Enhancing Flood Resilience and Floodplain Habitat Connectivity through Land-use Policy Scenarios under Future Climate Conditions in the Chao Phraya River Basin

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1.Introduction

Land-use → Climate

Hydrological processes

↓ *shaping*

Flood patterns

"How can land-use policies reduce **flood risk** while maintaining flood-dependent **ecological connectivity**?"

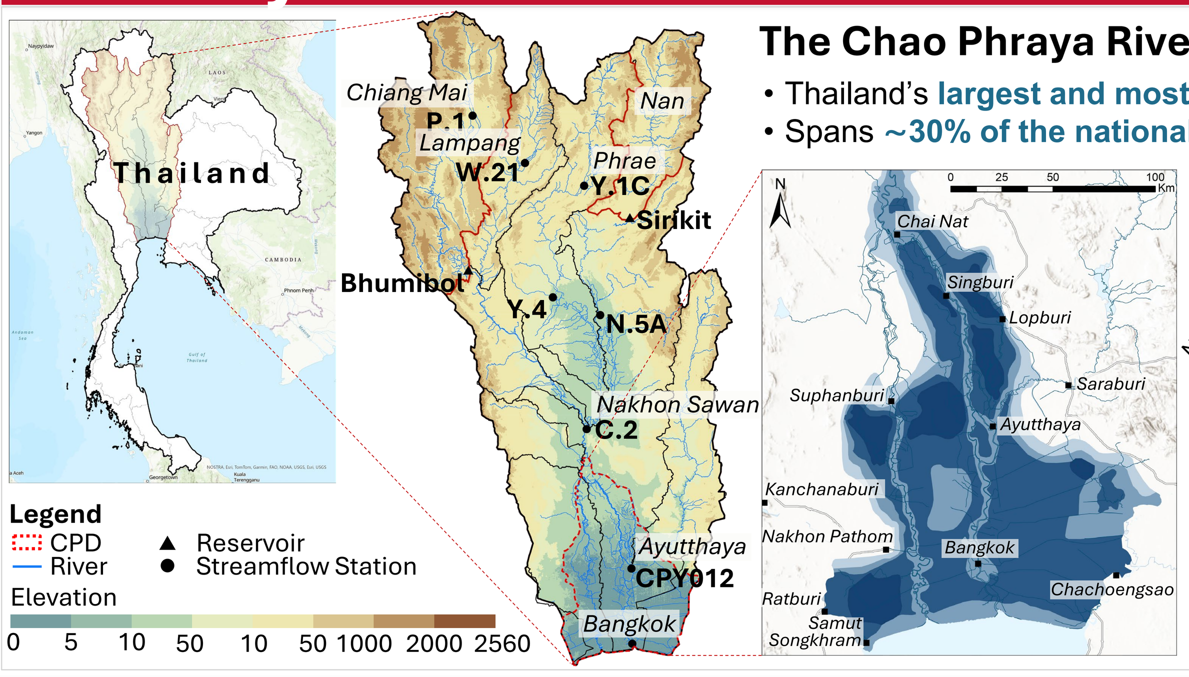
Research Gap:
Land-use policies are **rarely evaluated from both socio-hydrological and ecological perspectives.**

This study **bridges the gap** by **jointly evaluating flood resilience and flood-dependent habitat connectivity.**

Socio-Hydrology Perspective	Current gap	Ecological Perspective
Reduce flood extent, exposure, and hazard[1,2]		Maintain flood-dependent habitat connectivity[3,4]

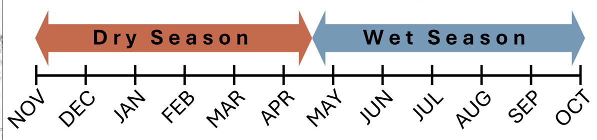
Objectives
- Quantify **future flood hazards** under **alternative land-use** and **climate scenarios.**
- Evaluate **trade-offs between flood risk reduction and flood-dependent habitat connectivity** across policy scenarios.
- **Provide insights** into how **land-use planning and nature-based solutions** can enhance **flood resilience** and **ecological functioning** in tropical deltas.

