Impacts of global river delta modification on ecosystem services

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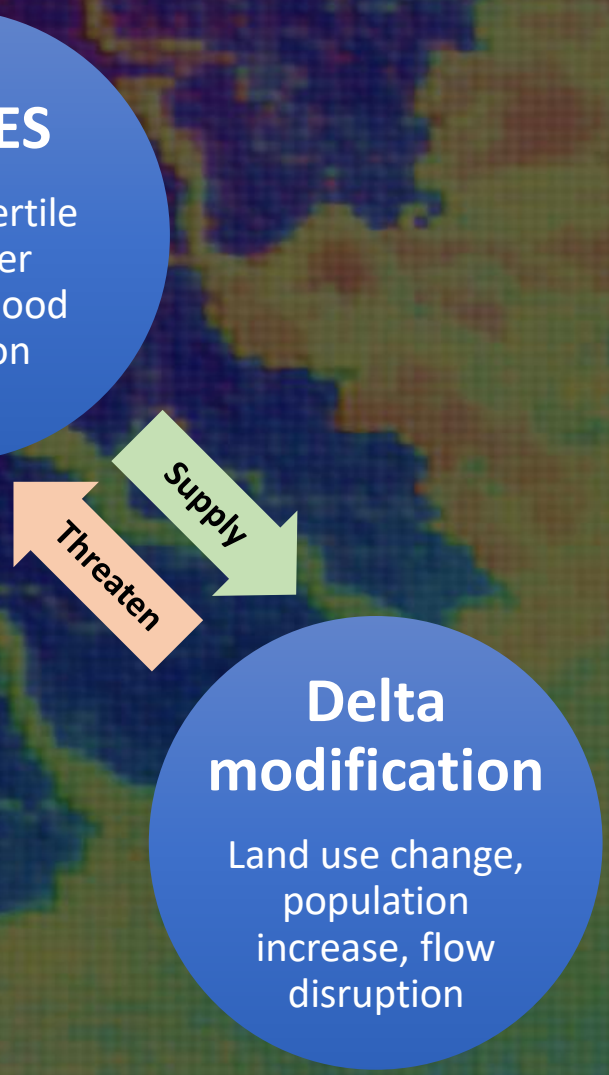
Picture - Ganges delta, courtesy NASA/JPL-Caltech

Ecosystem services are vital in deltas

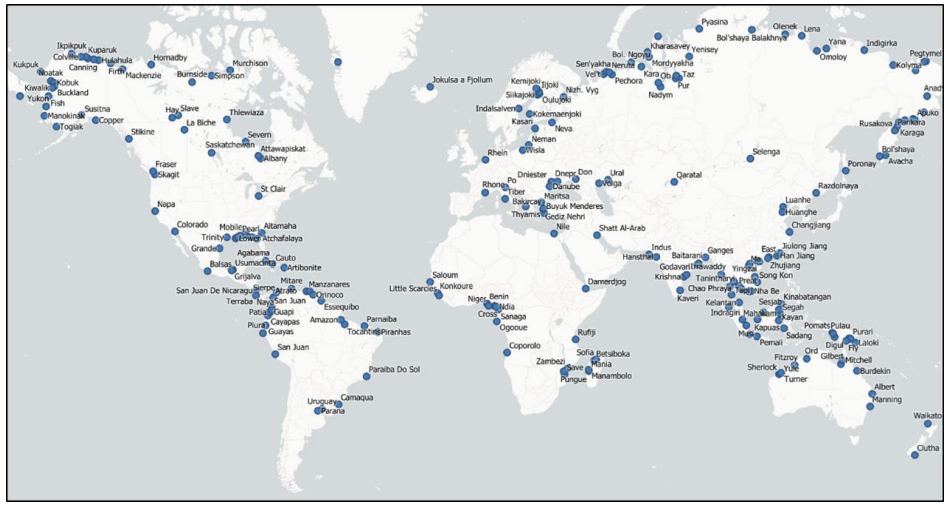
- Ecosystem services (ES) represent nature's contributions to human well-being – from food supply to flood mitigation
- Deltas supply many ES, contributing to their development and population growth
- However, this development can threaten ES, and in turn delta sustainability and resilience
- We investigate the **impacts of human modification on ES across deltas globally**



