Tyndall°Centre for Climate Change Research

University of East Anglia

University of Southampton

PROJECTED IMPACTS OF SEA-LEVEL RISE: STATE OF RESEARCH AND IMPLICATIONS FOR EBA

Robert J. Nicholls [1,2]

1. Tyndall Centre for Climate Change Research

University of East Anglia, UK

2. School of Engineering

University of Southampton, UK

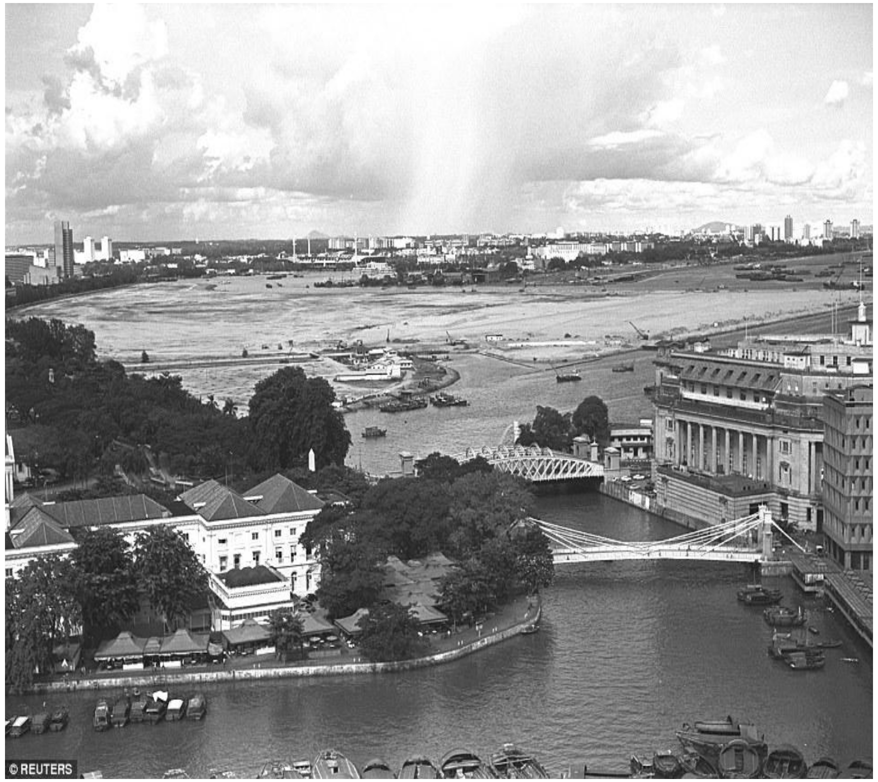
Ecosystem-based Adaptation for Coastal Resilience: In-depth Workshop on Stocktake and Finance Perspectives

Berlin

7 October 2025

Coasts are Changing

Coastal development in Singapore (land reclamation)



