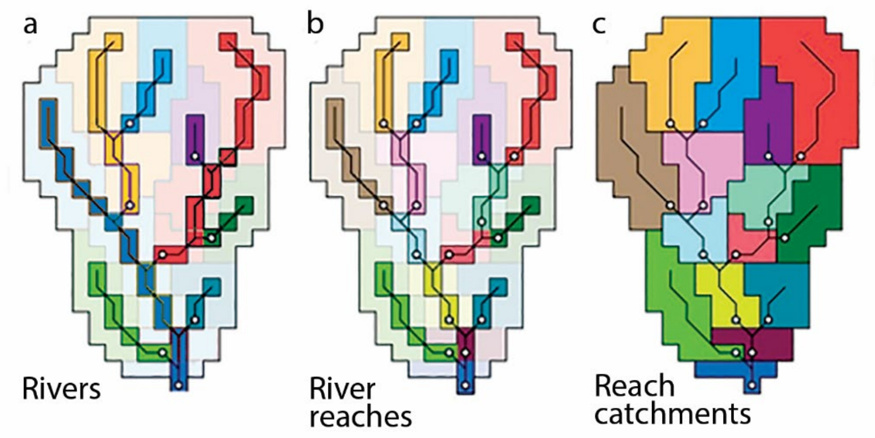
(a) physical infrastructure in the river channel, along riparian zones, or in adjacent floodplains;
(b) by hydrological alterations of river flow due to water abstractions or regulation; and
(c) by changes to water quality that lead to ecological barrier effects caused by pollution or alterations in water temperature."