1. Which ES bundles commonly occur in deltas?

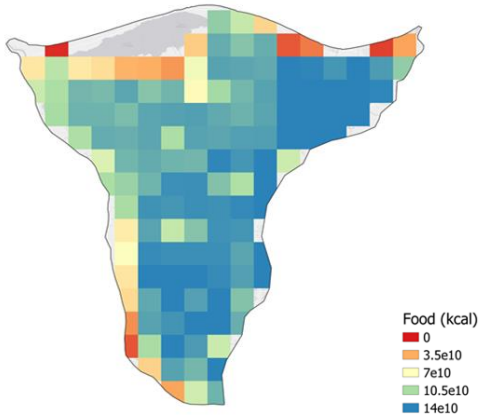
- We first calculate ‘bundles’ of ES, those commonly co-occurring in space and time
- This approach can identify the major ES groups and trade-offs
- We assessed 51 services, averaged across 237 deltas mapped worldwide

Deltas assessed



Mapping

Measurement of ES



1. Seven ecosystem service bundles were identified

- Across six clustering methods, we found seven bundles of services, six clustering consistently 50% of the time or more
- Bundles corresponded to logical ES groups: productivity, crops, threat reduction, water and fish, marine richness, and other

ES bundles

Productivity

5.30

Amphibian richness	6
Bird richness	6
Mammal richness	6
Plant richness	6
Vegetation carbon (pot.)	6
NPP (actual)	6
NPP (pot.)	6
Vegetation carbon (actual)	5
Forest cover	4
Attainable yield	2

Crops

5.25

Food crop area	6
Food crop calories	6
Nonfood crop area	6
Nonfood crop calories	6
Water withdrawal	6
Feed crop calories	5
Nonfood crop value	4
Fish catch (marine)	3

Intactness and soil

4.75

Alpha biodiversity intactness (%)	5
Biodiversity intactness abundance	5
Biodiversity intactness richness	5
Soil carbon storage	5
Soil carbon density	5
Soil cation exchange capacity	5
Soil N	4
Soil water	4

Threat reduction

4.11

Unthreatened amphibians (%)	6
Unthreatened seabirds (%)	6
Unthreatened mammals (%)	5
Soil N need	4
Soil P need	4
Unthreatened marine (%)	3
Pollination deficit	3
Water quality deficit	3
Soil loss	3

Other

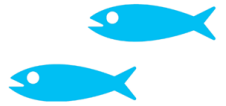
3.43

Food value	5
Invasive prevention	5
Pasture area	5
Seabird richness	3
Unthreatened birds (%)	2
Oil area	2
Soil workability	2

Water and fish

3.00

Aquaculture production	4
Fish catch (river)	4
Navigable water	3
Wetlands	3
Discharge	2
Water available	2



