Supplementary Information

The relationship between ecosystem services and human modification displays decoupling across global delta systems

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Supplementary Table

Supplementary Table 1. Ecosystem service (ES) indicators and sources. All indicators were publicly available for download at the time of analysis. Where two indicator names are given, the second is the shorter version used in some figures. Indicators with asterisks were reversed so larger values indicated a greater service. Sources indicate the citation given for the dataset analysed - in some cases these data are based upon one or several older datasets. Dates given are the year or years the newest data comes from, where not evident we have used < the publication date. Resolution is measured in arc-minutes unless specified. Typically, for raster data, we used the QGIS 3.10 zonal statistics tool to calculate the average. For vector data, we used the intersect tool to calculate the proportion of delta covered by the indicator. The Method column indicates where this method differed. See Supplementary Data for a spreadsheet of this table.

Category	Indicator	Description	ES	Type	Unit	Year	Resolution	Method, notes and download source	Citation
Agriculture	Attainable yield	Economically feasible yield given climate	Food	Supply	t/ha	2000	5 arc-min	The datasets for all 16 crops were combined to establish sum total attainable yield per cell. http://www.earthstat.org/yield-gaps-climate-bins-major-crops/	Mueller et al., 2012
	Food area	Area harvested for food crops	Food	Service	ha	2010	5 arc-min	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/PRFF8V	Wood-Sichra et al., 2016 International Food Policy Research Institute, 2019
	Food calories	Crop kilocalories produced for food	Food	Service	kcal	2000	5 arc-min	http://www.earthstat.org/crop-allocation-food-feed-nonfood/	Cassidy et al., 2013
	Food value	Value of food crop production	Food	Benefit	$ per ha	2010	5 arc-min	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/PRFF8V	Wood-Sichra et al., 2016 International Food Policy Research Institute, 2019
	Non-food area	Area harvested for non-food crops	Energy	Service	ha	2010	5 arc-min	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/PRFF8V	Wood-Sichra et al., 2016 International Food Policy Research Institute, 2019
	Non-food calories	Crop kilocalories produced for non-food uses, typically biofuel	Energy	Service	kcal	2000	5 arc-min	http://www.earthstat.org/crop-allocation-food-feed-nonfood/	Cassidy et al., 2013
	Non-food value	Value of non-food crop production	Energy	Benefit	$ per ha	2010	5 arc-min	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/PRFF8V	Wood-Sichra et al., 2016 International Food Policy Research Institute, 2019
	Feed production	Crop kilocalories produced for use as feed	Food	Service	kcal	2000	5 arc-min	http://www.earthstat.org/crop-allocation-food-feed-nonfood/	Cassidy et al., 2013

	Pasture area	Proportion of pasture land cover	Food	Service	Proportion	2000	30 arc-sec	https://sedac.ciesin.columbia.edu/data/set/aglands-pastures-2000	Ramankutty et al., 2008 Ramankutty et al., 2010
Fish and aquaculture	Aquaculture	Aquaculture harvest per unit of discharge	Food	Service	Index	1997-2006	30 arc-min	Deltas with a value of N/A were manually checked – 25 deltas downriver of the spatial extent of the dataset, were given average production values from the nearest cell. https://databasin.org/datasets/d61e398dc3b34fbaaf58ad41d432c300/	Vörösmarty et al., 2010
	River fish	River fish catches	Food	Service	Index	1997-2006	30 arc-min	Deltas with a value of N/A were manually checked – 25 deltas downriver of the spatial extent of the dataset, were given average production values from the nearest cell. https://databasin.org/datasets/62f23d092cbf402e8952f5ff56e0e6e6	Vörösmarty et al., 2010
	Marine fish	Marine fishing catch rate	Food	Service	tons/km^2/yr	2013	30 arc-min	Summed demersal destructive, demersal non-destructive high bycatch, demersal non-destructive low bycatch, pelagic high bycatch, and pelagic low bycatch values. https://knb.ecoinformatics.org/view/doi:10.5063/F1S180FS	Halpern et al., 2015
Water	Discharge	Annual river discharge	Water Water quality Energy	Supply	km^3/yr	<2001	30 arc-min	The gridded shapefile dataset was rasterised and zonal statistics calculated. Deltas outside of the dataset range, or those including a cell used the discharge of the nearest cell along the channel; or the nearest similar pixel where this was unavailable. https://databasin.org/datasets/3a2afd820d2d4185b5a5903d45c0e741/	Fekete et al., 2001
	Navigable water	Density of navigable water courses	Transportation	Supply	Index (0 - 4)	2009	30 arc-sec	Extracted from the human footprint dataset. https://datadryad.org/stash/dataset/doi:10.5061/dryad.052q5	Venter et al. 2016 Venter et al. 2018
	Sediment	Riverine sediment flux	Flood protection, Materials	Supply	kg/s	2010	6 arc-min	Divided by discharge https://sdml.ua.edu/datasets-2/datasets/	Cohen et al., 2013
	Water quality*	Water quality deficit (nitrogen export)	Water	Service	kg/ha	2015	10 arc-sec	Reversed so larger amount indicated greater service. http://ipbes-natcap-ecoshard-data-for-publication.ecoshard.org/	Chaplin-Kramer et al., 2019
	Available water	Blue water runoff available for human use	Water	Supply	cm	1948-2010	Catchment	The value was taken from the catchment closest to the delta centroid. https://www.wri.org/resources/data-sets/aqueduct-global-maps-21-data	Gassert et al., 2014

	Water withdrawal	Consumptive water use (drinking, domestic, agriculture, industry)	Water	Service	cm	2010	Catchment	The value was taken from the catchment closest to the delta centroid. https://www.wri.org/resources/data-sets/aqueduct-global-maps-21-data	Gassert et al., 2014
	Coastal flooding*	Average inundation depth for 100 year flood.	Flood protection	Service	dm	2010	5 arc-min	Reversed so larger amount indicated greater service. https://www.wri.org/applications/aqueduct/floods/	Ward et al., 2020
	River flooding*	Average inundation depth for 100 year flood.	Flood protection	Service	m	2000-2013	30 arc-sec	Reversed so larger amount indicated greater service. https://data.europa.eu/euodp/en/data/dataset/jrc-floods-floodmapgl_rp100y-tif	Dottori et al., 2016
Productivity	Actual NPP (NPP)	Actual net primary productivity	Supporting Food	Supply Service	gC/m²/yr	2000	5 arc-min	For three deltas just outside the dataset coastal extent, the value from the nearest cell was used. https://boku.ac.at/wiso/sec/data-download	Haberl et al., 2007
	Potential NPP (NPP pot.)	Potential net primary productivity	Supporting Food	Supply	gC/m²/yr	2000	5 arc-min	For three deltas just outside the dataset coastal extent, the value from the nearest cell was used. https://boku.ac.at/wiso/sec/data-download	Haberl et al., 2007
	Vegetation biomass (Carbon veg.)	Biomass stored above and belowground in living vegetation	Supporting C sequestration	Supply Service	0.01 t/ha	2000	30 arc-sec	https://data.ess-dive.lbl.gov/view/ess-dive-9242865369df02c-20180809T202418442766	Gibbs & Ruesch, 2008
	Potential vegetation biomass (Carbon veg. pot.)	Potential vegetation biomass storage	Supporting C sequestration	Supply	t/ha	<2010	5 arc-min	http://www.earthstat.org/carbon-stocks-potential-natural-vegetation/	West et al., 2010
Soil	Soil carbon density	Soil organic carbon density	Food Erosion prevention	Supply Service	kg/m³	<2017	250 m	https://data.isric.org/geonetwork/srv/eng/catalog.search#/metadata/c02ddf8b-cbfb-4533-a9c3-7bf0790fd042	Hengl et al., 2017
	Soil carbon	Soil organic carbon stock	Carbon sequestration	Service	Pg	2019	30 arc-min	http://www.fao.org/global-soil-partnership/pillars-action/4-information-and-data-new/global-soil-organic-carbon-gsoc-map/en/	FAO & ITPS, 2018
	Soil cation-exchange capacity (Soil CEC)	Soil capacity to retain nutrients	Food	Supply	cmolc/kg	<2017	250 m	https://data.isric.org/geonetwork/srv/eng/catalog.search#/metadata/5333b1af-7620-407f-8bca-2303fc5c7288	Hengl et al., 2017
	Soil loss*	Rate of soil erosion	Erosion prevention	Supply Service	t/ha/yr	2012	25 km	Reversed so larger amount indicated greater service. https://esdac.jrc.ec.europa.eu/content/global-soil-erosion#tabs-0-description=1	Borrelli et al., 2017
	Soil N	Concentration of soil nitrogen	Food	Supply	g/kg	1950-2015	30 arc-sec	The Access database containing the ES dataset was joined with the WISE30sec TIF raster in ArcGIS. The ES was then exported into a separate TIF using the Lookup tool. 'Sea and water' was reclassified as N/A to not influence the results where intersecting delta areas. Other land areas were reclassified as zero. One delta classified as 'sea and water' within the dataset was	Batjes, 2016

								manually checked and the value of the nearest terrestrial pixel assigned. https://data.isric.org/geonetwork/srv/eng/catalog.search#/metadata/dc7b283a-8f19-45e1-aaed-e9bd515119bc	
	Soil water availability (Soil water)	Soil available water capacity	Food	Supply	cm/m	1950-2015	30 arc-sec	The Access database containing the ES dataset was joined with the WISE30sec TIF raster in ArcGIS. The ES was then exported into a separate TIF using the Lookup tool. 'Sea and water' was reclassified as N/A to not influence the results where intersecting delta areas. Other land areas were reclassified as zero. One delta classified as 'sea and water' within the dataset was manually checked and the value of the nearest terrestrial pixel assigned. https://data.isric.org/geonetwork/srv/eng/catalog.search#/metadata/dc7b283a-8f19-45e1-aaed-e9bd515119bc	Batjes, 2016
Pollination	Pollination supply	Pollinator suitable habitat around farmland	Food	Supply Service	Proportion	2015	10 arc-sec	Excludes Arctic areas, but pollination supply for crops was considered unimportant here. Index indicates proportion of suitable habitat within 2 km of farmland, 30% designated as sufficient pollination, or 1. http://ipbes-natcap-ecoshard-data-for-publication.ecoshard.org/	Chaplin-Kramer et al., 2019
Ecosystems	Forest cover	Forest extent	Habitat Materials Climate regulation Erosion prevention Flood protection	Property Supply Service	Proportion	2000	1 arc-sec	Due to dataset size, mean cover was calculated using the Google Earth Engine mean reducer [24]. Cover was calculated by multiplying the proportion of forested area by the average proportion of cover within such areas. https://developers.google.com/earth-engine/datasets/catalog/UMD_hansen_global_forest_change_2019_v1_7	Hansen et al., 2013
	Wetlands	Wetland extent (marsh, swamp, pan, bog, intermittent)	Habitat Water quality Flood protection	Property Supply Service	%	2015	30 arc-sec	To calculate cover, water bodies were converted to no data, and no data values were converted to zero. All wetland types were reclassified as 1 (100% cover), excepting intermittent wetlands (reclassified as 0.5) and those with below 100% cover (reclassified as the midpoint of their range, 50 to 100% as 0.75, 25 to 50% as 0.375, and 0 to 25% as 0.125). The average of this proportion of cover was then calculated per delta. https://www.worldwildlife.org/pages/global-lakes-and-wetlands-database	Lehner & Döll, 2004

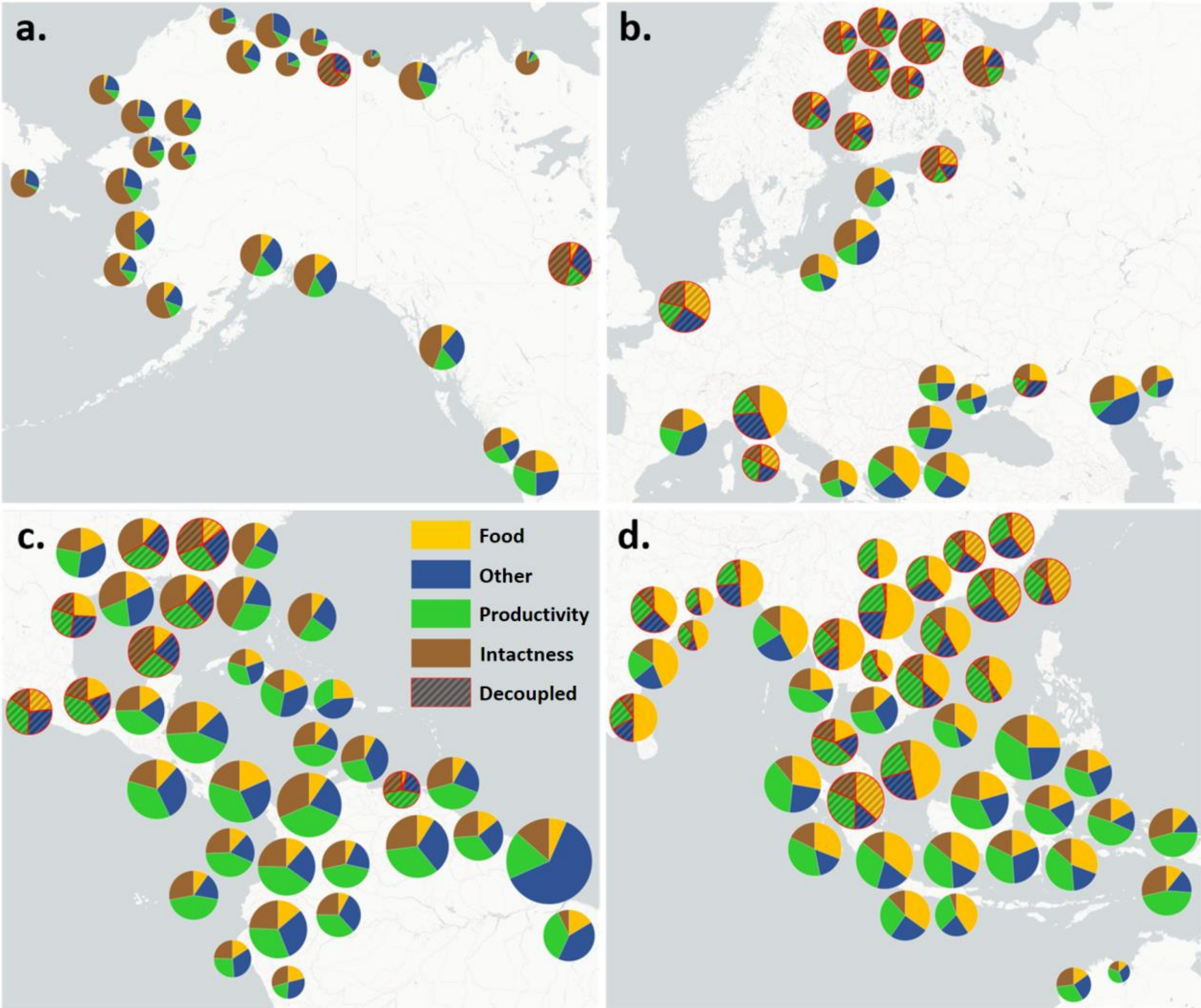
Biodiversity	Alpha diversity intactness (Alpha intactn. %)	Alpha biodiversity relative to pristine conditions	Supporting	Property	Proportion	2010	15 arc-min	https://vat.gfbio.org/geobon-cop/#/	Purvis et al., 2018
	Biodiversity intactness abundance	Species abundance compared to pristine conditions	Supporting	Property	Proportion	2005	30 arc-sec	https://data.nhm.ac.uk/dataset/global-maps-of-biodiversity-intactness-index-sanchez-ortiz-et-al-2019-biorxiv	Sanchez-Ortiz et al., 2019
	Biodiversity intactness richness	Species richness compared to pristine conditions	Supporting	Property	Proportion	2005	30 arc-sec	https://data.nhm.ac.uk/dataset/global-maps-of-biodiversity-intactness-index-sanchez-ortiz-et-al-2019-biorxiv	Sanchez-Ortiz et al., 2019
	Amphibian richness	Richness of amphibian species	Supporting	Property	No. per cell	2013	30 arc-sec	https://sedac.ciesin.columbia.edu/data/set/species-global-amphibian-richness-2015/data-download	IUCN & CIESIN, 2015a
	Amphibian unthreatened*	Proportion of amphibian species which are unthreatened	Supporting	Property	Proportion	<2017	10 km	Originally count data, converted to proportion of richness. Threatened species data reversed to show unthreatened species. https://biodiversitymapping.org/index.php/amphibians/	Jenkins et al., 2013 Pimm et al., 2014
	Bird richness	Richness of bird species	Supporting	Property	No. per cell	<2018	10 km	https://biodiversitymapping.org/index.php/birds/	Jenkins et al., 2013 Pimm et al., 2014
	Bird unthreatened*	Proportion of bird species which are unthreatened	Supporting	Property	Proportion	<2018	10 km	Originally count data, converted to proportion of richness. Threatened species data reversed to show unthreatened species. https://biodiversitymapping.org/index.php/birds/	Jenkins et al., 2013 Pimm et al., 2014
	Mammal richness	Richness of mammal species	Supporting	Property	No. per cell	2013	30 arc-sec	https://sedac.ciesin.columbia.edu/data/set/species-global-mammal-richness-2015	IUCN & CIESIN, 2015
	Mammal unthreatened*	Proportion of mammal species which are unthreatened	Supporting	Property	Proportion	<2018	10 km	Originally count data, converted to proportion of richness. Threatened species data reversed to show unthreatened species. https://biodiversitymapping.org/index.php/mammals/	Jenkins et al., 2013 Pimm et al., 2014
	Marine animal richness	Richness of marine animal species	Supporting	Property	No. per cell	<2019	30 arc-min	Converted into point data, then rasterised with the QGIS Rasterize tool to maximise compatibility with the other analyses. Points were shifted 0.25 degrees northwest to maintain the points as the centre of the cells created. https://www.aquamaps.org/	Kaschner et al., 2019
	Marine plant richness	Richness of marine plant species	Supporting	Property	No. per cell	<2019	30 arc-min	Converted into point data, then rasterised with the QGIS Rasterize tool to maximise compatibility with the other analyses. Points were shifted 0.25 degrees northwest to maintain the points as the centre of the cells created. https://www.aquamaps.org/	Kaschner et al., 2019

	Marine unthreatened*	Proportion of marine species which are unthreatened	Supporting	Property	Proportion	<2017	50 km	Marine species types summed. Originally count data, converted to proportion of richness. Threatened species data reversed to show unthreatened species. https://biodiversitymapping.org/	Jenkins & Van Houtan, 2016 Jenkins & Van Houtan, 2017
	Plant richness	Richness of native plant species	Supporting	Property	No. per cell	<2012	~95 km	http://ecotope.org/anthromes/biodiversity/plants/data/	Ellis et al., 2012
	Seabird richness	Richness of seabird species	Supporting	Property	No. per cell	<2017	50 km	https://datadryad.org/stash/dataset/doi:10.5061/dryad.3mn1t	Jenkins & Van Houtan, 2016 Jenkins & Van Houtan, 2017
	Seabird unthreatened*	Proportion of seabird species which are unthreatened	Supporting	Property	Proportion	<2017	50 km	Originally count data, converted to proportion of richness. Threatened species data reversed to show unthreatened species. https://datadryad.org/stash/dataset/doi:10.5061/dryad.3mn1t	Jenkins & Van Houtan, 2016 Jenkins & Van Houtan, 2017
Energy	Oil area	Extent of on-shore and off-shore oil and gas deposits	Energy	Supply	Proportion	1946-2003	Vector	On and off-shore deposit areas summed https://www.prio.org/Data/Geographical-and-Resource-Datasets/Petroleum-Dataset/Petroleum-Dataset-v-12/	Lujala et al., 2007

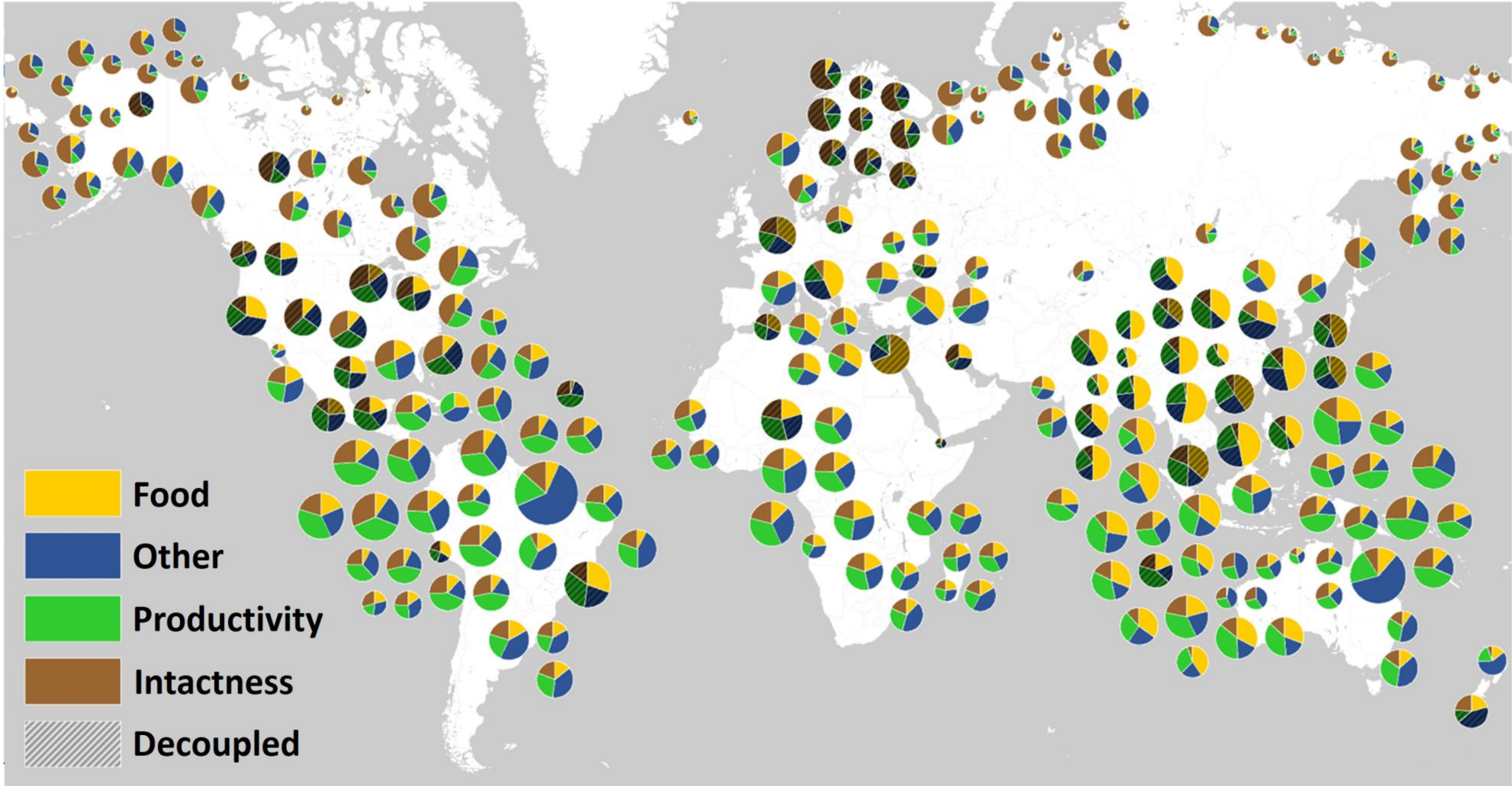
Supplementary Notes

Supplementary Note 1. Geographical variation in ecosystem service bundles

The supply of ecosystem services (ES) varied considerably between deltas, with proximate deltas sharing similar proportions of ES bundles, and tropical deltas showing the greatest total ES supply (Supplementary Figures 1 and 2). 'Productivity' showed the clearest latitudinal pattern, increasing towards tropical regions, as would be expected. The 'food' bundle was most prominent in Europe and Southeast Asia. 'Intactness' dominated the ES supply in the more pristine northern and Arctic deltas.



Supplementary Figure 1. Global delta ecosystem service (ES) bundle supply. Unsupervised ES bundle supply in selected regions: a. Northwest America. b. Europe. c. Central America. d. Southeast Asia. Overlapping pies are repositioned for visibility. Pie diameter indicates summed ES bundle supply for each delta. Decoupled ES bundles from the human footprint indicator are indicated by hatching and red outline.



Supplementary Figure 2. Global ecosystem service (ES) supply for each delta. ES are grouped into unsupervised bundles. Overlapping pies are repositioned for visibility – see Supplementary Figure 1 for more accurate locations. Pie diameter indicates summed ES bundle supply. Decoupled ES bundles from the human footprint indicator are indicated by hatching.

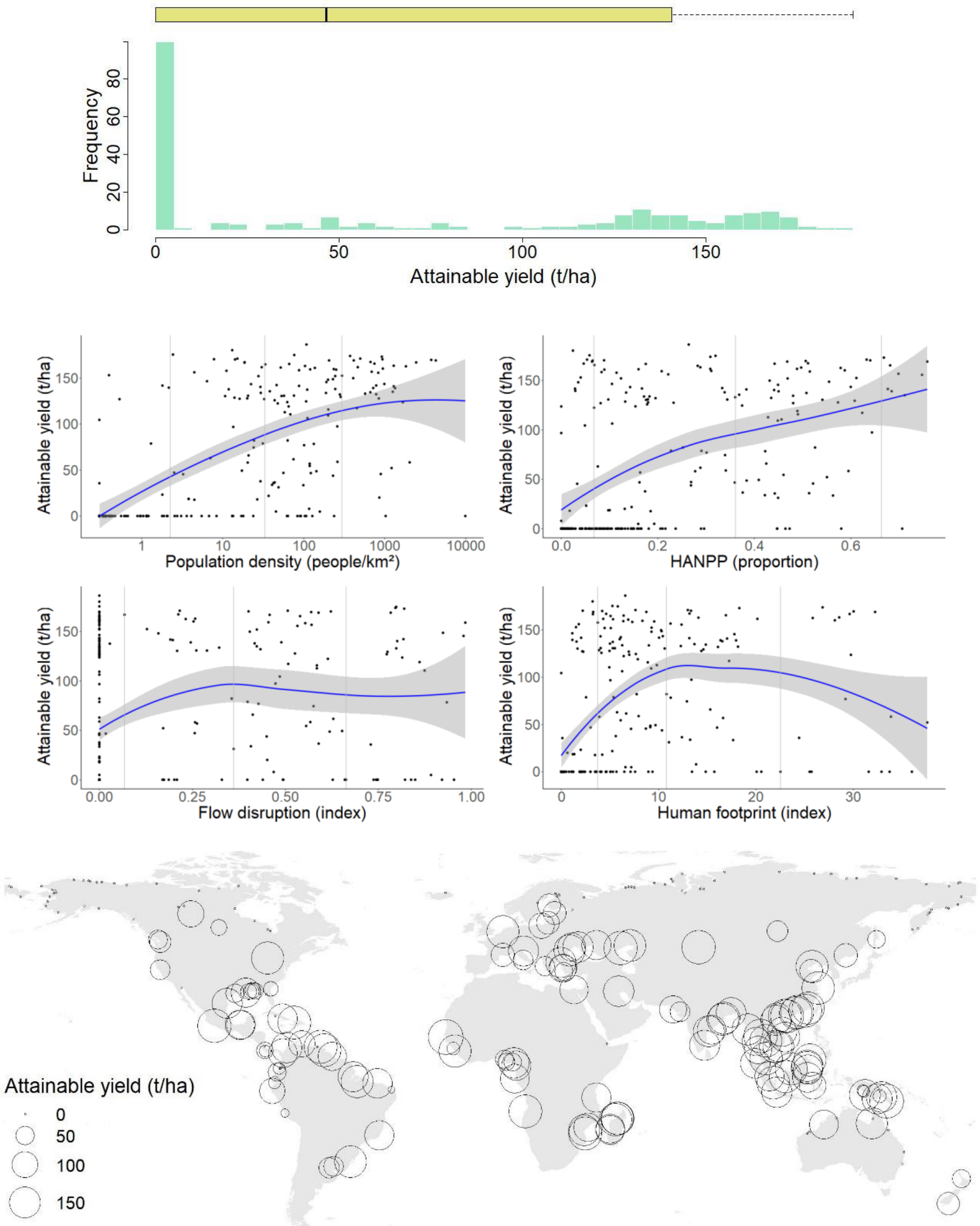
Supplementary Note 2. Ecosystem service indicator summary

This section summarises the ecosystem service indicators across all deltas, their relationship with the four modification indicators, and their global spatial distribution (Supplementary Figures 3 to 51). Sections are labelled using the short name of the indicator used elsewhere in figures and tables. See Supplementary Table 1 for more details on each indicator and their sources. When describing threats or deficiencies, the data was reversed so that the greater the value, the greater the supply of the service.

2.1. Agriculture

2.1.1. Attainable yield

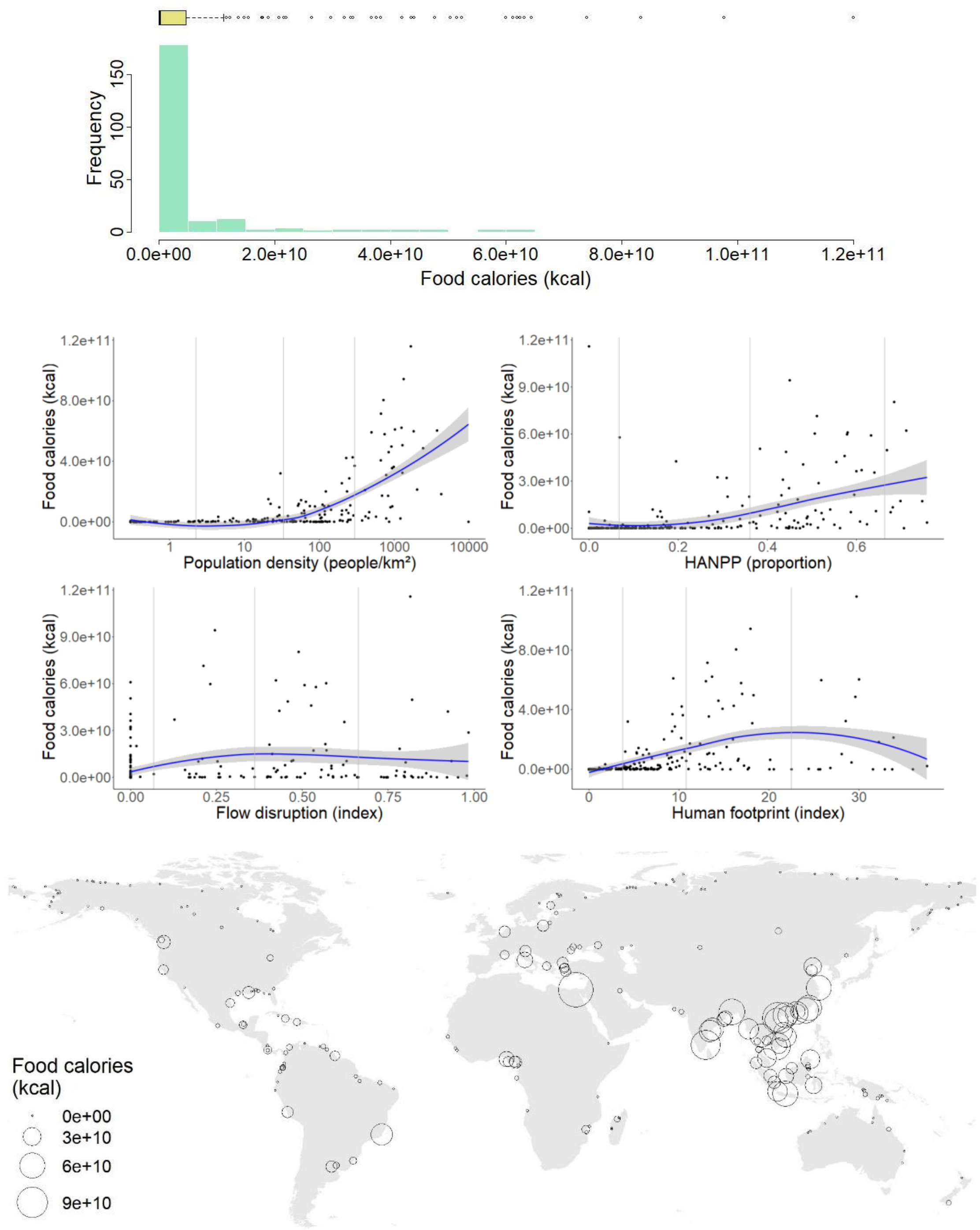
Economically feasible yield given climate.



Supplementary Figure 3. Summary of attainable yield indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.1.2. Food calories

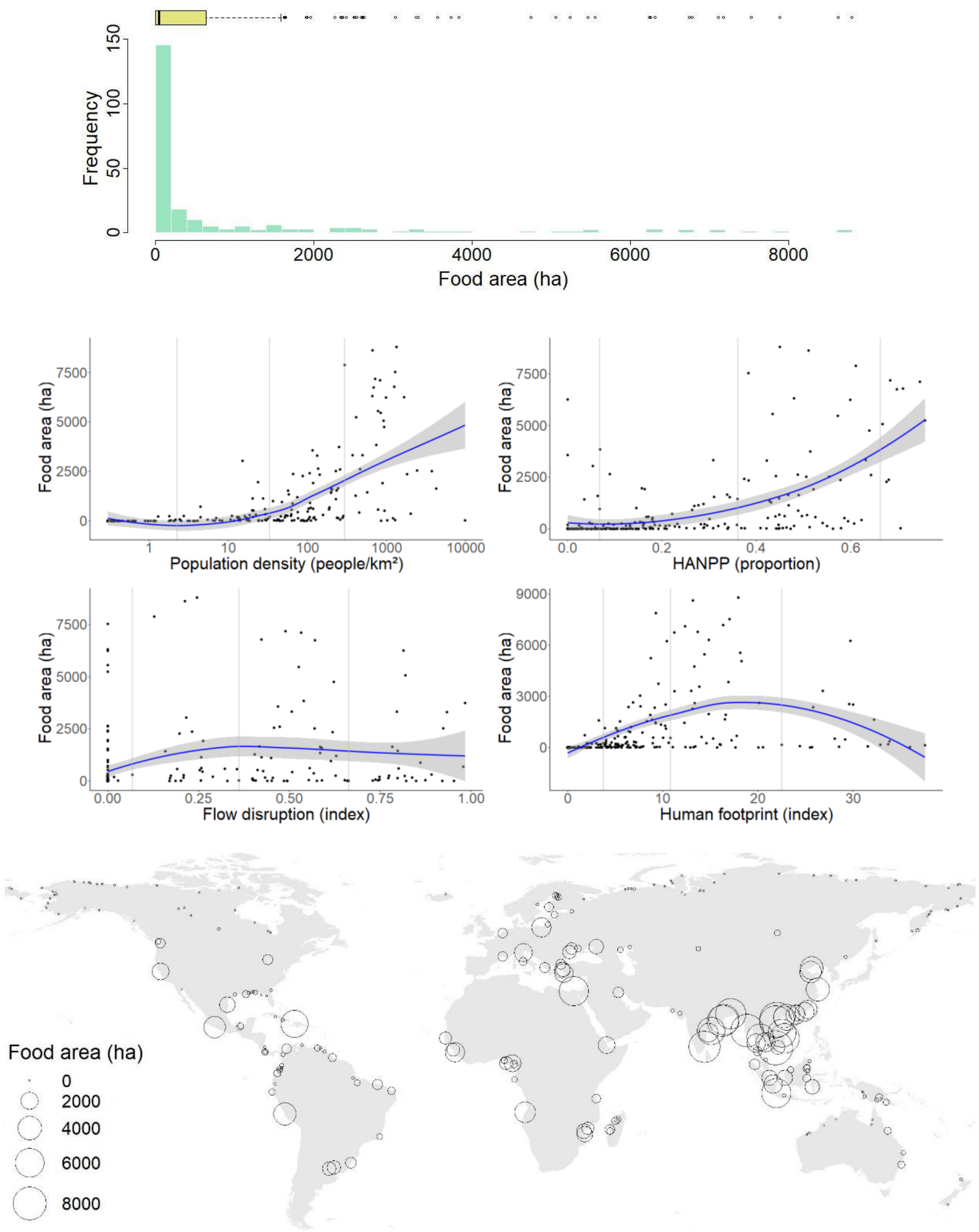
Crop kilocalories produced for food.



Supplementary Figure 4. Summary of food calories indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.1.3. Food area

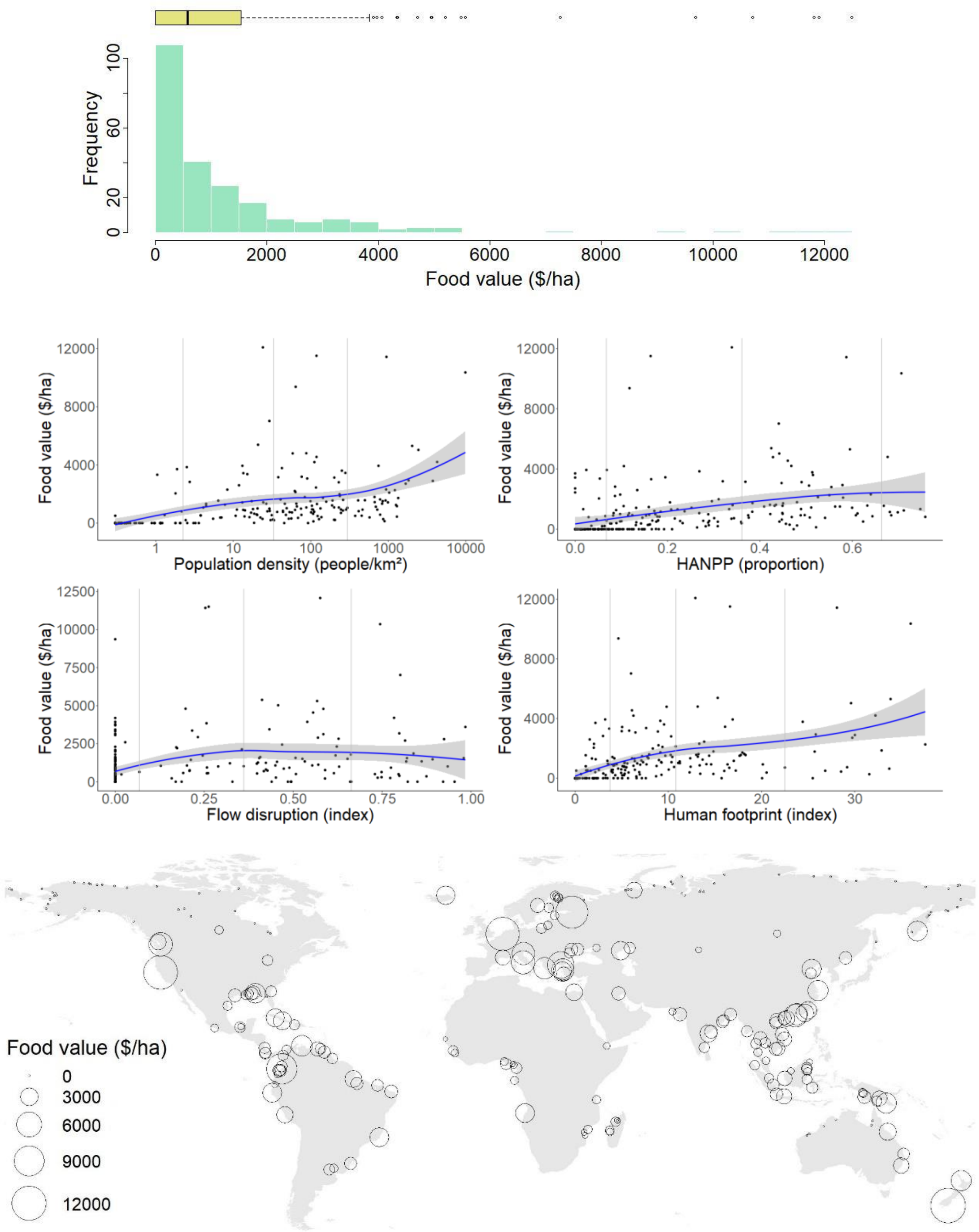
Area harvested for food crops.



