How can we work with the river?
Infrastructure, river dynamics and nature-based solutions

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Overview

Geomorphology, riverscapes and nature-based solutions

Philippine Rivers: How have nature and humans manufactured river form?

How much space do rivers in the Philippines need?

River channel change at critical bridge infrastructure

Rivers as natural infrastructure: healthy diets for rivers

Catchment Project

University of Glasgow

Policy Brief

Making space for Philippine rivers

Introduction

The Philippines is prone to hydrometeorological hazards, including floods, landslides and riverbank erosion. Embedding fluvial geomorphology, the study of the origin and evolution of river landscapes, into policy and practice is essential to achieve catchment-scale visions of sustainable river management.

Framing the Problem

A river's shape is the result of sediment erosion, transport and deposition, which are a consequence of water flow. Natural events (e.g. typhoons, earthquakes, volcanoes) and anthropogenic impacts (e.g. sand/gravel quarrying, riverbank protection) cause variation in sediment supply, which drive change in riverbed levels. These changes influence flow routing, and thus flood risk. The same factors determine variations in bank erosion rates; elevated rates result in the loss of developed floodplain and the failure of critical infrastructure such as road bridges. In the Philippines, rivers are particularly dynamic; risks arising from changes in a river's bed and bank position need to be assessed and incorporated into river and flood risk management to mitigate the impact on people's welfare and the economy.

Executive summary

This project developed tools and approaches that incorporate geomorphic principles towards sustainable river and flood management that recognises river diversity and supports practices that 'work with the river'.

Key research findings

Our work found differences in the character, behaviour and evolutionary trajectory of river systems in the Philippines. As yet, understanding of this diversity isn't often used to inform river and catchment management.

Our work showed how different rivers in different parts of the Philippines require different amounts of space as they adjust in different ways.

We developed simple equations to estimate flood volumes based on catchment size and regional location.

Findings from several case-study rivers showed how repeat topographic surveys can be used to quantify and explain channel change. This approach could be used to achieve sustainable sand and gravel quarrying.

We showed that flood maps need to be updated in catchments where there is significant river channel change.

We recommend incorporating our tools and approaches to enable and prioritise more sustainable management of Philippine rivers, in ways that will reduce disaster risk and improve the health of river ecosystems.

Nature-based solutions to manage flood risk 'work with the river'

Geomorphic principles provide an integrating template for coherent, proactive and cost-effective strategies at the catchment-scale

New and emerging technologies present opportunities for communities of practice to codevelop and enact transformative policies and actions

https://eprints.gla.ac.uk/338075/

Terms… (1) Geomorphology

derived from Greek

geomorphology

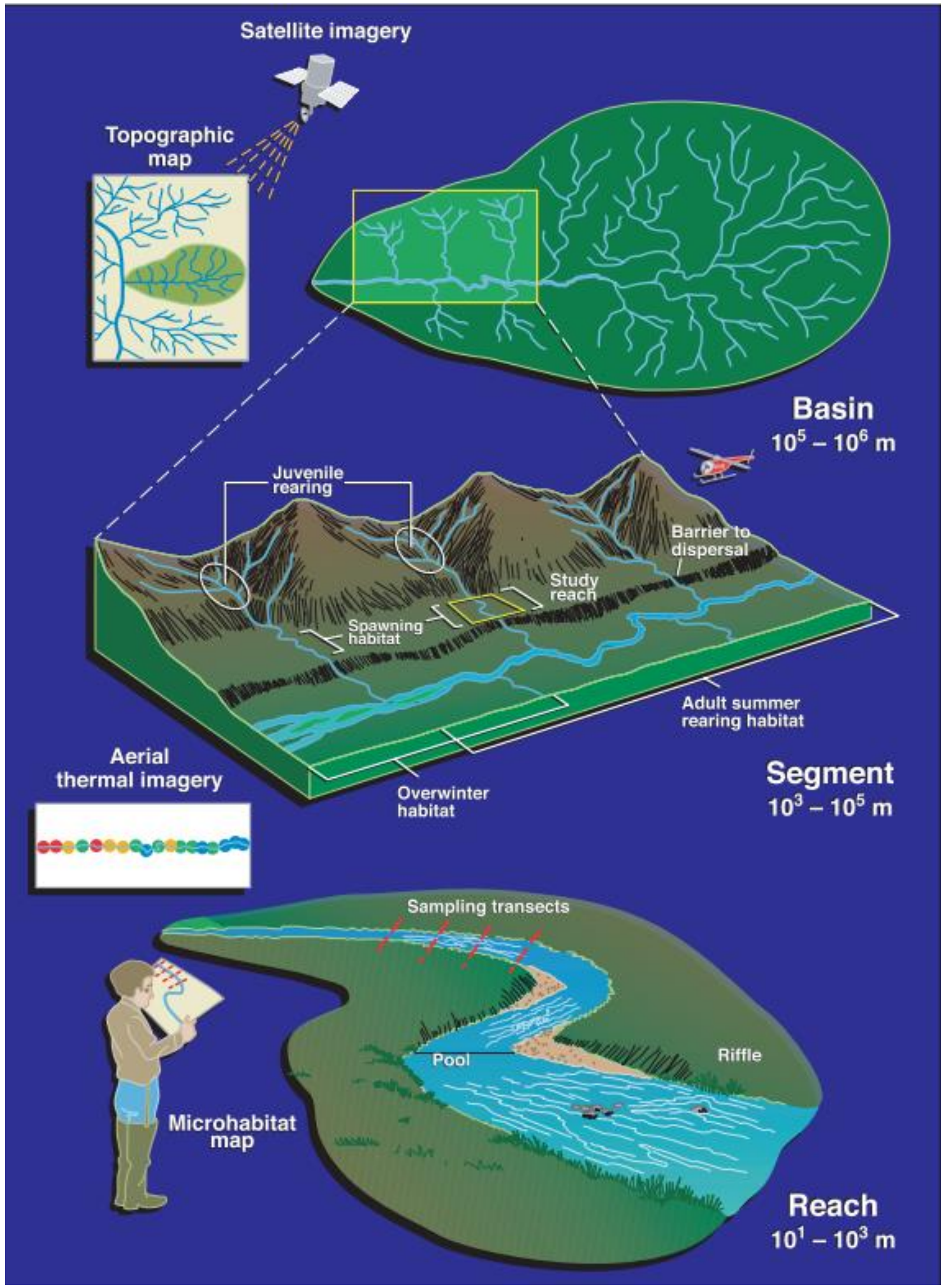
ge - 'earth'
morphe - 'form'
logos - 'discourse'

Tooth and Viles (2014) *10 reasons why geomorphology is important*

Terms… (2) Riverscapes

Multi-scale "*A continuous view of the river is needed to understand how processes interacting among scales set the context for stream fishes and their habitat*"

