

# **Planting mangroves for multiple benefits**

**On occasion of World Ocean Day, 8 June 2023**

**Centre on Integrated Rural Development for Asia and the Pacific,  
Dhaka, Bangladesh**

**Poh Poh Wong  
email: [wong3921@gmail.com](mailto:wong3921@gmail.com)  
website: [coast4all](http://coast4all.org)**

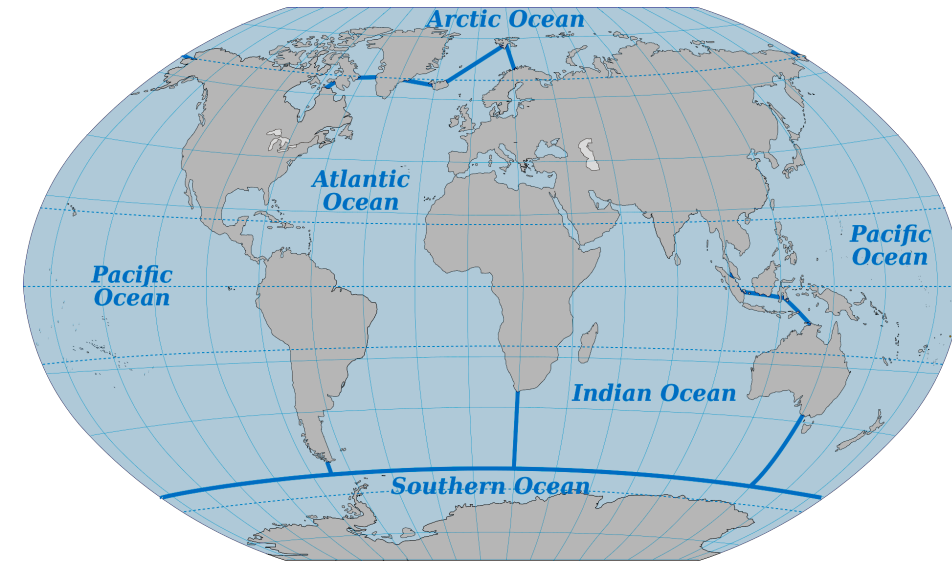
# World Ocean Day

- **World Ocean Day (WOD)** : international day that takes place annually on 8 June.
- **Concept** was originally proposed in **1992** by Canada's International Centre for Ocean Development (ICOD) & Ocean Institute of Canada (OIC) at Earth Summit in Rio de Janeiro. (UN Conference on Environment & Development; Agenda 21 in 1992).
- **Objectives** : move the ocean from sidelines to centre of intergovernmental & NGO discussions & policy & strengthen voice of ocean & coastal constituencies worldwide.
- **Globally coordinated efforts** : “The Ocean Project” & the “World Ocean Network” collaborating, dozens of events.
- **Annual themes : starting in 2009** : “Our Ocean, Our Responsibilities”.
- **2023** : “Planet Ocean : Tides are Changing”.



- Cover **70% of earth's surface**, contain **97% of earth's water**.
- Home to **94% of all life** on earth.
- **<10%** of world's ocean have been **mapped**.
- **Absorb around 30% CO<sub>2</sub>** produced by humans, buffering impacts of global warming.
- **>3 billion people** depend on marine & coastal biodiversity for their livelihoods. (Global population is almost 8 billion in 2023).
- Serve as **world's largest source of protein**, with >2.6 billion people depending on oceans as primary source of protein.
- Unfortunately, as much as **40% of world oceans heavily affected by human activities** like pollution, depleted fisheries, & loss of coastal habitats.
- **37 out of 50 critical minerals** found in oceans.

## Oceans : some facts



(Wikipedia)

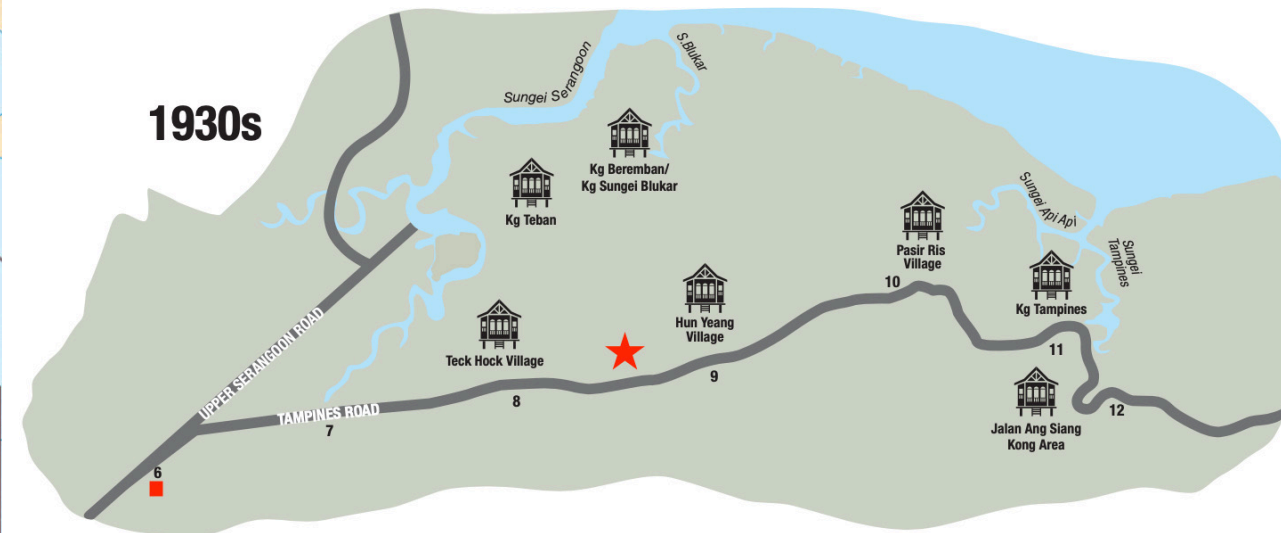
# Presentation : learning journey

- Mangrove experience at **early age** in primary school; main road to school cut through mangrove swamps; seen usual marine life in mudflats, including aftermath of snake battle.
- During **coastal work** seen mangroves in Singapore, Malaysia, Indonesia, Philippines, Thailand & some islands in Indian Ocean.
- **Academic interest/research** started after Dec 2004 Indian Ocean tsunami impact on mangroves with fieldwork in Aceh, Andaman coast & islands of Thailand, west & south coast of Sri Lanka & east coast of India (Tamil Nadu).
- Subsequently, spent more time on mangroves in **non-muddy environments**, e.g. Mactan Island, Philippines & Bunaken Island, Indonesia.

# Tampines area

Mangroves have long helped define the character and culture of the Tampines area. Kampong residents used the **Bakau Pasir** (*Rhizophora stylosa*) and **Perepat** (*Sonneratia alba*) mangrove timbers to construct kelong and boats, while the Api Api tree (*Avicennia*) lent its name to the eponymous river.

(Tampines Heritage Trail, p.14)



An illustration showing where some of kampongs in Tampines were located in the 1930s  
Courtesy of National Heritage Board

# Outline

- 1. Mangroves**
- 2. Adaptation and zonation**
- 3. Benefits**
- 4. Threats**
- 5. Coastal protection**
- 6. Planting and restoration**
- 7. Modular planting**
- 8. End note**

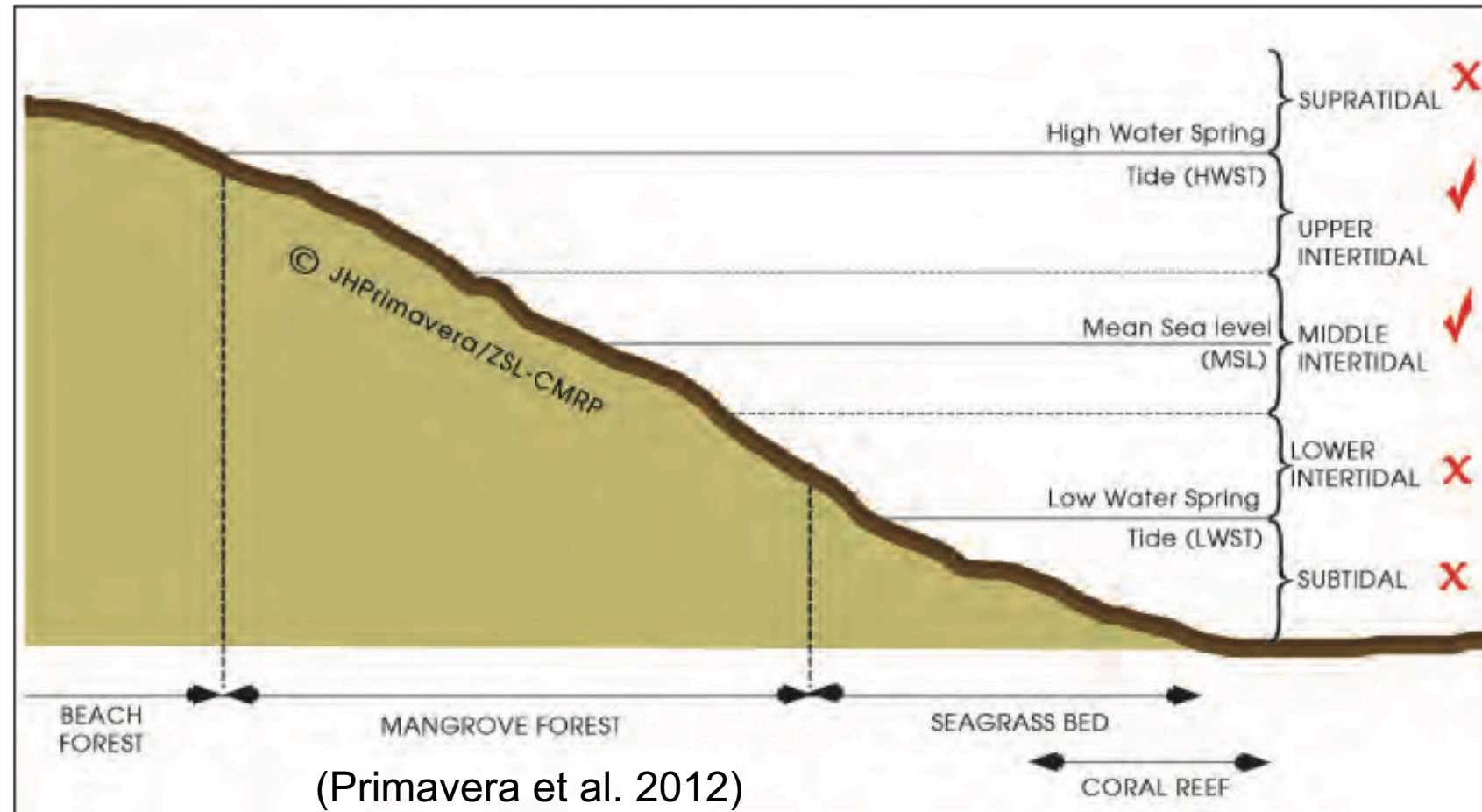
# 1. Mangroves



# Coastal ecosystem

- **Tropical plants** straddling **interface of land & sea**.
- **Significant coastal ecosystem** : with branches for birds, reptiles, mammals; roots when submerged as nurseries for fish & marine mammals.

**FIG. 1.**  
Location of mangroves in relation to other coastal habitats, and tidal elevation suitable (✓) for planting (mid- to upper intertidal). Lower intertidal and subtidal sites (X) experience high mortality.



(Primavera et al. 2012)

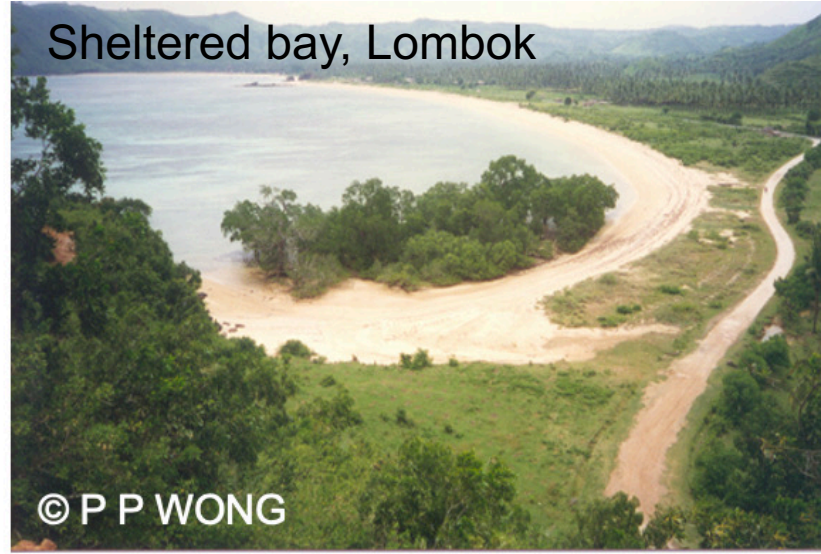


# Coastal locations

Estuary, Sabah



Sheltered bay, Lombok



Typical muddy environment



Coral flat, Bunaken Island



Infront of beach, Mactan Island





# Sandy shores, Bintan Island, Indonesia





# Sandy shores, Samal Island, Philippines





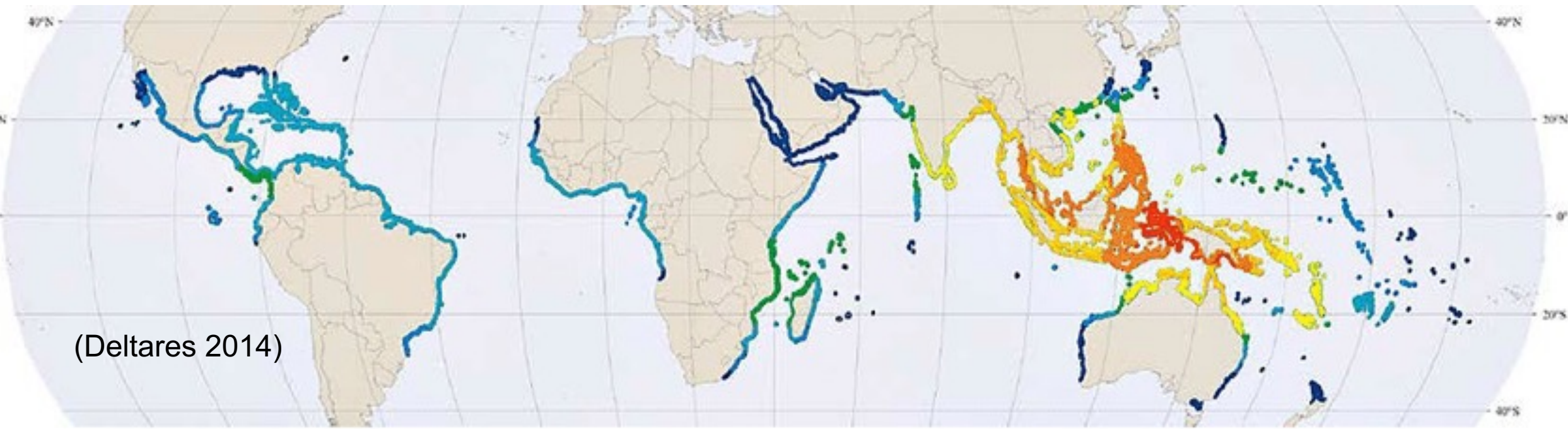
# Coral flats and rocks



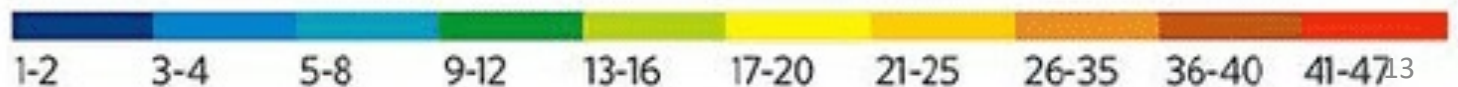


# Global distribution (1)

- Grow in **sheltered tropical & subtropical coastal areas** across globe, **generally between latitudes 25°N & 25°S**.
- **Roughly 54 true species of mangrove belonging to 16 different families**. When all plants living in mangrove environment are included, >80 mangrove species.

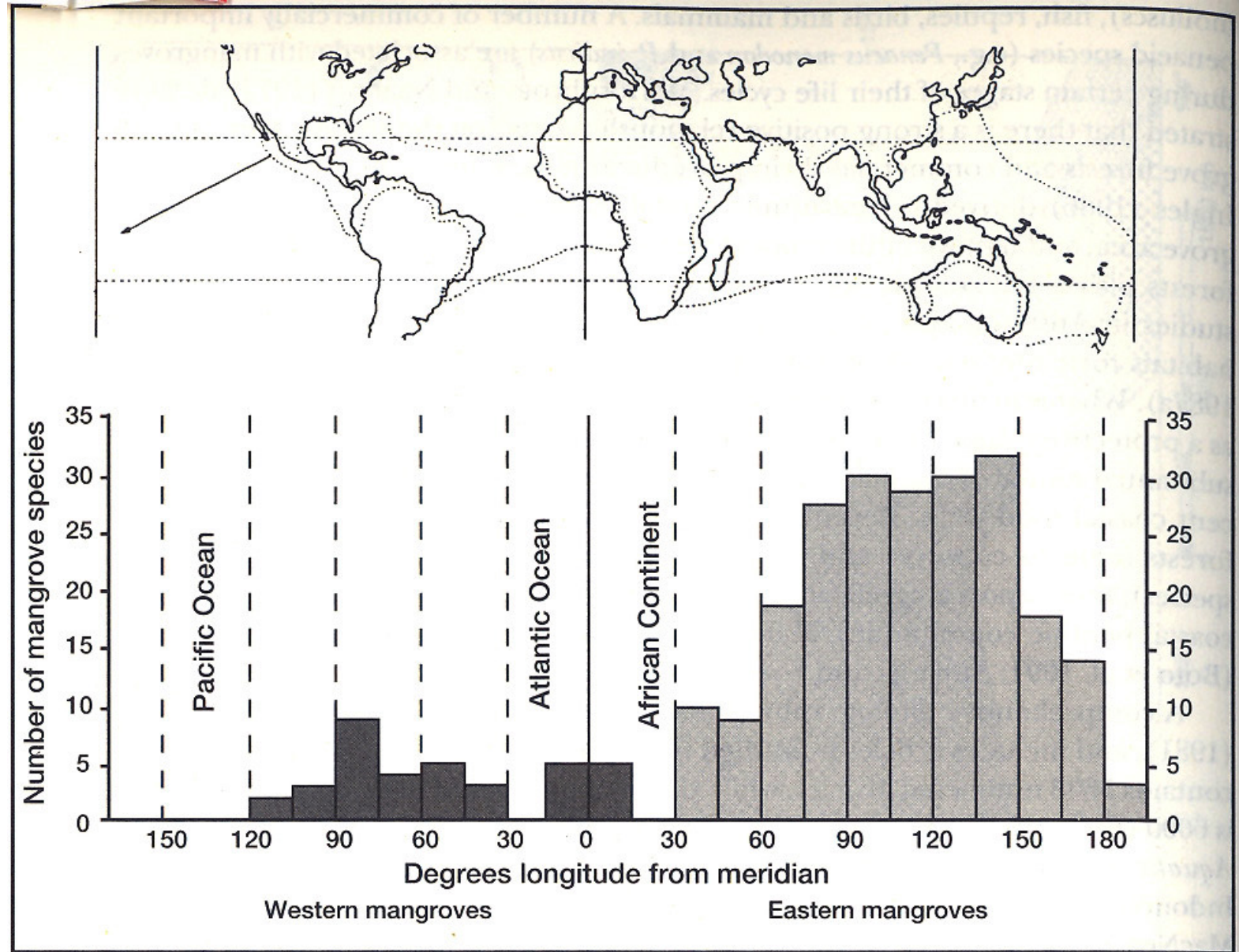


**MANGROVE  
SPECIES**



# Global distribution (2)

- **Bimodal** distribution.
- Differences in species differences between **western & eastern groups**.



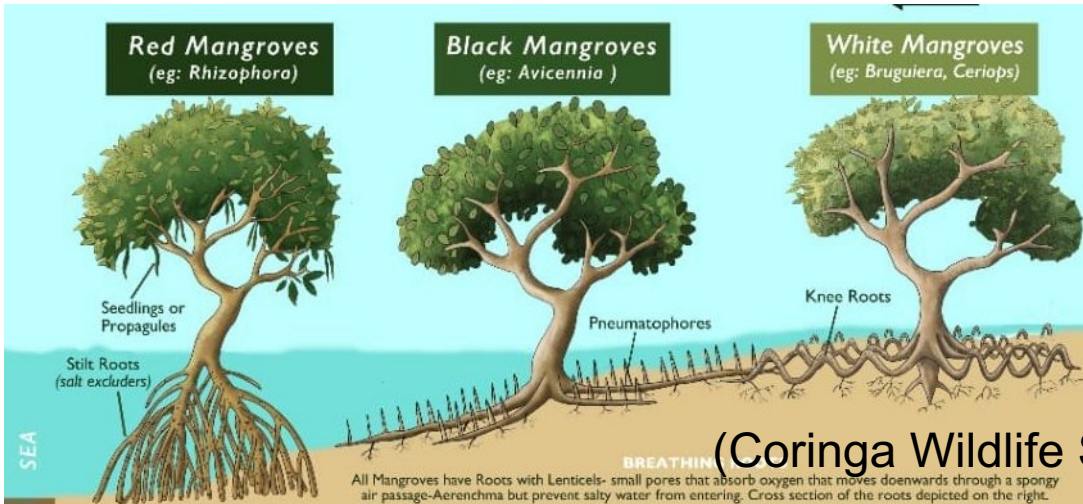
(Tomascik et al. 1997)

**Figure 19.4.** Global distribution of mangroves. Above: approximate distributional boundaries for west and east mangrove groups. Some overlap may exist in the western Pacific (*Rhizophora samoensis*) (arrow). Below: The bimodal distribution of mangroves, illustrating differences in species richness between the western and eastern groups.