Supplementary Figure 5. Summary of food area indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.1.4. Food value

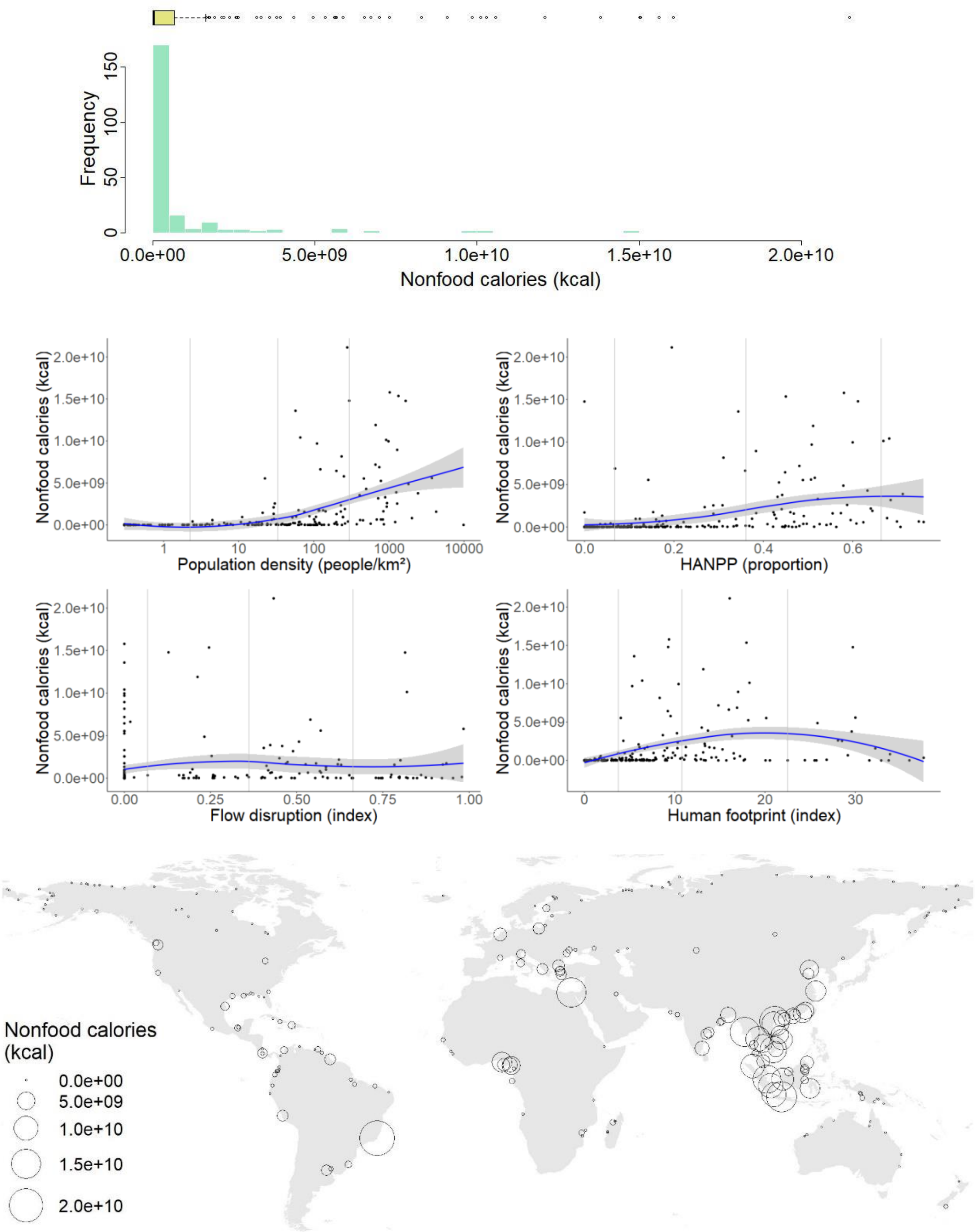
Economic value of food crop production.



Supplementary Figure 6. Summary of food value indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.1.5. Nonfood calories

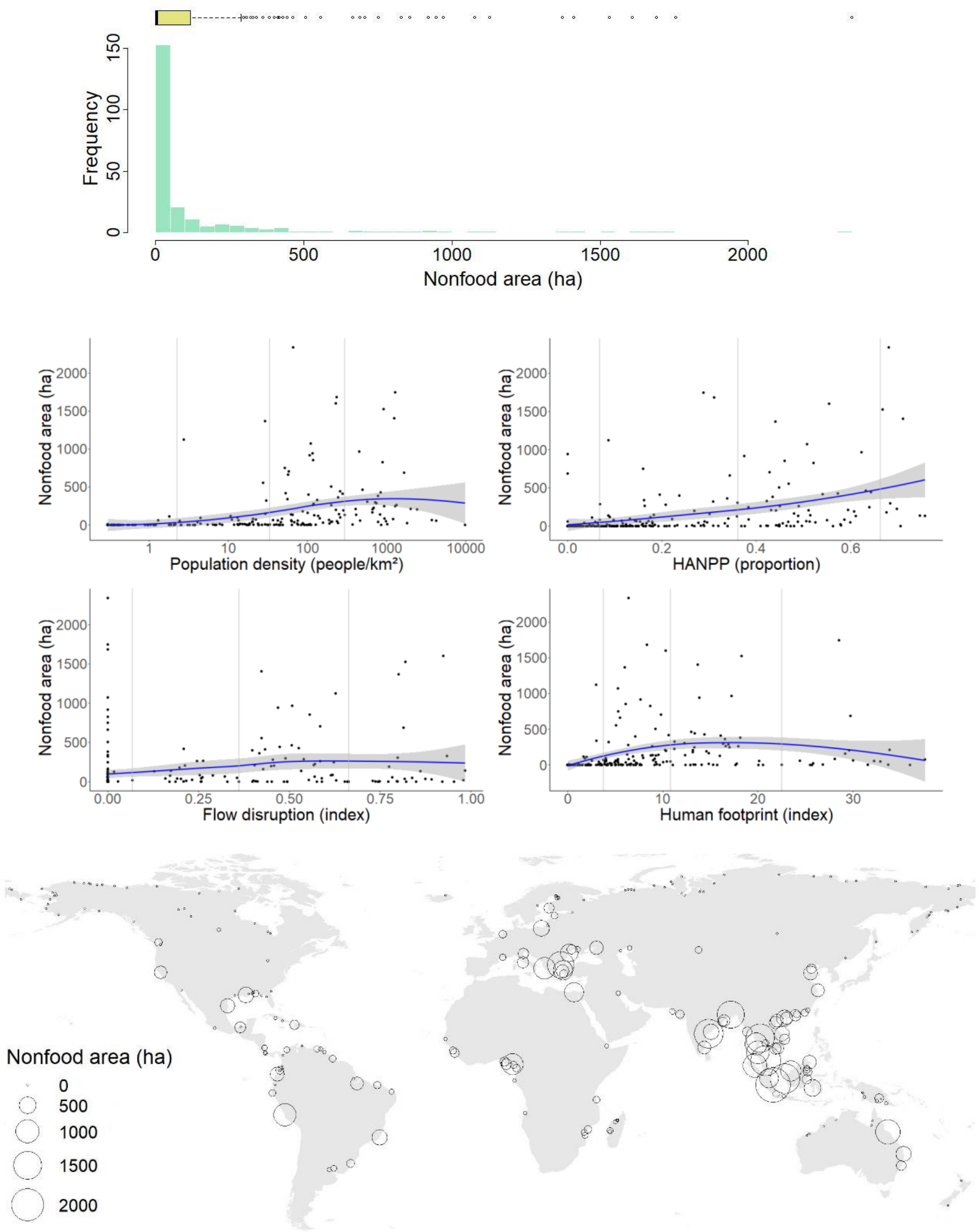
Crop kilocalories produced for non-food uses, typically biofuel.



Supplementary Figure 7. Summary of non-food calories indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.1.6. Nonfood area

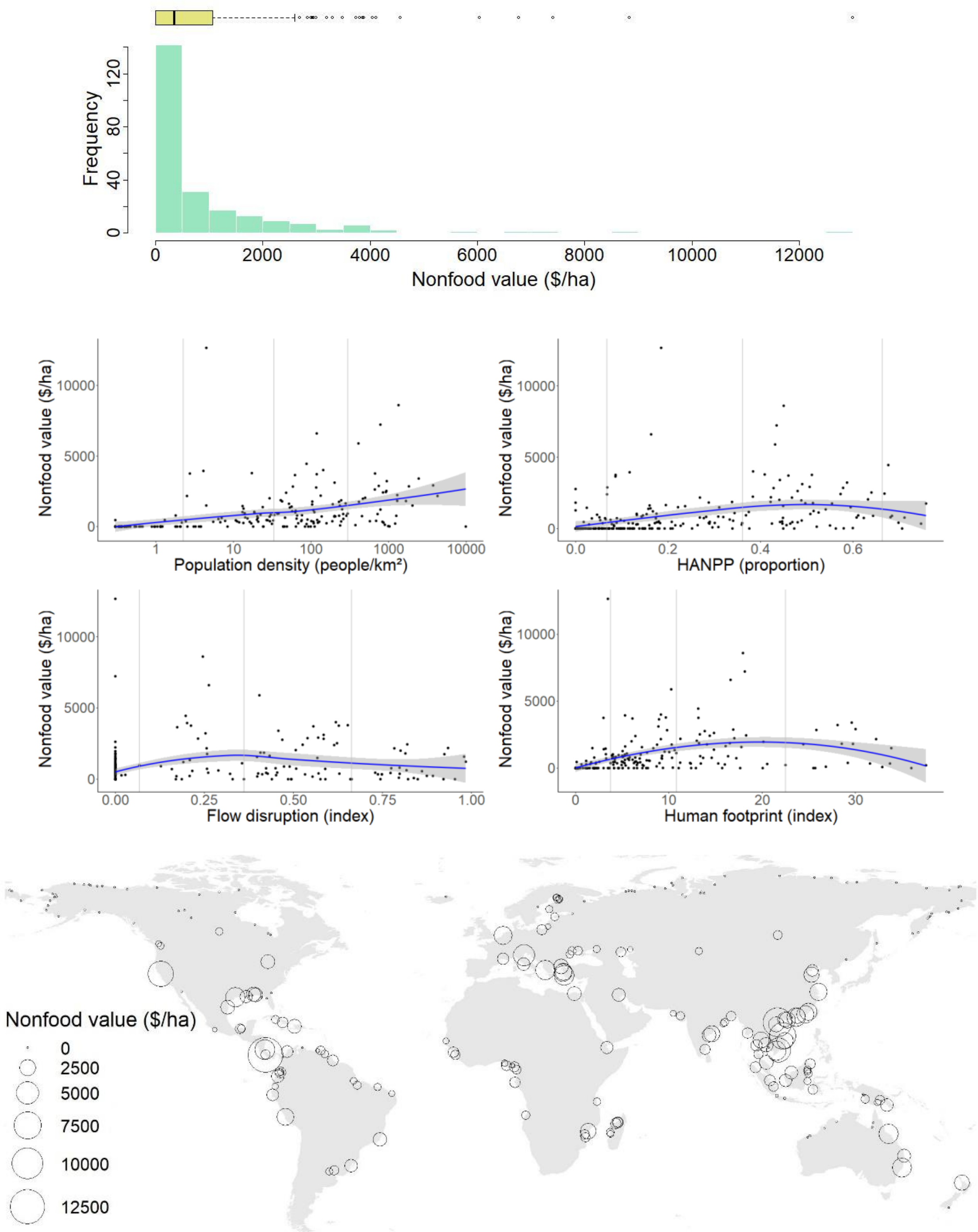
Area harvested for non-food crops.



Supplementary Figure 8. Summary of non-food area indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.1.7. Nonfood value

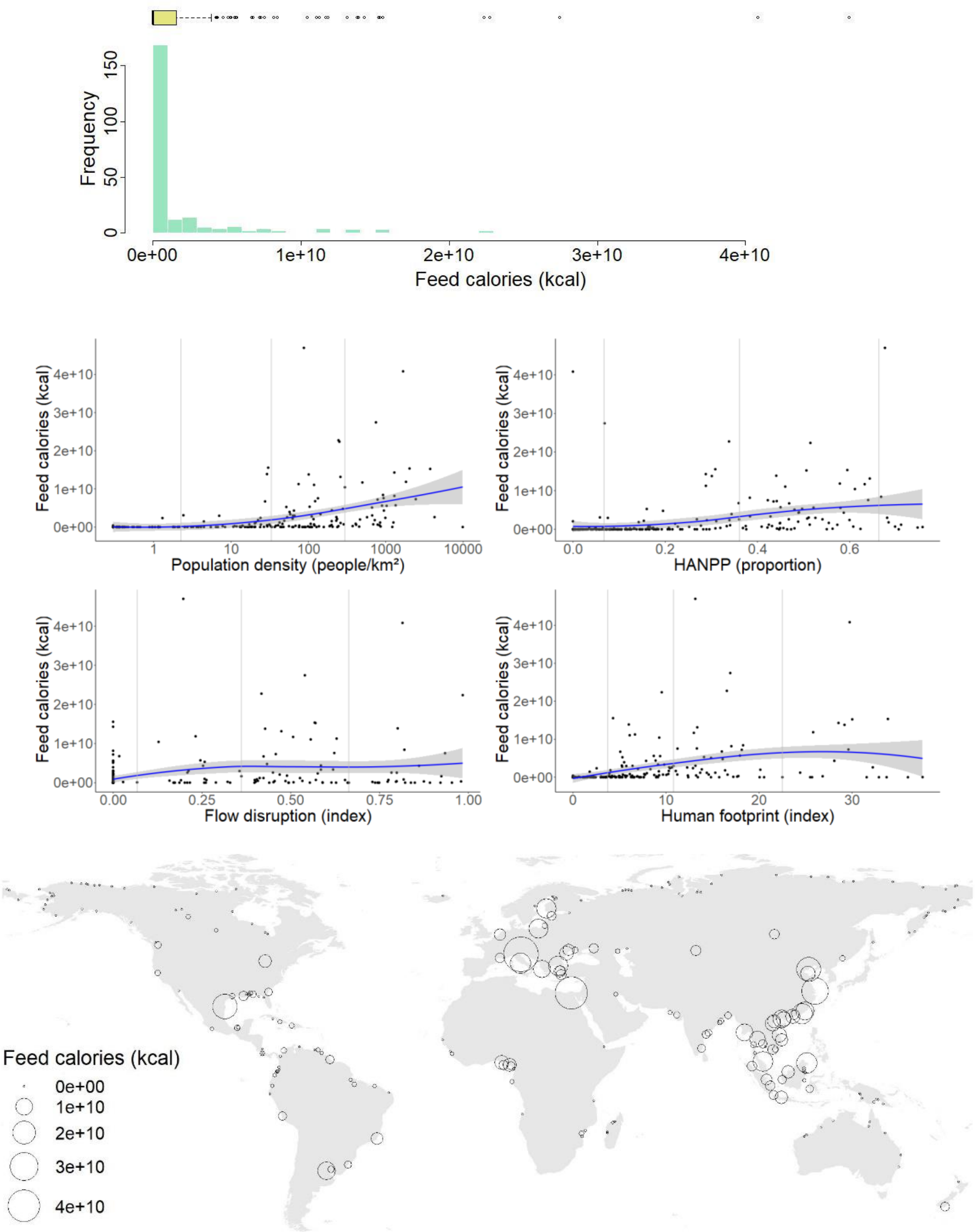
Economic value of non-food crop production.



Supplementary Figure 9. Summary of non-food value indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.1.8. Feed calories

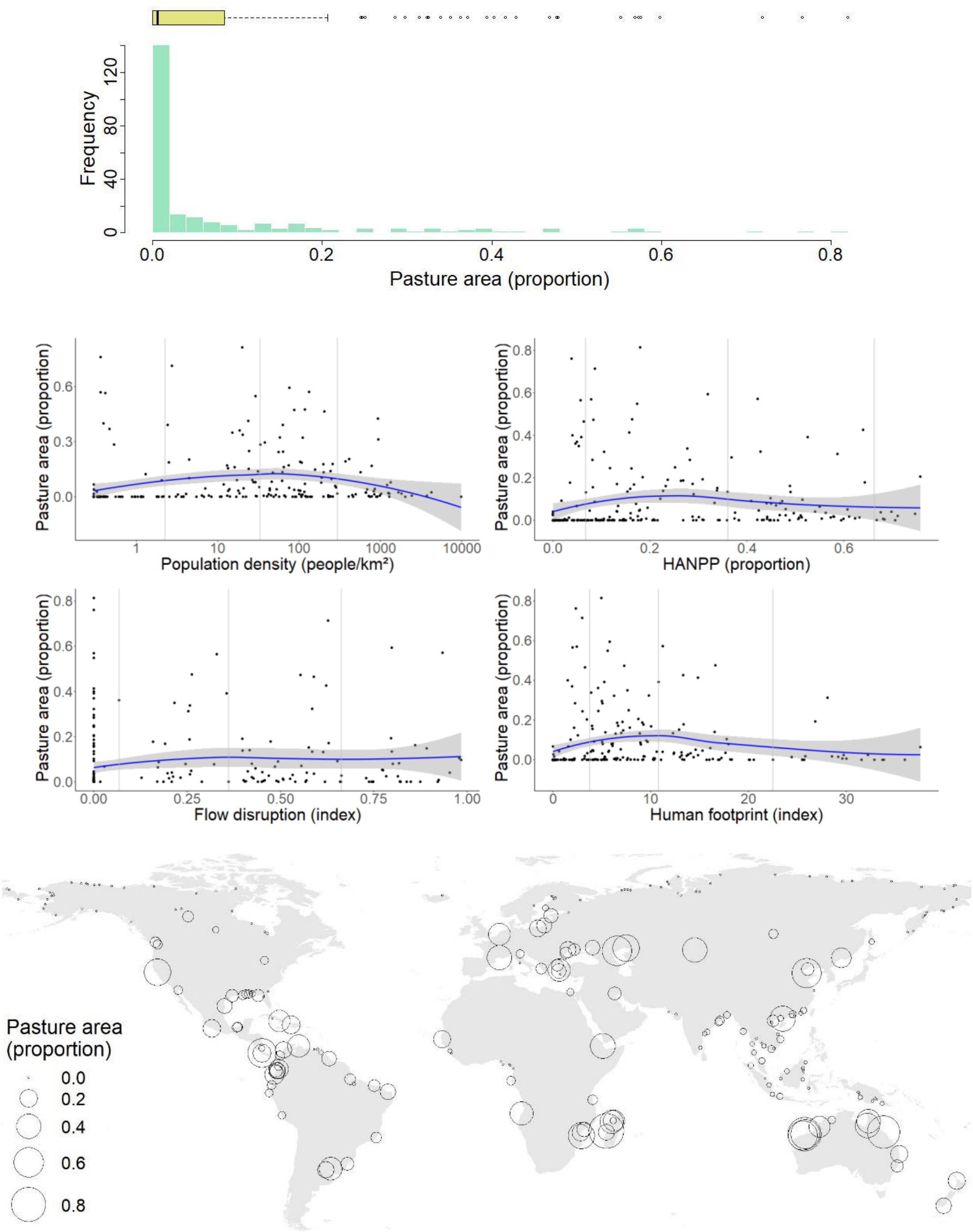
Crop kilocalories produced for use as feed.



Supplementary Figure 10. Summary of feed calories indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.1.9. Pasture area

Proportion of pasture land cover.

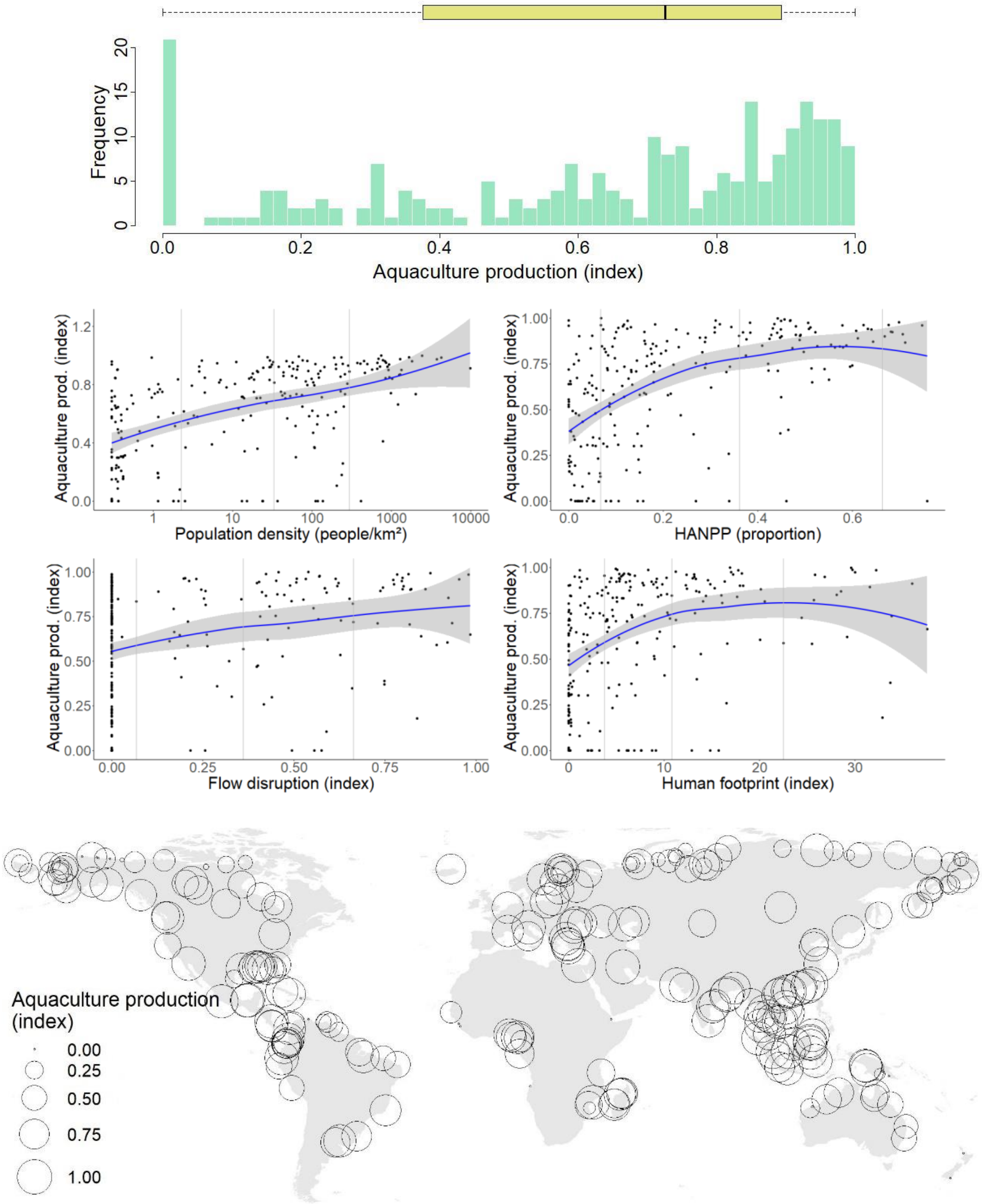


Supplementary Figure 11. Summary of pasture area indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.2. Fish and aquaculture

2.2.1. Aquaculture

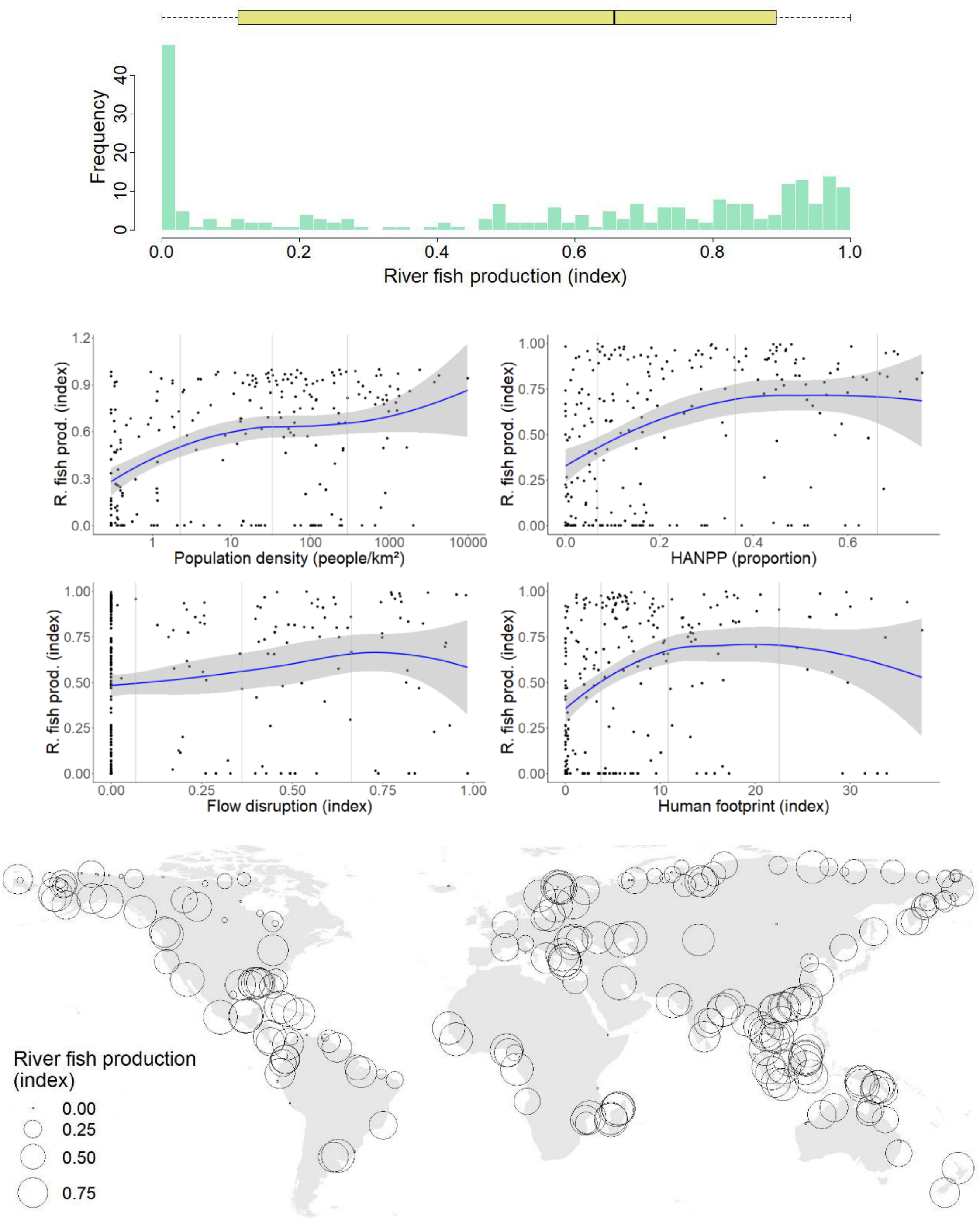
Aquaculture harvest per unit of discharge.



Supplementary Figure 12. Summary of aquaculture production indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.2.2. Fish river

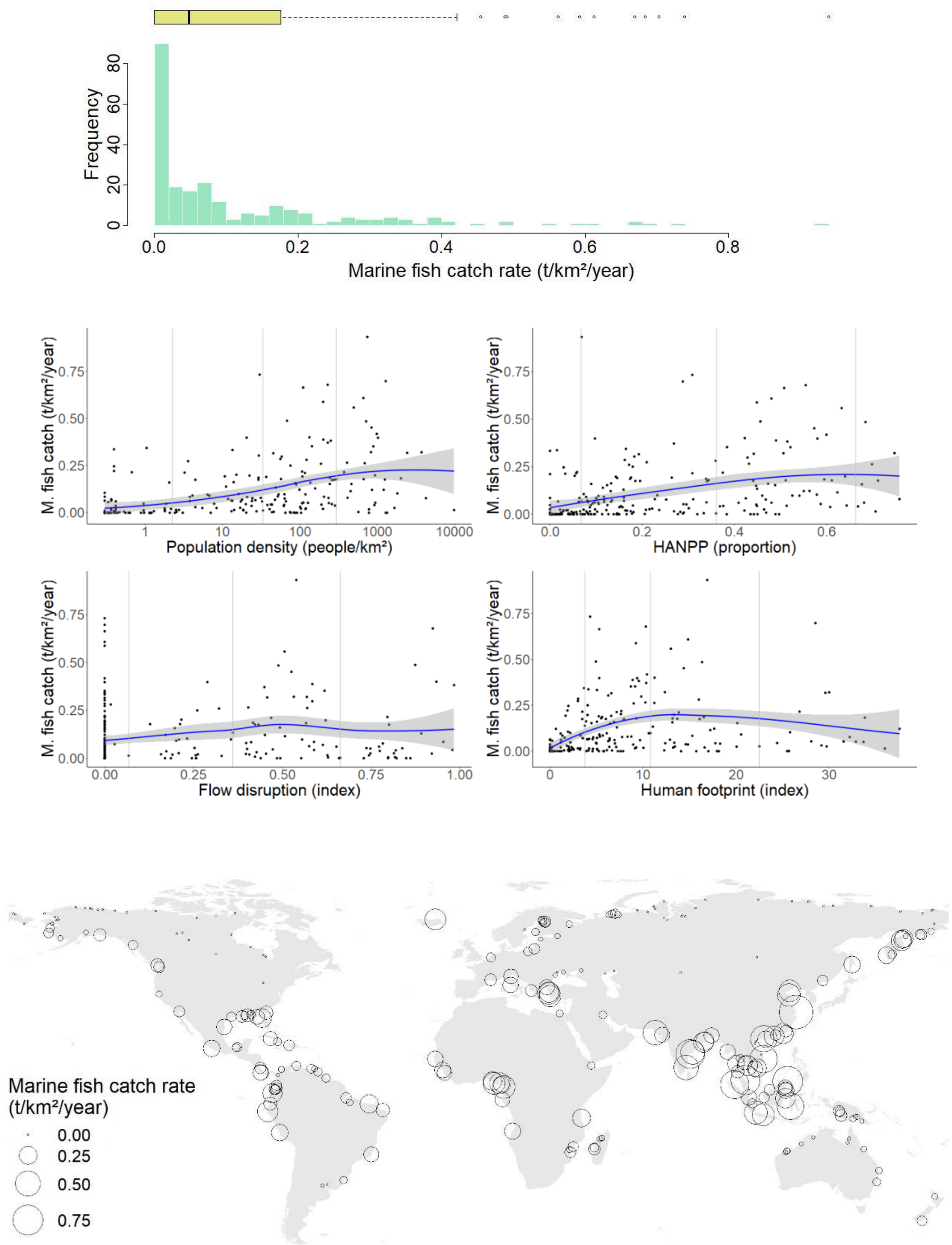
River fish production.



Supplementary Figure 13. Summary of river fish production indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.2.3. Fish marine

Marine fishing catch rate.

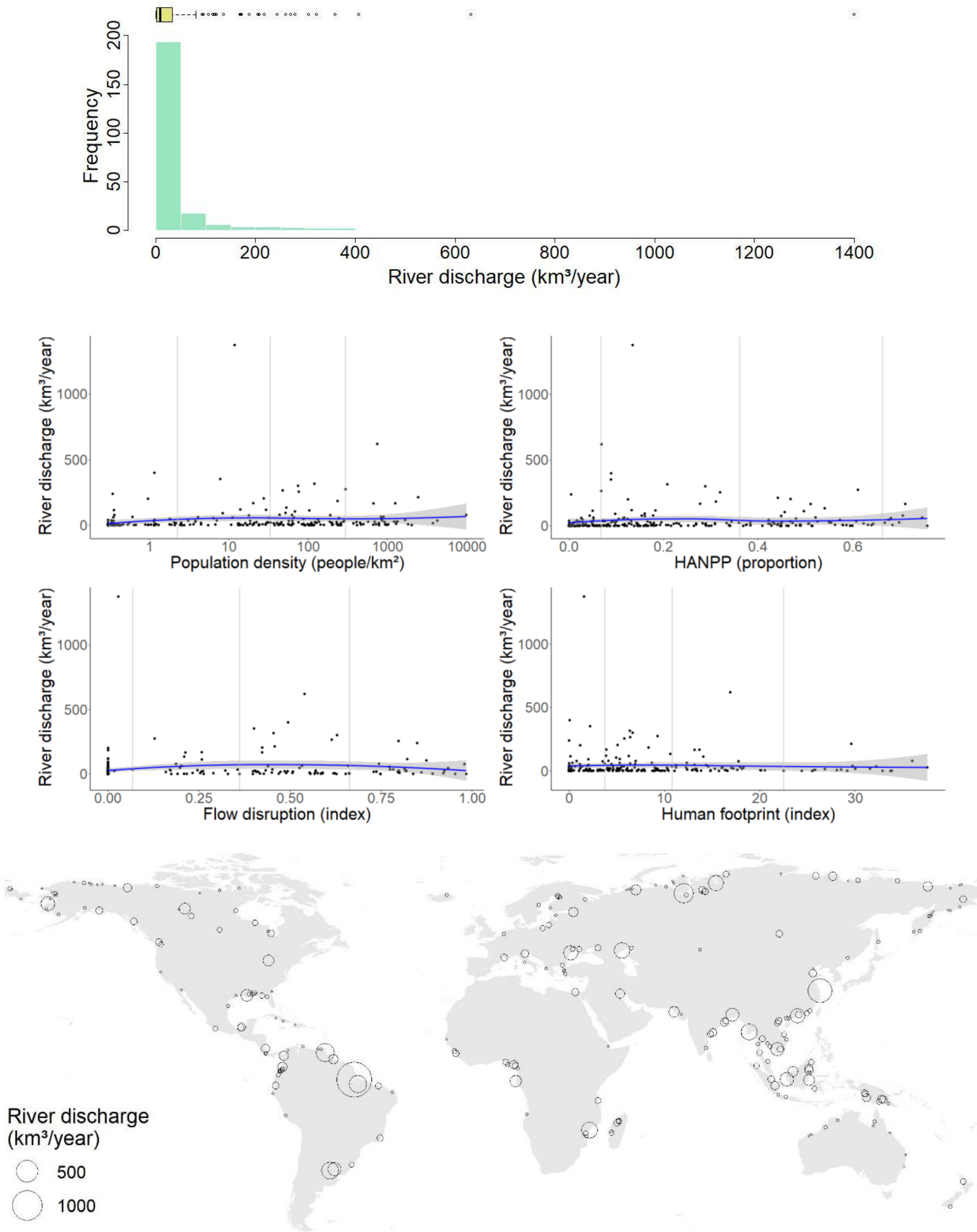


Supplementary Figure 14. Summary of marine fish production indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.3. Water

2.3.1. Discharge

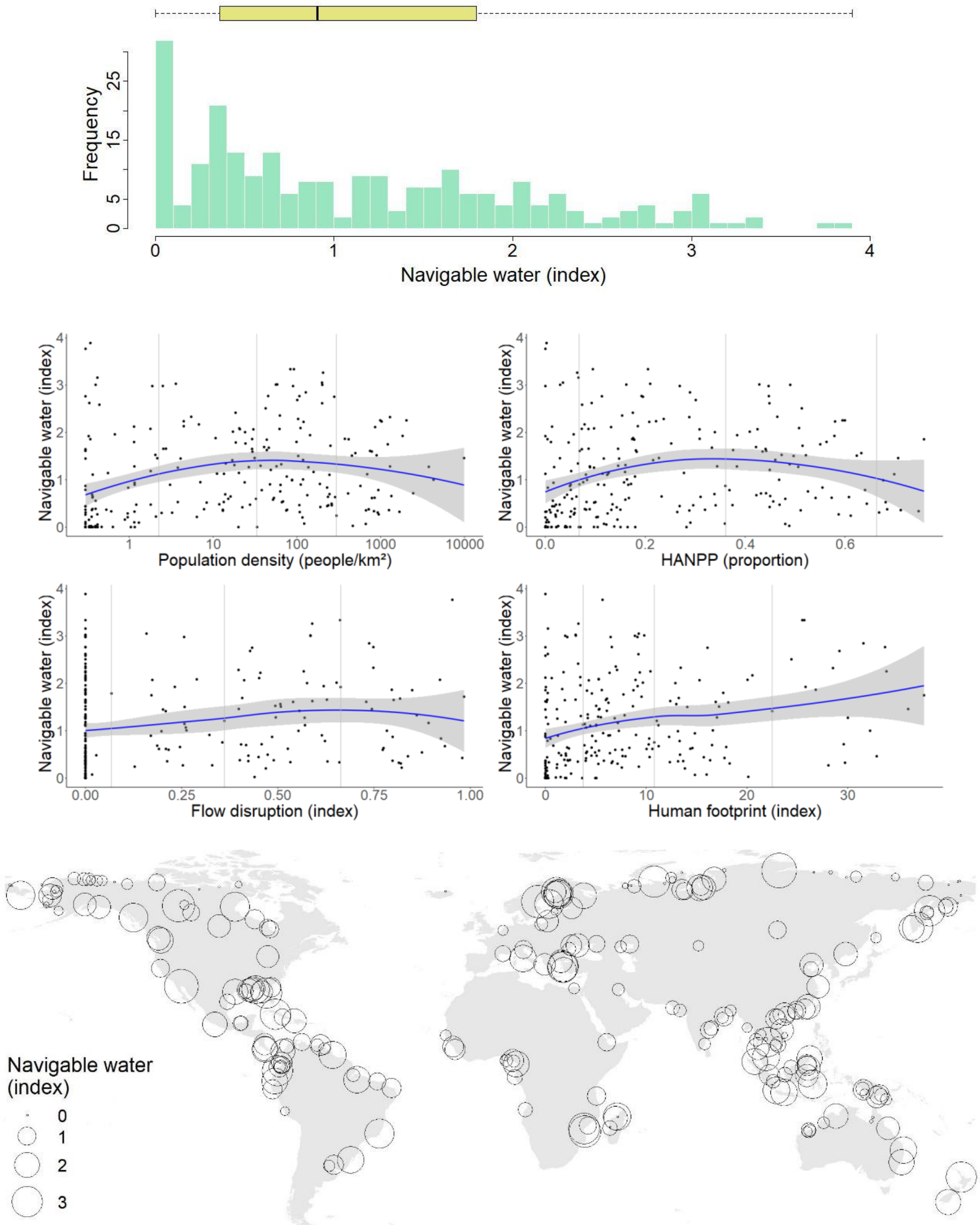
Annual river discharge.



Supplementary Figure 15. Summary of river discharge indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.3.2. Navigable water

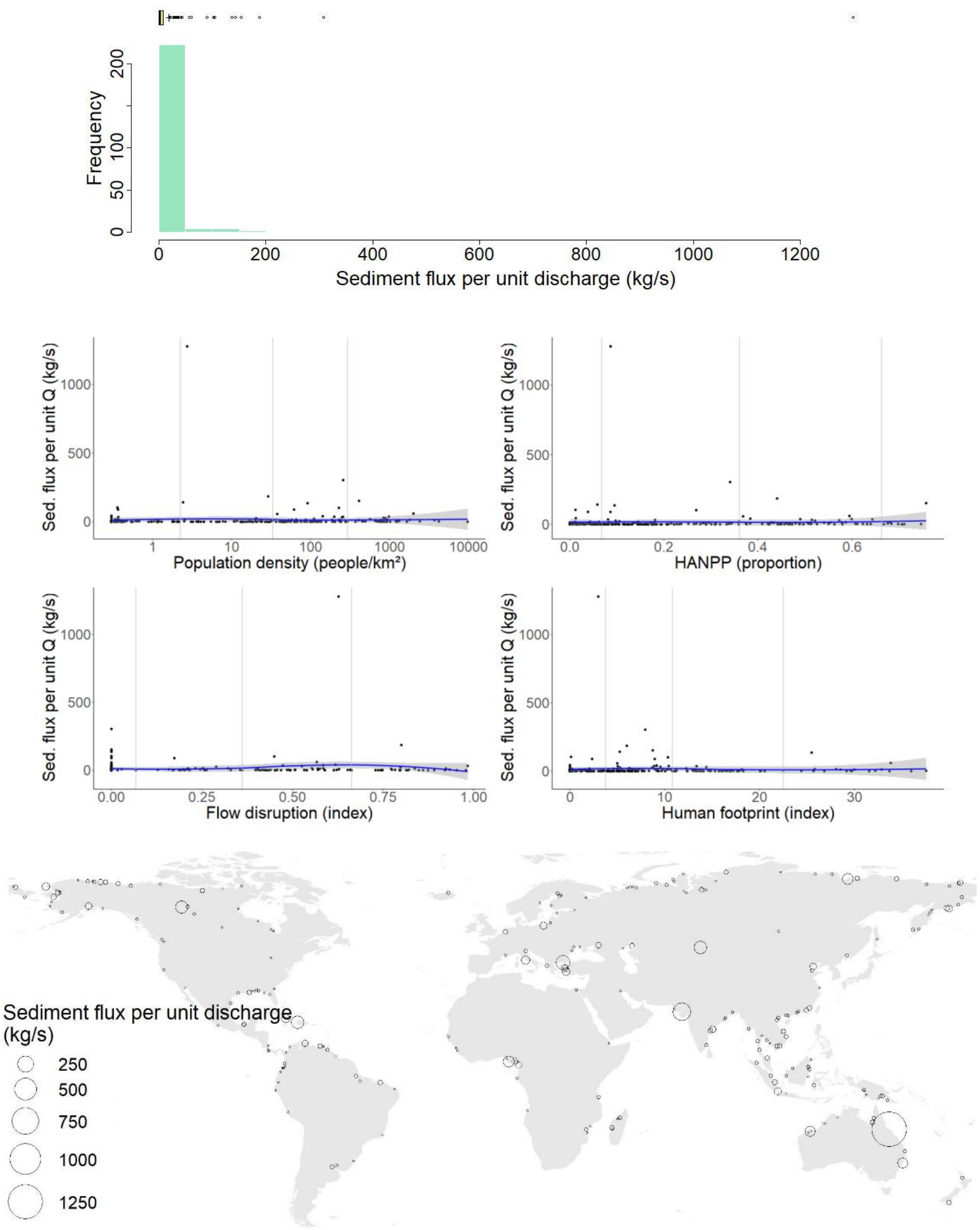
Density of navigable water courses.



