URBAN SOLUTIONS AND SUSTAINABILITY R&D CONGRESS 2023

BUILDING SUSTAINABLE, RESILIENT, AND LIVEABLE CITIES OF TOMORROW

4TH - 5TH OCTOBER 2023

Nature's Blueprint: Bolstering Coastal and Marine Ecosystem Resilience through Nature-Based Solutions

Karenne Tun
National Parks Board, Singapore

5 October 2023

The Marine Environment in Perspective

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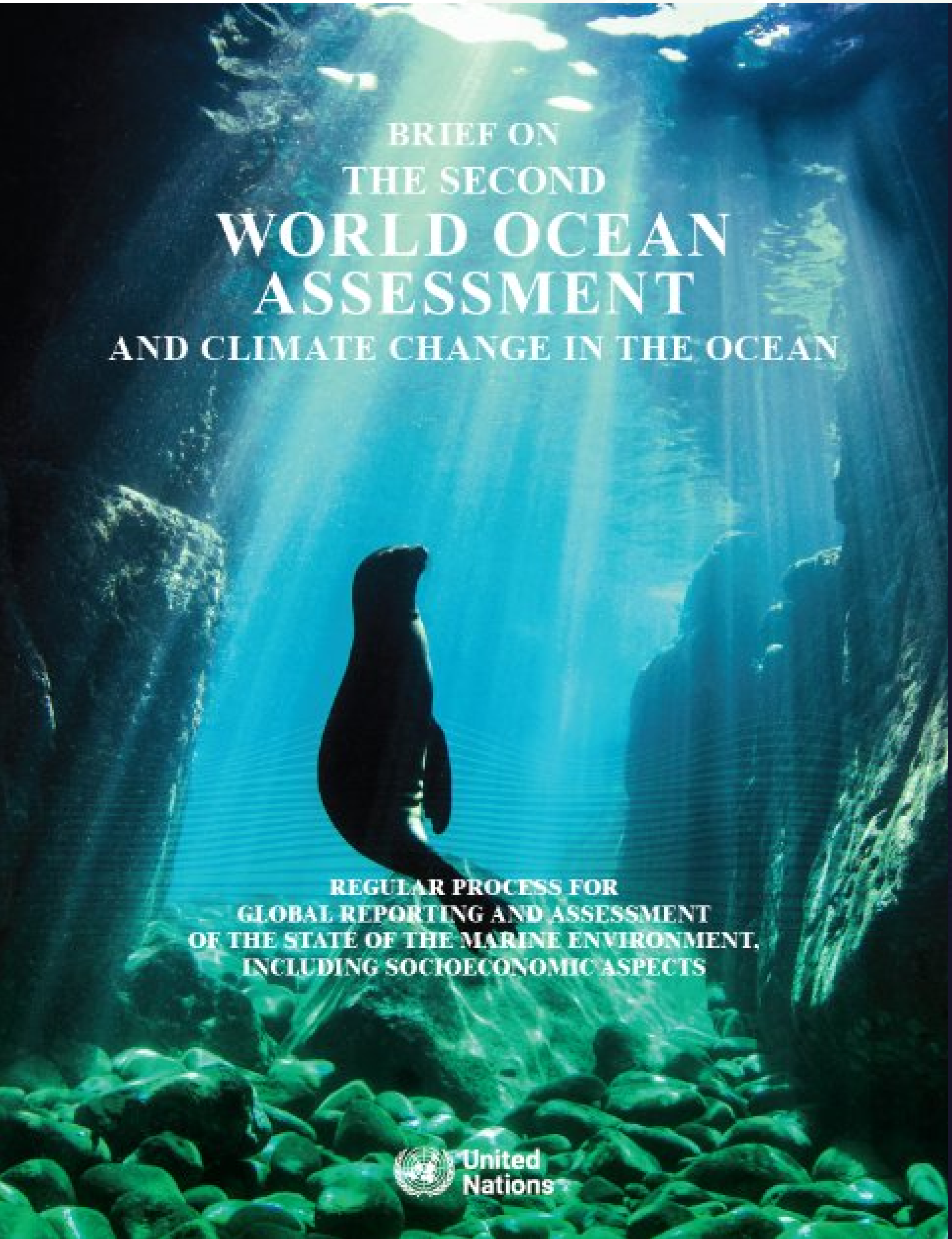
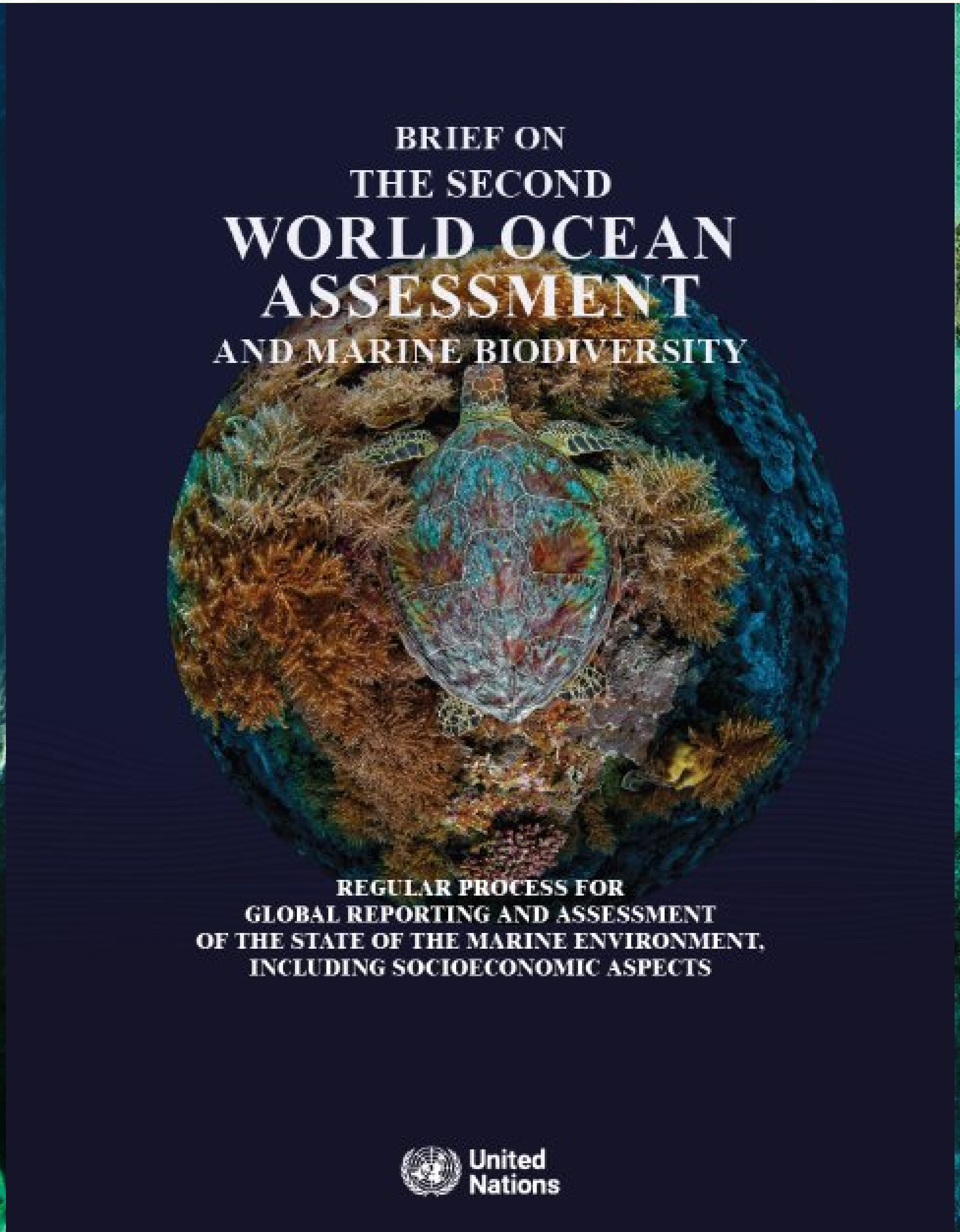
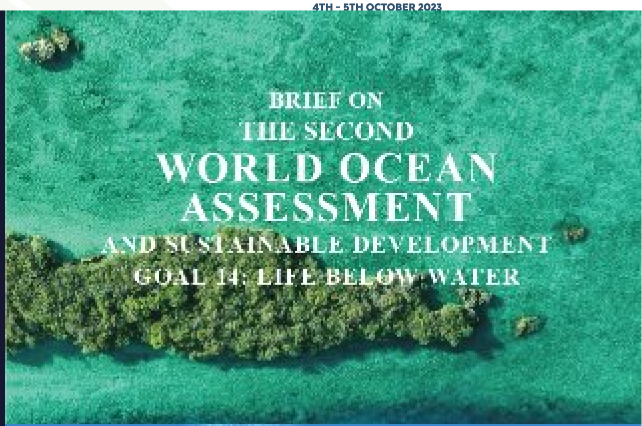
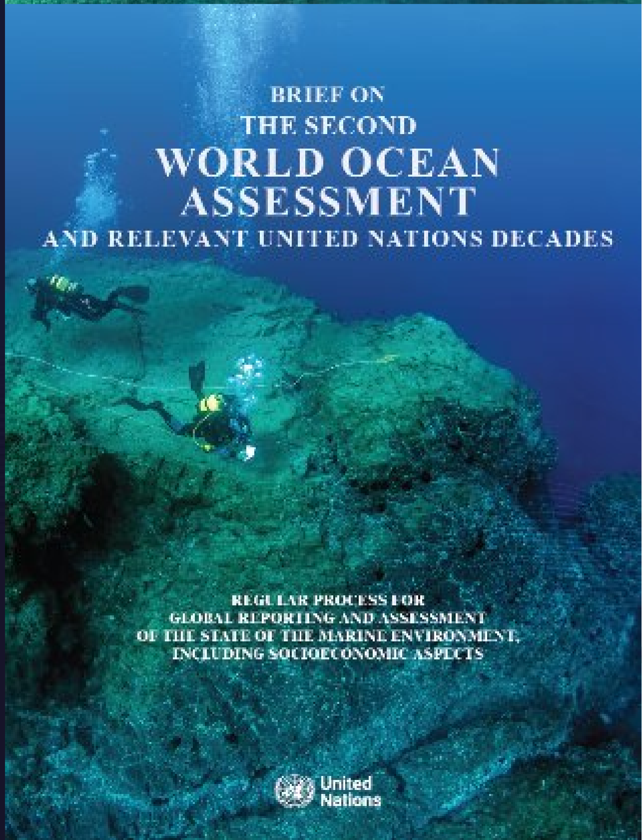