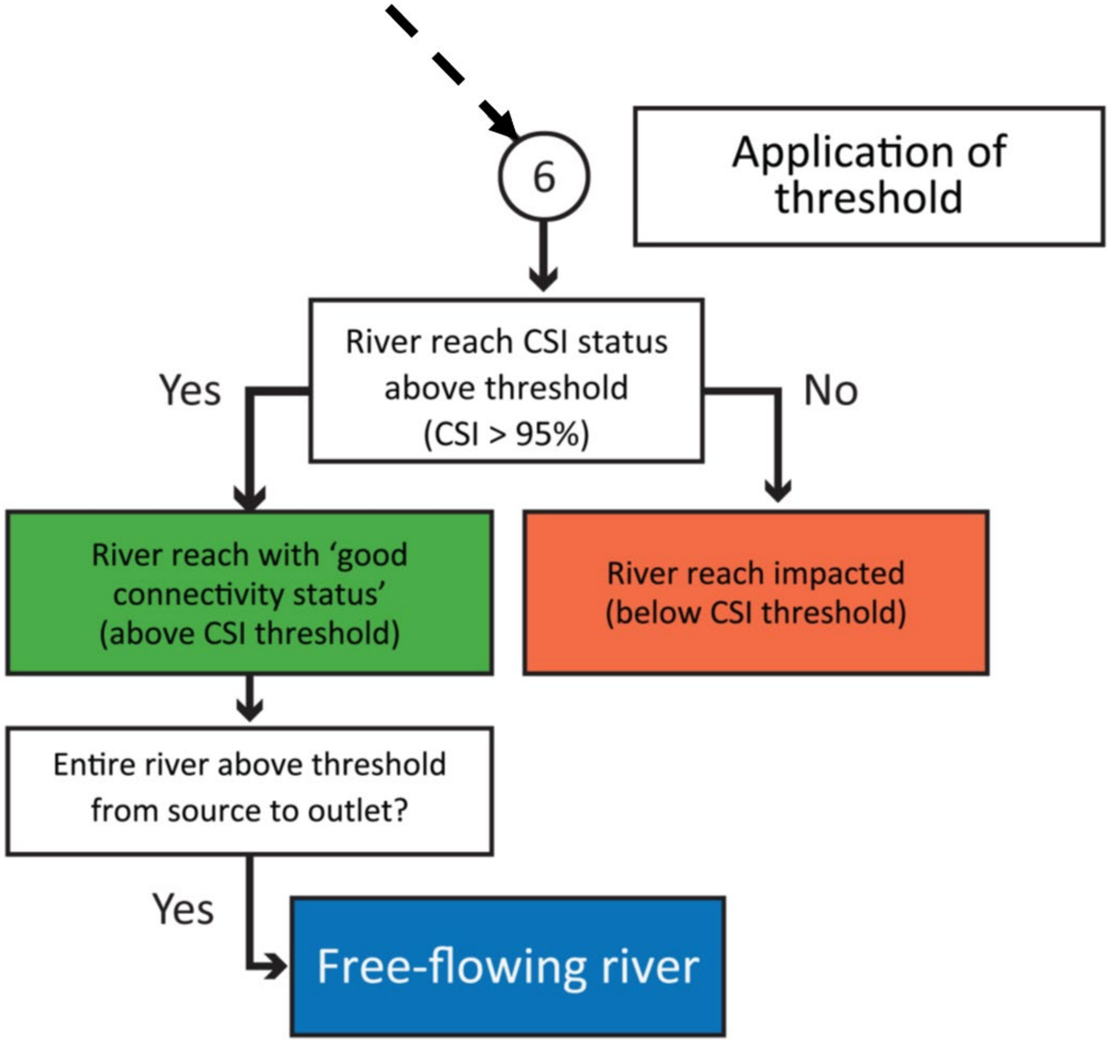
Conceptual overview of methodology



Conceptual overview of methodology (cont.)

- ❑ Free-flowing river status is determined at the river scale
- ❑ Threshold based on benchmarking and sensitivity analysis





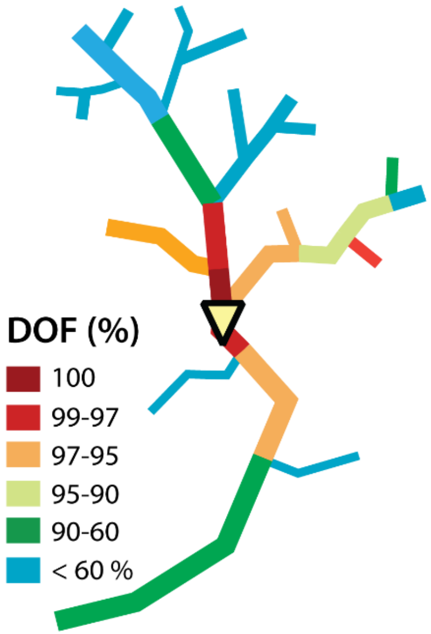
Overview of pressure factors and indicators

Pressure factor	Pressure indicator	Description	Connectivity aspect affected	Source data
River fragmentation	**DOF**	Degree of Fragmentation	Longitudinal	HydroSHEDS; Lehner et al. (2008); GRanD v1.1; Lehner et al. (2011); GOOD2 v1, Mulligan et al. (2009)
Flow regulation	**DOR**	Degree of Regulation	Lateral, temporal	HydroSHEDS; Lehner et al. (2008); GRanD v1.1; Lehner et al. (2011); GOOD2 v1; Mulligan et al. (2009); HydroLAKES, v1.0; Messager et al. (2016)
Sediment trapping	**SED**	Sediment trapping index	Longitudinal, lateral, vertical	Erosion map; Borrelli et al. (2017); HydroSHEDS; Lehner et al. (2008); GRanD v1.1; Lehner et al. (2011); GOOD2 v1; Mulligan et al. (2009); HydroLAKES, v1.0; Messager et al. (2016)
Water consumption	**USE**	Consumptive water use (abstracted from rivers)	Longitudinal, Lateral, vertical, temporal	WaterGAP(Alcamo et al., 2003; Döll et al., 2003) (v2.2 as of 2014); HydroSHEDS; Lehner et al. (2008)
Infrastructure development in riparian and floodplain areas	**RDD**	Road density	Lateral, longitudinal	GRIP v3; Meijer and Klein Goldewijk (2009)
	URB	Nightlight intensity in urban areas	Lateral	DMSP-OLS v4; Doll (2008); Modis-derived urban areas by Schneider et al. (2009)

1) River fragmentation

Relates to potential loss of longitudinal connectivity

- > 20,000 dams from GRanD and GOOD2 database (Lehner et al., 2011; Mulligan et al. 2009)
- 2,435 waterfalls were geo-located to our river reaches (natural fragmentation effect)
- Calculated using new indicator: "Degree of Fragmentation" (DOF)