## 2. Adaptation and zonation

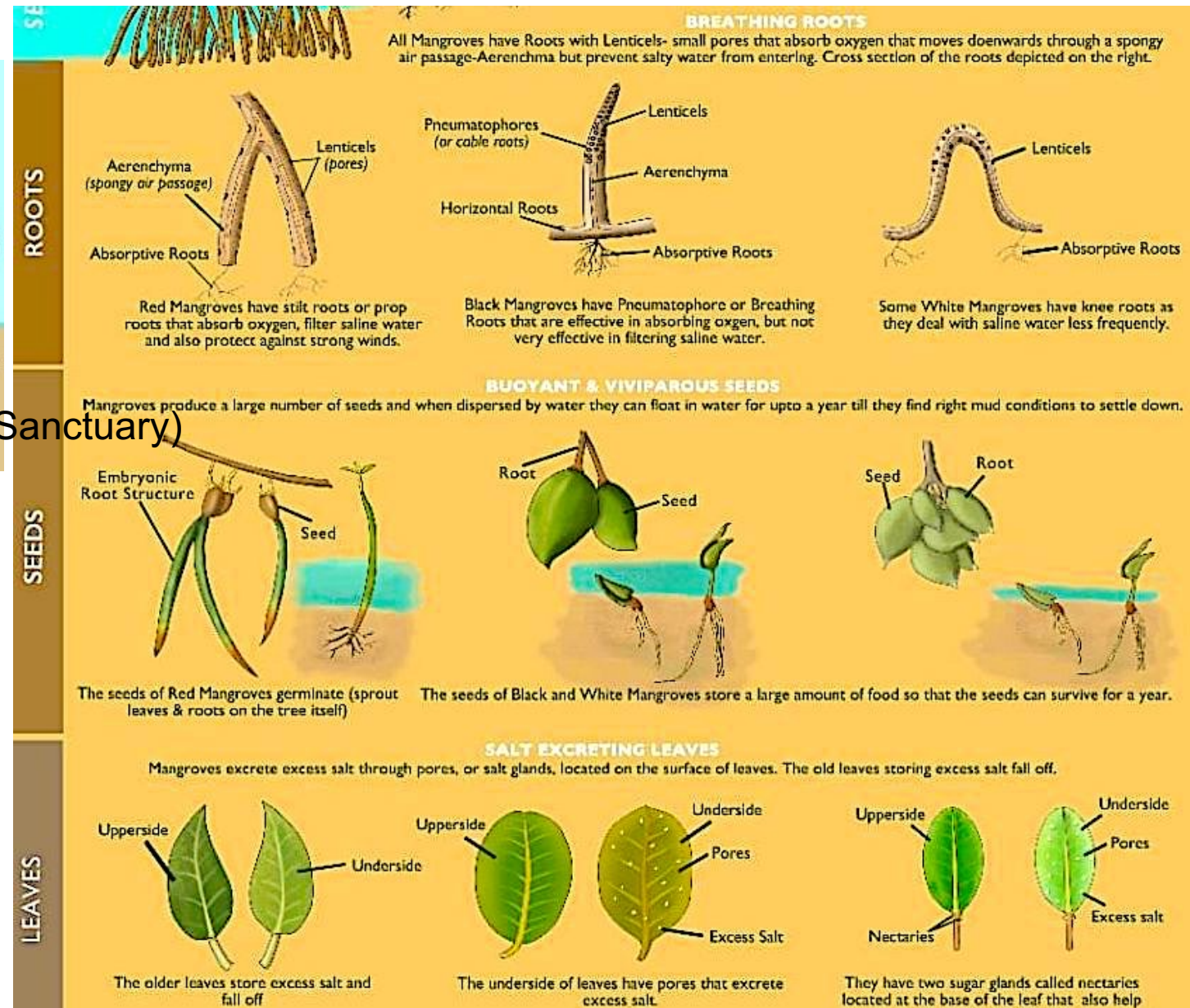


# Root, seed and leaf adaptations



(Coringa Wildlife Sanctuary)

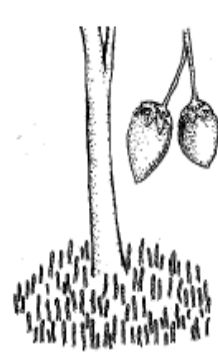
**Salt crystals** on *A. marina* leaf





# Roots adapt to changes in sea level

“Mangroves have **special root systems ... and may adapt to changes in sea level by growing upward in place, or by expanding landward or seaward.**” (McLeod & Salm 2006)



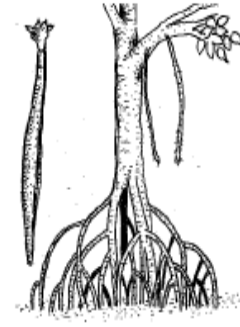
Peg roots of  
*Avicennia*



Knee Roots of  
*Bruguiera*



Peg roots of  
*Sonneratia*

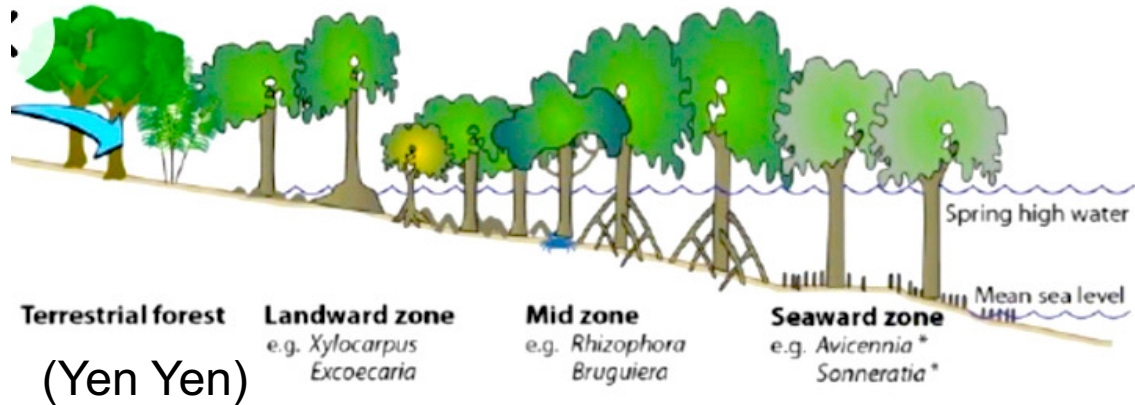


Prop roots of  
*Rhizophora*

(Mehta 1999)

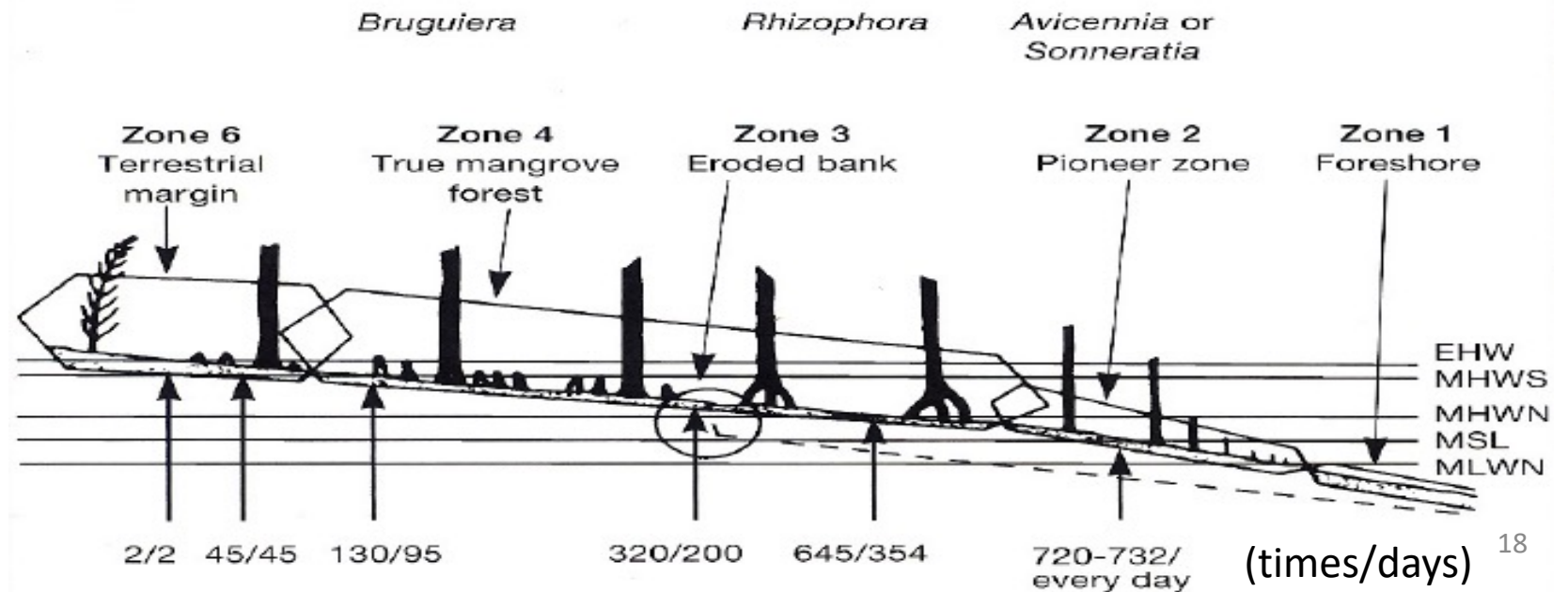
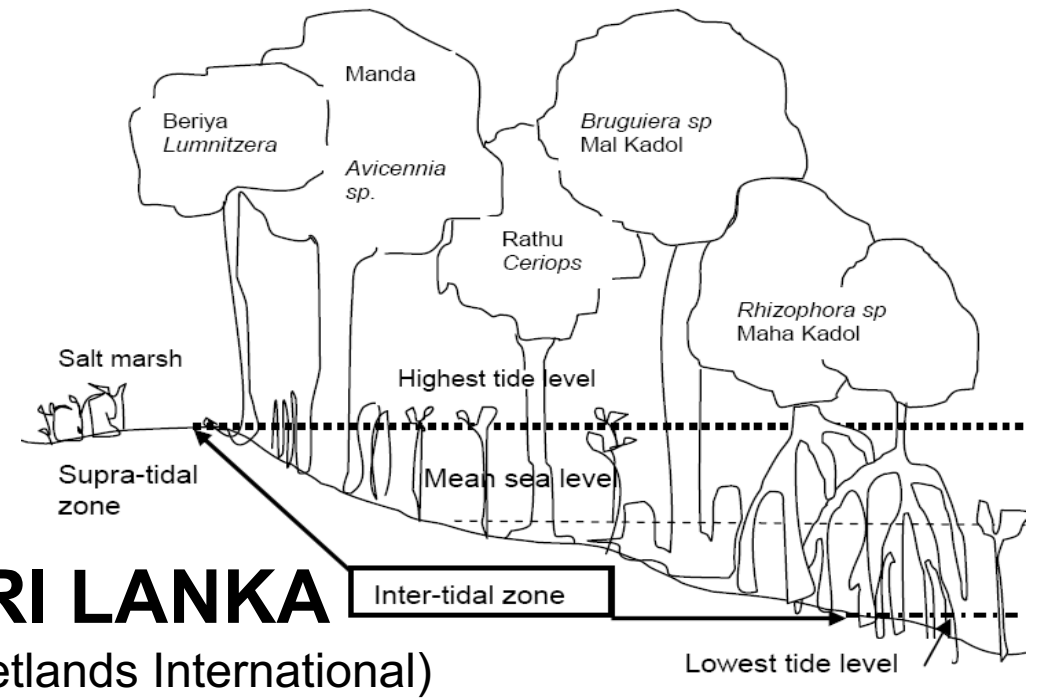


# Zonation



## INDONESIA

(Whitten et al. 1997)





# Inland mangroves

- **Mexico. *R. mangle***, >160 km inland on Yucatan peninsula, besides waterfall.
- Able to survive due to surrounding soils that leach calcium into lagoon & river waters, creating environment similar enough for trees to persist. (Top)
- At elevation of 6-9 m when sea level was >100,000 yr ago. (Aburto-Oropeza et al. 2021).
- **Pakistan : *A. marina*** in low-lying area of about 4.5 ha isolated from Keenjhar lake by narrow embankment as high as 4 m. Mangroves as tall as 1.5 m.
- Earlier, large trees as high as 10 m or more used to grow in area but were all cut by local dwellers for wood & now only their cut stumps are left over. (Bottom) (Saifullah & Rasool 2007).



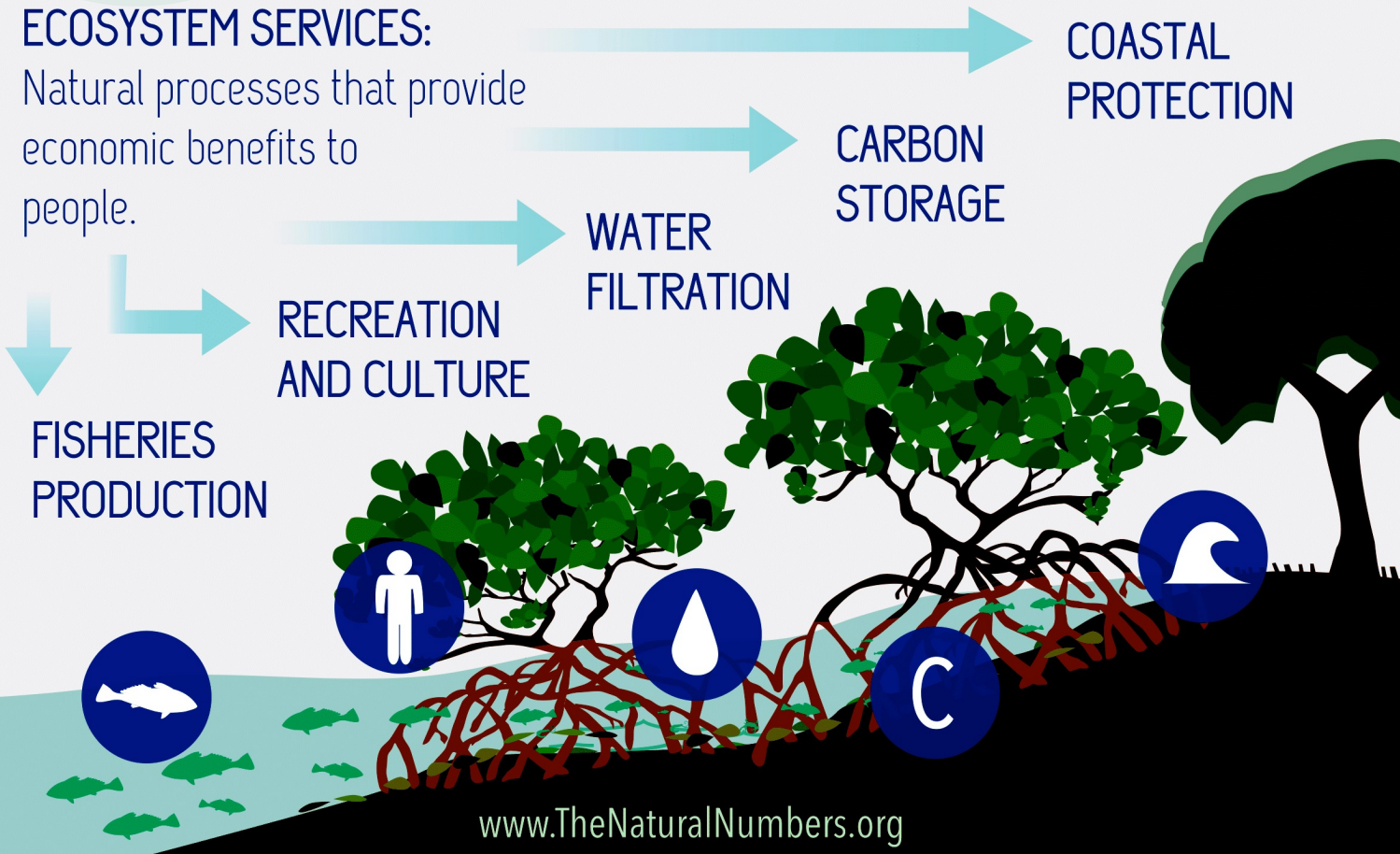
# 3. Benefits



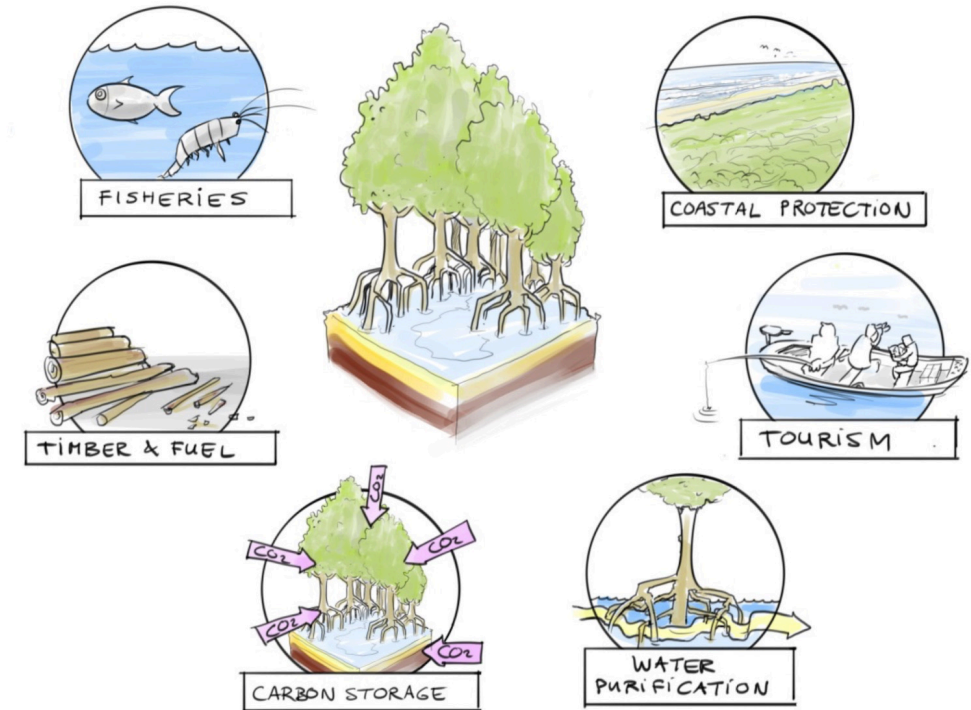
# What makes mangroves valuable to people?

## ECOSYSTEM SERVICES:

Natural processes that provide economic benefits to people.



