Deserving a better fate: mangroves and sea-level rise

Catherine Lovelock
School of Biological Science
The University of Queensland

Sea level rise

- Aboriginal story memories- 8000 years old:
  - The Narrangga tribe living on Yorke Peninsula ‘had a story that has been handed down through the ages’ which recalled a time when Spencer Gulf was dry land, ‘marshy country reaching into the interior of Australia’….
  - ‘the sea broke through, and came tumbling and rolling along in the track…it flowed into the lagoons and marshes which completely disappeared’

Patrick D. Nunn & Nicholas J. Reid (2016) Aboriginal Memories of Inundation of the Australian Coast Dating from More than 7000 Years Ago, Australian Geographer, 47:1, 11-47, DOI: 10.1080/00049182.2015.1077539

theguardian

Climate change: Will '1.5 to stay alive' deal be enough to save Seychelles?

The half a degree difference between the target of 1.5C - included in the draft text with the agreed goal of 2C - is critical for small, low-lying coastal states

theguardian

Food shortages and sea level rise US voters' top climate change concerns

Survey of Guardian readers appalled at lack of climate discussion in 2016 campaign finds food and water shortages viewed as most pressing consequence

Climate change has barely registered as a 2016 campaign issue, but in Florida, the state which usually decides the presidential election, the waters are lapping at the doors of Donald Trump's real estate empire

July 17, 2016

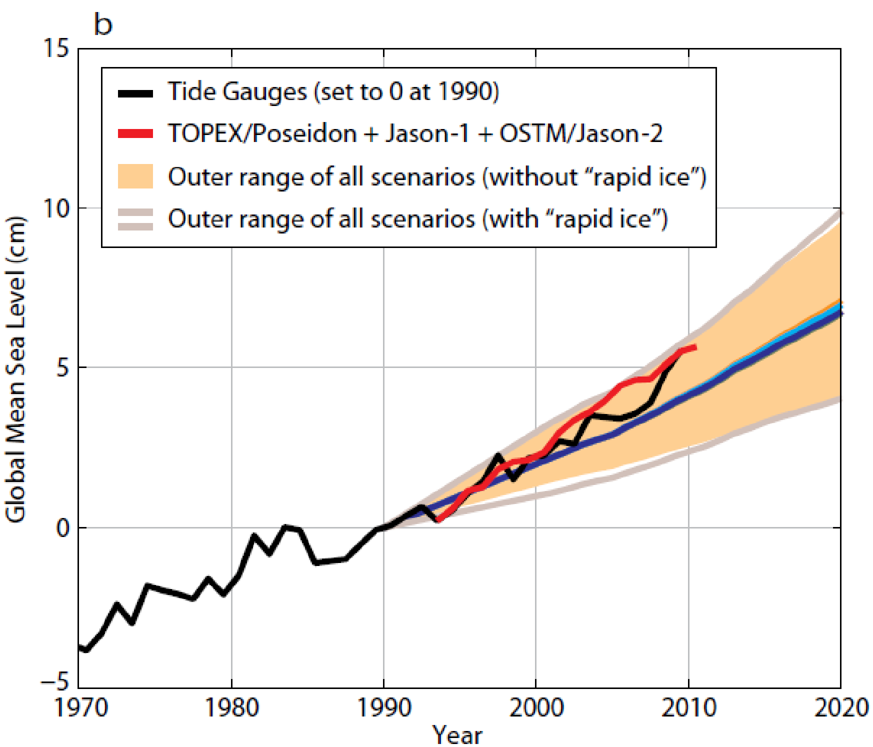
Agenda

1. Review vulnerability to sea level rise
2. Additional environmental factors
3. Some direct human impacts
4. Pathways for the future