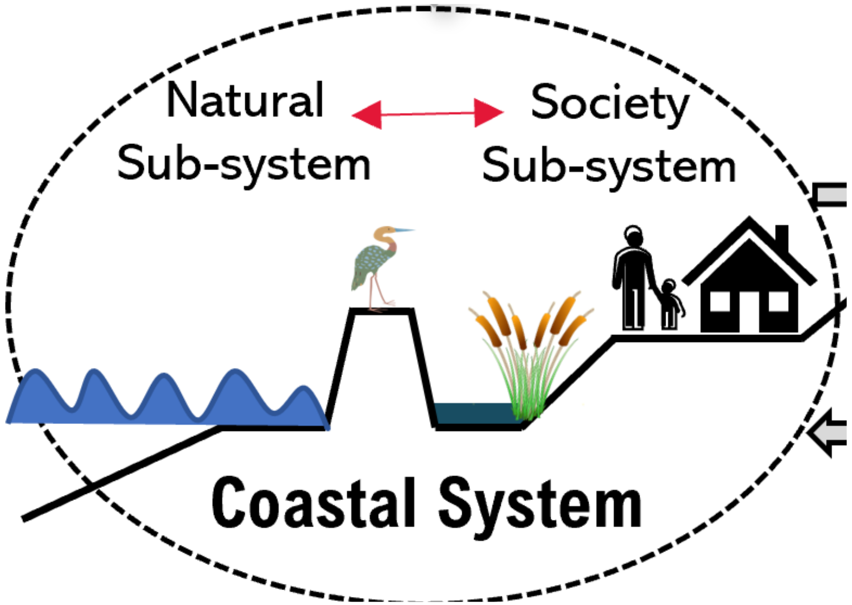
1976

2015

Sea-level rise and climate change are not happening in isolation

The Coastal System

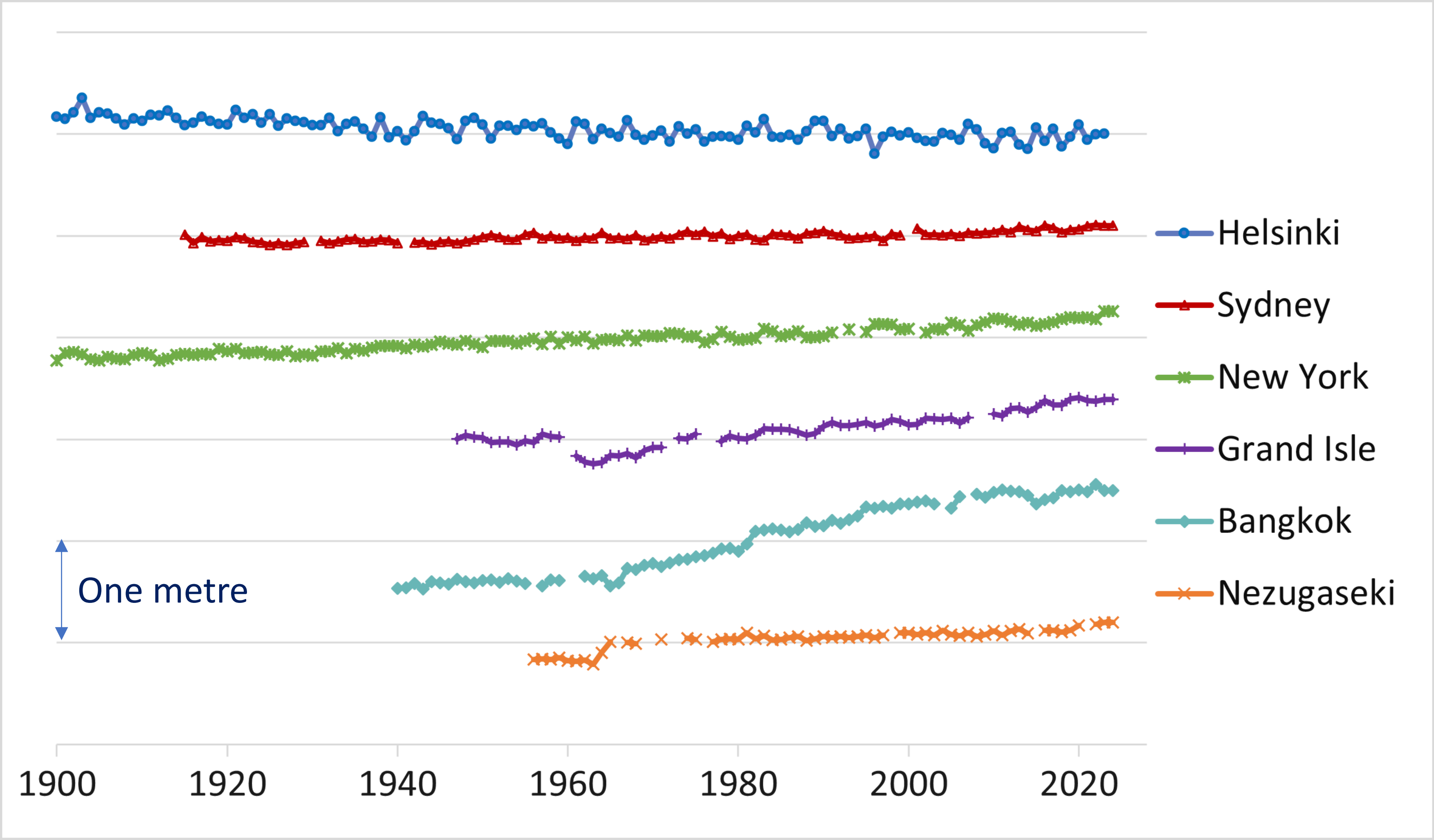
This systemic perspective sets the context for understanding coastal risks and adaptation: risks are often compound with multiple drivers



Source: Nicholls and Ballesteros, 2025

Sea-level trends from around the world

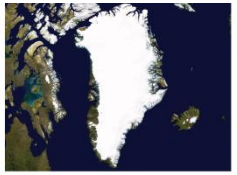
(measured with tide gauges and offset for display purposes)



Source: Nicholls and Ballesteros, 2025

Relative Sea-Level Components

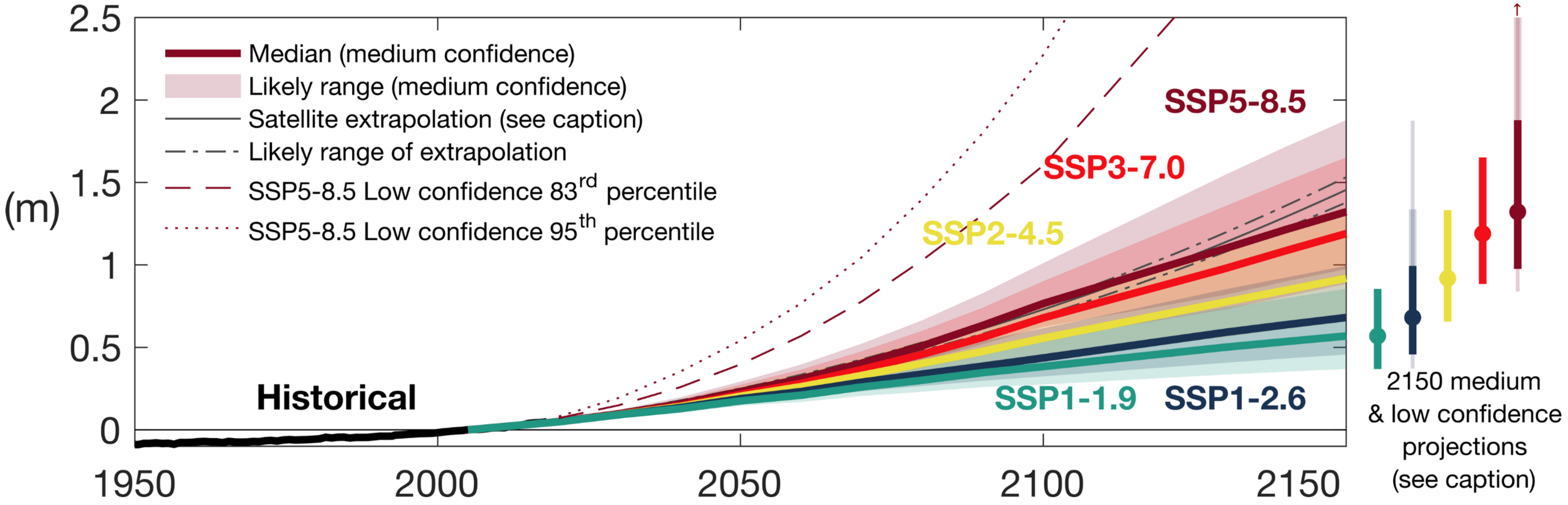
- Global components – changing ocean volume
  - Thermal expansion of sea water
  - Melting of land-based ice
    - Glaciers
    - Greenland ice sheet
    - Antarctic ice sheet



Impacts and adaptation to sea-level rise need to
r relative
l change

Projected Global-Mean Sea-Level Rise to 2150

under the Shared Socio-economic Pathway (SSP) scenarios



Source: IPCC AR6 (Pearson et al., 2021). See also Fox-Kemper et al. (2021)