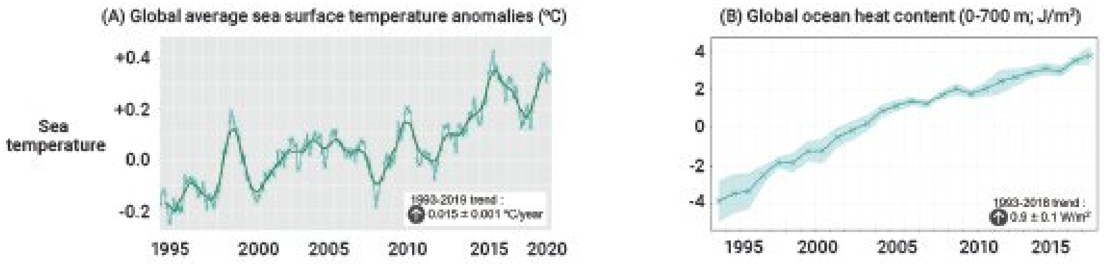






Climate Change Resulting in Warming Seas

GLOBAL OCEAN TRENDS DURING RECENT DECADES, ELABORATED BY THE COPERNICUS MARINE ENVIRONMENT MONITORING SERVICE

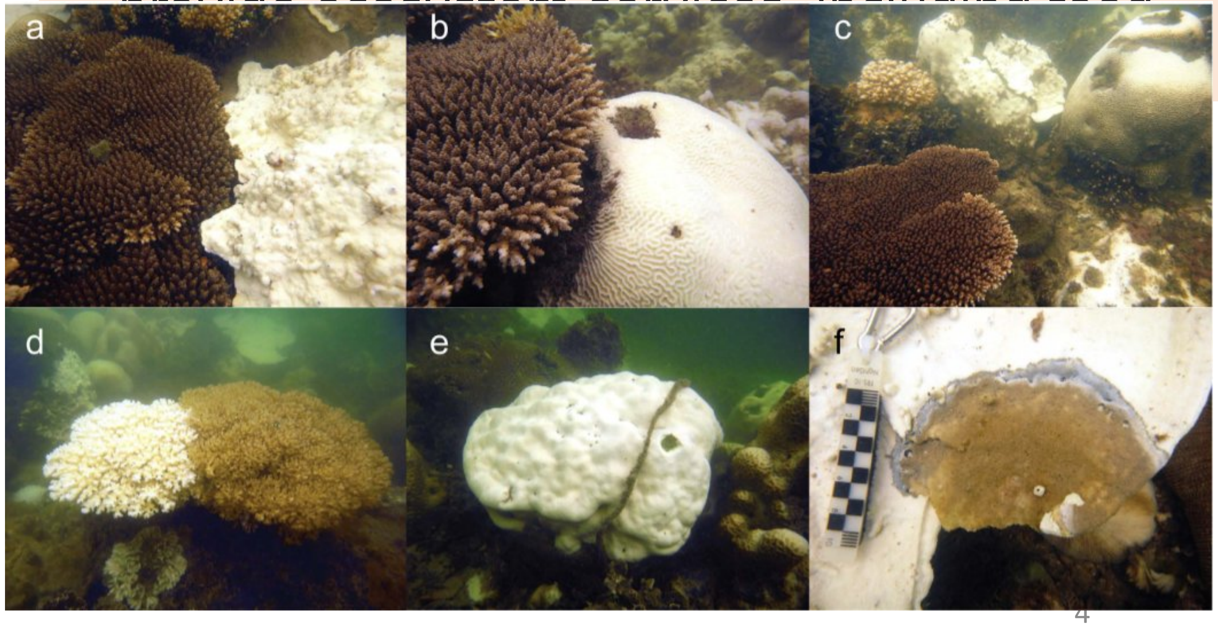


Source: Garcia-Soto, C., and others, 2021.[8]

- Globally averaged sea surface temperature between 1900 to 2018:
  - warming of **0.62 ± 0.12°C per century**
  - The 10 warmest years on record have all occurred since 1997, with the **5 warmest occurring since 2014**
  - Recent decade (2009–2018) shows **a rate of warming approximately four times higher** (2.56 ± 0.68°C per century) than the long-term trend (0.62 ± 0.12°C per century)

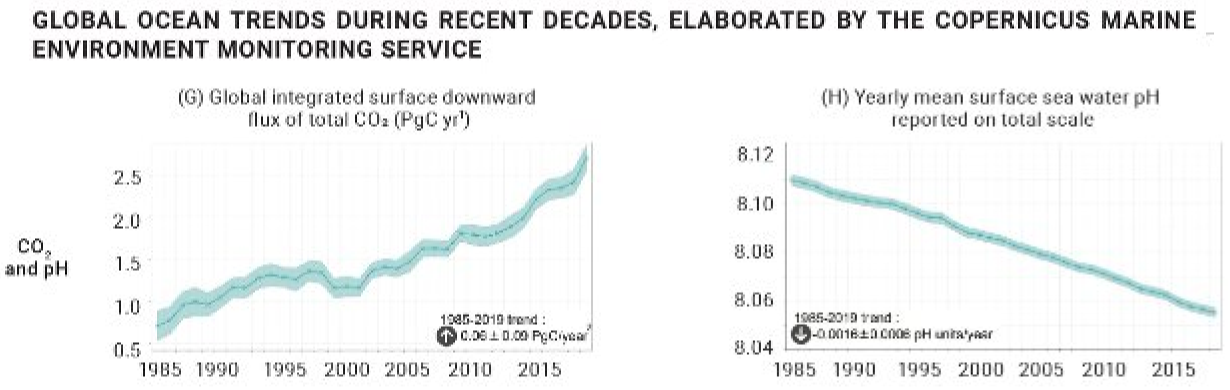
Consequence of warming seas:

- Correspond to an uptake of over **90 per cent of the excess** heat accumulated in the Earth system
- Marine species distributions are **shifting to the poles**
- **Increase frequency and intensity** of coral bleaching events
- **Reduced ability** for tropical ecosystems to