2.Study Site



The Chao Phraya River Basin (CPRB)
- Thailand's **largest and most economically significant** river basin
- Spans **~30% of the national territory**

Two distinct seasons under a tropical monsoon climate in the CPRB



Chao Phraya River Delta (CPD)
Flood zoning based on a late-1940s map *(Ministry of Agriculture and Cooperatives (TH), 1950)*

Legend
- Deeply flooded every year
- Flooded every year
- Flooded during average high floods
- Flooded only during extreme floods
- Above highest flood level

3.Methods

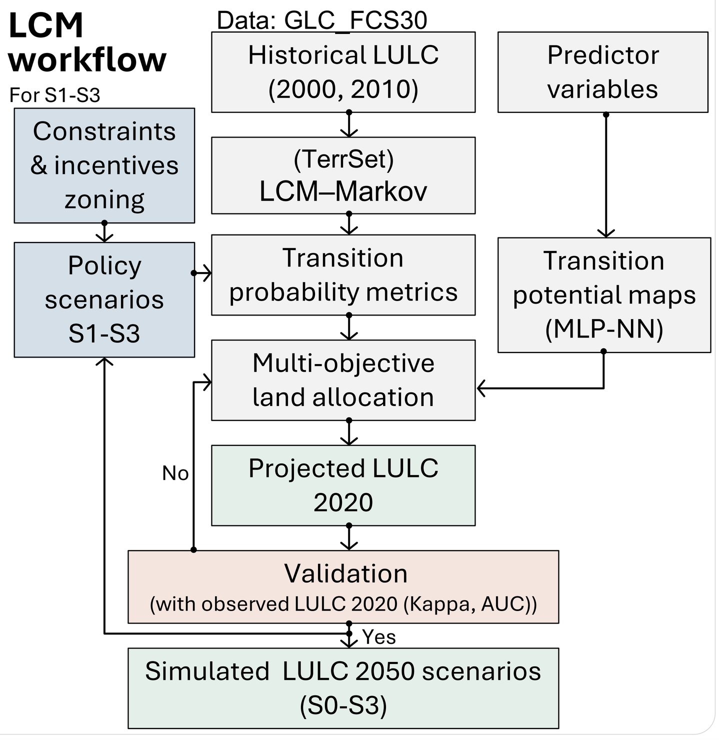
3.1 Future Land-use Simulation (Land Change Modeler, TerrSet)

Scenario design
4 LULC scenarios: BAU scenario (S0) and 3 policy intervention scenarios (S1-S3)

Scenarios	Policy interventions		
	Urban expansion restriction	Promoting paddy-field expansion or restoration	Urban relocation and replacement with paddy fields
	• −30% transition to Urban	• +20% transition to Paddy • −10% transition to Other Agriculture	• −50% Urban persistence • Urban → Paddy
S0	✗	✗	✗
S1	✔	✗	✗
S2	✔	✔	✗
S3	✔	✗	✔

Legend ✔: applied ✗: not applied

LCM workflow



3.2 Future Flood Simulation (Rainfall–Runoff–Inundation Model)

Climate scenario

SSP245	SSP585
25th 50th 75th 100th	25th 50th 75th 100th
Percentiles of projected annual rainfall (Dry → Wet)	Percentiles of projected annual rainfall (Dry → Wet)

2 SSPs × 4 rainfall percentiles × 4 land-use scenarios
= 32 scenarios

LULC maps (LCM outputs) | Daily precipitation (CMIP6) | River geometry & topography (river section, DEM, etc.) | Other inputs (soil texture, etc.)

RRI model[6]
(Rainfall-Runoff-Inundation)

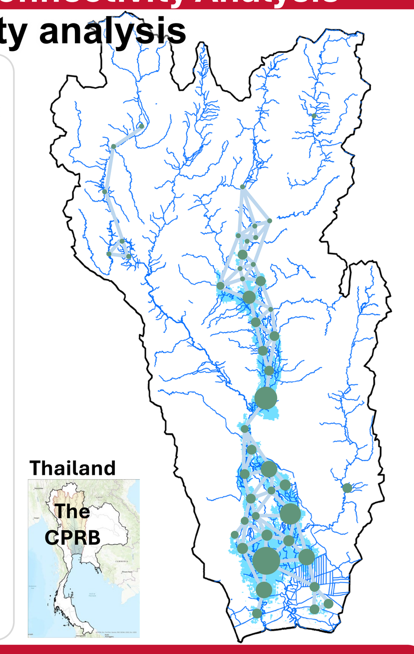
Outputs (Flood Metrics)
Extent | Depth | Duration | Urban Exposure