Tyndall°Centre for Climate Change Research

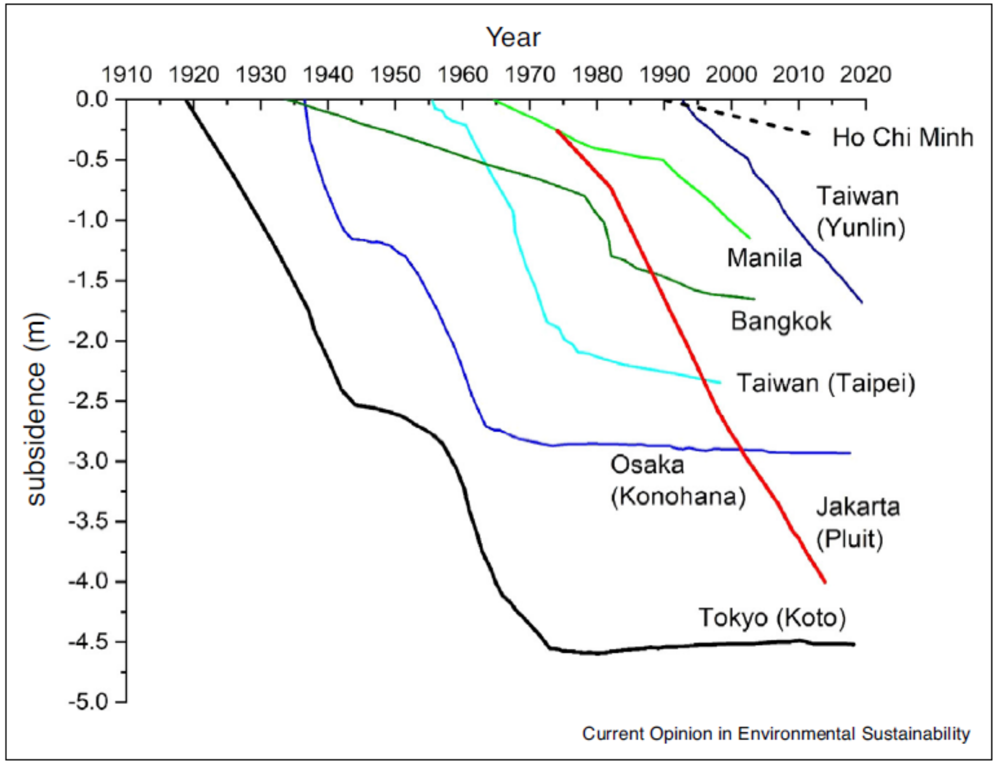
UNIVERSITY OF Southampton

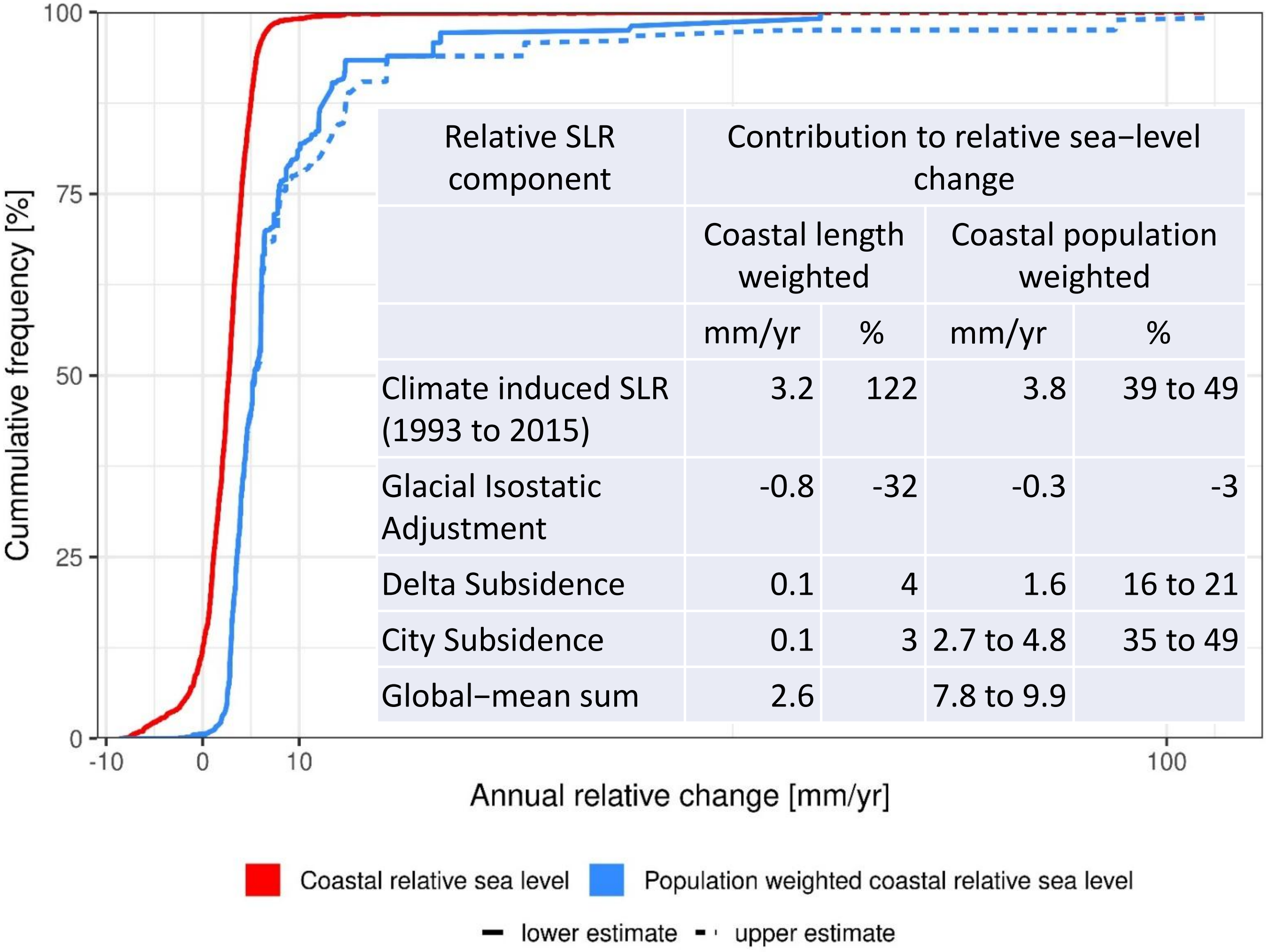
Contemporary global-mean coastal relative sea-level rise

Coastal length versus coastal population weightings (Source: Nicholls et al., 2021)

Subsiding Coastal cities

(Source: Cao et al., 2021)





Relative SLR component	Contribution to relative sea−level change			
	Coastal length weighted		Coastal population weighted	
	mm/yr	%	mm/yr	%
Climate induced SLR (1993 to 2015)	3.2	122	3.8	39 to 49
Glacial Isostatic Adjustment	-0.8	-32	-0.3	-3
Delta Subsidence	0.1	4	1.6	16 to 21
City Subsidence	0.1	3	2.7 to 4.8	35 to 49
Global−mean sum	2.6		7.8 to 9.9	

Physical Impacts of RSLR and potential adaptations

Examples of potential interacting factors which could offset or exacerbate these RSLR impacts due to climate and non-climate factors are shown. Adaptation options are coded: Ad – Advance, Ph and Ps – Hard or Soft Protection, respectively; Ac – Accommodation; R – Retreat.