# Ecosystem services

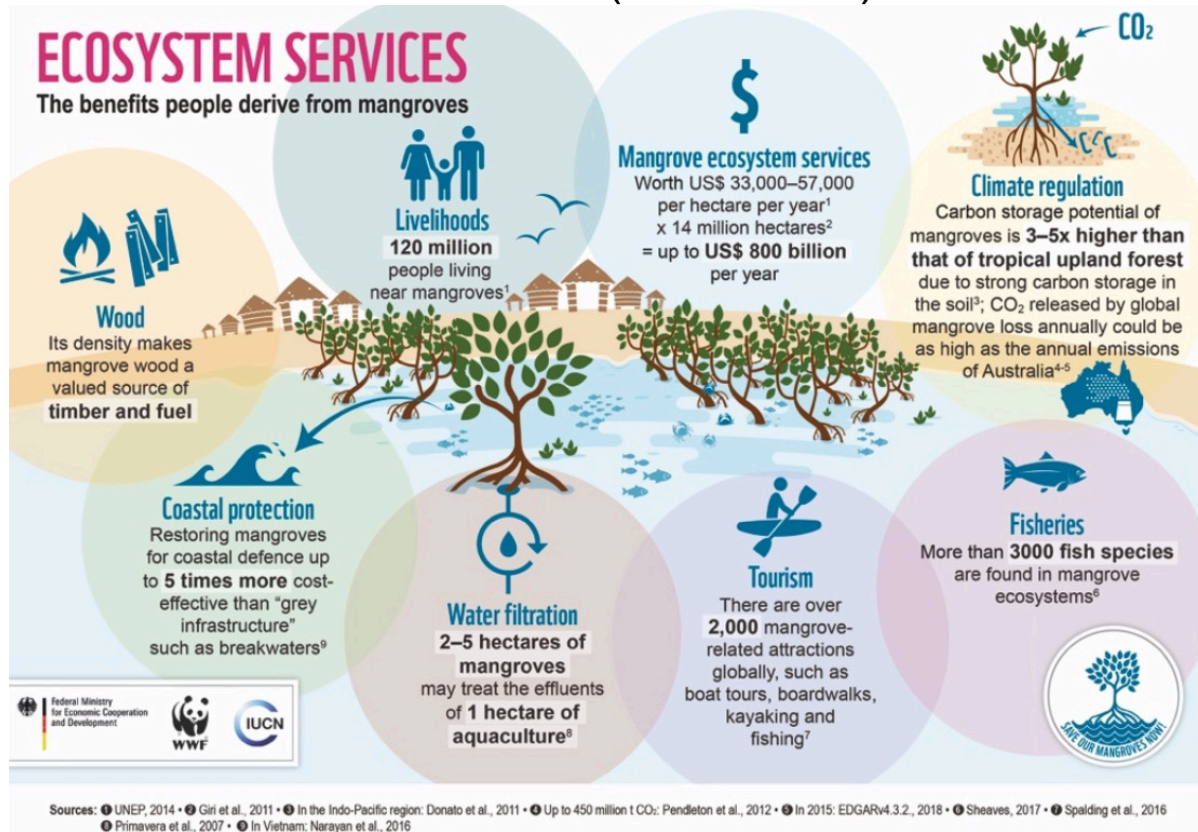


(Tonneijck et al. 2015)



# Ecosystem services : people & \$

(IUCN 2019)



## What are the economic benefits of mangroves?

Though it varies by region, the ecosystem services provided by mangrove forests per hectare each year have enormous economic value:



**RECREATION AND CULTURE<sup>1</sup>**  
**\$37,500 +**



**WATER FILTRATION<sup>3</sup>**  
**\$5,500 +**



**COASTAL PROTECTION<sup>5</sup>**  
**\$3,200 +**



**FISHERIES PRODUCTION<sup>2</sup>**  
**\$37,500 +**



**CARBON STORAGE<sup>4</sup>**  
**\$13,500 +**

Plus additional economic values unaccounted for here including: biodiversity, raw materials, education, forestry, and more.

**Worth over \$100,000 USD**  
per hectare per year

[www.TheNaturalNumbers.org](http://www.TheNaturalNumbers.org)



# Livelihoods

Living in mangrove environment



© P P WONG

Attap (from nipah palm)



© PP WONG



(Zeng Yiwen)

Photo: Zeng Yiwen

Mangrove crab



© PP WONG

Aquaculture



© PP WONG



## COOKING WITH MANGROVES

### 36 INDONESIAN MANGROVE RECIPES

ADAPTED FROM YAYASAN MANGROVE BY MANGROVE ACTION PROJECT



(MAP\_2006)

- Sonneratia Wajit (Sticky Mangrove Apples).....
- Sonneratia Lempok (Candied Mangrove Apples).....
- Sonneratia Juice (Mangrove Apple Juice).....
- Sonneratia Dodol.....  
(Taffy made of sticky rice, coconut milk, and palm sugar)
- Bolu Api-Api (Avicennia Spongecake).....
- Bolu Agar-Agar Api-Api (Avicennia Agar-agar cake)..
- Onde-Onde Api-Api (Round Fried Avicennia cakes)..
- Kripik Manis Buah Api-Api (Sweet Avicennia Crisps).....
- Kripik Asin Buah Api-Api (Salty Avicennia Crisps).....
- Avicennia Crisps.....
- Kue Talam Api-Api (Avicennia Sheet Cake).....
- Kue Talam Manis Api-Api (Sweet Avicennia Sheet Cake)..

# Fruits for food



© PP WONG



## Preperation of *Avicennia* spp. fruits for cooking



© PP WONG

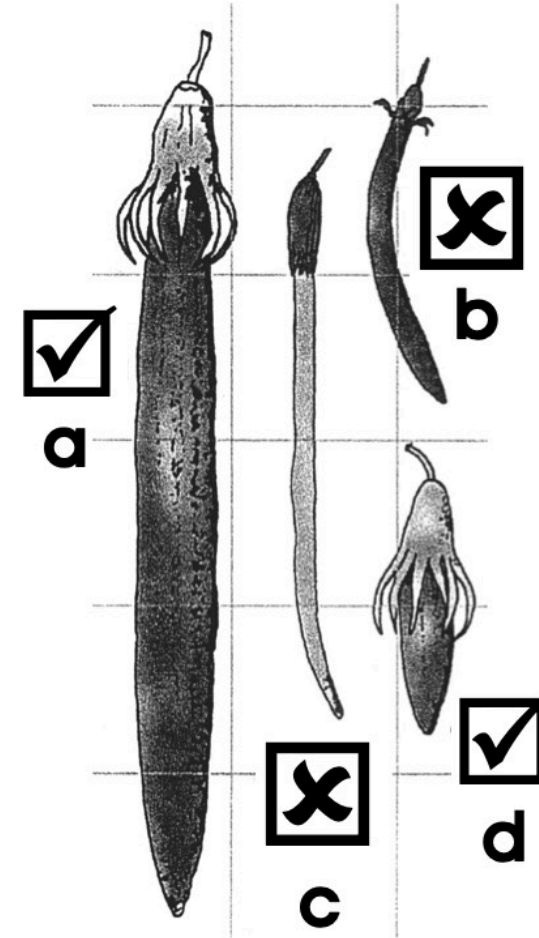
1. Use ripe *Avicennia* fruit. Ripe fruits are yellowish green in color. Ripe fruits are split and have seperated from the calyx. They can be collected from the ground or tree. Do not use fruit that have already developed roots.
2. Remove outer skin
3. Split into four pieces, remove the root bud/pistil
4. Boil *Avicennia* fruits in water and and ash, stir until ash is evenly spread.
5. Remove from heat and clean fruit until color is green.
6. Soak in clean fresh water for two days, changing water every 6 hours.

*Alternatively* you can peel the fruits, soak in water for 3 days, boil, and soak for another three days. During soaking the water is changed every 8 hours.

(MAP 2006) *Note:* In general, *Avicennia alba* is used for making flour for cakes and *Avicennia marina* for fried crackers.

## Preperation of *Bruguiera* spp. fruits for cooking

1. Pick *Bruguiera* fruits from trees  
Ripe fruits are greenish brown in color.
2. Remove calyx
3. Cut into inch long pieces
4. Soak fruits in clean fresh water for two days, changing water every 8 hours.
5. Boil
6. Soak in clean fresh water for two more days, changing water every 8 hours.



(MAP 2006)

- a - *Bruguiera gymnorhiza* (ok to eat)  
b - *Bruguiera parviflora* (not for consumption)  
c - *Bruguiera cylindrica* (not for consumption)  
d - *Bruguiera sexangula* (ok to eat)



# *Avicennia marina* : bread

- I calculated **amount of flour & bread that could be extracted from one hectare (ha) of *A. marina*.**
- According to a source in S China (UNEP 2003), **one ha** of pure forest of *A. marina* can produce **750 kg (wet wt) of fruits per yr.**
- Based on about **35% of water content** in fruits (Sulistiyati et al. 2015) a **ha would therefore yield 487 kg (dry wt) of fruits per yr.** Based on one pound of flour for a large loaf, **487 gm** (more than usual one pound or 454 gm) **of dry flour would produce large loaf of bread as daily food for two persons.** If available, pieces of dried fruits (bananas, pineapples), tubers (sweet potatoes, yams) could be added.
- **In one year, one ha of *A. marina* can produce 487 kg of flour to make 1,000 loaves of bread sufficient to feed 2,000 persons per day or 20 persons for 100 days (>three months).**
- **During WWII**, isolated coastal communities used *Avicennia spp* for food; also noted immediately **after Dec 2004 Indian Ocean tsunami.**
- ***Avicennia marina* :** probably most versatile mangrove species for food as it can establish on wide range of substrates, has widest geographical range & only species to survive in dry conditions & away from sea.

# Timber for wood chips

- **PT. Bintuni Utama Murni Wood Industries (BUMWI)** established in 1988 with licence up to 2052.
- **82,120 ha concession area** covers large part of Bintuni Bay mangrove forest. **2015 : largest mangrove concession in world to obtain international forest management certification.**
- Woodchips exported to Taiwan, China & previously Japan for mixing with other species to increase pulp density & strength (Bottom).
- **Contributed significantly to local economy,** employing average of 800 workers/yr & contributed to **protection of mangrove ecosystem.**

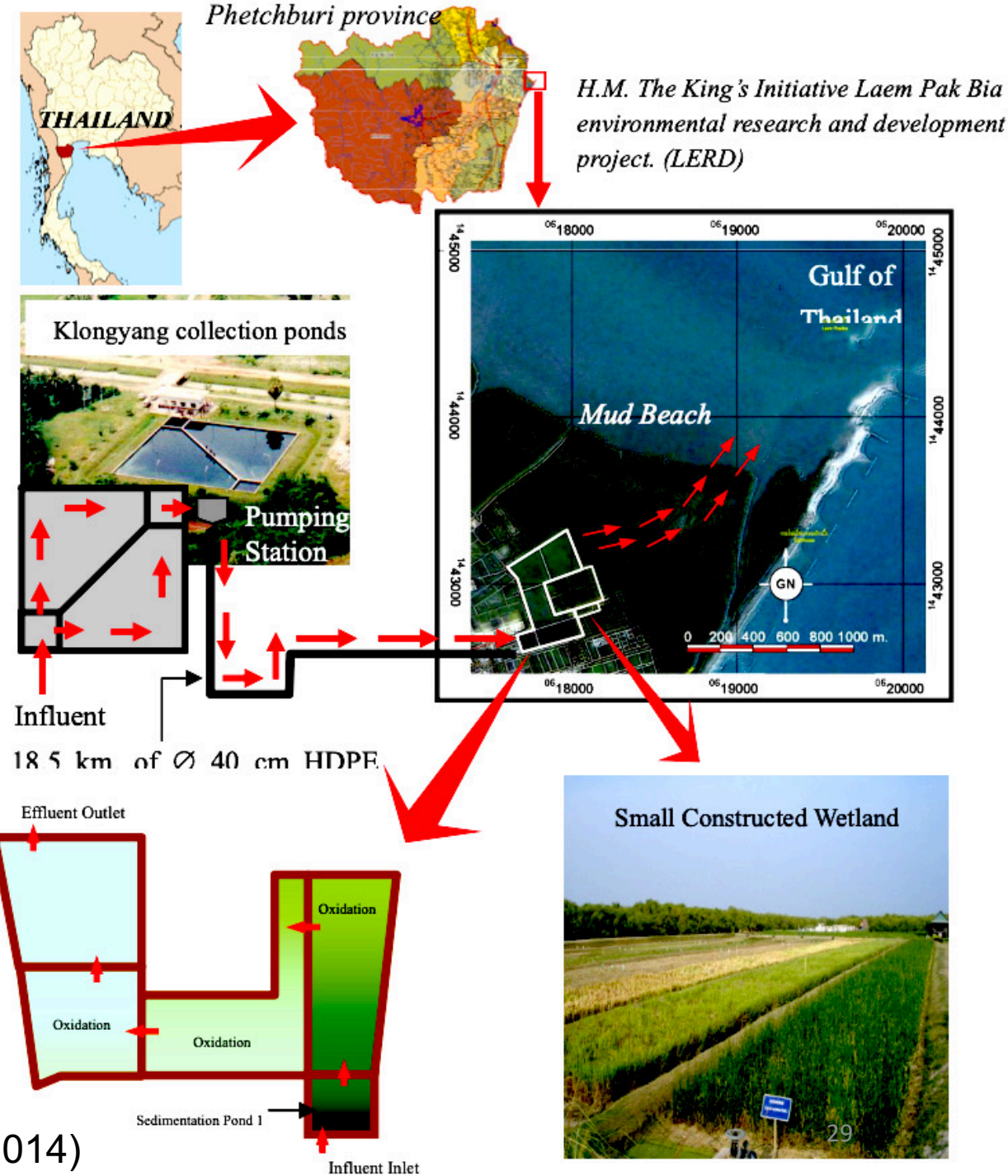




# Wastewater purification



- Treat both wastewater & solid waste through environmentally & ecologically sustainable methods.
- Three methods of wastewater treatments :  
1. Oxidation pond; 2. Constructed wetland;  
3. **Mangrove forest which filtrates wastewater from municipality of Phetchaburi.**
- **300-m route through mangrove forest : mangrove crabs, mudskippers & birds.**



(Chunkao et al. 2014)

# Medicinal uses

**Table 2: Medicinal uses of mangroves and halophytes**

Mangrove plant names	Medicinal uses
<i>Acanthus ilicifolius</i>	To treat paralysis, asthma, diuretic, dyspepsia, hepatitis, leprosy, rheumatic pains. analgesic, anti-inflammatory, leishmanicidal
<i>Aegiceras corniculatum</i>	Cure for asthma, diabetes, rheumatism, fish poison
<i>Avicennia marina</i>	Cure for skin diseases
<i>Avicennia officinalis</i>	Aphrodisiac, diuretic, hepatitis and leprosy.
<i>Bruguiera gymnorhiza</i>	Eye diseases
<i>Bruguiera parviflora</i>	Antitumor.
<i>Ceriops decandra</i>	Hepatitis and ulcers
<i>Lumnitzera racemosa</i>	Antifertility, asthma, diabetes and snake bite
<i>Rhizophora mangle</i>	Angina, boils and fungal infections, antiseptic, diarrhoea, dysentery, elephantiasis, fever, malaria, leprosy, minor bruises, plaster for fractured bones and tuberculosis.
<i>Rhizophora mucronata</i>	Elephantiasis, febrifuge, haematoma, hepatitis and ulcers.
<i>Salicornia brachiata</i>	Hepatitis
<i>Sesuvium portulacastrum</i>	Hepatitis
<i>Sueda maritima</i>	Hepatitis
<i>Sueda monoica</i>	Hepatitis



# Ecotourism

- **The International Ecotourism Society** : “responsible travel to natural areas that conserve the environment, sustains the well-being of the local people, and involves interpretation and education”. **Australian National Ecotourism** : “ecologically sustainable tourism with a primary focus on experiencing natural areas that fosters environmental and cultural understanding, appreciation and conservation.”
- **Ecotourism resources** : plant & animal biodiversity, local livelihoods, indigenous knowledge & culture.
- **Benefits** : benefits for local communities; environmental protection; awareness.
- **Forms** : local private, community-based, private sector, NGO, government-based.
- **Some issues** : negative environmental impacts, garbage generation, risk of turning into mass tourism, off-site negative impacts, etc.

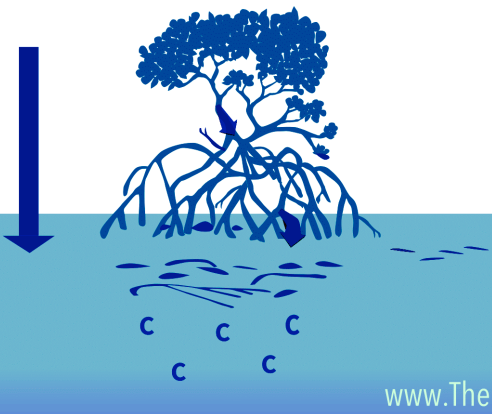


# Mangroves and climate change

How are mangroves and climate connected?

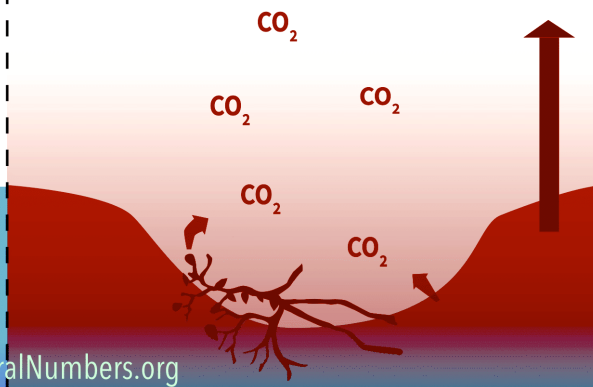
Carbon dioxide (CO<sub>2</sub>) from the atmosphere is taken up by mangroves, slowing climate change by storing the carbon belowground.

CARBON SEQUESTRATION AND STORAGE



When destroyed, this carbon is released from the soil into the air, contributing to climate change by increasing carbon emissions.

CARBON EMISSIONS INTO ATMOSPHERE



© PP WONG

- *R. mucronata*, 25 yr old (2013) : Fastest-growing species.
- Some erosion but not seriously.



# Carbon sequestration

- Account for only approximately **1%** (13.5 Gt year<sup>-1</sup>) of carbon sequestration by world's forests; as coastal habitats they account for **14%** of carbon sequestration by global ocean.

- Carbon from dead material remains trapped in sediment** rather than quickly escaping into atmosphere.

- Watery carbon reservoir : **“blue carbon”**.

(Alongi 2012)

Table 2. Global contribution of mangroves and other coastal habitats to carbon sequestration in the global coastal ocean.

Habitat	Area (10 <sup>12</sup> m <sup>2</sup> )	Sequestration rate (gC m <sup>-2</sup> year <sup>-1</sup> )	Global carbon sequestration (Tg year <sup>-1</sup> )
Mangroves	0.14 (0.5%)	174	24 (14%)
Salt marshes	0.22 (0.8%)	150	33 (20%)
Seagrasses	0.3 (1.1%)	54	16 (10%)
Estuaries	1.1 (4.0%)	45	50 (30%)
Shelves	26 (93.6%)	17	44 (26%) <sup>†</sup>
Total			167

<sup>†</sup>Assumes that depositional areas cover 10% of total shelf area [9].  
Data from [41,60–62].