Fausch et al., 2002

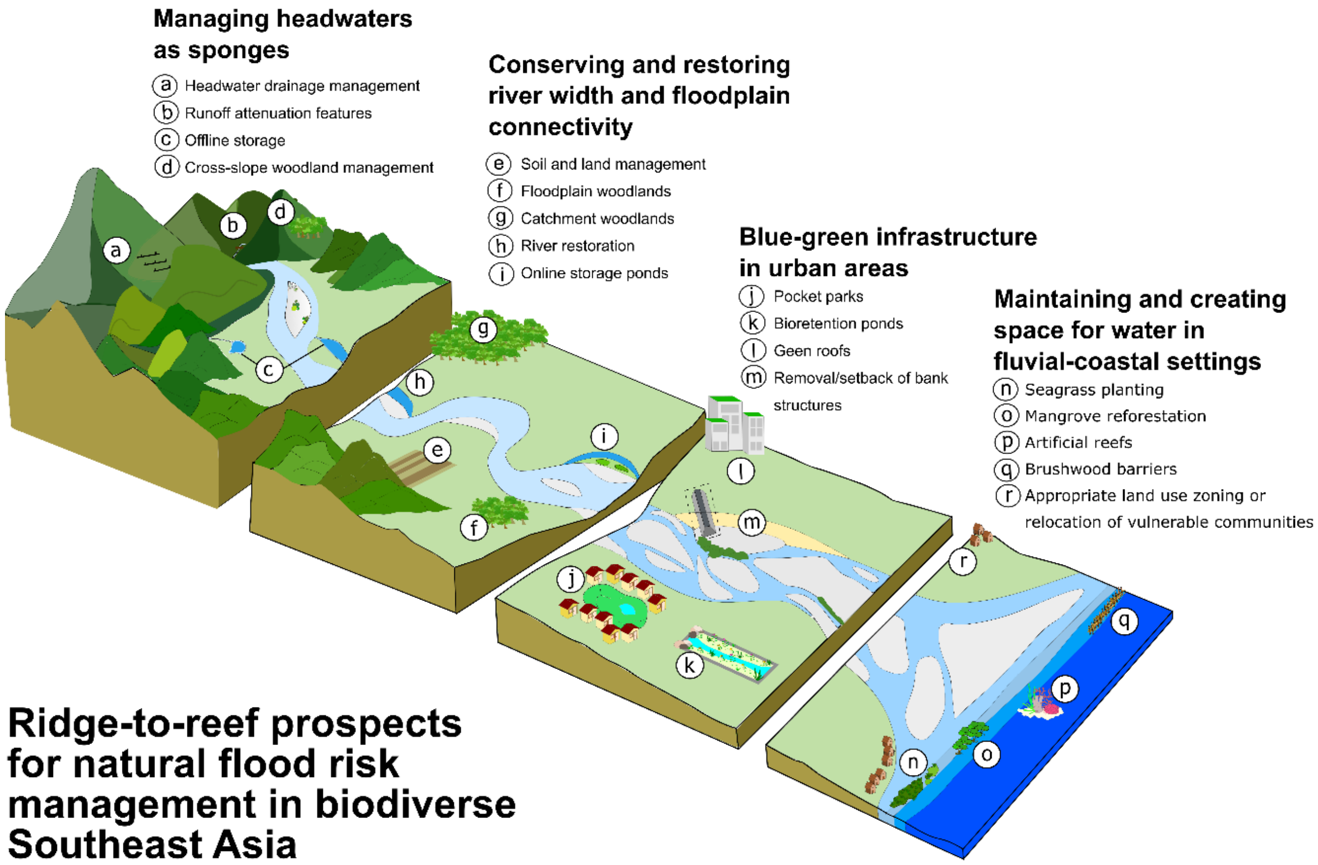


UNITED NATIONS DECADE ON
ECOSYSTEM RESTORATION
2021-2030

Terms... (3) Nature-based solutions

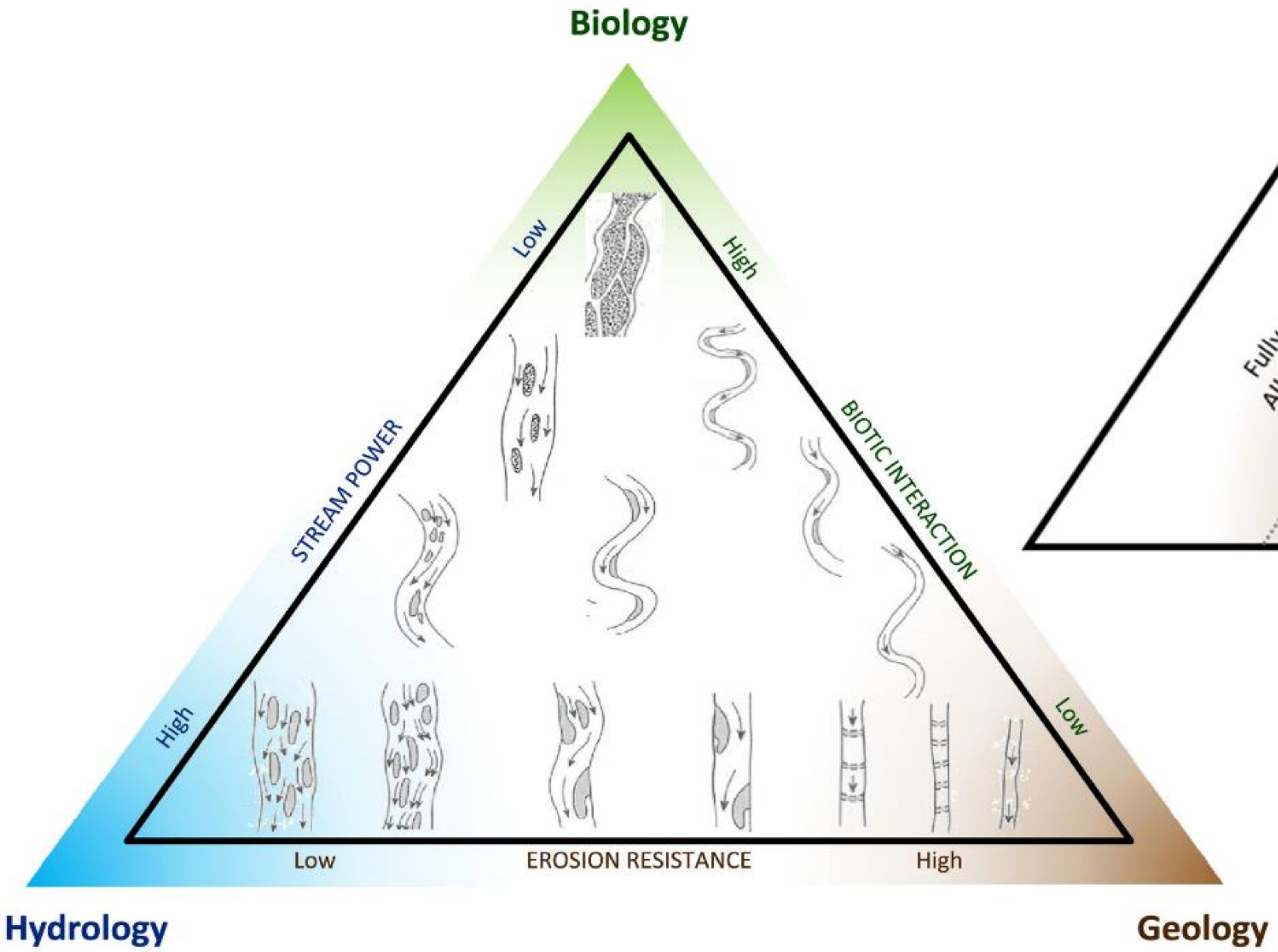
"Nature-based solutions (NbS) are actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature."

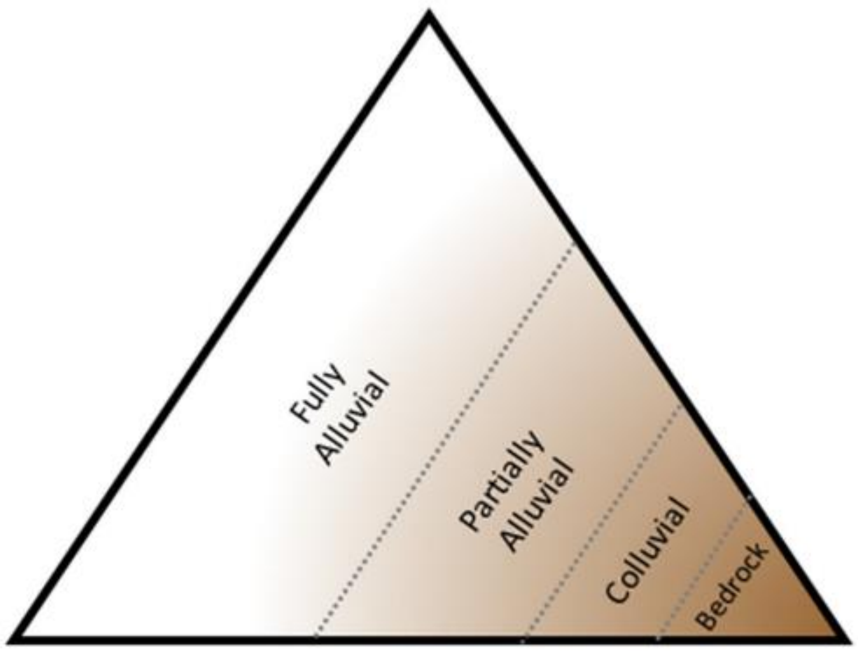
UN environment programme



Tolentino et al. *(2025) WIRES Water*

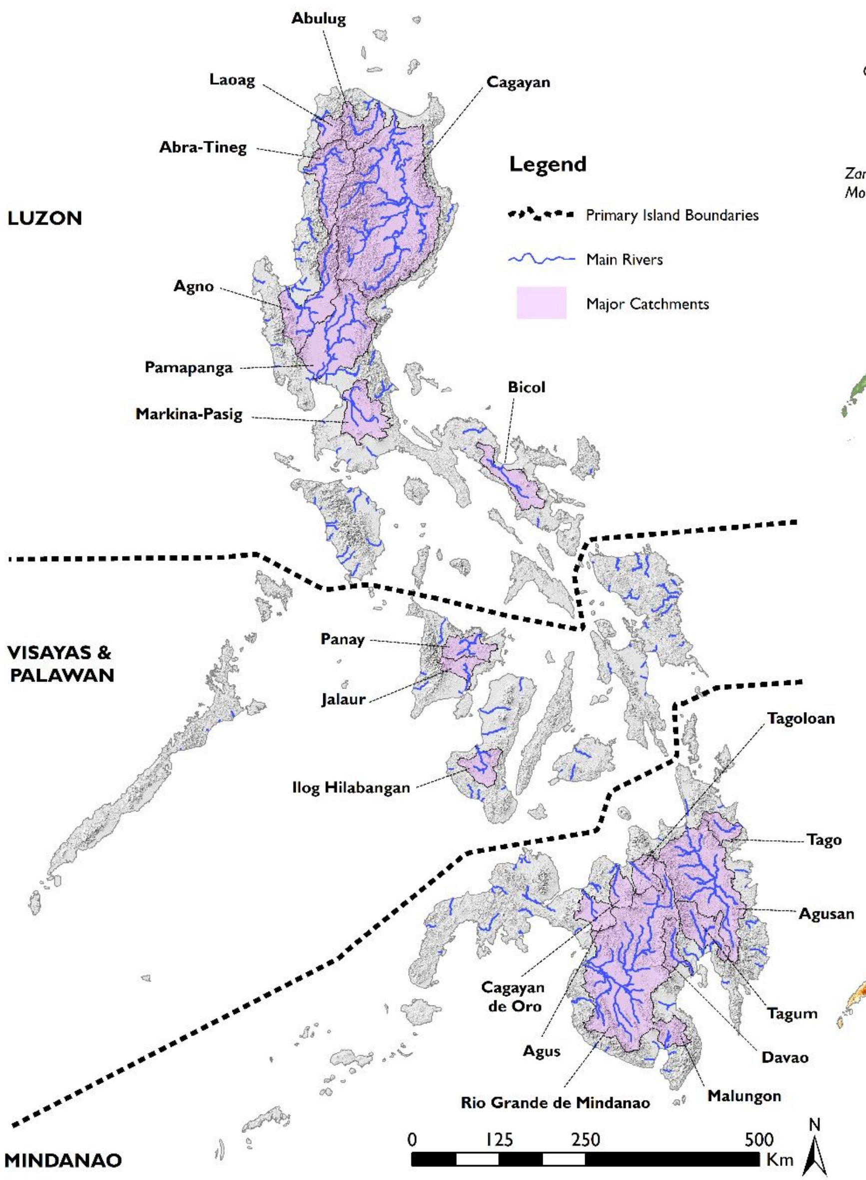
How does nature shape rivers?

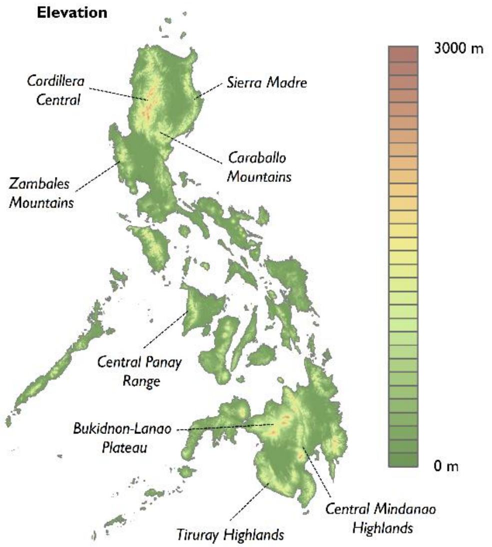


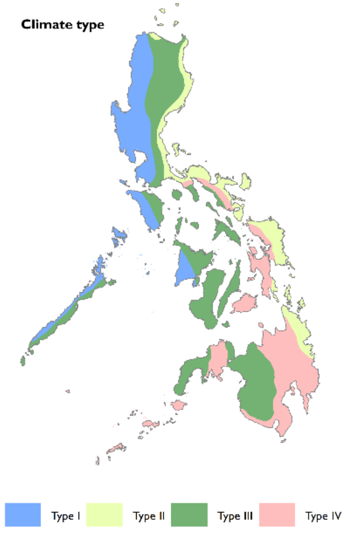


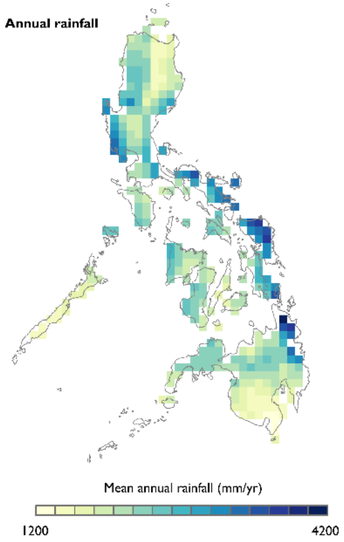
Castro and Thorne (2020) *RRA*

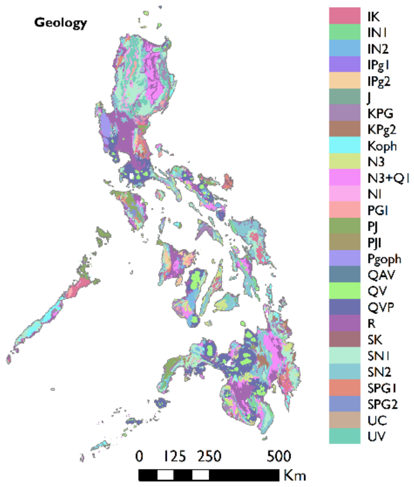
How has nature shaped river form in the Philippines?

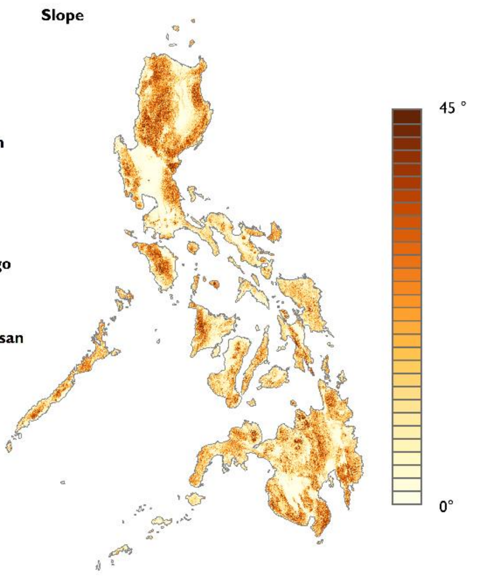












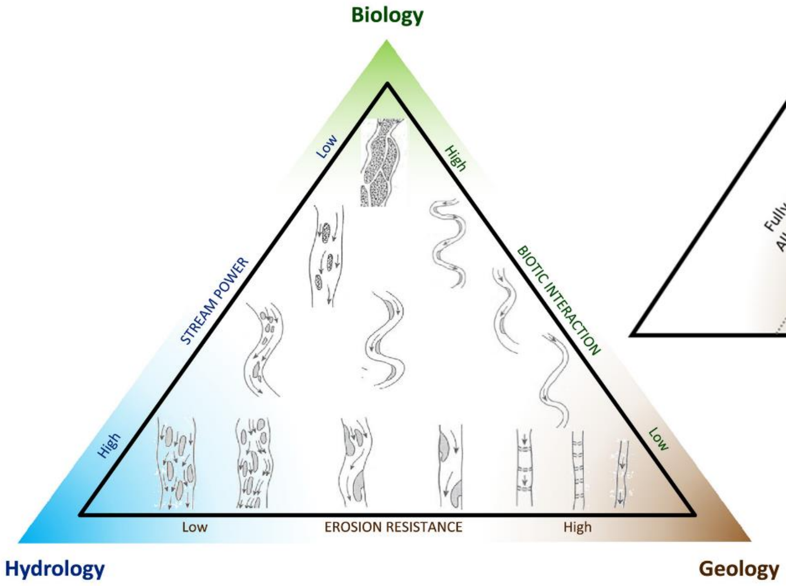
Hydrometeorological hazards

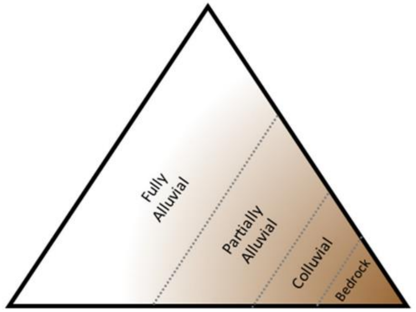
Variable sediment inputs and land use practices