Supplementary Figure 16. Summary of navigable water indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.3.3. Sediment flux

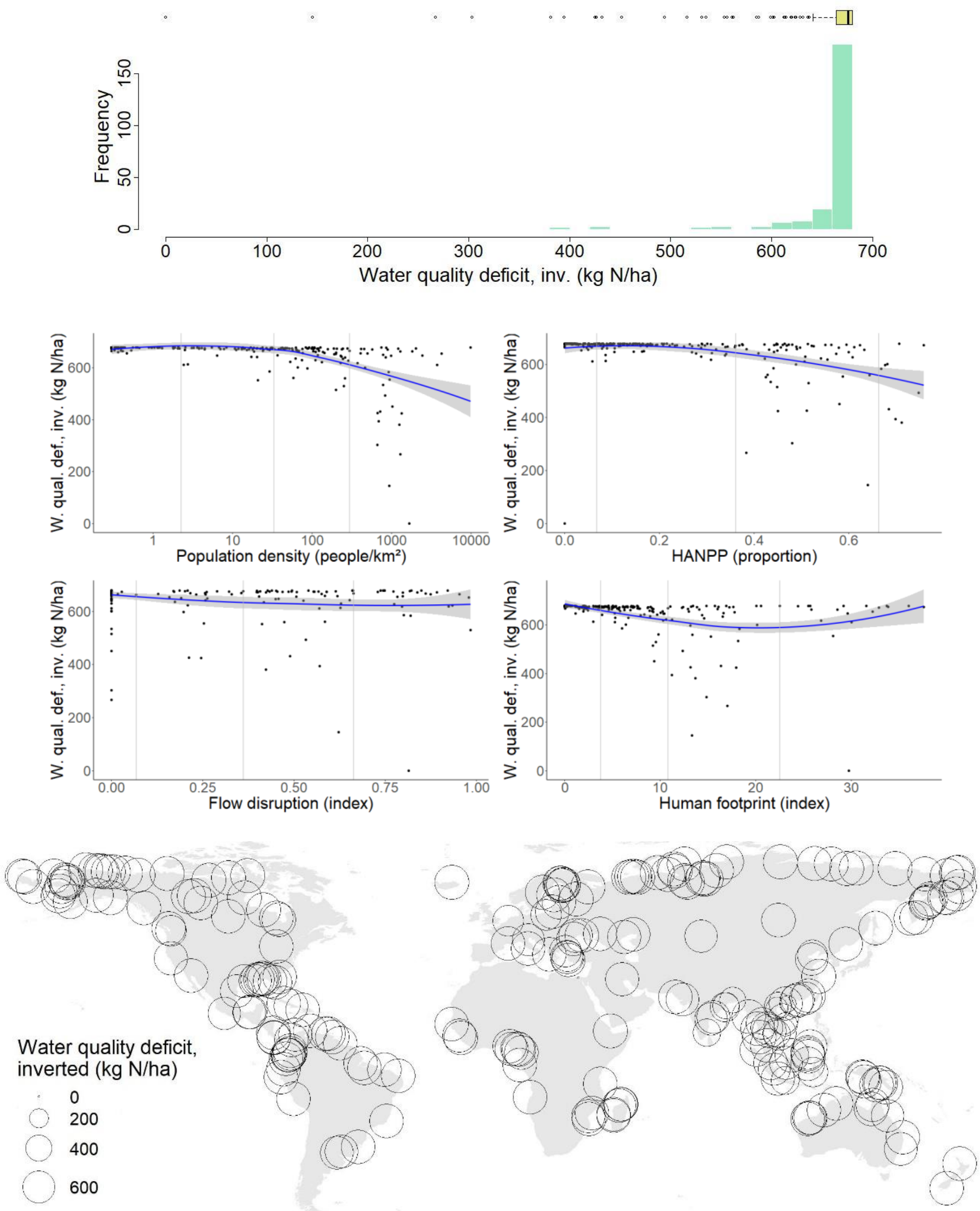
Sediment flux per unit discharge (kg/s).



Supplementary Figure 17. Summary of sediment flux indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.3.4. Water quality

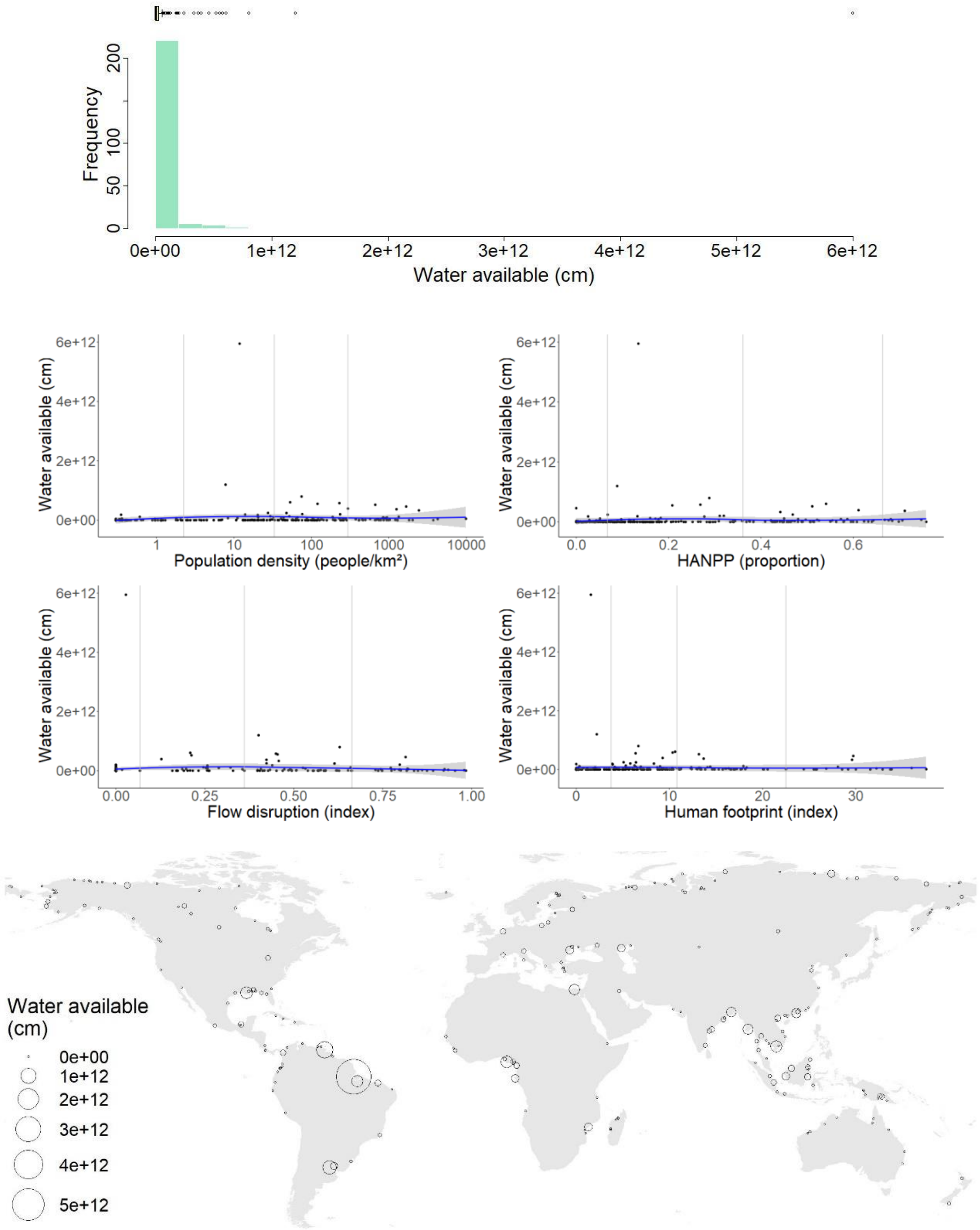
Water quality deficit (nitrogen export).



Supplementary Figure 18. Summary of water quality indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.3.5. Water available

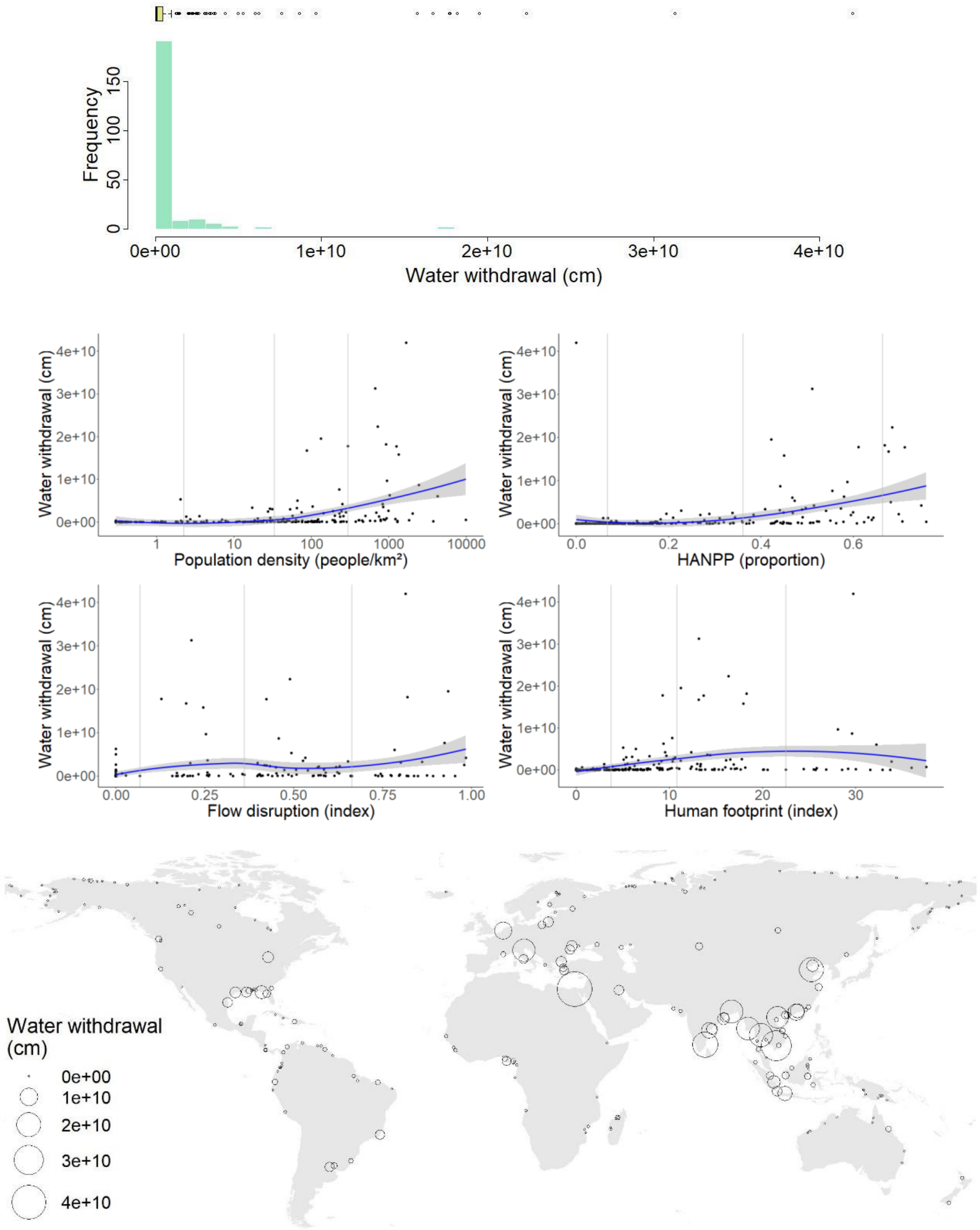
Blue water runoff available for human use.



Supplementary Figure 19. Summary of water availability indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.3.6. Water withdrawal

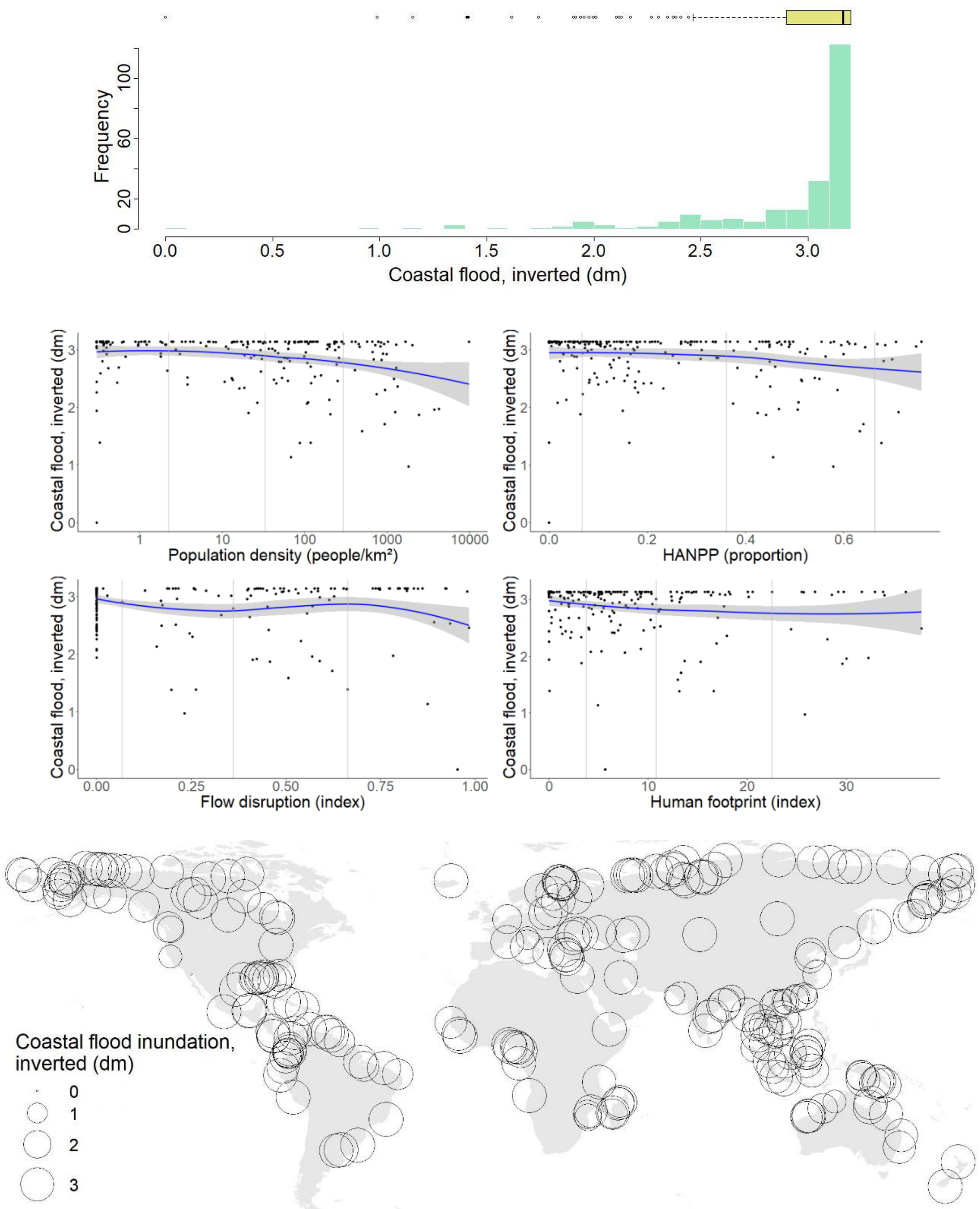
Consumptive water use (drinking, domestic, agriculture, industry).



Supplementary Figure 20. Summary of water withdrawal indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.3.7. Coastal flooding

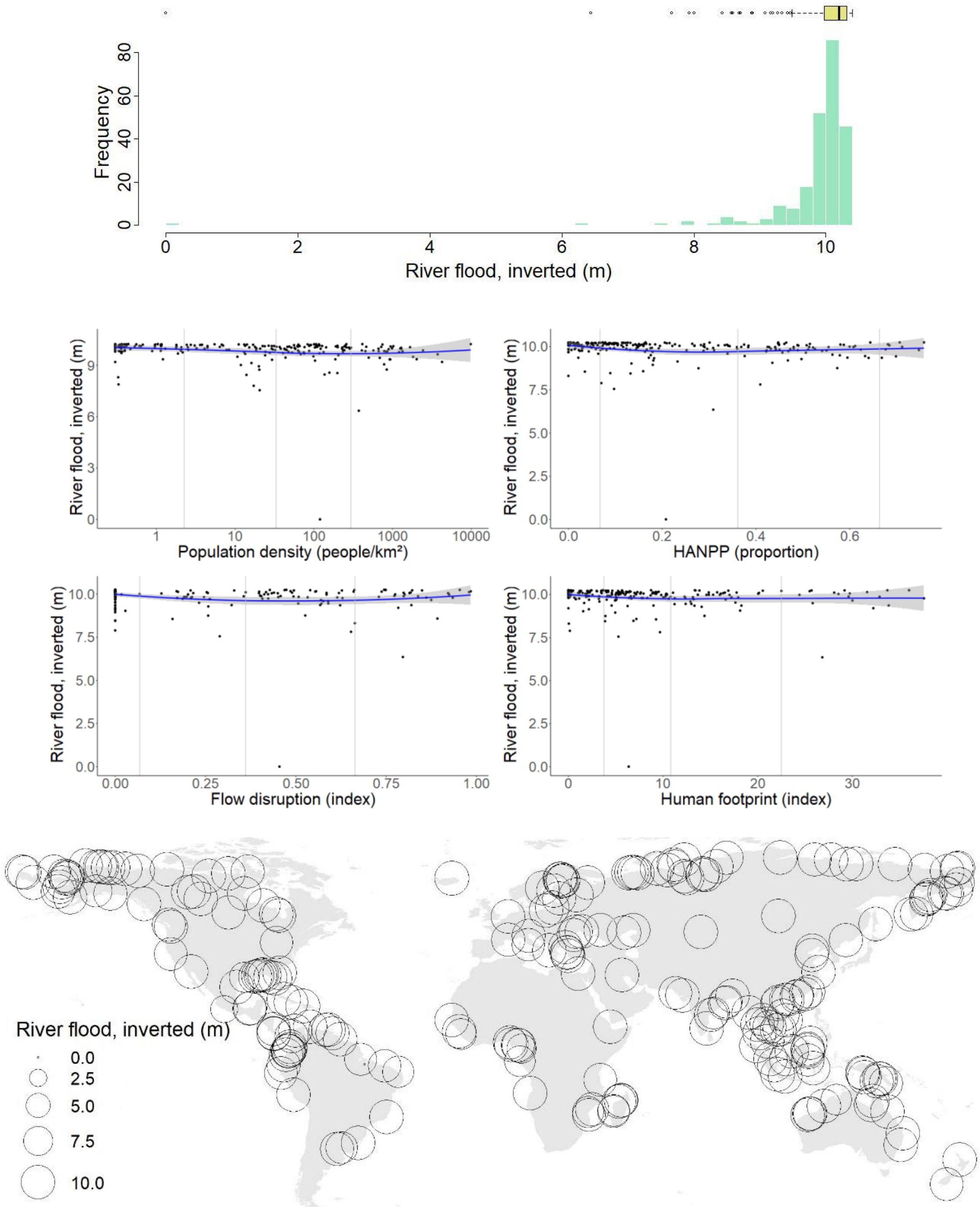
Average inundation depth for 100 year flood.



Supplementary Figure 21. Summary of coastal flooding indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.3.8. River flooding

Average inundation depth for 100 year flood.

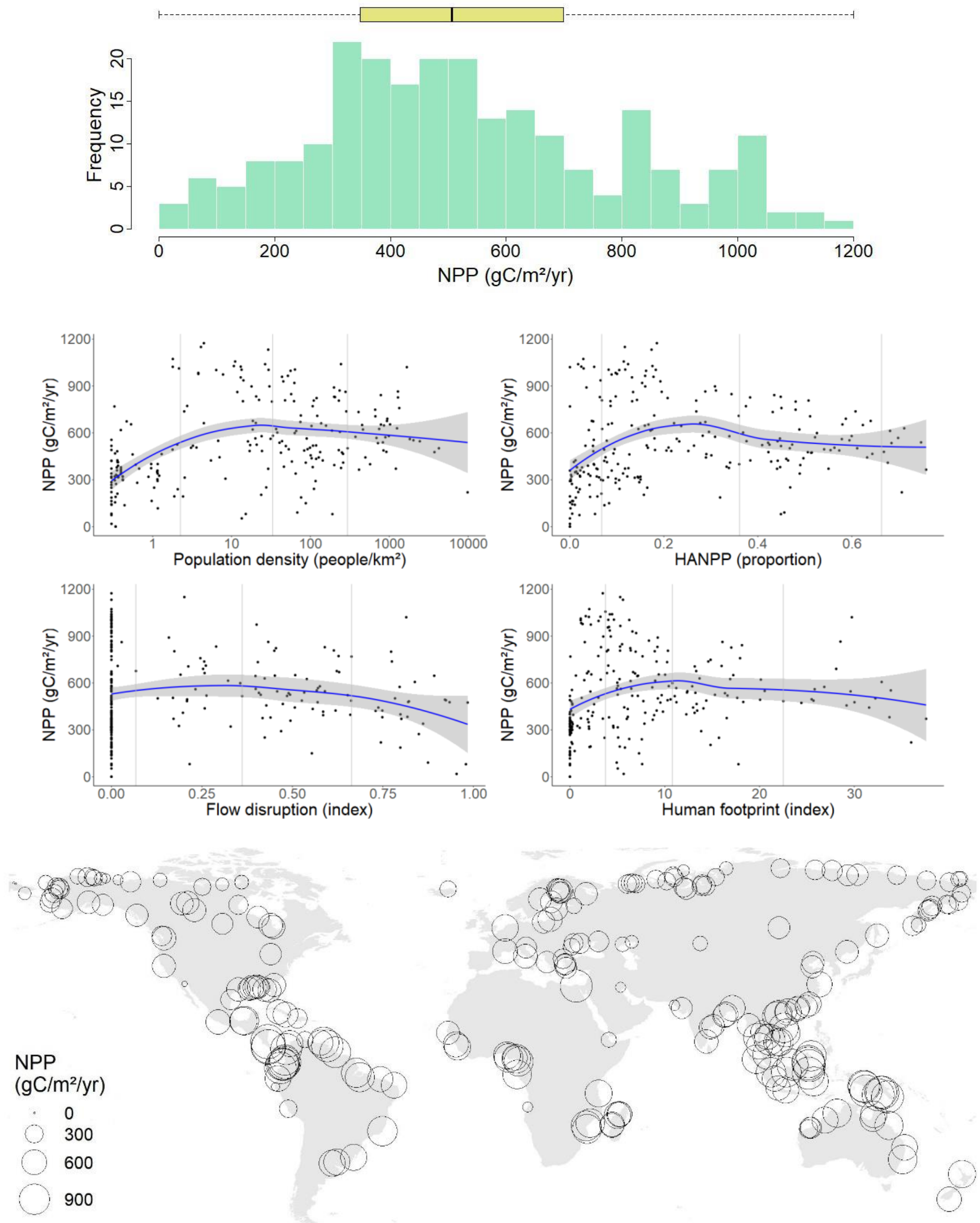


Supplementary Figure 22. Summary of river flooding indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.4. Productivity

2.4.1. NPP

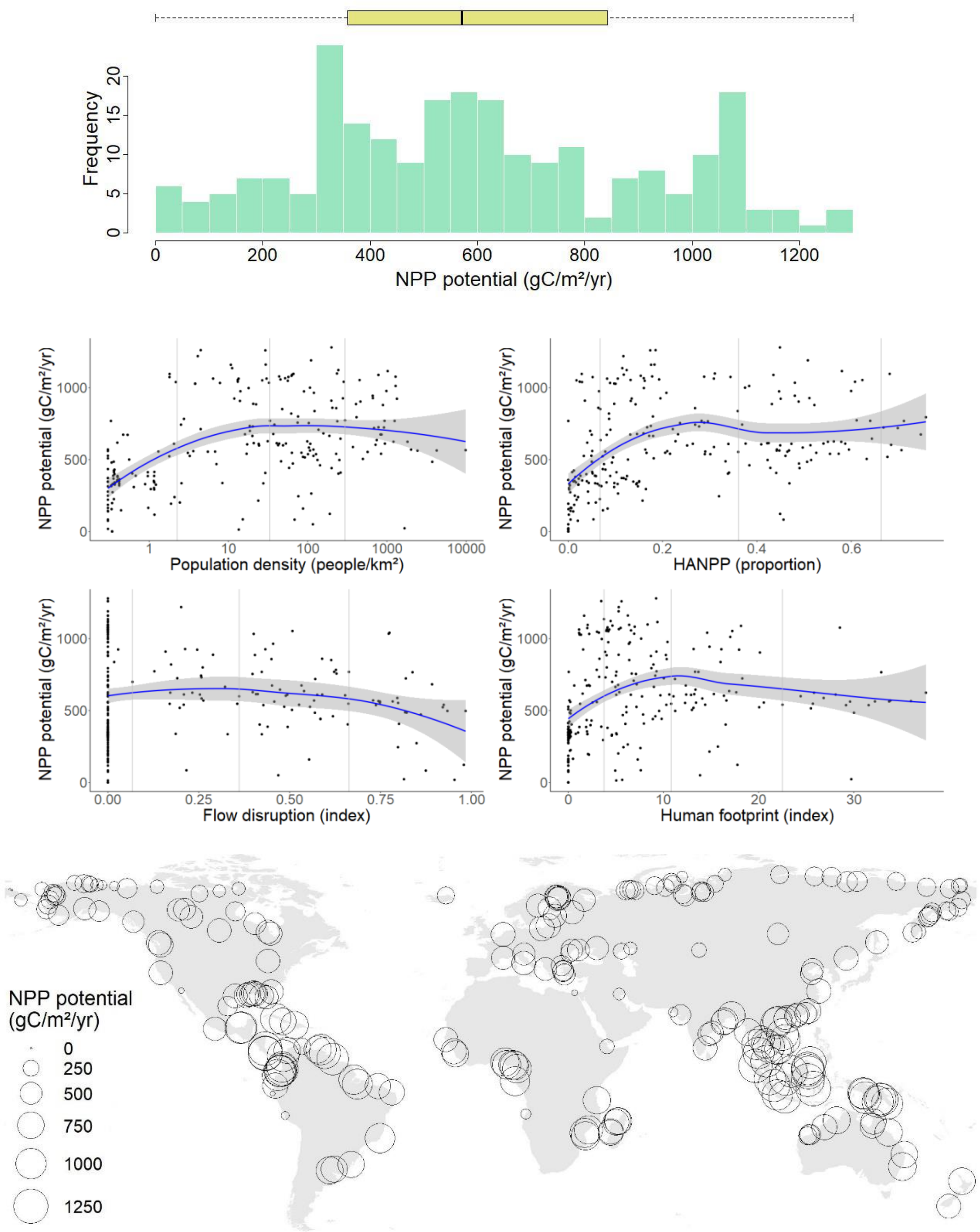
Actual net primary productivity.



Supplementary Figure 23. Summary of net primary productivity (NPP) indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.4.2. NPP potential

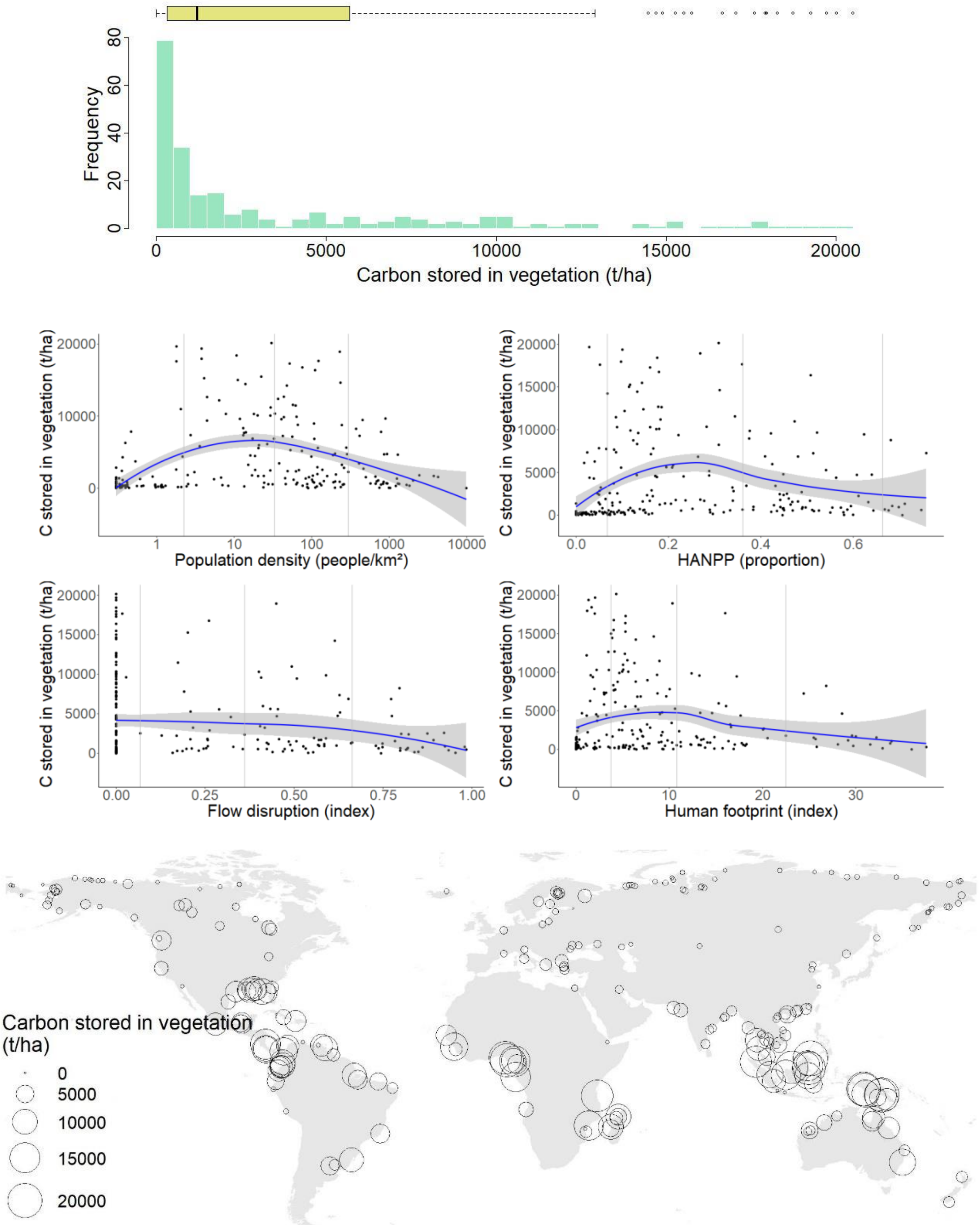
Potential net primary productivity.



Supplementary Figure 24. Summary of potential net primary productivity (NPP) indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.4.3. Carbon vegetation

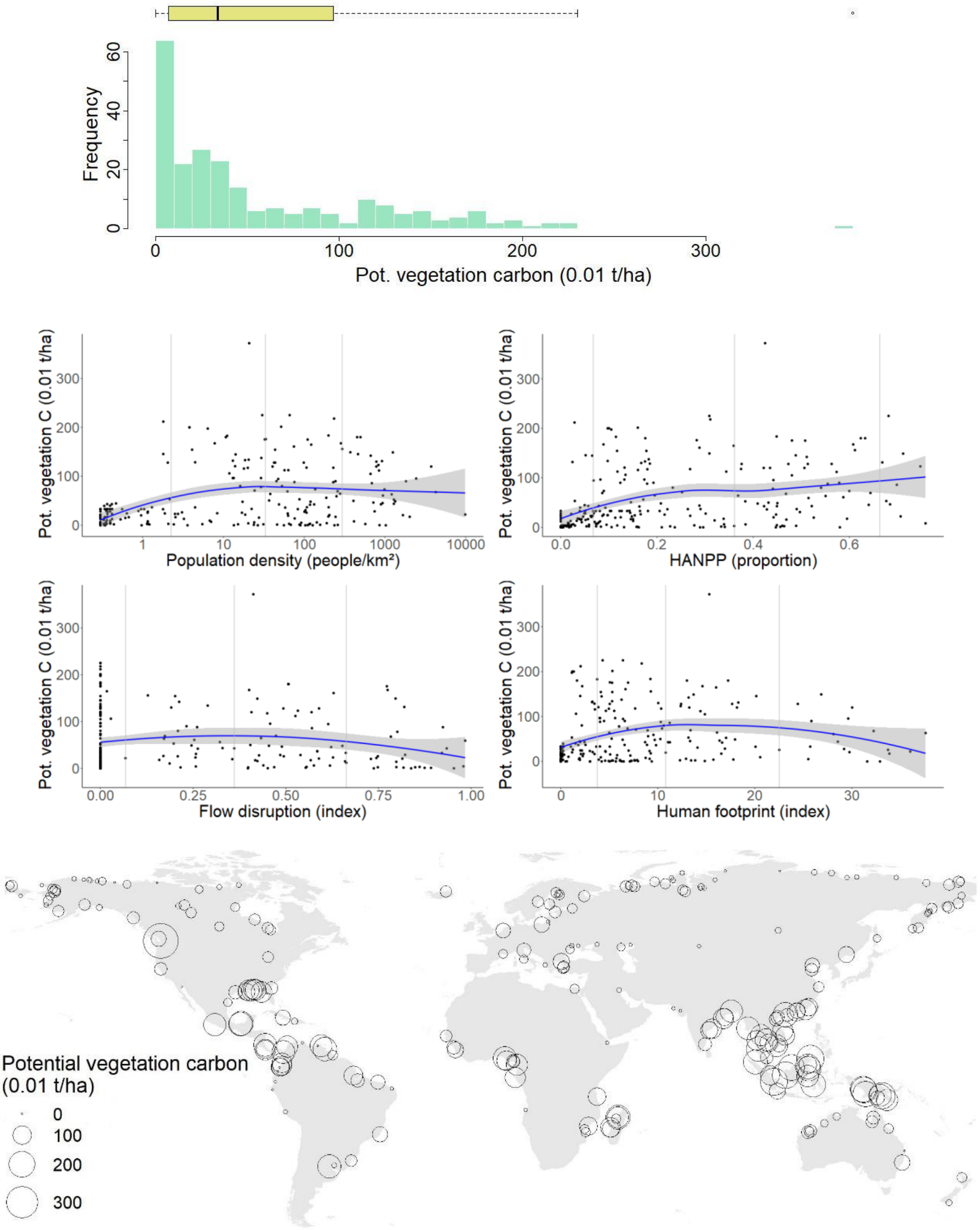
Biomass stored above and belowground in living vegetation.



Supplementary Figure 25. Summary of vegetation carbon indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.4.4. Carbon vegetation potential

Potential vegetation biomass storage.

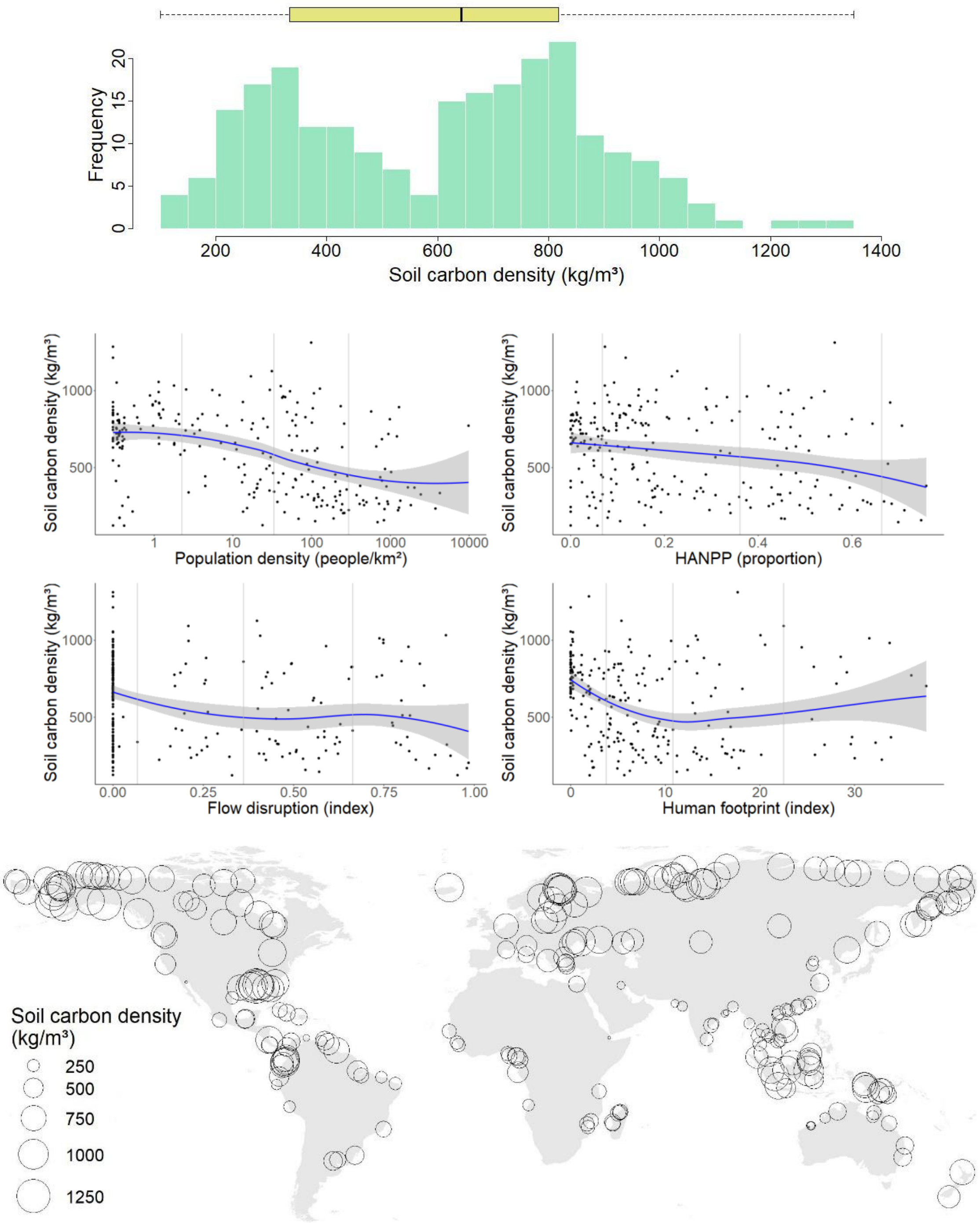


Supplementary Figure 26. Summary of potential vegetation carbon indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.5. Soil

2.5.1. Soil carbon density

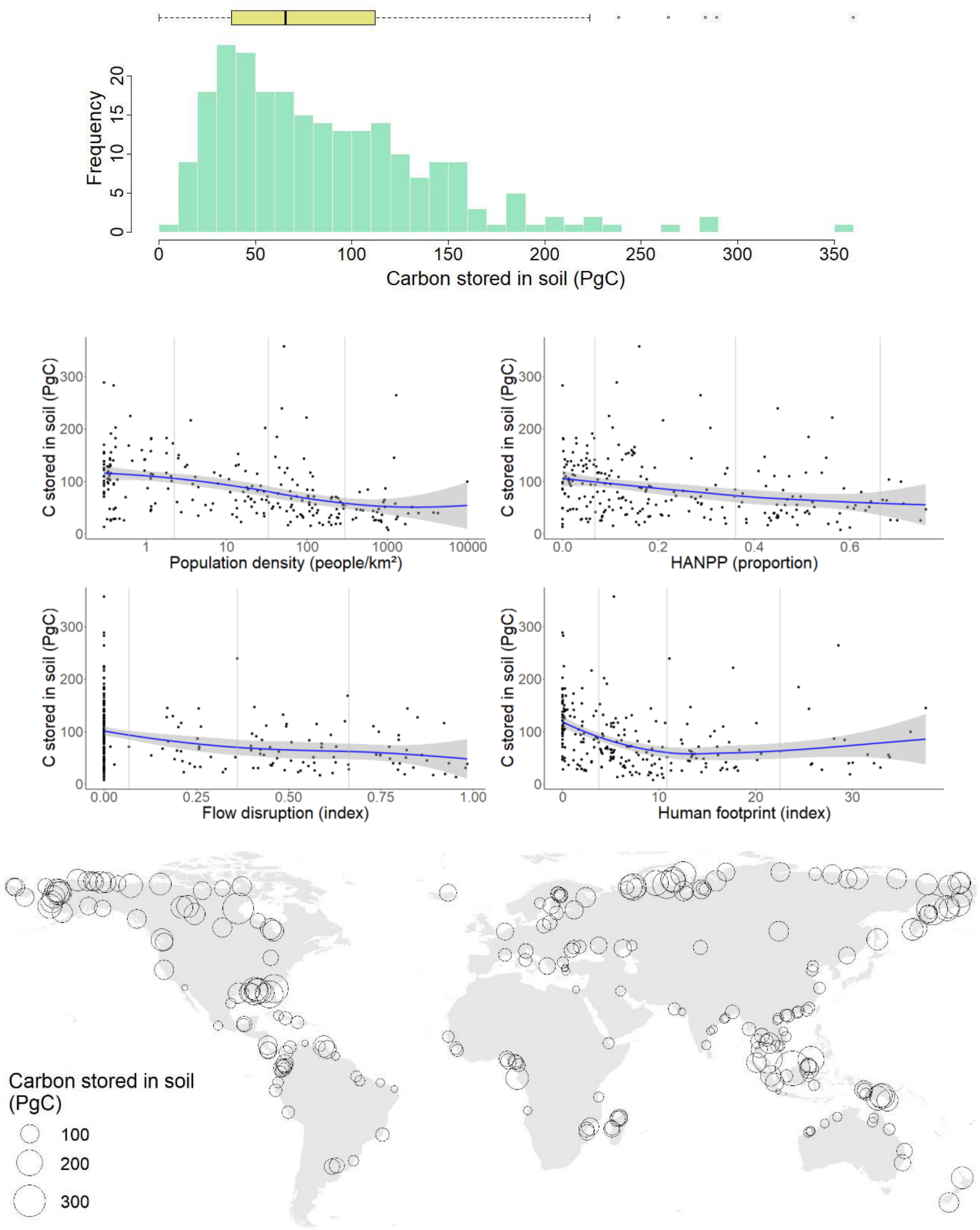
Soil organic carbon density.