© Guest *et al.*, 2016

Climate Change Resulting in Ocean Acidification

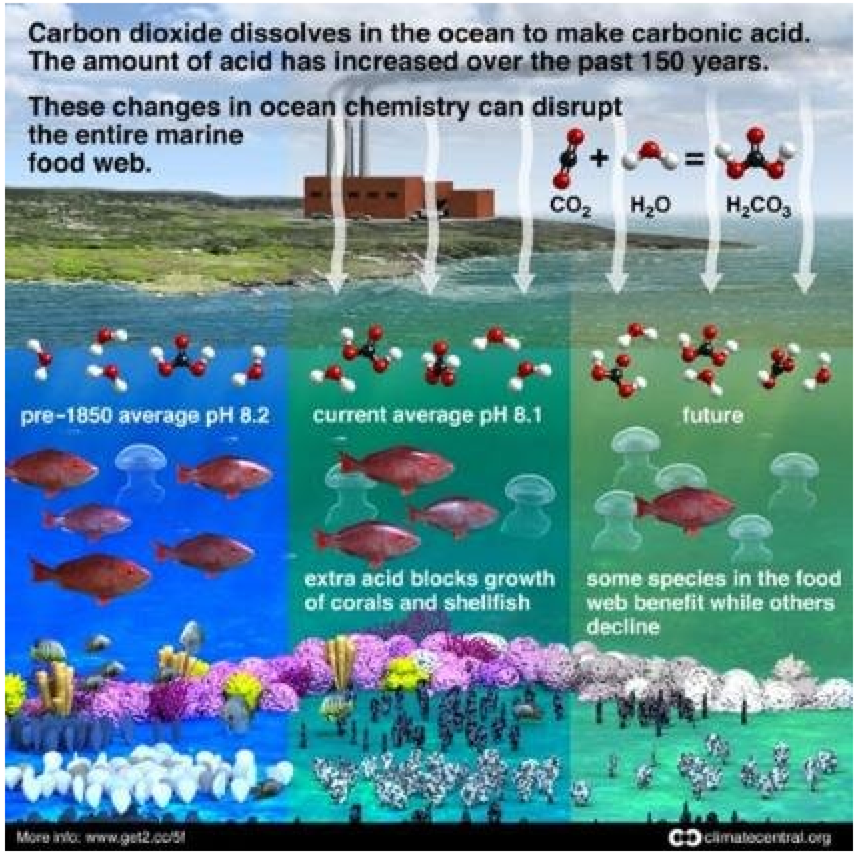


Source: Garcia-Soto, C., and others, 2021.[8]

Consequence of Ocean Acidification:

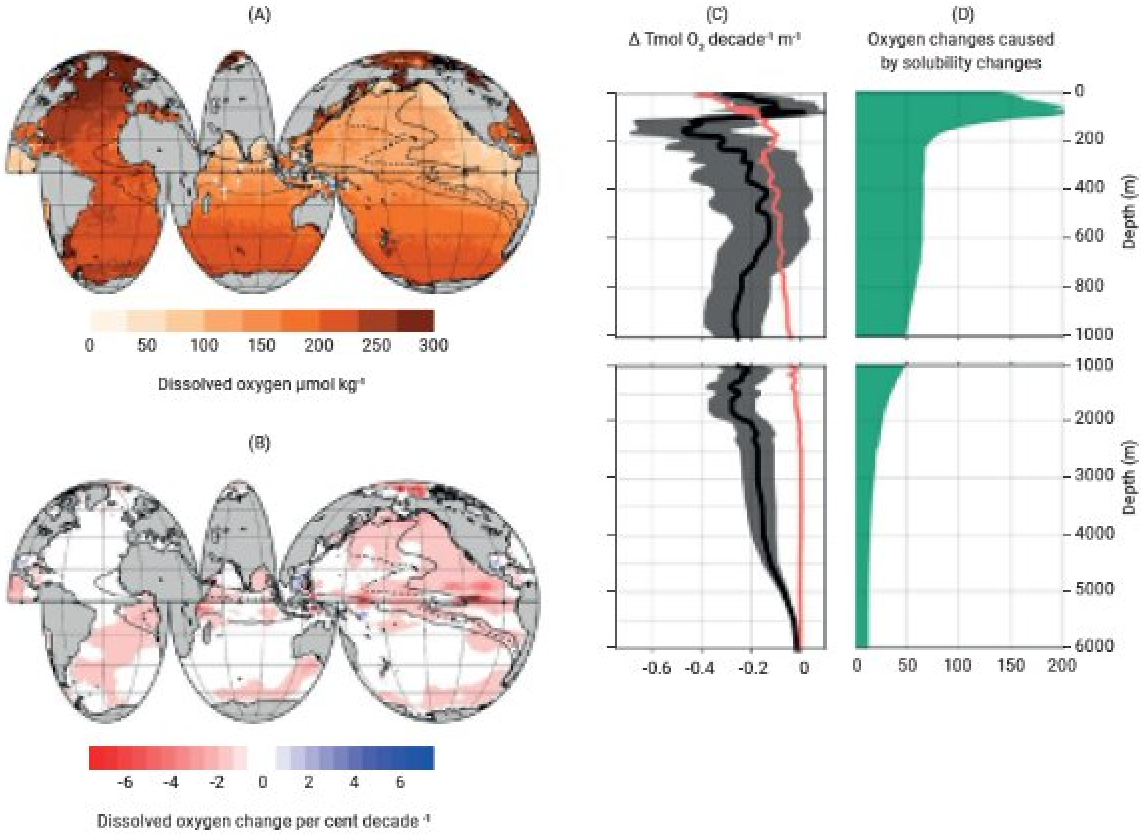
- **Reduce the ability of calcifying marine organisms** like corals and shellfish to form calcium carbonate shells and skeleton
- **Lower fitness** in species, possible cascade effects impacting the food chain

- Global surface ocean pH has declined by ~0.1pH units since pre-industrial times; a **30% increase in acidity**
- Ocean pH is projected to decline approximately by an **additional 0.2–0.3 pH units over the next century** unless global carbon emissions are significantly curtailed
- The recent rate of change is likely **unparalleled** in at least the past 66 million years



Climate Change Resulting in Deoxygenation

FIGURE II: SPATIAL AND TEMPORAL TRENDS OF DISSOLVED OXYGEN CONCENTRATION: (A) Mean oxygen concentration, with the lines indicating the maximum extent of the oxygen minimum zone with 40, 80, and 120 µmol kg⁻¹ dissolved oxygen anywhere in the water column; (B) Trend of oxygen over five decades (1960–2010); (C) Vertical distribution of deoxygenation (black curve) and error (gray area), with the red line indicating the loss expected from oceanic warming detected in the same data set; and (D) Percentage of deoxygenation due to warming for the water column, with values above 100 per cent indicating that processes counteracting solubility deoxygenation are at play.[9]



Source: Garcia-Soto, C., and others, 2021.[10]

- The global O_2 budget has **decreased by 2% since 1960**
- Warming ocean **decrease O_2 solubility** in the uppermost water layers from air-sea gas exchange
- **Accelerating warming and anthropogenic drivers will exacerbate** deoxygenation in coastal areas

Consequence of Deoxygenation:

- Increase prevalence and frequency of **hypoxia and creation of dead zones**
- **Loss of biodiversity, biomass** and reduced environmental **resilience**

Climate Change Resulting in Sea Level Rise (SLR)