Marine richness

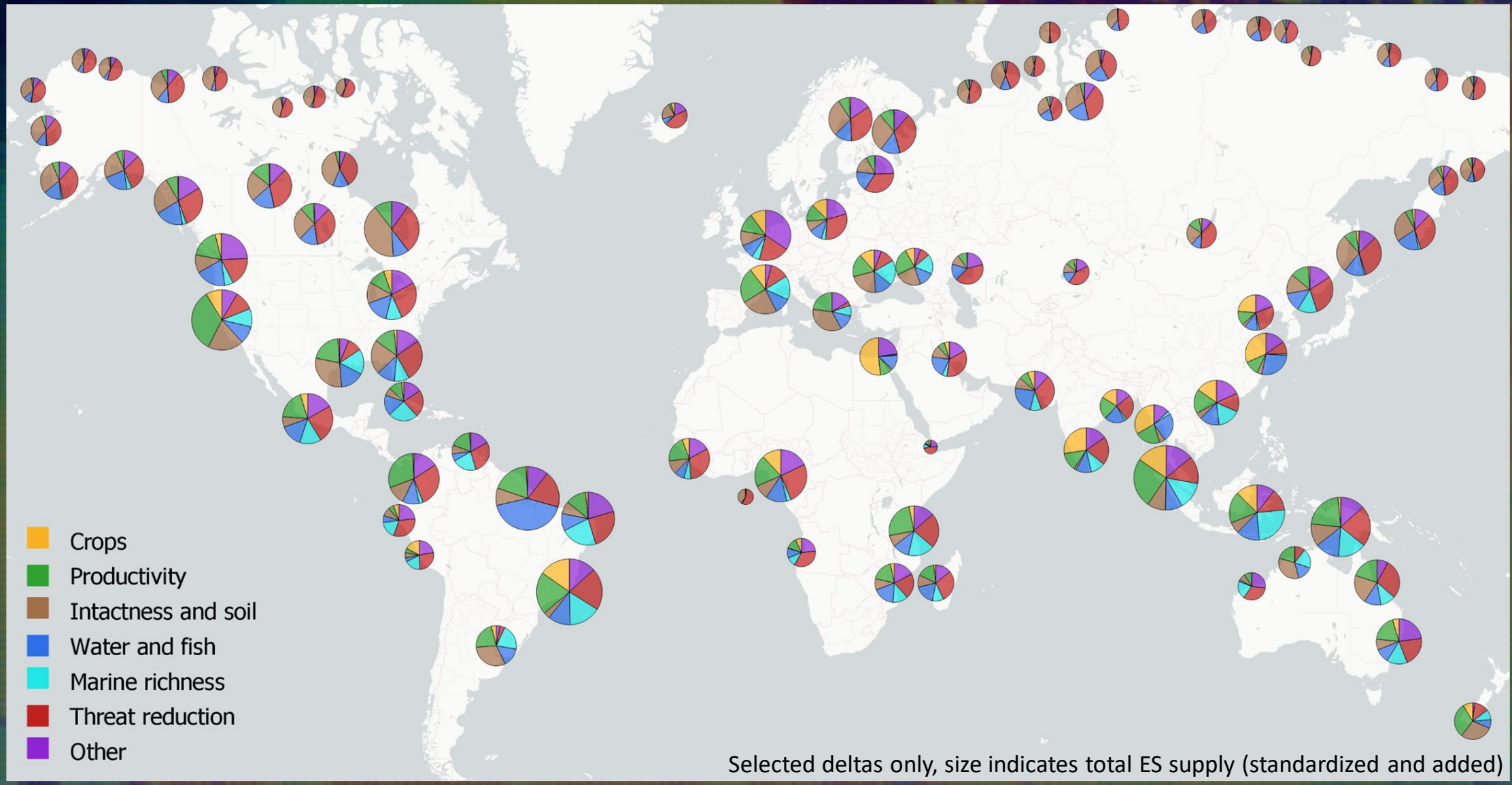
2.67

Marine animal richness	3
Marine plant richness	3
Pollination	2

Bundle robustness

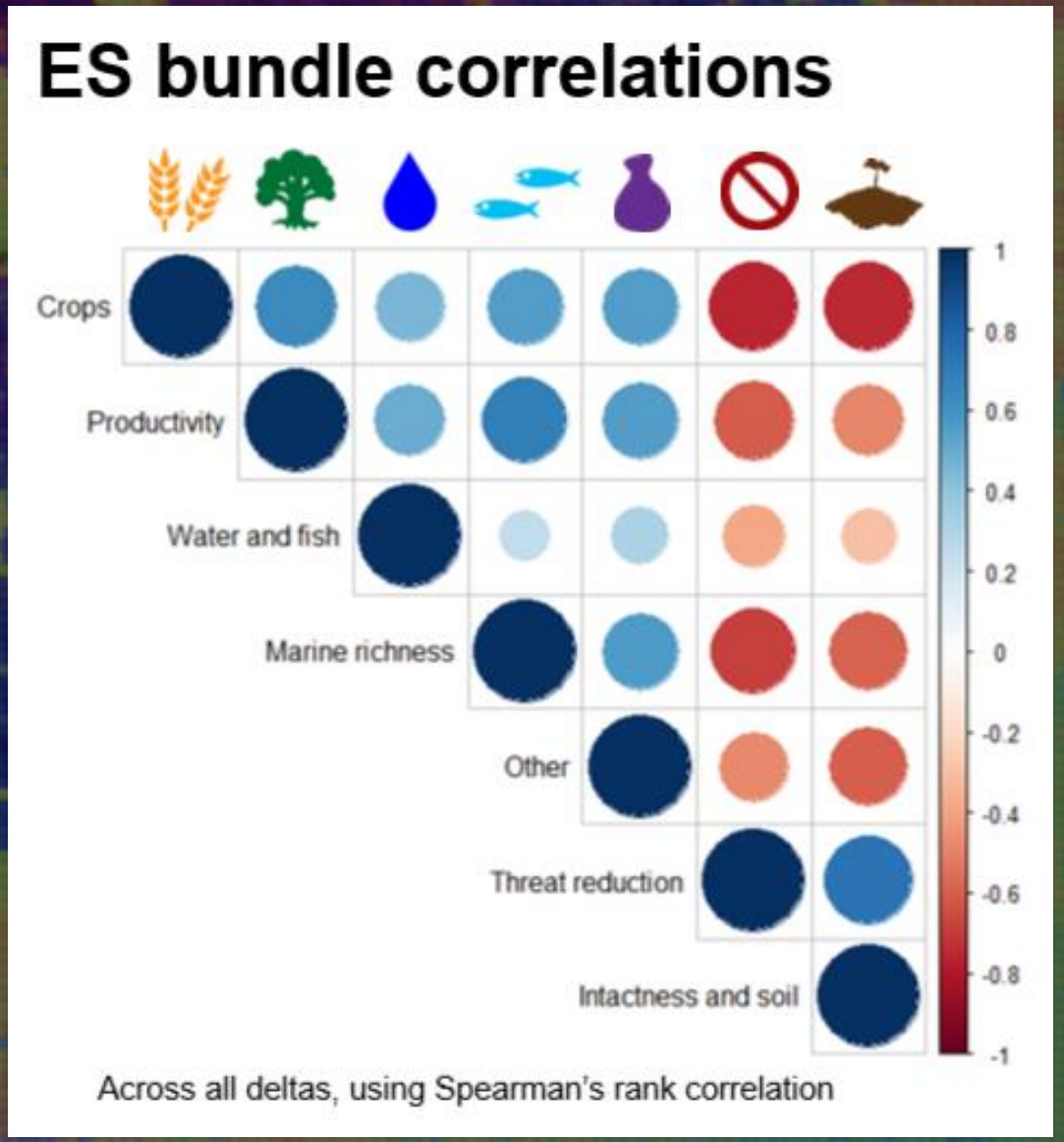
Numbers beside each ES show the number of times it was selected in this cluster. Robustness indicates the average amount of times each ES within the cluster was selected within it.