Supplementary Figure 27. Summary of soil carbon density indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.5.2. Soil carbon storage

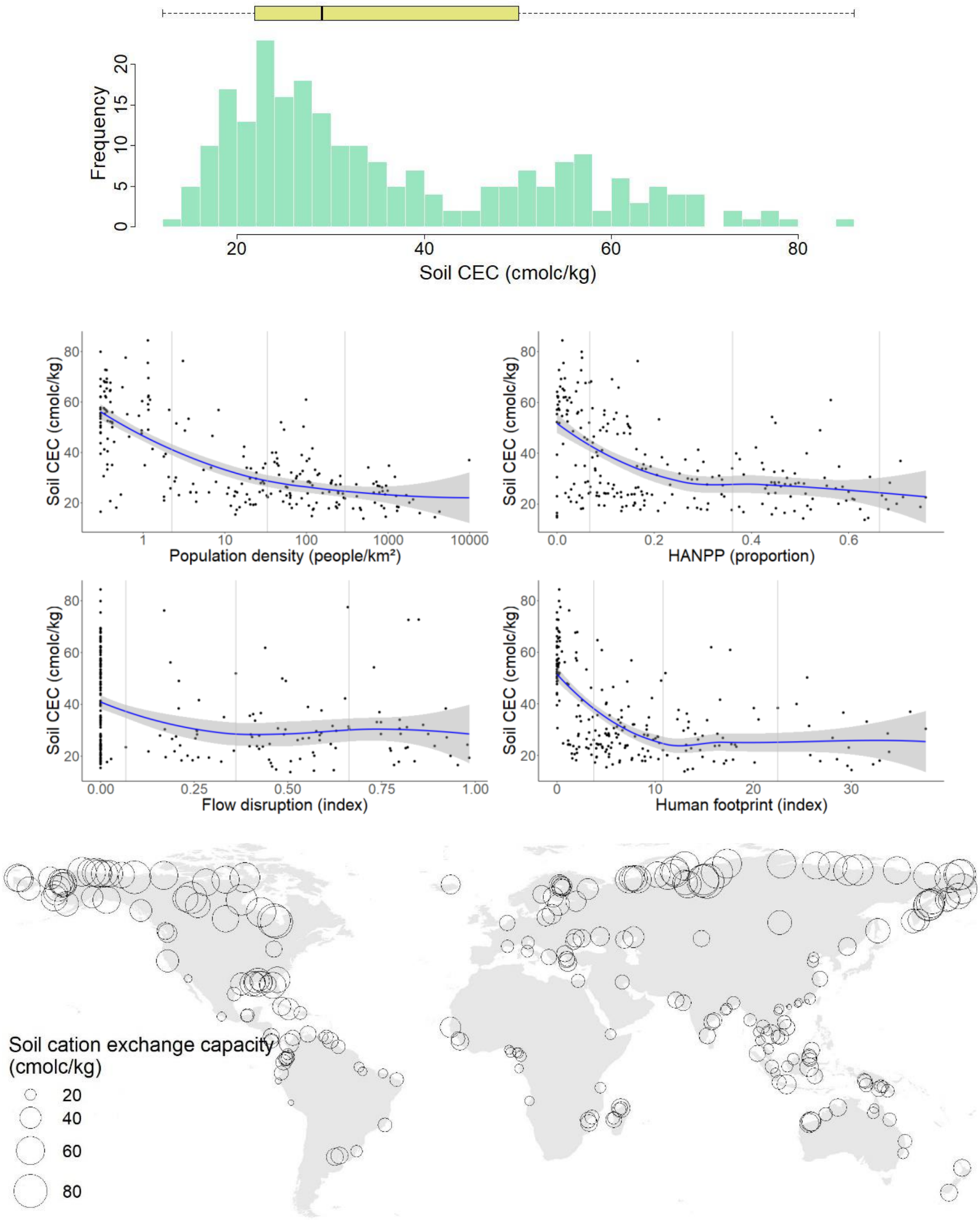
Soil organic carbon stock.



Supplementary Figure 28. Summary of soil carbon storage indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.5.3. Soil cation exchange capacity (CEC)

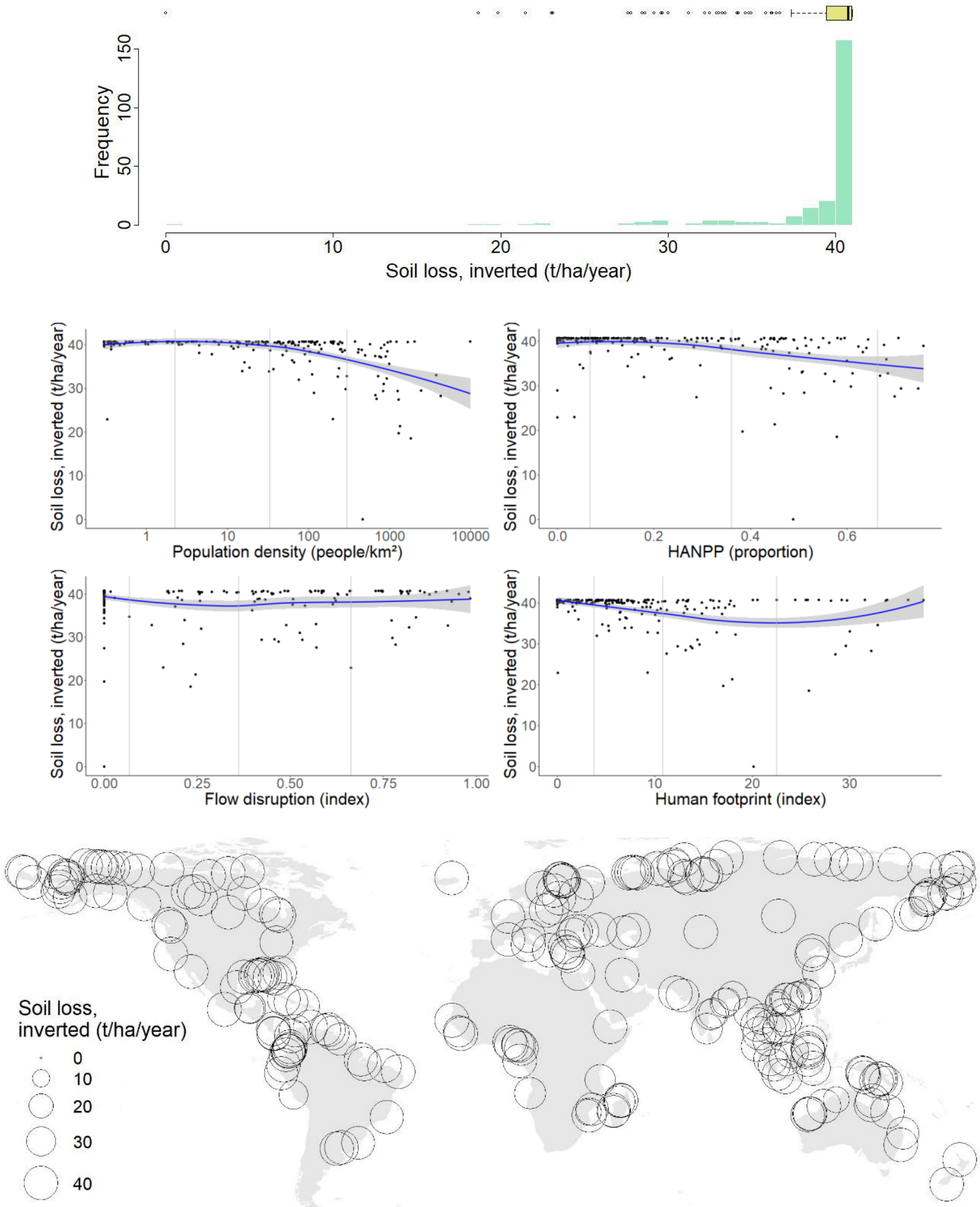
Soil capacity to retain nutrients.



Supplementary Figure 29. Summary of soil cation exchange capacity (CEC) indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.5.4. Soil loss

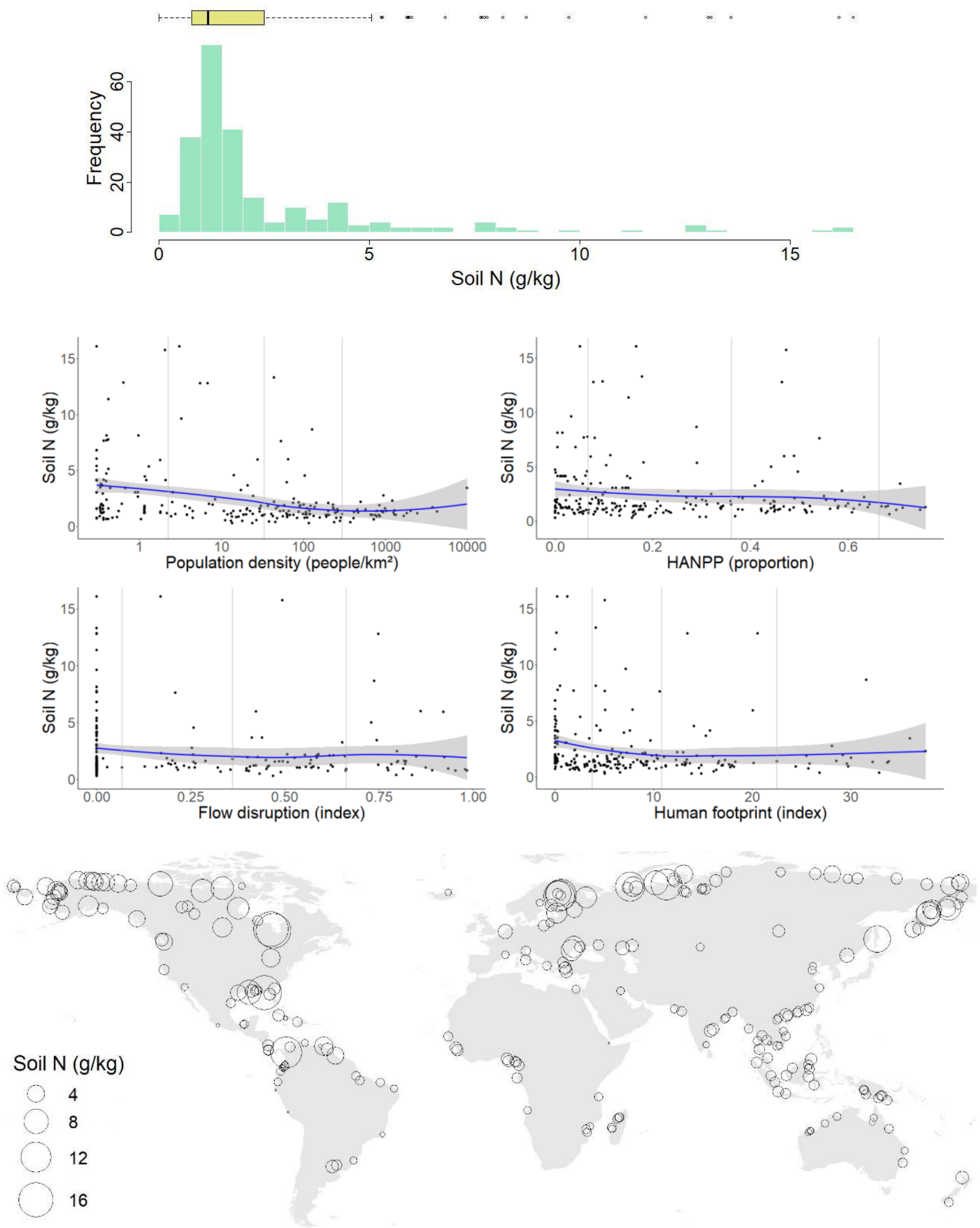
Rate of soil erosion.



Supplementary Figure 30. Summary of soil loss indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.5.5. Soil N

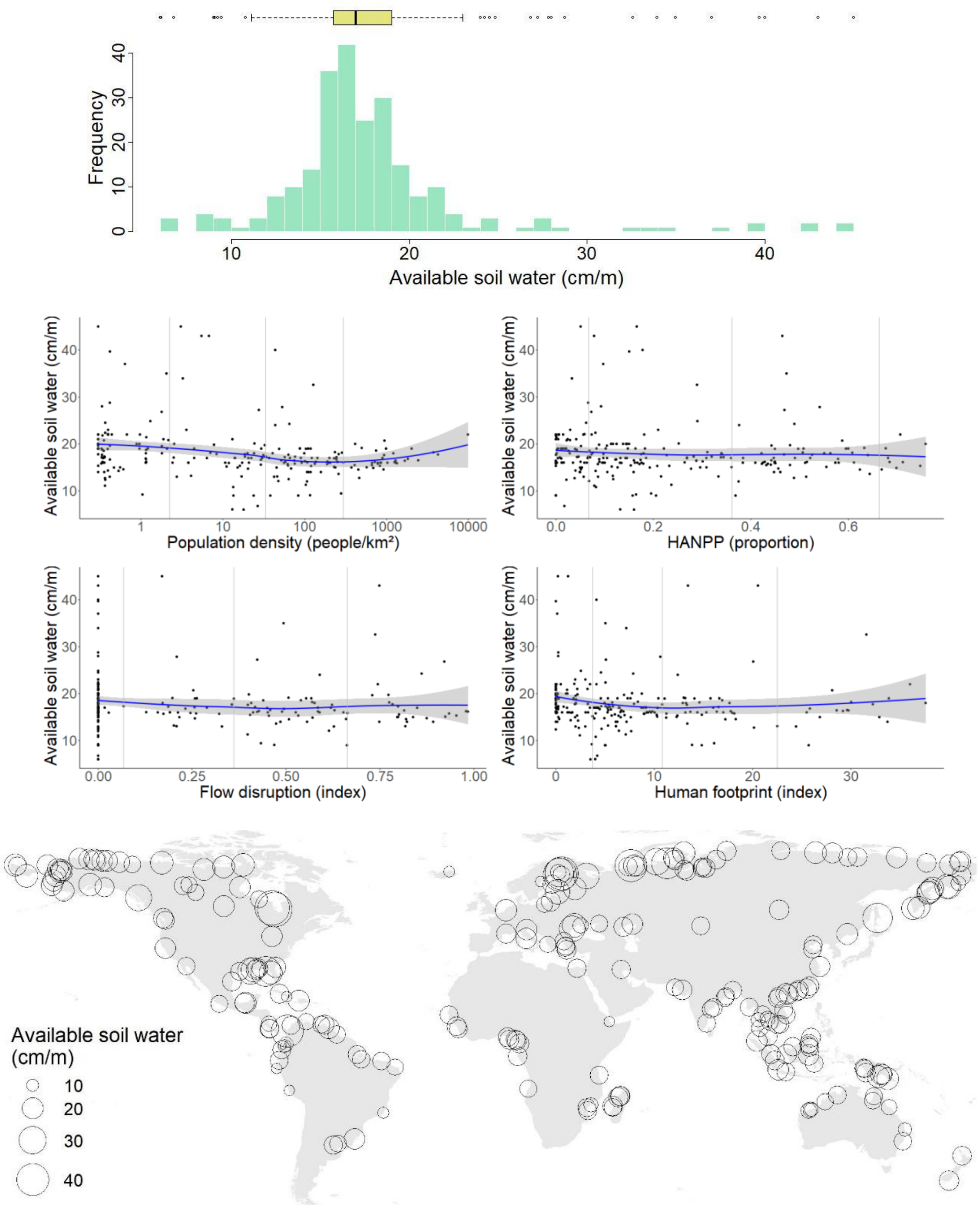
Concentration of soil nitrogen.



Supplementary Figure 31. Summary of soil nitrogen indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.5.6. Soil water availability

Available soil water.

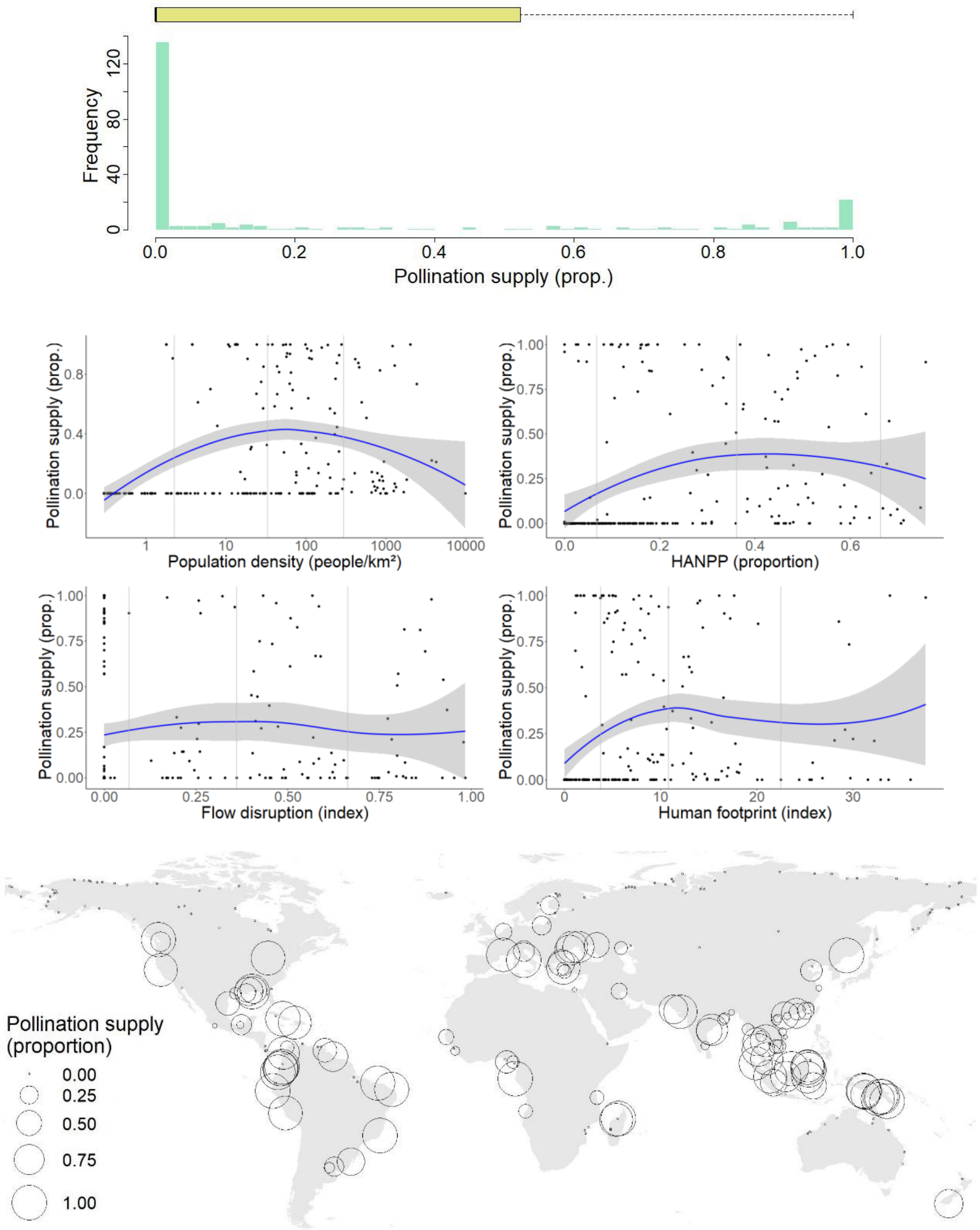


Supplementary Figure 32. Summary of soil water availability indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.6. Pollination

2.6.1. Pollination supply

Pollinator suitable habitat around farmland.

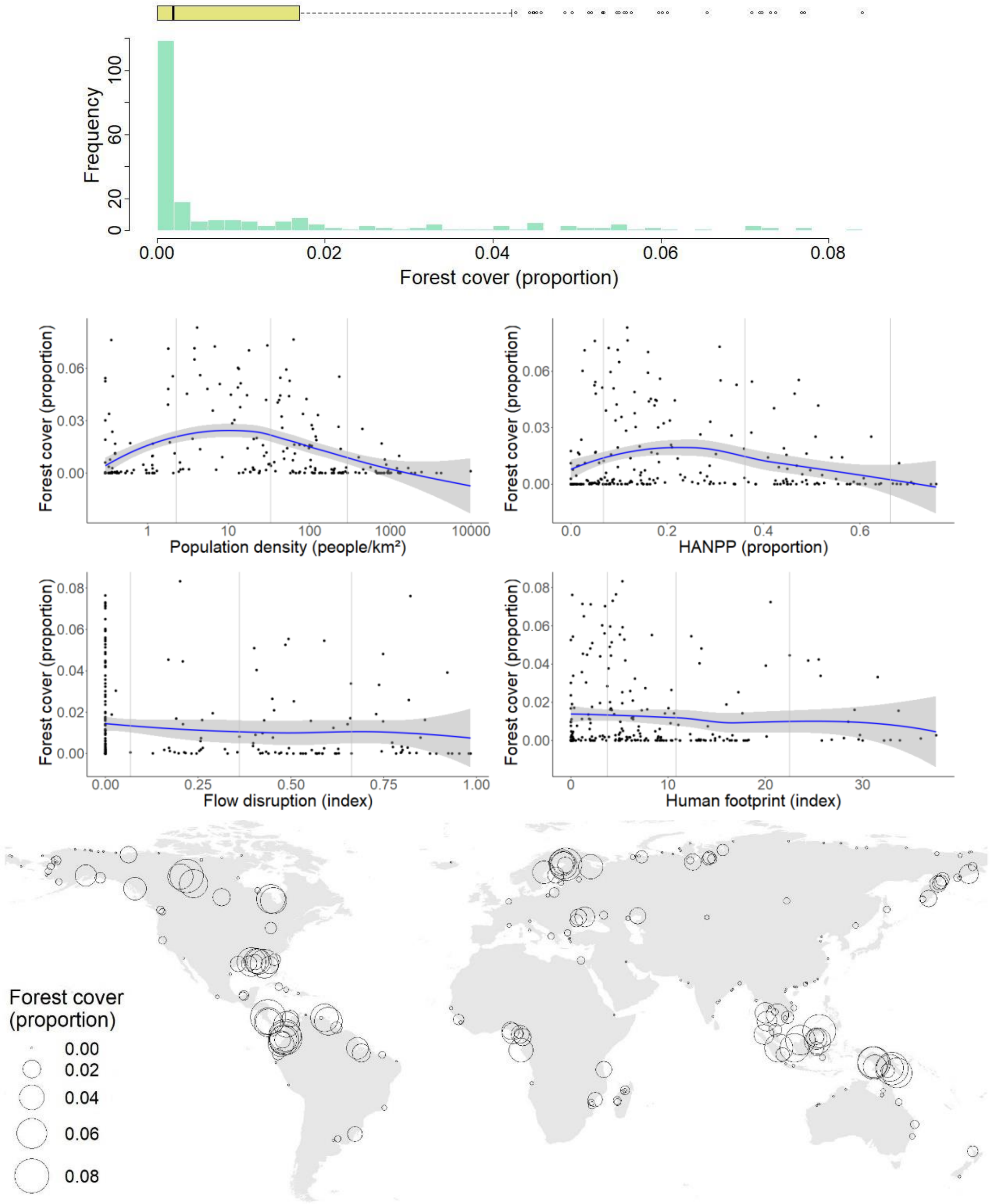


Supplementary Figure 33. Summary of pollination supply indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.7. Ecosystems

2.7.1. Forest cover

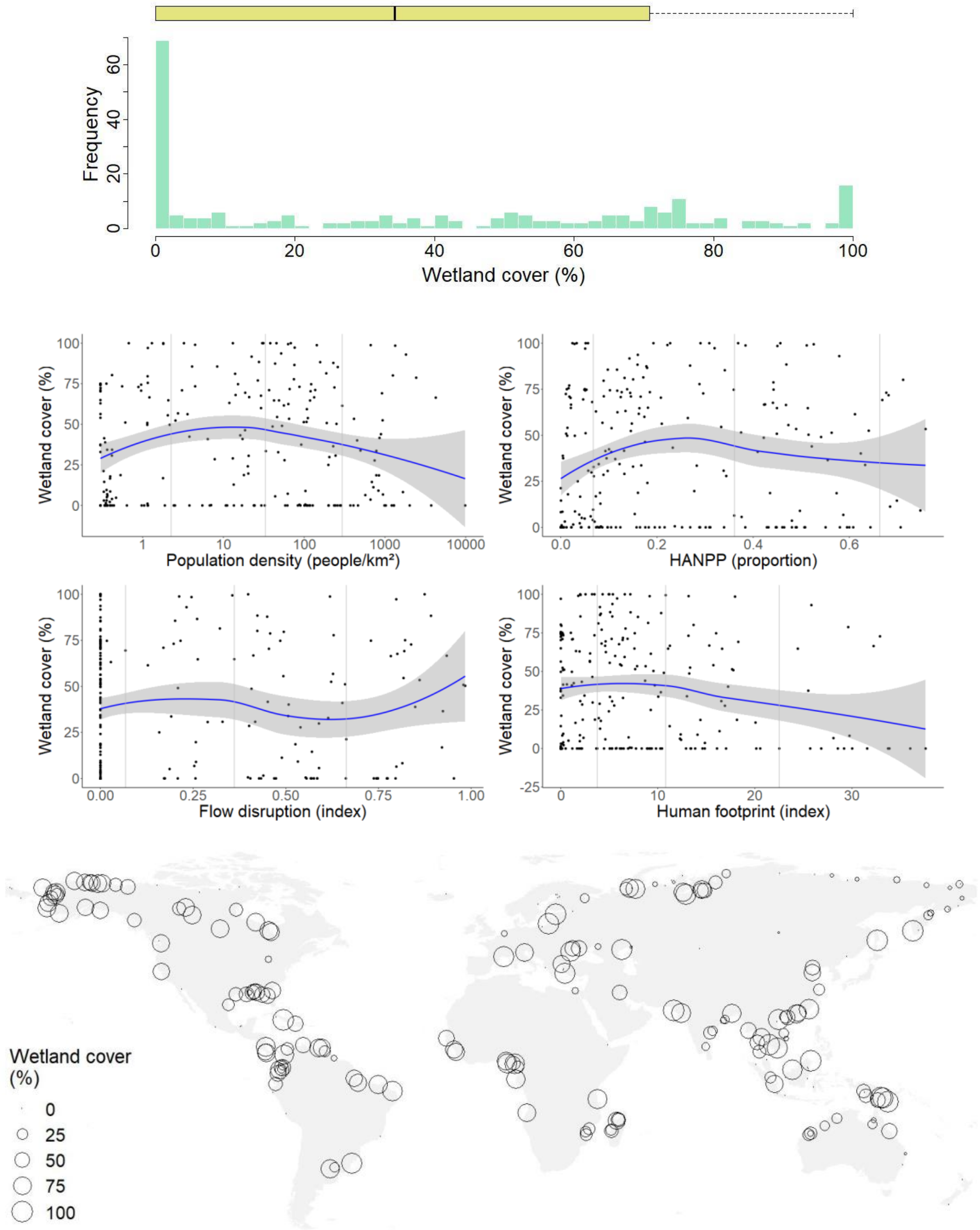
Forest proportion of land cover.



Supplementary Figure 34. Summary of forest cover indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.7.2. Wetland cover

Wetland (marsh, swamp, pan, bog, intermittent) proportion of land cover.

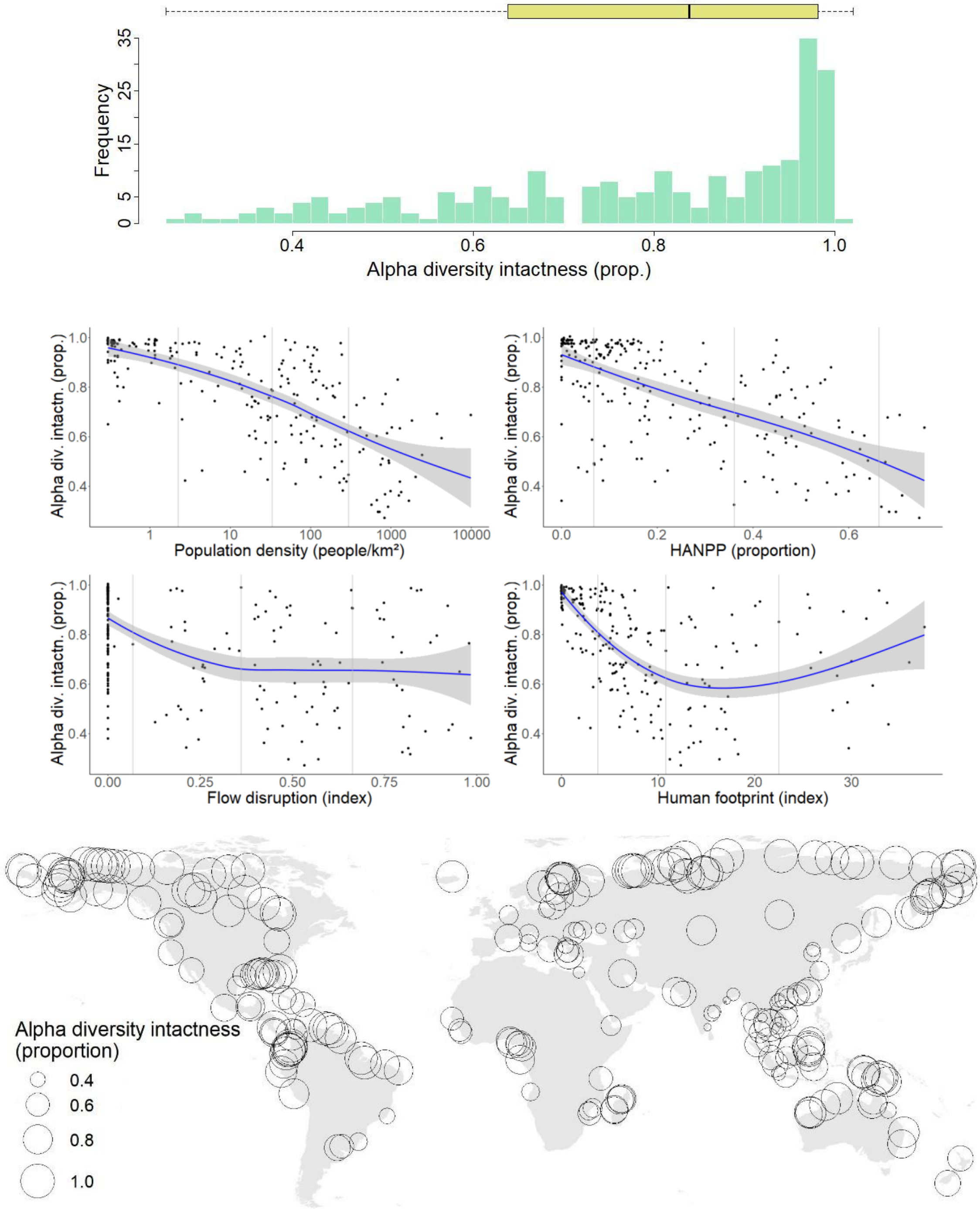


Supplementary Figure 35. Summary of wetland cover indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.8. Biodiversity

2.8.1. Alpha diversity intactness

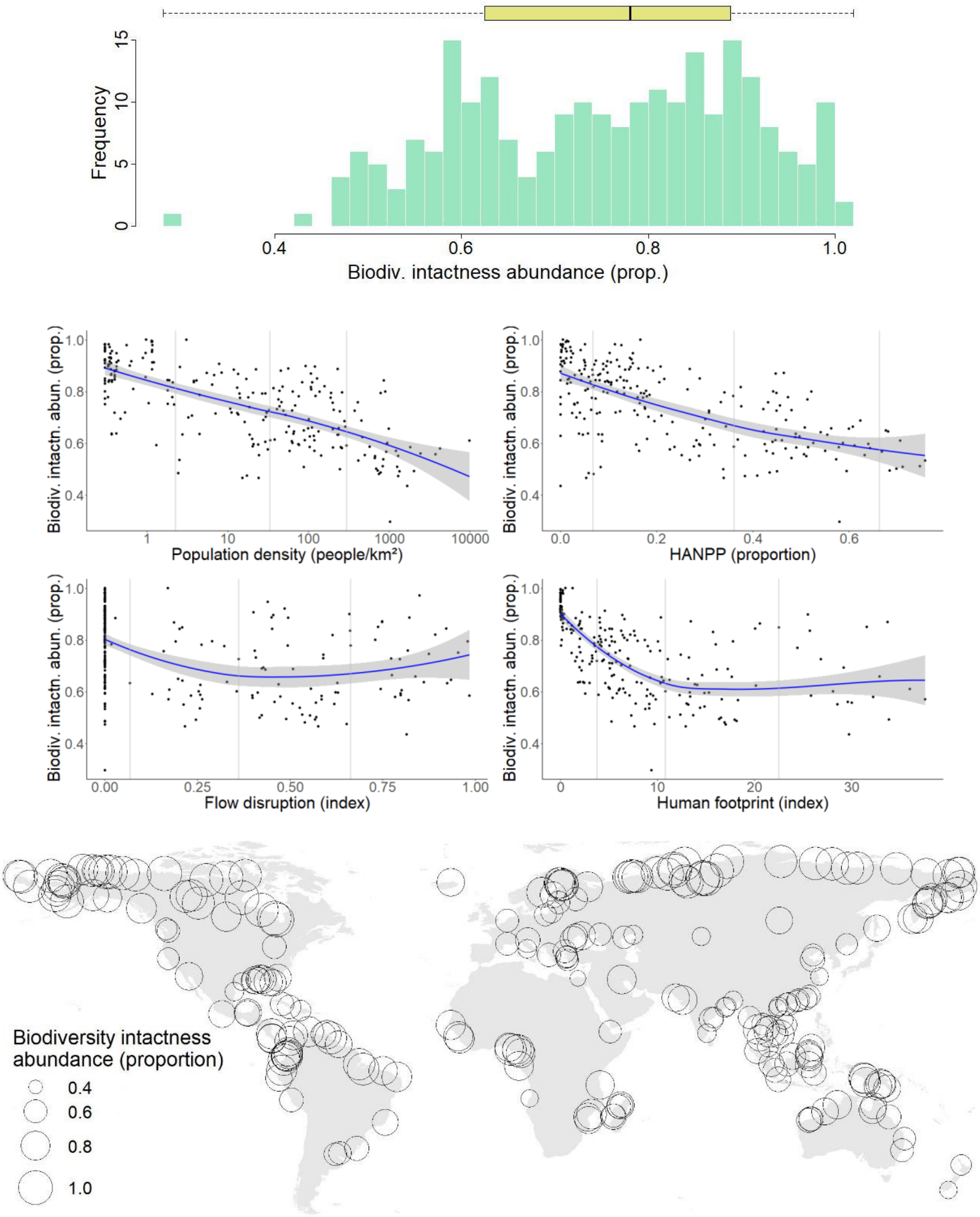
Alpha biodiversity relative to pristine conditions.



Supplementary Figure 36. Summary of alpha diversity intactness indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.8.2. Biodiversity abundance

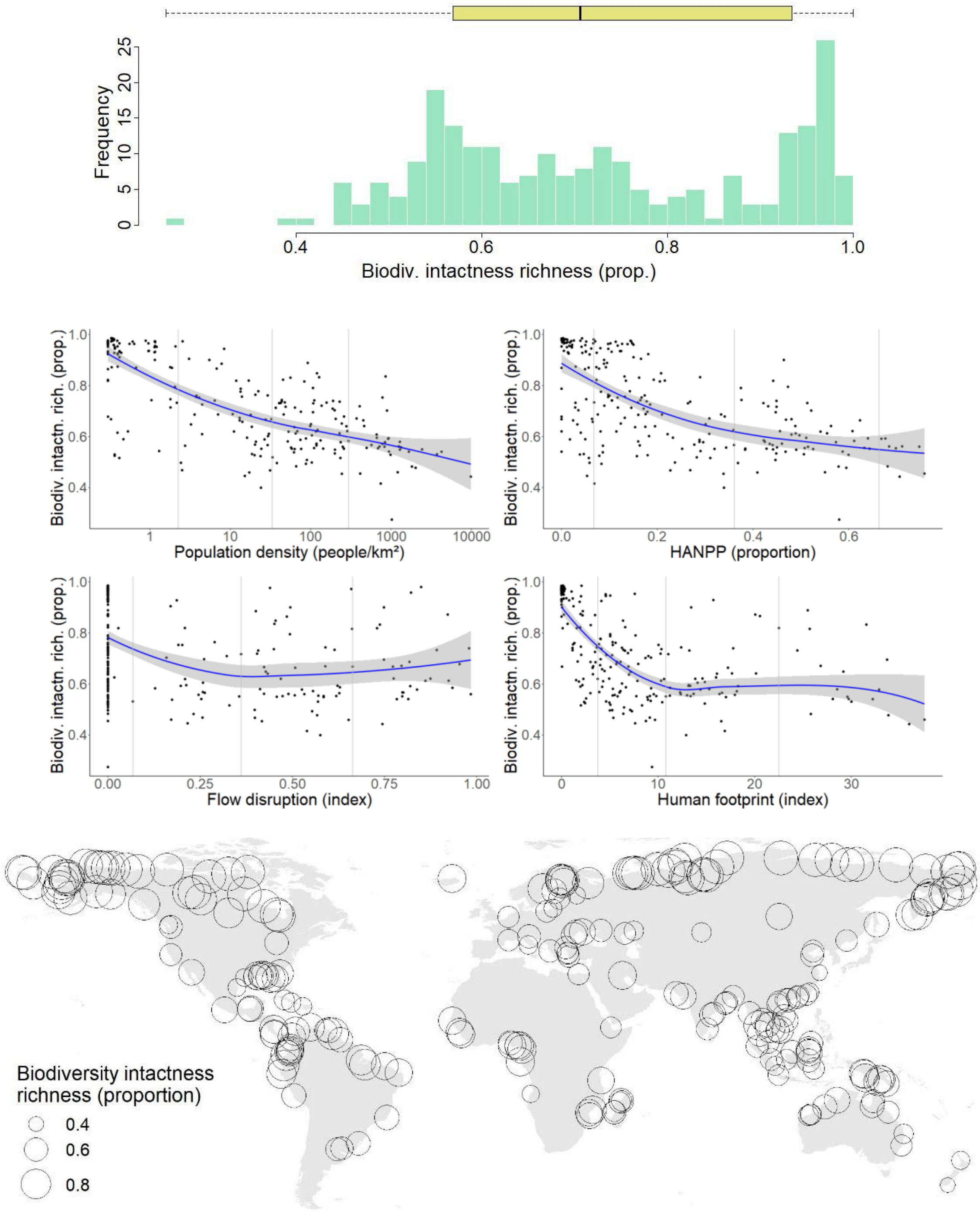
Species abundance compared to pristine conditions.