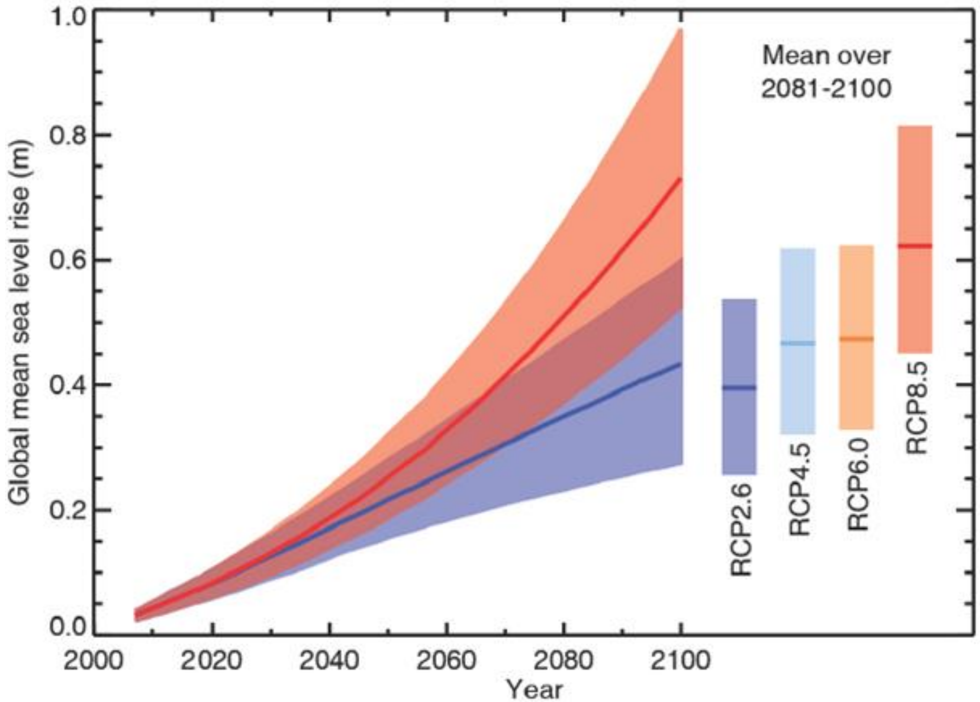
Mangrove forests and tidal marshes – exceptional plant communities exposed to climate change

- There are physiological limits to plant tolerances of inundation

Sea level rise – instrumental record and predictions



Church et al. 2011



nature

PROGRESS ARTICLE

Subsidence – deeper processes

Sinking deltas due to human activities

James P. M. Syvitski[1]*, Albert J. Kettner[1], Irina Overeem[1], Eric W. H. Hutton[1], Mark T. Hannon[1], G. Robert Brakenridge[2], John Day[3], Charles Vörösmarty[4], Yoshiki Saito[5], Liviu Giosan[6] and Robert J. Nicholls[7]