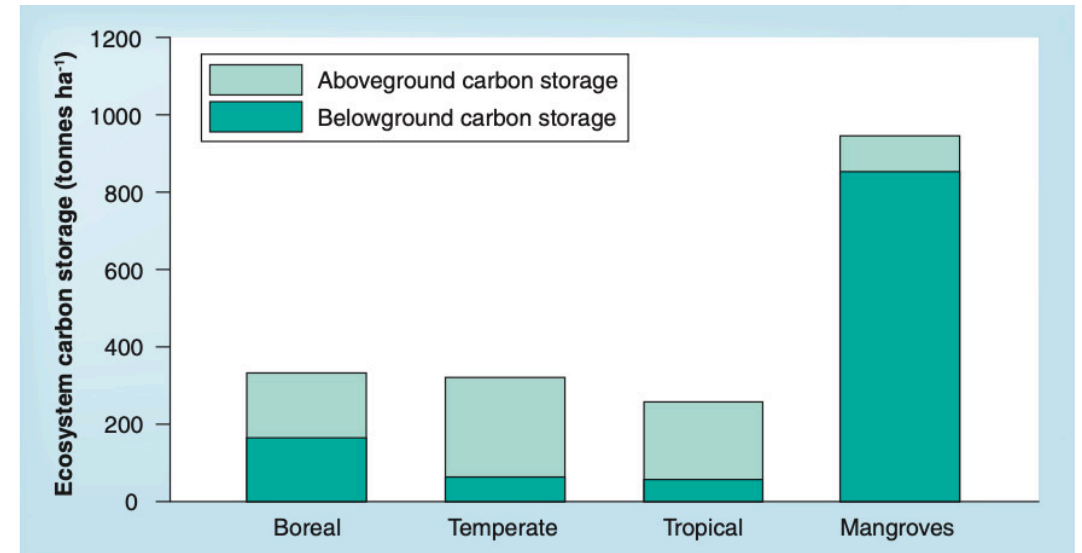
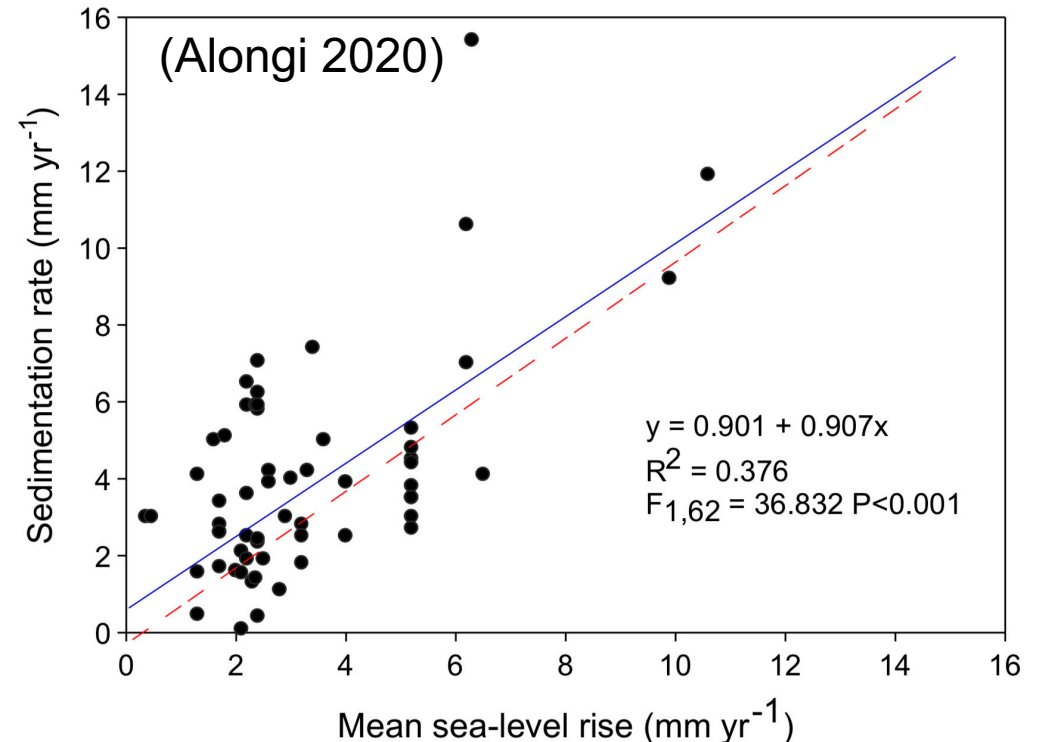
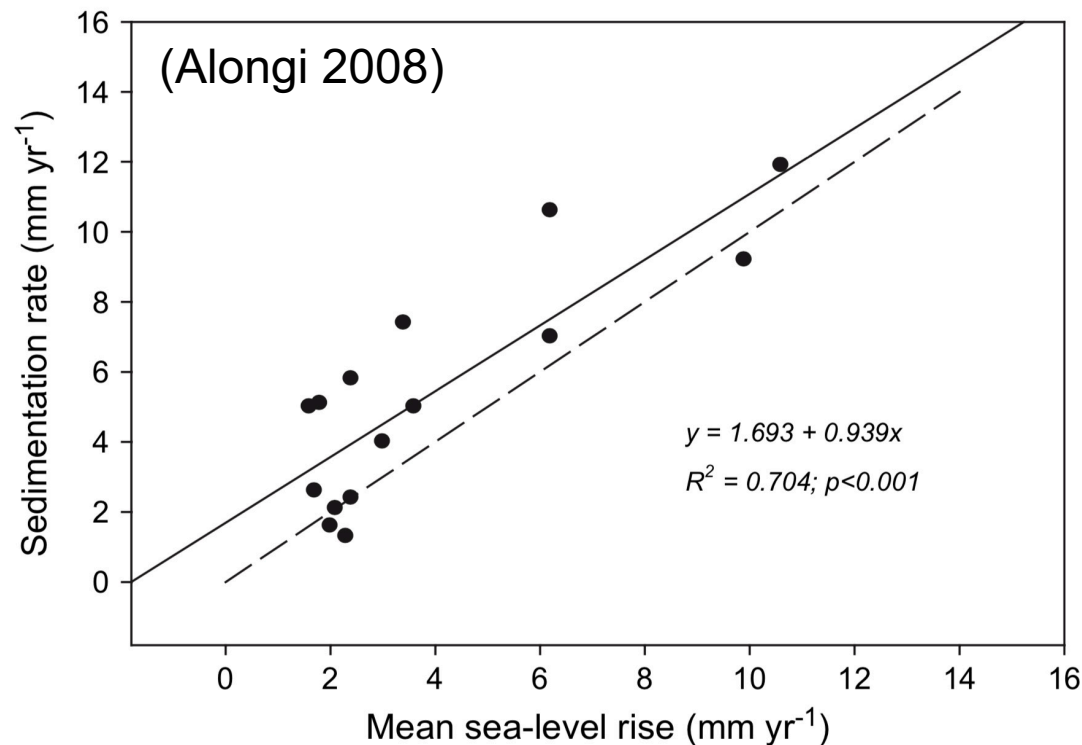


Figure 1. Differences in whole-ecosystem carbon stocks among boreal, temperate and tropical terrestrial forests, and subtropical and tropical mangrove forests.

# Mangroves and sea-level rise

- Mangroves can keep up with SLR of at less 1 mm/annum & higher if conditions are suitable.
- “Intact and healthy mangrove systems can adapt to sea level rise; their growth can accommodate to increases of 3.8 up to 9 millimetres per year depending on local circumstances..” (Wetlands International).





# Processes controlling sedimentation

- Sediment **accretion & erosion** – tides, waves, storms, etc.
- **Biotic contributions** – leaf litter, algal mats.
- **Belowground primary production** – roots, soil organic matter.
- **Autocompaction.**
- **Fluctuations in water table & pore water** – hydrology & groundwater inputs.

(Gillman et al. 2008)

# 4. Threats



# What are the greatest threats to mangroves?

#1 Deforestation  
from 4 main factors

35%  
of the world's  
mangroves are  
GONE.



**AQUACULTURE**  
(e.g. shrimp farms)



**AGRICULTURE**  
(e.g. palm oil plantations)



**TOURISM**  
(e.g. cruise ports,  
mega-developments)

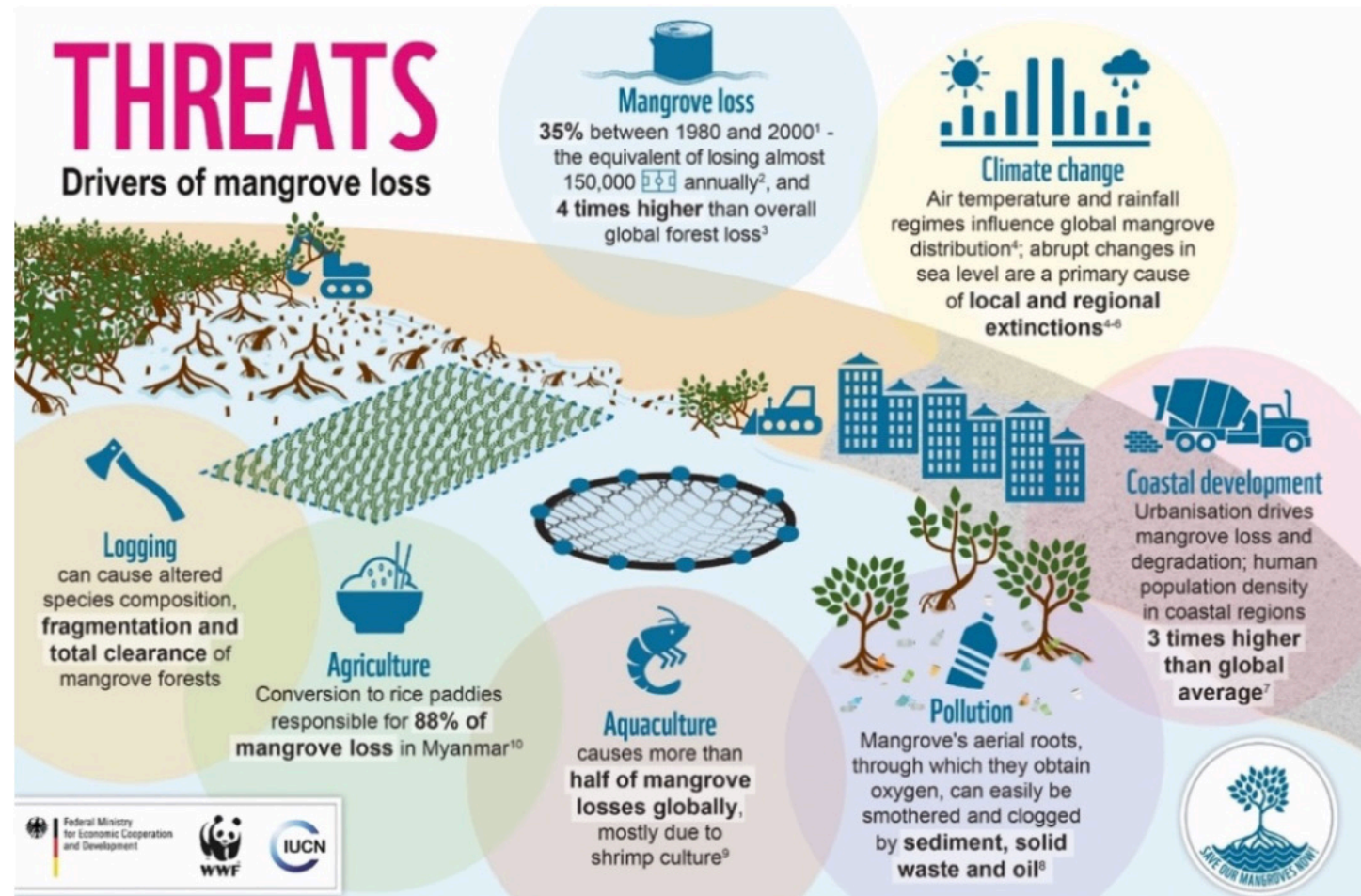


**URBAN SPRAWL**  
(e.g. residential housing,  
commercial developments)



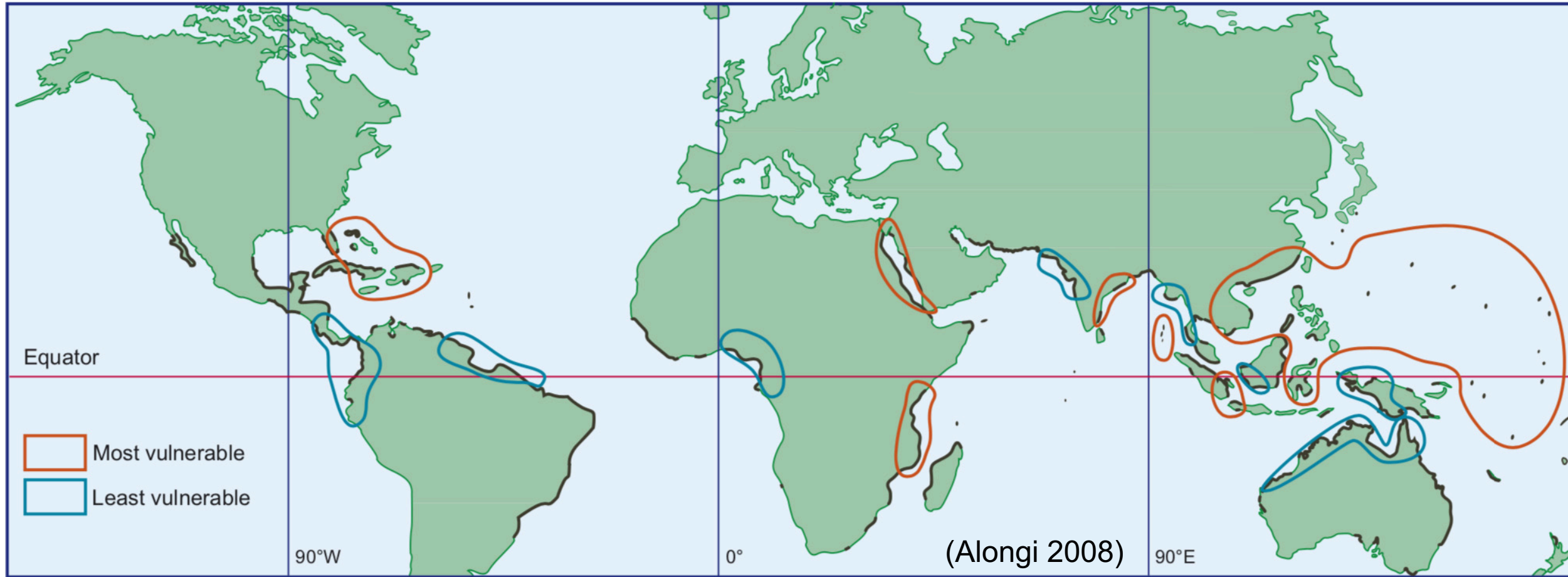
www.TheNaturalNumbers.org

# Threats ⇒ Loss



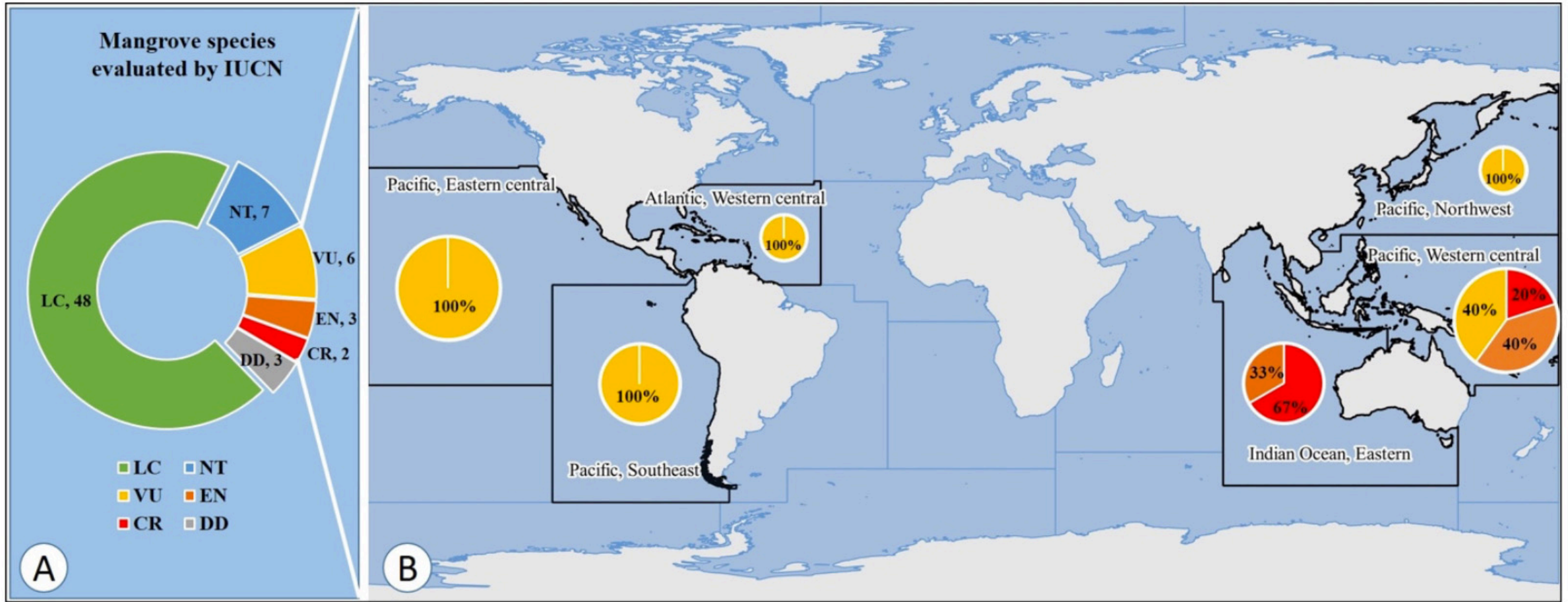
(IUCN 2019)

# Vulnerability





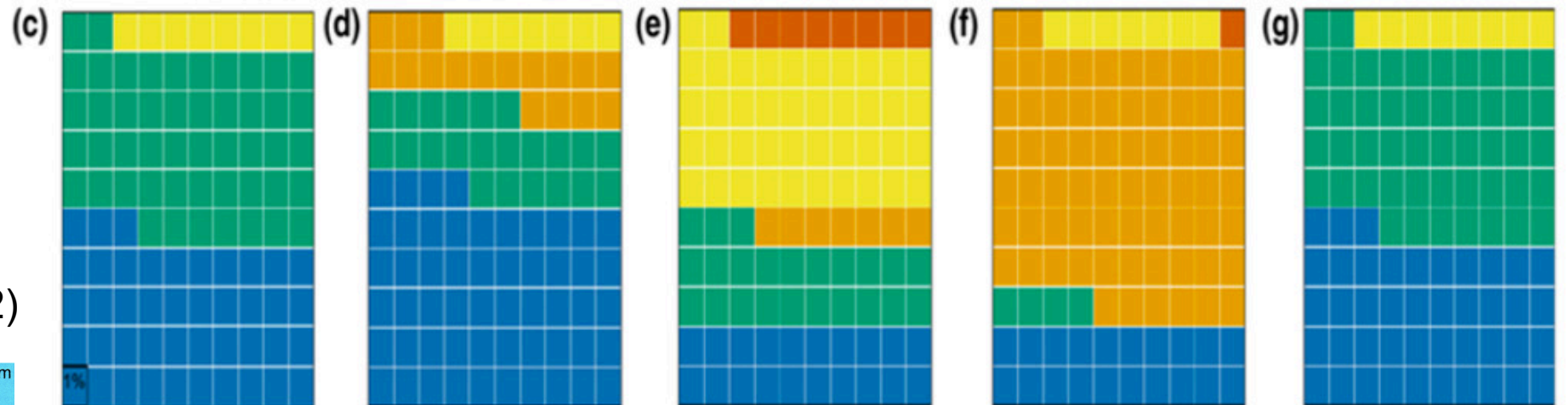
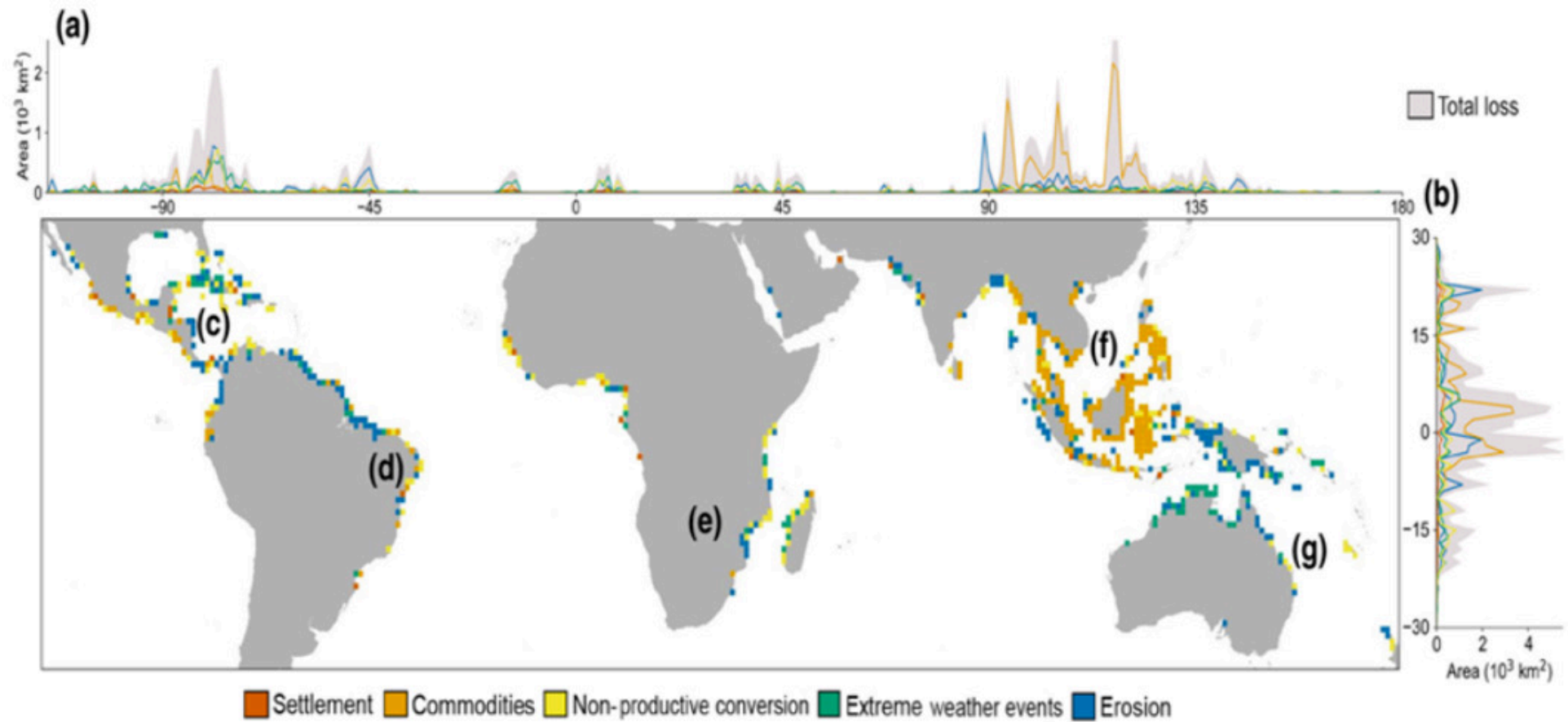
# Vulnerable, Endangered & Critically Endangered



(Bhowmik et al. 2022)

**Figure 1.** (A) Status of the global mangrove species and (B) geographic coverage of the threatened mangrove species (LC: Least Concern; VU: Vulnerable; CR: Critically Endangered; NT: Not Threatened; EN: Endangered; DD: Data Deficient).