3.3 Floodplain Habitat Connectivity Analysis

Graph-based connectivity analysis

Connectivity Metric:
Integral index of connectivity (IIC)
Ranges **0 to 1**, with 1 indicating a fully connected landscape

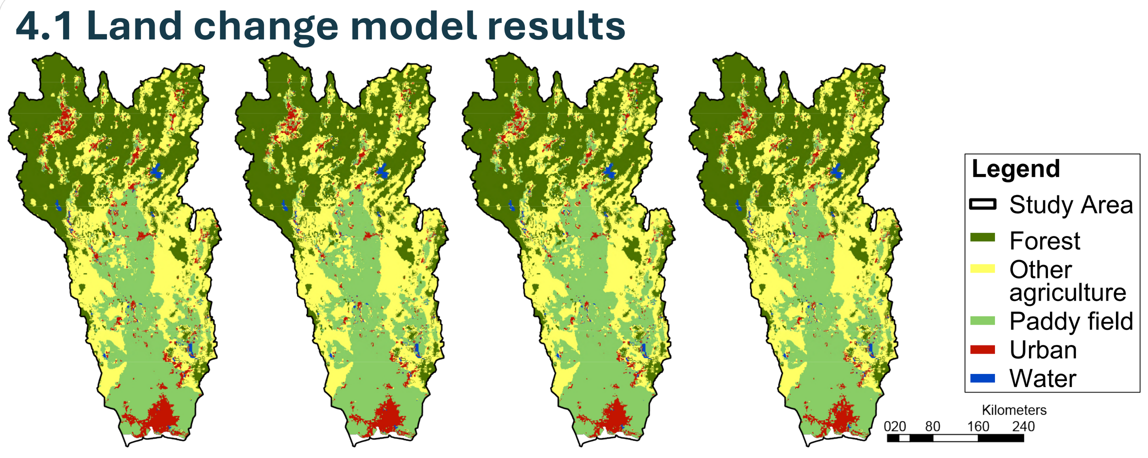
Network construction
- **Nodes:**
  Flooded paddy fields
  - Land-use: **paddy field**
  - Flood depths **≥ 0.2 m[7,8]**
  - Flood durations **≥ 30 days[7,8]**
- **Links:**
  - **Watercourses**
    e.g., agricultural ditches, streams, rivers
    Hydrologic connectivity – fish[8]
  - **Euclidean distance**
    Spatial connectivity - aquatic insects and amphibians[8]



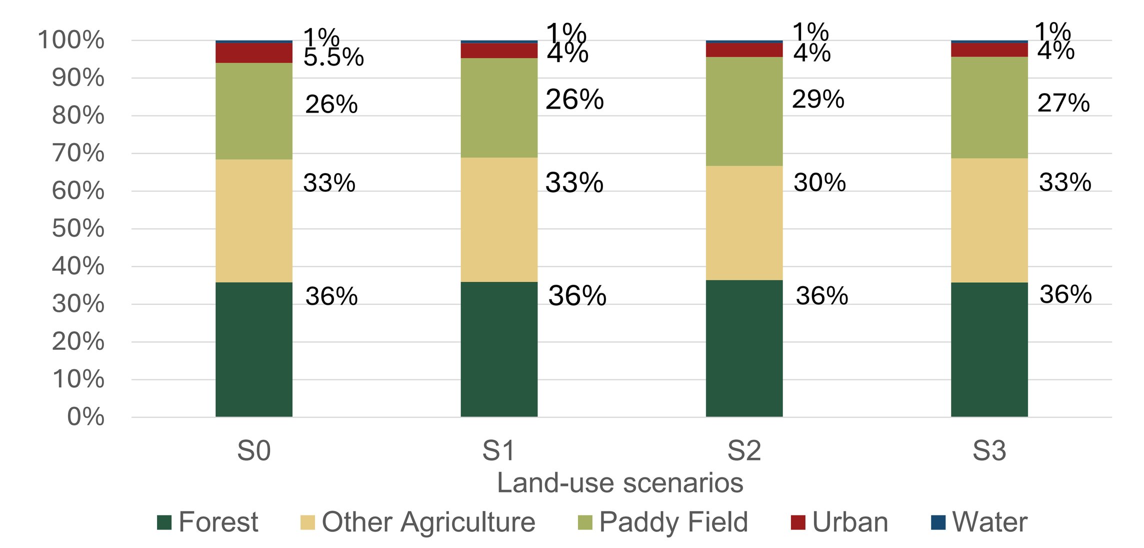
3.4 Comparison & Evaluation
Evaluate trade-offs between flood risk reduction and flood-dependent habitat connectivity.