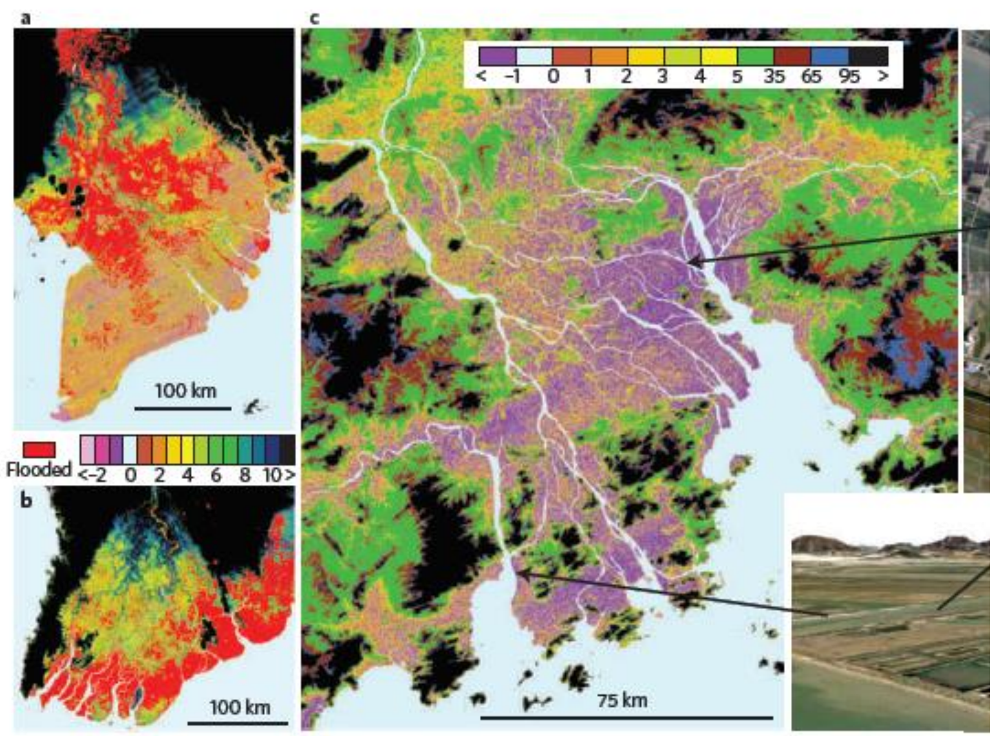


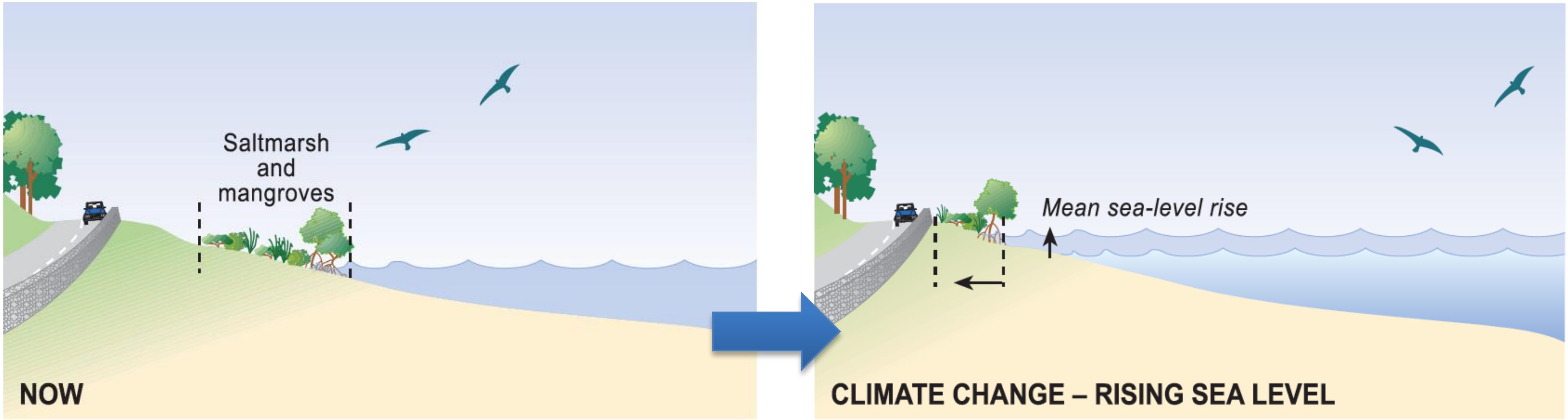
Figure 2 | Examples of actual and potential delta flooding. a, Mekong, Vietnam, and **b**, Irrawaddy, Myanmar, flooded areas in dark red, based on MODIS imaging. The Mekong River flooded on 8 November 2007. A coast Irrawaddy on 5 May 2008. **c**, The Pearl Delta, China, displayed with SRTM altimetry, with areas below sea lev from storm surges by coastal and channel barriers as seen in associated Digital Globe images (Google Earth).

- Extraction of oil, gas, ground water
- Also local compaction (Swales et al. 2016 – *Marine Geology*)

Expectations for coastal wetlands

Expected:

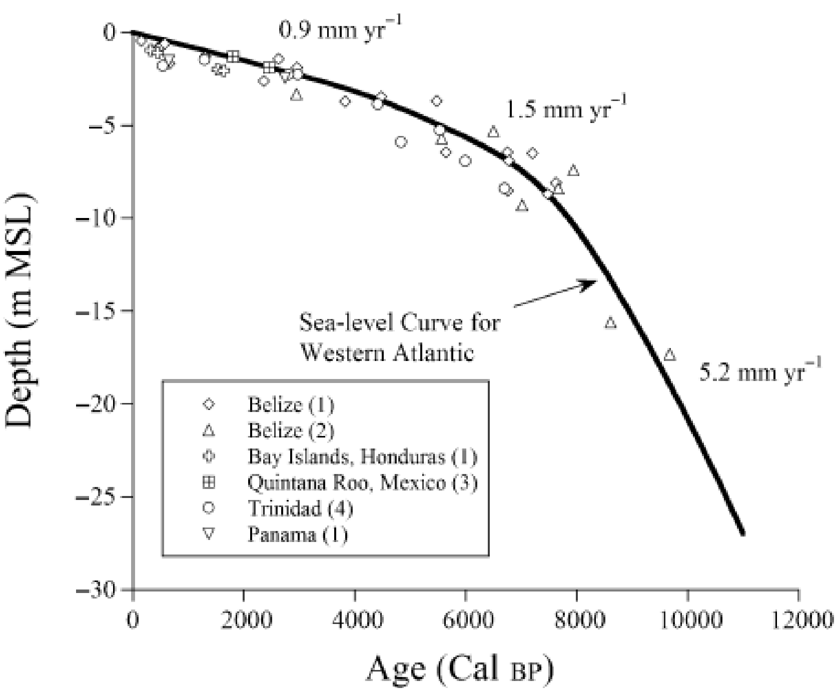
- Habitat become inundated (physiological tolerances overwhelmed)
- Mangroves and marsh move inland (shoreline retreat)
- Barriers to movement impede migration and reduce extent of coastal wetlands
- Subsidence due to geological processes and human activities in the catchment will exacerbate these processes (effectively speeds up rate of sea level rise)