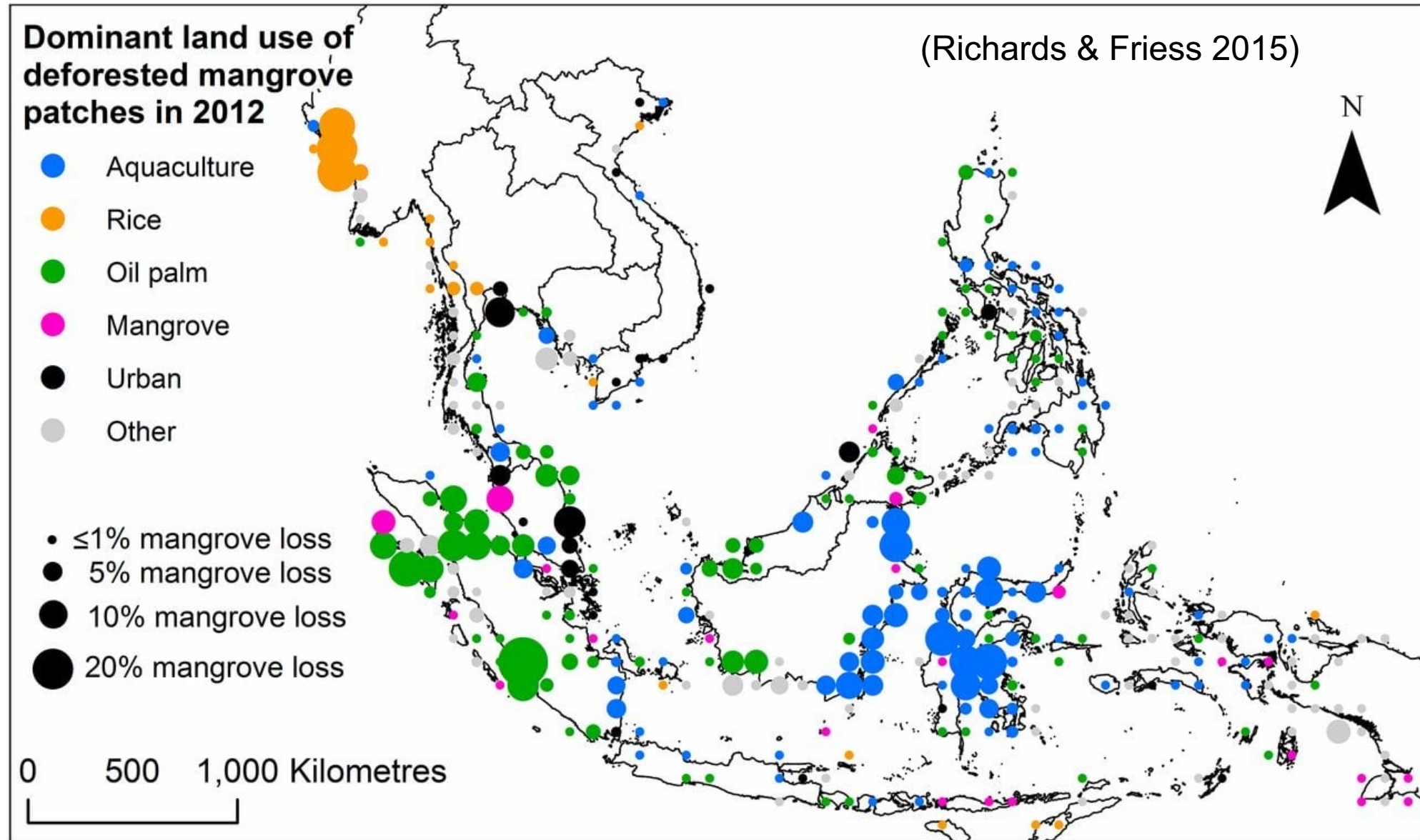
# Mangrove loss



(Goldberg et al. 2022)



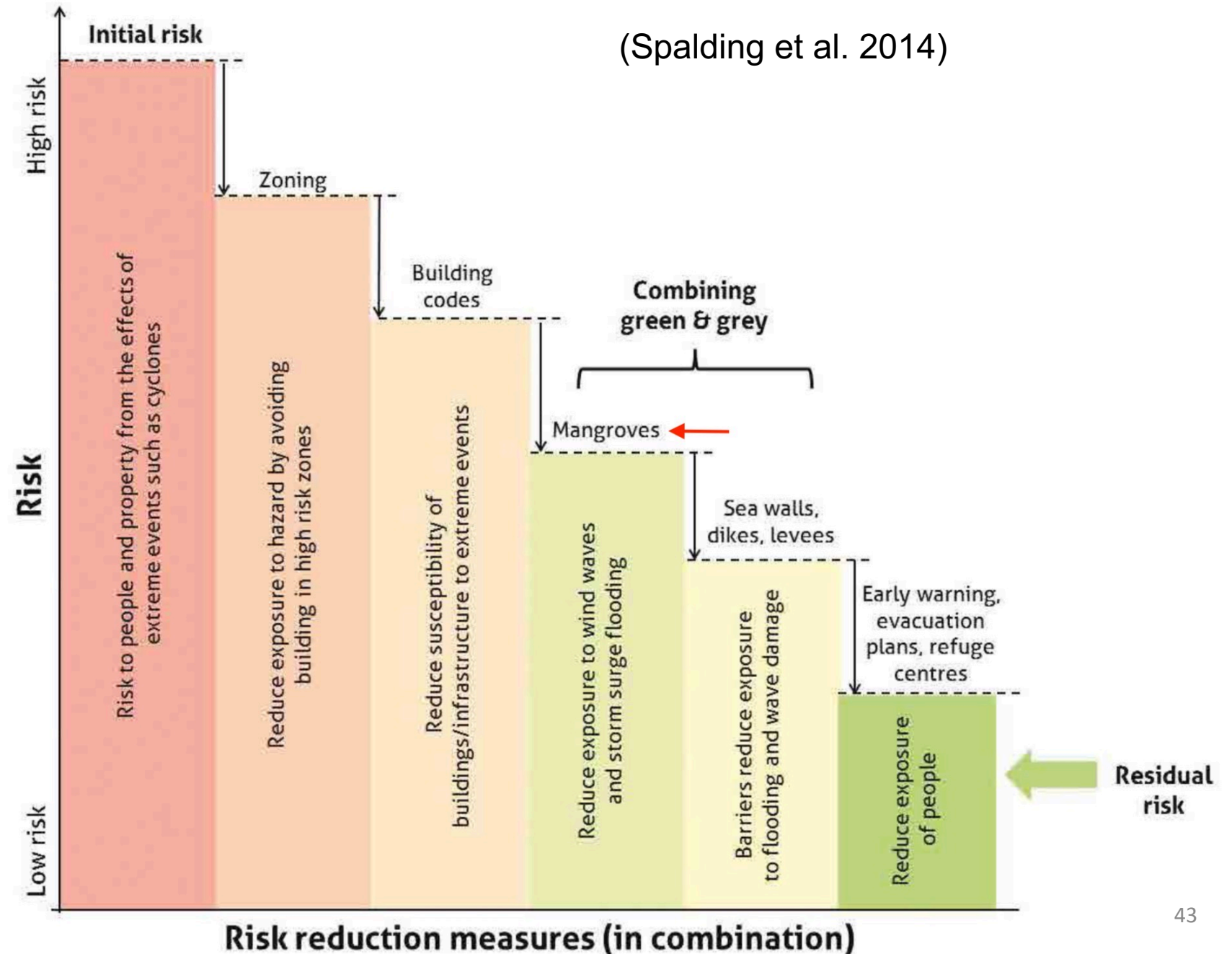
# SE Asia : deforestation in 2012



# 5. Coastal protection



# Risk reduction at coasts



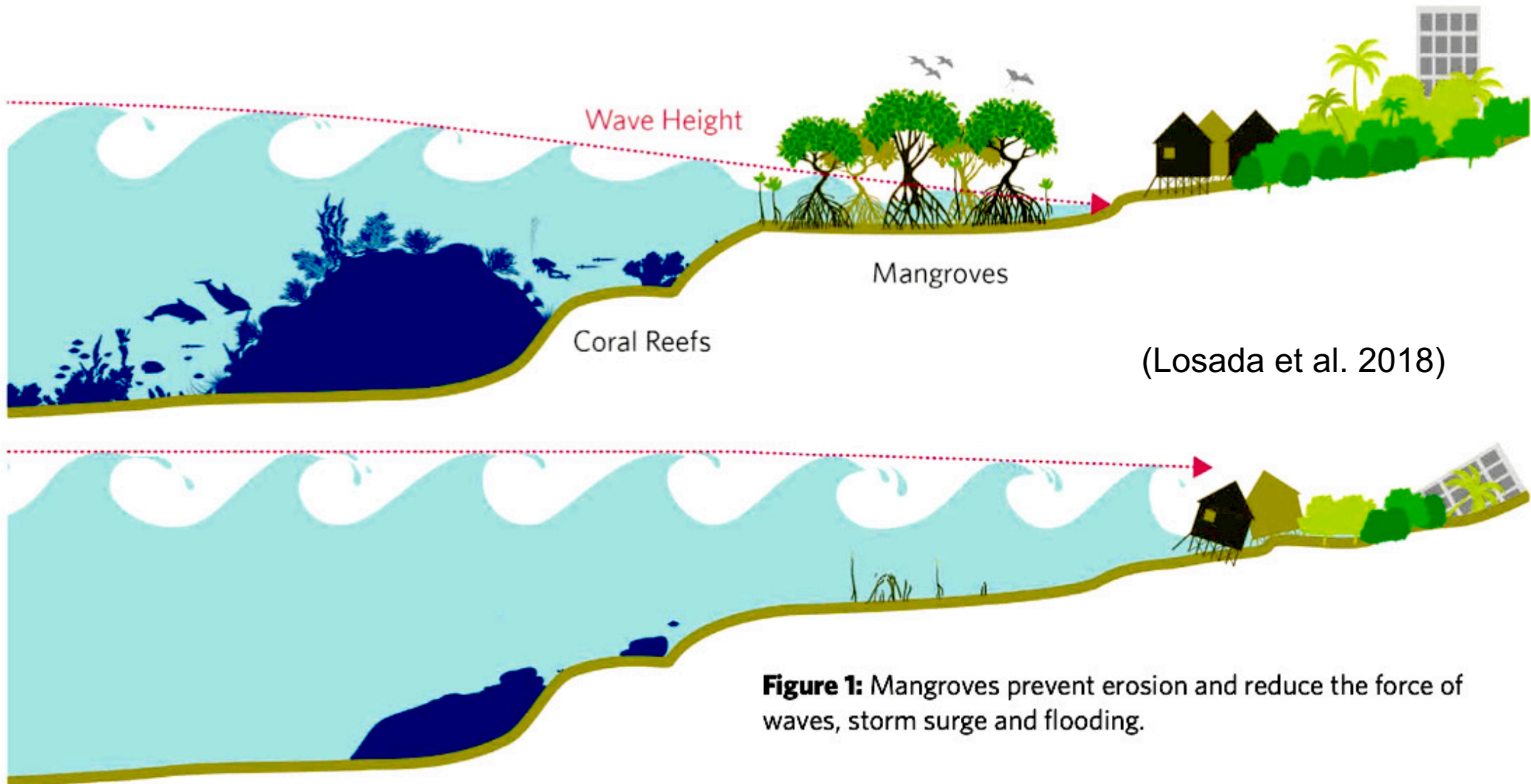
# 26 Dec 2004 tsunami : mangroves

- **Anecdotal evidence** of mangroves protecting villages in the rear of mangrove forests which slow down tsunami waves.
- Publications on **protection** include (Danielson et al. 2005; Dahdoub-Guebas et al. 2005; Kathiresan & Rajendran 2005; Chang et al. 2006; Tanaka et al. 2007).
- Publications **disputing the evidence/countering** argument include (Kerr et al. 2006; Kerr & Baird 2007; Bhalla 2007).
- **Watershed for conservation** of global mangroves.

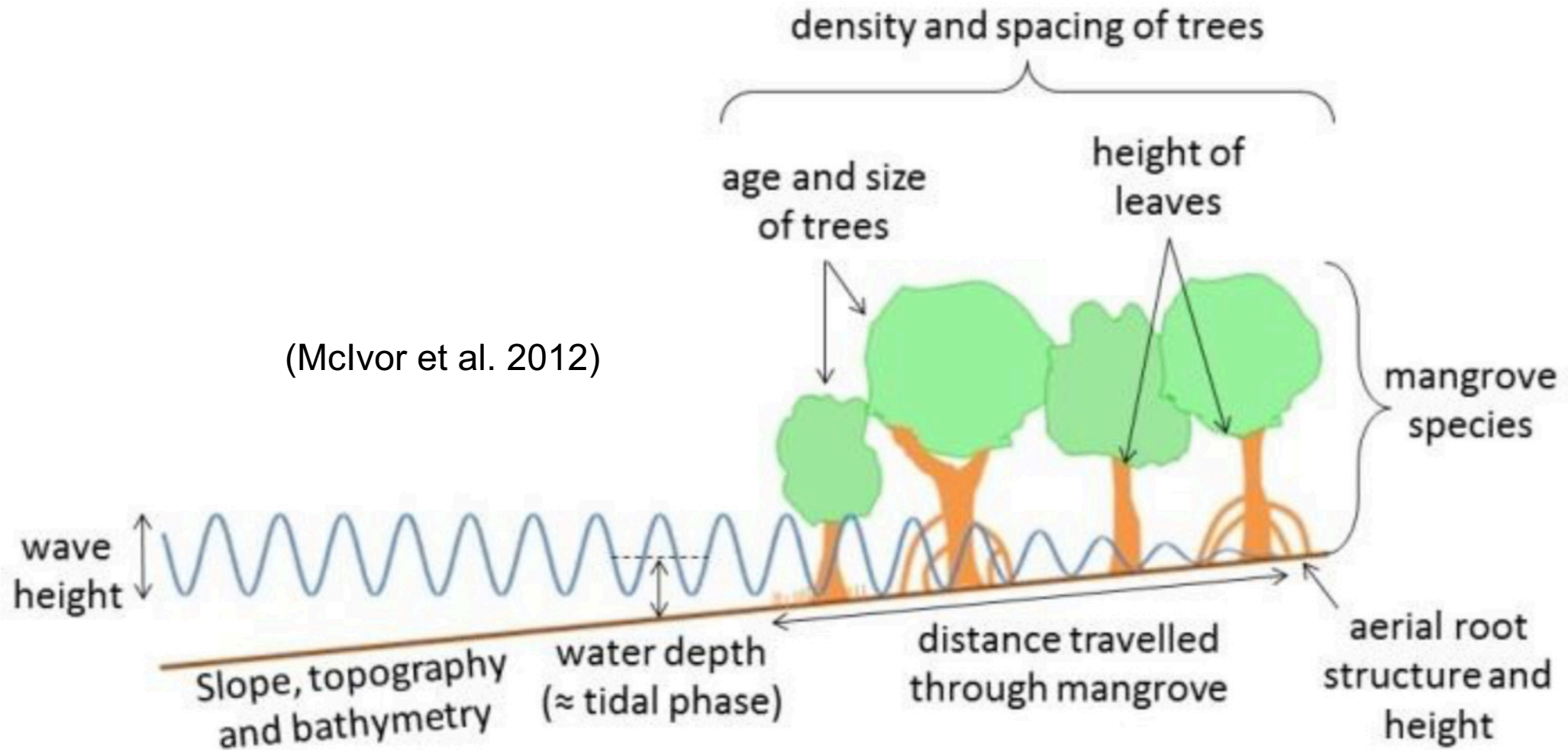




# Mangroves reduce wave height



# Mangroves : factors in wave height reduction











# Mangroves as wave buffer (1)

- Publications on **experiments & field studies done on effectiveness of mangroves** (Mazda et al. 2007).
- All evidence suggests that mangroves can reduce height of wind & swell waves over relatively short distances: wave height can be **reduced by 13 - 66% over 100 m of mangroves** (McIvor et al. 2012).
- Review by Cochard et al. (2008) & other studies show that mangrove forests can be a **significant buffer to waves up to 4 m.**




# Mangroves as wave buffer (2)

Ecosystem type	Dominant ecosystem processes	Dominant buffer composition	Approximate wave buffer effectiveness range				Expected tsunami energy exposure
			Normal waves	Storm waves	< 4 m high tsunami	> 8 m high tsunami	
(a) Coral reefs	Biotic	Physical	▼~▼ <sup>1</sup>	X~▼ <sup>1</sup>	▲~▼ <sup>6</sup>	▲~▼ <sup>6</sup>	
(b) Seagrass beds	Biotic/physical	Biotic/physical	▼~▼ <sup>2</sup>	X~▼ <sup>2</sup>	▼~▼ <sup>7</sup>	X~▼ <sup>7</sup>	
(c) Mangrove forests	Biotic/physical	Biotic	▼~▼ <sup>3</sup>	▼~▼ <sup>3,5</sup>	▼~▼ <sup>8</sup>	▲~▼ <sup>8</sup>	
(d) Beaches and dunes	Physical	Physical	▼ <sup>4</sup>	▼~▼ <sup>4,5</sup>	▼~▼ <sup>9</sup>	X~▼ <sup>9</sup>	
(e) Beach forest	Biotic	Biotic	—	▼~▼ <sup>5</sup>	▼~▼ <sup>10</sup>	X~▼ <sup>10</sup>	
(f) Other dense forests	Biotic	Biotic	—	▼~▼ <sup>5</sup>	▼~▼ <sup>10</sup>	X~▼ <sup>10</sup>	

Legend:

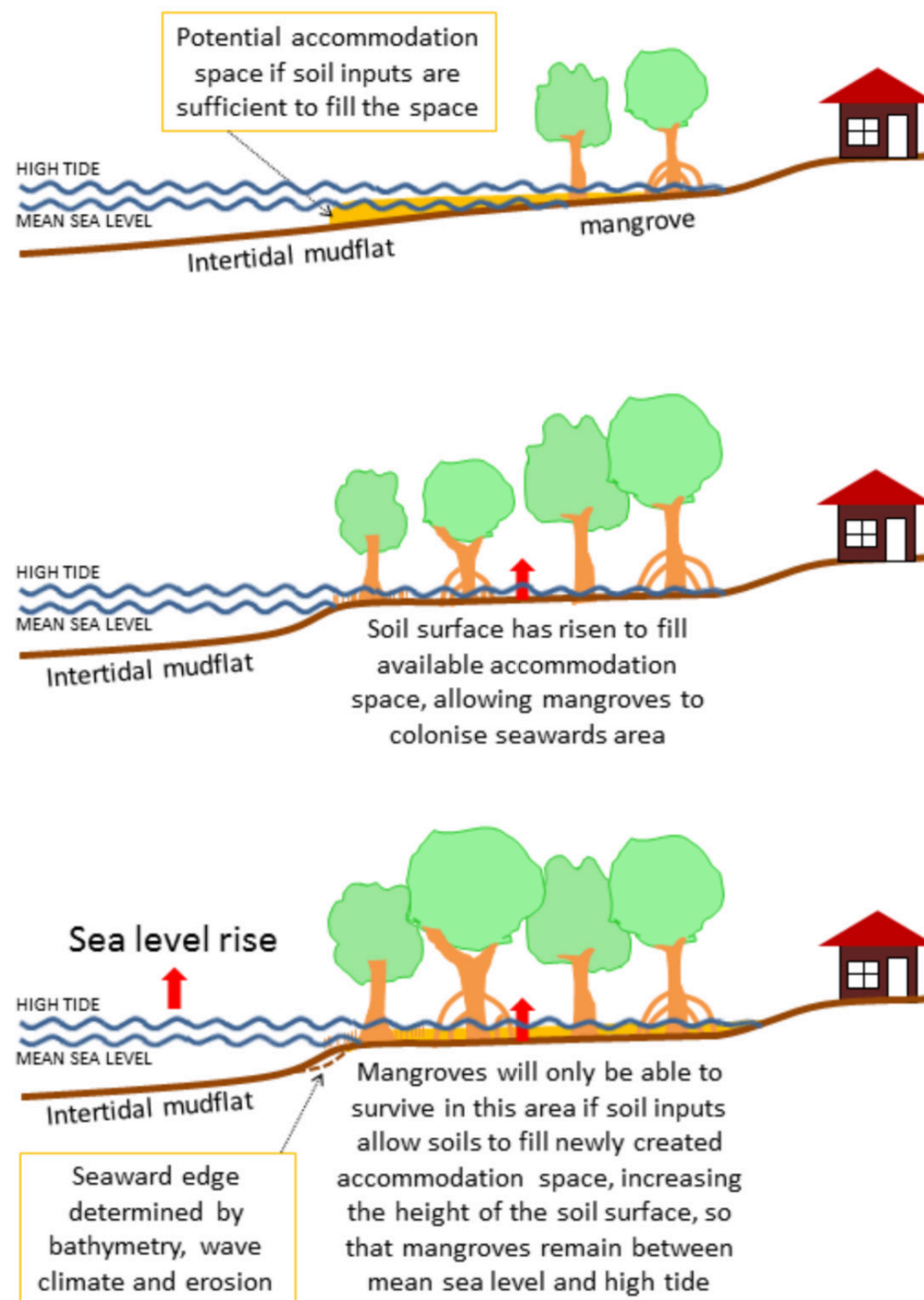
▲ Hazard amplification  
▼ Hazard mitigation  
X No effect

▼ ▲ Slight effect (not evident, but measurable)  
▼ Moderate effect (evident, ~20–50% energy reduction)  
→ ▼ Considerable effect (~50–100% energy reduction)

 Small  
 Medium  
 High



# Mangroves for coastal protection : need for soil inputs



(McIvor et al. 2013)