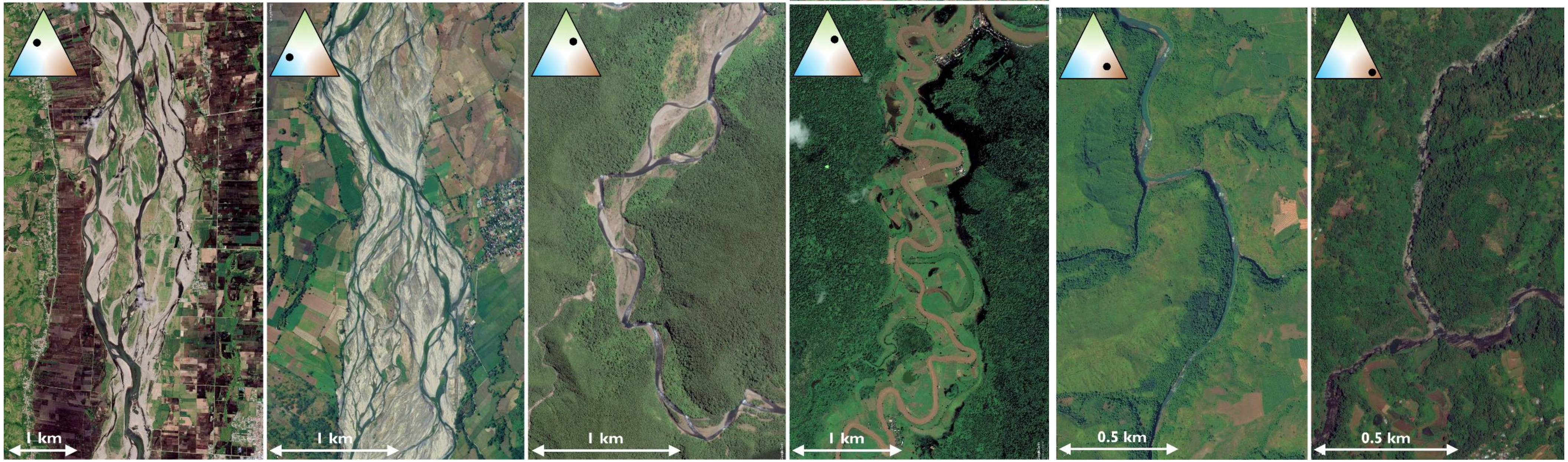
Legacy effects

Diverse and distinctive rivers

How has nature shaped river form in the Philippines?







How have humans influenced river form in the Philippines?

Impoundments

Ambuklao Dam, Agno catchment

How have humans influenced river form in the Philippines?

Flood and erosion control structures

Norzagaray River, Luzon

How have humans influenced river form in the Philippines?

Flood and erosion control structures

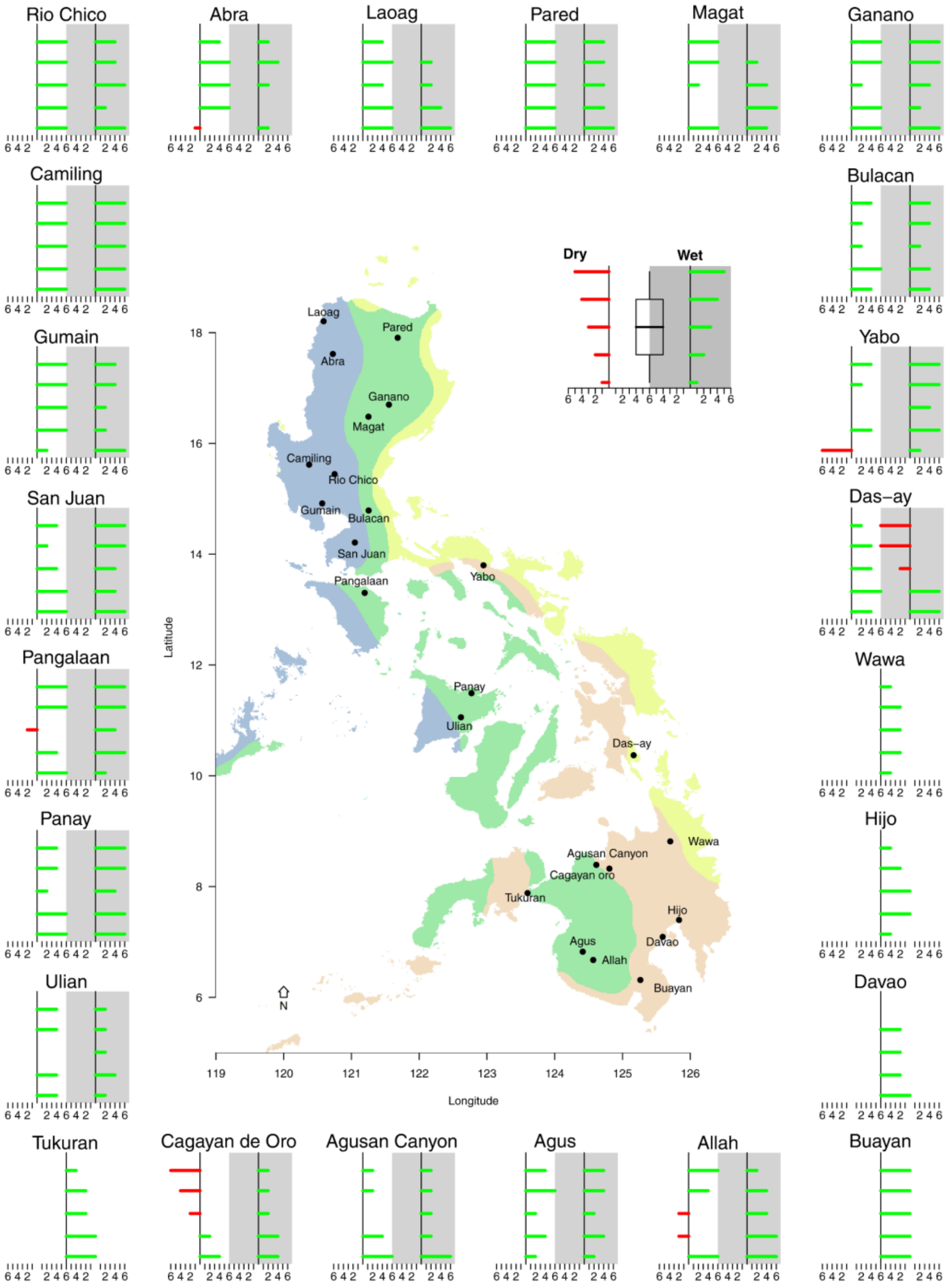
Norzagaray River, Luzon

How have humans influenced river form in the Philippines?

Climate change

"A very consistent overall increase in streamflow is predicted by all GCMs and all scenarios for the whole country in both the dry and wet season."

Tolentino et al., 2016, *PLOS One*



How have humans influenced river form in the Philippines?

Quarrying

Image credit: Kim Cabrera, UPLB

Ambayaoan River, tributary of Agno, Luzon

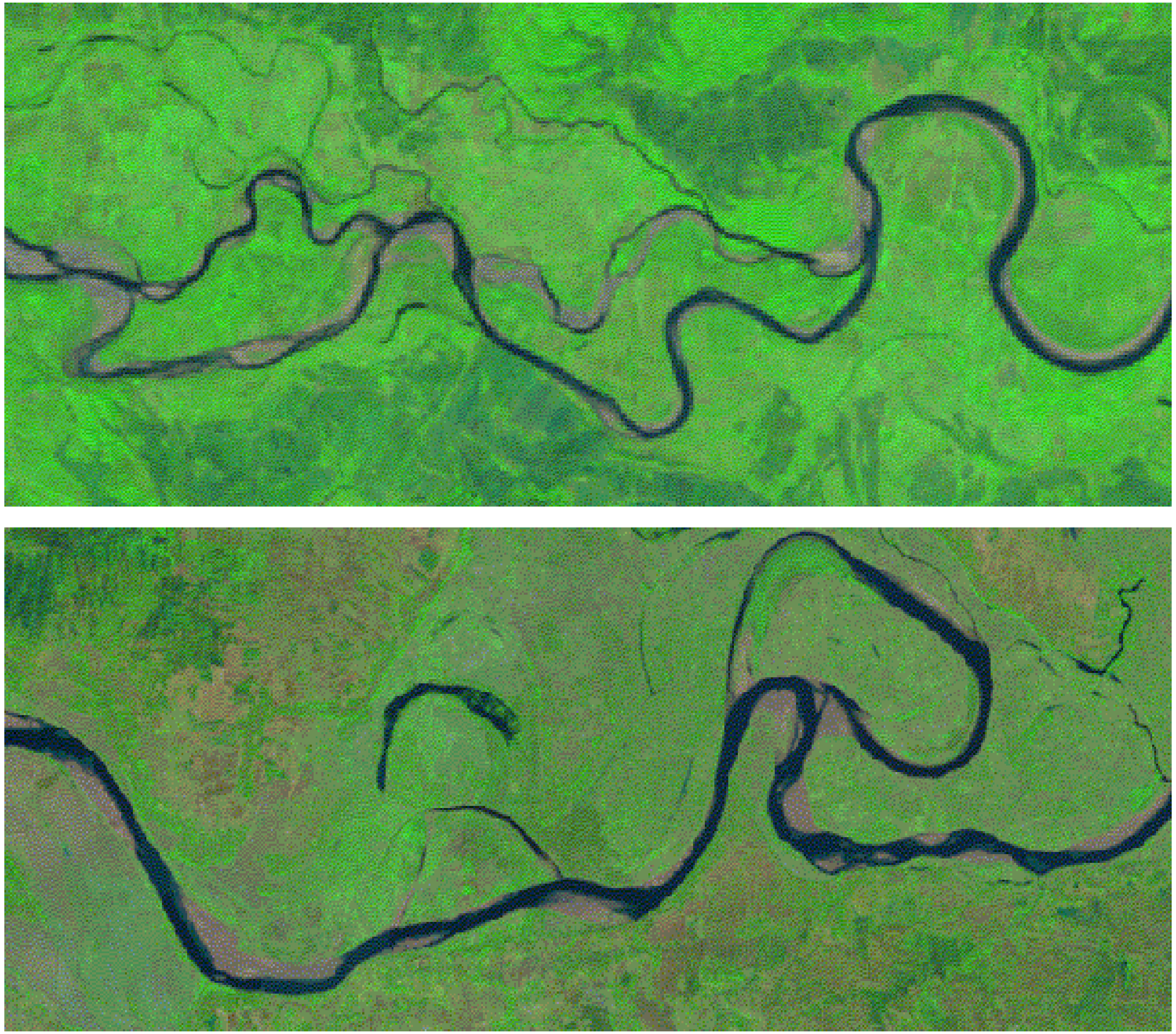
How have humans influenced river form in the Philippines?