Supplementary Figure 37. Summary of biodiversity abundance intactness indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.8.3. Biodiversity richness

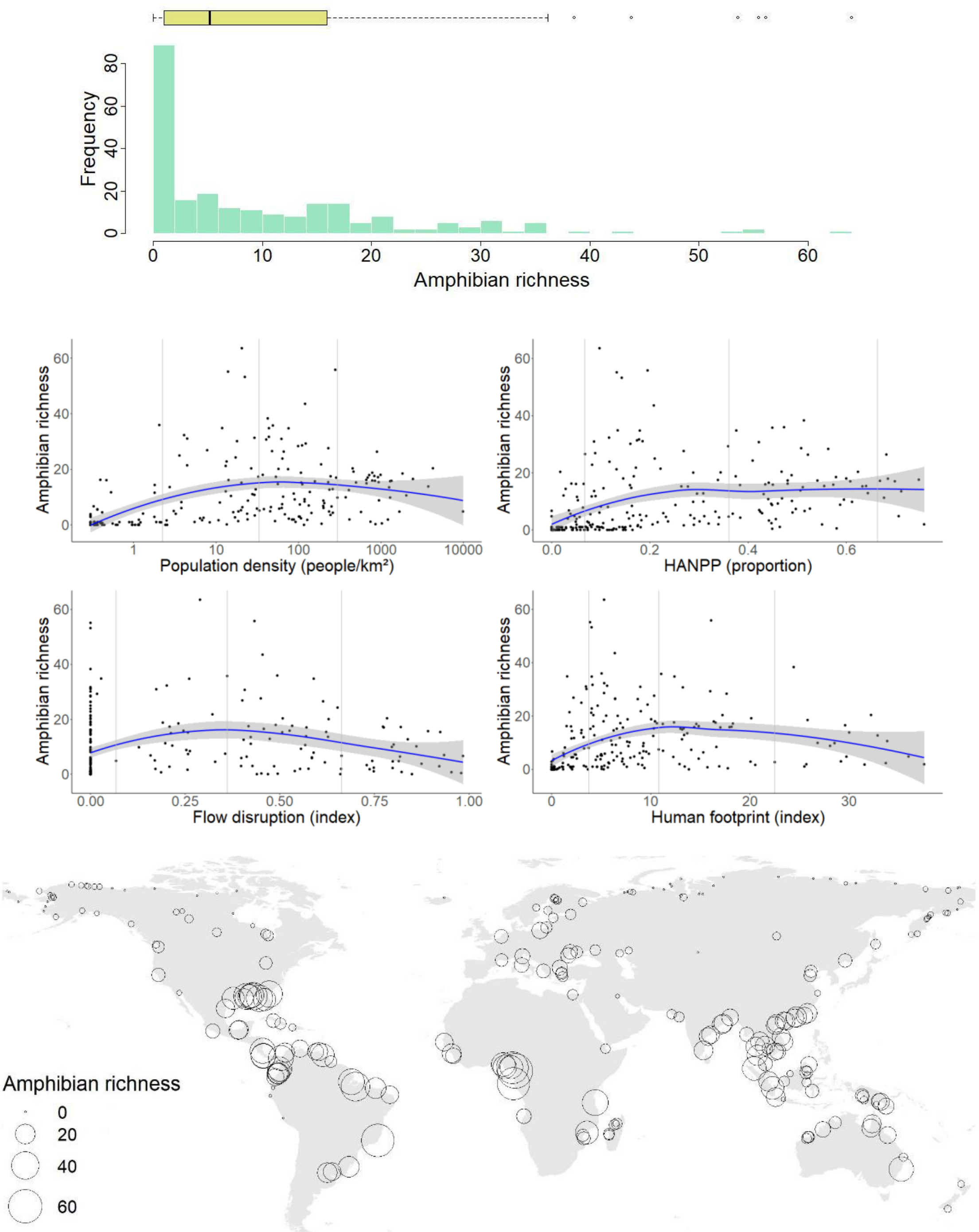
Species richness compared to pristine conditions.



Supplementary Figure 38. Summary of biodiversity richness intactness indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.8.4. Amphibian richness

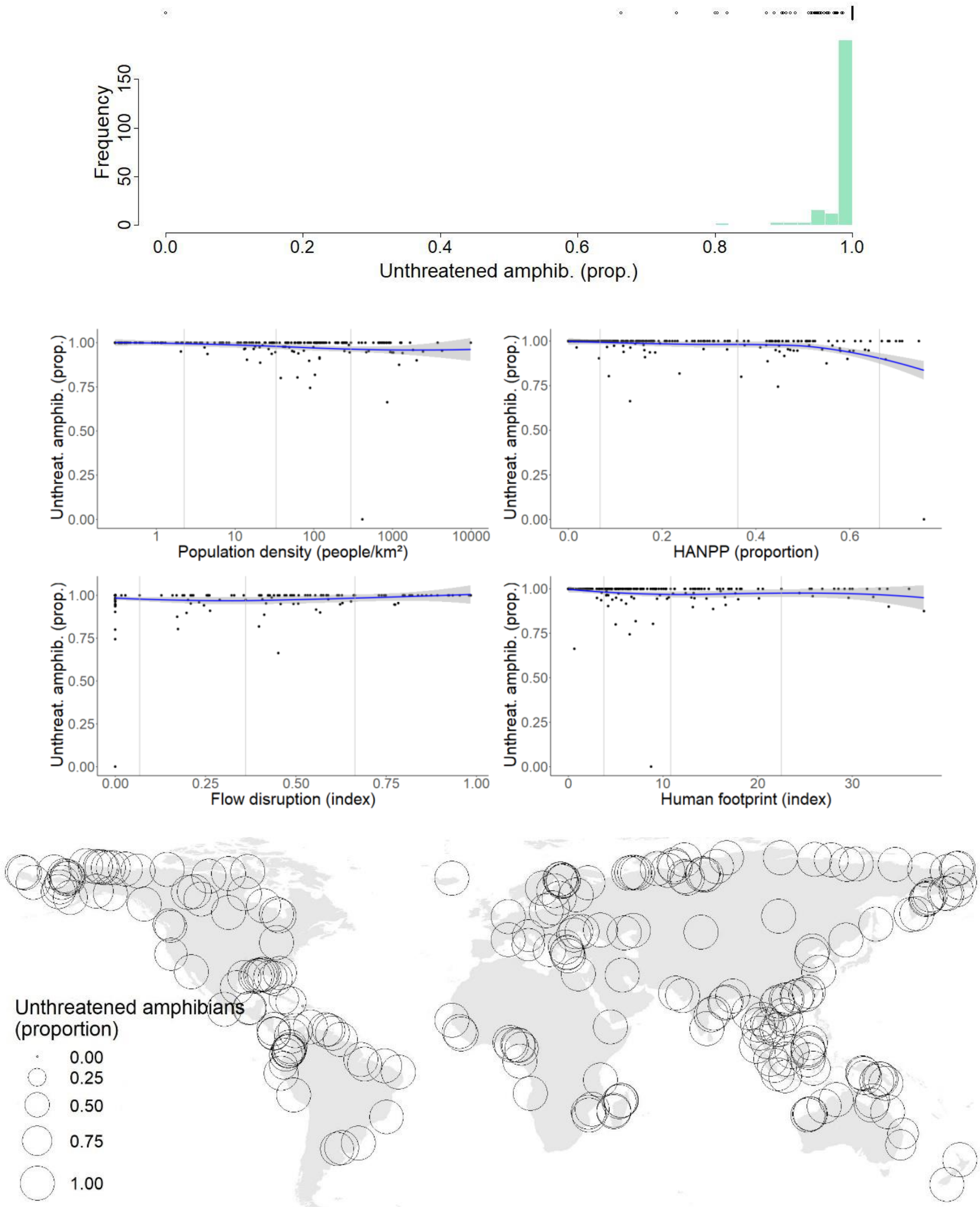
Richness of amphibian species.



Supplementary Figure 39. Summary of amphibian richness indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.8.5. Amphibian unthreatened

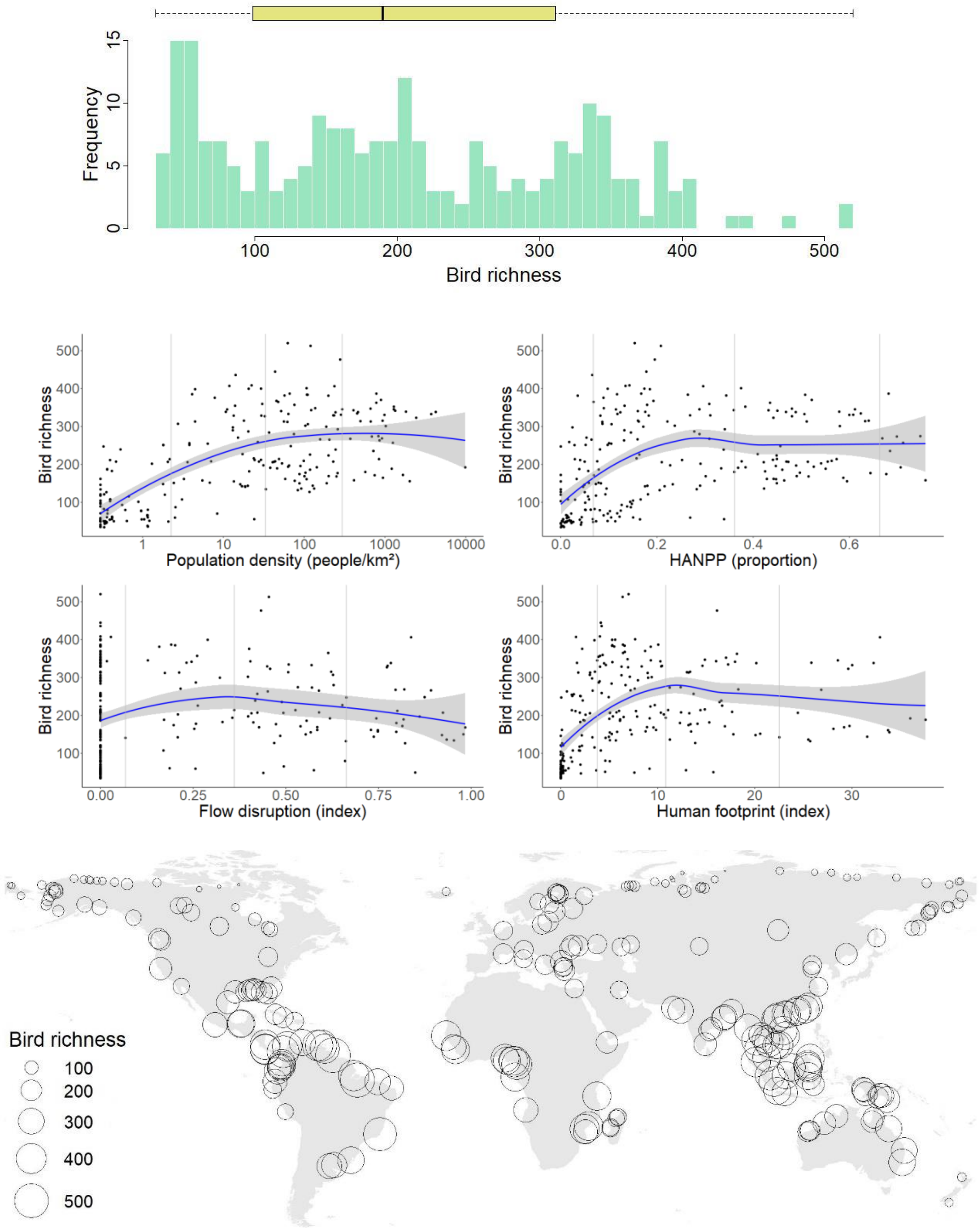
Proportion of amphibian species which are unthreatened.



Supplementary Figure 40. Summary of unthreatened amphibian species indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.8.6. Bird richness

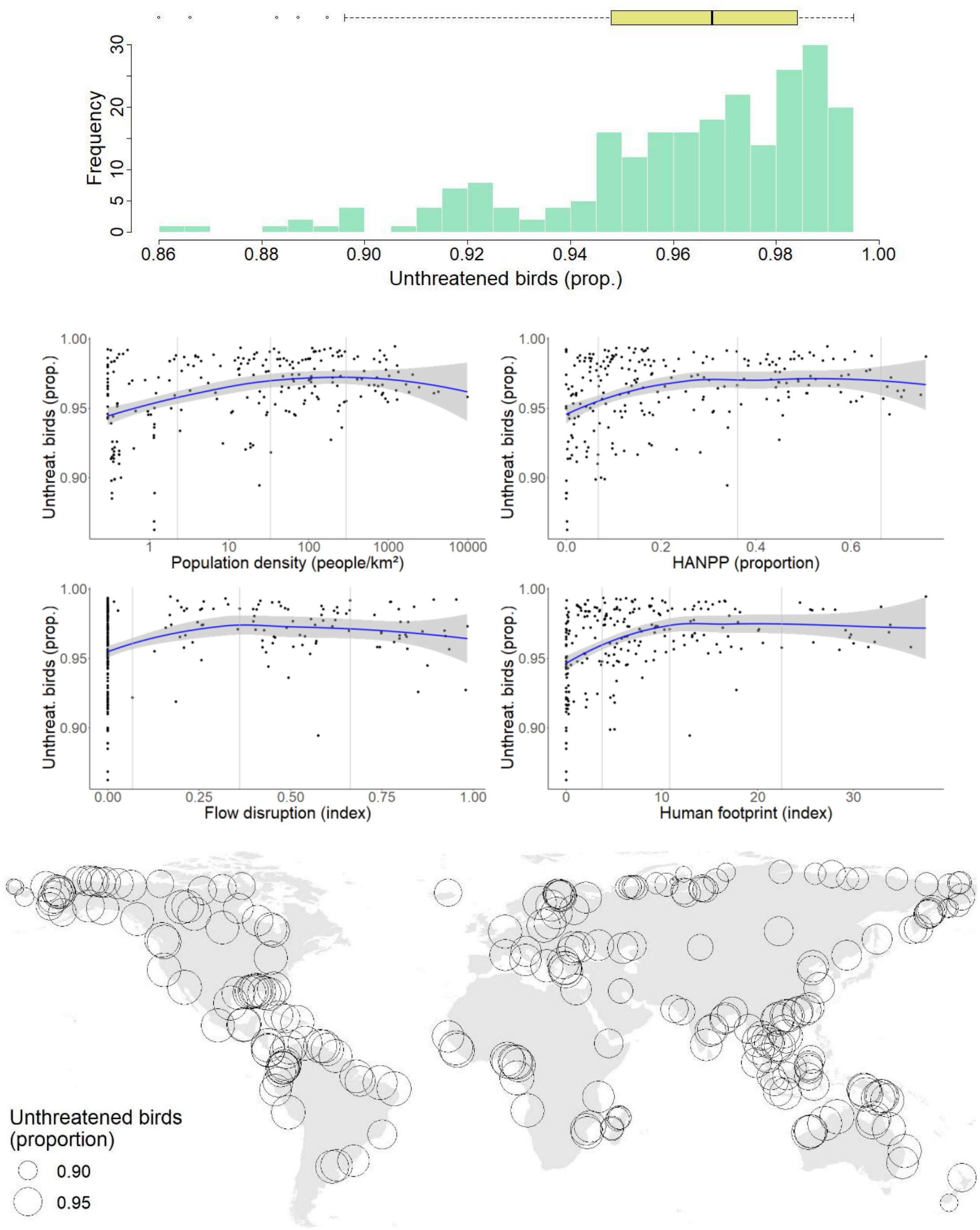
Richness of bird species.



Supplementary Figure 41. Summary of bird species richness indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.8.7. Bird unthreatened

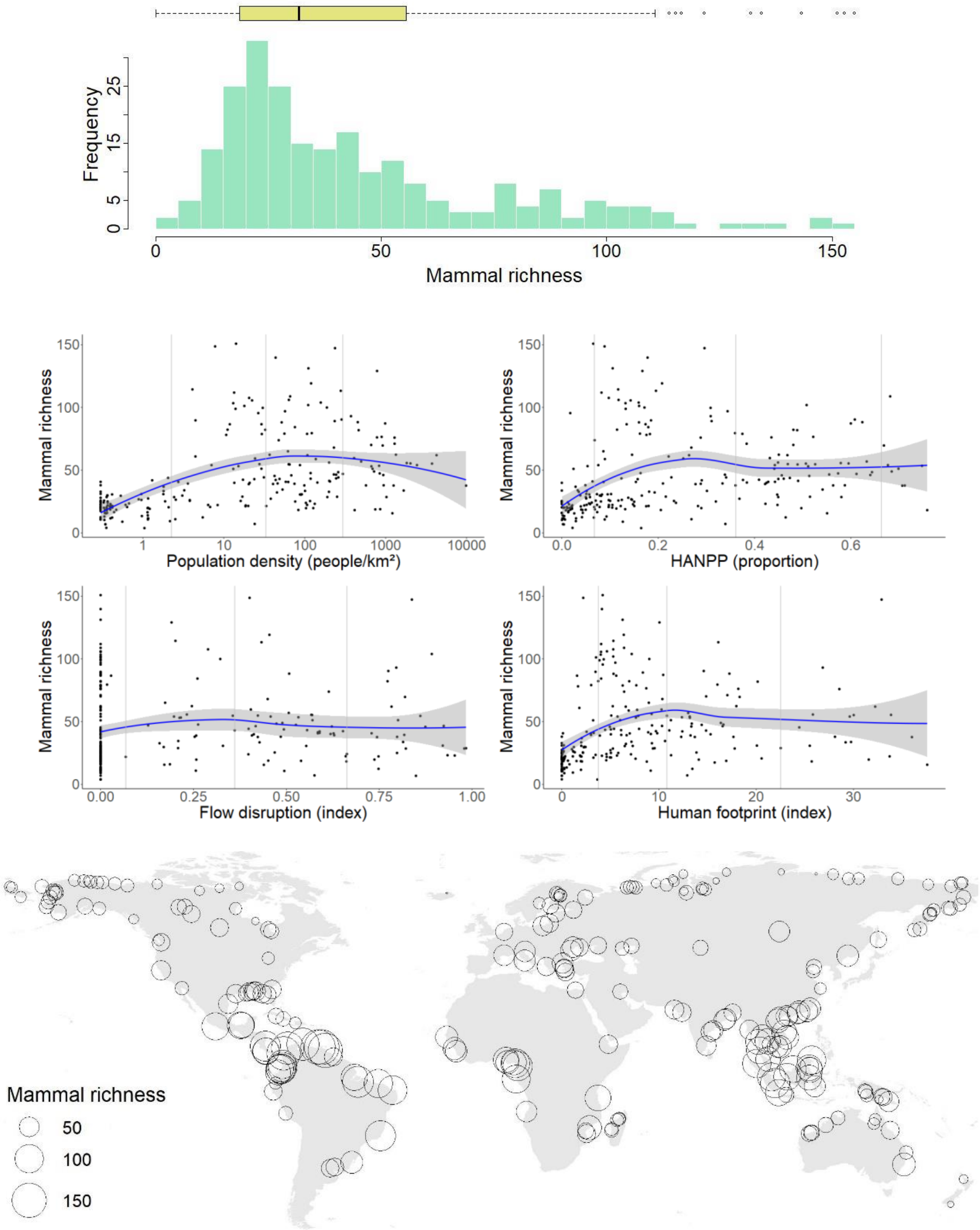
Proportion of bird species which are unthreatened.



Supplementary Figure 42. Summary of unthreatened bird species indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.8.8. Mammal richness

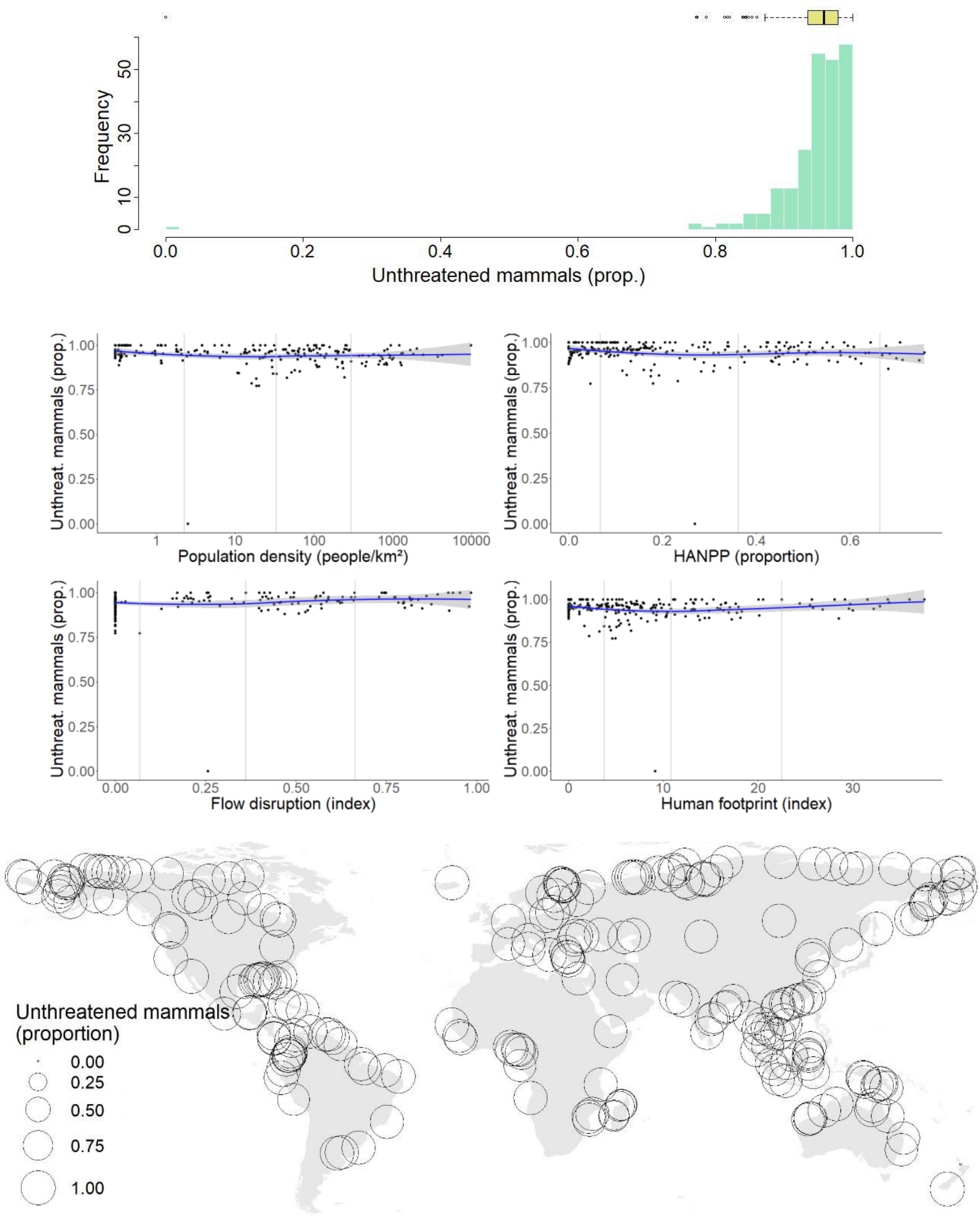
Richness of mammal species.



Supplementary Figure 43. Summary of mammal species richness indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.8.9. Mammal unthreatened

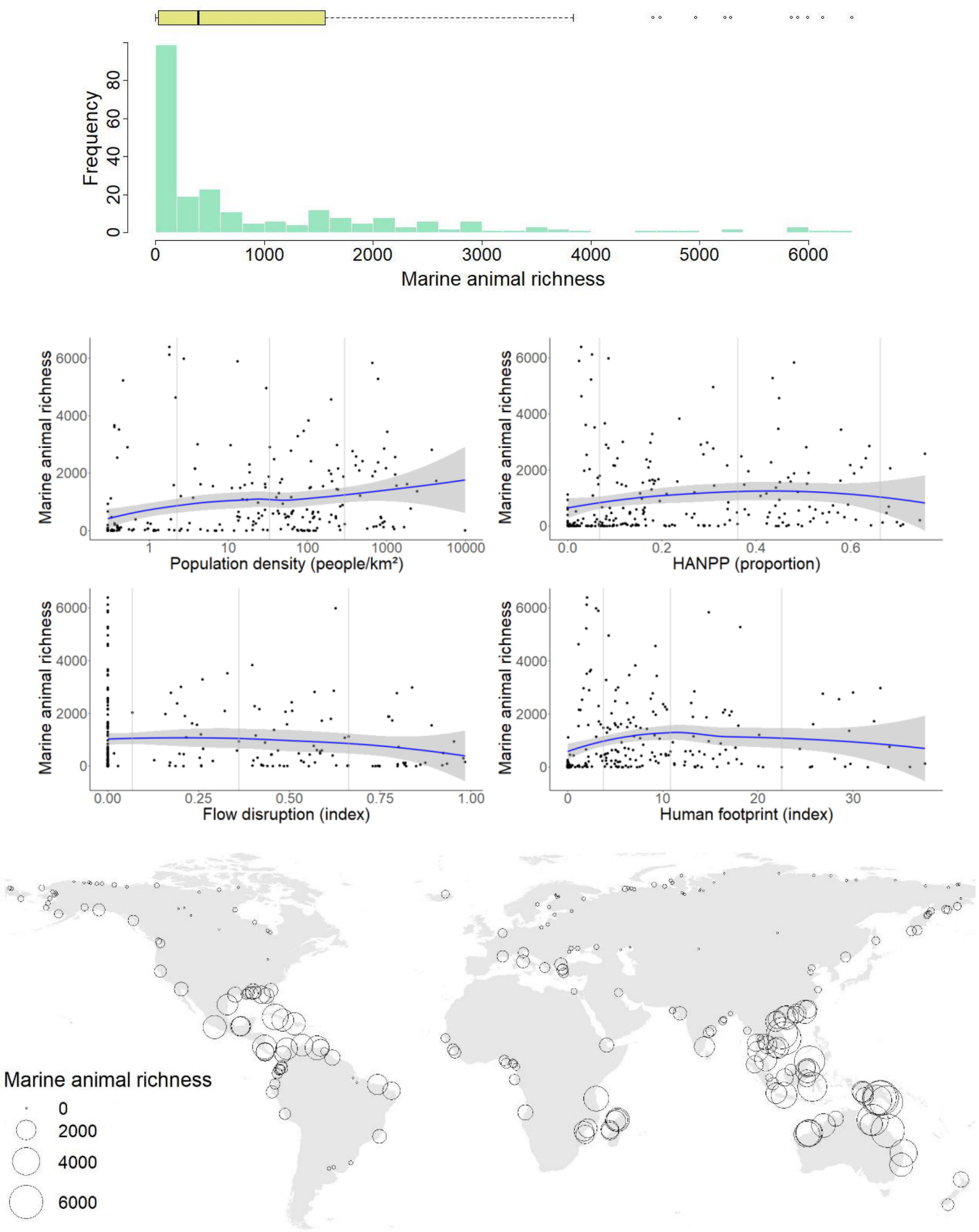
Proportion of mammal species which are unthreatened.



Supplementary Figure 44. Summary of unthreatened mammal species indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.8.10. Marine animal richness

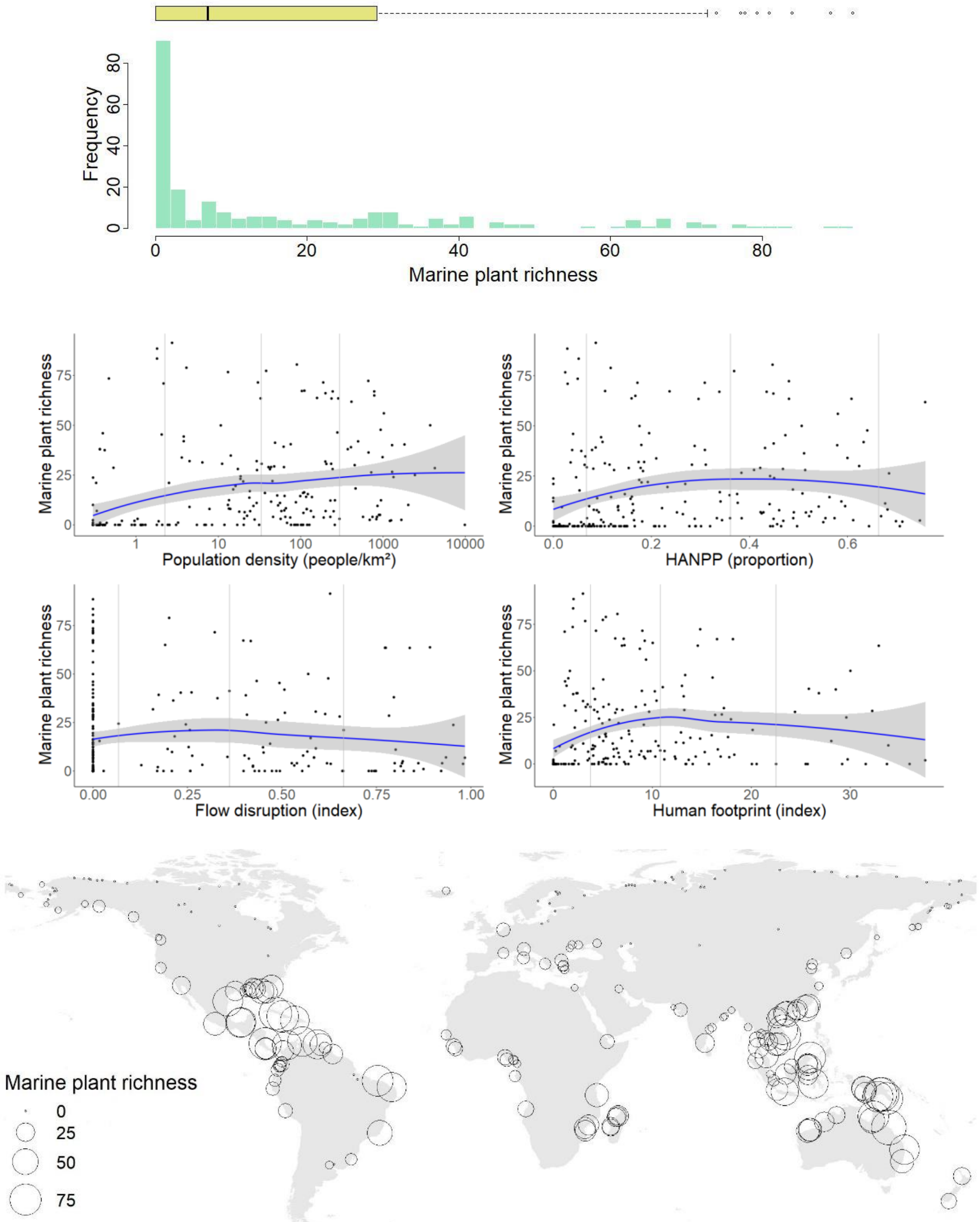
Richness of marine animal species.



Supplementary Figure 45. Summary of marine animal species richness indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.8.11. Marine plant richness

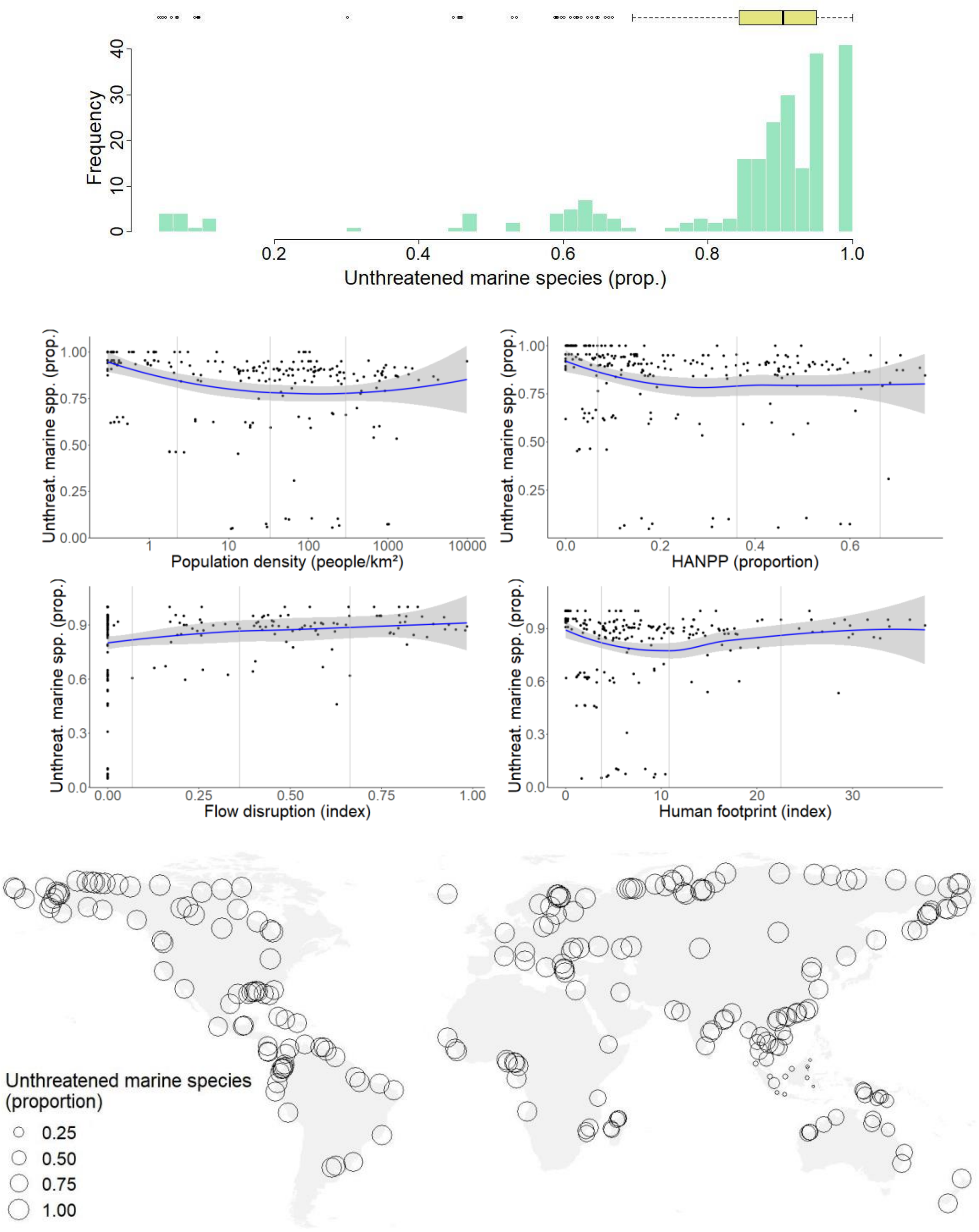
Richness of marine plant species.



Supplementary Figure 46. Summary of marine plant species richness indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.8.12. Marine unthreatened

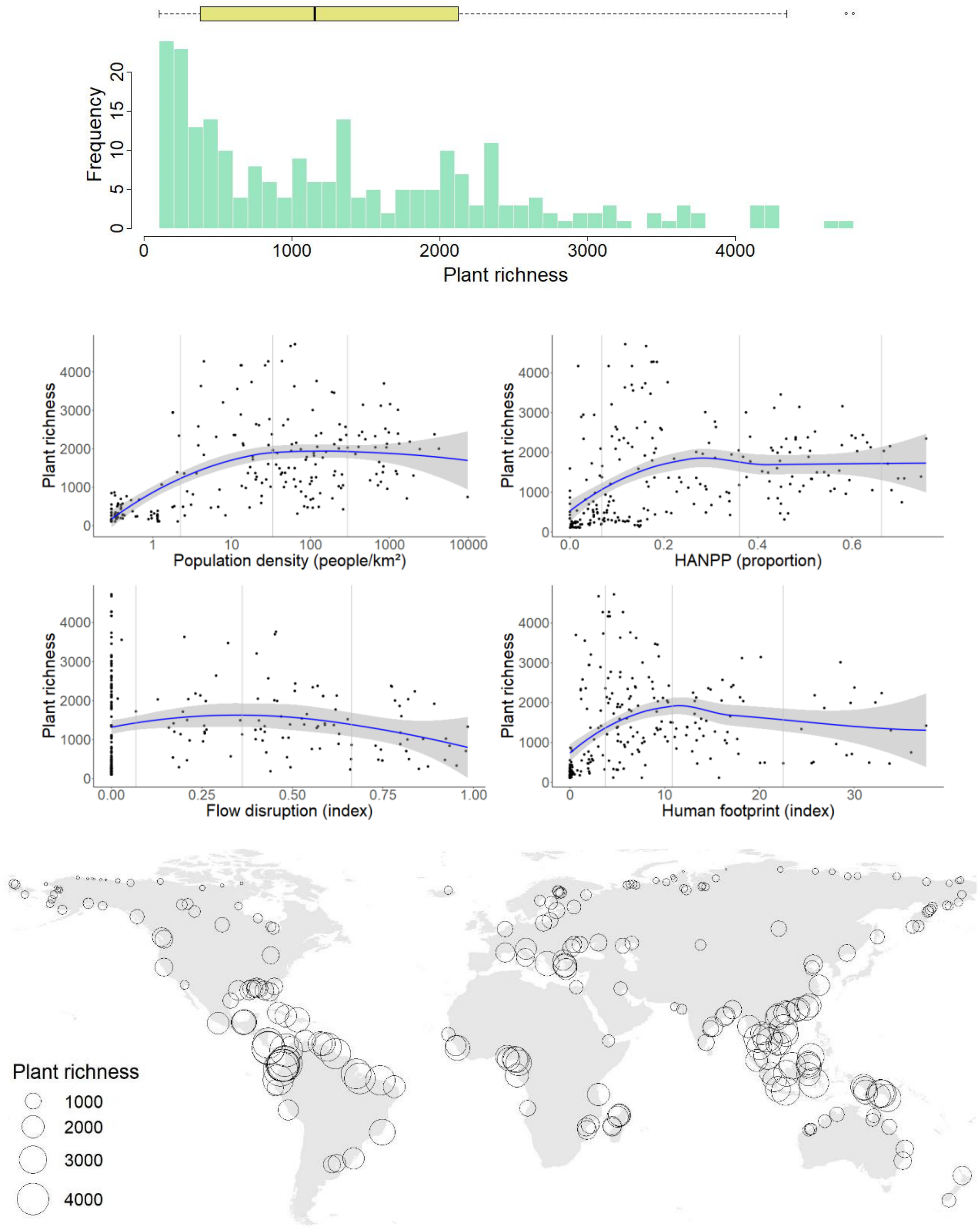
Proportion of marine species which are unthreatened



Supplementary Figure 47. Summary of unthreatened marine species indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.8.13. Plant richness

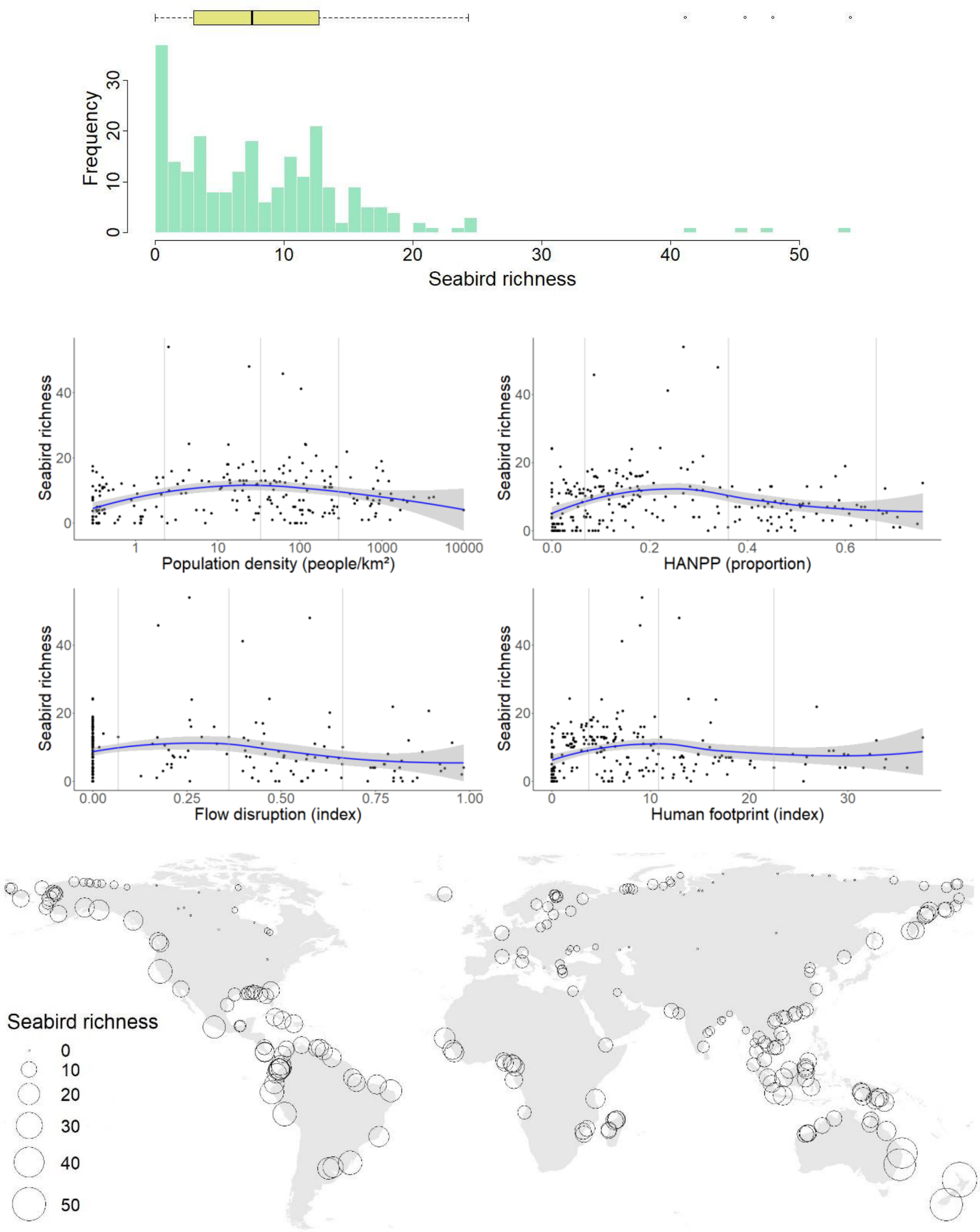
Richness of native plant species.