1. ES supply similar in geographically-related deltas



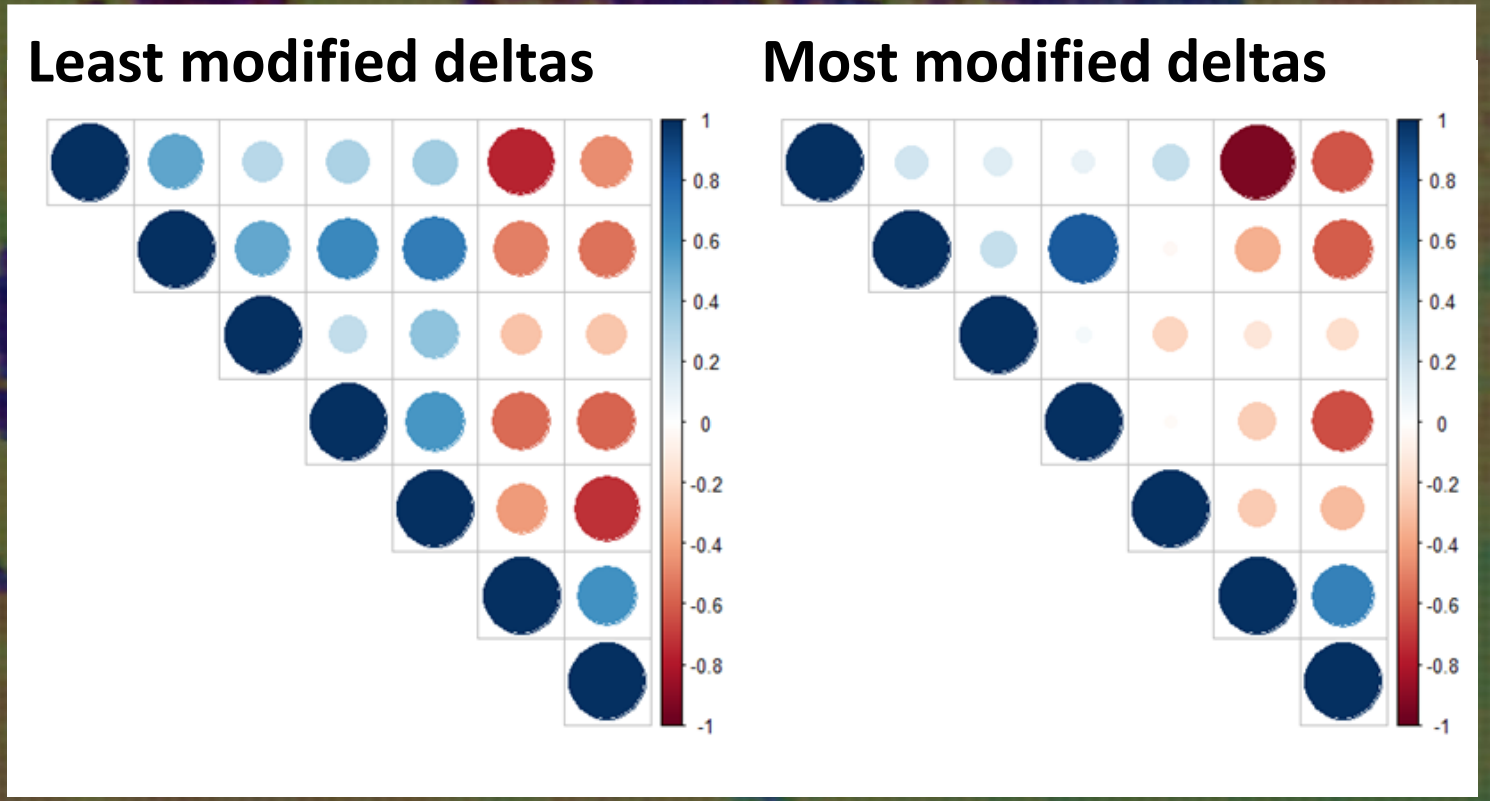
2. Do synergies and trade-offs exist between bundles?