NATURAL SYSTEM EFFECT		POSSIBLE INTERACTING FACTORS		POSSIBLE ADAPTATION OPTIONS
		CLIMATE	NON-CLIMATE	
1. Inundation/ flooding	a. Surge (sea flooding)	Wave/storm climate, Erosion, Sediment supply.	Sediment supply, Flood management, Erosion.	Land claim [Ad] Dikes/surge barriers/closure dams [Ph], Nourishment, including dune construction [Ps], Ecosystem-based barriers (e.g., mangroves) [Ps], Building codes/flood-proof buildings/raise buildings [Ac], Land use planning/hazard mapping [Ac/R], Planned migration [R].
	b. Backwater effect (river flooding)	Run-off, Rainfall.	Catchment management and land use.	
2. Wetland loss (and change)		CO_2 fertilisation, Ocean pH, Sediment supply, Accommodation space.	Sediment supply, Accommodation space, Land claim.	Gabions/breakwaters [Ph], Nourishment/sediment management [Ps], Wetland planting [Ps], Land use planning [Ac/R], Managed realignment/ forbid hard defences [R].
3. Erosion (of 'soft' morphology)		Sediment supply, Wave/storm climate.	Sediment supply.	Land claim [Ad] Coastal defences/seawalls [Ph], Ecosystem-based barriers (e.g., mangroves) [Ps], Nourishment [Ps], Building setbacks/rolling easements [R].
4. Saltwater Intrusion	a. Surface Waters	Run-off.	Catchment management, Land use.	Saltwater intrusion barriers [P], Desalination [Ac], Relocate water abstraction upstream [R].
	b. Ground-water	Rainfall.	Land use, Aquifer utilisation.	Impermeable groundwater barriers [P] Freshwater injection [P], Desalination [Ac], New salinity-tolerant crop varieties [Ac], Change water abstraction [Ac/R].

Adapted from Nicholls, 2018; Nicholls and Ballesteros, 2025

Socio-Economic Impacts of RSLR

Coastal socioeconomic sectors	Inundation/ flooding	Wetland loss	Erosion	Saltwater intrusion	Impeded drainage
	Sea-level rise natural system effect				
Freshwater Resources	Strong	Weak	Negligible or not established	Strong	Strong
Agriculture and forestry	Strong	Weak	Negligible or not established	Strong	Strong
Fisheries and Aquaculture	Strong	Strong	Weak	Strong	Negligible or not established
Health	Strong	Strong	Negligible or not established	Strong	Weak
Recreation and tourism	Strong	Strong	Strong	Negligible or not established	Negligible or not established
Biodiversity	Strong	Strong	Strong	Strong	Strong
Settlements/ infrastructure	Strong	Strong	Strong	Strong	Strong

Strong Weak Negligible or not established

RSLR – Relative sea-level rise

Source: Nicholls and Ballesteros, 2025

Coastal Areas Vulnerable to RSLR

Settings

- Small islands
- Deltas
- Coastal cities
- Coastal ecosystems

Regions

- South Asia
- East Asia
- South-East Asia

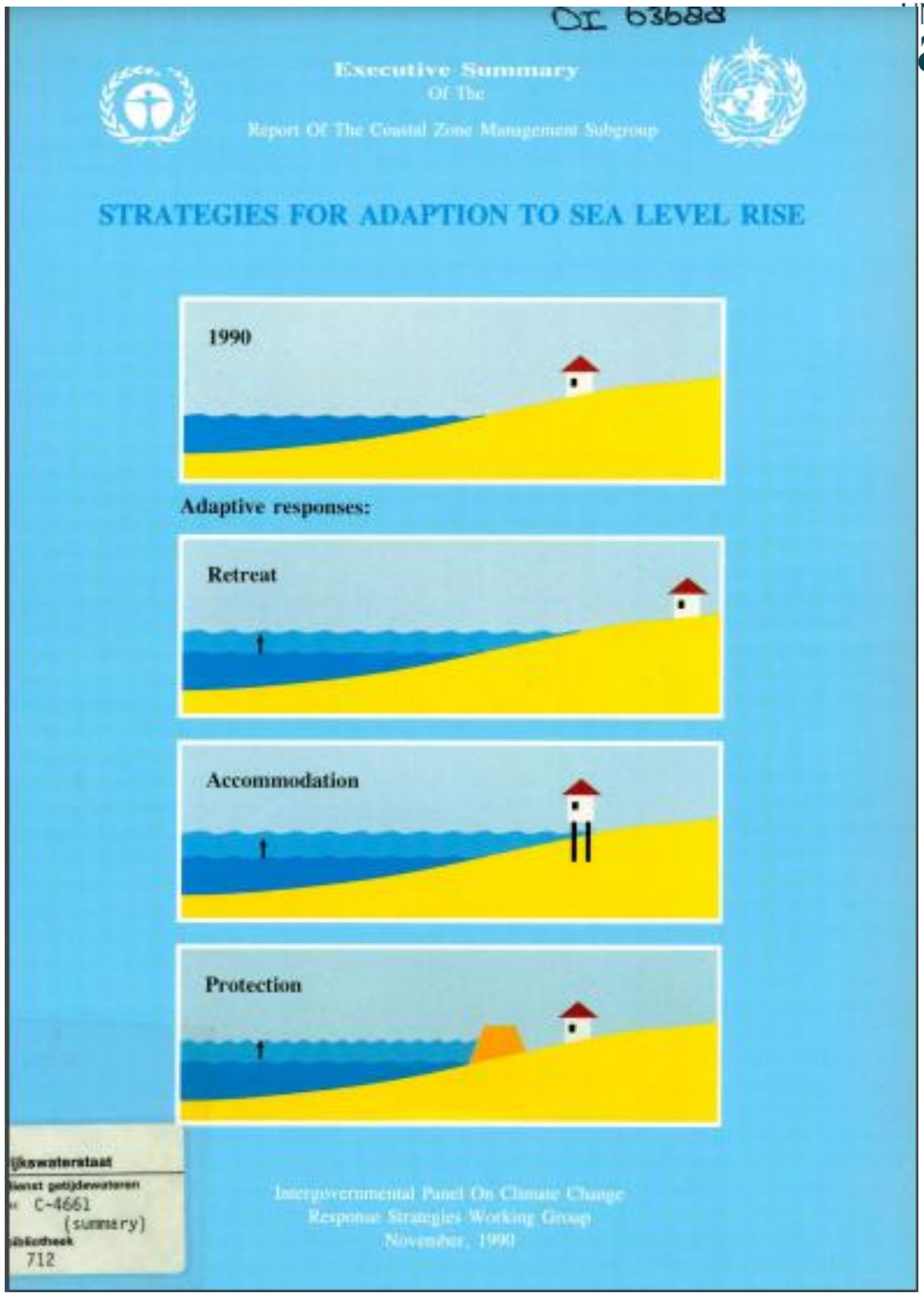
- Caribbean
- Pacific Islands
- Indian Ocean Islands