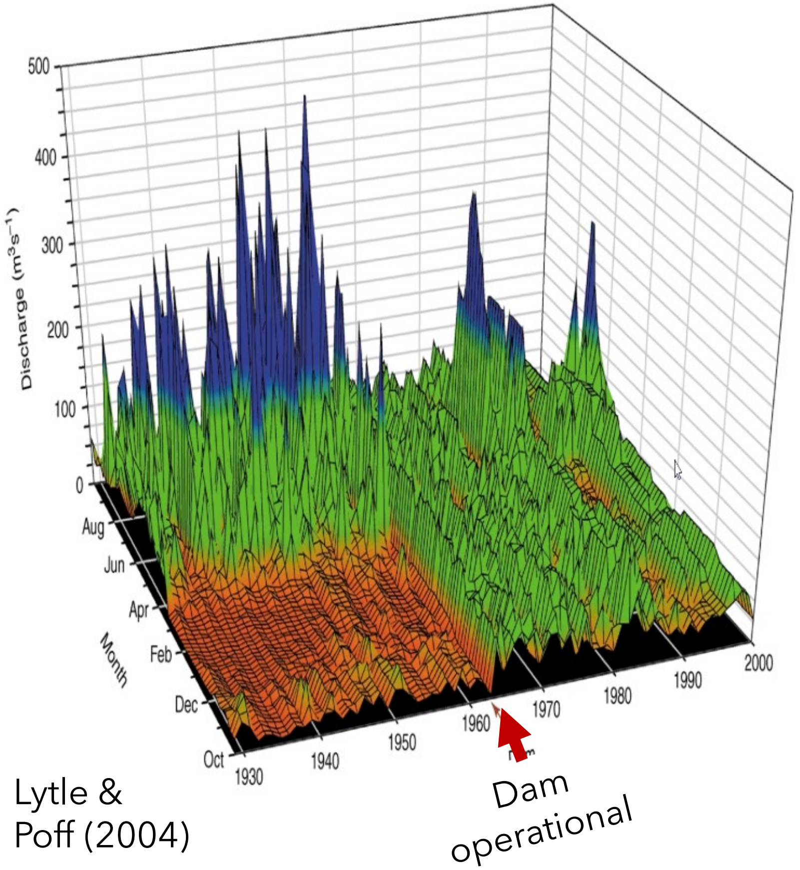
$$DOF_j = 100 - \frac{\left|\log_{10} d_{bloc} - \log_{10} d_j\right| * 100}{\log_{10} dr}$$

DOF_j = DOF at river reach j;
d_j is the discharge of river reach j;
d_{bloc} is the discharge at the location of the barrier; and
dr is the maximum discharge range.

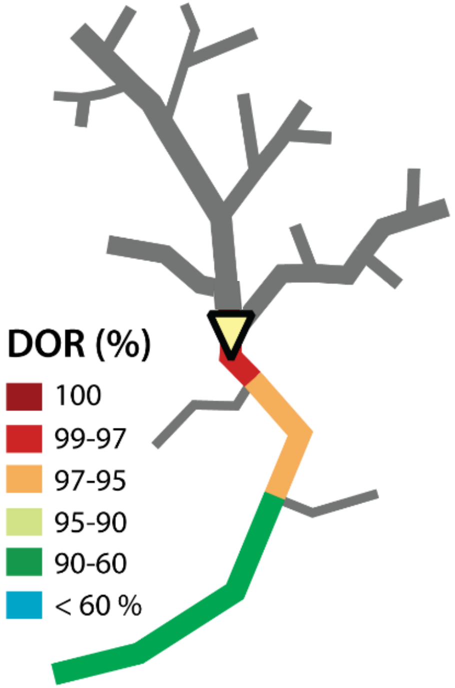
2) River Regulation

Potential loss of longitudinal and lateral connectivity through flow regulation

- Calculated as the "Degree of Regulation" (DOR)
  (Lehner et al., 2011)



Lytle & Poff (2004)



$$DOR_j = 100 * \frac{\sum_{i=1}^{n} svol_i}{d_{vol}}$$

$$DOR_j = 100 * \frac{Total\ upstream\ storage\ capacity}{Total\ annual\ flow\ volume}$$