# EbA and NbS

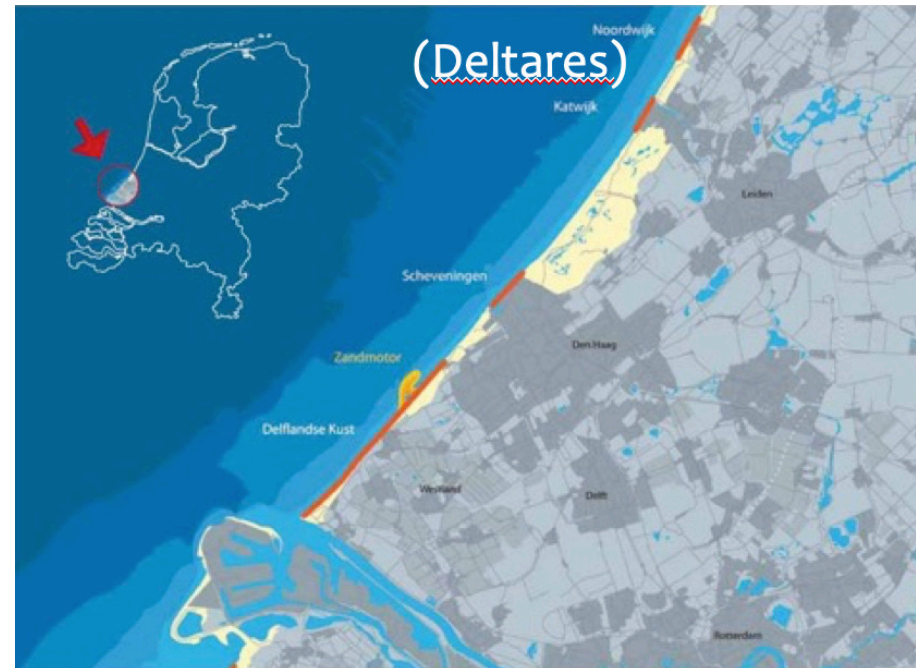
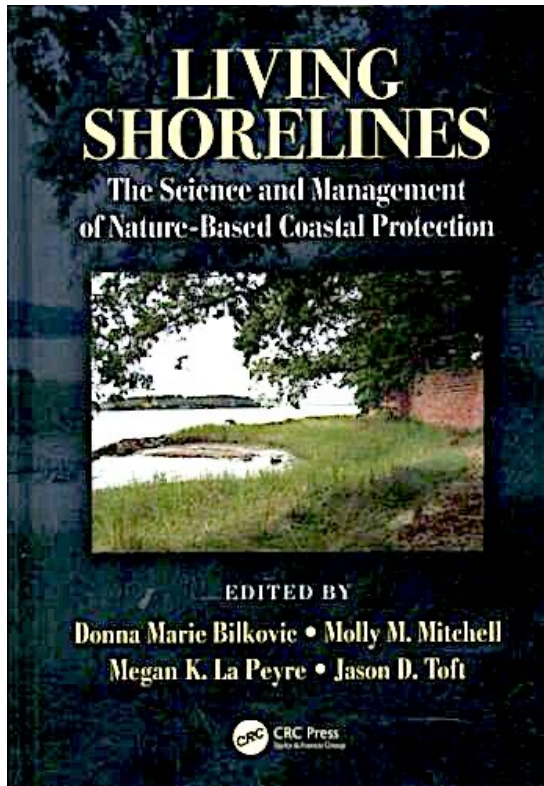
- “**Natural ecosystems** such as coastal forests, coral reefs, **mangrove belts**, beach ridges, sand dunes or forested slopes **are effective barriers against many types of natural disasters**. Such reinforcements can be a cost-effective insurance against storm surges, tsunami and sea-level rise for coastal communities that cannot afford expensive infrastructural protection.”  
(*Planet Prepare* 2008: 63)





# Living shorelines

- **Delfland Sand Engine** : mega-nourishment of 21.5 million m<sup>3</sup> of sand in single location at +5 msl.



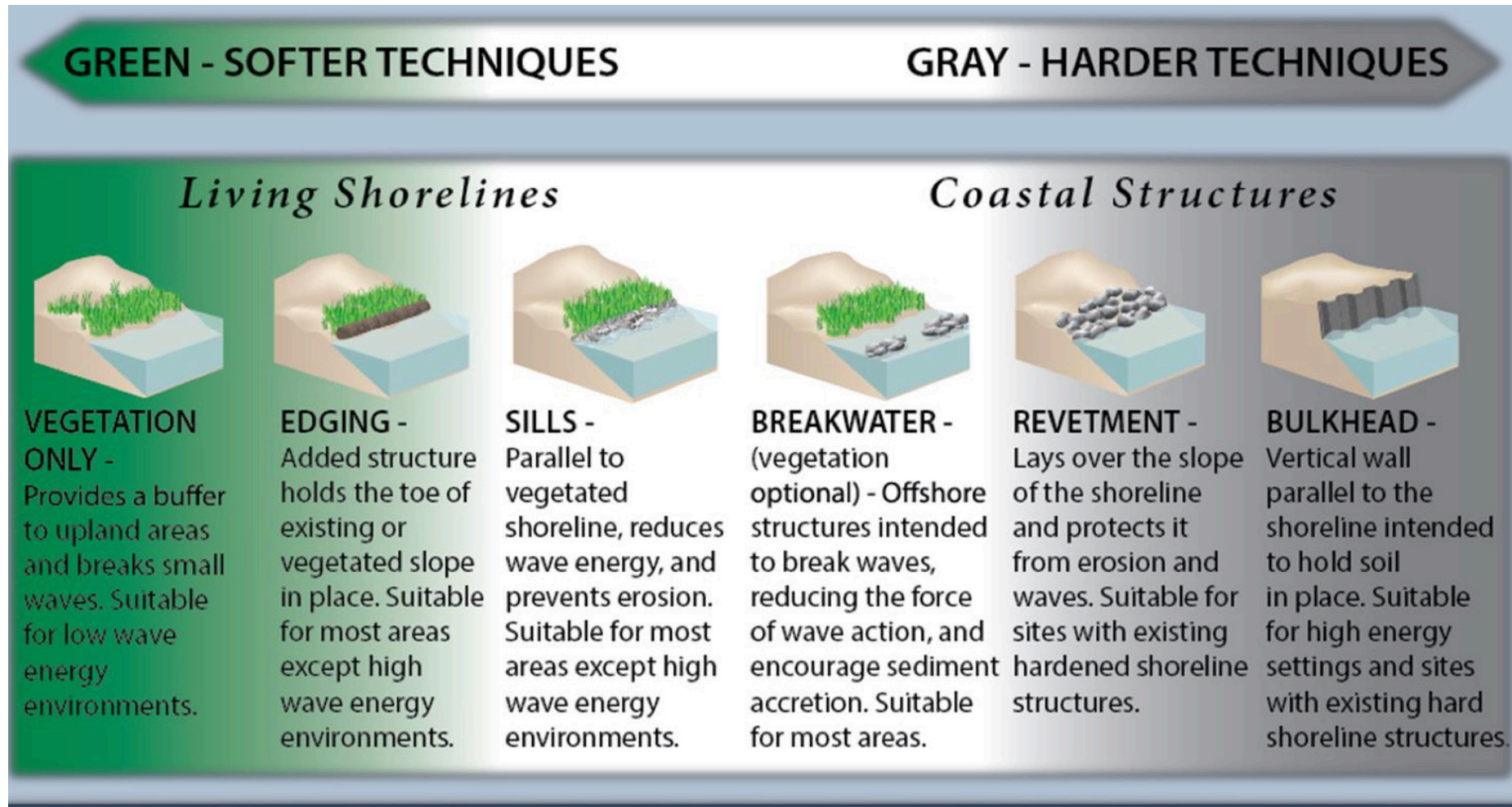
The Delfland Sand Engine after realisation (2011)



The Delfland Sand Engine in 2015  
(Ecoshape)



# System Approach to Geomorphic Engineering (1)



**Figure 1:** A continuum of green (soft) to gray (hard) shoreline stabilization techniques. Source: This continuum is based on the more detailed continuum in the Systems Approach to Geomorphic Engineering (SAGE) Natural and Structural Measures for Shoreline Stabilization brochure (SAGE 2015).



# System Approach to Geomorphic Engineering (2)

**GREEN - SOFTER TECHNIQUES**  
Small Waves | Small Fetch | Gentle Slope | Sheltered Coast

**HOW GREEN OR GRAY**  
**SHOULD YOUR SHORELINE SOLUTION BE?**

**GRAY - HARDER TECHNIQUES**  
Large Waves | Large Fetch | Steep Slope | Open Coast

## LIVING SHORELINE

VEGETATION ONLY	EDGING	SILLS	BEACH NOURISHMENT ONLY	BEACH NOURISHMENT & VEGETATION ON DUNE
<p>Roots hold soil in place to reduce erosion. Provides a buffer to upland areas and breaks small waves.</p> <p><b>Suitable For</b> Low wave energy environments.</p> <p><b>Material Options</b></p> <ul style="list-style-type: none"> <li>Native plants*</li> </ul> <p><b>Benefits</b></p> <ul style="list-style-type: none"> <li>Dissipates wave energy</li> <li>Slows inland water transfer</li> <li>Increases natural storm water infiltration</li> <li>Provides habitat and ecosystem services</li> <li>Minimal impact to natural community and ecosystem processes</li> <li>Maintains aquatic/terrestrial interface and connectivity</li> <li>Flood water storage</li> </ul> <p><b>Disadvantages</b></p> <ul style="list-style-type: none"> <li>No storm surge reduction ability</li> <li>No high water protection</li> <li>Appropriate in limited situations</li> <li>Uncertainty of successful vegetation growth and competition with invasive</li> </ul>	<p>Structure to hold the toe of existing or vegetated slope in place. Protects against shoreline erosion.</p> <p><b>Suitable For</b> Most areas except high wave energy environments.</p> <p><b>Vegetation</b>* Base with Material Options</p> <ul style="list-style-type: none"> <li>"Snow" fencing</li> <li>Erosion control blankets</li> <li>Geotextile tubes</li> <li>Living reef (oyster/mussel)</li> <li>Rock gabion baskets</li> </ul> <p><b>Benefits</b></p> <ul style="list-style-type: none"> <li>Dissipates wave energy</li> <li>Slows inland water transfer</li> <li>Provides habitat and ecosystem services</li> <li>Increases natural storm water infiltration</li> <li>Toe protection helps prevent wetland edge loss</li> </ul> <p><b>Disadvantages</b></p> <ul style="list-style-type: none"> <li>No high water protection</li> <li>Uncertainty of successful vegetation growth and competition with invasive</li> </ul>	<p>Parallel to existing or vegetated shoreline, reduces wave energy and prevents erosion. A gapped approach would allow habitat connectivity, greater tidal exchange, and better waterfront access.</p> <p><b>Suitable For</b> Most areas except high wave energy environments.</p> <p><b>Vegetation</b>* Base with Material Options</p> <ul style="list-style-type: none"> <li>Stone</li> <li>Sand breakwaters</li> <li>Living reef (oyster/mussel)</li> <li>Rock gabion baskets</li> </ul> <p><b>Benefits</b></p> <ul style="list-style-type: none"> <li>Provides habitat and ecosystem services</li> <li>Dissipates wave energy</li> <li>Slows inland water transfer</li> <li>Provides habitat and ecosystem services</li> <li>Increases natural storm water infiltration</li> <li>Toe protection helps prevent wetland edge loss</li> </ul> <p><b>Disadvantages</b></p> <ul style="list-style-type: none"> <li>Require more land area</li> <li>No high water protection</li> <li>Uncertainty of successful vegetation growth and competition with invasive</li> </ul>	<p>Large volume of sand added from outside source to an eroding beach. Widens the beach and moves the shoreline seaward.</p> <p><b>Suitable For</b> Low-lying oceanfront areas with existing sources of sand and sediment.</p> <p><b>Material Options</b></p> <ul style="list-style-type: none"> <li>Sand</li> </ul> <p><b>Benefits</b></p> <ul style="list-style-type: none"> <li>Expands usable beach area</li> <li>Lower environmental impact than hard structures</li> <li>Flexible strategy</li> <li>Redesigned with relative ease</li> <li>Provides habitat and ecosystem services</li> </ul> <p><b>Disadvantages</b></p> <ul style="list-style-type: none"> <li>Requires continual sand resources for replenishment</li> <li>No high water protection</li> <li>Appropriate in limited situations</li> <li>Possible impacts to regional sediment transport</li> </ul>	<p>Helps anchor sand and provide a buffer to protect inland area from waves, flooding and erosion.</p> <p><b>Suitable For</b> Low-lying oceanfront areas with existing sources of sand and sediment.</p> <p><b>Material Options</b></p> <ul style="list-style-type: none"> <li>Sand with vegetation</li> <li>Can also strengthen dunes with: <ul style="list-style-type: none"> <li>Geotextile tubes</li> <li>Rocky core</li> </ul> </li> </ul> <p><b>Benefits</b></p> <ul style="list-style-type: none"> <li>Expands usable beach area</li> <li>Lower environmental impact</li> <li>Flexible strategy</li> <li>Redesigned with relative ease</li> <li>Vegetation strengthens dunes and increases their resilience to storm events</li> <li>Provides habitat and ecosystem services</li> </ul> <p><b>Disadvantages</b></p> <ul style="list-style-type: none"> <li>Requires continual sand resources for replenishment</li> <li>No high water protection</li> <li>Appropriate in limited situations</li> <li>Possible impacts to regional sediment transport</li> </ul>

\* Native plants and materials must be appropriate for current salinity and site conditions.

Initial Construction: ● = up to \$1000 per linear foot, ●● = \$1001 - \$2000 per linear foot, ●●● = \$2001 - \$5000 per linear foot, ●●●● = \$5001 - \$10,000 per linear foot  
Operations and Maintenance (yearly for a 50 year project life): ● = up to \$100 per linear foot, ●● = \$101 - \$500 per linear foot, ●●● = over \$500 per linear foot

## COASTAL STRUCTURE

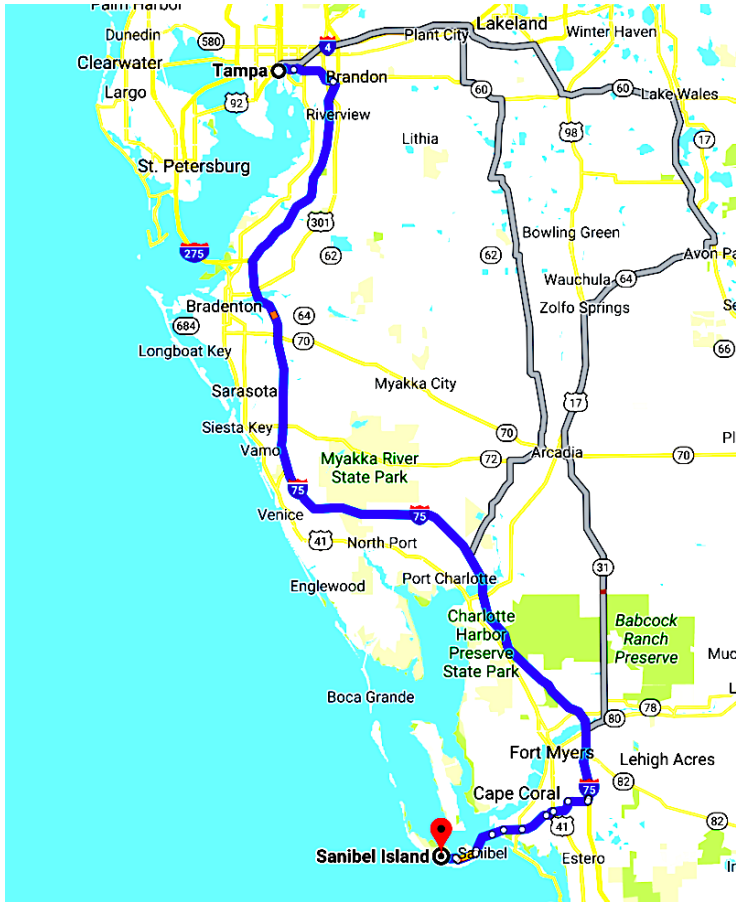
BREAKWATER	GROIN	REVEMENT	BULKHEAD	SEAWALL
<p>Offshore structures intended to break waves, reducing the force of wave action and encourages sediment accretion. Can be floating or fixed to the ocean floor, attached to shore or not, and continuous or segmented. A gapped approach would allow habitat connectivity, greater tidal exchange, and better waterfront access.</p> <p><b>Suitable For</b> Most areas except high wave energy environments often in conjunction with marinas.</p> <p><b>Material Options</b></p> <ul style="list-style-type: none"> <li>Grout-filled fabric bags</li> <li>Armorstone</li> <li>Pre-cast concrete blocks</li> <li>Living reef (oyster/mussel) if low wave environment</li> <li>Wood</li> <li>Rock*</li> </ul> <p><b>Benefits</b></p> <ul style="list-style-type: none"> <li>Reduces wave force and height</li> <li>Stabilizes wetland</li> <li>Can function like reef</li> <li>Economical in shallow areas</li> <li>Limited storm surge flood level reduction</li> </ul> <p><b>Disadvantages</b></p> <ul style="list-style-type: none"> <li>Expensive in deep water</li> <li>Can reduce water circulation (minimized if floating breakwater is applied)</li> <li>Can create navigational hazard</li> <li>Require more land area</li> <li>Uncertainty of successful vegetation growth and competition with invasive</li> <li>No high water protection</li> <li>Can reduce water circulation</li> <li>Can create navigation hazard</li> </ul>	<p>Perpendicular, projecting from shoreline. Intercept water flow and sand moving parallel to the shoreline to prevent beach erosion and break waves. Retain sand placed on beach.</p> <p><b>Suitable For</b> Coordination with beach nourishment.</p> <p><b>Material Options</b></p> <ul style="list-style-type: none"> <li>Concrete/stone rubble*</li> <li>Timber</li> <li>Metal sheet piles</li> </ul> <p><b>Benefits</b></p> <ul style="list-style-type: none"> <li>Protection from wave forces</li> <li>Methods and materials are adaptable</li> <li>Can be combined with beach nourishment projects to extend their life</li> </ul> <p><b>Disadvantages</b></p> <ul style="list-style-type: none"> <li>Erosion of adjacent sites</li> <li>Can be detrimental to shoreline ecosystem (e.g. replaces native substrate with rock and reduces natural habitat availability)</li> <li>No high water protection</li> </ul>	<p>Lays over the slope of a shoreline. Protects slope from erosion and waves.</p> <p><b>Suitable For</b> Sites with pre-existing hardened shoreline structures.</p> <p><b>Material Options</b></p> <ul style="list-style-type: none"> <li>Stone rubble*</li> <li>Concrete blocks</li> <li>Cast concrete slabs</li> <li>Sand/concrete filled bags</li> <li>Rock-filled gabion basket</li> </ul> <p><b>Benefits</b></p> <ul style="list-style-type: none"> <li>Mitigates wave action</li> <li>Little maintenance</li> <li>Indefinite lifespan</li> <li>Minimizes adjacent site impact</li> </ul> <p><b>Disadvantages</b></p> <ul style="list-style-type: none"> <li>No major flood protection</li> <li>Require more land area</li> <li>Loss of intertidal habitat</li> <li>Erosion of adjacent unreinforced sites</li> <li>Require more land area</li> <li>No high water protection</li> <li>Prevents upland from being a sediment source to the system</li> </ul>	<p>Parallel to the shoreline, vertical retaining wall. Intended to hold soil in place and allow for a stable shoreline.</p> <p><b>Suitable For</b> High energy settings and sites with pre-existing hardened shoreline structures. Accommodates working water fronts (e.g. docking for ships and ferries).</p> <p><b>Material Options</b></p> <ul style="list-style-type: none"> <li>Steel sheet piles</li> <li>Timber</li> <li>Concrete</li> <li>Composite carbon fibers</li> <li>Gabions</li> </ul> <p><b>Benefits</b></p> <ul style="list-style-type: none"> <li>Moderates wave action</li> <li>Manages tide level fluctuation</li> <li>Long lifespan</li> <li>Simple repair</li> </ul> <p><b>Disadvantages</b></p> <ul style="list-style-type: none"> <li>No major flood protection</li> <li>Erosion of seaward seabed</li> <li>Erosion of adjacent unreinforced sites</li> <li>Loss of intertidal habitat</li> <li>May be damaged from overtopping oceanfront storm waves</li> <li>Prevents upland from being a sediment source to the system</li> <li>Induces wave reflection</li> </ul>	<p>Parallel to shoreline, vertical or sloped wall. Soil on one side of wall is the same elevation as water on the other. Absorbs and limits impacts of large waves and directs flow away from land.</p> <p><b>Suitable For</b> Areas highly vulnerable to storm surge and wave forces.</p> <p><b>Material Options</b></p> <ul style="list-style-type: none"> <li>Stone</li> <li>Rock</li> <li>Concrete</li> <li>Steel/vinyl sheets</li> <li>Steel sheet piles</li> </ul> <p><b>Benefits</b></p> <ul style="list-style-type: none"> <li>Prevents storm surge flooding</li> <li>Resists strong wave forces</li> <li>Shoreline stabilization behind structure</li> <li>Low maintenance costs</li> <li>Less space intensive horizontally than other techniques (e.g. vegetation only)</li> </ul> <p><b>Disadvantages</b></p> <ul style="list-style-type: none"> <li>Erosion of seaward seabed</li> <li>Disrupt sediment transport leading to beach erosion</li> <li>Higher up-front costs</li> <li>Visually obstructive</li> <li>Loss of intertidal zone</li> <li>Prevents upland from being a sediment source to the system</li> <li>May be damaged from overtopping oceanfront storm waves</li> </ul>