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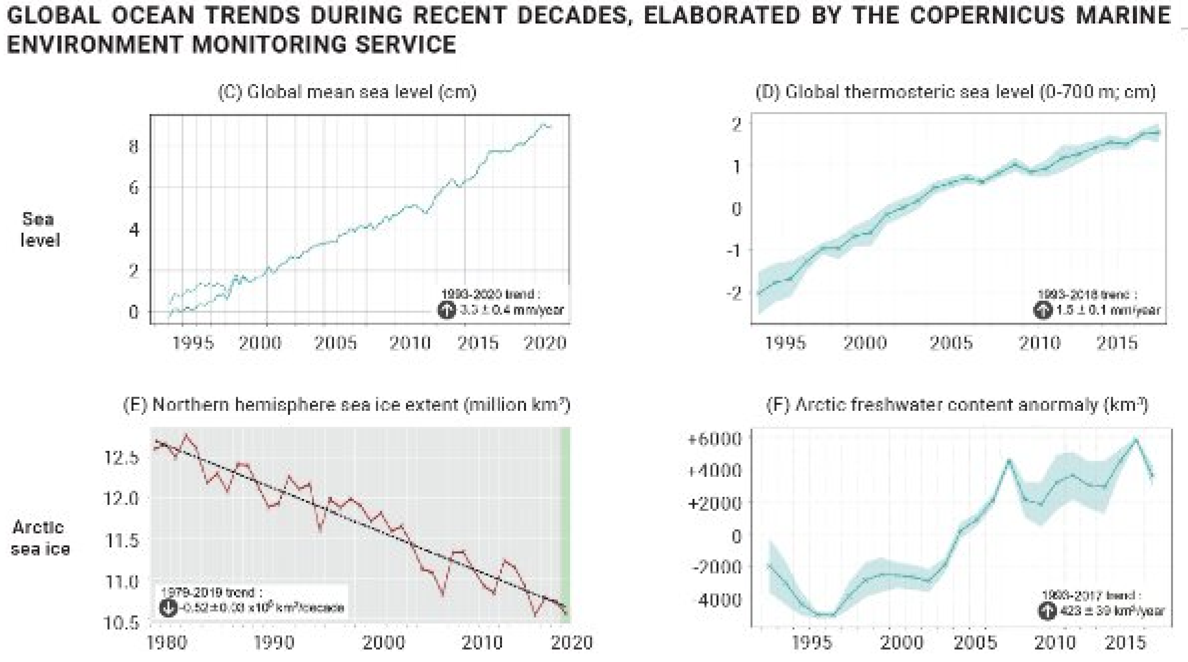

Source: Garcia-Soto, C., and others, 2021.[8]

- Since 1993, the global mean SL has been **rising at a mean rate of 3.15** +/- 0.3mm per year, and **accelerating by ~0.1 mm/year²**
- In 2010, the global average SL was 52.4mm above the 1993 level; in 2018, increased to 89.9mm
- Caused by **thermal expansion** from a warming ocean with melting ice
- Strong regional variability in rates of sea level change; **fastest in the Indo-Pacific**, NW Pacific and Subtropical North Atlantic

Consequence of SLR:

- Significant threat to coastal systems and to low-lying areas around the world through **inundations and erosion of coastline**
- Previously rare extreme sea level events will become common by 2100
- **SLR will continue for centuries**, even if mitigation measures for greenhouse gases are put in place now
- **Limited option for retreat** for island nations
- **Coastal habitats maybe able to "grow" with SRL**, if not compromised by other climate stressors*

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Impacts of SLR on Coastal Habitats

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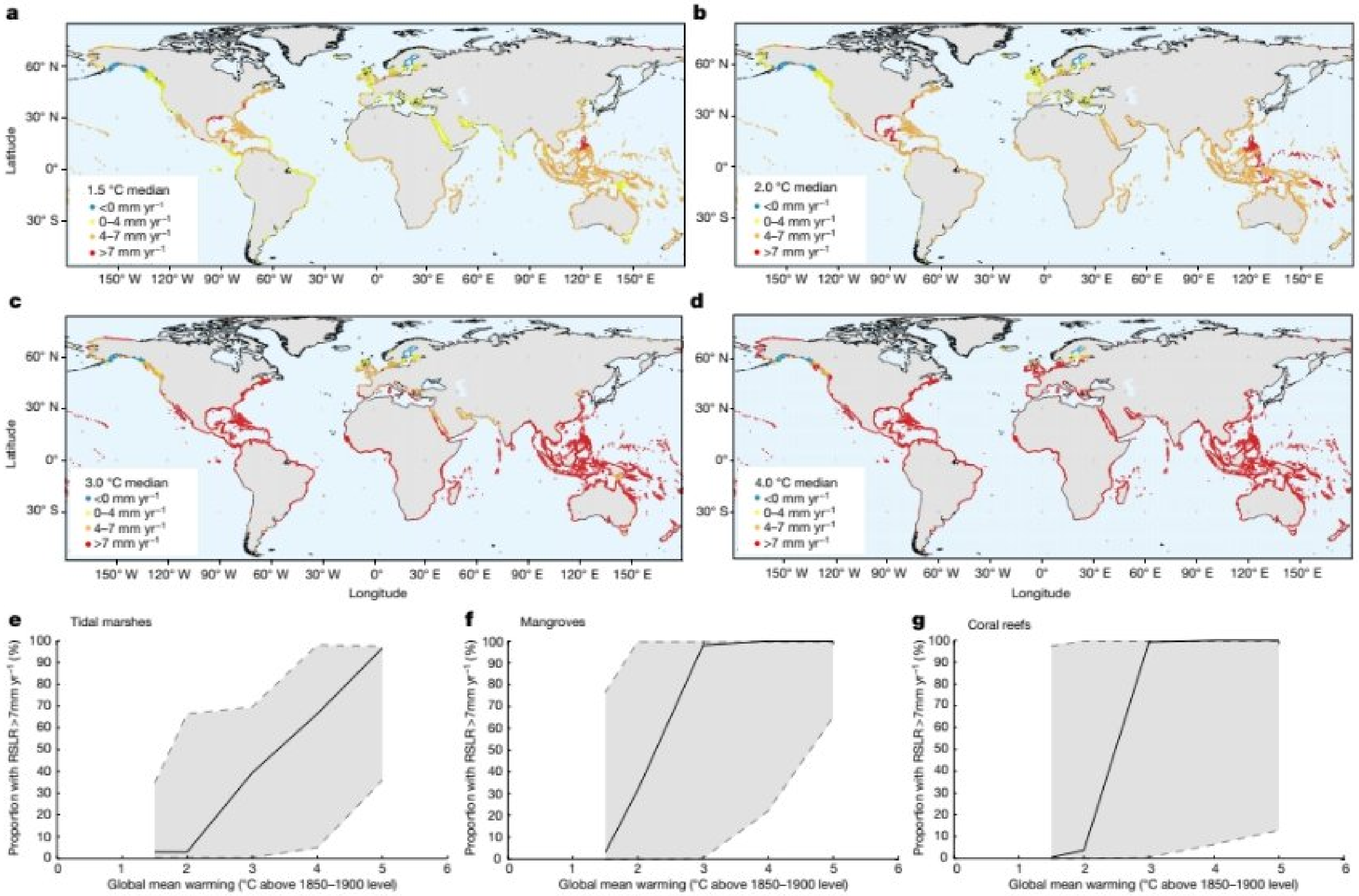

Fig. 3 | Projected exposure of coastal ecosystems to RSLR. a–d, Coastlines with mapped mangrove, tidal marsh or reef habitat subject to >4 mm yr^{-1} and >7 mm yr^{-1} RSLR over 2080–2100 under the median projections for 1.5 °C (**a**), 2.0 °C (**b**), 3.0 °C (**c**) and 4.0 °C (**d**) warming scenarios relative to 1850–1900. Note that projected rates of RLSR rely to a considerable extent on tide gauge records that may capture local anomalies (for example, due to fluid extraction) that could produce locally higher rates. **e–g**, The proportion of global tidal marsh (**e**), mangrove (**f**) and coral reef (**g**) habitat subject to 7 mm yr^{-1} of RSLR by 2100 in the scenarios shown in **a–d**, as well as the 5 °C scenario. Error bands show the 17–83% likely range. These projections do not take into account the possibility that ice sheet instabilities substantially increase RSLR in warming scenarios exceeding 2 °C.

A deficit between tidal marsh and mangrove adjustment and RSLR is likely at 4 mm yr^{-1} and highly likely at 7 mm yr^{-1} of RSLR.

As rates of RSLR exceed 7 mm yr^{-1}, the probability that reef islands destabilize through increased shoreline erosion and wave over-topping increases.

Increased global warming from 1.5 °C to 2.0 °C would double the area of mapped tidal marsh exposed to 4 mm yr^{-1} of RSLR by between 2080 and 2100.

With 3 °C of warming, nearly all the world's mangrove forests and coral reef islands and almost 40% of mapped tidal marshes are estimated to be exposed to RSLR of at least 7 mm yr^{-1}.

Coastal Protection from Natural Coastlines

Evolutionarily, biogenic habitats provide key natural coastal defenses

- Healthy coral reefs reduce wave energy by up to 97 percent
- A 100-meter-wide belt of healthy mangroves can reduce wave heights between 13 and 66 percent, and up to 100 percent where mangroves reach 500 meters or more in width

Coastal ecosystems – our allies in coastal defense!

Climate and the Coast – Retreat is Not an Option

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How will Climate Change Affect our Coast?