Supplementary Figure 48. Summary of plant species richness indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.8.14. Seabird richness

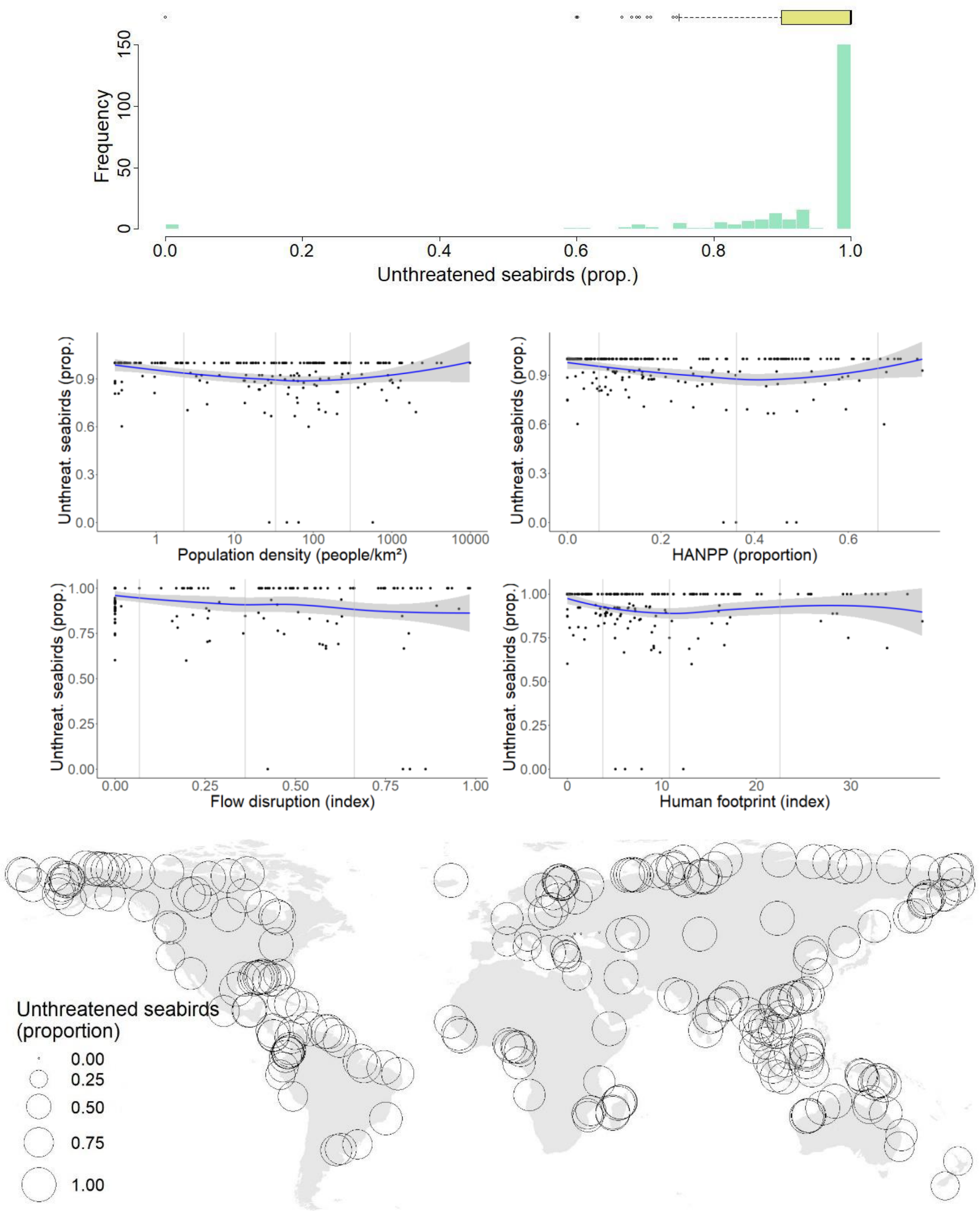
Richness of seabird species.



Supplementary Figure 49. Summary of seabird species richness indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.8.15. Seabird unthreatened

Proportion of seabird species which are unthreatened.

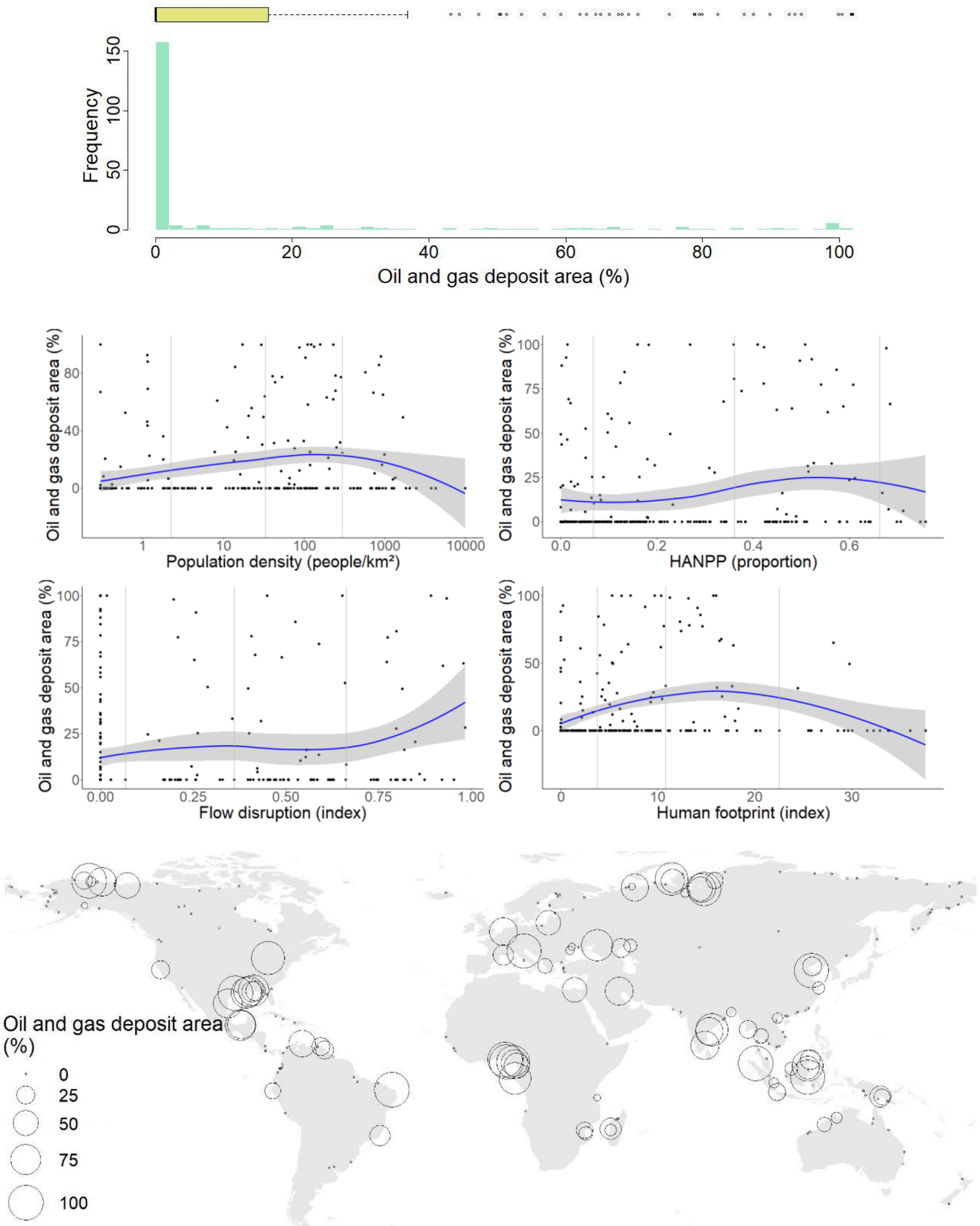


Supplementary Figure 50. Summary of unthreatened seabird species indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

2.9. Energy

2.9.1. Oil area

Proportion of delta area covered by on-shore and off-shore oil and gas deposits.



Supplementary Figure 51. Summary of oil area indicator across all deltas, its relationship with the modification indicators, and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers. Each point on the scatter plots indicates the average value of the indicator for an individual delta. Blue line on scatter plots indicates LOESS regression with span = 1. Shaded areas around trend line indicate 0.95 CI. Grey vertical lines show bin edges in modification data, calculated with breakpoint analysis.

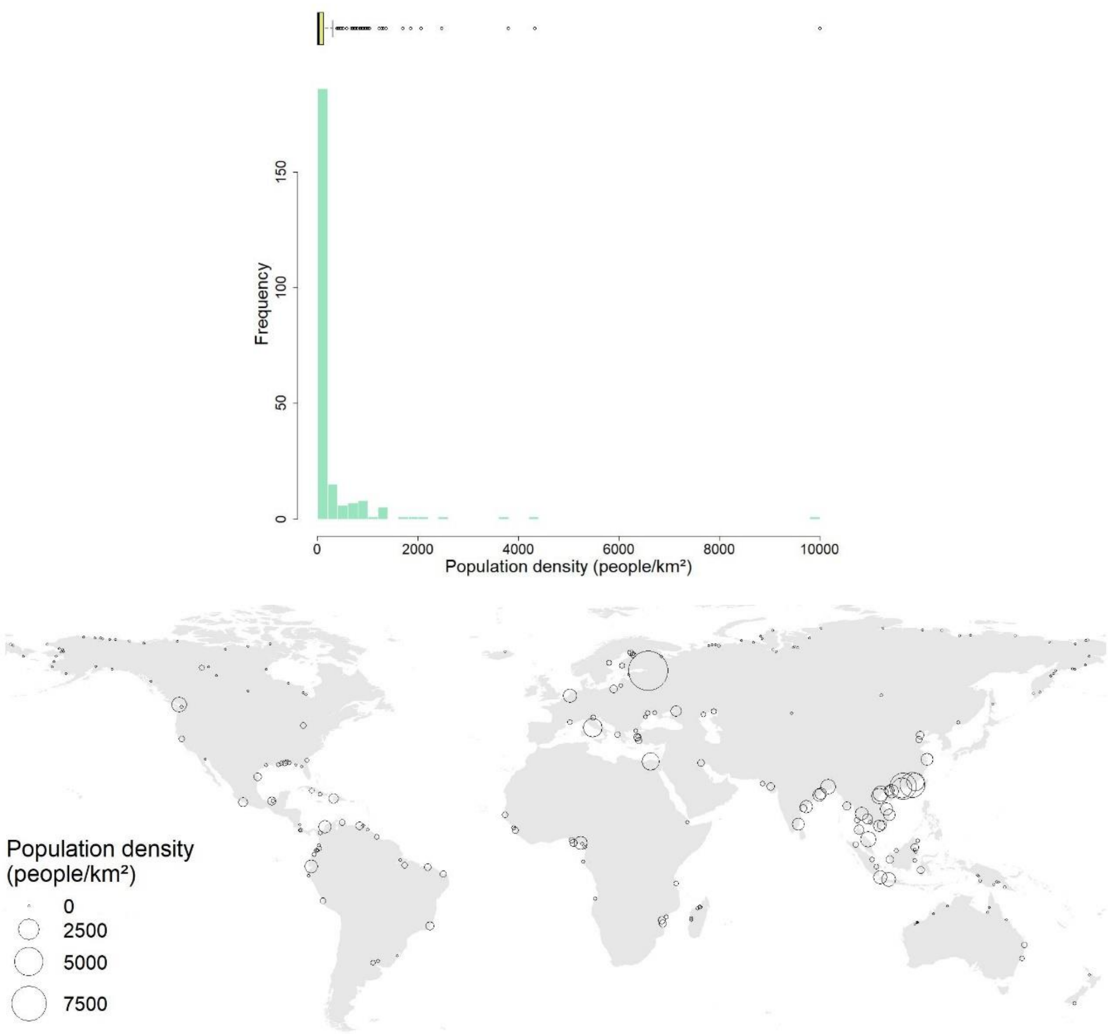
Supplementary Note 3. Modification indicator summary

This section summarises the modification indicators across all deltas and their global spatial distribution (Supplementary Figures 52 to 55).

3.1. Population

Population density (people/km^2)[38]

Downloaded from https://sedac.ciesin.columbia.edu/data/collection/gpw-v4

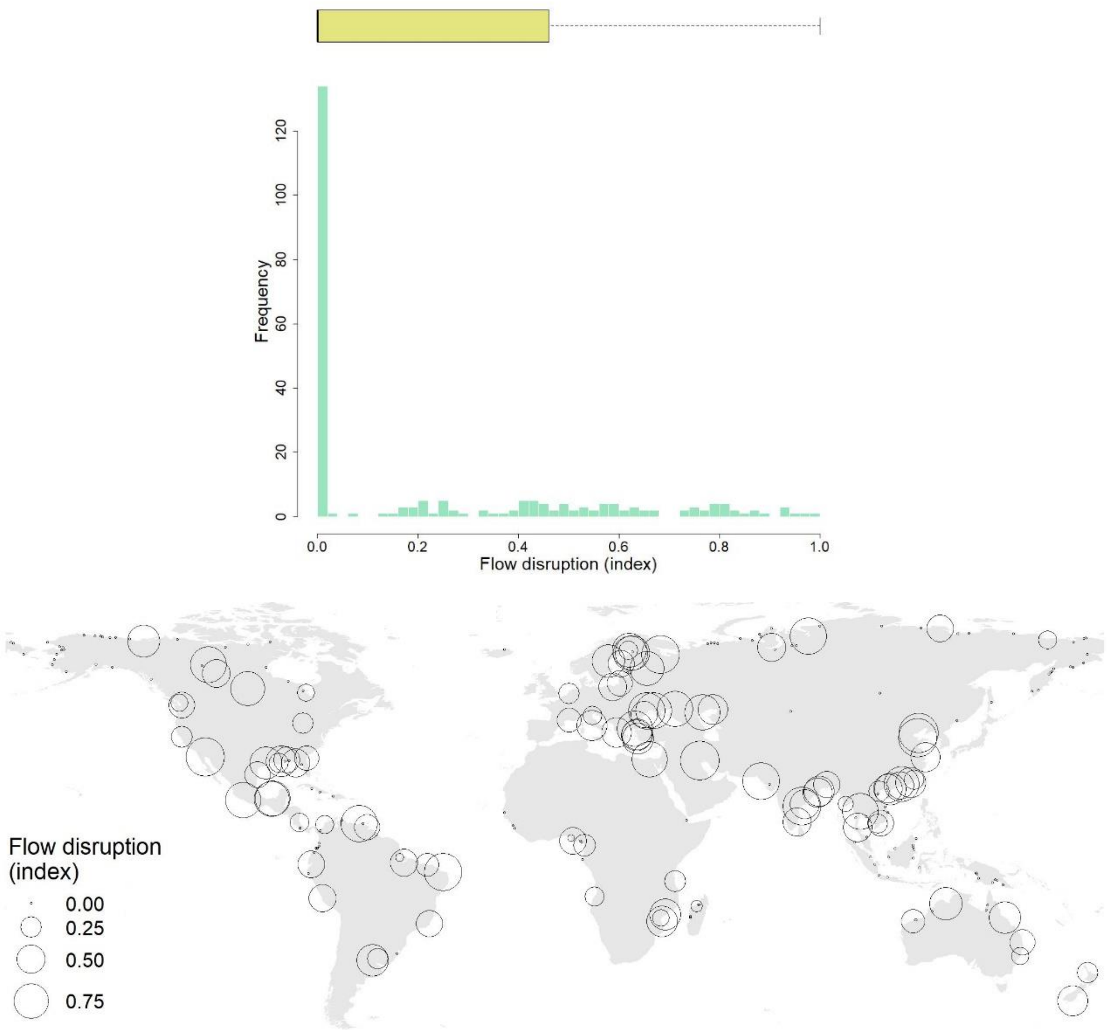


Supplementary Figure 52. Summary of the population density indicator across all deltas and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers.

3.2. Flow disruption

Index indicating time water spends in reservoir storage[7]

Downloaded from https://databasin.org/datasets/e1f75e49e51249b5aab4ce58280b2dd9

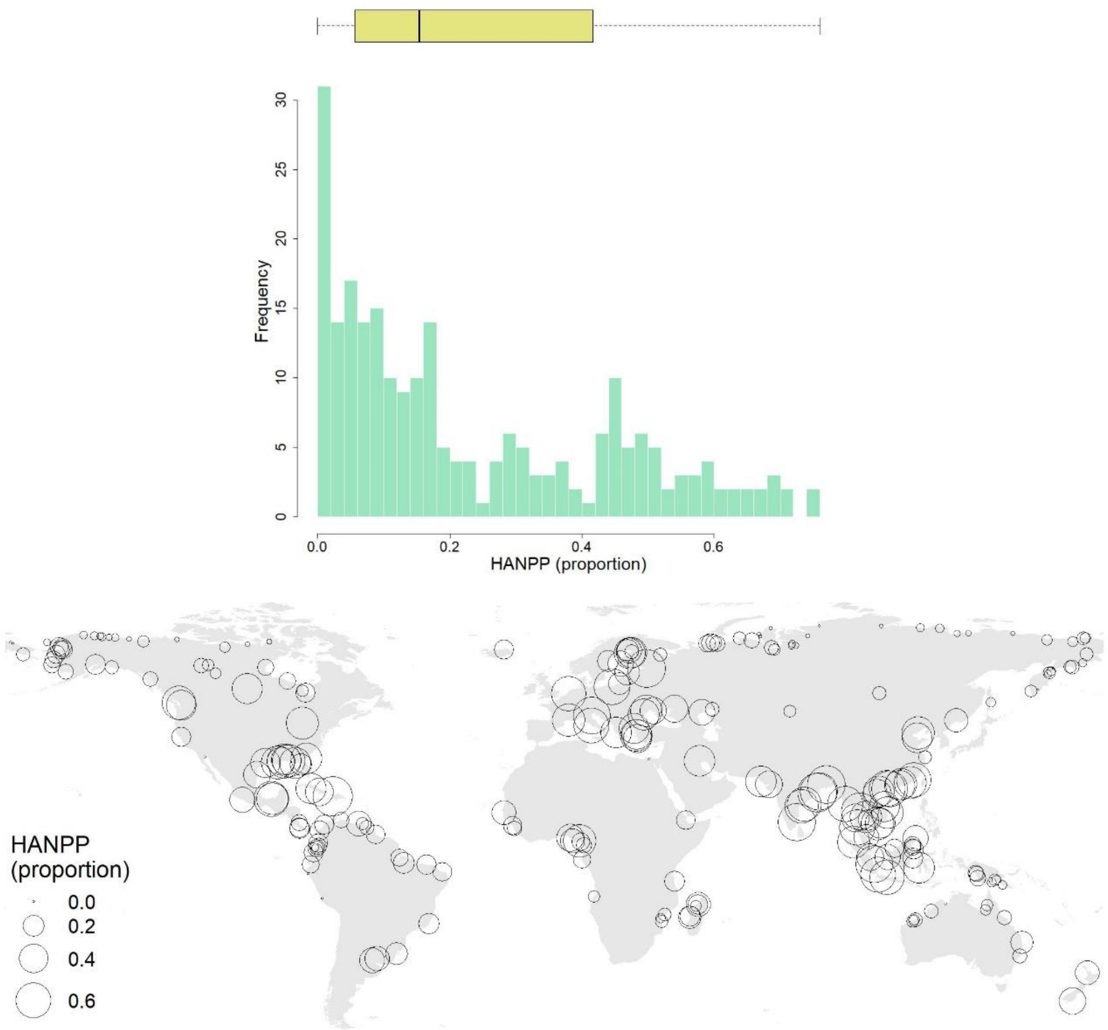


Supplementary Figure 53. Summary of the flow disruption indicator across all deltas and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers.

3.3. HANPP

Human Appropriation of Net Primary Productivity[17]

Downloaded from https://boku.ac.at/wiso/sec/data-download

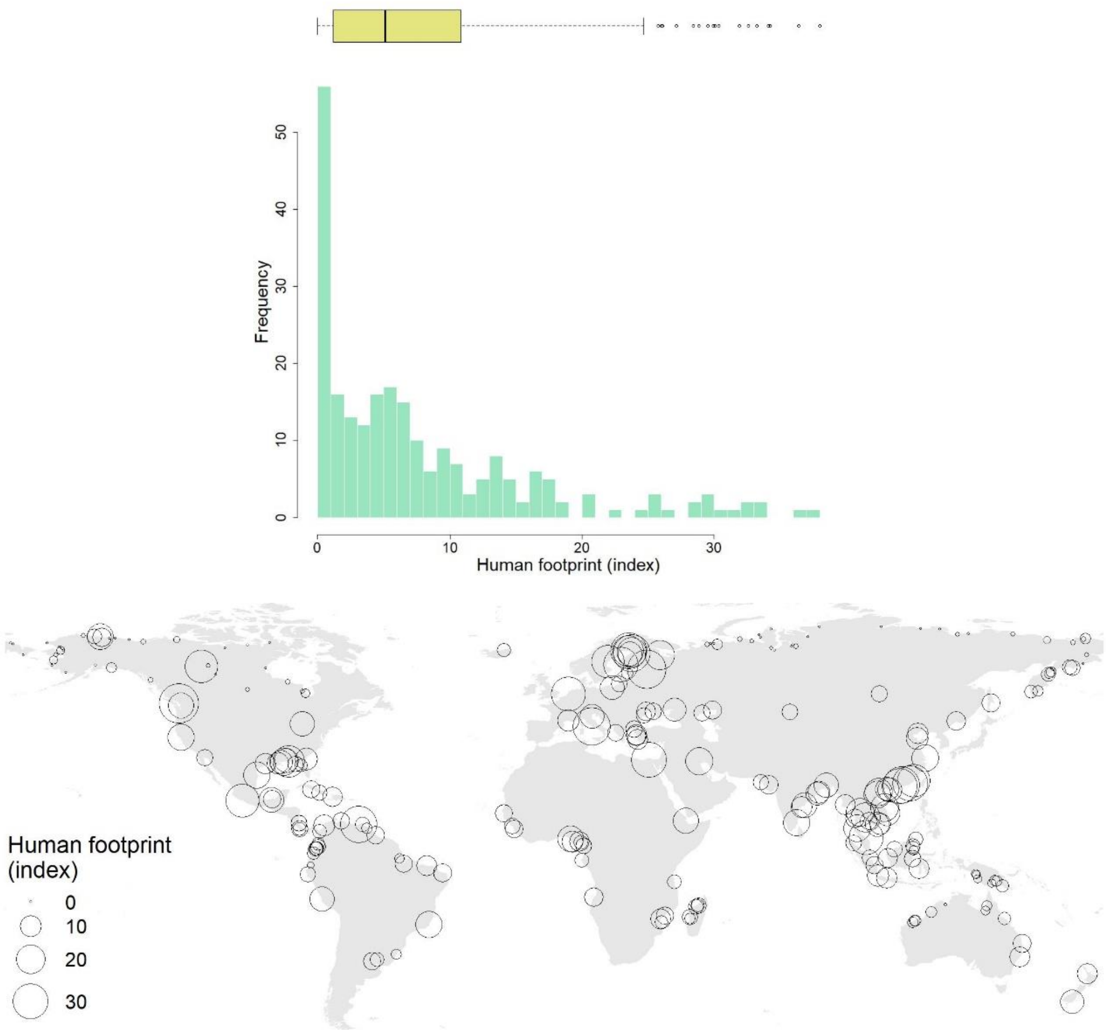


Supplementary Figure 54. Summary of the human appropriation of net primary productivity (HANPP) indicator across all deltas and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers.

3.4. Human footprint

Index showing cumulative human pressure[10,11]

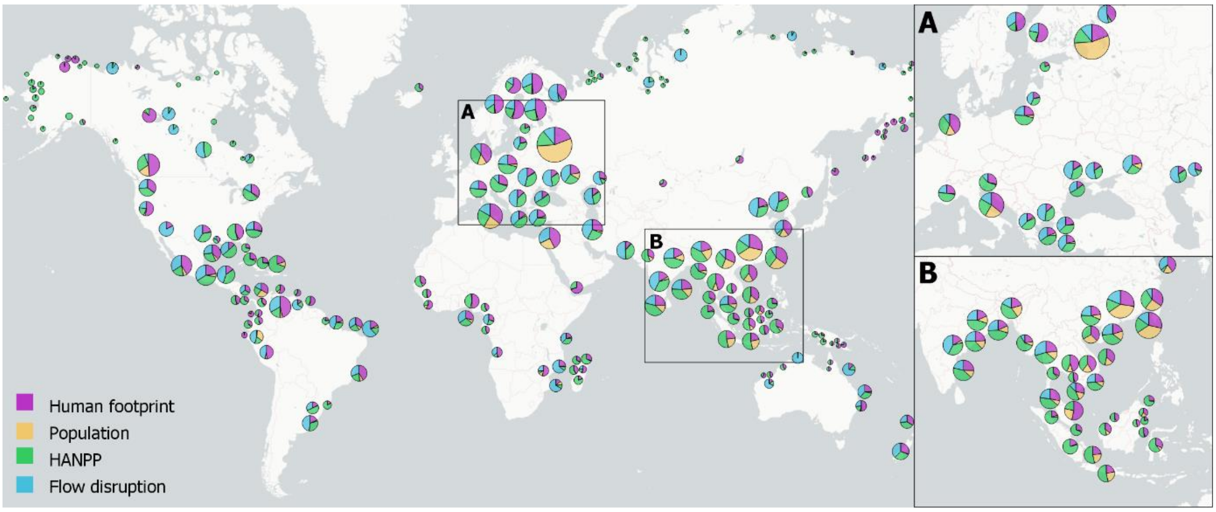
Downloaded from https://sedac.ciesin.columbia.edu/data/set/wildareas-v3-2009-human-footprint



Supplementary Figure 55. Summary of the human footprint indicator across all deltas and its spatial distribution. Box plot centre lines indicate the median, box limits indicate upper and lower quartiles, whiskers indicate 1.5 × interquartile range, and points indicate outliers.

Supplementary Note 4. Delta modification levels

Globally, deltas exhibit very different levels of human modification (population density, HANPP, flow disruption and human footprint), but these levels are often similar in proximate deltas (Supplementary Figure 56). We find groups of highly modified deltas in Europe, and South and Southeast Asia, while modification in the Americas and Africa is far more variable, with several more modified deltas mixed with many less modified. Population density is very variable, only 13 deltas with a population of over 1000 per km^2 where much of the delta is covered by urban area; these are found mostly in Southeast Asia and Europe, the Neva delta a particular outlier with around 10,000 people per km^2 due to urban St. Petersburg. Flow disruption had higher values spread across all continents and latitudes, although was not present in many deltas (57%), in particular smaller Arctic and Indonesian deltas. HANPP shows some latitudinal bias, making up a large proportion of the modification of all deltas in the Tropics, while also often the dominant form of modification in the least modified deltas. Finally, almost all deltas (88%) have some human footprint, with hotspots in North Europe, Southeast Asia and North America and the Arctic as the main exception. All the modification indicators were positively correlated with one another, with stronger correlations between population density and human footprint (Spearman's $\rho = 0.84$), strong correlations between population density, human footprint and HANPP (Spearman's $\rho > 0.7$), and weaker correlations with flow disruption and the others (Spearman's $\rho = 0.42$ to 0.52).



Supplementary Figure 56. Relative proportion of global delta modification. Pie proportions indicate relative amount of standardised indicators for population density, flow disruption, HANPP and human footprint. Pie diameter indicates total modification, the sum of standardised modification indicators. Overlapping deltas omitted from global view are shown in submaps A and B.

Supplementary Note 5. Statistical summary of indicators and created bundles

Supplementary Table 2 summarises each ecosystem service and modification indicator.

Supplementary Table 2. The mean, standard deviation (SD), minimum and maximum of the raw ES and modification indicators across all deltas.

Ecosystem service

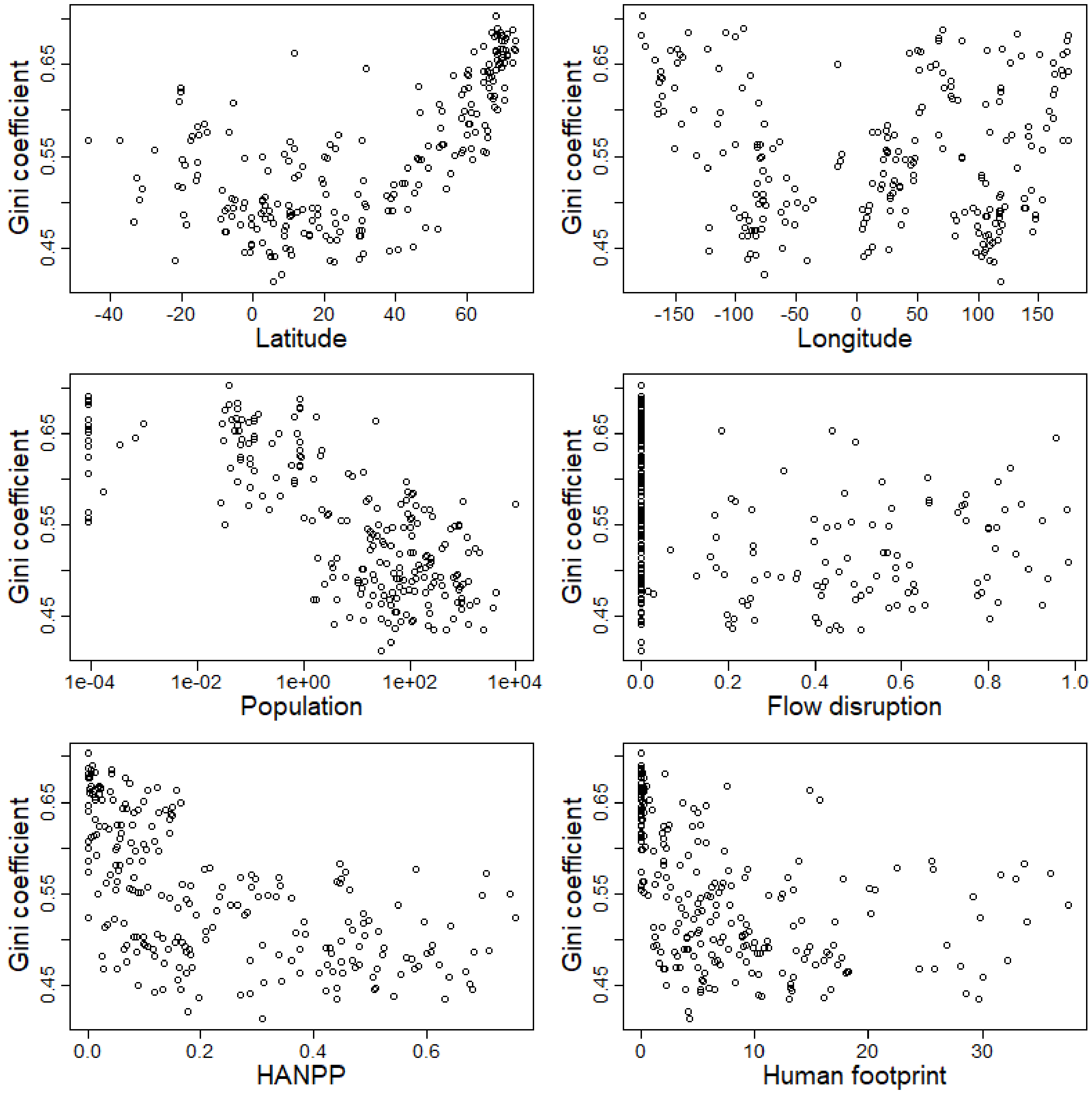
	Mean	SD	Min	Max
Attainable yield	67.322	68.862	0.000	186.473
Food area	872.577	1780.408	0.000	8793.728
Food calories	7493204052.471	17398187428.189	0.000	116000000000.000
Food value	1204.299	1927.024	0.000	12077.456
Nonfood area	147.799	340.514	0.000	2341.276
Nonfood calories	1288048529.510	3186685884.372	0.000	21130309886.000
Nonfood value	862.311	1507.283	0.000	12660.350
Feed calories	2191281430.161	5664082642.384	0.000	46976295564.000
Pasture area	0.080	0.151	0.000	0.814
Aquaculture	0.627	0.313	0.000	1.000
Fish river	0.535	0.373	0.000	0.999
Fish marine	0.111	0.158	0.000	0.933
Discharge	41.413	114.778	0.010	1373.962
Navigable water	1.135	0.938	0.000	3.889
Sediment	16.195	88.280	0.000	1277.917
Water quality	648.492	80.510	0.000	678.301
Water available	69365760266.744	406799550698.930	0.000	5950000000000.000
Water withdrawal	1426675195.928	4700338210.939	0.000	41962300000.000
Coastal flooding	2.889	0.453	0.000	3.141
River fooding	9.852	0.811	0.000	10.248
NPP	530.768	260.907	0.000	1173.815
NPP potential	600.100	307.878	0.000	1280.389
Carbon vegetation	3708.942	4988.019	0.000	20131.704
Carbon vegetation pot.	57.011	62.833	0.000	372.000
Carbon soil	86.505	56.409	7.590	357.738
Soil carbon density	600.309	268.040	122.970	1311.994
Soil CEC	36.276	16.787	13.822	84.398
Soil loss	38.707	4.620	0.000	40.728
Soil nitrogen	2.506	2.770	0.320	16.110
Soil water	18.055	5.769	6.000	45.000
Pollination supply	0.249	0.376	0.000	1.000
Forest cover	0.013	0.020	0.000	0.083
Wetlands	385.234	349.263	0.000	1000.000
Alpha diversity intactness	0.782	0.200	0.273	1.004
Biodiversity abundance	0.751	0.149	0.298	1.002
Biodiversity richness	0.725	0.174	0.274	0.985
Amphibian richness	9.838	11.713	0.000	63.595
Bird richness	204.458	117.666	34.250	519.857
Mammal richness	44.650	31.303	3.833	150.800
Marine animal richness	980.747	1358.531	0.000	6393.500
Marine plant richness	17.313	22.801	0.000	91.416
Plant richness	1366.553	1104.917	109.700	4720.100
Seabird richness	8.677	7.787	0.000	54.000
Amphibian unthreatened	0.982	0.076	0.000	1.000
Bird unthreatened	0.962	0.026	0.862	0.995
Mammal unthreatened	0.947	0.076	0.000	1.000
Marine unthreatened	0.833	0.218	0.049	1.000
Seabird unthreatened	0.931	0.151	0.000	1.000
Oil area	15.339	28.825	0.000	100.000

Modification

	Mean	SD	Min	Max
Population	245.780	810.631	0	9862.999
Flow disruption	0.224	0.302	0	0.984
Dam capacity	119.210	1318.009	0	20155.601
HANPP	0.228	0.208	0	0.758
Human footprint	7.663	8.445	0	37.576

Supplementary Note 6. Diversity of ecosystem services across deltas

Diversity of ecosystem service values increased with latitude, but decreased with most indicators of human modification (Supplementary Figure 57).



Supplementary Figure 57. Diversity of ecosystem services with modification. Diversity of ES within each delta (y-axis) against latitude, longitude, and the four indicators of human modification. We calculated diversity using the Gini coefficient of the standardised values of the 49 ES indicators for each delta.

Supplementary Note 7. Bundle consistency and alternative ecosystem service bundling results

Our unsupervised method only accounts for statistical correlation rather than any mechanistic link between indicators – which means the bundles consisted of ecosystem services (ES) which tended to be found together at similar values. The three more consistent bundles ('intactness', 'productivity' and 'food') appear coherent and robust. Where individual ES responses to modification were present ($r > 0.1$) they typically shared the characteristic curve of their parent bundle (in 91% of cases; Table 2, main text). Similarly, pairwise correlations of ES within these bundles were remarkably consistent (Figure 3, main text), excepting the forest and wetland indicators, which as discussed in the main text, may relate to several ES.

In terms of composition, the three robust bundles present logically connected ES. The 'intactness' bundle represents many measures of the pristineness of the environment that could be expected to correlate. This includes measures of unthreatened species, biodiversity intactness and soil and water quality. It combines them with the absence of flooding and soil erosion. These latter indicators may not be linked to ecosystems in all cases, but there is a strong relationship between ecosystem integrity and such regulating services[39,40].

The 'productivity' bundle includes indicators with strong links to ecosystem productivity – particularly actual and potential net primary productivity and vegetation carbon. The other indicators, predominately based on species richness, are understandable given the broad global relationships between productivity and biodiversity[41]. Pollination supply is very inconsistently bundled with 'productivity', selected within the bundle by only two of six algorithms. This inconsistency may stem from the nature of the indicator, which measures pollinator habitat in proximity to farmland[42]; habitats and farmlands perhaps correlating differently from one another at the global scale. It also includes unthreatened birds, which may be an artefact of the data, or may reflect the distinctiveness of birds from solely terrestrial biota.

The 'food' bundle appears reasonably consistent – with indicators for food and non-food agriculture, aquaculture and fish catch. This reflects the distinct position of deltas, where fertile areas for crops and fish production combine[43]. More generally, provisioning services are likely to have similar requirements for their development, such as nearby population, accessibility, and flat, fertile land. The inclusion of water withdrawal in the bundle is understandable given that globally the agricultural sector has the highest water usage[44].

The final bundle contains mostly water-related indicators such as wetlands, navigable water, discharge, sediment and available water. While seabird richness might be expected to correlate with wetland habitats, it also contains indicators such as pasture area and oil, with little mechanistic link. This reflects that when clustering indicators, one group will be the least correlated. The component ES of this bundle have weaker within and across bundle correlations (Figure 3, main text). This 'other' bundle can be an advantage, as it reduces the influence of these indicators on the trends shown by the stronger bundles. We can see that it does not disguise any strong responses of the indicators within: only one of 32 responses had an $r > 0.1$, seabird richness responding similarly to the other richness indicators with HANPP (Table 3, main text).

In addition to the unsupervised approach discussed in the main results, we also grouped ES indicators using categories from pre-existing frameworks. The Millennium Ecosystem Assessment (MEA) supervised approach categorised ES indicators into provisioning ($n = 15$), supporting ($n = 19$) and regulating ($n = 15$) groups. The ES cascade supervised approach categorised the ES indicators into property ($n = 19$), supply ($n = 14$) and service/benefit ($n = 16$) groups (Supplementary Table 3). We then then created bundles within these categories using k-medoids clustering, set to two clusters based on the most common results of the elbow method (Supplementary Table 3, see Supplementary Methods 2 for details). Supplementary Table 4 shows the proportions of deltas which exhibit decoupling under these groups and bundles. Supplementary Figures 58 to 61 show the response curves of these groups and bundles to modification.