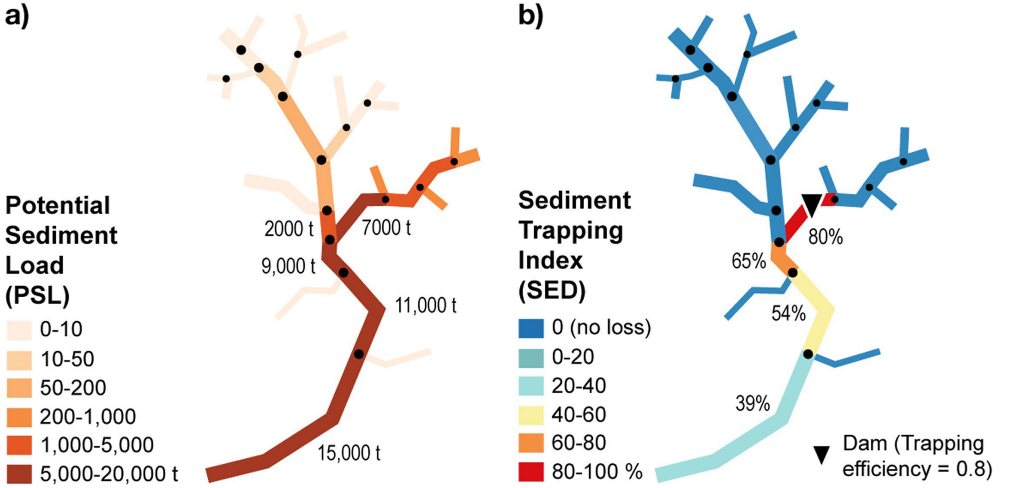
3) Sediment Trapping

A proxy of dam impacts on longitudinal sediment fluxes in a river network

- using erosion map as basis; both natural and artificial sediment trapping in lakes and reservoirs is considered
- sediment trapping calculations using established Brune's method (1953)
- Sediment Trapping Indicator (SED) at river reach scale = ratio of sediment loss to natural sediment load

$$SED_j = \frac{PSL_j - MSL_j}{PSL_j} * 100$$

SED_j = Sediment trapping index at reach j;
PSL_j = Potential Sediment Load at reach j;
MSL_j = Modified Sediment Load at reach j;



4) Water consumption

Proxy for effects on temporal connectivity and indirectly, lateral connectivity

- Water consumption from irrigation, industry, domestic use and animals (WaterGAP; Döll et al., 2008)
- Ratio of water consumption to mean annual discharge
- For example, ratio of 20% or higher indicates high water stress (Alcamo et al., 2000; Smathkin et al., 2004)

Lower Colorado; Photos: Dale Turner / TNC

$$USE_j = 100 * \frac{d_{nat} - d_{ant}}{d_{nat}}$$

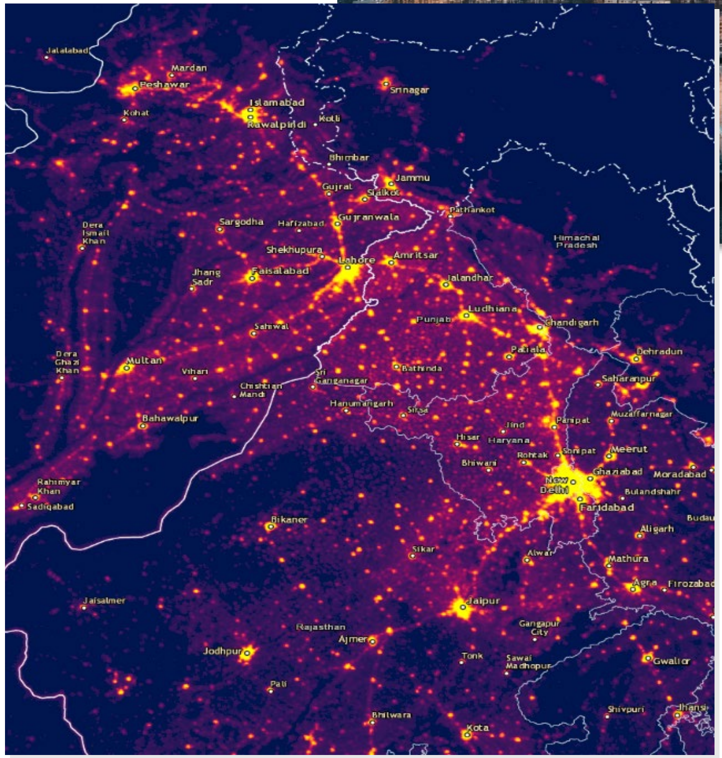
USE_j is the consumptive water use at river reach j;
d_{nat} represents the discharge without human influences, and
d_{ant} represents the discharge with human abstractions and use.

5) Urban development

Proxy for infrastructure development, such as levees, canals, etc.