Quarrying

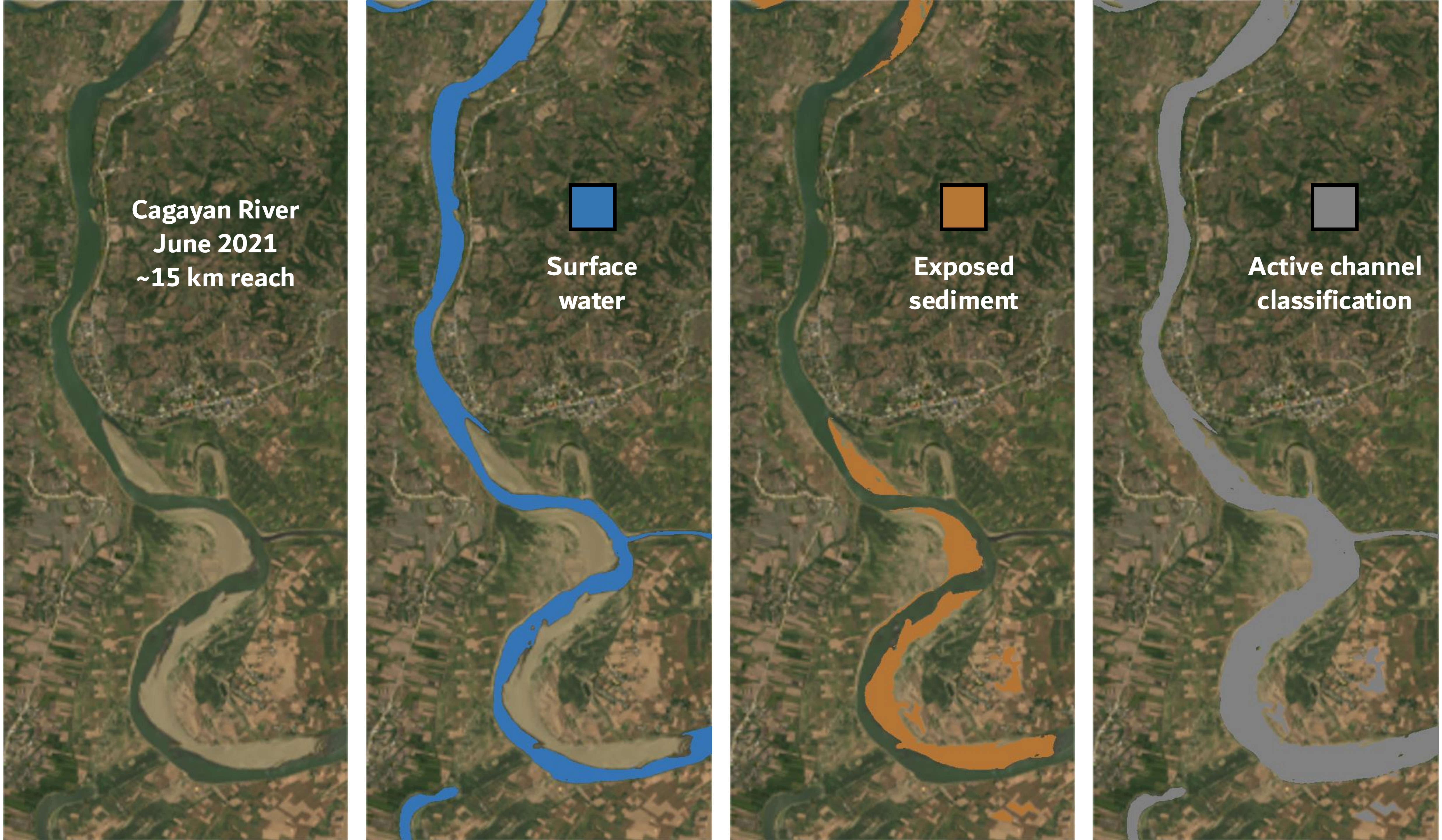
Ambayaoan River, tributary of Agno, Luzon

Different rivers need different amounts of space

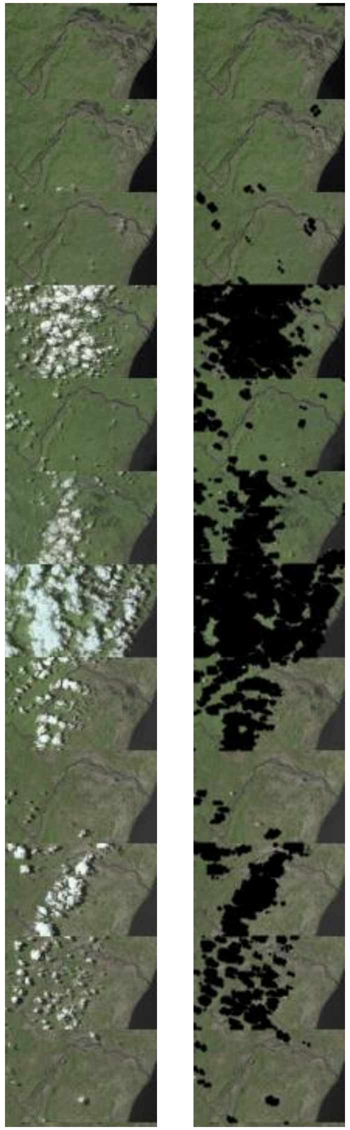
How much space do active rivers use?



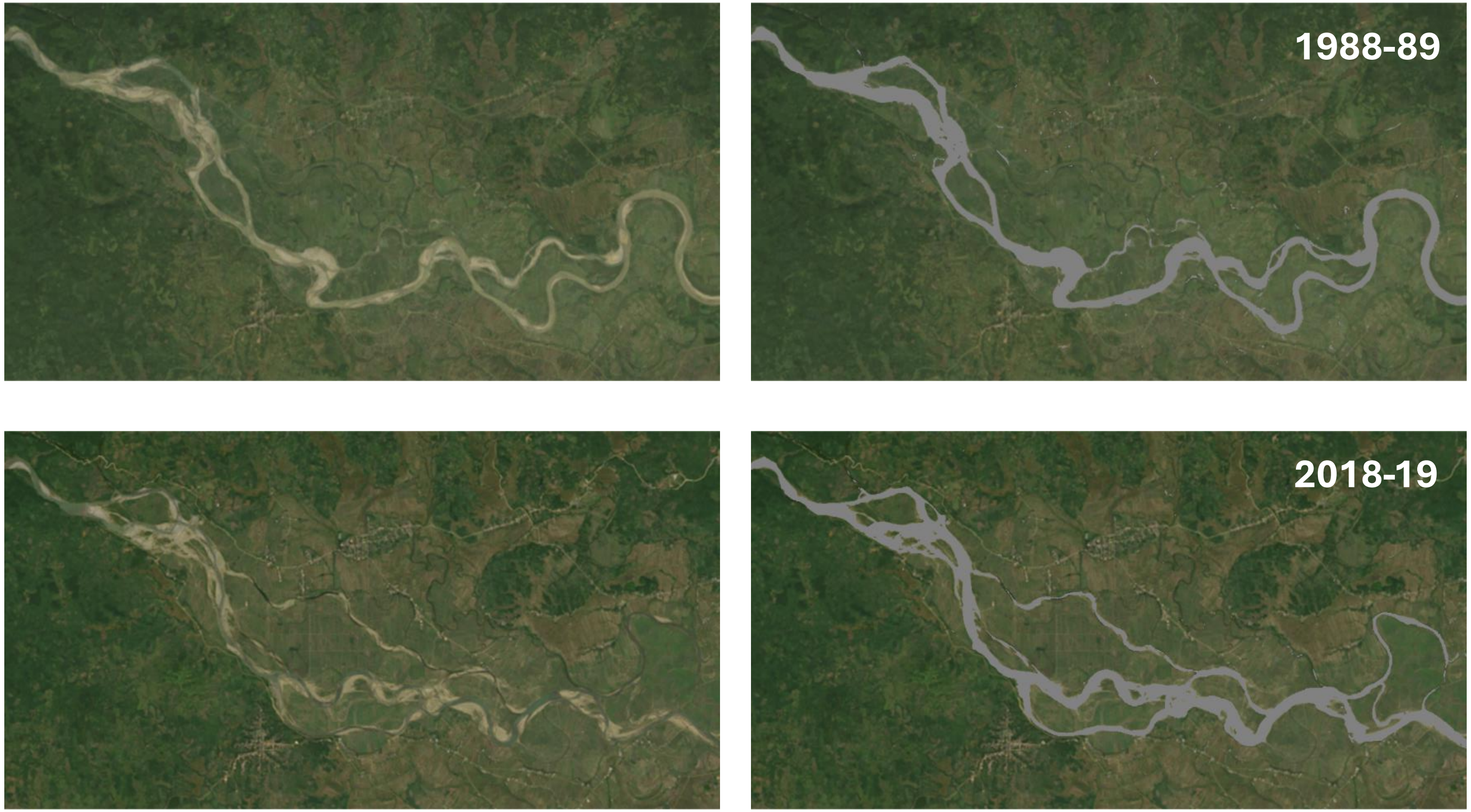
Boothroyd et al., accepted, *Nature Communications*


Cagayan River
June 2021
~15 km reach
Surface water
Exposed sediment
Active channel classification

Active channel classification from temporal composite imagery



Temporal composite | Active channel

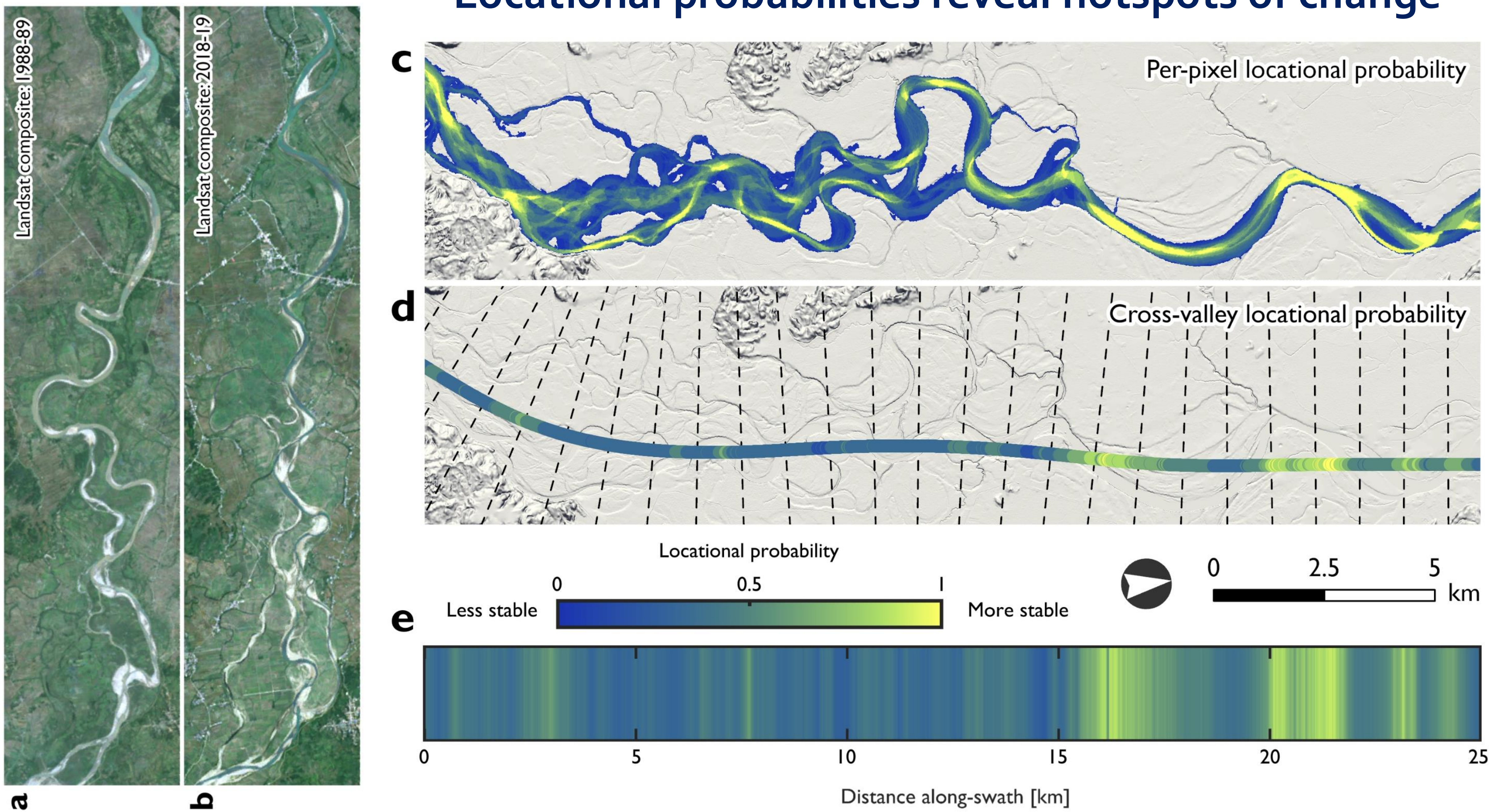


Uses ~30 images every 2 years for the temporal composite image (x 16)