MEA and ES cascade supervised groups showed decoupling at different modification levels, with 70% of deltas showing decoupling across at least one MEA supervised category, and 56% for at least one ES cascade supervised category. We found consistencies and differences between the results of the unsupervised and supervised methods. For MEA groups (Supplementary Figure 58), we found very similar responses and fits for 'provisioning' services and the unsupervised 'food' bundle ($0.14 < r < 0.67$), understandable given the large crossover in indicators. The 'regulating' category shares indicators with the 'intactness' bundle and also shows similar responses and fits ($0.1 < r < 0.25$), although decoupling later from human footprint. 'Supporting' services include ES indicators from the unsupervised 'intactness' and 'productivity' bundles, and shows very weak relationships with modification ($0.02 < r < 0.06$). For the ES cascade approach (Supplementary Figure 59), we find weak or no relationships with the modification indicators, except for the category 'service' ($0.1 < r < 0.55$), which again shares indicators with the 'food' bundle. Response curves were more similar to our unsupervised approach when clustering was applied within these frameworks (see main text, Supplementary Figures 60 and 61). We found that response curves were consistent whether ES indicators fitting multiple categories, such as forests and wetlands, were included or not (Supplementary Note 11).

Supplementary Table 3. Ecosystem service (ES) bundle composition using a. the ES cascade framework and b. the Millennium Ecosystem Assessment (MEA) framework. The titles in bold represent the framework categories, and the subgroups in italic represent our classification of the bundles created by unsupervised clustering within each category.

a. Ecosystem service cascade framework

Property/Function		**Supply**		**Service/Benefit**	
Intactness	*Richness*	*Productivity and water*	*Soil*	*Food*	*Regulating*
Alpha diversity intactness	Amphibian richness	Attainable yield	Soil carbon	Food area	Pasture area
Biodiversity abundance	Bird richness	Pollination supply	Soil carbon density	Food calories	Coastal flooding
Biodiversity richness	Mammal richness	Carbon vegetation	Soil cation-exchange cap.	Food value	River flooding
Amphibian unthreatened	Marine animal richness	Carbon vegetation pot.	Soil N	Nonfood area	Soil loss
Bird unthreatened	Marine plant richness	Oil area	Soil water availability	Nonfood calories	
Mammal unthreatened	Plant richness	Available water	Sediment	Nonfood value	
Marine unthreatened	Seabird richness	Navigable water		Feed production	
Seabird unthreatened	Actual NPP	Discharge		Aquaculture	
	Potential NPP			Fish river	
	Forest cover			Fish marine	
	Wetlands			Water withdrawal	
				Water quality	

b. Millennium Ecosystem Assessment framework

Provisioning		**Supporting**		**Regulating**	
Food	*Fish and water*	*Intactness*	*Richness and productivity*	*Soil and water*	*Carbon and water*
Food area	Pasture area	Alpha diversity intactness	Forest cover	Soil carbon density	Carbon vegetation
Food calories	Aquaculture	Biodiversity abundance	Wetlands	Soil carbon	Carbon vegetation pot.
Nonfood area	Fish river	Biodiversity richness	Amphibian richness	Soil cation-exchange cap.	Pollination supply
Nonfood calories	Oil area	Amphibian unthreatened	Bird richness	Soil loss	Sediment
Nonfood value	Available water	Mammal unthreatened	Mammal richness	Soil N	Discharge
Feed production	Attainable yield	Marine unthreatened	Marine animal richness	Soil water availability	Navigable water
Fish marine	Food value	Seabird unthreatened	Marine plant richness	Coastal flooding	
Water withdrawal			Plant richness	River flooding	
			Seabird richness	Water quality	
			Bird unthreatened		
			Actual NPP		
			Potential NPP		

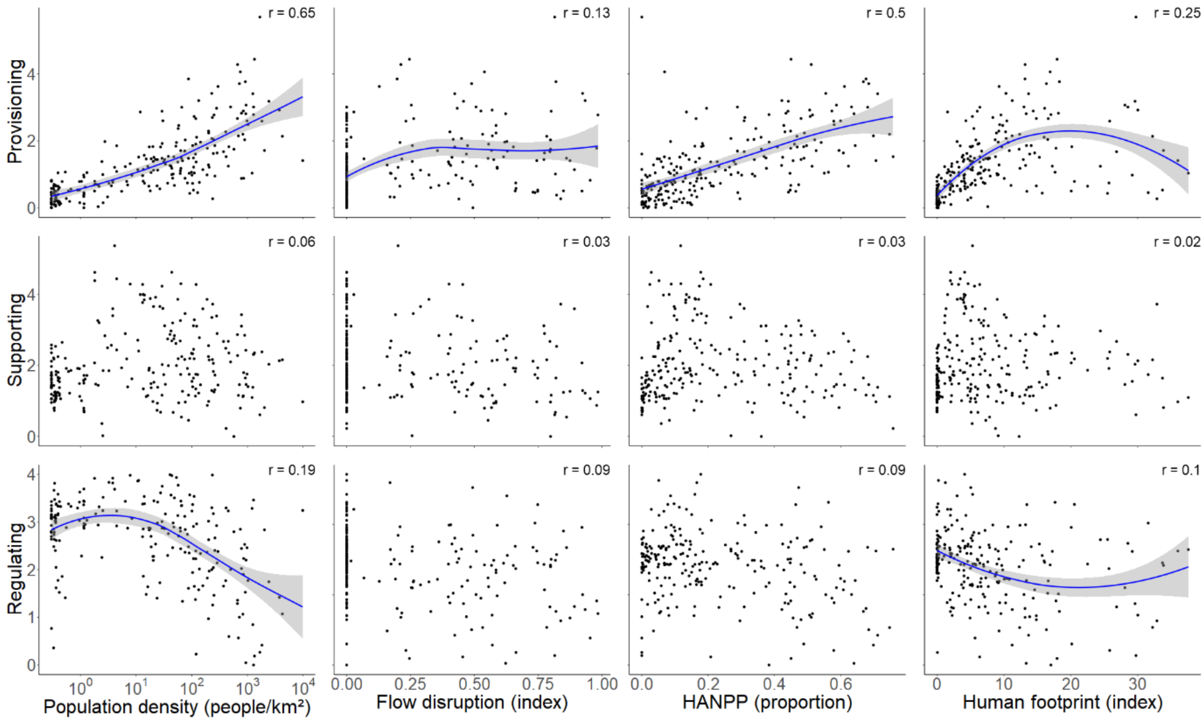
Supplementary Table 4. Percentage of decoupled deltas and the threshold of modification for decoupling for each ecosystem service (ES) category. a. Millennium Ecosystem Assessment (MEA) categories. b. ES cascade categories. c. Bundles based on sub-setting MEA categories. d. Bundles based on sub-setting ES cascade categories. The rightmost column indicates the percentage of deltas decoupled for that ES bundle for one or more modification indicators. The bottom row indicates the percentage of deltas decoupled for that modification indicator for one or more ES bundles. The bottom right figure indicates the total percentage of deltas decoupled at least once. Thresholds marked with an asterisk indicate a response curve with a pseudo-r > 0.1 (see Supplementary Figures 58 to 61).

a. MEA		*Population (per km^2)*	*Flow disruption (proportion)*	*HANPP (proportion)*	*Human Footprint (index)*	*Total deltas decoupled*
Provisioning	Decoupled (%)		30.64		8.09	34.47
	Threshold		0.36*		20.14*	
Supporting	Decoupled (%)	48.94	39.15	36.60	31.49	60
	Threshold	20.54	0.19	0.25	8.95	
Regulating	Decoupled (%)	61.28	30.64	46.81	7.66	69.36
	Threshold	3.79*	0.36	0.16	20.55*	
Total deltas decoupled		61.28	39.15	46.81	31.49	70.21

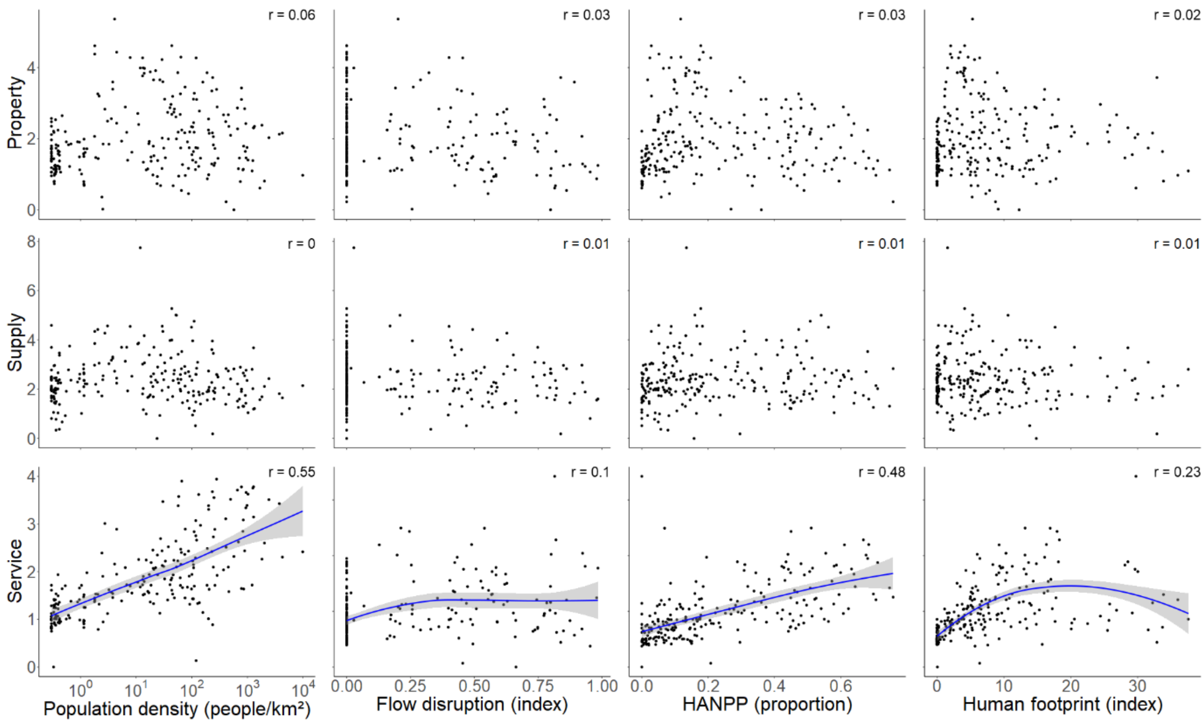
b. ES cascade		*Population (per km^2)*	*Flow disruption (proportion)*	*HANPP (proportion)*	*Human Footprint (index)*	*Total deltas decoupled*
Property	Decoupled (%)	48.94	39.15	36.60	31.49	59.57
	Threshold	20.54	0.19	0.25	8.95	
Supply	Decoupled (%)	56.60		34.89	43.83	61.28
	Threshold	10.71		0.28	6.00	
Service	Decoupled (%)		28.51		8.51	32.34
	Threshold		0.41*		20.06*	
Total deltas decoupled		56.60	39.15	36.60	43.83	66.38

c. MEA subset		*Population (per km²)*	*Flow disruption (proportion)*	*HANPP (proportion)*	*Human Footprint (index)*	*Total deltas decoupled*
Provisioning						
Food	Decoupled (%)		30.64		7.66	33.62
	Threshold		0.36*		20.55*	
Water	Decoupled (%)		30.64	3.40	17.87	40.43
	Threshold		0.36	0.64*	13.68	
Supporting						
Intactness	Decoupled (%)		30.64		21.70	40
	Threshold		0.36		12.39*	
Richness	Decoupled (%)		31.49	34.89	22.98	55.32
	Threshold	31.29*	0.33*	0.28*	11.24*	
Regulating						
Carbon	Decoupled (%)		21.28	34.47	22.98	54.89
	Threshold	24.34*	0.49*	0.28*	11.24*	
Soil	Decoupled (%)		28.09		8.51	32.34
	Threshold		0.41		20.06*	
Total deltas decoupled		31.29	31.49	34.89	22.98	56.60

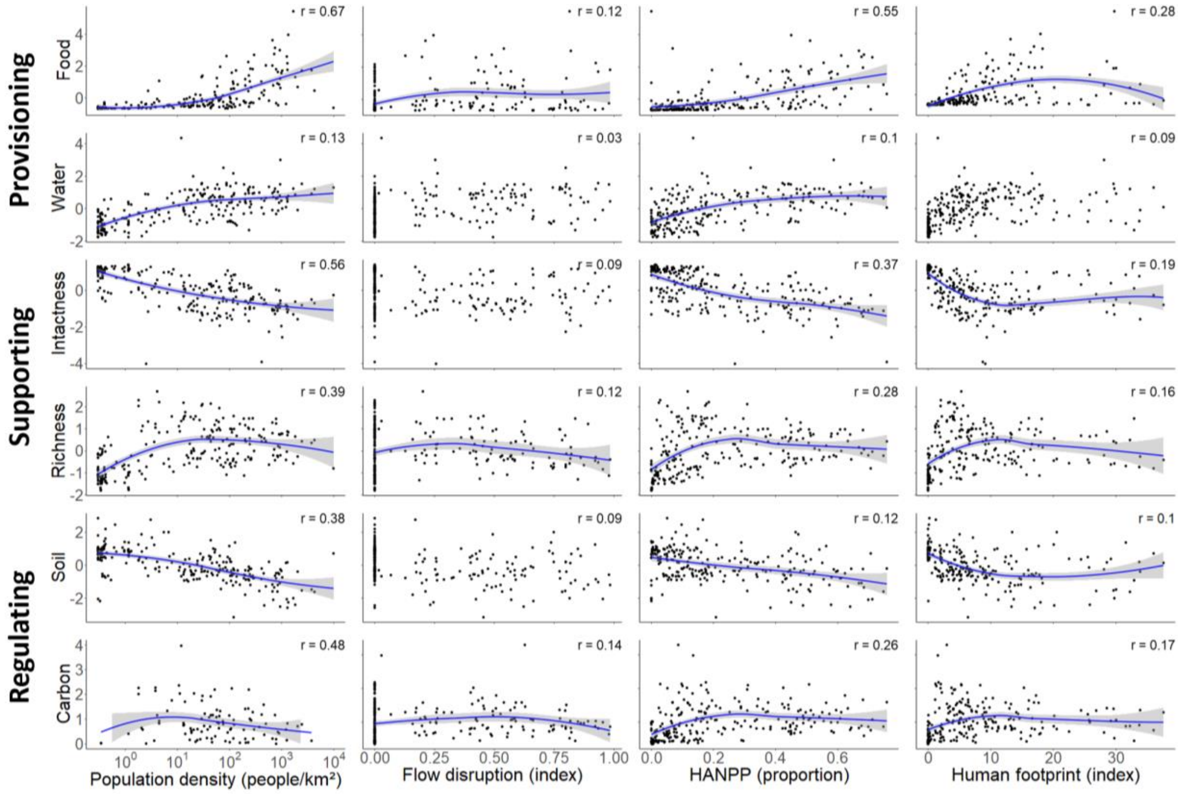
d. ES cascade subset		*Population (per km²)*	*Flow disruption (proportion)*	*HANPP (proportion)*	*Human Footprint (index)*	*Total deltas decoupled*
Property						
Intactness	Decoupled (%)		30.64		21.70	40
	Threshold		0.36		12.39*	
Richness	Decoupled (%)	43.83	31.49	34.89	22.98	55.32
	Threshold	31.29*	0.33*	0.28*	11.24*	
Supply						
Productivity	Decoupled (%)	37.02	30.64	30.64	22.55	51.91
	Threshold	57.10*	0.36*	0.31*	12.28*	
Soil	Decoupled (%)	4.68	30.21		21.28	39.57
	Threshold	1025.14*	0.40		12.90*	
Service						
Food	Decoupled (%)		30.21		7.66	33.62
	Threshold		0.40*		20.55*	
Regulating	Decoupled (%)	62.13	31.06	57.87	6.38	74.04
	Threshold	3.24*	0.36	0.11*	25.50*	
Total deltas decoupled		62.13	31.49	57.87	22.98	74.47



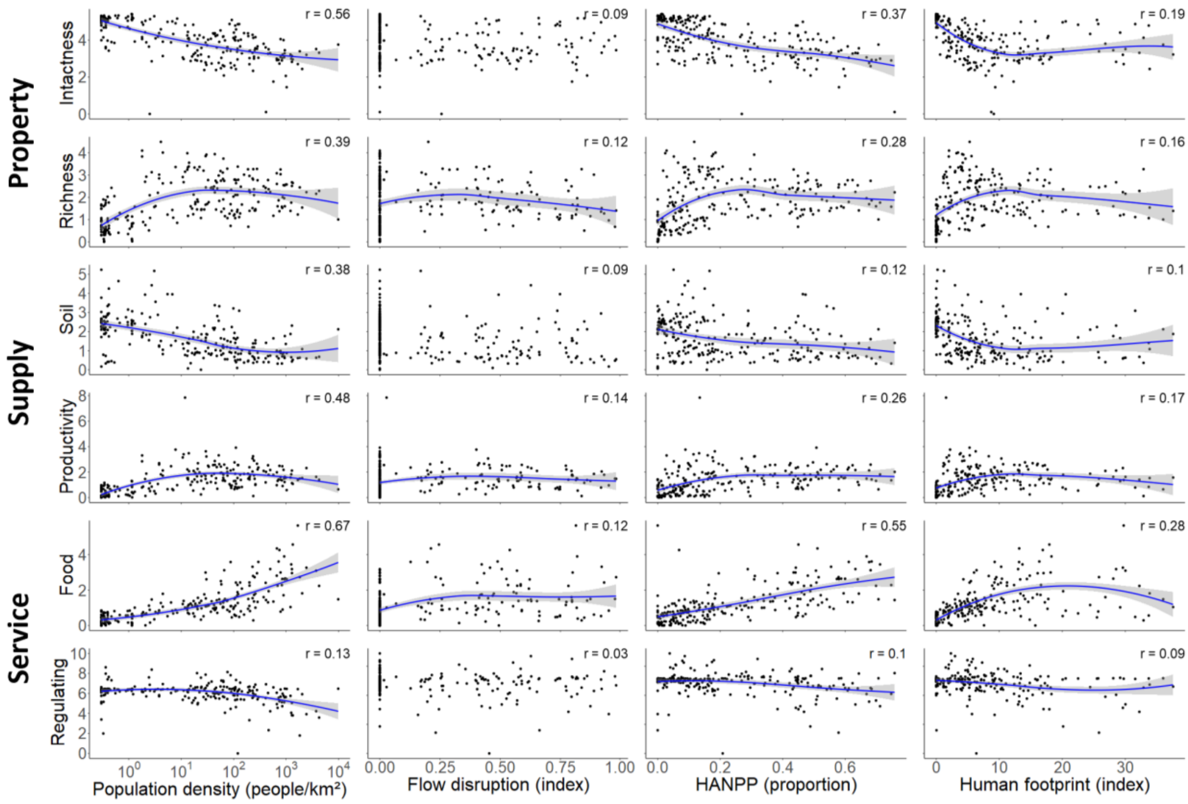
Supplementary Figure 58. Responses of combined provisioning (top), supporting (middle) and regulating (bottom) services to different indicators of modification. ES within each category were standardised, summed and standardised again. r indicates pseudo-r fit of smoothed regression line (LOESS, span = 1) to data. Shaded areas around trend line indicate 0.95 CI. Curves with a pseudo-r < 0.1 are not shown.



Supplementary Figure 59. Responses of combined ecosystem property (top), supply (middle) and service (bottom) categories to different indicators of modification. ES within each category were standardised, summed and standardised again. r indicates pseudo-r fit of smoothed regression line (LOESS, span = 1) to data. Shaded areas around trend line indicate 0.95 CI. Curves with a pseudo-r < 0.1 are not shown.



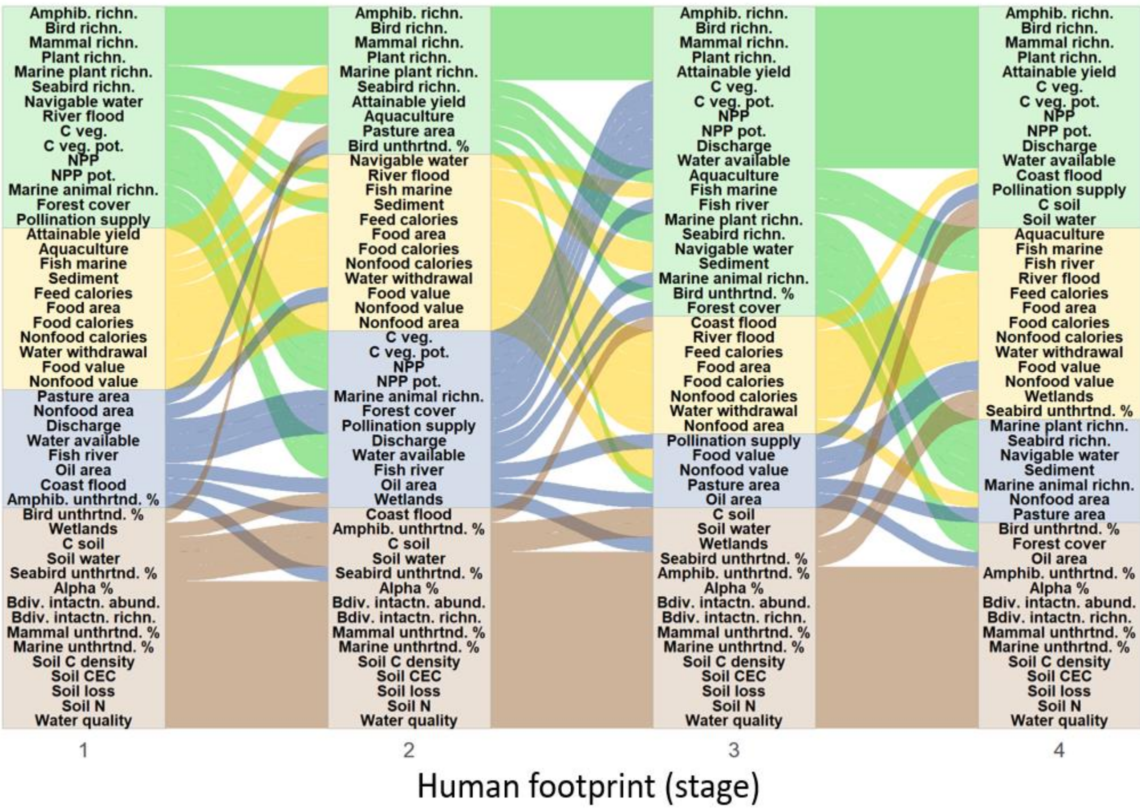
Supplementary Figure 60. Response curves to modification of ES indicators bundled within provisioning, supporting and regulating categories. r indicates pseudo-r fit of smoothed regression line (LOESS, span = 1) to data. Shaded areas around trend line indicate 0.95 CI. Curves with a pseudo-r < 0.1 are not shown.



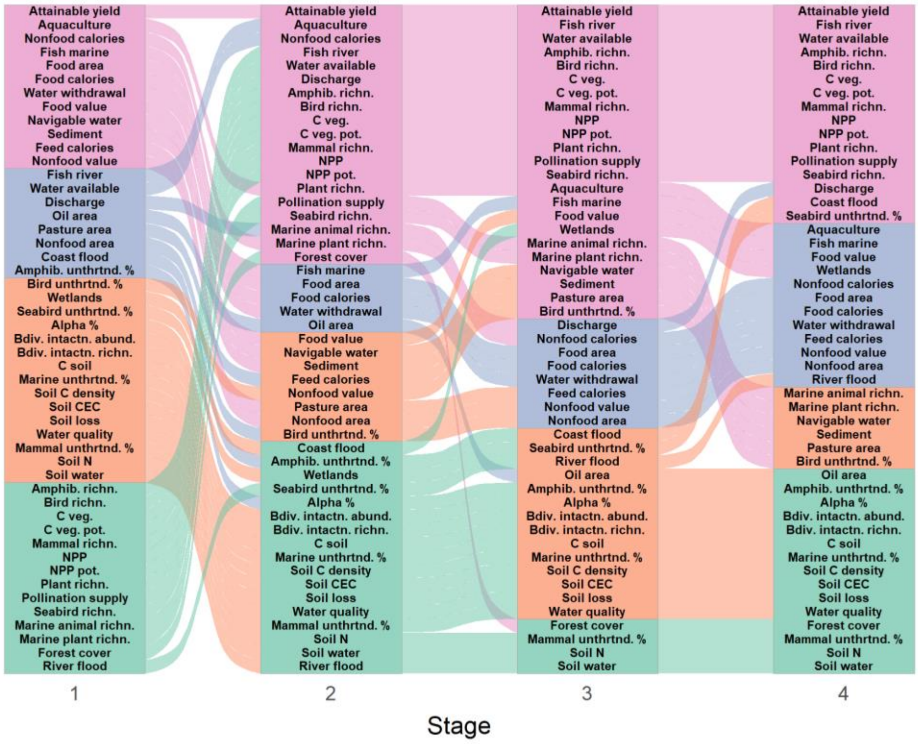
Supplementary Figure 61. Response curves to modification of ES indicators bundled within ecosystem property, supply and service categories. r indicates pseudo-r fit of smoothed regression line (LOESS, span = 1) to data. Shaded areas around trend line indicate 0.95 CI. Curves with a pseudo-r < 0.1 are not shown.

Supplementary Note 8. Bundle change with modification

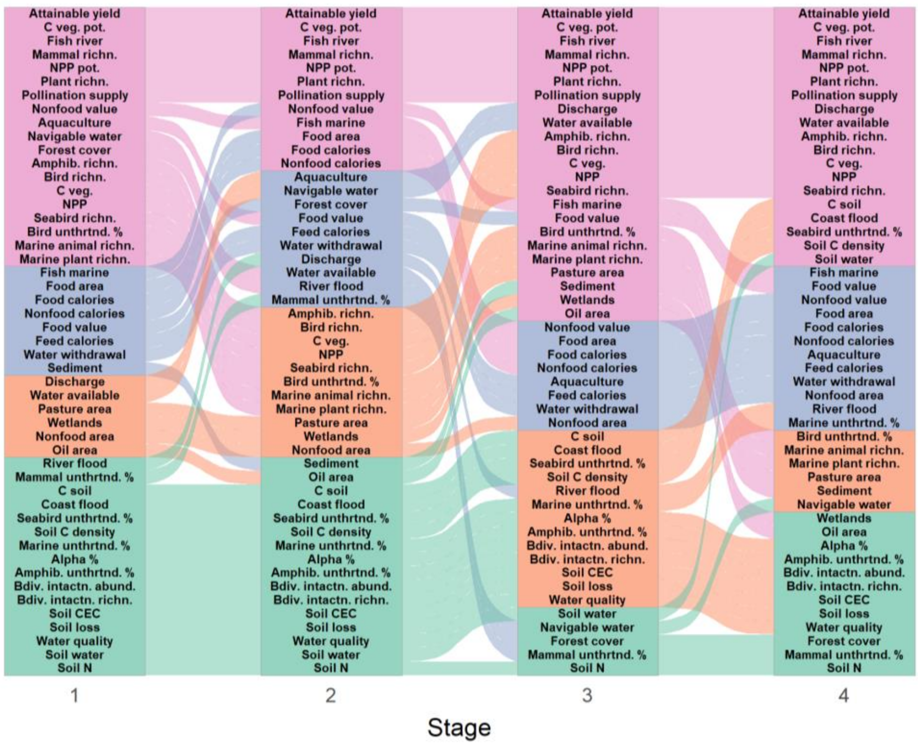
We examined if ecosystem service (ES) bundle composition shifted at different levels of modification, and found that the bundles were largely stable when the clustering process was repeated across deltas binned into four stages of each modification gradient. Results across the modification indicators were broadly similar (Supplementary Figures 62 to 65), we examine human footprint in more detail here (Supplementary Figure 62). Shifts in ES composition occurred most often between stage 1 and 2 of human footprint. 'Productivity' ES indicators were consistently bundled together along the stages of modification, except at stage 2 where this bundle shifted from being the most to the second least distinct – distinctness indicating that its ES were most similar to one another, and dissimilar to those in other bundles. 'Food' ES indicators were also consistently bundled together except at stage 3, and this was typically the second most distinct bundle. Changes in bundle make-up coincided with decoupling points identified in the previous analyses (Figure 2, main text). The 'intactness' bundle included ES that were the least similar to one another, but which rarely clustered in another bundle – 73% of its ES remained consistent between one stage of modification and the next. 'Other' ES indicators were the most unstable, with the bundle being unrecognisable from its global composition except at modification stage 1.



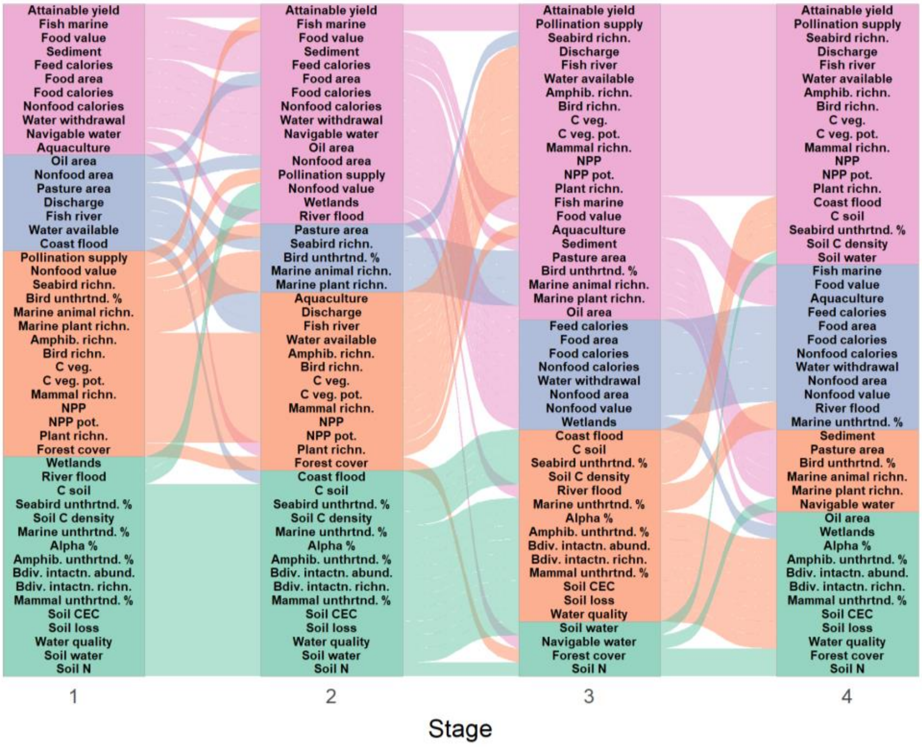
Supplementary Figure 62. Change in ecosystem service (ES) bundle composition as human footprint increases. The deltas were divided into four stages of modification using breakpoint analysis (n = 93, 83, 40, 19). ES were then clustered into four bundles for each stage of modification using the k-medoids algorithm. The arrows indicate the movement of ES from one bundle to another between one stage and the next, although for visual clarity they do not always link an ES to its exact place in its new bundle. Colours indicate the unsupervised bundle formed across all the deltas that each group is most similar to – 'productivity' (green, top), 'food' (yellow), 'other' (blue), and 'intactness' (brown, bottom).



Supplementary Figure 63. ES bundles formed by k-medoids clustering as population modification increases. The deltas were divided into four stages of modification using breakpoint analysis (n = 84, 48, 67, 36). The colours separate one bundle from another – these were not reordered, so the uppermost bundle represents the first ES cluster which formed under k-medoids clustering.



Supplementary Figure 64. ES bundles formed by k-medoids clustering as flow disruption modification increases. The deltas were divided into four stages of modification using breakpoint analysis (n = 135, 26, 46, 28). The colours separate one bundle from another – these were not reordered, so the uppermost bundle represents the first ES cluster which formed under k-medoids clustering.

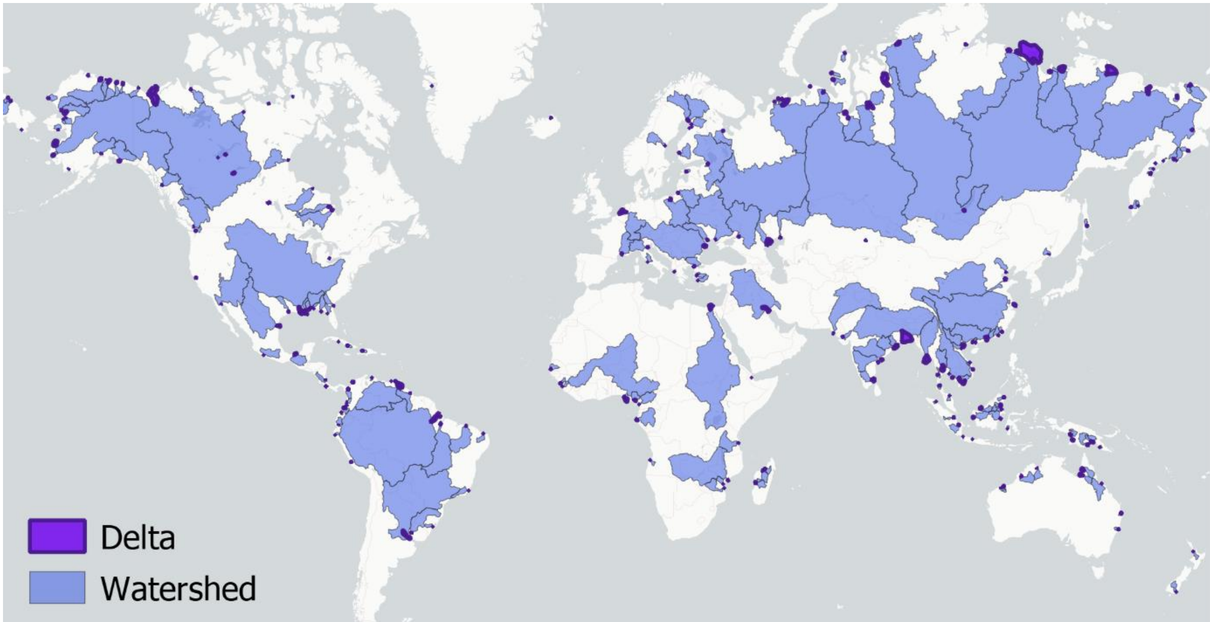


Supplementary Figure 65. ES bundles formed by k-medoids clustering as HANPP modification increases. The deltas were divided into four stages of modification using breakpoint analysis (n = 104, 57, 48, 26). The colours separate one bundle from another – these were not reordered, so the uppermost bundle represents the first ES cluster which formed under k-medoids clustering.

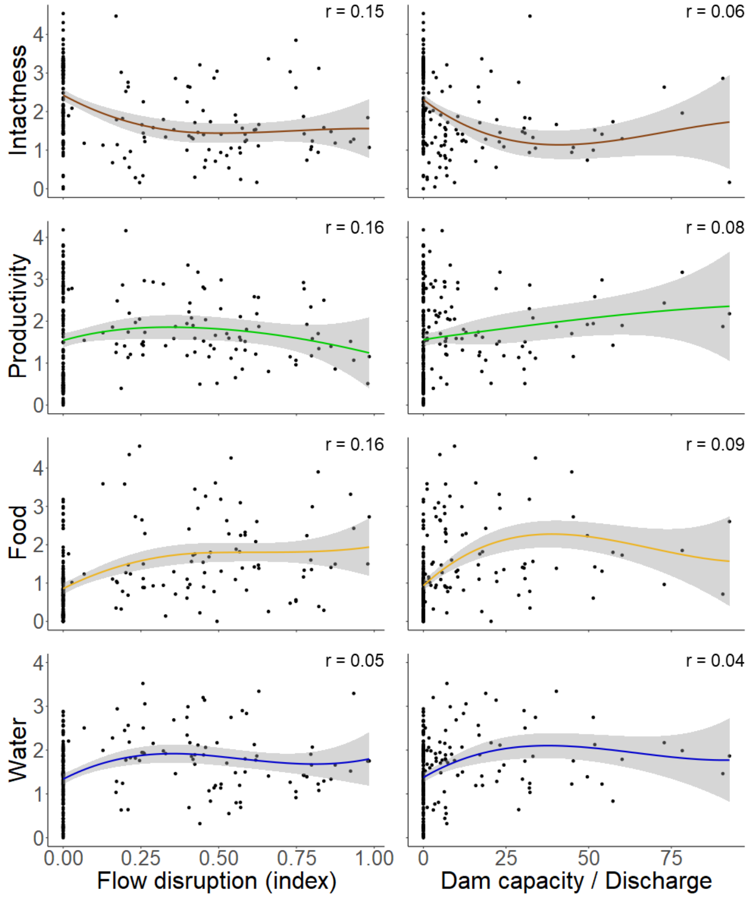
Supplementary Note 9. Flow disruption indicator

To account for the upstream influence of river basins on delta flow we used the flow disruption indicator[7]. This indicator is based on the GRanD database[45], and measures the increased residence time of water in river systems due to dams and reservoirs. We examined the impact of the choice of this indicator by creating an alternative dam capacity indicator. To create this indicator we summed mean dam capacity[45] in each delta watershed[46] and divided it by the total watershed discharge[9] (Supplementary Figure 66).

Our dam capacity indicator was highly correlated with flow disruption (Spearman's $\rho = 0.8$, $p < 0.001$). Smoothed plots between the two are similarly weak (Supplementary Figure 67). However, the dam capacity regression fit showed lower pseudo-r values ($r < 0.1$) than flow disruption, and includes extreme values (for example, the Colorado, where discharge is low and reservoir capacity extremely high). Therefore, we continued our analysis using only the flow disruption indicator.



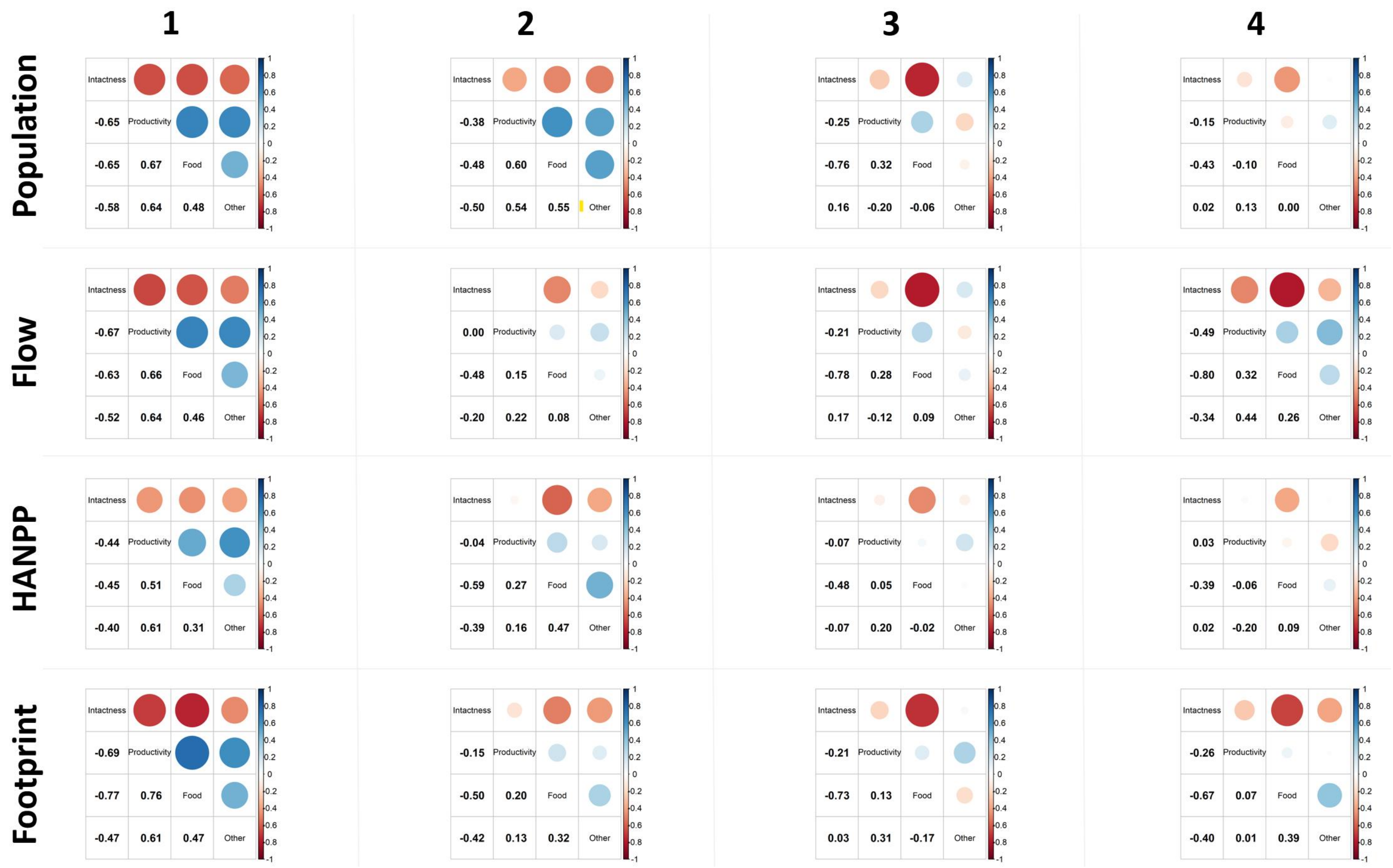
Supplementary Figure 66. Large delta areas and their watersheds (watershed data from [46]).