- The correlation between ES bundles shows us how developing one ES can impact another
- We show pair-wise correlations between the bundles: positive (blue, synergies) and negative (red, trade-offs)
- Threat reduction and biodiversity intactness ES bundles showed clear trade-offs with the rest



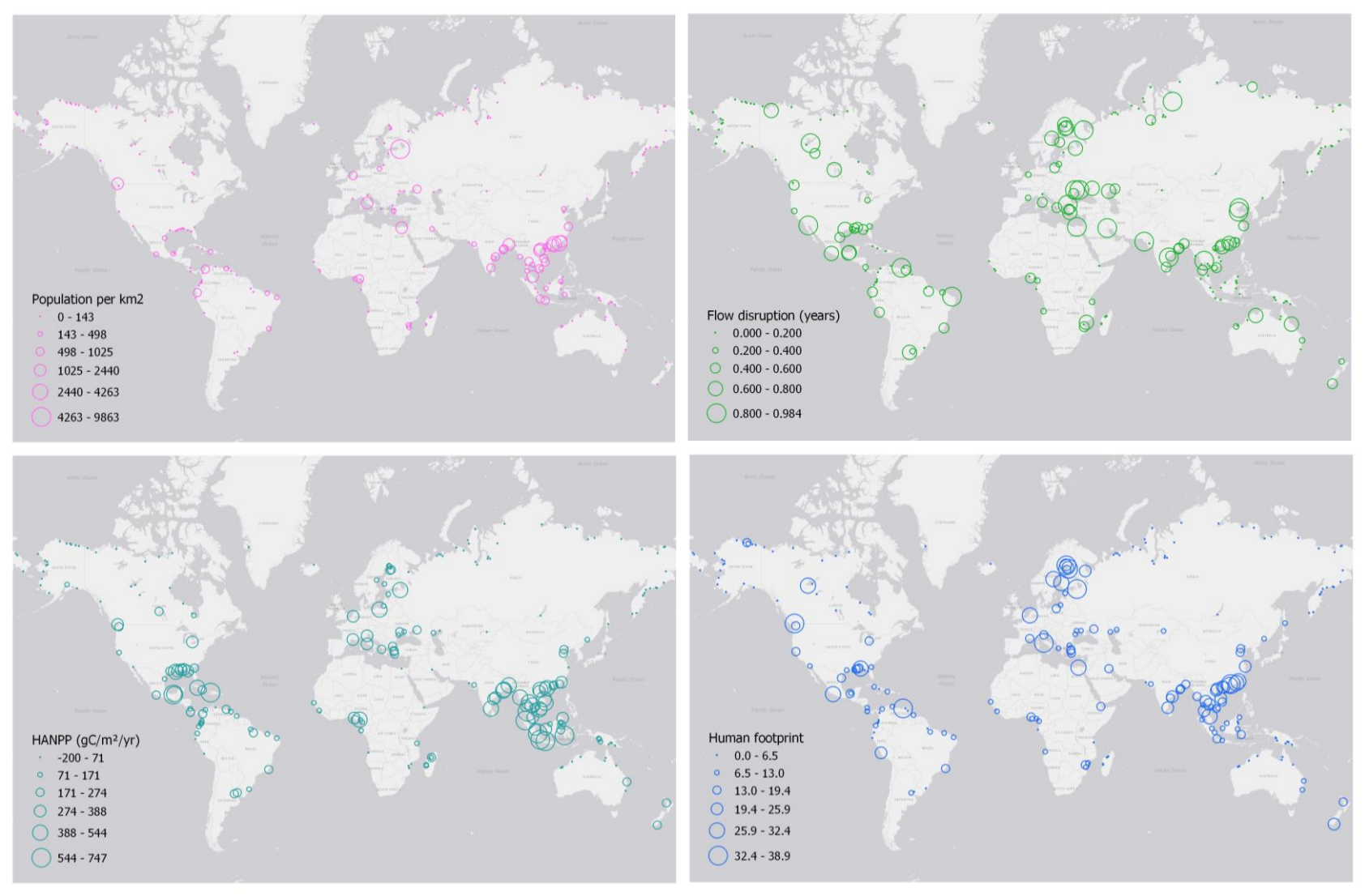
2. Synergies and trade-offs weaken with delta modification