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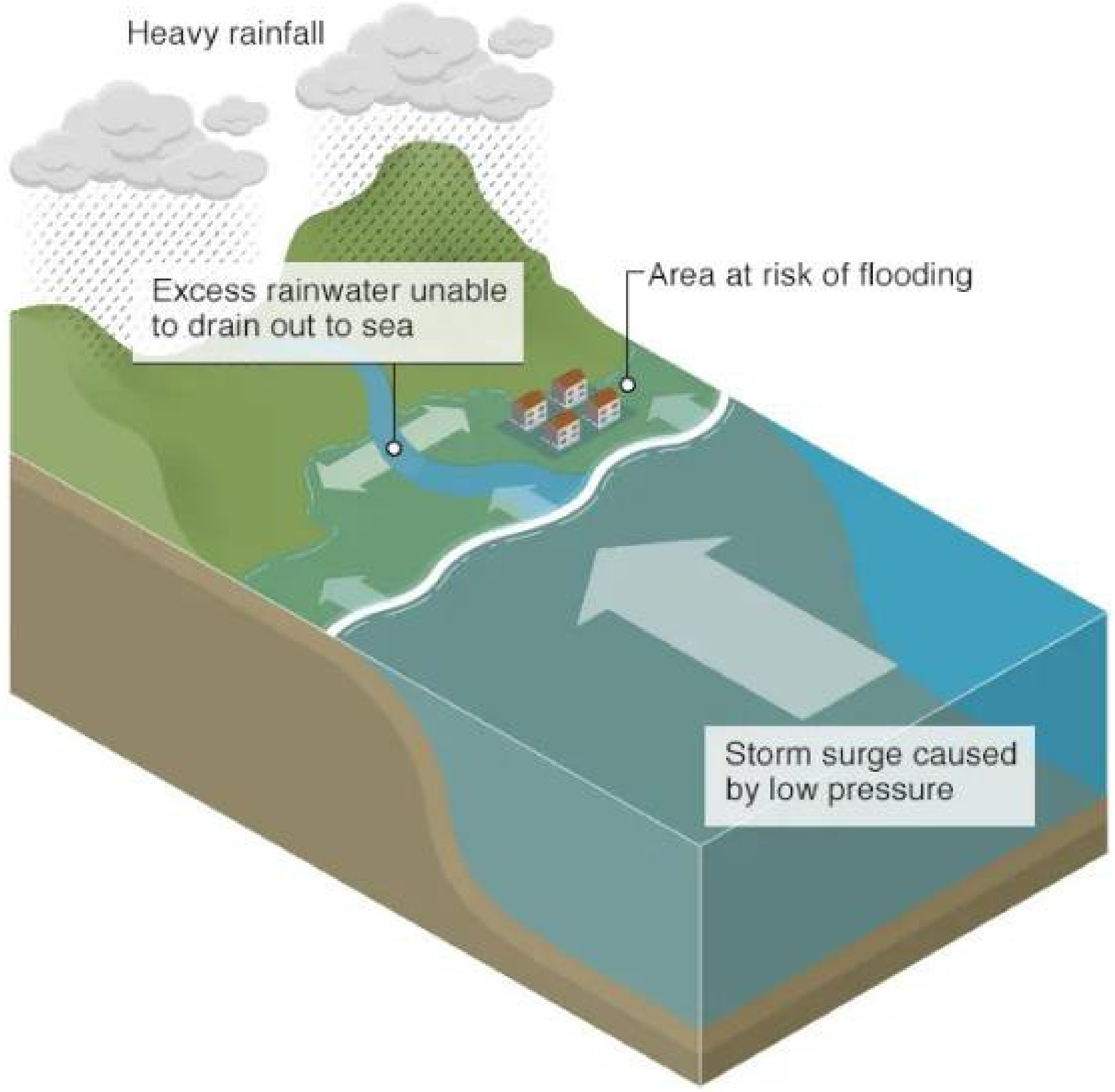

Source: Douglas Maraun/Science Advances

BBC

- Heavier and more frequent storms can compound coastal and inland flooding
- Coastlines will be increasingly eroded with sea level rise and storms
- Increase in mass coral bleaching events
- **Singapore's coastal ecosystems are general resilient** but the highly urbanized coastline will impede the ability of existing wetlands to migrate landward, a key mechanism to cope with SLR
- However **slower rates of SLR in the earlier half relative to the latter half of this century**, bolstered by the **resilience of existing ecosystems**, present an **opportunity to introduce interventions** that could ameliorate coastal degradation in the long term

Changing Coastlines, Changing Baselines

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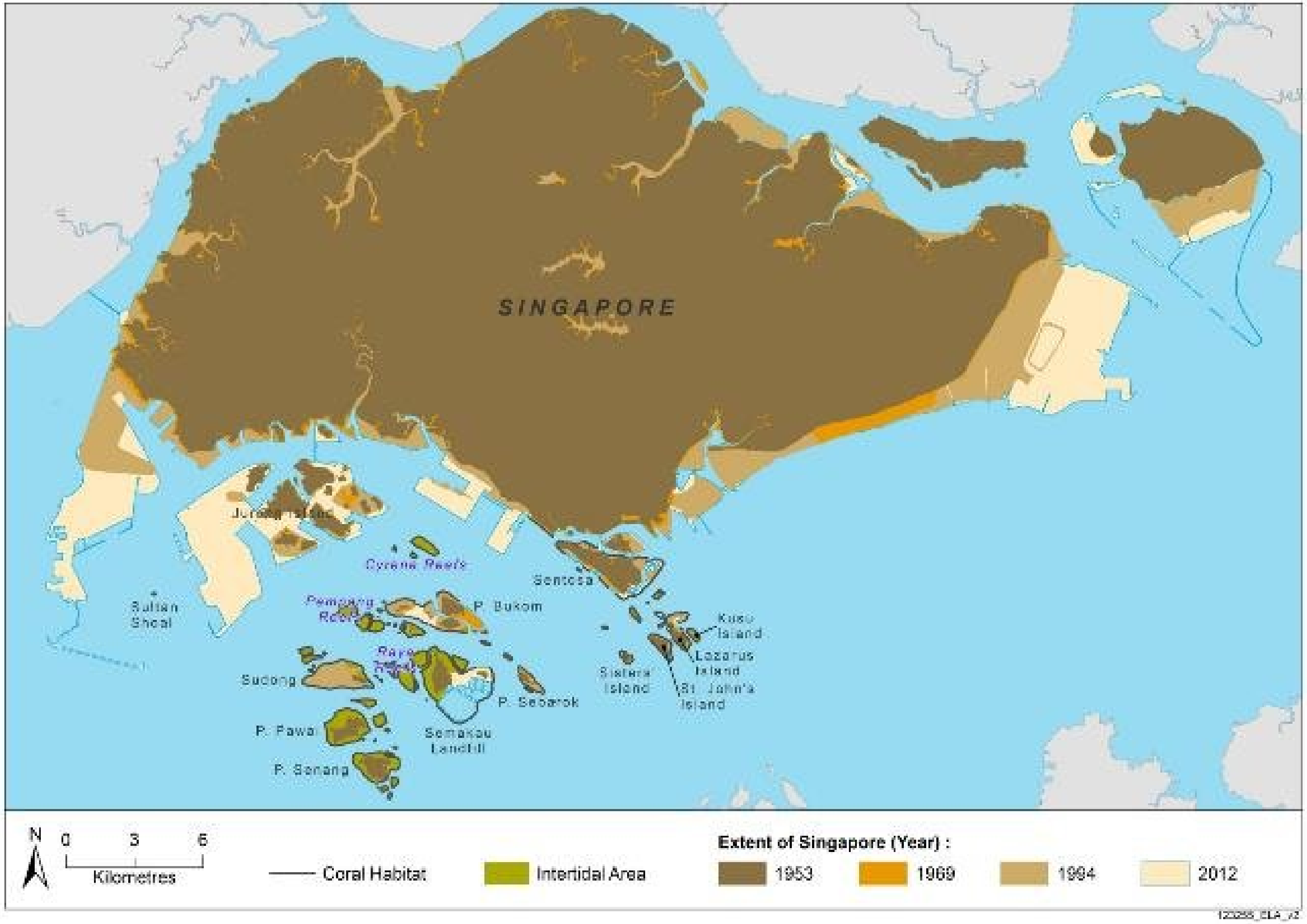

Year	Est. Land Area (km²)	Total % increase	% decadal increase
1819	578	0	0
1960	581.5	0.6%	0.6%
1980	617.8	6.9%	6.3%
1990	633	9.5%	2.6%
2000	682.7	18.1%	8.6%
2010	720	24.6%	6.5%
2020	728.3	26.0%	1.4%