Supplementary Figure 67. Flow disruption and dam capacity response curves with the unsupervised ecosystem service bundles. Dam capacity is calculated by maximum dam storage (million m^3) per annual discharge (m^3). The fifteen deltas with the highest proportion dam capacity were excluded for visualisation purposes, given this was often several orders of magnitude higher. Each point represents the averaged values of the most recently available indicators for one delta. The trend line shows a LOESS regression with span of one. Shaded areas around trend line indicate 0.95 CI. 'r' indicates pseudo r value, the fit of this regression based on sum of squared residuals.

Supplementary Note 10. Synergies and trade-offs at increasing levels of modification

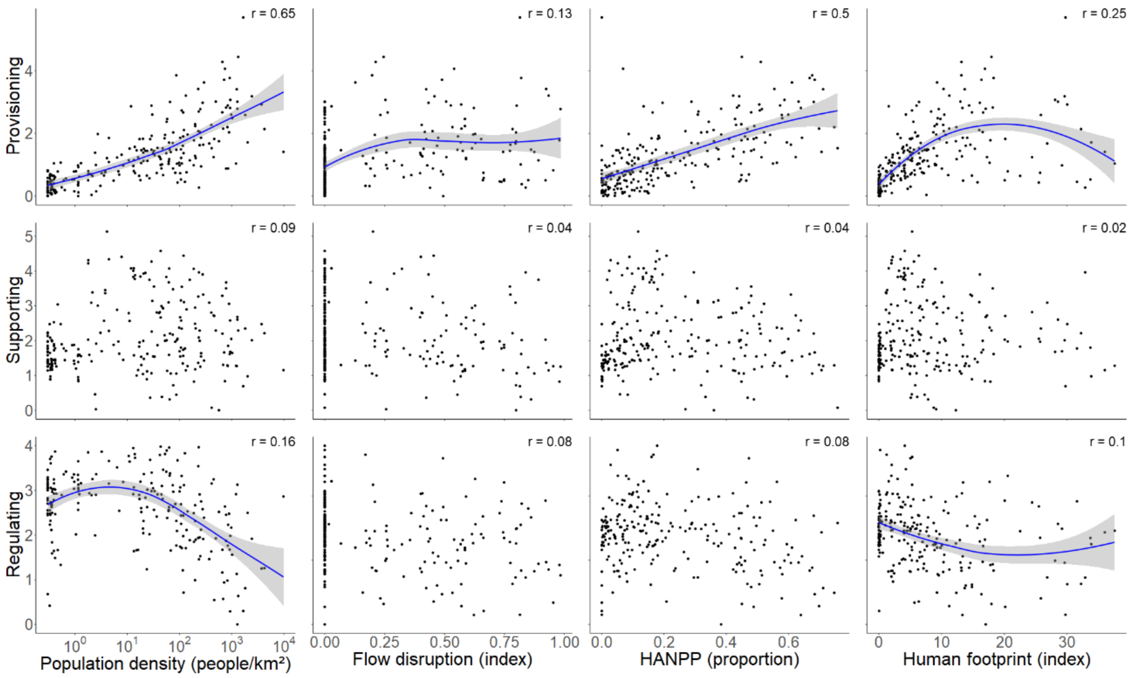
Positive and negative correlations between ecosystem service bundles weakened as modification increased (Supplementary Figure 68).



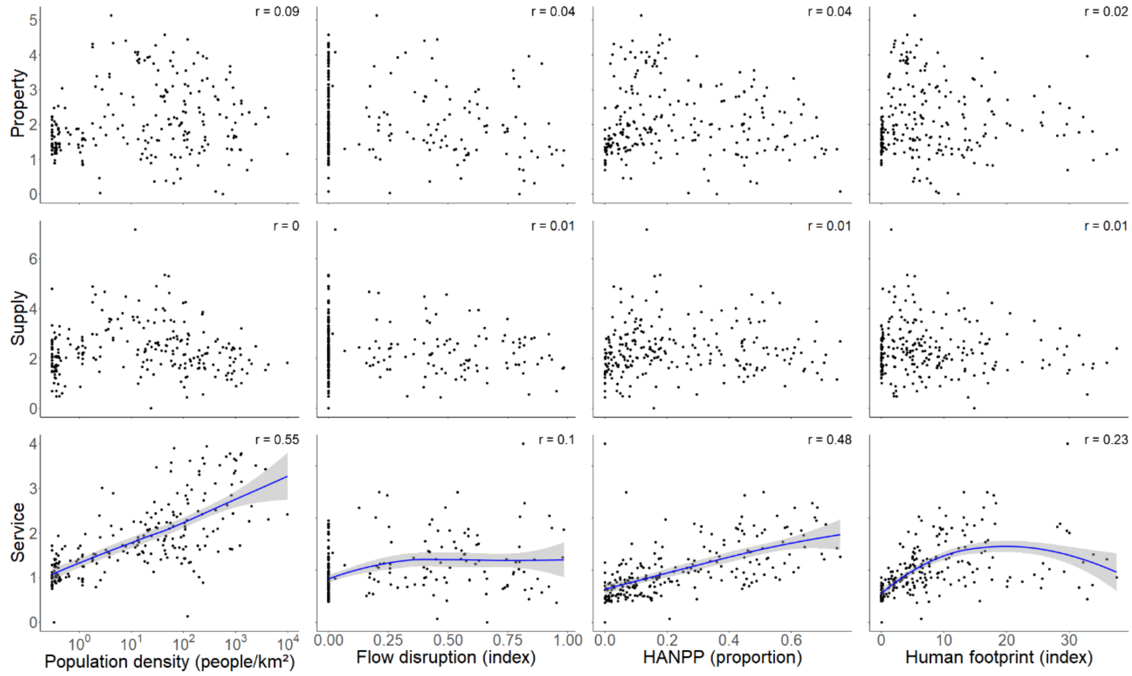
Supplementary Figure 68. Correlations between bundled ecosystem services across delta systems. Pairwise correlation (Spearman's ρ) between each ecosystem service bundle in deltas at different stages of each modification indicator (from 1 to 4, representing least to most modified). We divided deltas into these four stages using breakpoint analysis. Colour darkness and circle diameter are proportional to the correlation coefficient. Blue indicates synergies, red indicates trade-offs.

Supplementary Note 11. Effect of different categorisations

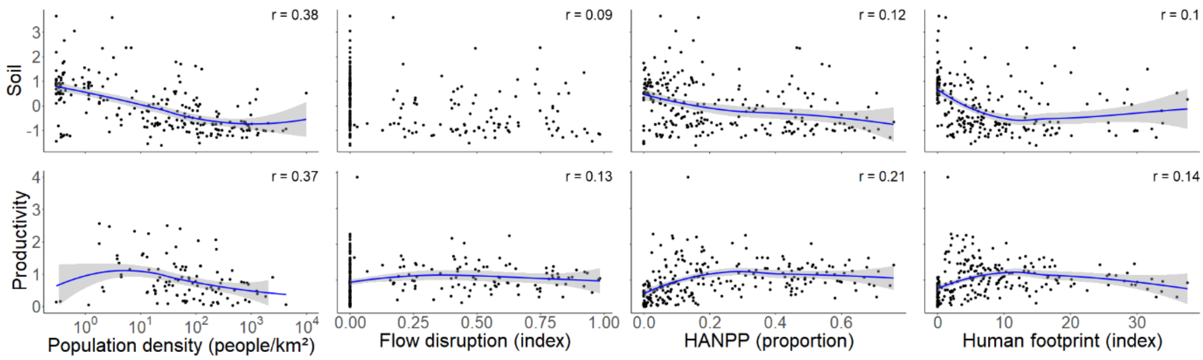
Some ecosystem service (ES) indicators can fit into multiple categories. For example, forests and wetlands provide regulating and material services alongside properties and habitats which enable other ES to function. We examined how overall group and bundle responses would alter if forests and wetlands were shifted from their original supporting/property categorisations, to regulating/supply categorisations. Overall impact on the groups was low, with slight changes to the fit of the response curves (Supplementary Figures 69 and 70). Bundle composition shifted slightly. In the Millennium Ecosystem Assessment (MEA) framework forest cover and wetlands clustered with the 'carbon and water' bundle. In the ES cascade framework forest cover and wetlands clustered with the 'productivity and water' bundle, sediment also moving into this bundle. Again, the shape of the response curves for these new bundles was similar to those in Supplementary Note 7, although the fit was stronger in some bundles, such as 'soil and water' and weaker in others such as 'carbon and water' (Supplementary Figures 71 and 72).



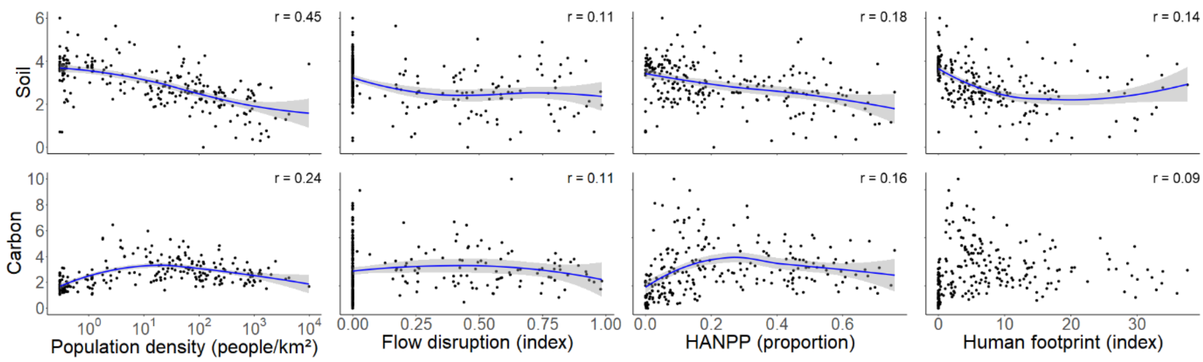
Supplementary Figure 69. Responses of combined provisioning (top), supporting (middle) and regulating (bottom) services to different indicators of modification. ES within each category were standardised, summed and standardised again. r indicates pseudo-r fit of smoothed regression line (LOESS, span = 1) to data. Shaded areas around trend line indicate 0.95 CI. Curves with a pseudo-r < 0.1 are not shown.



Supplementary Figure 70. Responses of combined ecosystem property (top), supply (middle) and service (bottom) categories to different indicators of modification. ES within each category were standardised, summed and standardised again. r indicates pseudo-r fit of smoothed regression line (LOESS, span = 1) to data. Shaded areas around trend line indicate 0.95 CI. Curves with a pseudo-r < 0.1 are not shown.



Supplementary Figure 71. Response curves to modification of ES indicators bundled within the ecosystem service cascade supply category. r indicates pseudo-r fit of smoothed regression line (LOESS, span = 1) to data. Shaded areas around trend line indicate 0.95 CI. Curves with a pseudo-r < 0.1 are not shown.



Supplementary Figure 72. Response curves to modification of ES indicators bundled within the MEA regulating category. r indicates pseudo-r fit of smoothed regression line (LOESS, span = 1) to data. Shaded areas around trend line indicate 0.95 CI. Curves with a pseudo-r < 0.1 are not shown.

Supplementary Methods

Supplementary Methods 1. Protocol for delta identification and mapping

All visually identifiable deltas were mapped as points using QGIS 3.6.0[47], based on visual inspection of all global coastlines (including major lakes) using Google Earth Pro and Sentinel 2 imagery in Google Earth Engine[24], using an RGB composite of the NIR (band 8, central wavelength at 842 nm), SWIR (band 11, central wavelength at 1610 nm), and red (band 4, central wavelength at 665 nm) to highlight water. For efficiency and consistency, we used a resolution of 1:1,000,000 for initial inspection of the global coastline, zooming in on recognisable distributary networks or coastline protrusions. This excluded deltas too small to observe (although sufficient to recognise many under the minimum size, below), those undetectable at the time of imagery acquisition, with less obvious shape and/or abandoned, and potentially those in urban areas where the distributaries have been canalised. To ensure globally important deltas were included, we cross-checked the selection against pre-existing datasets and literature[48–50]. Deltas below 10 km^2 were excluded to ensure suitable coverage and variability of ecosystem services (ES) and modifications. Where delta area overlapped (where for example two rivers separately joined the same distributary network) the larger was selected. Of 584 deltas identified, 236 met the criteria (Supplementary Figure 73). An unidentified delta in Greenland was omitted from analysis as many datasets did not cover it, leaving 235 deltas in total.

Next, the delta area was outlined. Starting where the main channel first splits into a distributary reaching the coast, polygons were hand drawn, using as boundaries the watershed outside the outer distributaries of the delta, and the coastline or water body where they terminate (Supplementary Figure 73). Watershed data from the 15 arc-second resolution HYDROSHEDS basins[51] was used for latitudes below 60^{o}N, otherwise we used the $\sim$1 km resolution HYDRO1k[52] dataset, as Wu et al.[53]. Given the resolution with which delta modification and ES were measured (often 1 km), and the variation in coastline between images, small deviations should have negligible effect on our results. We then created another polygon for use with coastal and marine indicators with a buffer of 22 km, representative of territorial waters, around this polygon.

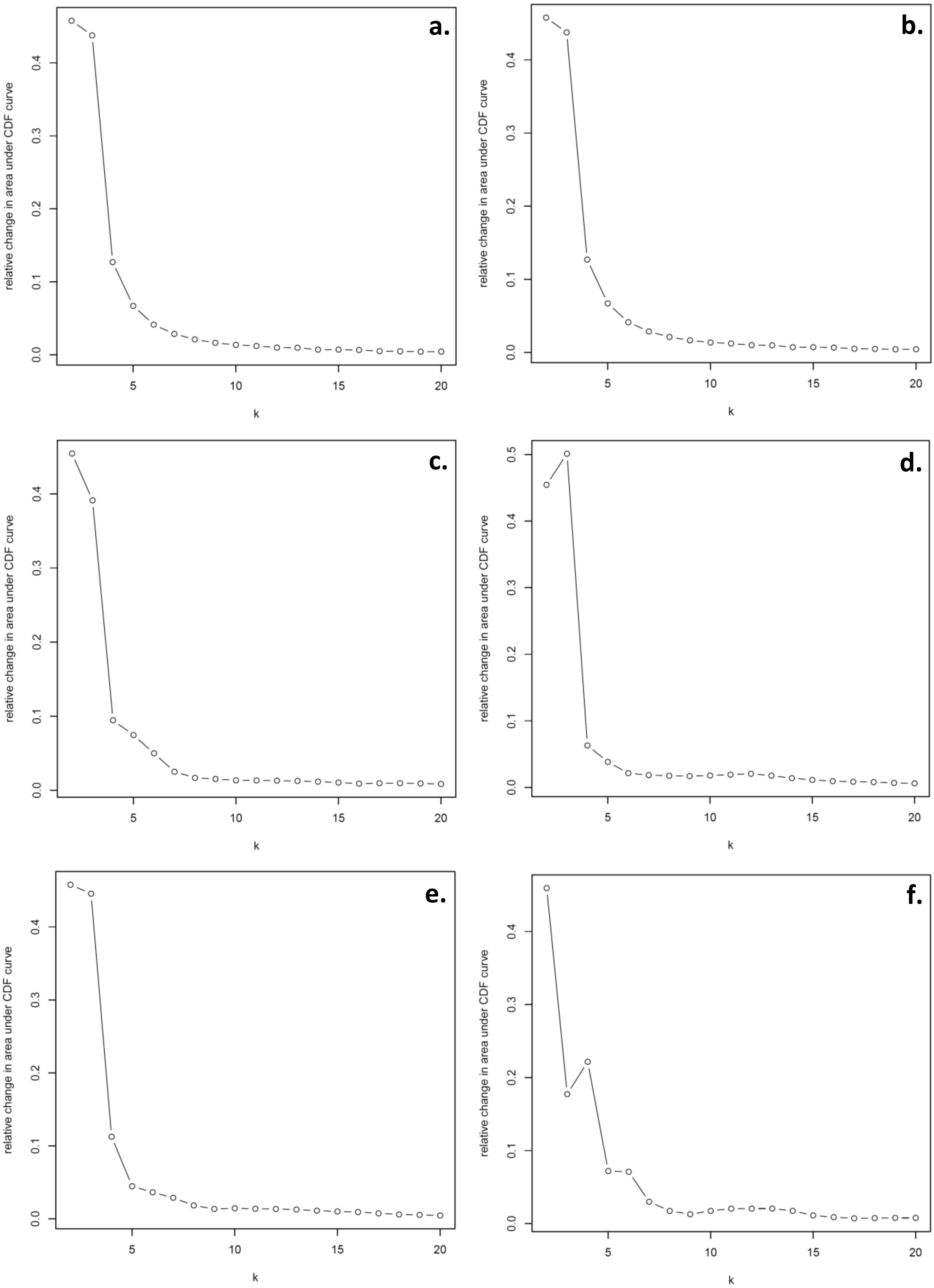
Supplementary Figure 73. Global delta identification and mapping. Extents of identified deltas (left). Delta mapping technique (right). Red dot shows beginning of distributary network, red hatches show delta extent, drawn using the blue lined watersheds either side of the outermost distributaries. Imagery hosted by Esri, source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community.

Supplementary Methods 2. Clustering of ecosystem services

Here we outline the processes and intermediate results involved in clustering the ecosystem services (ES:) selecting the number of clusters (2.1), the clustering methods (2.2), and the robustness of these clusters (2.3).

2.1. Calculating how many clusters to use

Firstly, we assessed *k*, the number of clusters to use which best fit the data. This is a subjective process, with many available methods – to visualise how clusters formed we used consensus clustering[54], which performs clustering multiple times on subsets of the data (0.8) to show cluster and item stability. With the 'ConsensusClusterPlus' R package[55], we repeated the process for all available methods – k-means, k-medoids, and hierarchical clustering, for both Euclidean distance and spearman correlation metrics (1000 repetitions, 20 clusters maximum). To find the number of clusters we used the 'elbow' in the relative change in area under the cumulative distribution function (CDF) curve – this indicated that diminishing returns in cluster consensus begins between 4 and 7 clusters across the methods (Supplementary Figure 74).



Supplementary Figure 74. Relative change in cumulative distribution function (CDF) curve as number of clusters, *k* increases. a. k-means with Euclidean distance, b. k-means with Spearman correlation, c. k-medoids with Euclidean distance, d. k-medoids with Spearman correlation, e. Hierarchical clustering with Euclidean distance, f. Hierarchical clustering with Spearman correlation.

2.2. Cluster ensemble

The selection of clustering method is subjective and can result in radically different clusters. Using an ensemble of methods and distance metrics can both increase classification accuracy and robustness[56], while also indicating the strength of each cluster. We used six unsupervised methods reflecting different ways to cluster the ES data:

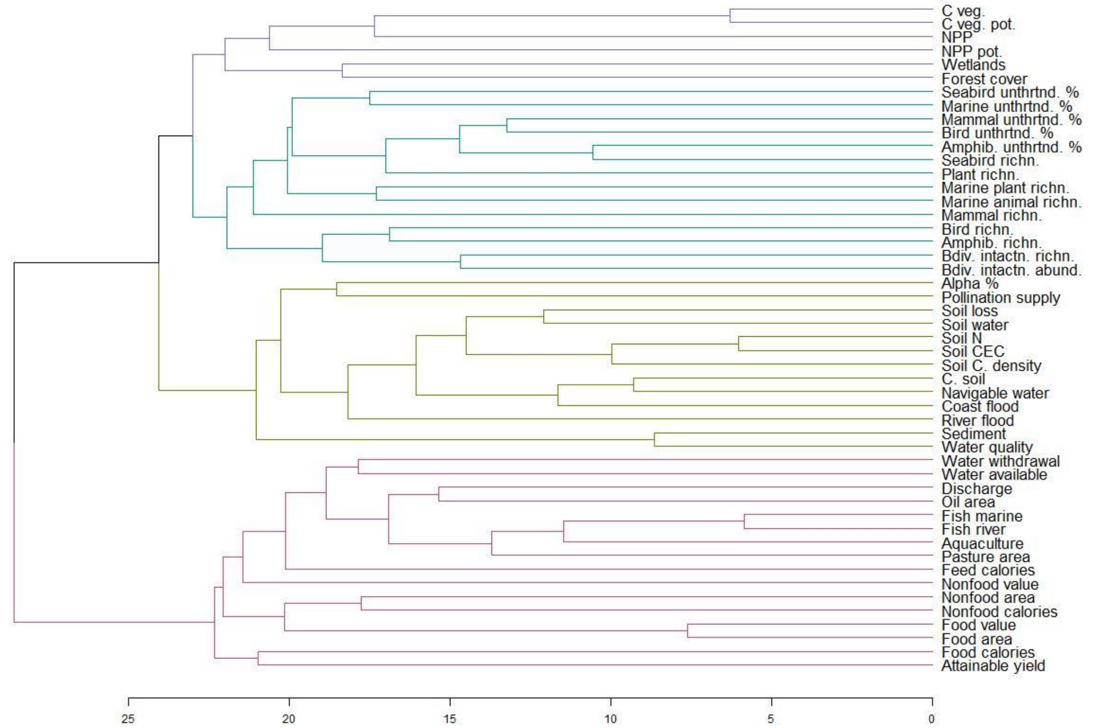
1. k-means, a widely-used clustering technique that uses iterative refinement to minimise within-cluster variance. Means are randomly assigned to the dataset (5,000 starts), and each observation assigned to the closest mean; the means or centroids are then recalculated for each cluster. These two steps are repeated until the clusters stabilise.
2. k-medoids or portioning around medoids, a similar technique choosing data points as clusters centres, which is more robust to noise and outliers. We used the 'cluster' package[57] for both these steps.
3. Random forest with k-means clustering. Random forest creates many decision trees, randomly selecting which features to include in each, and outputting a dissimilarity matrix, showing the proportion of times both observations were in the same terminal node. This can then be clustered as above. We used the 'randomForest' package[58], with 5,000 trees.
4. Random forest with k-medoids clustering.
5. Hierarchical clustering using Euclidean distance. This method treats each observation as a cluster, firstly identifying the two closest clusters, and then merging them, repeating until all clusters are merged. This produces a dendrogram showing the distances between each subcluster.
6. Hierarchical clustering using absolute correlation.

Each method requires a defined number of clusters to resolve to, we repeated these for four to seven clusters to assess how the number of clusters influenced bundle composition. Given the different methods labelled the clusters inconsistently (cluster 1 from one method may share most of the ES from cluster 4 from another), we created an algorithm that runs through each possible labelling for each method until each ES had the maximum number of matching labels, which became the final bundle set. This was consistent with results when the clusters were manually inspected and relabelled.

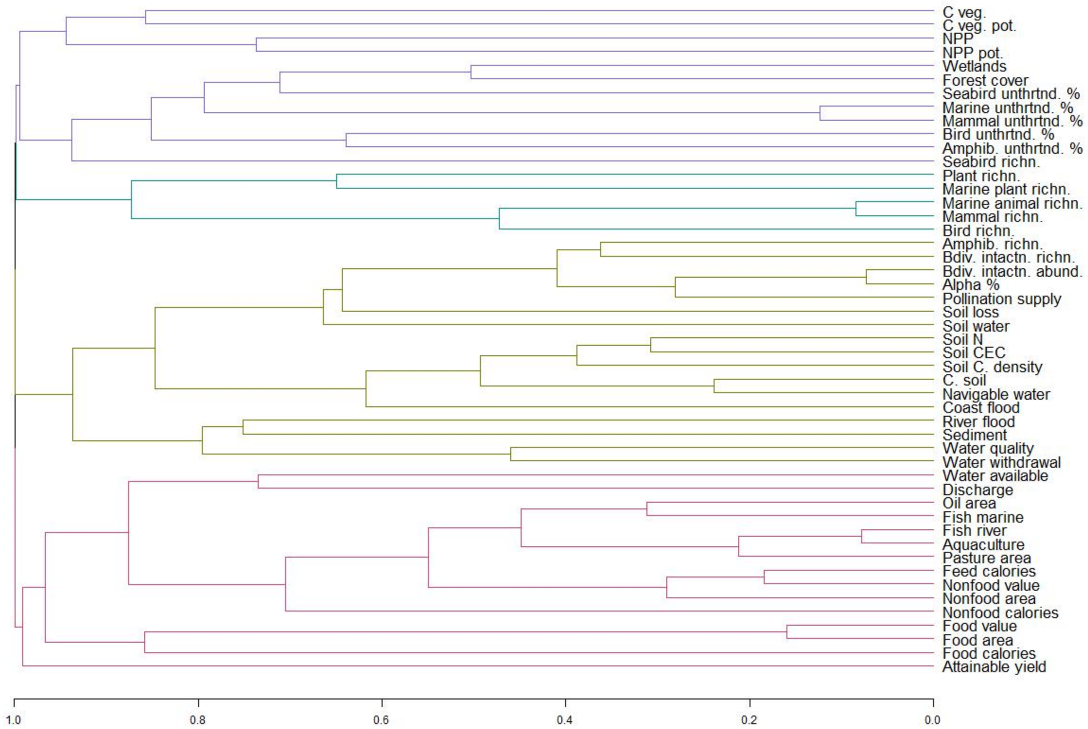
We then validated these methods. Firstly, we tested the methods on five artificial bundles created using a variance-covariance matrix with five blocks of positive covariance. Every method consistently clustered each variable together. Secondly, we repeated our methods with random data, this showed on average that each ES was selected by in the same cluster by each method 57% of the time, for five clusters.

Supplementary Figures 75 to 77 visualise the results of the six cluster analyses (the dendrograms created by hierarchical clustering and the first two dimensions of the other methods).

Hierarchical clustering – Euclidean distance

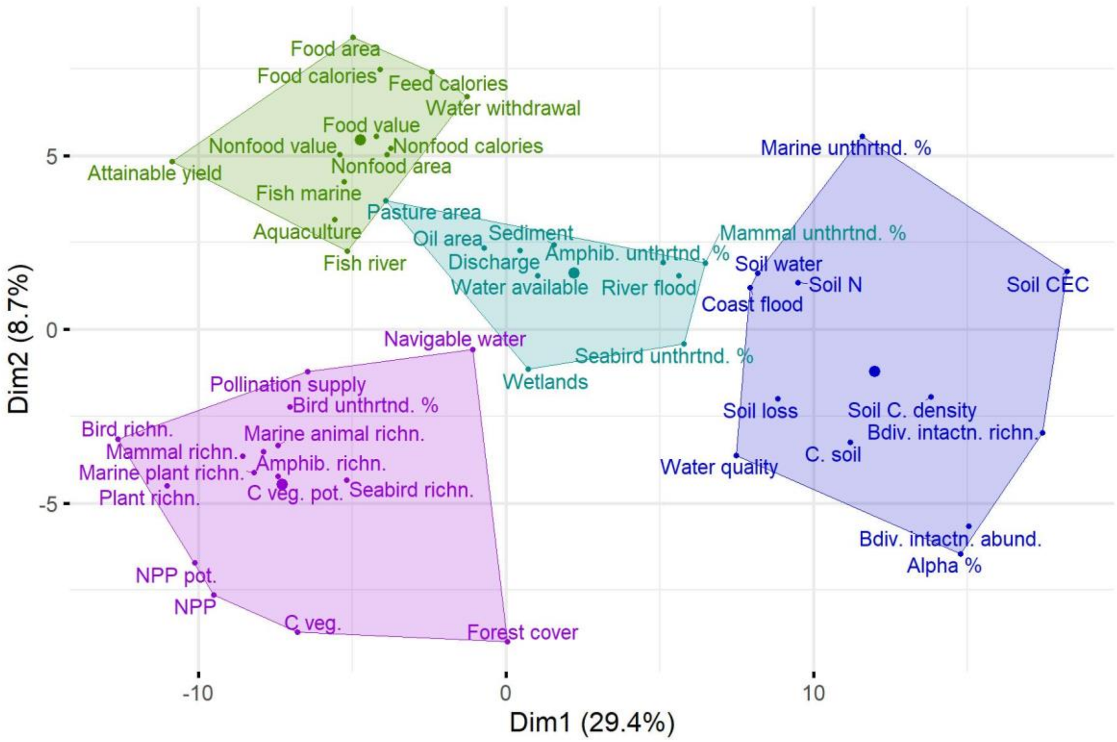


Hierarchical clustering – absolute correlation

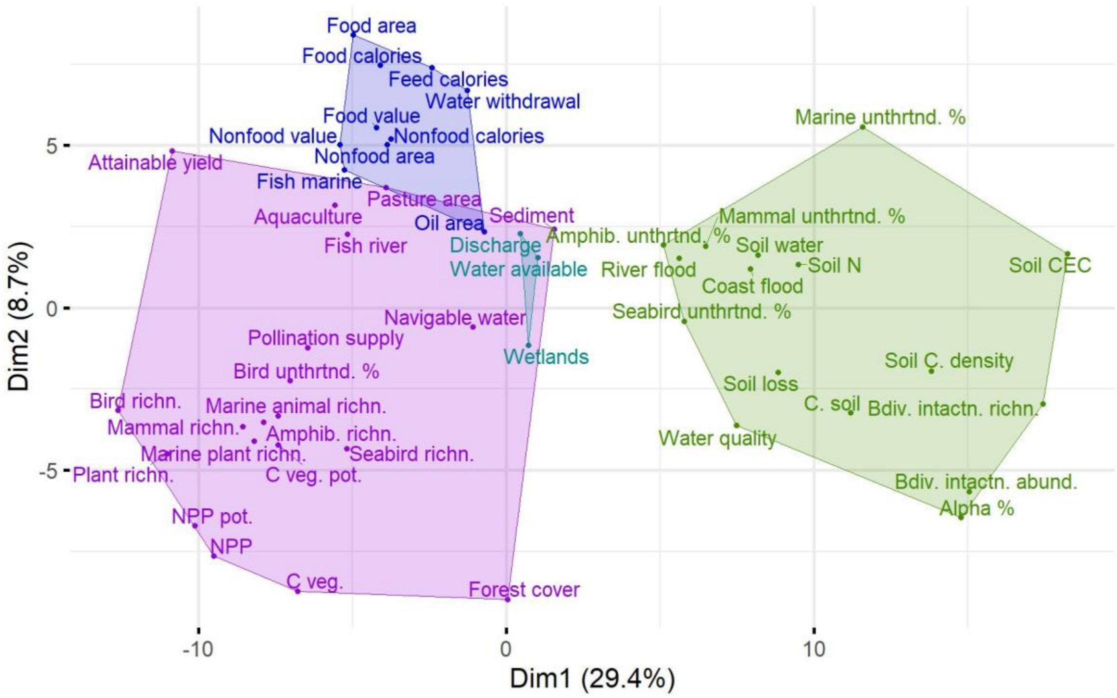


Supplementary Figure 75. Dendrograms created by hierarchical clustering of ecosystem services across all deltas. The unitless scale indicates the distance of each ES and cluster from one another, the lower on the scale, the closer the clusters. At different distances, the dataset resolves into a different number of clusters.

k-means

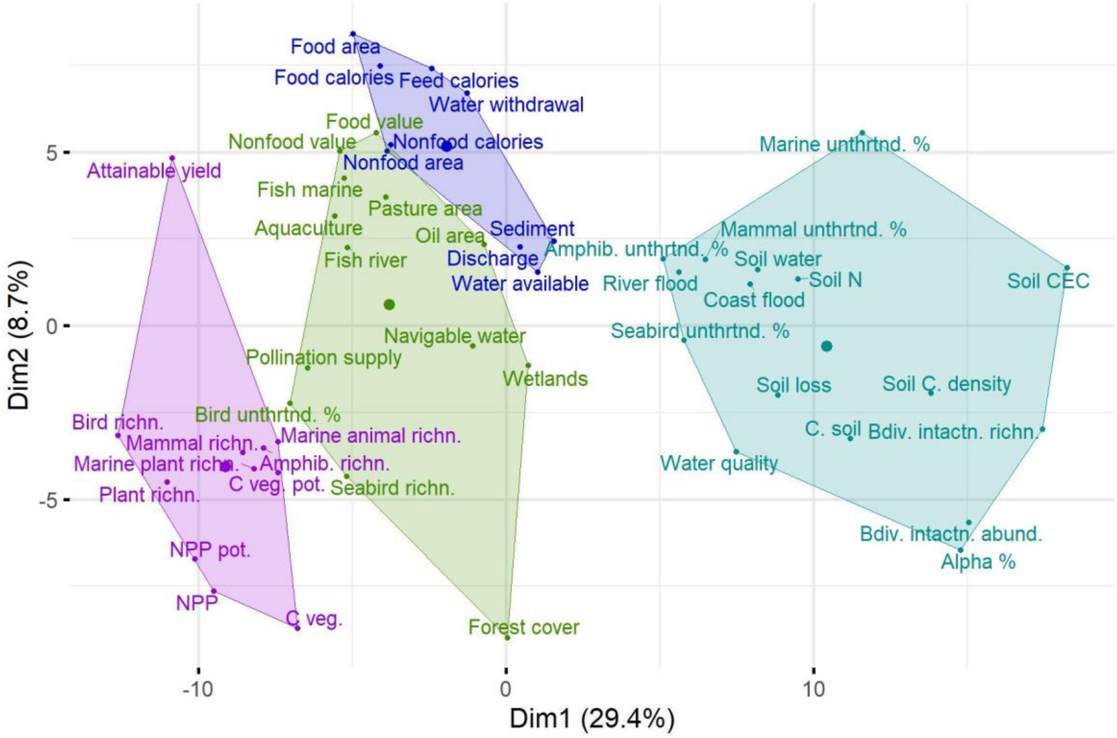


k-medoids

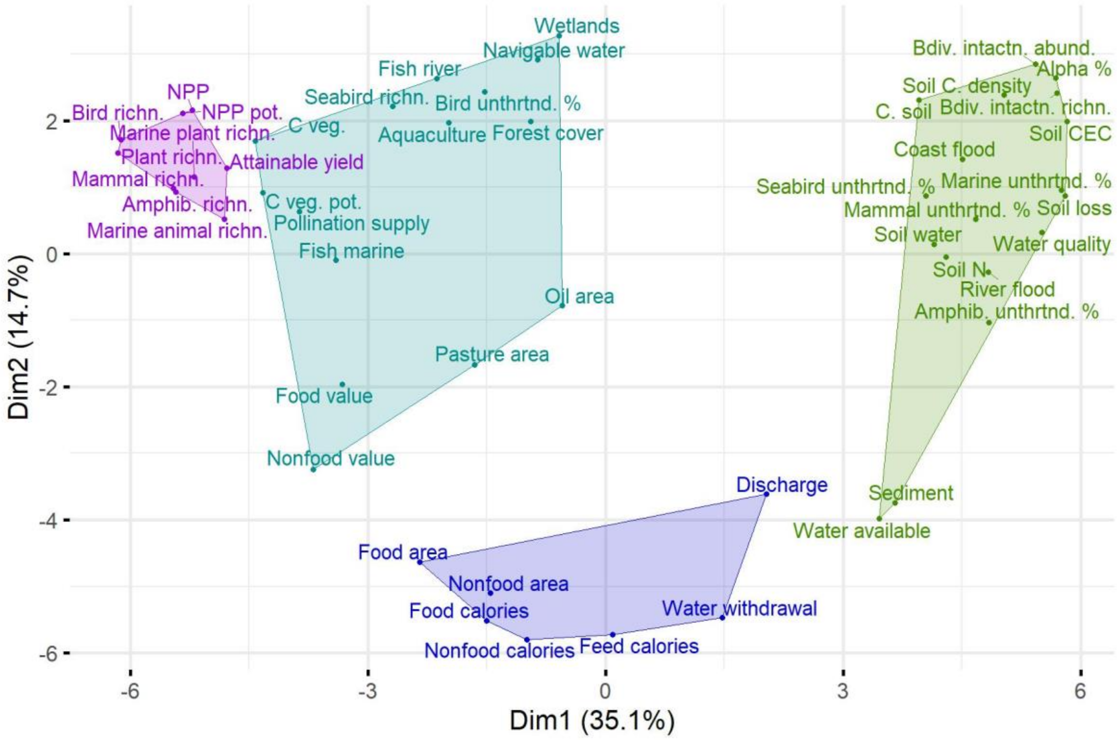


Supplementary Figure 76. Visualisations of k-means (top) and k-medoids (bottom) clustering showing the first two unitless dimensions (Dim1 and Dim2). Each point represents an ecosystem service. The percentages on each scale indicate the extent to which that axis explains the dataset. The axes were created using principal component analysis, reducing the variation in the dataset into several linear dimensions.

Random forest and k-means



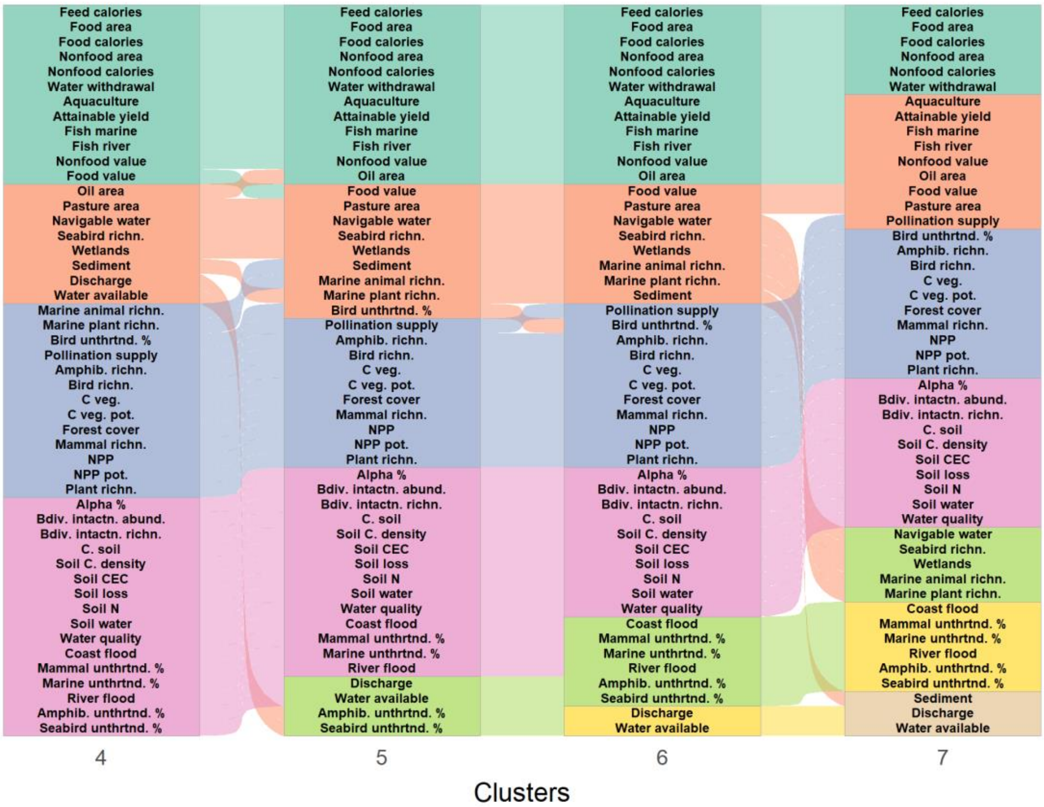
Random forest and k-medoids



Supplementary Figure 77. Visualisations of k-means (top) and k-medoids (bottom) clustering performed after random forest classification showing the first two unitless dimensions (Dim1 and Dim2). Each point represents an ecosystem service. The percentages on each scale indicate the extent to which that axis explains the dataset. The axes were created using principal component analysis, reducing the variation in the dataset into several linear dimensions.

2.3. Change in clusters as *k* increases

We tested how the number of clusters selected influenced the bundles found by rerunning our method for the four to seven clusters indicated by the consensus clustering technique (Supplementary Figure 78). For *k* = 4, the ES split into threat reduction, intactness and soil; productivity and species richness; agriculture and fishing; and water related bundles. At *k* = 5, these bundles broadly persisted, water available and discharge splitting from the other water related ES, which became a weak bundle with some agricultural and marine species richness indicators. At *k* = 6, the threat reduction, intactness and soil bundles splits into soil and intactness, and flood regulation and unthreatened species. At *k* = 7 the agriculture bundle splits from fishing and related indicators, while the marine species richness indicators become a more distinct bundle. The agriculture, productivity and richness, and intactness and soil bundles are consistently more robustly bundled than average.



Supplementary Figure 78. Change in the groups (indicated by different colours) each ES is clustered within as the number of clusters increases.

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