GRAY CAN BE GREENER: e.g., "Living Breakwater" using oysters to colonize rocks or "Greenwall/BioWall" using vegetation, alternative forms and materials

(NOAA-SAGE)



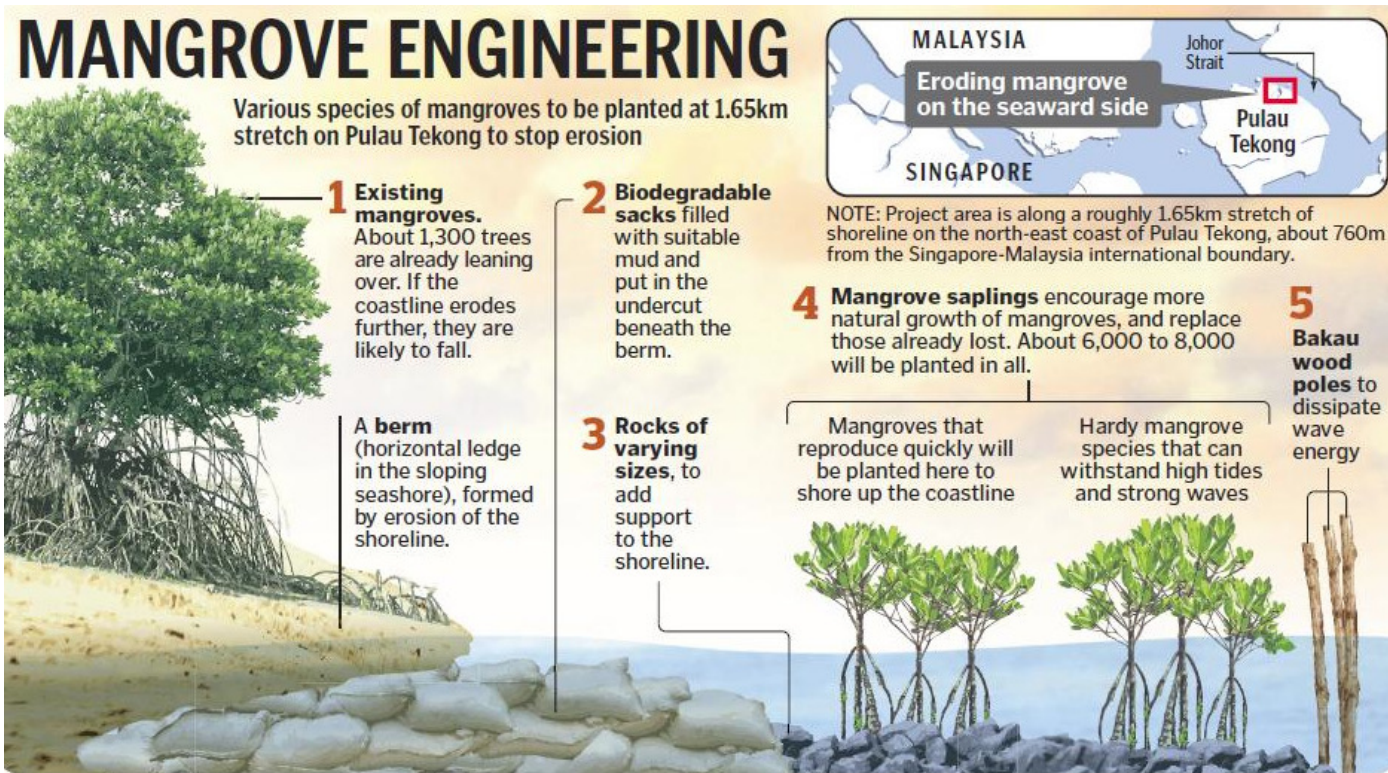
# Living shoreline, Sanibel, Florida



(Sanibel & Captiva  
News 28.5.2022)



# Mangrove engineering, Singapore



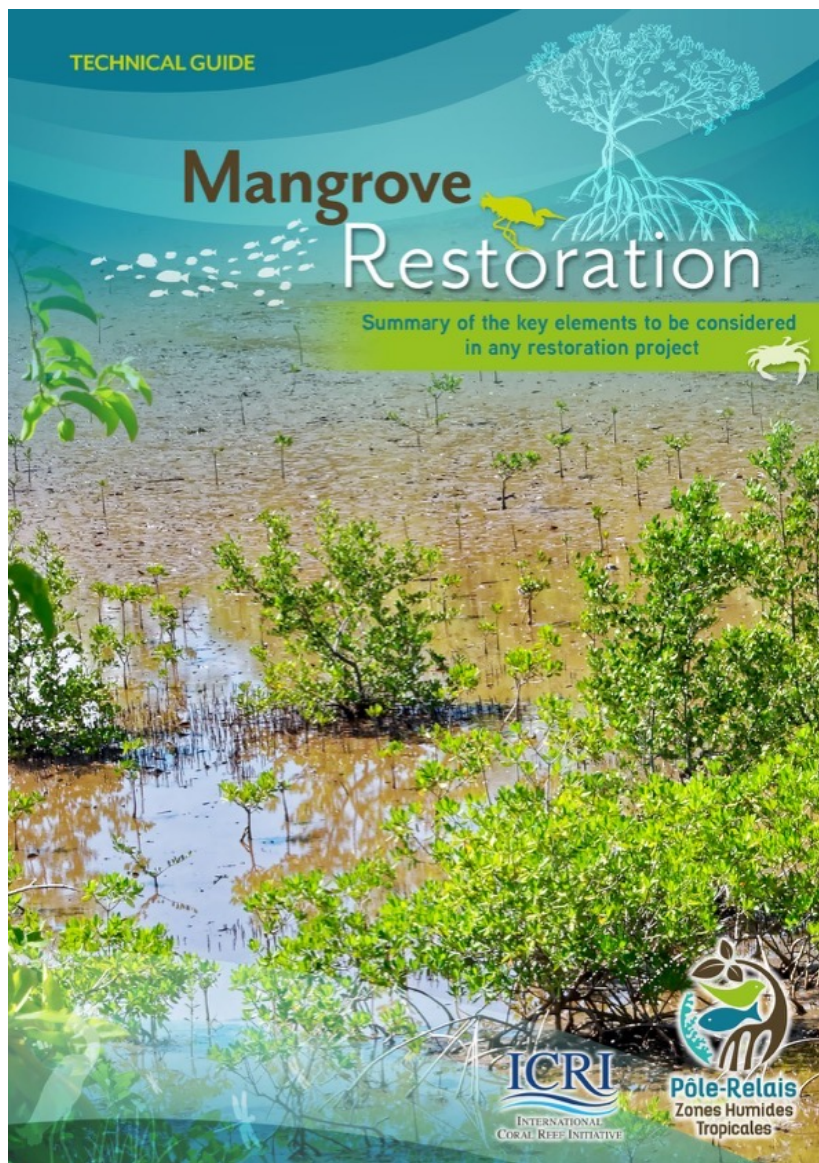
(National Parks)



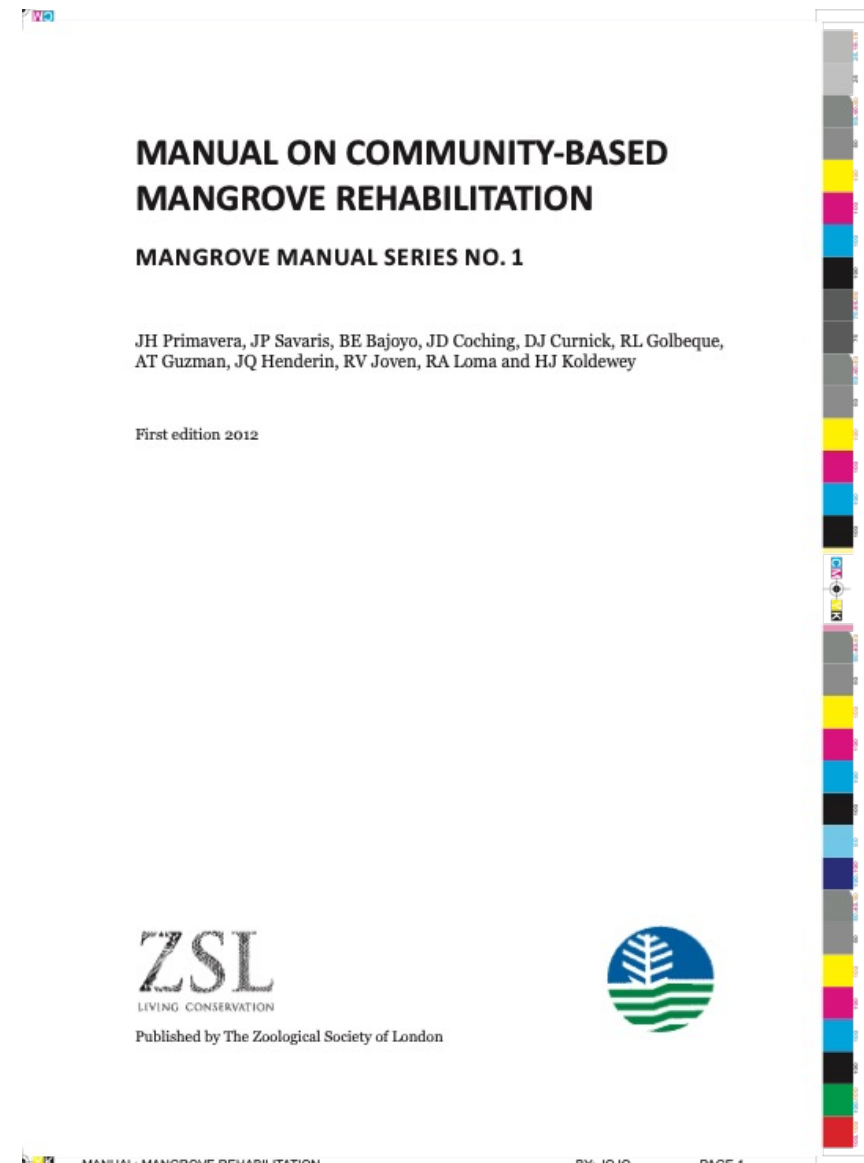
(Straits Times 12.5.2010)

# 6. Planting and restoration





**Pôle-Relais Zones Humides Tropicales 2018.**  
***Mangrove Restoration. Technical Guide.***



**Primavera, JH et al. 2012. *Manual on Community-based Mangrove Rehabilitation***



# Planting : success and failure





# Restoration : factors

- **Reforestation** : generic term for replanting trees in a specific area with various goals.
- **Forest restoration** : involves all activities, including reforestation, helping forests return to healthy state.

Factors affecting mangrove restoration success	
	<ul style="list-style-type: none"><li>▪ Soil stability and flooding pattern</li><li>▪ Elevation of the site</li><li>▪ Soil/ water salinity and freshwater input to the site</li><li>▪ Tidal and wave energy associated with the site</li><li>▪ Availability of propagules/ seed material</li><li>▪ Spacing and thinning of plants</li><li>▪ Presence of weeds</li><li>▪ Success of nursery techniques</li><li>▪ Monitoring the progress</li><li>▪ Incidence of propagule predation</li><li>▪ Cost of restoration</li><li>▪ Cooperation of the local inhabitants</li></ul>

# Planting pitfalls

- **Wrong site** : Popular choice of **mudflats** because of few competing claims to land. But too saturated with water for roots to source enough oxygen.
- **Wrong species**. *Rhizophora* with their **propagules** on exposed coasts & mudflats failed. *A. marina* & *S. alba* are better choice.
- **Unavailable best sites**, e.g. former mangrove areas converted to fish & shrimp ponds, are **not readily available** : not easy to identify or owners do not want to give them up.
- **Lack of monitoring** after planting.
- **Solution** : put needs of local communities first; find ways to make conservation pay off for them.



If restoration efforts plant mangrove species in the wrong places, they will fail. These *Rhizophora* seedlings are planted on a poorly drained area and are likely to die in the salty, waterlogged soils. Experts say the more salt-tolerant mangrove *Avicennia marina* would make a better choice.

(Knowable Magazine 22.7.2021)



# Replanting : concession in Papua

*B. gymnorrhiza* & *R. mucronata*; fastest-growing species, *R. mucronata*.





# Restoration : post-tsunami May 2005, Aceh

- (L) Luepueng, west coast : Mangrove restoration.
- (R) East of Lam Bada Lhok, north coast : Mangrove restoration include *Rhizophora stylosa*, *R. apiculata*, *Ceriops* sp; 267,000 saplings planned in 50-ha site.





# Restoration : Ko Samui (Thailand), Jakarta

- (L) Bang Keow, Ko Samui : Line of bamboo poles as wave shelter to protect & enclose earlier planting which has failed. Replanting is sponsored; mangroves behind barrier.
- (C) Taman Wisata, Jakarta. Only conservation programme in Jakarta & created by Sri Lela Muniwati with initial 100 ha of cut mangrove land. About 50 ha have been planted by volunteers & much donation is required. Boardwalk to the sea. Main replanting area. (R) Planting module.



# Ecological mangrove restoration

- If coastal habitats are degraded, mangroves may need a little help from workers to restore right conditions : approach called “**ecological mangrove restoration**”.
- On rapidly eroding coast in **Java** in Indonesia, Wetlands International workers built semi-permeable dams to stop sediment from washing away, allowing seafloor to rise just enough for mangroves to grow back.
- In **Guinea Bissau**, workers broke dikes around abandoned rice fields to restore tidal flow. Soon, *Avicennia* & *Rhizophora* propagules from nearby forests washed into sites & started growing more successful & suitable than planting.

(Knowable Magazine 22.7.2021)



# 7. Modular planting

# Mangroves – coastal protection measure for tsunamis and sea-level rise

Coastal zone management in relation to extreme events

University of Twente, 19 June 2009

Poh Poh Wong  
National University of Singapore  
geowpp@nus.edu.sg



I have argued that atoll nations should think of sacrificing some islands now in order to raise the level of others – a strategy of “better to save some than not to have any” (*Wiley Interdisciplinary Reviews: Climate Change*, DOI: 10.1002/wcc.84).

A new method of large-scale modular planting of mangroves, complemented by the addition of sediments, is another option that should be considered. Mangroves can grow on non-muddy substrates, including sand, gravels, coral flats, rock surfaces and even on the boulders of some sea defences.

*Singapore*

***New Scientist*, 6 Nov 2010**



# Proposed large-scale modular planting

- Large-scale planting using **modular system** to **meet needs of various coastal locations**.
- **Modular system** of planting & deployment is comparable to LEGO® set on a large scale.
- **Faster deployment** using wooden sledges. Modules anchored by wooden sticks/pegs if necessary.
- **Suitable for wide range of coastal types** & not confined to muddy tidal flats.

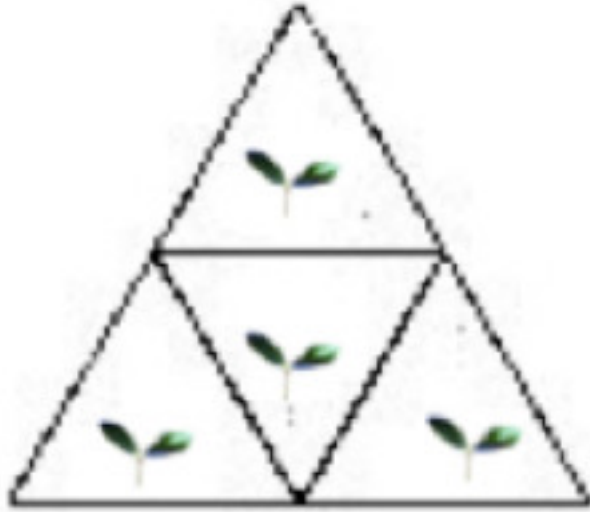
# Modules

- Ideally of **space-fitting shapes** (triangles, squares, rectangles, hexagons) containing sediments with mangroves grown to various heights or maturity.
- Made of mixture of **compressed sediments that become self-destructive & formed part of sediments** supporting mangroves. Alternatively of local materials.
- **Nutrients & sediments added** to growing mangroves in field.

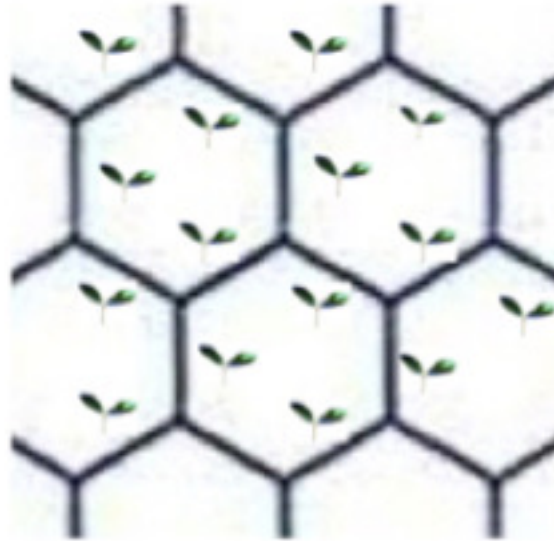




# Layout examples



© PP Wong

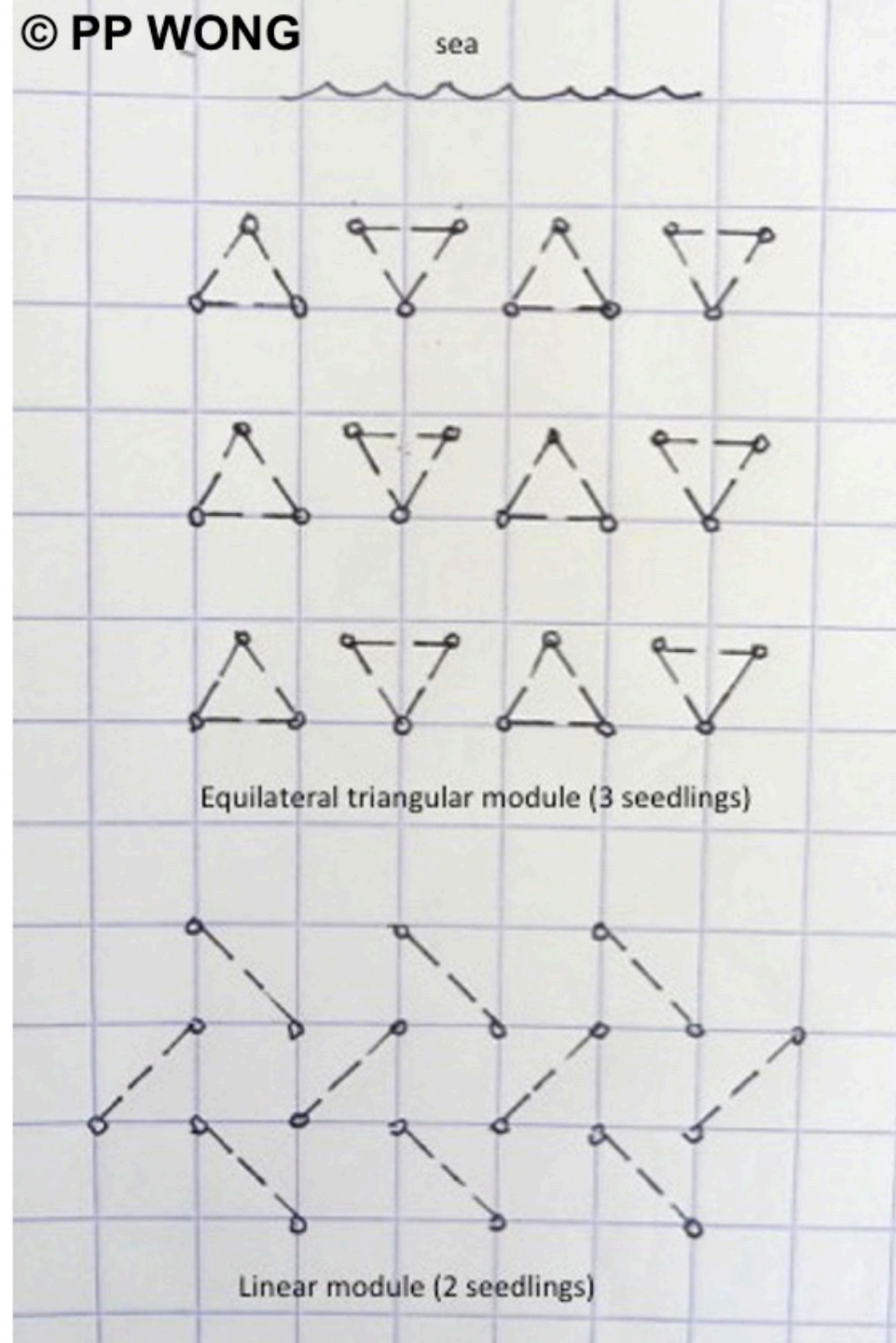


© PP Wong

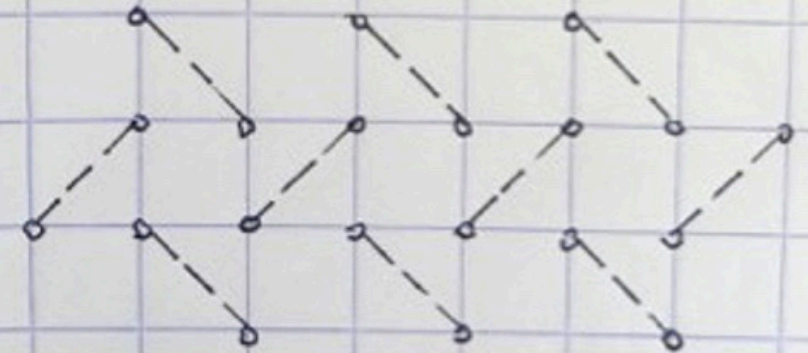


(IOC 2011)