RSLR – Relative sea-level rise

Adaptation to Sea-Level Rise

Dronkers et al (1990)

- Risks are strongly influenced by adaptation
- Arguably the biggest uncertainty in future risk is adaptation and its success or failure

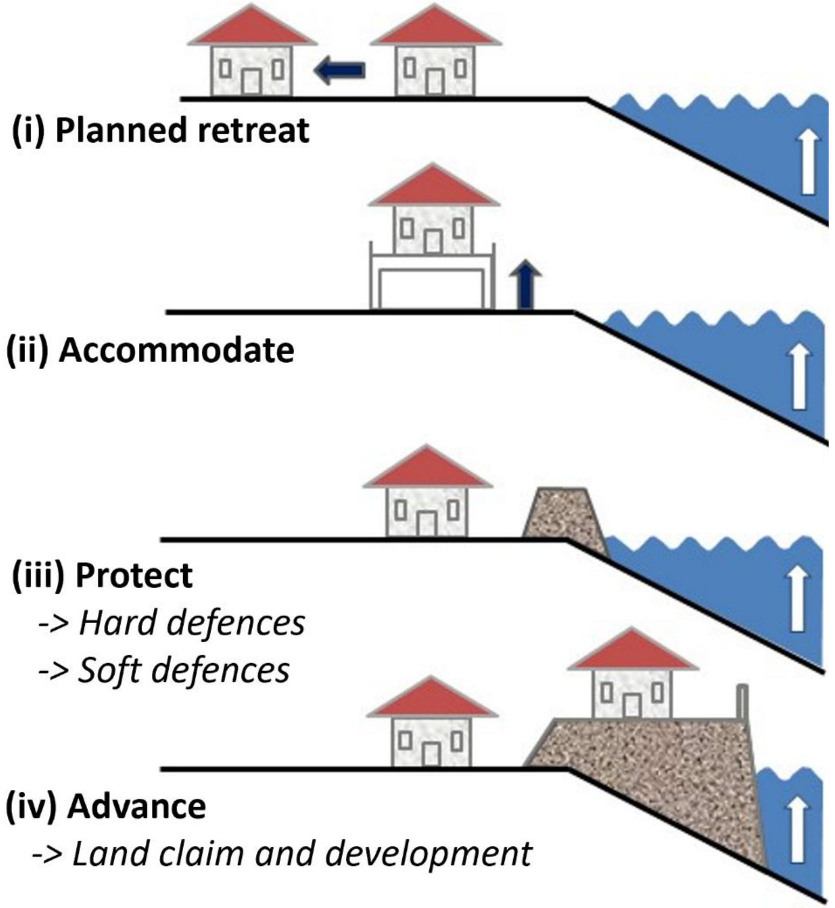


Tyndall°Centre
for Climate Change Research

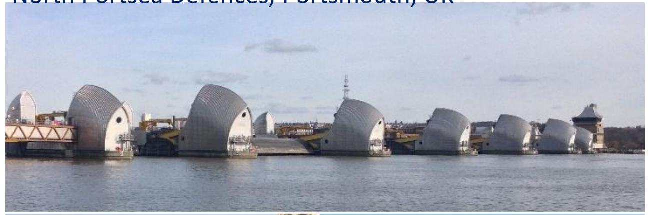
Coastal Adaptation


Planned retreat at Medmerry, UK – see sources


Structural Accommodation in North Carolina, USA




North Portsea Defences, Portsmouth, UK



Thames Estuary and Barrier, London, UK


Hulhumale, the Maldives. Copyright: Völz and Gussmann.