- Combining urban areas (Schneider et al., 2008) with nightlight intensity
- Nightlights (Doll, 2008) blend population density and GDP
- Index of urbanization (URB): Intensity from 0 to 100 % within 1 km buffer of river

Photo by Benjamin Davies on Unsplash



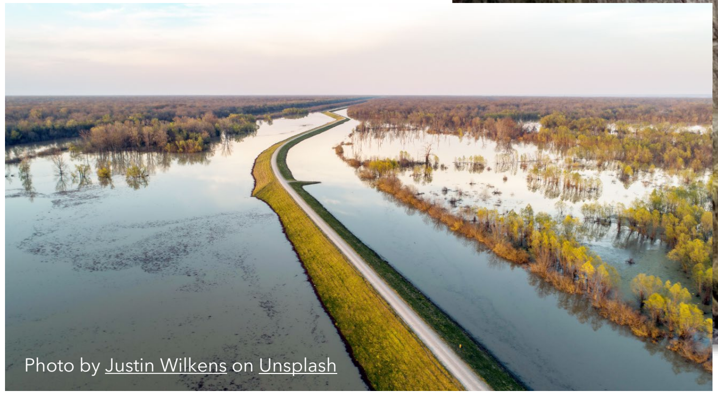
(NOAA; Doll, 2008)

6) Road development

Proxy for assessing effects on lateral connectivity as well as longitudinal connectivity (culverts) at intersections

- Index of road construction (RDD): road density within 1 km buffer of river
- GRIP v3 dataset (Meijer and Klein Goldewijk, 2009)

Photo by Eryk on Unsplash



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Summary of Pressure indicators