4.Results

4.1 Land change model results

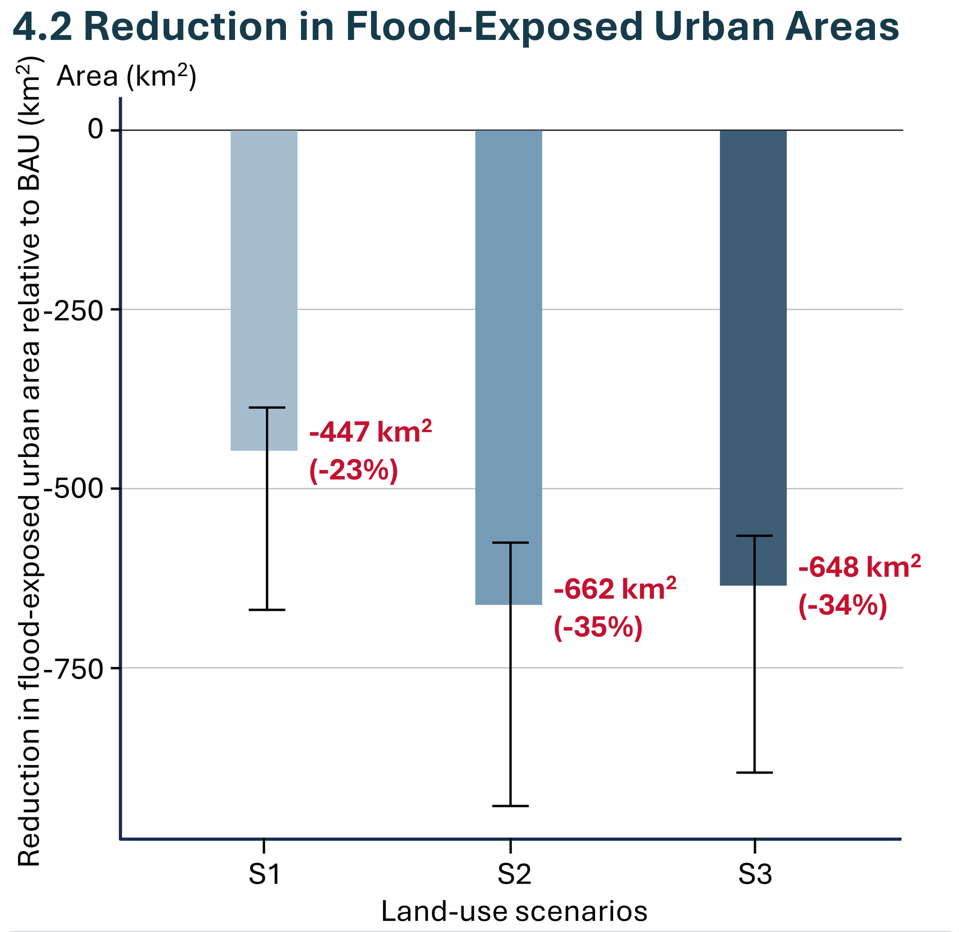


Simulated land-use composition under alternative land-use policy scenarios (2050)