(www.data.gov.sg)

- **Population: 5.69 million**
- **Population density: ~7810/km^2**

Changing Coastlines, Changing Baselines

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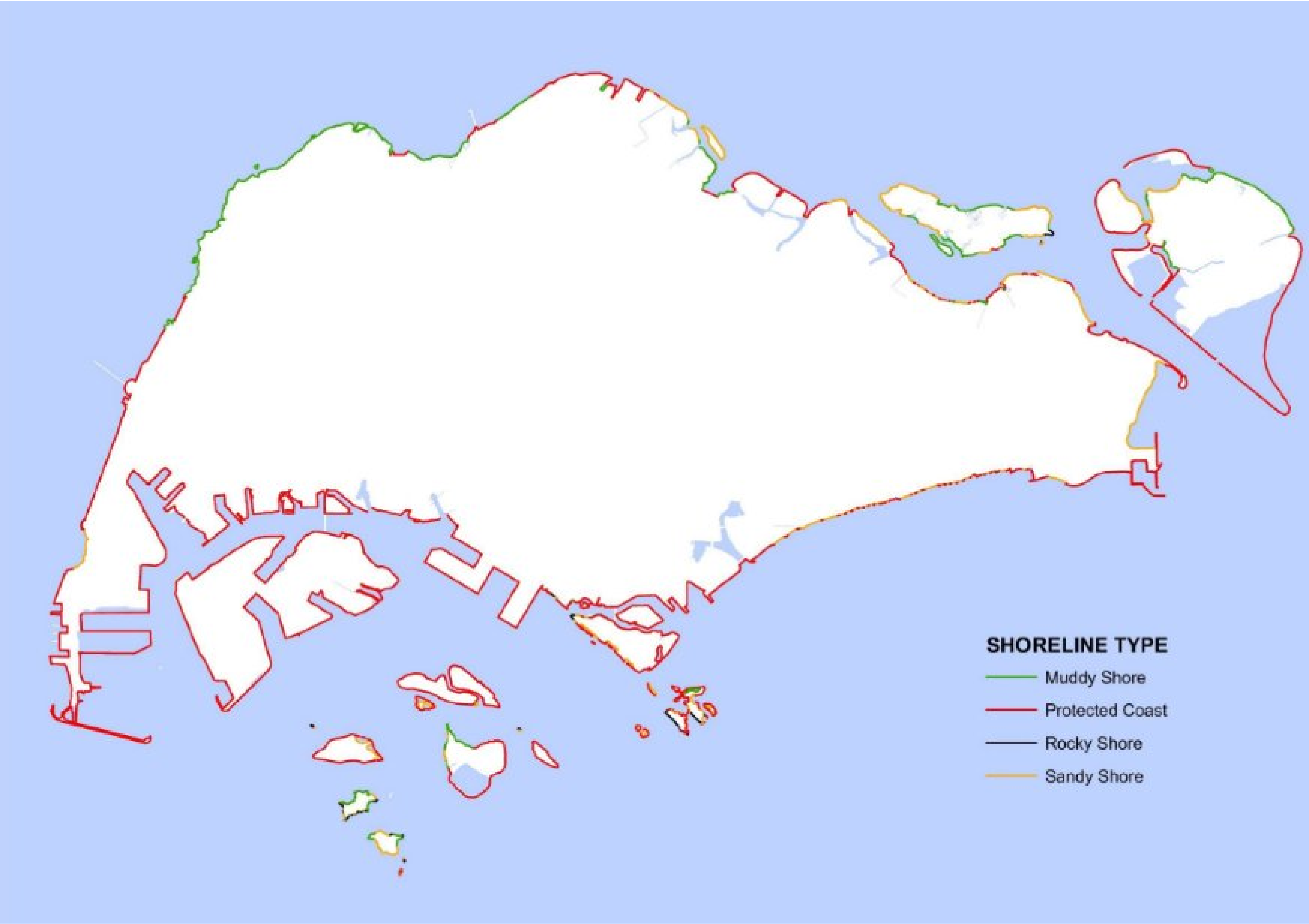

Changing Coastlines, Changing Baselines

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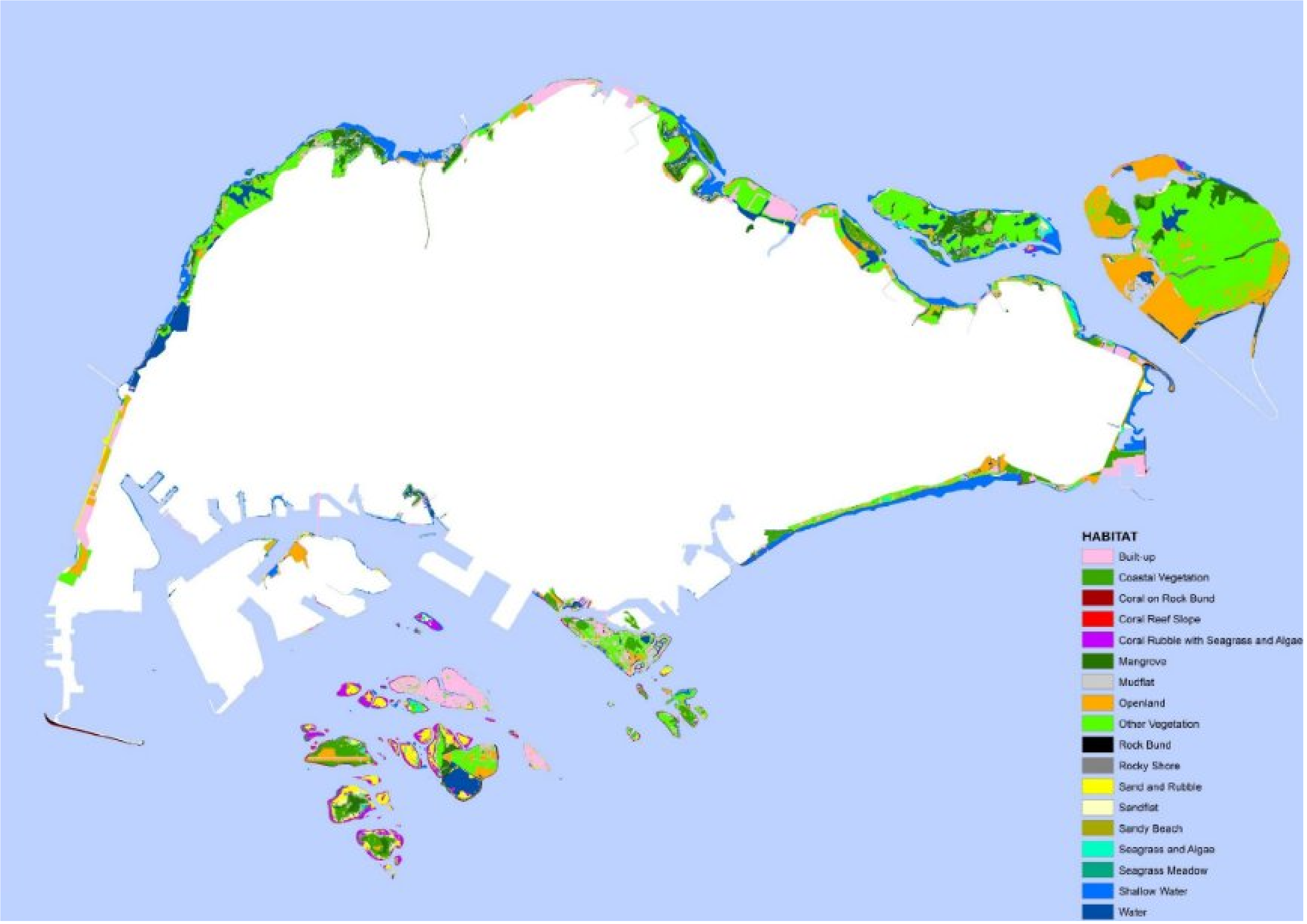