DOF – Degree of Fragmentation

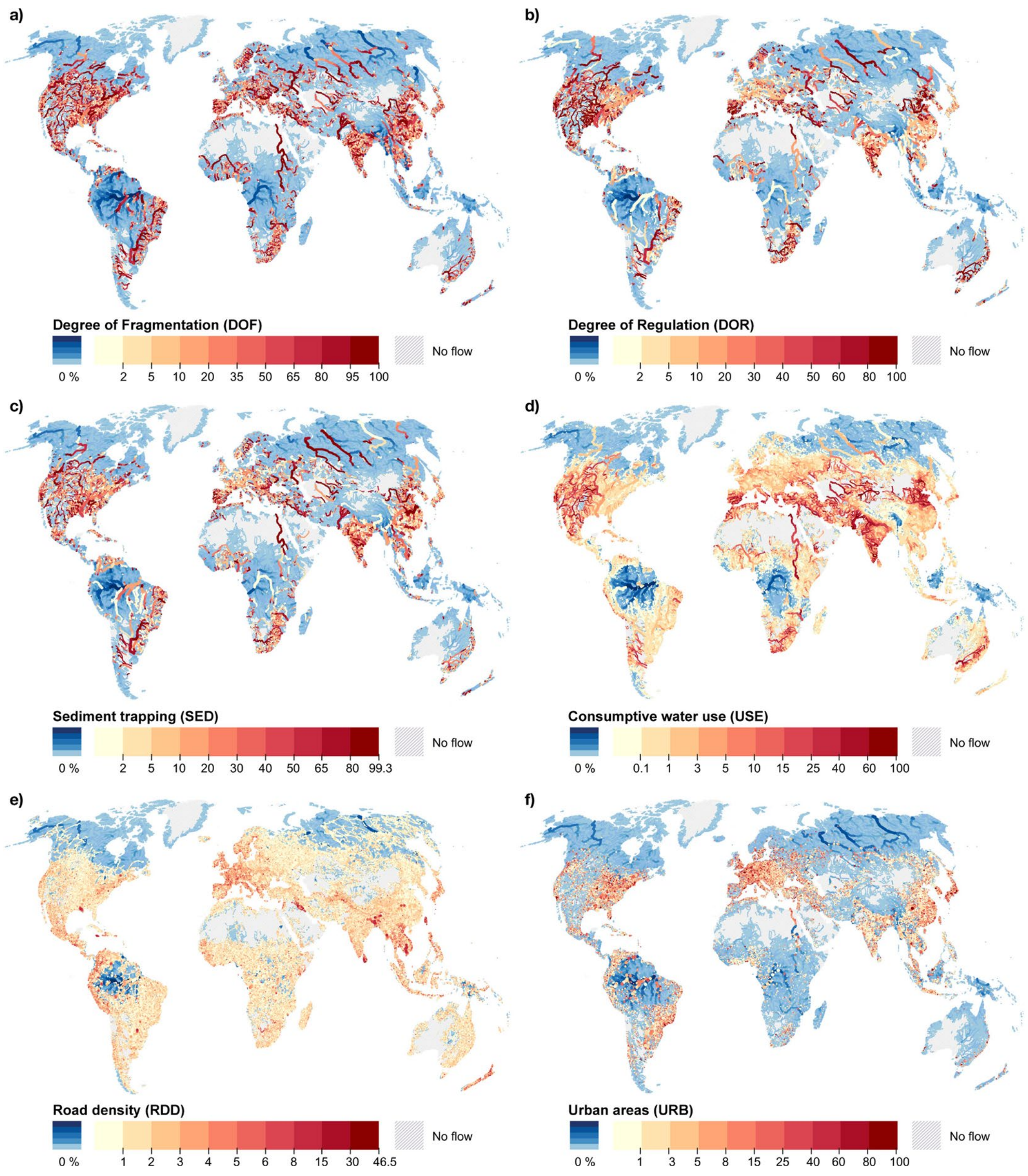
DOR – Degree of Regulation

SED – Sediment Trapping

USE – Water Consumption

URB – Urbanization

RDD – Road construction



Connectivity Status Index (CSI)

Weighted overlay

$$CSI_j = 100 - \frac{\sum_{i=1}^{n} x_i * w_i}{\sum_{i=1}^{n} w_i}$$

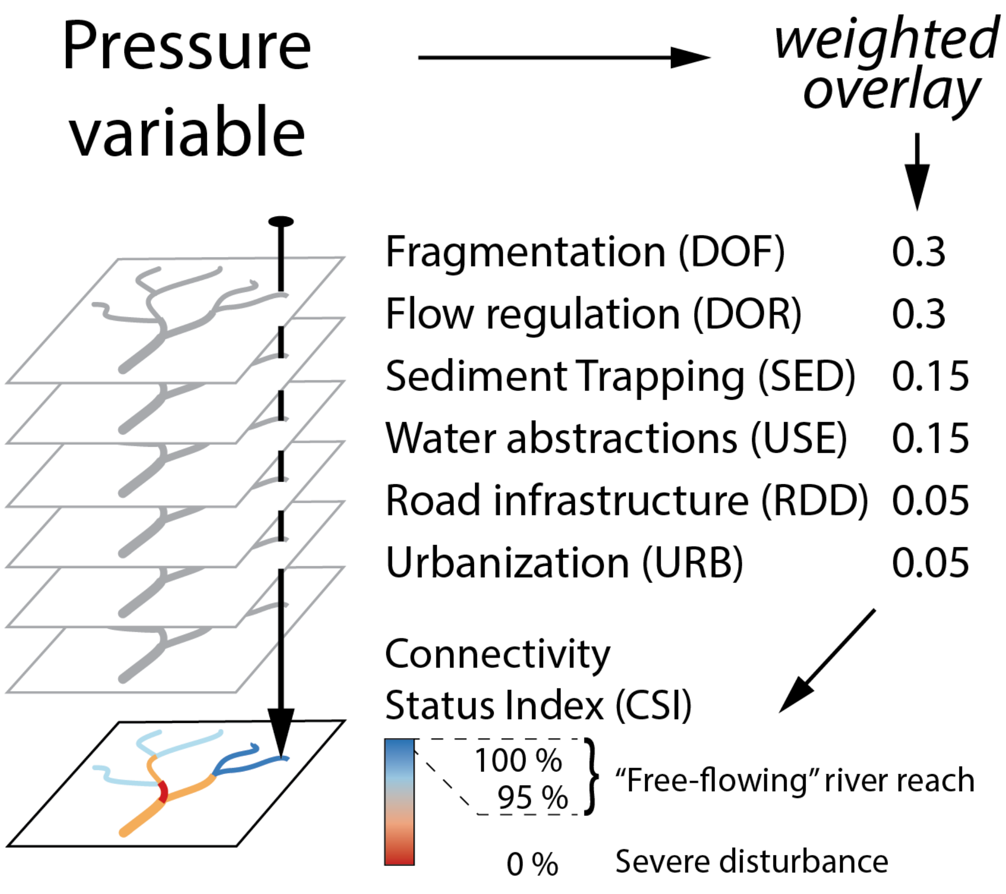
CSI_j is the Connectivity Status Index at reach j;
x_i is the value of pressure indicator i;
w_i is the weight applied to the pressure indicator i;
n is the number of pressure indicators

Special weighting if URB or RDD in floodplains

Floodplain weighting:

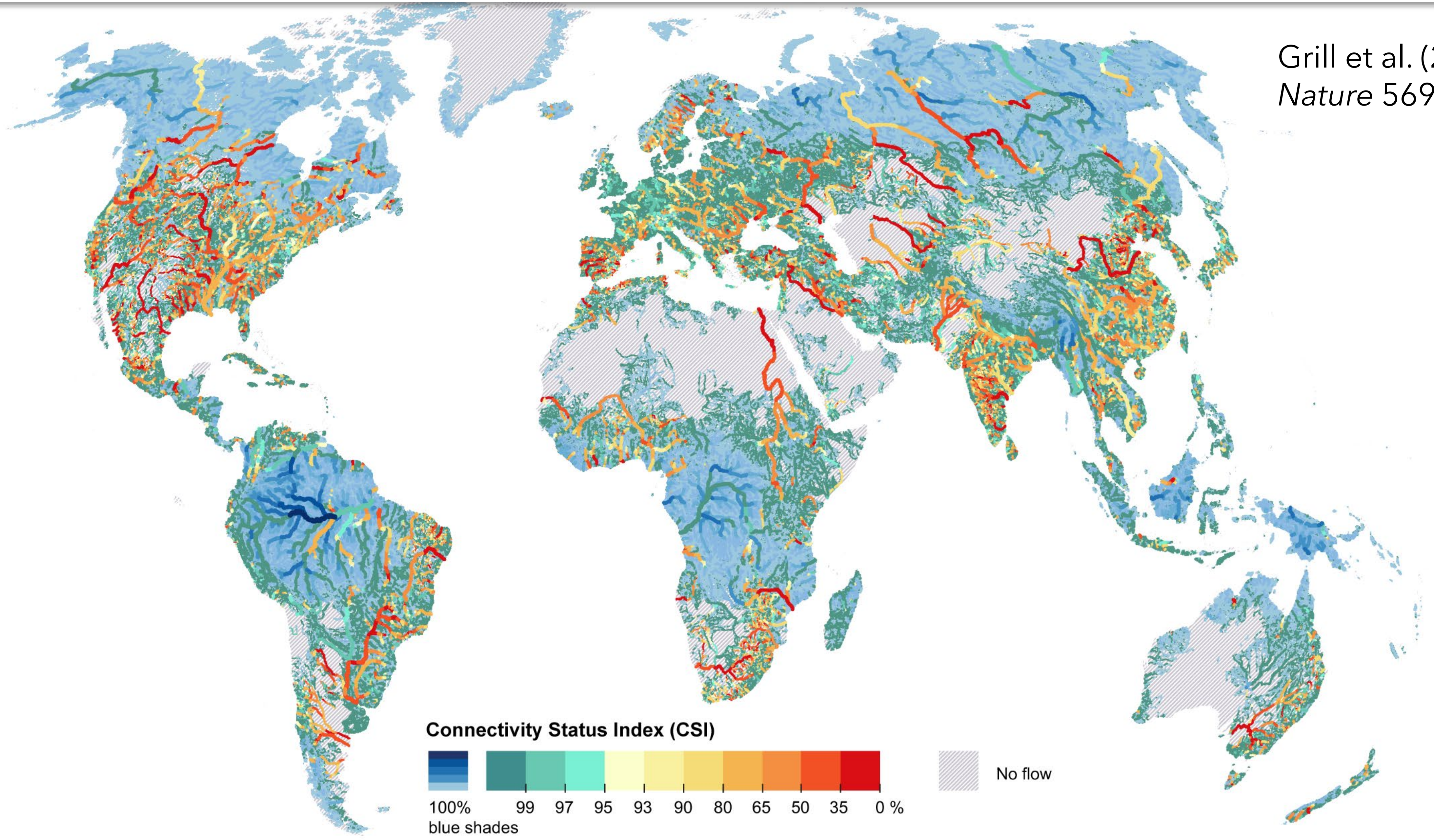
$$x_i = \tilde{x}_i * (1 + \frac{f_j}{2})$$

x_i is the value of the pressure indicator i (RDD or URB); $\tilde{x}_i$ is the value of the pressure indicator i (RDD or URB) without floodplain weighting; and f_j is the fraction of floodplain extent within the contributing sub-catchment of reach j.