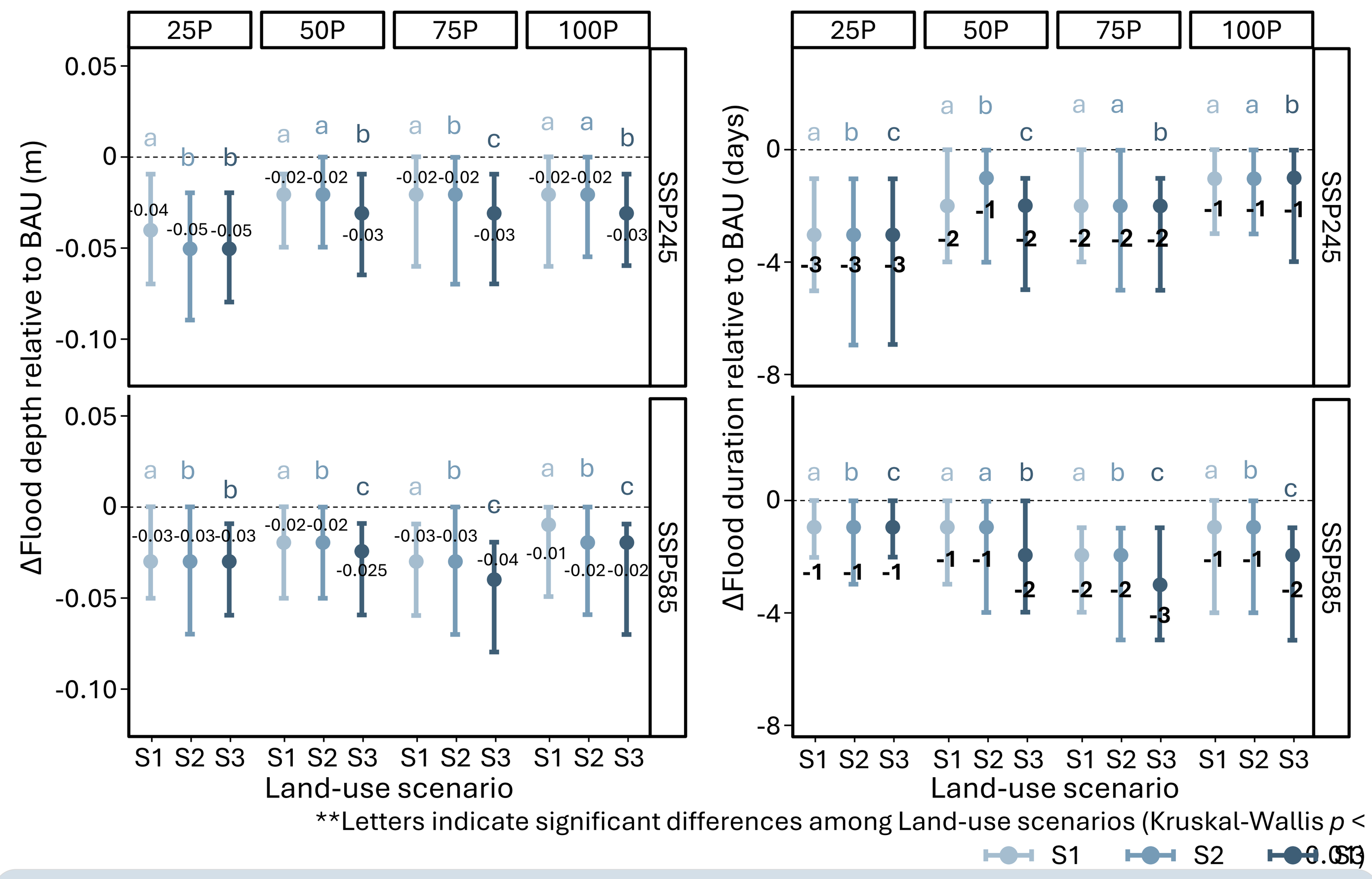
- **S2** exhibits the **largest expansion of paddy fields**, increasing their share to 29% of the basin
- Forest and water cover **remain relatively stable** across all scenarios.