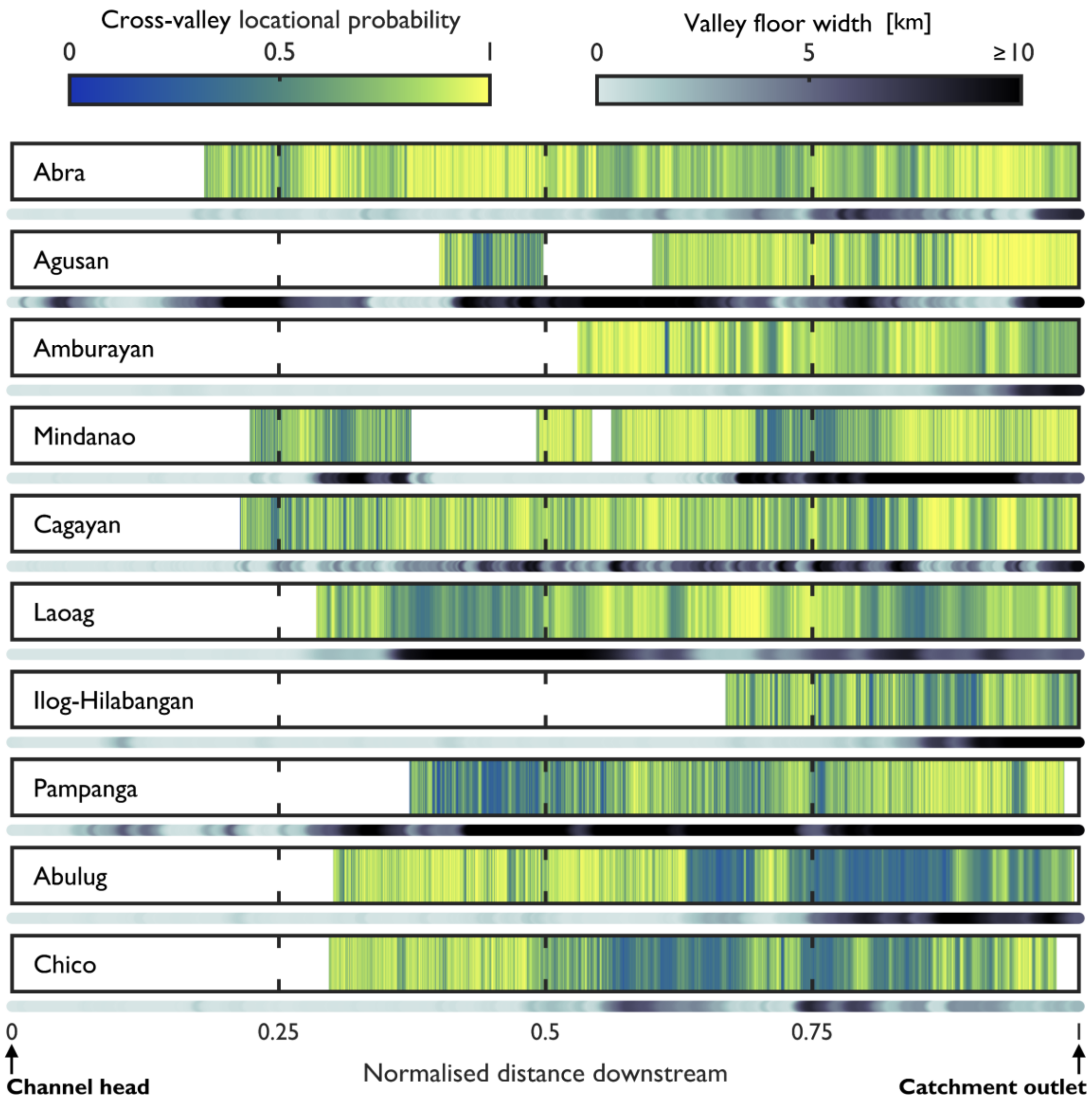
Unfeasible to analyse this many images using traditional approaches

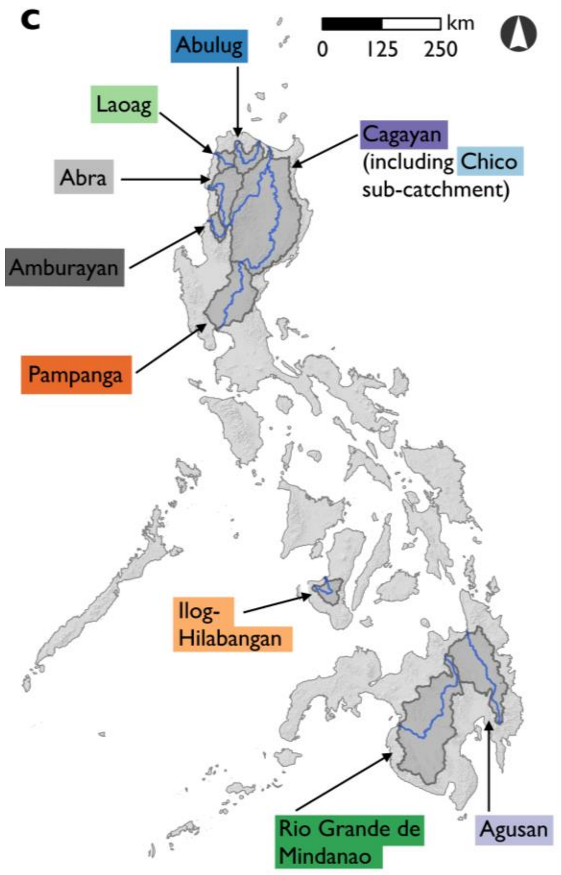
2018-19
2016-17
2014-15
2012-13
2010-11
2008-09
2006-07
2004-05
2002-03
2000-01
1998-99
1996-97
1994-95
1992-93
1990-91
1988-89

Locational probabilities reveal hotspots of change



Spatially heterogeneous nature of river planform mobility





Idiosyncratic patterns and rates

of geomorphic river mobility

Boothroyd et al., accepted, *Nature Communications*

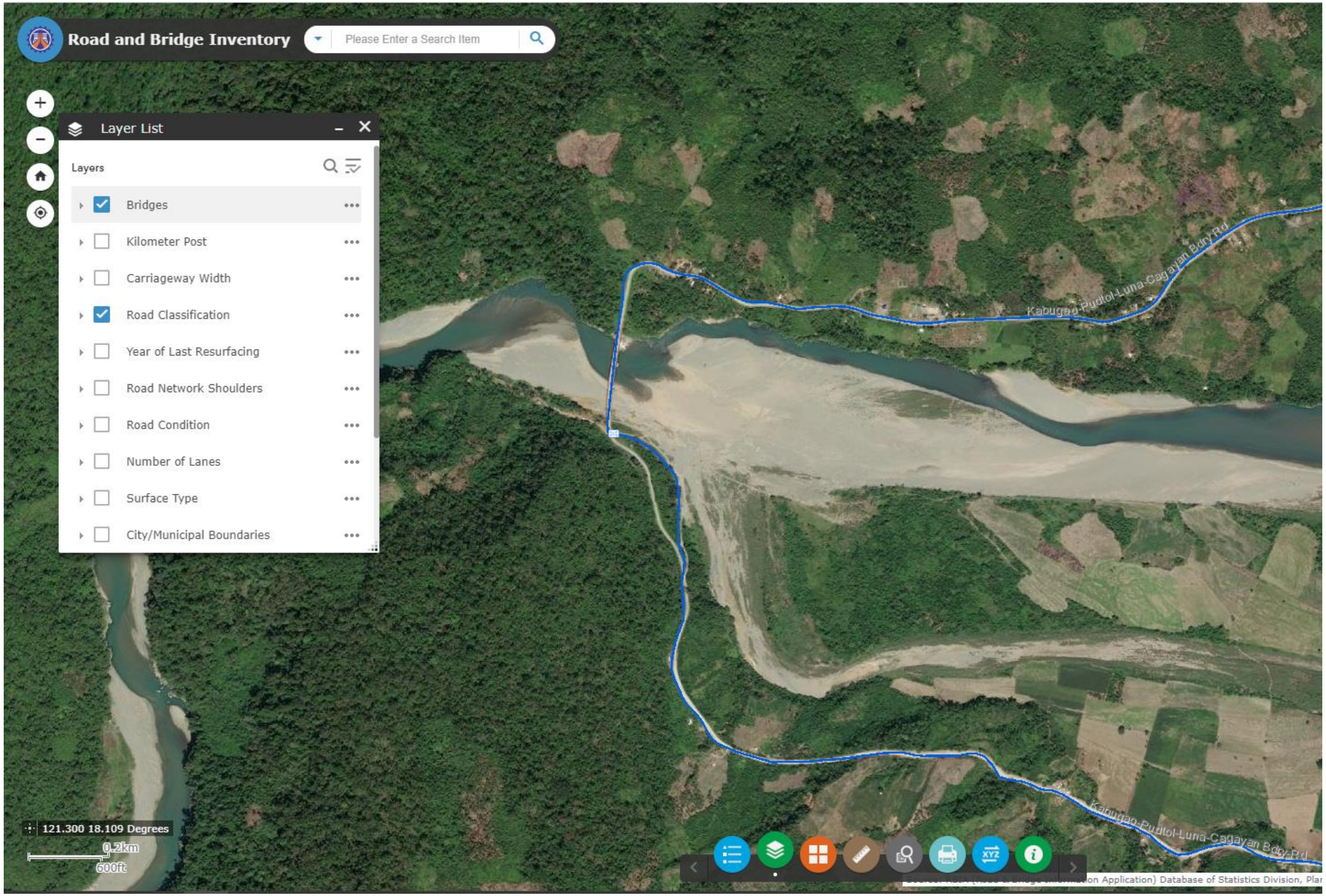
Critical infrastructure: bridges

River bridges are vulnerable nodes in transport and utility networks; exposed to hydrometeorological hazards more than other forms of infrastructure and associated with high socio-economic costs when damaged.

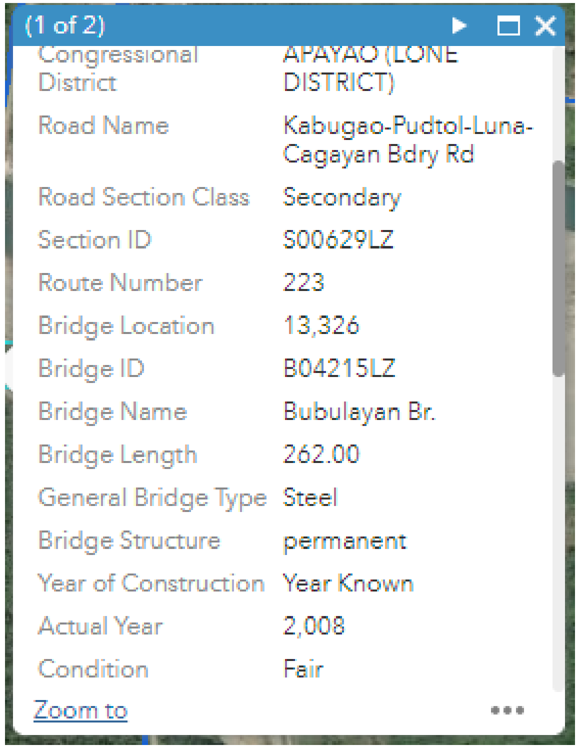
In the Philippines, the road network handles 90% of passenger and 50% of freight transportation, providing a vital link between communities. Critical infrastructure is often located close to rivers, but rivers in the Philippines are particularly dynamic and societal exposure to hazards is high.

Geomorphic and flood-related hazards can cause substantial damages to critical bridge infrastructure, as shown at Caraycaray Bridge (Biliran Island).

DPWH Philippines bridge and road geodatabase



Geospatial information for 8410 bridges along national roads, with attribute data including bridge deck length, year of construction and road type.