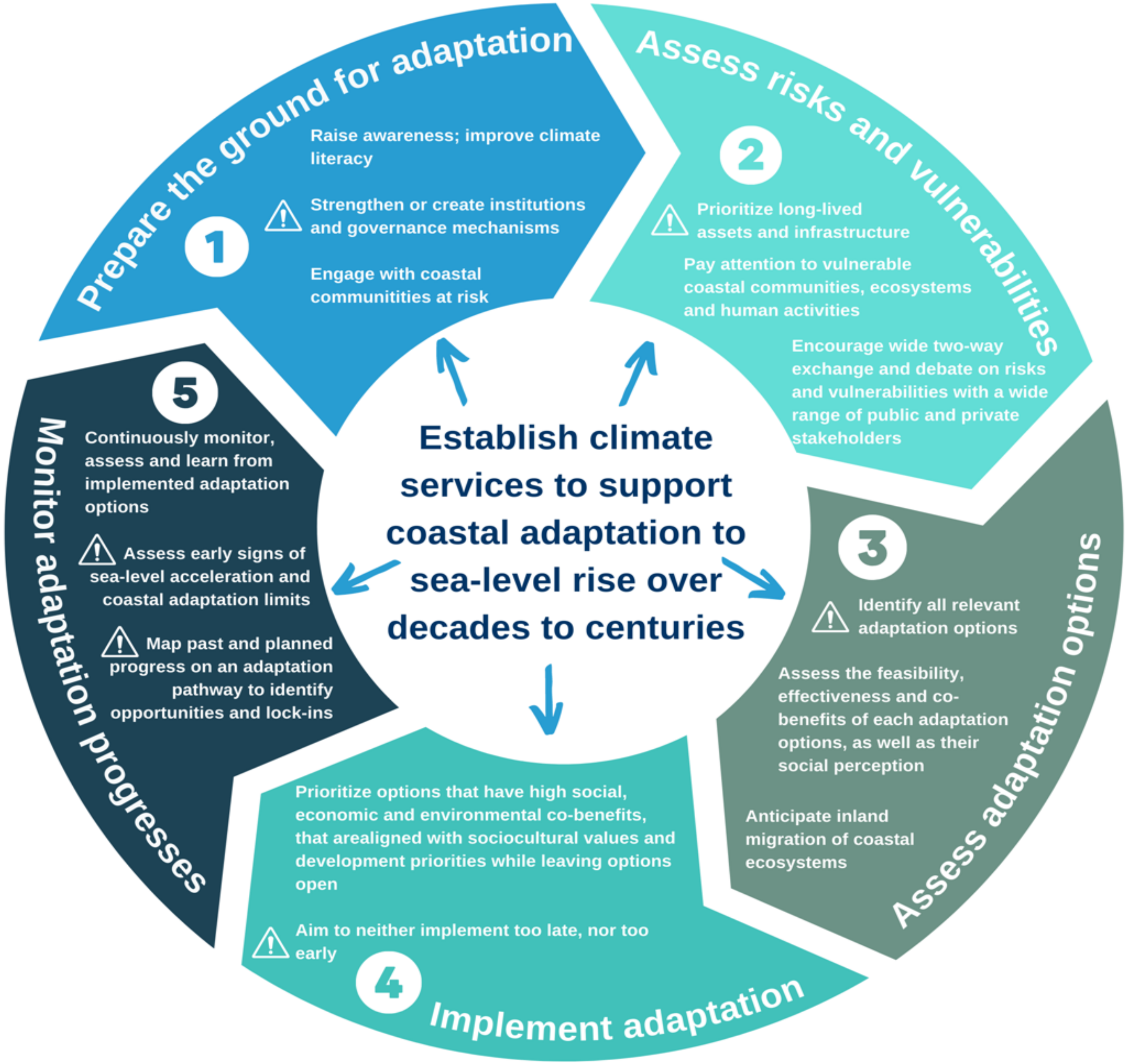
Source: Nicholls and Ballesteros, 2025, unless otherwise indicated

Physical Impacts of RSLR and potential adaptations

Examples of potential interacting factors which could offset or exacerbate these RSLR impacts due to climate and non-climate factors are shown. Adaptation options are coded: Ad – Advance, Ph and Ps – Hard or Soft Protection, respectively; Ac – Accommodation; R – Retreat.

NATURAL SYSTEM EFFECT		POSSIBLE INTERACTING FACTORS		POSSIBLE ADAPTATION OPTIONS
		CLIMATE	NON-CLIMATE	
1. Inundation/ flooding	a. Surge (sea flooding)	Wave/storm climate, Erosion, Sediment supply.	Sediment supply, Flood management, Erosion.	Land claim [Ad] Dikes/surge barriers/closure dams [Ph], Nourishment, including dune construction [Ps], Ecosystem-based barriers (e.g., mangroves) [Ps],
	b. Backwater effect (river flooding)	Run-off, Rainfall.	Catchment management and land use.	Building codes/flood-proof buildings/raise buildings [Ac], Land use planning/hazard mapping [Ac/R], Planned migration [R].
2. Wetland loss (and change)		CO_2 fertilisation, Ocean pH, Sediment supply, Accommodation space.	Sediment supply, Accommodation space, Land claim.	Gabions/breakwaters [Ph], Nourishment/sediment management [Ps], Wetland planting [Ps], Land use planning [Ac/R], Managed realignment/ forbid hard defences [R].
3. Erosion (of 'soft' morphology)		Sediment supply, Wave/storm climate.	Sediment supply.	Land claim [Ad] Coastal defences/seawalls [Ph], Ecosystem-based barriers (e.g., mangroves) [Ps], Nourishment [Ps], Building setbacks/rolling easements [R].
4. Saltwater Intrusion	a. Surface Waters	Run-off.	Catchment management, Land use.	Saltwater intrusion barriers [P], Desalination [Ac], Relocate water abstraction upstream [R].
	b. Ground-water	Rainfall.	Land use, Aquifer utilisation.	Impermeable groundwater barriers [P] Freshwater injection [P], Desalination [Ac], New salinity-tolerant crop varieties [Ac], Change water abstraction [Ac/R].

Adapted from Nicholls, 2018; Nicholls and Ballesteros, 2025



UNIVERSITY OF Southampton

Adaptation is a process

Enabling conditions

- *Long-term perspective*
- *Cross-scale coordination*
- *Address vulnerability and equity*
- *Inclusive public participation*
- *Capability to address complexity*
- *Recognition of multiple steps (adaptation/restoration pathways and learning)*