4.2 Reduction in Flood-Exposed Urban Areas



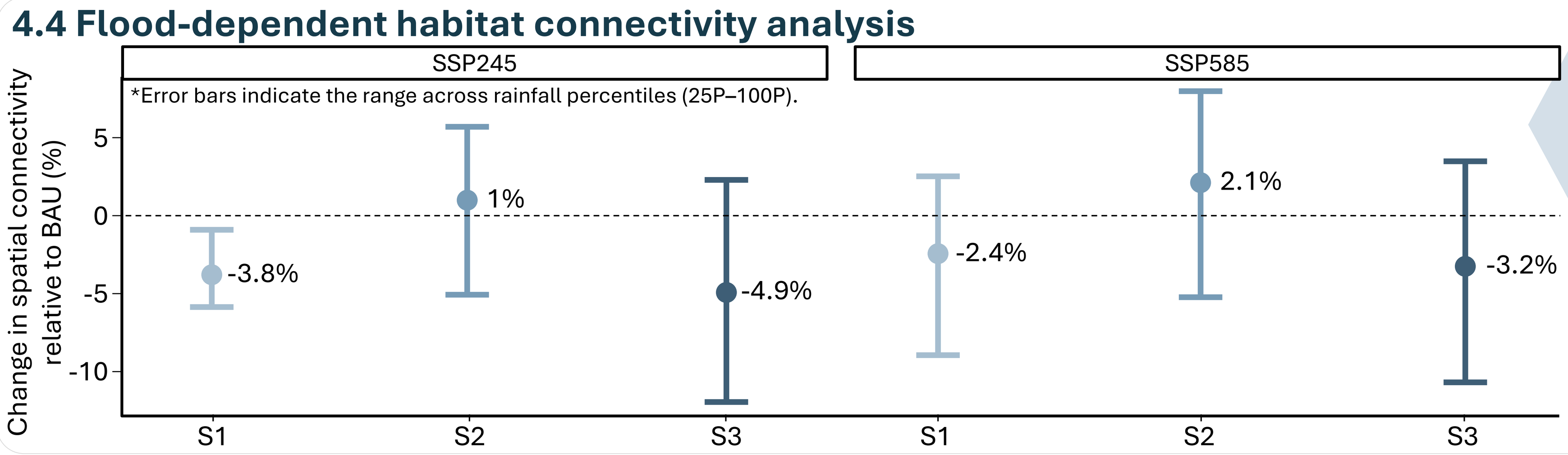
- Despite variation among climate scenarios, **all policy scenarios (S1–S3) consistently reduced** basin-wide **flood exposure** relative to BAU.
- **S2** achieved the **largest reductions in flood-exposed urban areas** by 34%-38% (600-900 km²) relative to BAU.

4.3 Effects of Land-use Scenarios on Flood Depth & Duration

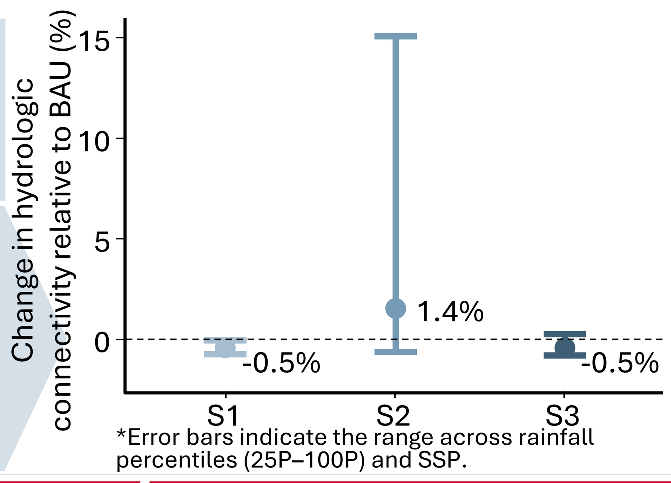


- **Land-use policies reduced median flood duration by 1–3 days,** while effects on flood depth remained small (<0.05 m).
- Differences among policy scenarios were **generally small in magnitude** (typically <1–2 days and <0.02 m) **despite statistical significance.**