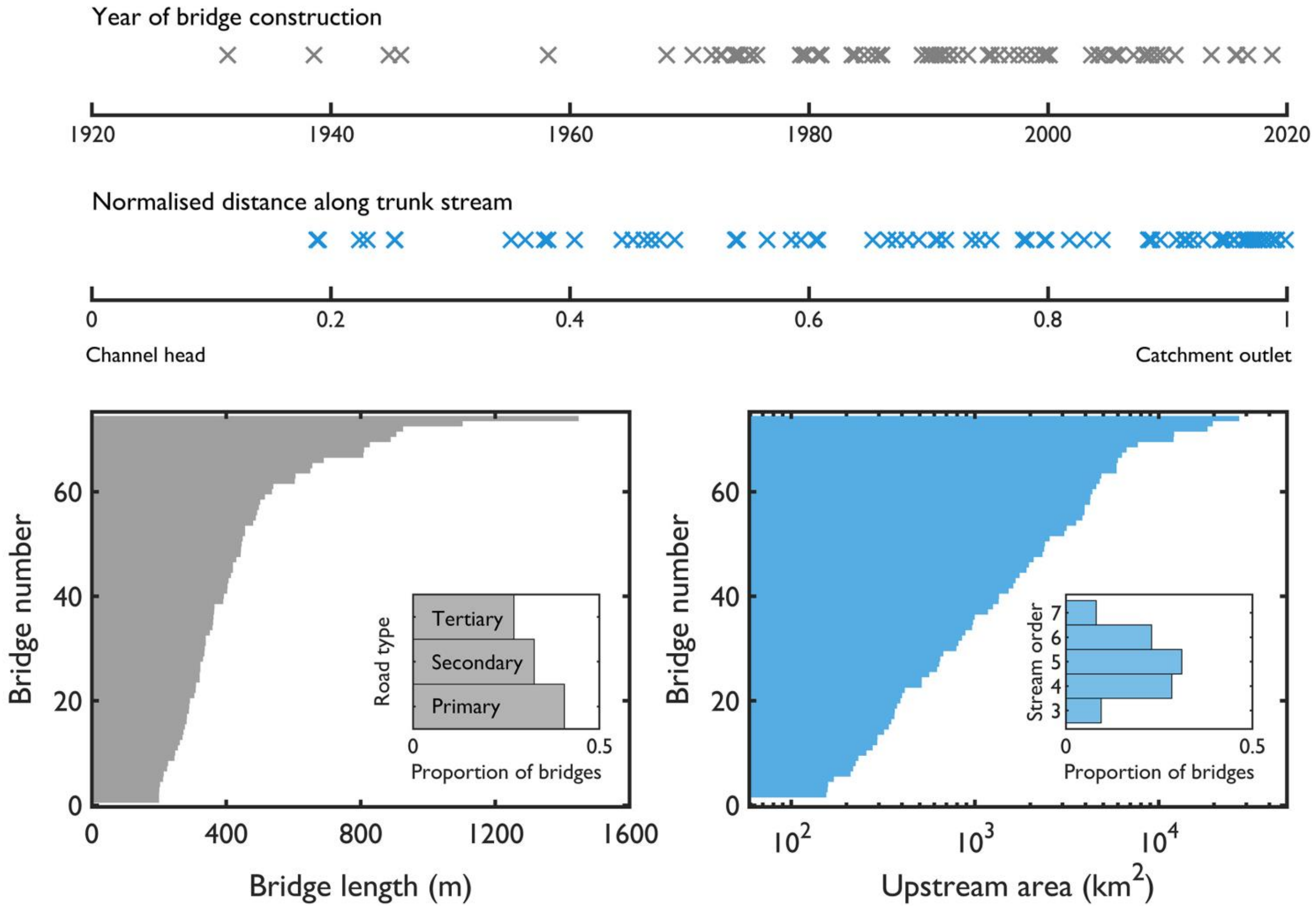
Filtered geodatabase to include large river bridges (deck length > 200 m)

The database was filtered to include only permanent bridges where the bridge deck length was equal to or greater than 200 m (n = 256).

A visual inspection was performed to ensure that bridges were located at contemporary river crossings (n = 182).

Only those bridges where the active channel width exceeded 150 m (equivalent to five Landsat pixels) were retained for analysis (n = 74).

Extracted stream network information upstream of each bridge.



Boothroyd et al., 2021, *STOTEN*

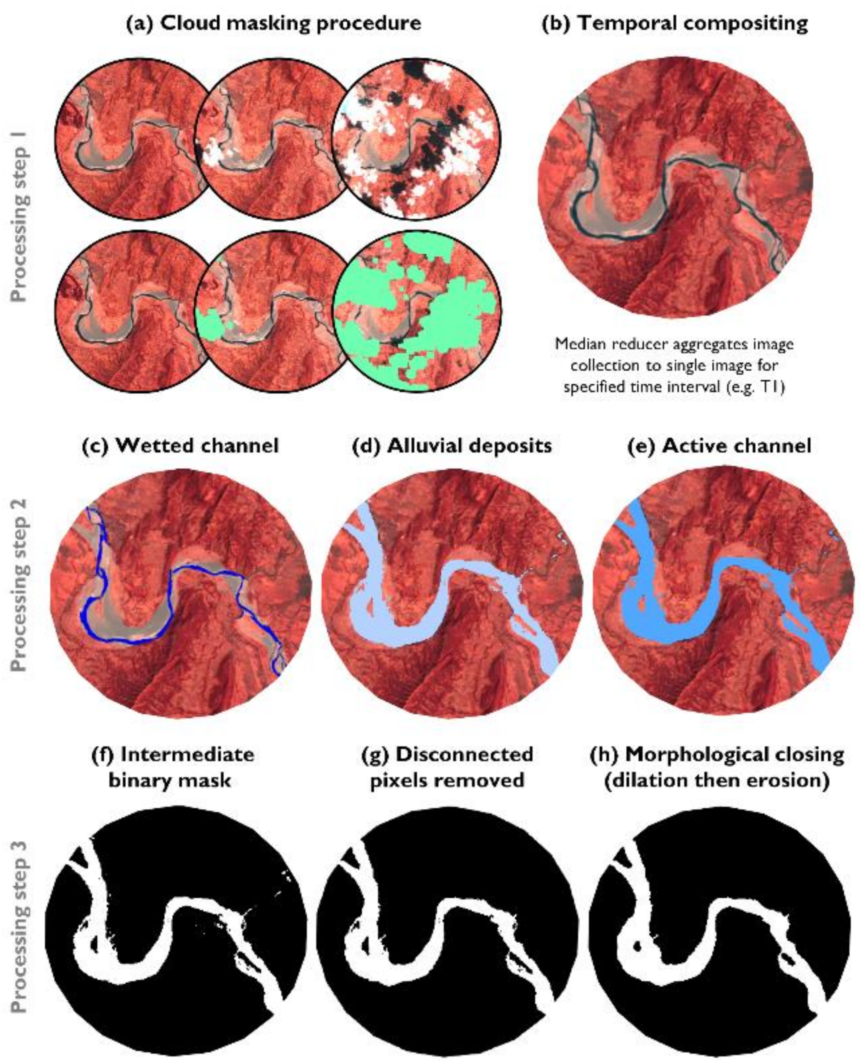
GEE Processing Workflow

Inputs

Data sources

Processed using Google Earth Engine

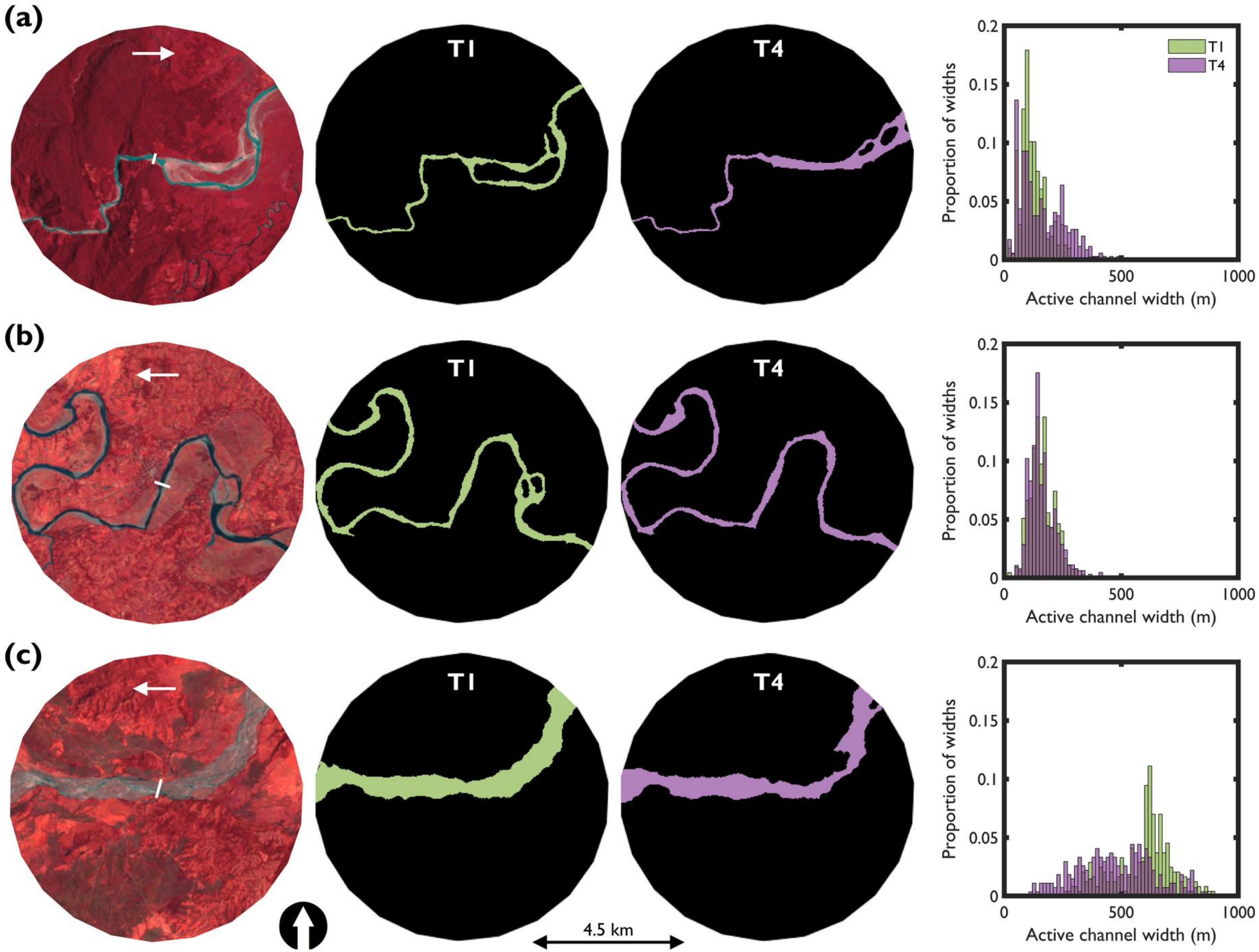
Processing workflow



Outputs

$$\text{IoU} = \frac{\text{Area of Overlap}}{\text{Area of Union}}$$

The Jaccard index ranges between 0 and 1, whereby calculated values closer to 1 indicate greater similarity between active river channel masks (i.e. less planform adjustment).



Bubulayan Bridge on the Abulug River (Apayao, Luzon) marked planform adjustment (Jaccard index 0.33) resulted in overall **channel expansion**.