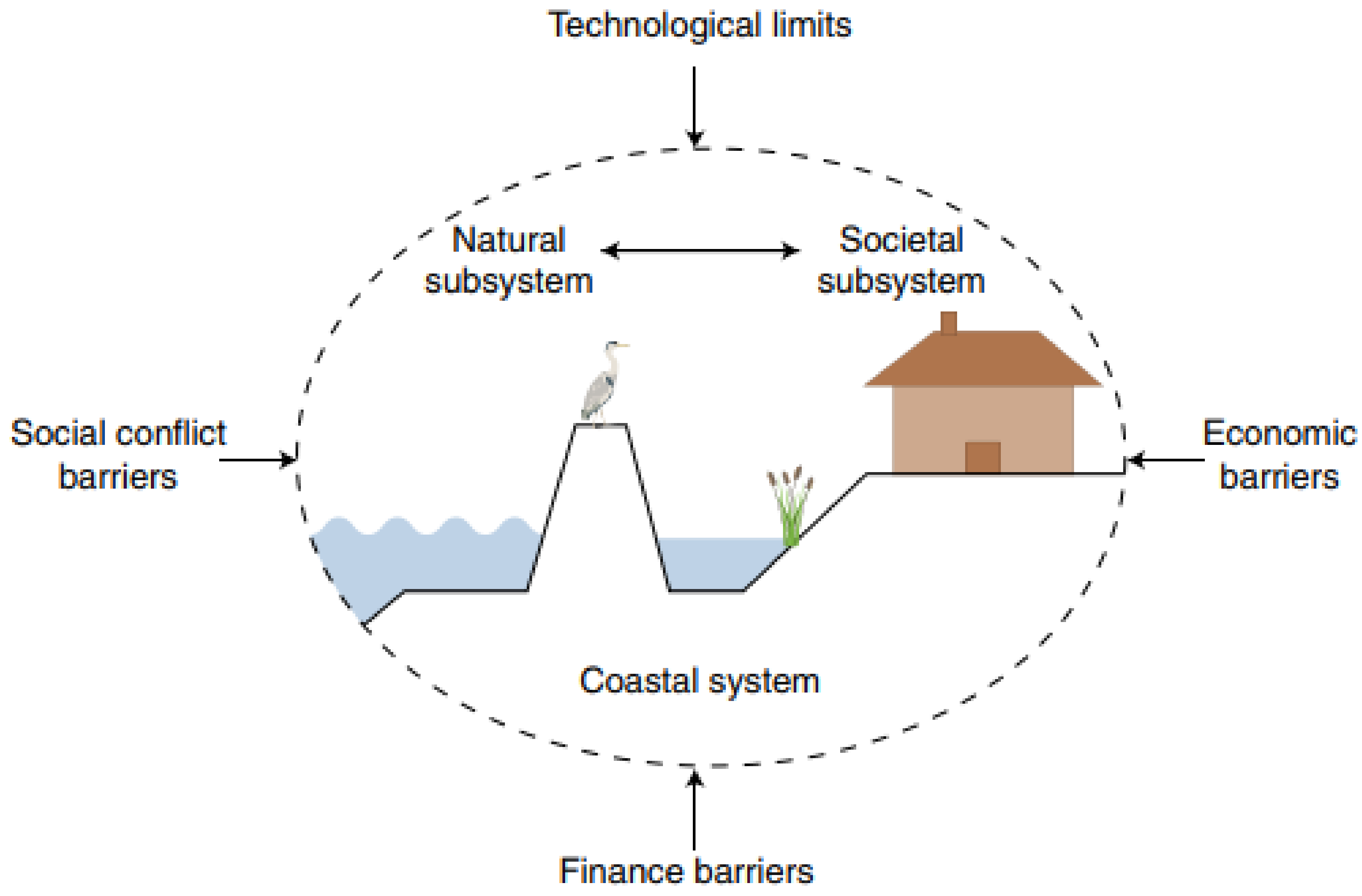
Think strategically: what is your vision for the future and what steps do you need to take to get there?