Nature-Based Solutions (NbS) to Promote Coastal and Marine Ecosystem Resilience

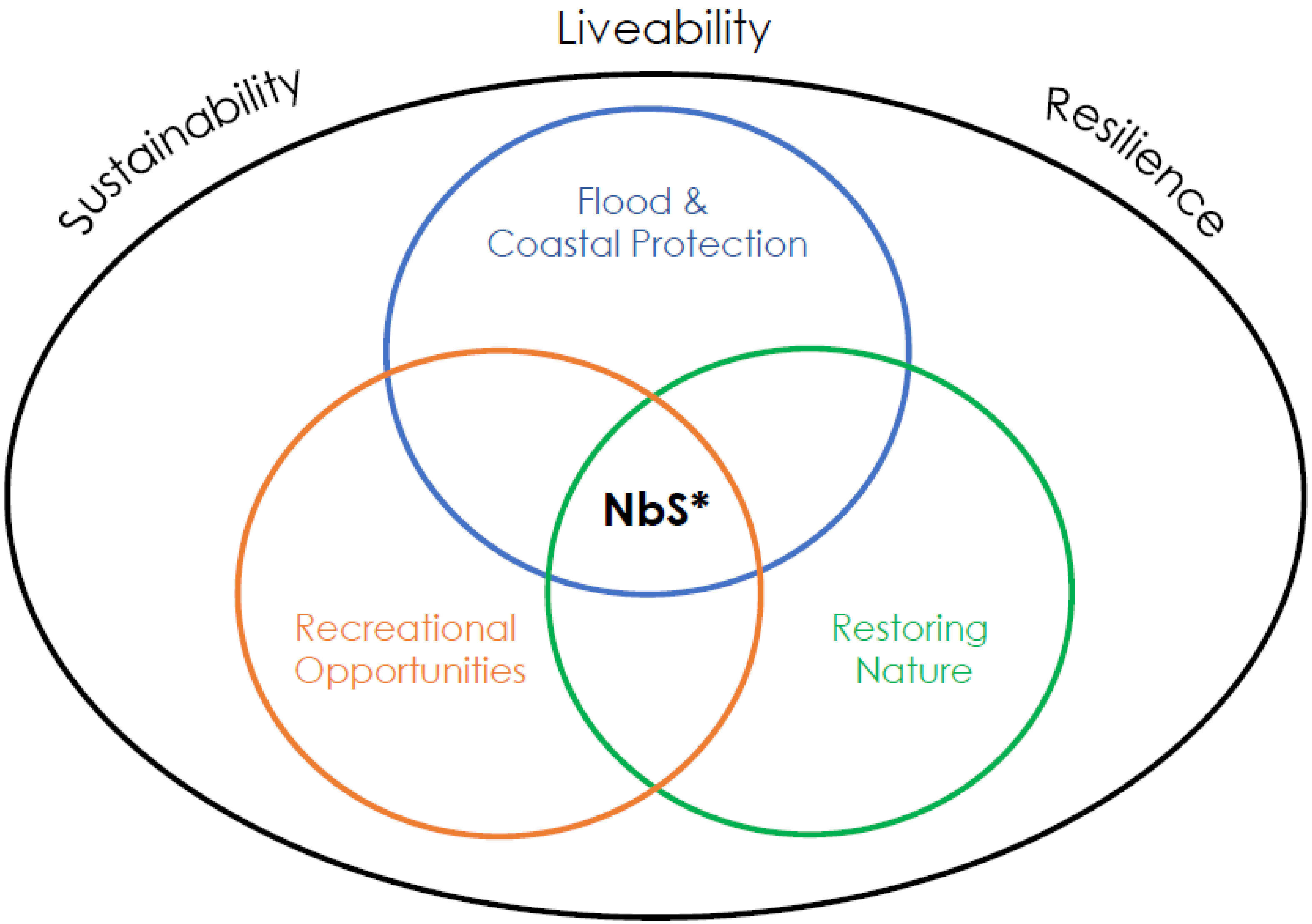
Conceptual framework for Nature-based Solutions. *Source: IUCN*

- In March 2022, the 5th United Nations Environment Assembly formally adopted the definition of NbS as:

"*actions to* ***protect, conserve, restore, sustainably use*** *and* ***manage*** *natural and modified terrestrial, freshwater, coastal and marine* ***ecosystems*** *which address* ***social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits***"

- Emphasizes the importance of working with nature to tackle societal challenges by producing benefits to biodiversity and human wellbeing
- NbS cover a wide range of approaches, encompassing both structural and non-structural options

Benefits of NbS



Taking a Page from Nature's Blueprint

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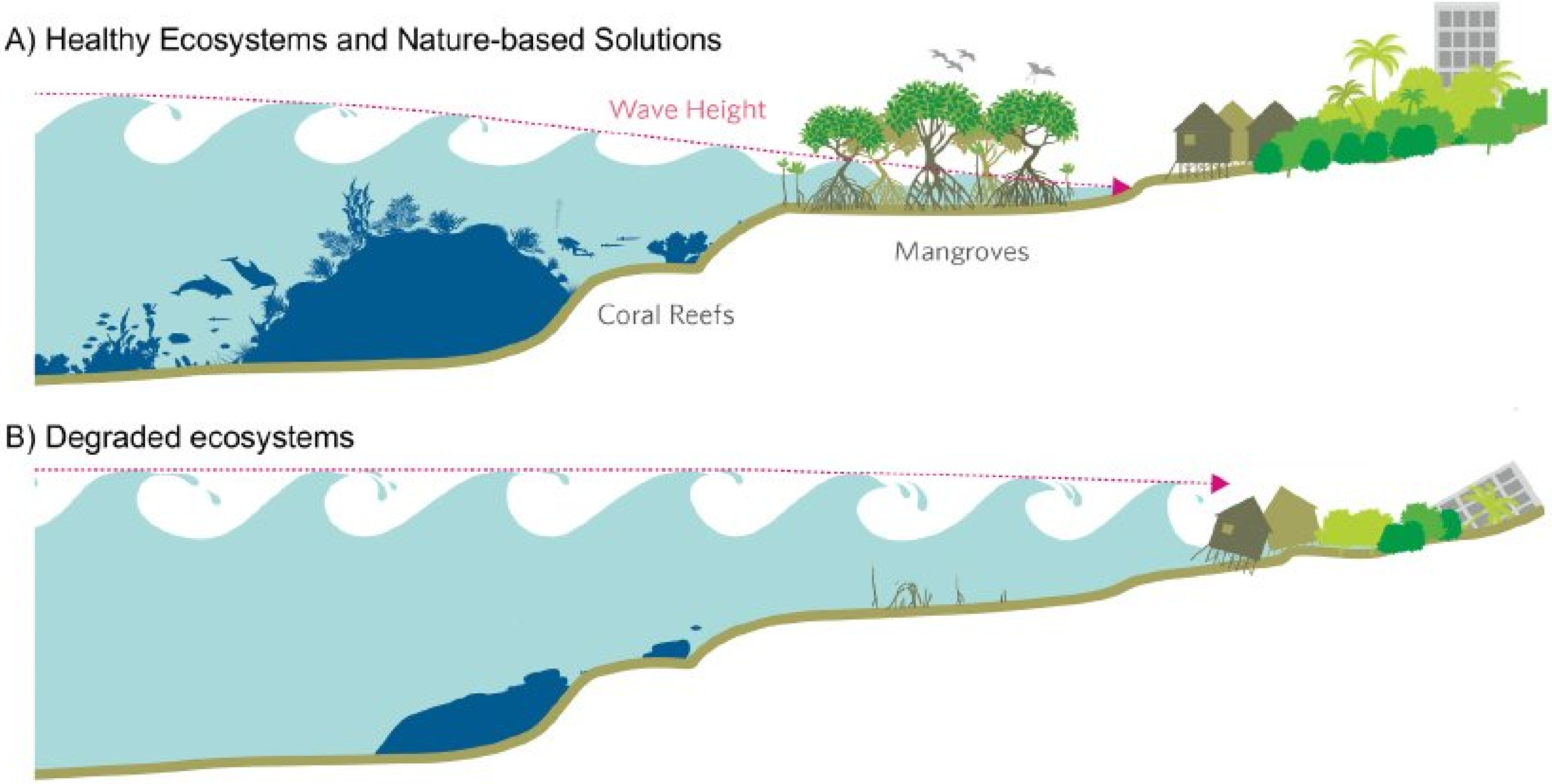

What kinds of coastal NbS may work for Singapore?