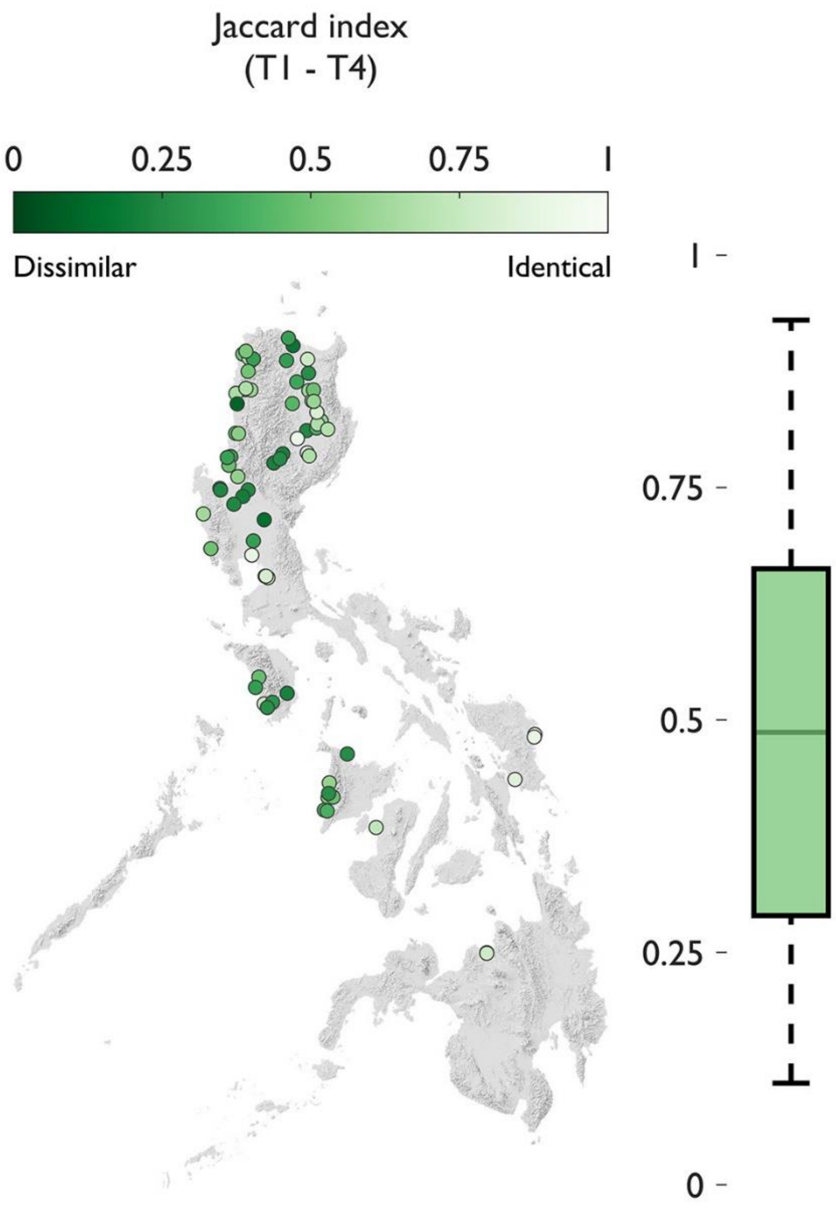
Jones Bridge on the Cagayan River (Isabela, Luzon) planform adjustment was less marked (Jaccard index 0.66) with only **negligible change** in active channel width

Lumintao Bridge on the Lumintao River (Mindoro Occidental, Luzon) relatively minor planform adjustment (Jaccard index 0.75) through **channel contraction**.

Boothroyd et al., (2021) – *STOTEN*

National-scale assessment of river migration at critical bridge infrastructure

- Channel adjustment in the vicinity of large bridges varies across the Philippines in the national-scale analysis.
- Over the 30-year engineering timescale, the mean Jaccard index is 0.50 (median = 0.49), indicating considerable **planform adjustment** at sites of critical bridge infrastructure.
- However, the spread of the 25th and 75th percentiles (50% of values in the range 0.30 to 0.66) and standard deviation of the Jaccard index (0.22) show substantial variation among bridge sites.
- **The key finding was the diversity in the range of river behaviours exhibited; different types of river adjust in different ways and the relative risk of river migration varies between sites.**

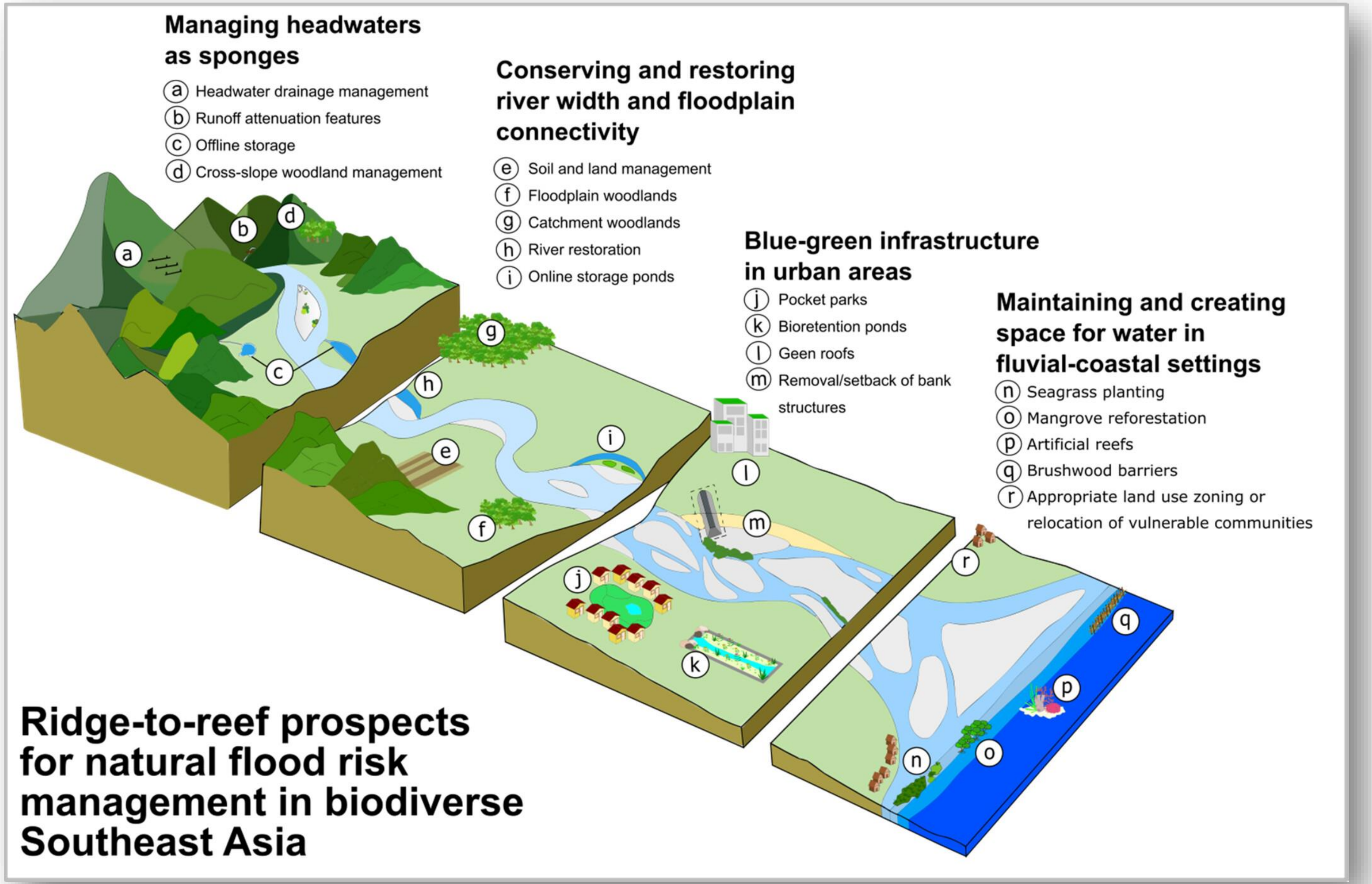


Boothroyd et al., (2021) – *STOTEN*

Cascading consequences of structural interventions

Tolentino, Williams, et al., 2025, *River Research and Applications*

Towards nature-based river and flood risk management?

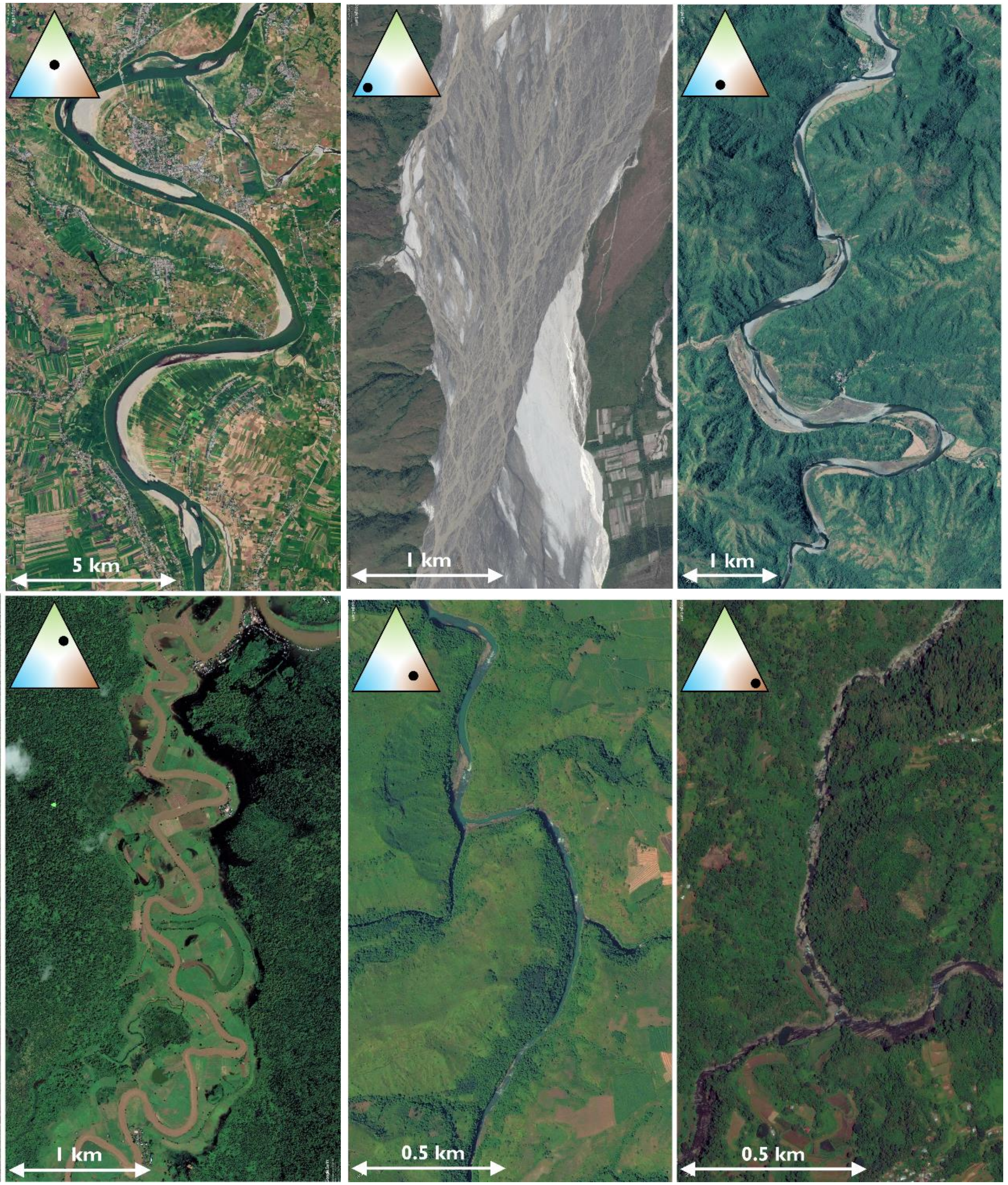


Tolentino, Williams, et al., 2025, *WIRES Water*

Rivers as resilient natural infrastructure

Space for:

- Thriving ecosystems for nature and food
- Flood storage and conveyance
- Adaptation to climate change impacts



Geomorphologically informed river management → towards nature-based sustainability?

In understanding geomorphic hazards at critical bridge infrastructure, it is essential to recognise the diversity, appraise the dynamics and understand the trajectory of each river system individually.

Satellite data analyses could be formally incorporated into bridge monitoring investigations and used to inform the strategic design and placement of future bridge infrastructure.

Satellite data analyses offer a low-cost approach for monitoring the relative risk of river migration in large rivers; the approach can be extended to include other critical infrastructure adjacent to rivers (e.g., road, rail pipelines).