Source: Le Cozannet et al (2023) ERL
See also Policy Brief @ https://t.ly/dptsp

Protect CRYOSPHERE & SEA LEVEL

CoCliCo coastal climate core services

Adaptation Constraints



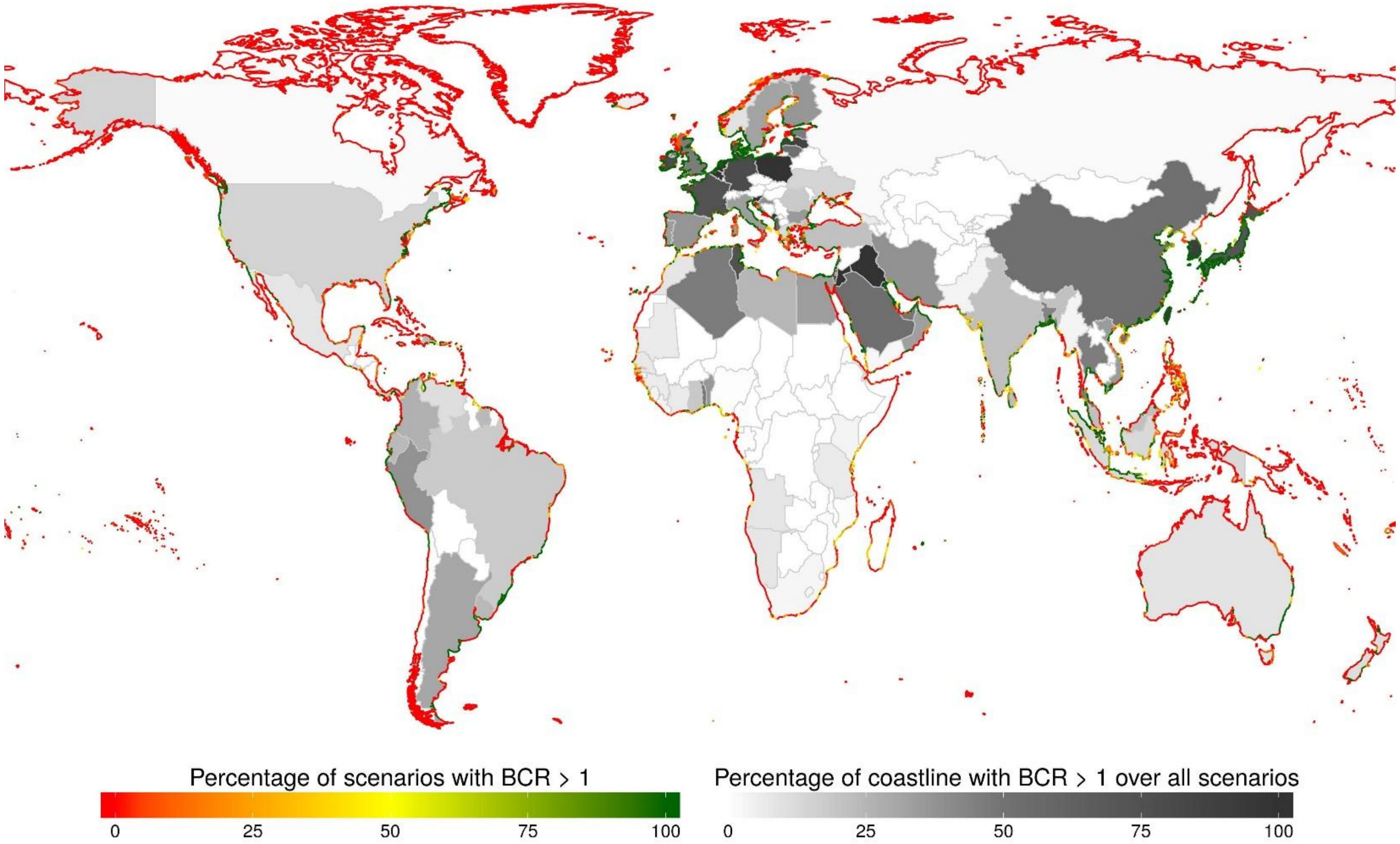
Relevance to EbA

- Technological limits – limited understanding of EbA compared to conventional engineering – use adaptive and learning approaches
- Economic barriers – is it worth it; can we evaluate the value of EbA?
- Finance barriers – can we fund EbA?
- Social conflict barriers – widespread support for nature – BUT – people dislike change

Source: Hinkel et al. (2018)

Economic robustness of coastal protection vs. retreat

SLR scenarios from 0.3 m to 2.0 m, the five SSPs and 10 discount rates of up to 6%.



- 92,500 km is always protected (13%): 90% of global coastal floodplain population
- 451,000 km is never protected (65%): 0.2% of coastal floodplain population
- 22% world's coast and 9.8% of coastal flood plain population – result is scenario dependent
- large potential for coastal restoration and EbA, in unprotected areas
- how can coastal restoration and EbA support protection?

Source: Lincke and Hinkel (2018)

Concluding Thoughts

- Coastal restoration and ecosystem-based adaptation (EbA) needs to address sea-level rise, climate change and all the other relevant changes in the coastal system – we need evidence-based assessment to assess the relevant drivers and select appropriate adaptation approaches
- Coastal restoration and EbA (and all adaptation) will be happening under great uncertainty and adaptive approaches are effective to address this – learn from adaptive pathways
- In general, our limited understanding of EbA is a barrier to application – again adaptive approaches and active experiments are a positive way to address this
- The largest scope for coastal restoration and EbA approaches exists where population is low
- More densely populated, developed coasts present more challenges (and potential benefits), requiring innovation (e.g., soft engineering approaches) – compromises will be necessary, hybrid approaches should be considered and costs will be higher

Sources

- Cao, A., Esteban, M., Valenzuela, V.P.B., Onuki, M., Takagi, H., Thao, N.D. and Tsuchiya, N., 2021. Future of Asian Deltaic Megacities under sea level rise and land subsidence: current adaptation pathways for Tokyo, Jakarta, Manila, and Ho Chi Minh City. Current opinion in environmental sustainability, 50, pp.87-97.
- Dronkers, J.J., Misdorp, R. and Spradley, J.R., 1990. Strategies for adaptation to sea level rise. Geneva, Switzerland: Ministry of Transport and Public Works, Rijkswaterstaat, Tidal Waters Division. (Intergovernmental Panel on Climate Change. Coastal Zone Management Subgroup)
- Fox-Kemper, B., H.T. Hewitt, C. Xiao, et al', 2021: Ocean, Cryosphere and Sea Level Change. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1211–1362, doi:10.1017/9781009157896.011.
- Hinkel, J., Aerts, J. C. J. H., Brown, S., Jiménez, J. A., Lincke, D., Nicholls, R. J., Scussolini, P., Sanchez-Arcilla, A., Vafeidis, A., & Addo, K. A., 2018. The ability of societies to adapt to twenty-first-century sea-level rise. In Nature Climate Change Vol. 8, Issue 7, pp. 570–578. doi:10.1038/s41558-018-0176-z
- Le Cozannet, G., Nicholls, R. J., Durand, G., Slangen, A., Lincke, D., and Chapuis, A. , 2023. Adaptation to multi-meter sea-level rise should start now. Environmental Research Letters doi: 10.1088/1748-9326/acef3f
- Lincke, D. and Hinkel, J., 2018. Economically robust protection against 21st century sea-level rise. Global environmental change, 51, pp.67-73.
- Nicholls, R.J., 2018. Adapting to sea-level rise. In Zommers, Z. and Alverson, K. eds., Resilience: the science of adaptation to climate change. Elsevier., pp.13-29.
- Nicholls, R.J., Lincke, D., Hinkel, J., Brown, S., Vafeidis, A.T., Meyssignac, B., Hanson, S.E., Merkens, J.L. and Fang, J., 2021. A global analysis of subsidence, relative sea-level change and coastal flood exposure. Nature Climate Change, 11(4), pp.338-342.
- Nicholls, R. and Ballesteros, C., 2025, Sea level change and its implications. in Reference Module in Earth Systems and Environmental Sciences. 3rd edition, Elsevier. https://doi.org/10.1016/B978-0-323-96026-7.00203-4
- Pearson, B., Fox-Kemper, B., Kopp, R., Berger, S., Doerr, J., Krinner, G., Notz, D., Ruiz, L., Jourdain, N., Froelicher, T., Garner, G., Hemer, M., Hermans, T., Jackson, L., Menary, M., Mix, A., Palmer, M., & Sweet, W. (2021). IPCC WGI AR6 Chapter 9 (v.1.0). Zenodo. https://doi.org/10.5281/zenodo.5217365
- Retreat image on Slide 12 -- https://upload.wikimedia.org/wikipedia/commons/c/c6/New_drainage_channel%2C_Medmerry_Managed_Realignment_%28geograph_5976842%29.jpg

PROJECTED IMPACTS OF SEA-LEVEL RISE: STATE OF RESEARCH AND IMPLICATIONS FOR EBA

Robert J. Nicholls [1,2]

1. Tyndall Centre for Climate Change Research
University of East Anglia, UK
2. School of Engineering
University of Southampton, UK

Ecosystem-based Adaptation for Coastal Resilience: In-depth Workshop on Stocktake and Finance Perspectives

Berlin

7 October 2025