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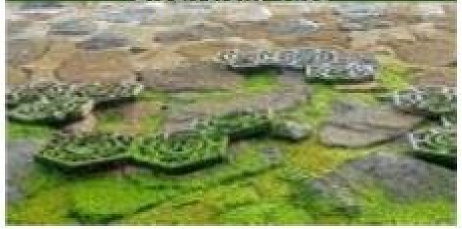
- Singapore has limited land and sea space; little room to advance or retreat
- Soft NbS alone to prevent coastal inundation (e.g. sand dunes) not feasible due to high land-take required
- Most NbS for protection against inundation will be hard or hybrid eco-engineering
- Seawalls where there are critical assets or minimal land availability, and softening to add recreational and ecological value
- Hybrid systems for recreational areas e.g. beach berms with seagrass lagoons and offshore artificial reefs
- Soft NbS (e.g. mangroves) can still mitigate erosion, with hard edge inland to prevent inundation

Examples of (unintended) NbS implemented in Singapore

Intertidal Terrace and Pools

Changi Beach Park

Biodiversity Tiles

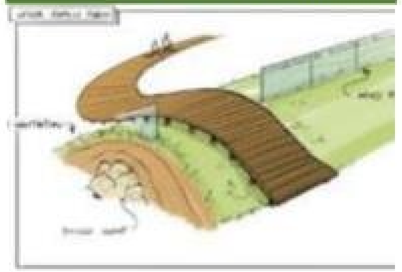


Changi Bay

Floating Reefs

Keppel Marina

Upper Beach Berm



(Not trialled in SG)

Intertidal Seawall Reefs

Tanah Merah

Artificial Reefs

Sisters' Islands

Subtidal Seawall Reefs

Southern Islands

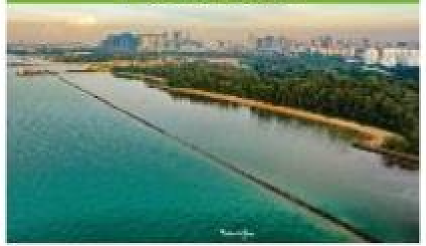
Reclaimed Lagoons

Sisters' Islands

Mangrove Restoration

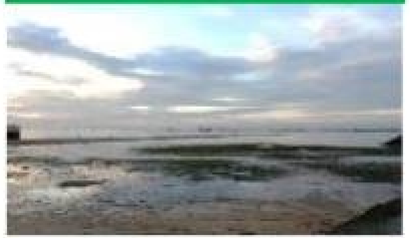
Pulau Semakau

Perched Beach



Marina East

Intertidal Bays

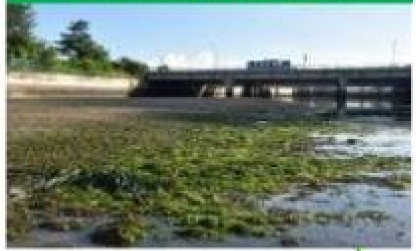


East Coast Park

Mangrove Revetment

Pulau Tekong

Outlet Drain Intertidal Flats



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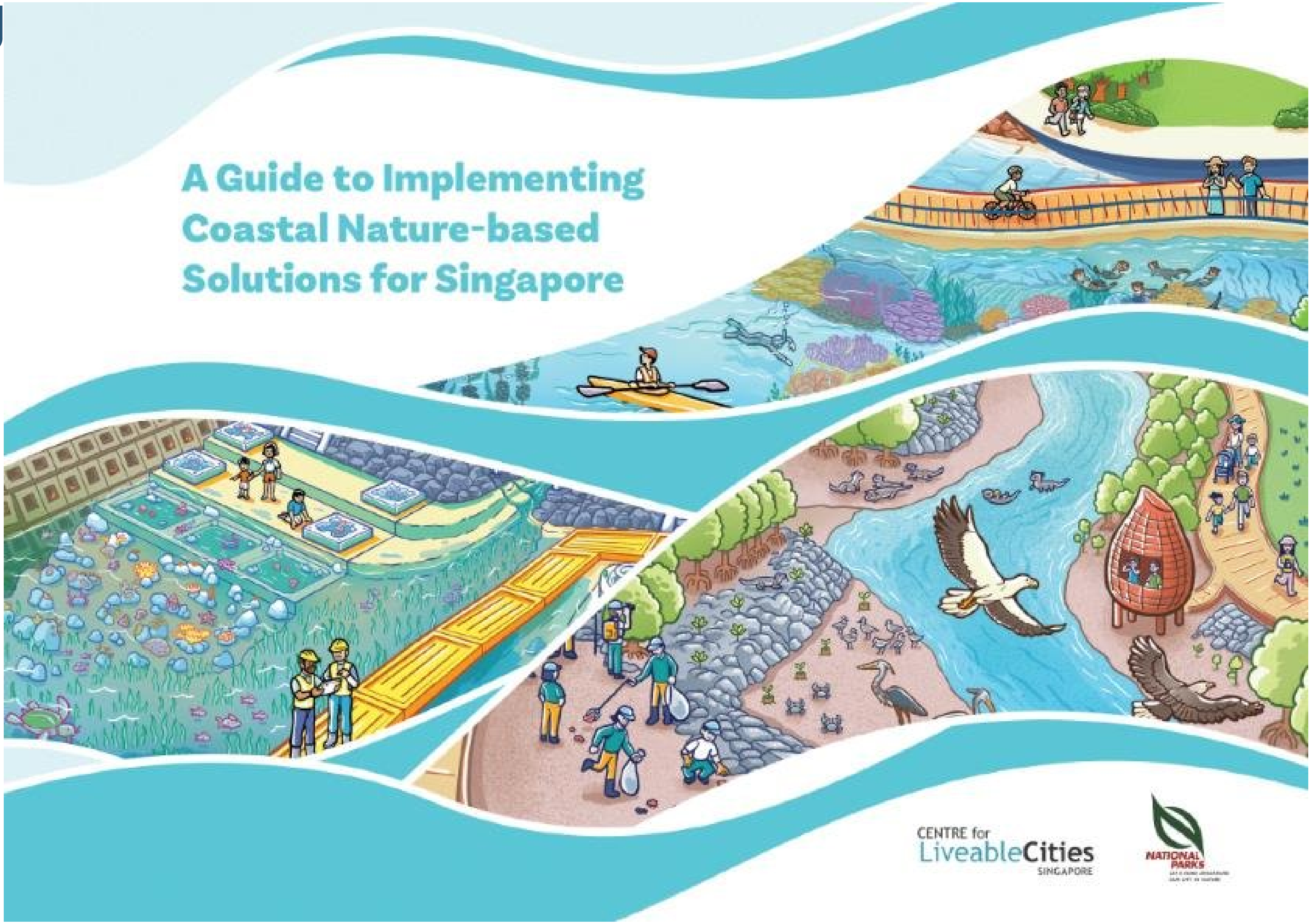
Hard (Artificial) ← **Hybrid** → **Soft (Natural)**

Image credits: MSE, NUS-Deltares, The Straits Times, Loh Kok Sheng, Lynette Loke, Jonathan Tan, Kikuzawa Yuichi, Nathaniel Soon, Ria Tan

A Guide to Implementing Coastal NbS for Sing



Singapore's NbS Implementation Framework

To identify and safeguard opportunity areas for consideration of Green-Blue strategies upfront

Broad framework to guide implementation of nature-based (NbS)

Plan

Identify Objectives/Outcomes

- Define vision, goal or outcome for identified sites, e.g. flood protection, recreation, biodiversity, livability

Understand the System

- Ecosystem and ecological process
- Hydrology, rainfall patterns, runoff projections
- Recreational opportunities

Identify Areas and Solutions

- Identify areas based on spatially overlaying drain/coastline segments with flood protection solutions, recreational/ecological connectivity, agencies' development plans and timelines
- Conduct prelim assessment on suitability of options for flood protection

Implement

Conduct Cost-Benefit Analysis & Implement NbS Strategies

- Consider the efficacy of the measures, as well as aspects such as land-take, cost, maintainability

Monitor

Develop Indicators, Collect Data, & Implement Monitoring Plan

Adaptative Management

Verify Outcomes

Mainstreaming NbS through Outreach, Education & Capacity Building

Chee *et al.*, 2022. Enhancing Uptake of NBS for Informing Coastal Sustainable Development Policy and Planning-A Malaysia Case Study

- Outreach, education and capacity building programs to increase awareness and increase success of NbS efforts
- Jurisdictions, legislations, and regulations will be required and standardized to avoid the “fish ball stick” effect
- Long-term, sustained monitoring required to monitor NbS implementation success
- Existing policies should be strengthened and made more inclusive of NbS
- Communication and collaborative efforts among all stakeholders should be strengthened to best use resources and facilitate stewardship

Thank You