Source: DCC, 2009

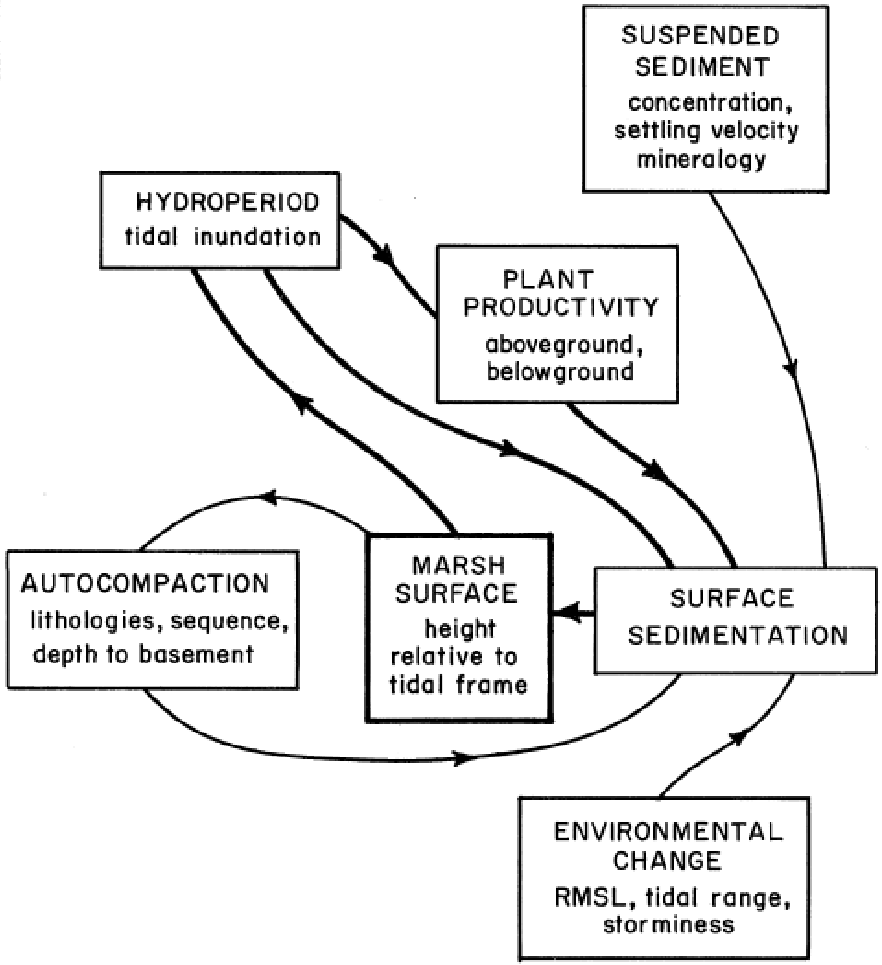
Mangrove stability – sediment record

- "Kept up" with sea level in some locations
- Mangrove soils accrete – increase in soil volume
- Wetland soil surface elevation can match the rate of sea level rise
- Organic matter inputs are important