Rethinking river and infrastructure management: key messages

1. Rivers are not problems to fix, but systems to work with
2. Each river is unique, respect its natural diversity
3. A river is a connected system; what happens upstream affects downstream
4. Spending on prevention not only saves lives and money but reduces the cycle of repeated damage
5. Communities are not just stakeholders, they are knowledge holders
6. Think beyond today, plan for tomorrow's river
7. Building capacity means embracing collaboration and continuous learning

Thank you

“Humans as part of nature” vs “command and control”

Unless we **Respect Diversity**, we fail to protect place-based values (biodiversity, etc)

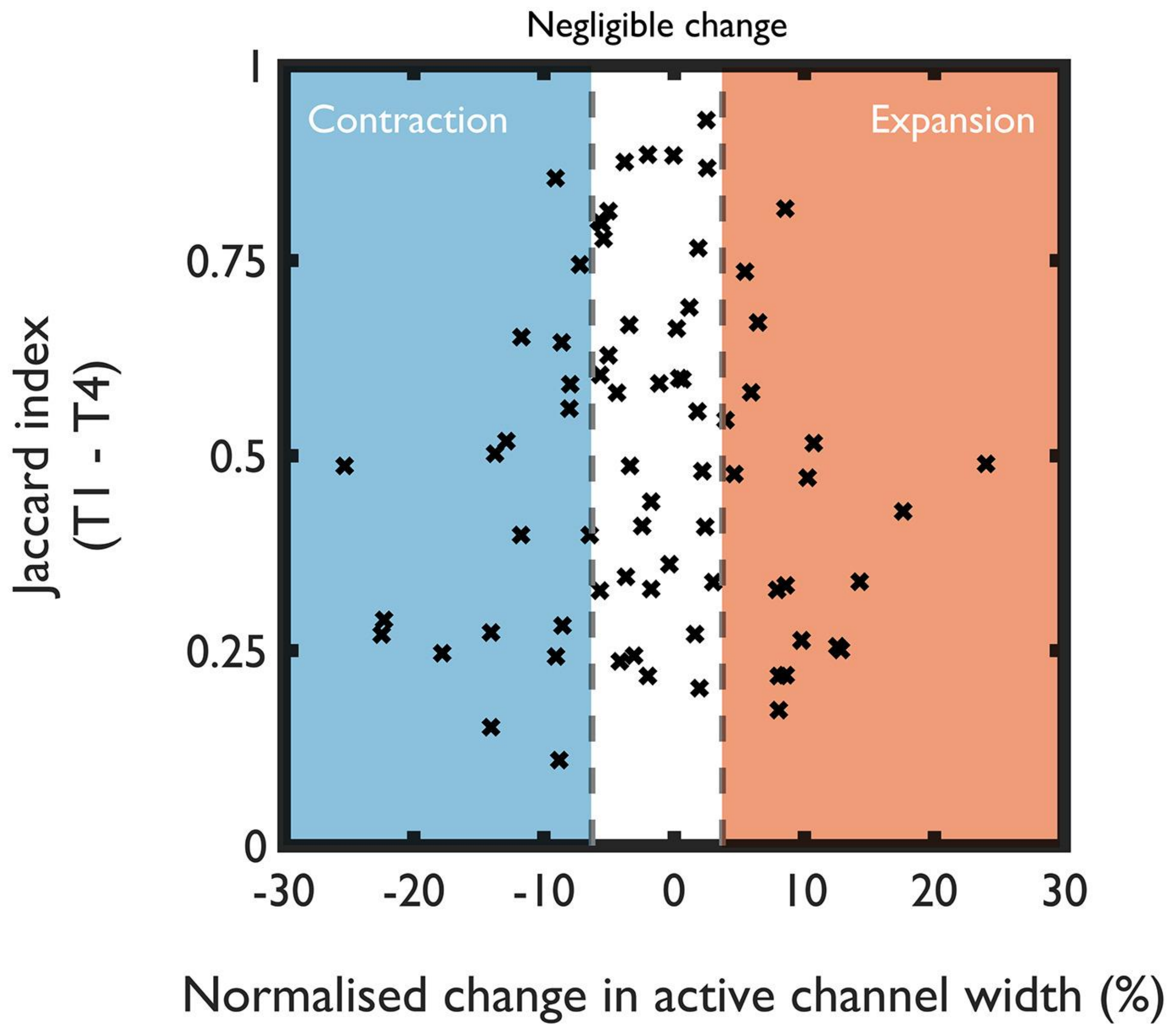
Unless we **Work with Process**, we fail to rectify problems, prompting society to question scientific guidance

Unless we **Assess River Condition**, we do not know if river health is improving or deteriorating, and we cannot assess the effectiveness of management actions

Unless we scope the future, **Determining what is realistically achievable**, we fail to meet the generative potential of scientific insight

Brierley and Fryirs, 2022, Geoscience Letters

Morphological change at critical bridge sites

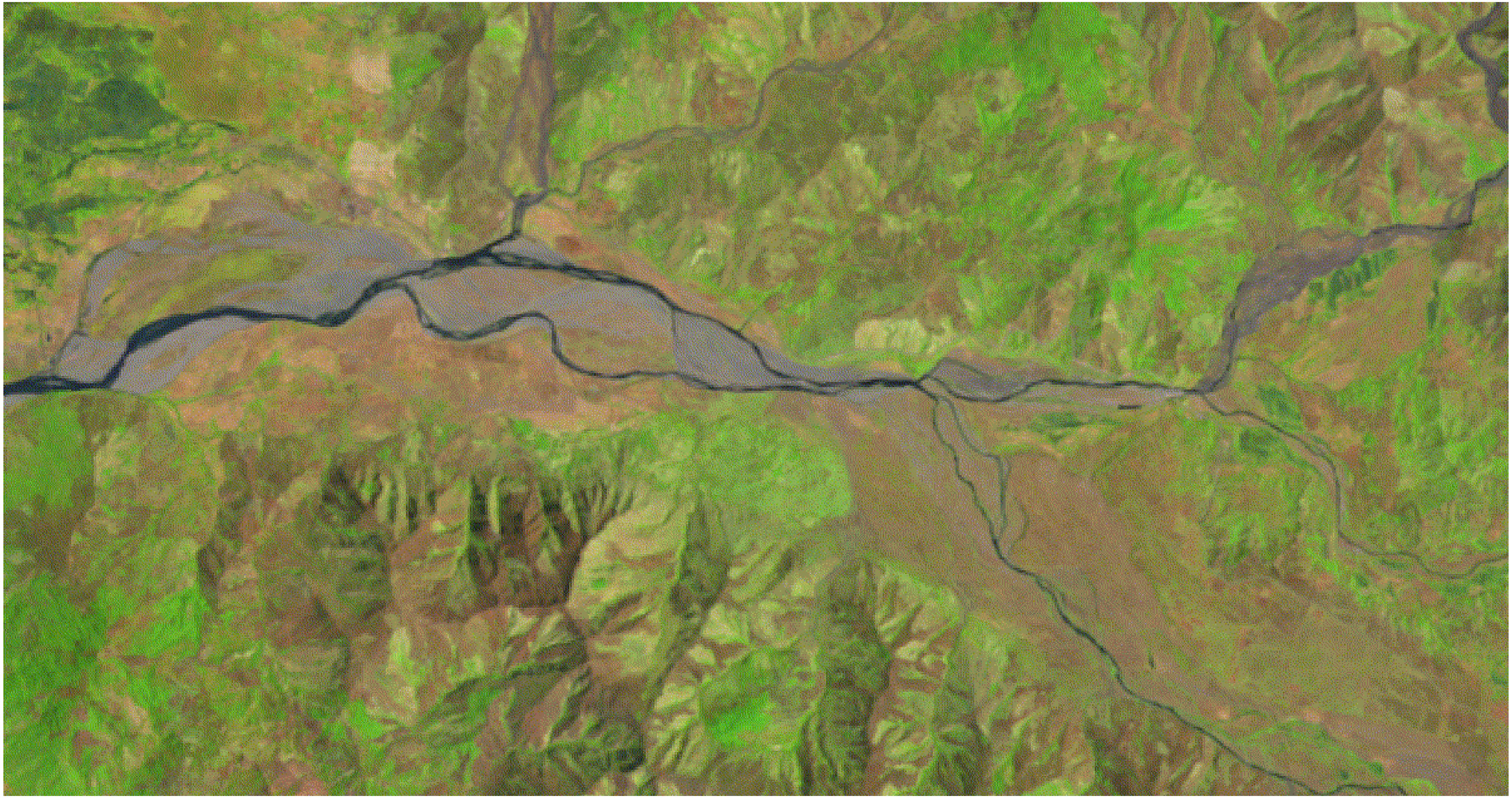


Absolute changes in width were normalised by the mean active channel width over the analysis period (to account for rivers having different active channel widths).

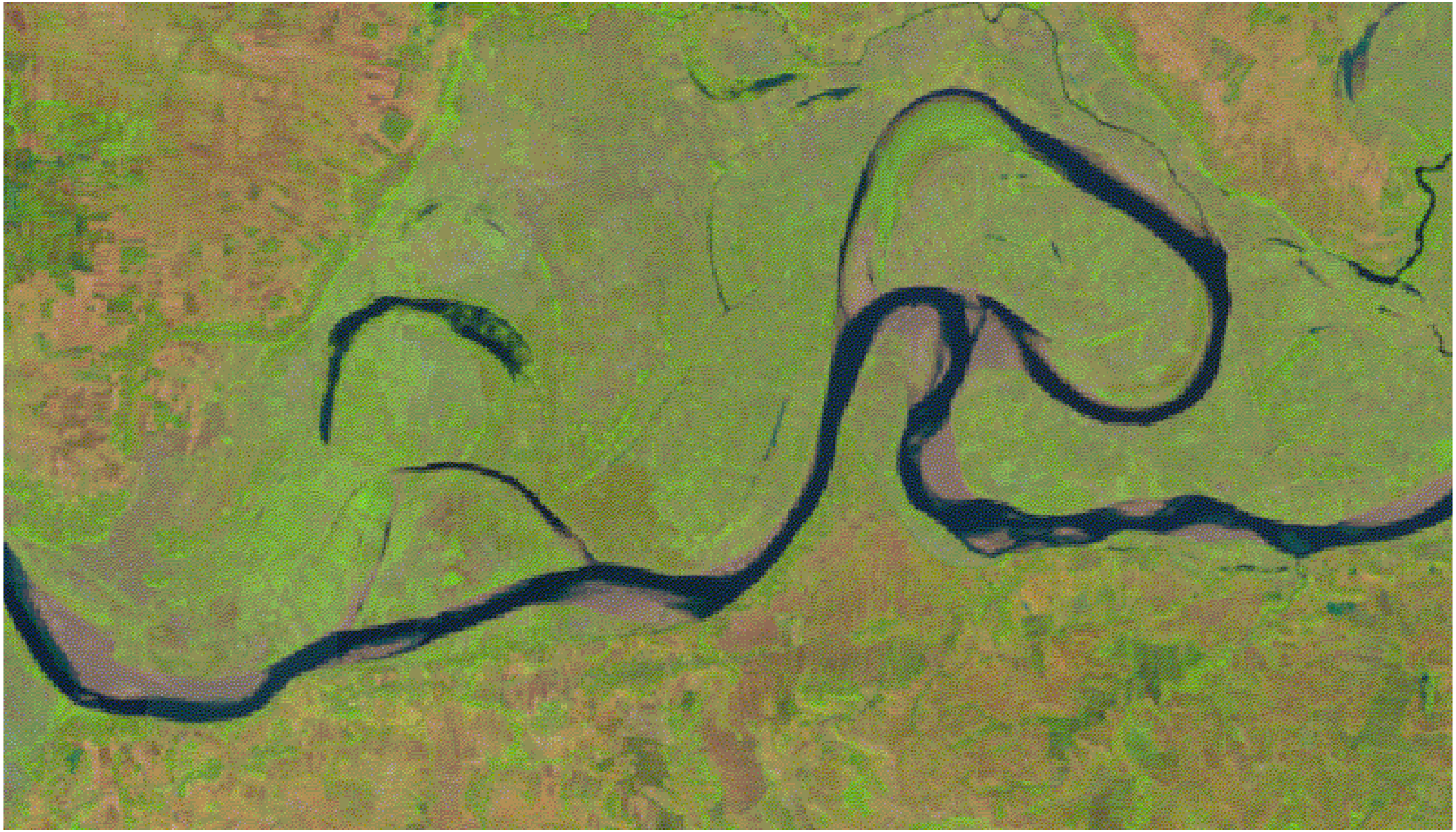
The average normalised change is small (mean = −1.5%; median − 1.9%; 50% of values in range −6.3 to +3.7%)

Outliers show substantial geomorphic change, with active channel contraction and expansion equal to approximately 25% of channel width (maximum contraction = −25.3%, maximum expansion = +24.0%).

Braided river adjustment – Bucao River



Meandering river adjustment – Cagayan River



Wandering gravel bed river adjustment – Abulug River