- We assessed if relationships between ES bundles vary with human modification
- We clustered deltas by level of human modification
- Almost all ES bundles synergies and trade-offs weakened in the most modified deltas



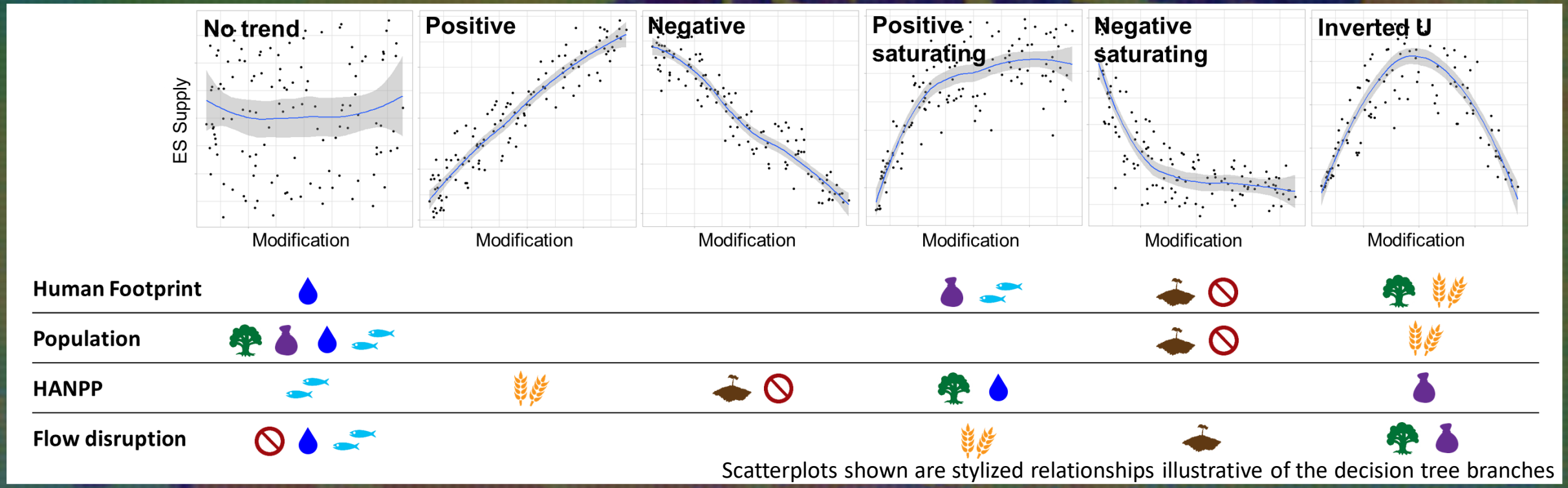
3. How does ES supply change with modification?

- We explored risks of continuing modification of delta systems to ES
- We examined modification by:
  - Population density
  - Flow disruption
  - Human appropriation of NPP
  - Human footprint (overall indicator)



3. Five relationships between modification and ES

- We used a LOESS regression between each bundle and modification indicator
- We used a decision tree to classify the regression line based on slope direction, saturation and if it remained monotonic
- Most relationships were non-linear, showing thresholds after which the relationship decayed or inverted



Conclusions

- We found seven logical bundles of commonly occurring delta ecosystem services
- ES bundles showed trade-offs between biodiversity intactness and threat reduction, with the other services
- Trade-offs and synergies between bundles weakened with modification – many ES showed non-linear relationships with modification
- Modification impacts vary by ES bundle, but biodiversity intactness and threat reduction consistently decline