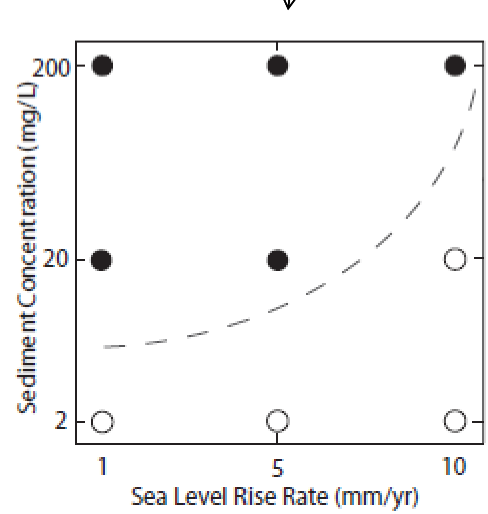
McKee et al. 2007

Theoretical models



Allen 2000

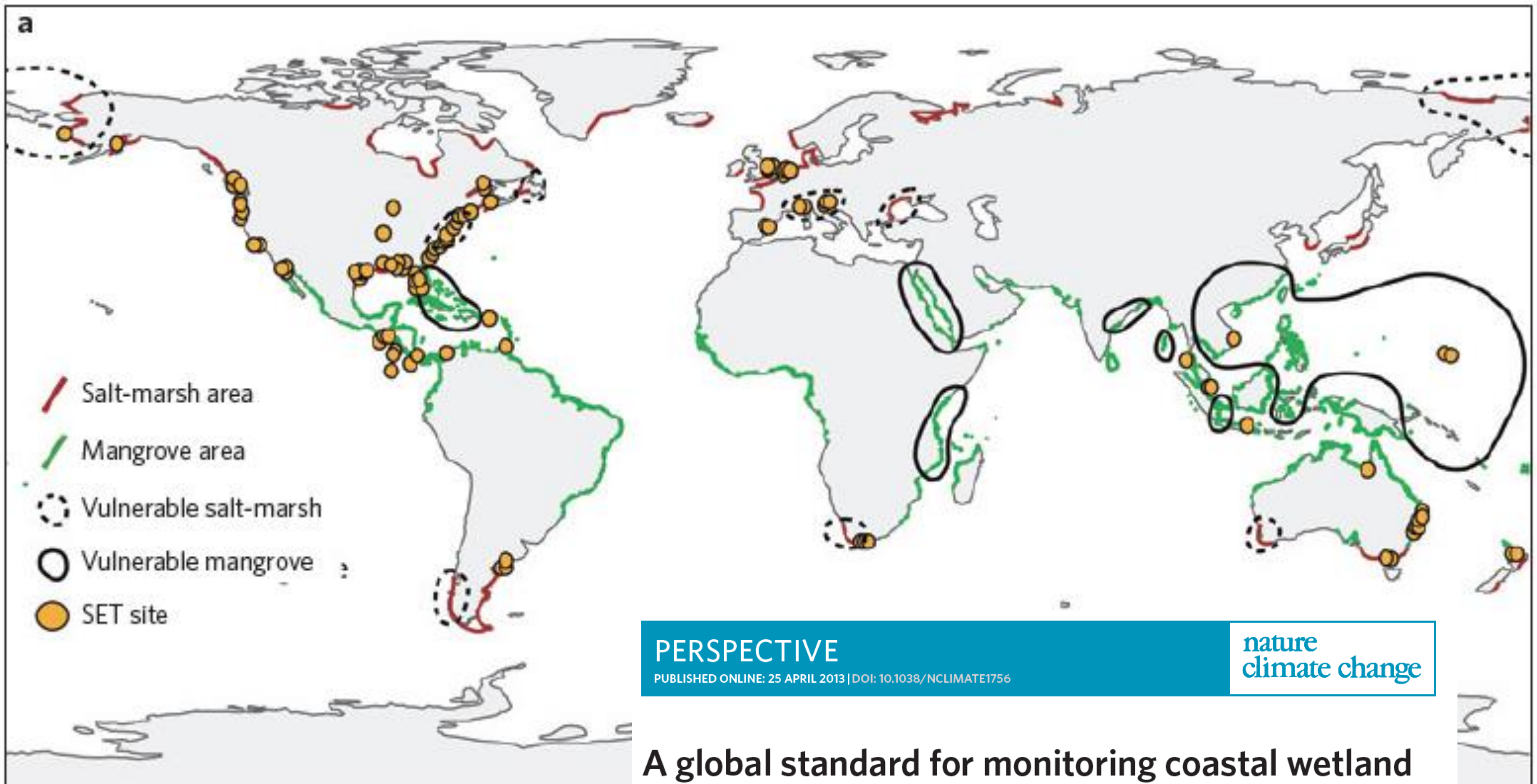
Stable marsh



Kirwan and Murray 2007

Mangroves of the Indo-Pacific

- Indo-Pacific has about 60% of the worlds mangroves
- High diversity
- Vulnerable because of high rates of sea level rise, intense human pressures on coasts, typhoons/cyclones



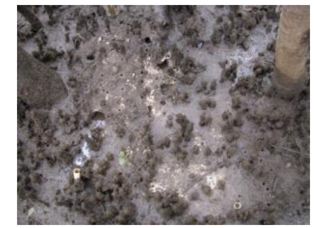
PERSPECTIVE
PUBLISHED ONLINE: 25 APRIL 2013 | DOI: 10.1038/NCLIMATE1756
nature climate change

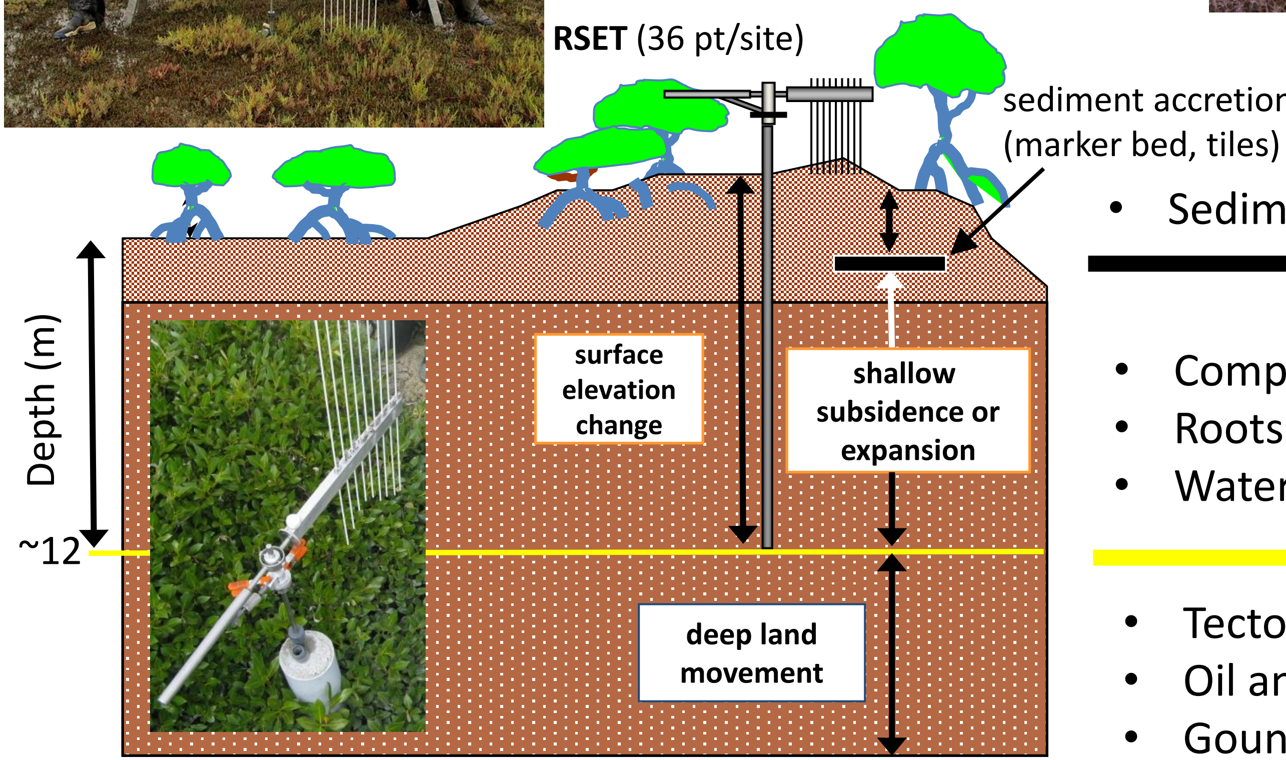
A global standard for monitoring coastal wetland vulnerability to accelerated sea-level rise