© PP WONG



Equilateral triangular module (3 seedlings)



Linear module (2 seedlings)

# Modular planting = Development

- Modular planting moves to higher level of development for villages, as **suitable materials have to be sourced, adapted & manufactured.**
- **Small machine shops** to produce modules in larger numbers & in standardized format, thus pushing development to a higher level. **More skills** as modules are deployed to coasts.
- When mangroves are fully grown, forests themselves could open **opportunities for** villages to another level of development, e.g. **ecotourism development.**
- Timeline from mangrove seedlings to their maturity along coasts generates **increasing levels of development/opportunities** for villages & **at same time brings many benefits.**

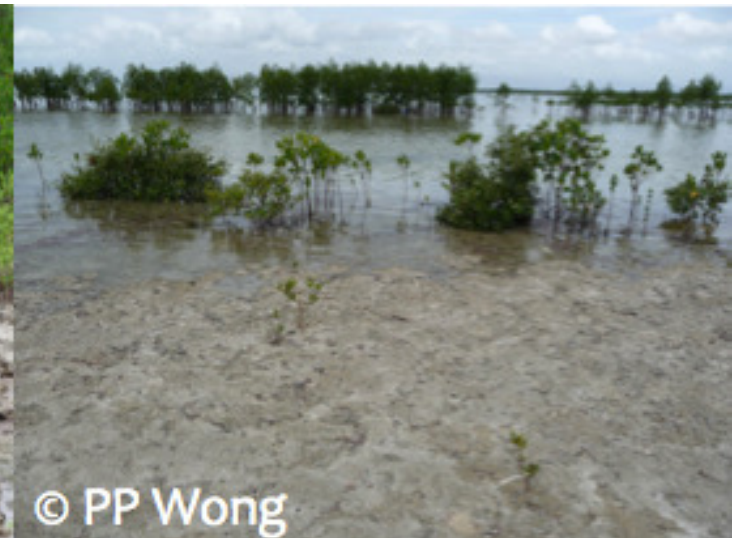
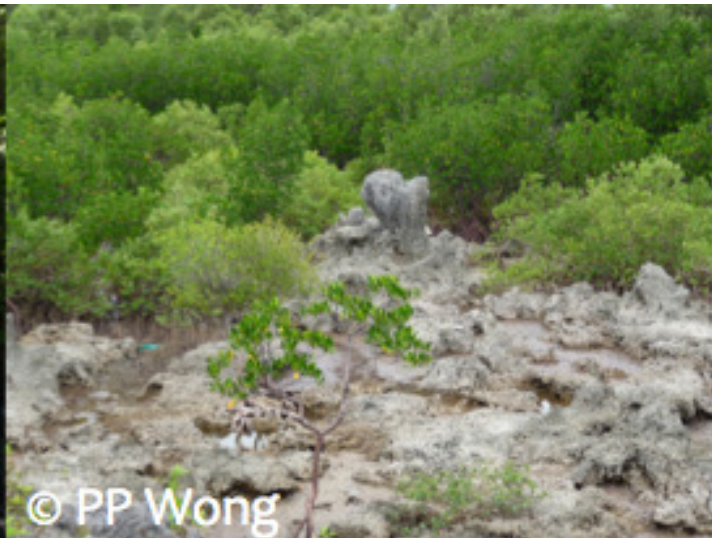


# Short-term and long-term benefits

- **Provides employment**; utilizes existing skills of coastal communities in mangrove planting.
- **Restores degraded coasts** caused by shrimp farming & other activities.
- **Improves biodiversity**; mangroves are nurseries for fish.
- **Low cost** protection measure compared to seawalls & dikes.
- Offers **coastal protection** from erosion, storm surges & buffer to tsunami waves.
- **Adaptation to sea-level rise.**
- Important **carbon sink.**
- Supplementary/emergency **food supply.**
- **'No regrets' measure**; beneficial irrespective of future outcome of climate change.

# *Avicennia marina* : ideal

- **Widest latitudinal range**, ability to adapt to wide range of physical conditions; only mangrove to survive in arid areas.
- Present on both **seaward & landward margin of mangrove belt** ('disjunct' zonation).
- **'Opportunistic' colonization** due to ecological characteristics.
- Grows on **mud, sand, gravels, rubble, rock surfaces**.
- Most **tolerant to sea-level rise**.





# PROPOSED MODULAR MANGROVE PLANTING

Poh Poh Wong, Visiting Associate Professor, School of Social Sciences, University of Adelaide

The rivers from the Himalayas have caused erosion and deposition on the floodplains of Bangladesh (Fig. 1). In some cases, deposition has been encouraged by channelling sediments to fill up 'beels' (local depressions) and raising the ground level suitable for cultivation (Fig. 2). This method is seen as a suitable measure to protect the eroding coast from a rising sea level (Fig. 3).

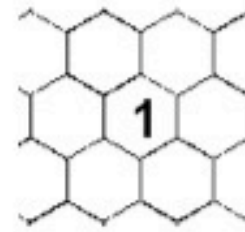


Fig. 4



Fig. 5 (Xin Yong Yuan)

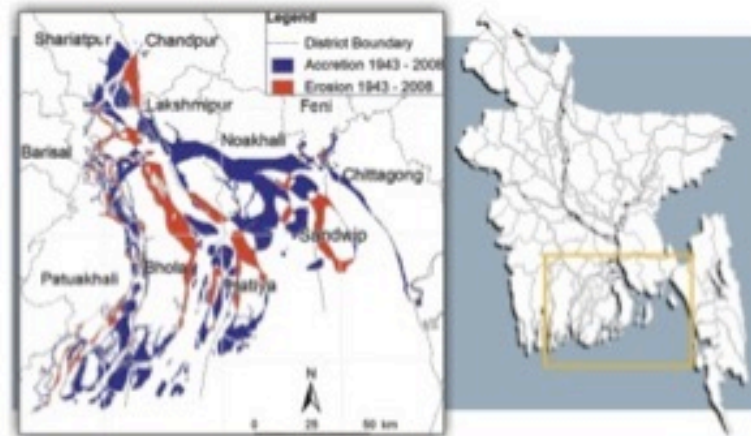


Fig. 1 (Daily Star, 27.4.2010)



Fig. 2 (NYT, 20.3.2009)



Fig. 3 (Practical Action 2009)



Fig. 6 (PP Wong)

Fig. 7 (PP Wong)

Fig. 8 (PP Wong)

Knowledge on planting mangroves and local materials for the modules are readily available within Bangladesh. Mangroves also serve as an important carbon sink and planting them is a 'no regrets' measure and conforms to the 'precautionary principle'.





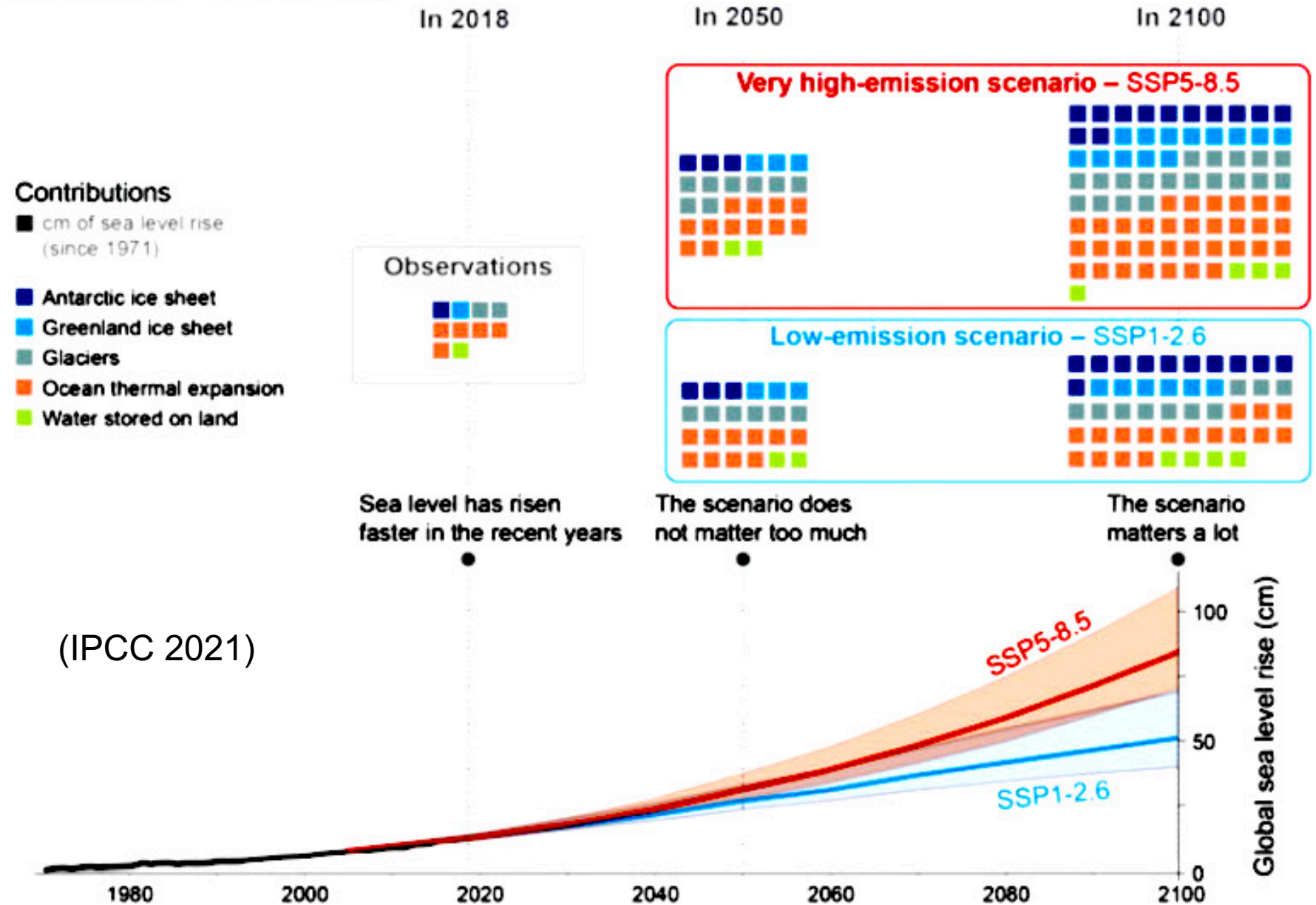


## 8. End note

# Sea-level rise...

## FAQ 9.2: How much will sea level rise in the next few decades?

Emissions scenarios influence little sea level rise of the coming decades but has a huge effect on sea level at the end of the century.

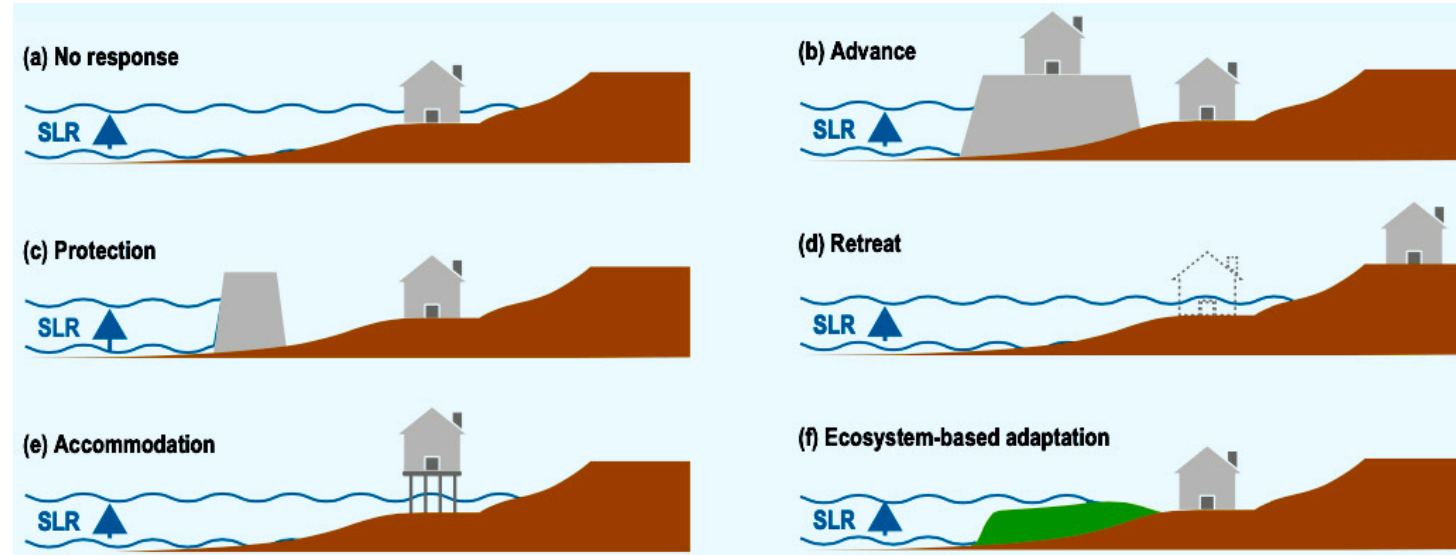




# ...and adaptation

	<i>Protect</i> = effort to continue use of vulnerable areas	<i>Accommodate</i> = effort to continue living in vulnerable areas by adjusting living and working habits	<i>Retreat</i> = effort to abandon vulnerable areas
<i>Hard</i>	Dikes, seawalls, groins, breakwaters, salt water intrusion barriers	Building on pilings, adapting drainage, emergency flood shelters	Relocating threatened buildings
<i>Soft</i>	Sand nourishments, dune building, wetland restoration or creation	New building codes, growing flood or salt tolerant crops, early warning and evacuation systems, risk-based hazard insurance	Land use restriction, set-back zones

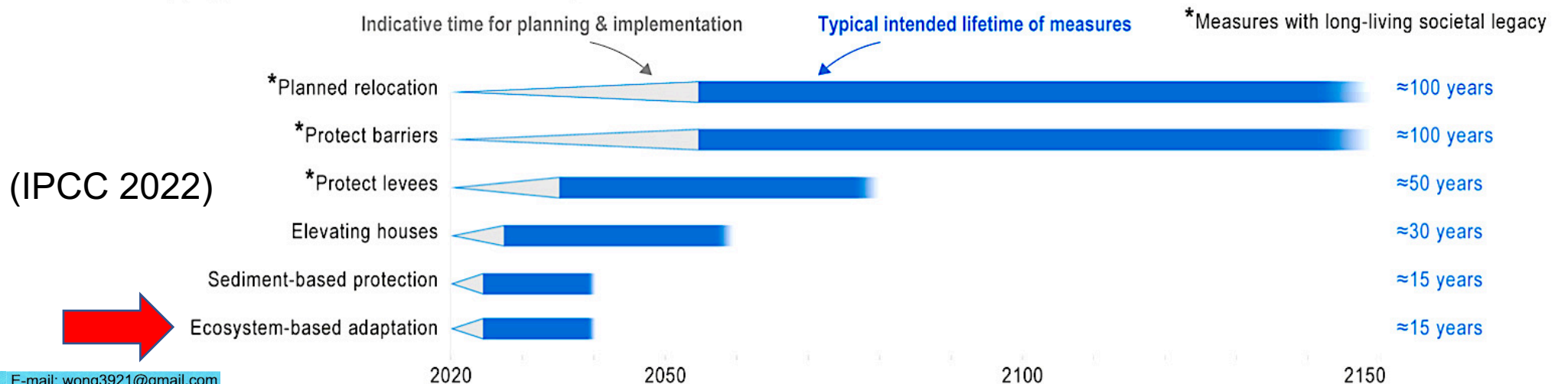
(Policy Research Corporation)



(IPCC 2019)

## Sea-level rise challenges the timing of coastal adaptation planning & implementation

(a) Typical timescales of coastal risk management

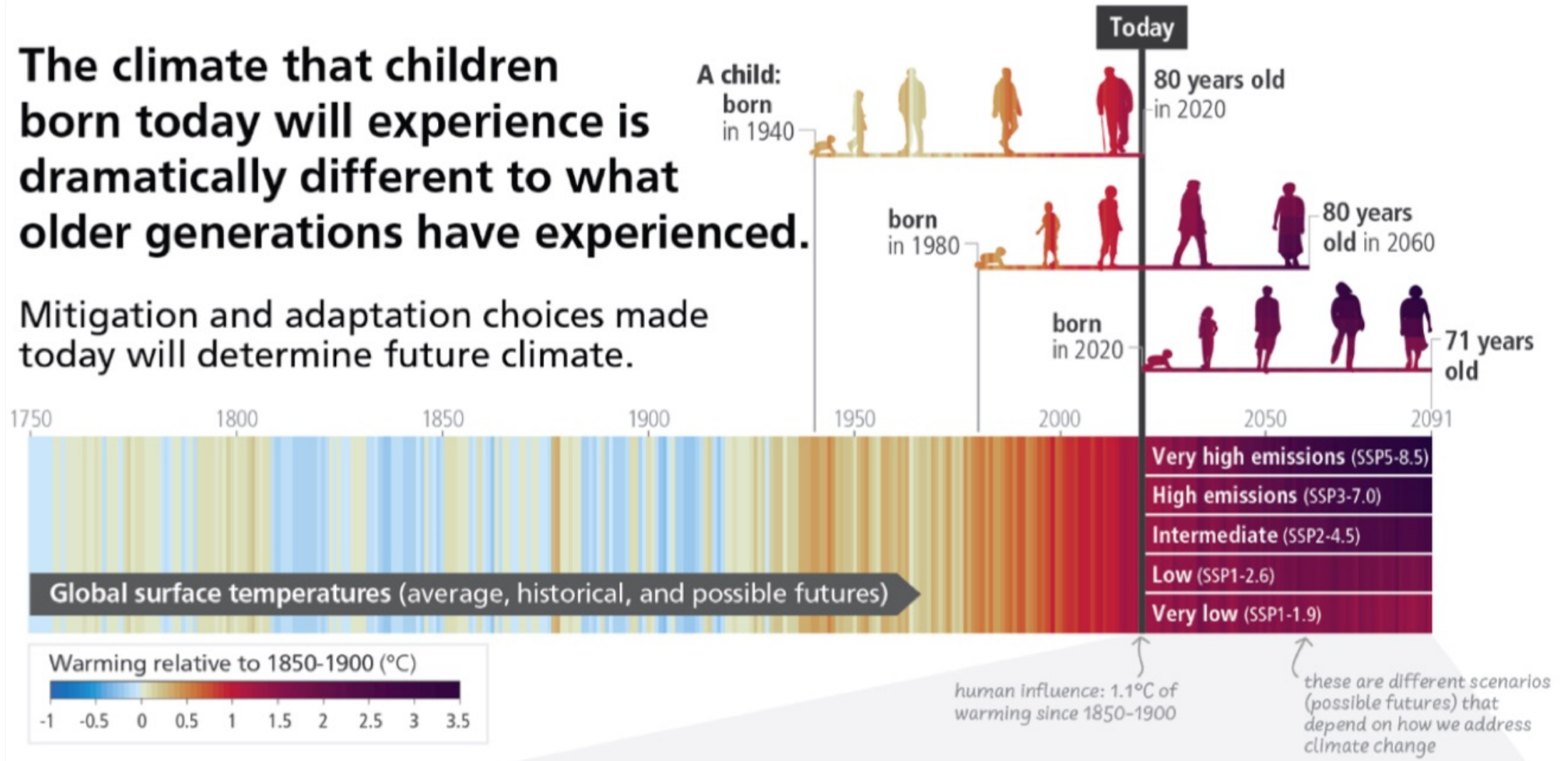


(IPCC 2022)

# OUR future climate

The climate that children born today will experience is dramatically different to what older generations have experienced.

Mitigation and adaptation choices made today will determine future climate.



(IPCC 2022)



Where there's a will there's a way



*Thank you*

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**WONG Poh Poh**

Ph.D.

Visiting Associate Professor  
School of Social Sciences and  
Centre for Coastal Research  
University of Adelaide, South Australia

E-mail: [wong3921@gmail.com](mailto:wong3921@gmail.com)

Website: [coast4all](http://coast4all)

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