4.4 Flood-dependent habitat connectivity analysis



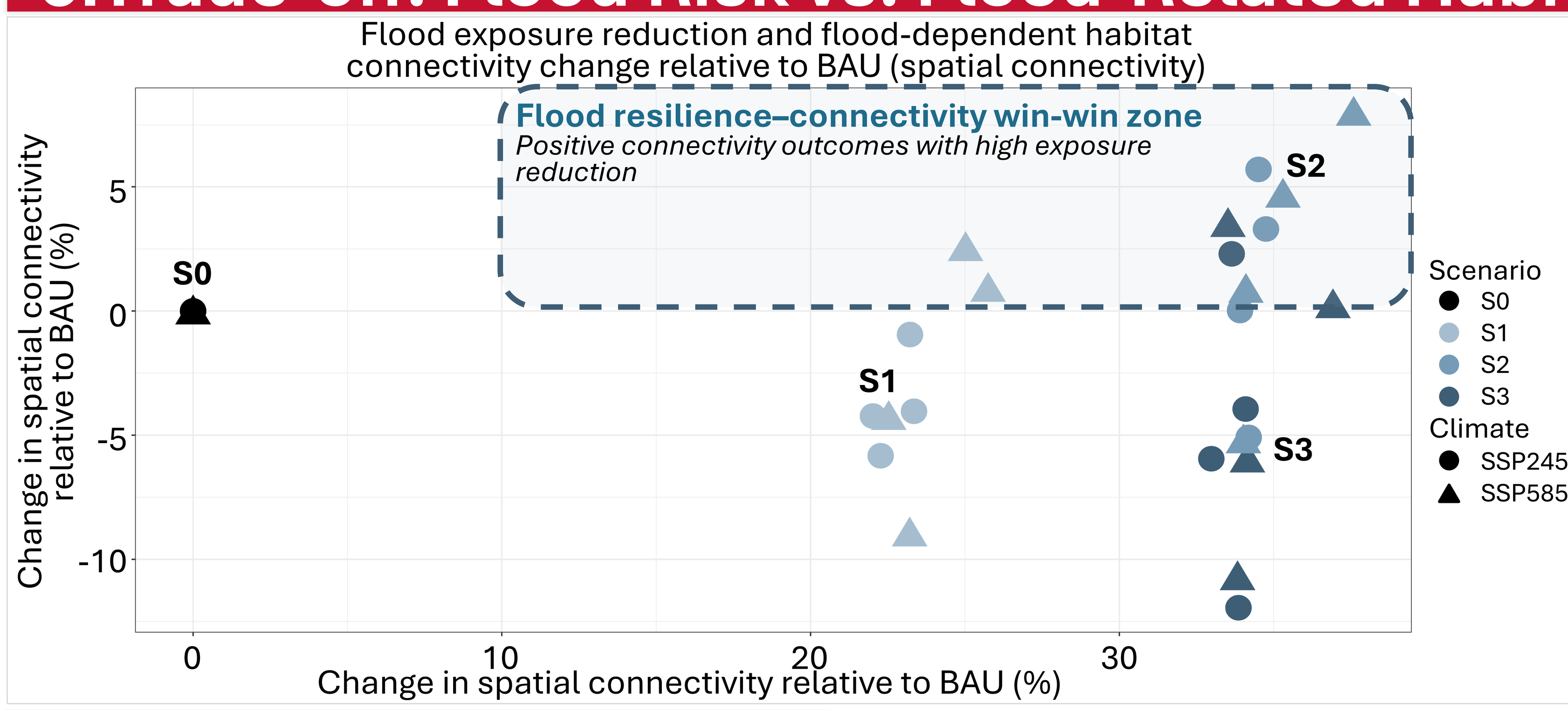
- Spatial connectivity was **consistently maintained or improved under S2** across both SSPs.
- Hydrologic connectivity showed **smaller responses to land-use policy** and was **more sensitive to climate conditions.**



- Land-use strategies **aimed at reducing flood exposure do not** necessarily **compromise floodplain habitat connectivity**
- Land-use strategies that **maintain continuous flood-supported habitats (e.g., S2)** may better support floodplain ecological processes in modified deltas

5.Trade-off: Flood Risk vs. Flood-Related Habitat Connectivity

Flood exposure reduction and flood-dependent habitat connectivity change relative to BAU (spatial connectivity)



- **S2** achieved **the largest reductions** in flood-exposed urban areas (≈34–38%).
- **S2 maintained or improved spatial connectivity** across climate scenarios.
- **S2 provided the most balanced outcome** between flood-risk reduction and habitat conservation.