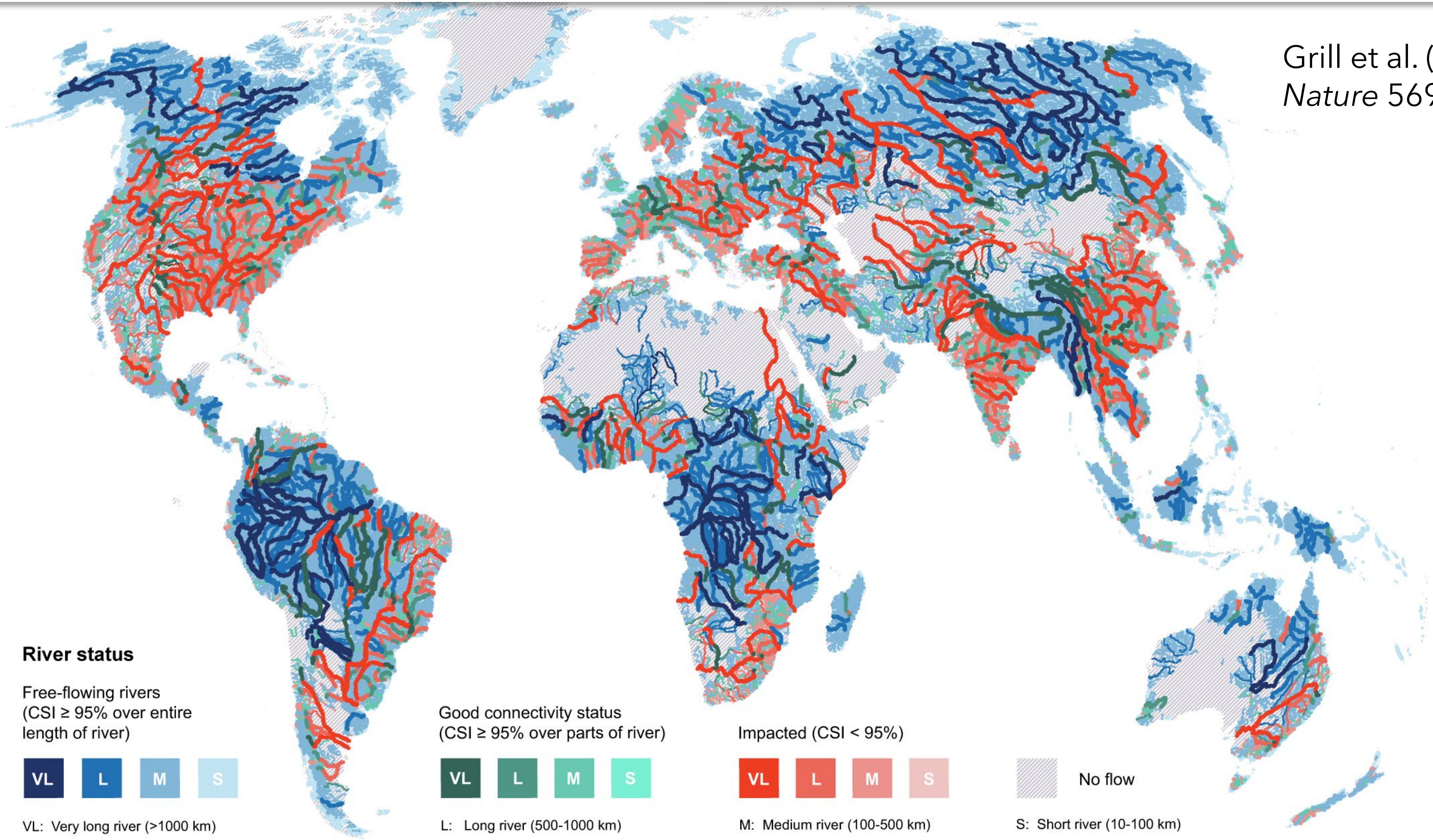
Global Connectivity Status (CSI)

Grill et al. (2019)
Nature 569



Free-flowing river status

Grill et al. (2019)
Nature 569



Conclusion

- Connectivity Status Index (CSI) assesses river connectivity quantitatively in multiple dimensions at the river reach scale
- Free-flowing Status assesses status of entire river based on CSI
- This global assessment provides a baseline for global monitoring of the free-flowing status of rivers.
- Methodology and results can provide valuable inputs to:
  - conduct basin-level planning and decision making,
  - identify rivers for protection,
  - program monitoring and evaluation,
  - targeting restoration opportunities,
  - the evaluation of alternative scenarios for future hydropower and other infrastructure planning

Thank you for your attention!

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