6.Discussion: Policy Implications

Strategic paddy-field conservation and expansion can simultaneously **reduce flood risk and maintain floodplain habitat connectivity.**

Paddy-field promotion intervention

Reduce urban flood exposure	Maintain flood-dependent habitat connectivity
Socio-hydrological perspective	**Ecological perspective**

Flood Resilience
Restricting urban expansion in flood-prone areas reduced flood-exposed urban areas by 23–38% and shortened flood duration by approximately 1–3 days.

Nature-based Solutions
Paddy-field promotion (S2) achieved the largest reductions in flood-exposed urban areas while maintaining habitat connectivity, highlighting the role of paddy fields as multifunctional nature-based infrastructure.

Biodiversity Conservation
Maintaining floodplain connectivity may support movement of flood-dependent species and help sustain ecological processes under changing climate conditions.

Key Takeaway

Paddy-field conservation and restoration can serve as **nature-based solutions** that **reduce urban flood exposure** while **maintaining flood-dependent habitat connectivity** under future climate conditions in the CPRB.
These co-benefits highlight the importance of paddy landscapes for building resilient and ecologically connected **monsoon-dominated deltas.**

References / Footnotes

1. Guido, B. I., Popescu, I., Samadi, V., & Bhattacharya, B. (2023). An integrated modeling approach to evaluate the impacts of nature-based solutions of flood mitigation across a small watershed in the southeast United States. *Natural Hazards and Earth System Sciences*, 23(7), 2663–2681. https://doi.org/10.5194/nhess-23-2663-2023
2. Huang, D., & Xiao, G. (2025). Exploring urban expansion pattern associations with flood Vulnerability: Spatial heterogeneity in multidimensional linkages across China's Min Delta urban agglomeration. *Journal of Environmental Management*, 394, 127449. https://doi.org/10.1016/j.jenvman.2025.127449
3. Amezcua, F., Rajnohova, J., Flores-de-Santiago, F., Flores-Verdugo, F., & Amezcua-Linares, F. (2019). The Effect of Hydrological Connectivity on Fish Assemblages in a Floodplain System From the South-East Gulf of California, Mexico. *Frontiers in Marine Science*, 6. https://doi.org/10.3389/fmars.2019.00240
4. Bai, X., Zhang, P., Xiong, L., Yang, Z., Wang, S., Dong, X., Sun, H., Li, W., & Chang, J. (2025). River Network Connectivity Reductions Dominate Declines in the Richness of Plateau Fish Species Under Climate Change in the Upper Yangtze River Basin. *Water Resources Research*, 61(6), e2024WR037557. https://doi.org/10.1029/2024WR037557
5. Petsut, N., Panitvong, N., Kulabtong, S., Petsut, J., & Nonpayom, C. (2014). The first record of Trigonostigma somphongsi (Meinken, 1958), a critically endangered species, in its natural habitat of Thailand (Cypriniformes Cyprinidae). *Biodiversity Journal*, 5(4), 471–474.
6. Sayama, T., Ozawa, G., Kawakami, T., Nabesaka, S., & Fukami, K. (2012). Rainfall–runoff–inundation analysis of the 2010 Pakistan flood in the Kabul River basin. *Hydrological Sciences Journal*, 57(2), 298–312. https://doi.org/10.1080/02626667.2011.644245
7. Pratt, O. P., Beesley, L. S., Gwinn, D. C., Tayer, T. C., Pusey, B. J., Keogh, C. S., Setterfield, S. A., & Douglas, M. M. (2025). Large, prolonged flooding and pool persistence promote floodplain fish diversity in a threatened river. *Ecological Applications*, 35(7), e70155. https://doi.org/10.1002/eap.70155
8. Ishiyama, N., Akasaka, T., & Nakamura, F. (2014). Mobility-dependent response of aquatic animal species richness to a wetland network in an agricultural landscape. Aquatic Sciences, 76(3), 437–449. https://doi.org/10.1007/s00027-014-0345-8

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