Edward L. Webb[1]*, Daniel A. Friess[2,3]*, Ken W. Krauss[4], Donald R. Cahoon[5], Glenn R. Guntenspergen[5] and Jacob Phelps[1]

Methodology – surface elevation gains

- Rod Surface Elevation Tables (RSETs or SETs)
- Assesses changes in the level of the sediment relative to sea level rise





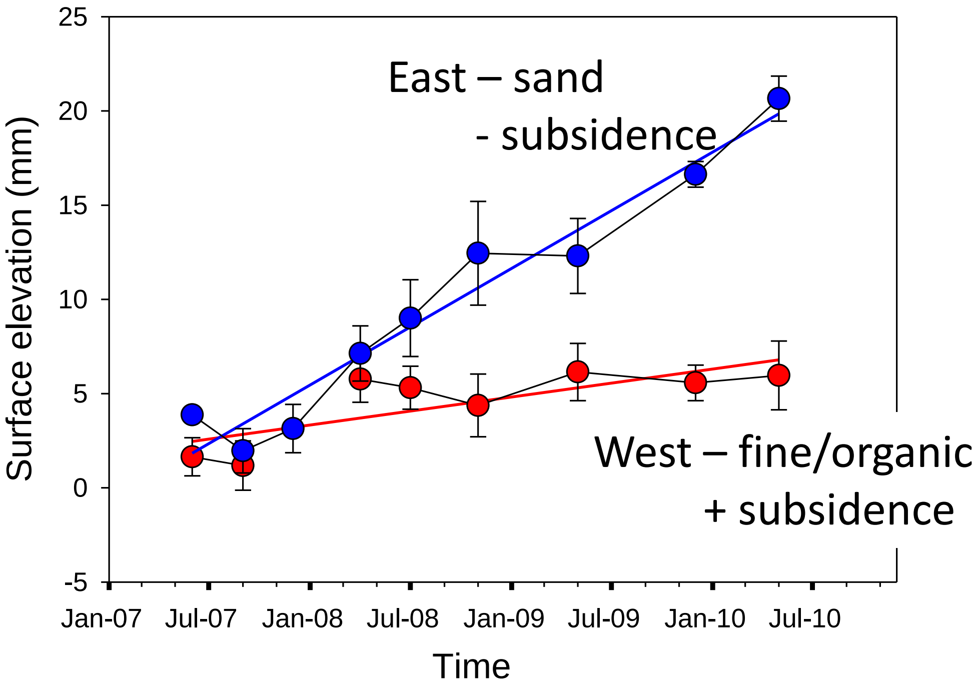
- Sediment or organic (mats)

- Compaction
- Roots +/-
- Water +/-

- Tectonic movements
- Oil and gas extraction
- Goundwater extraction

Typical kinds of data

- Rate of surface elevation gain varies over sites
- Contributions of organic and inorganic material to surface elevation gains varies



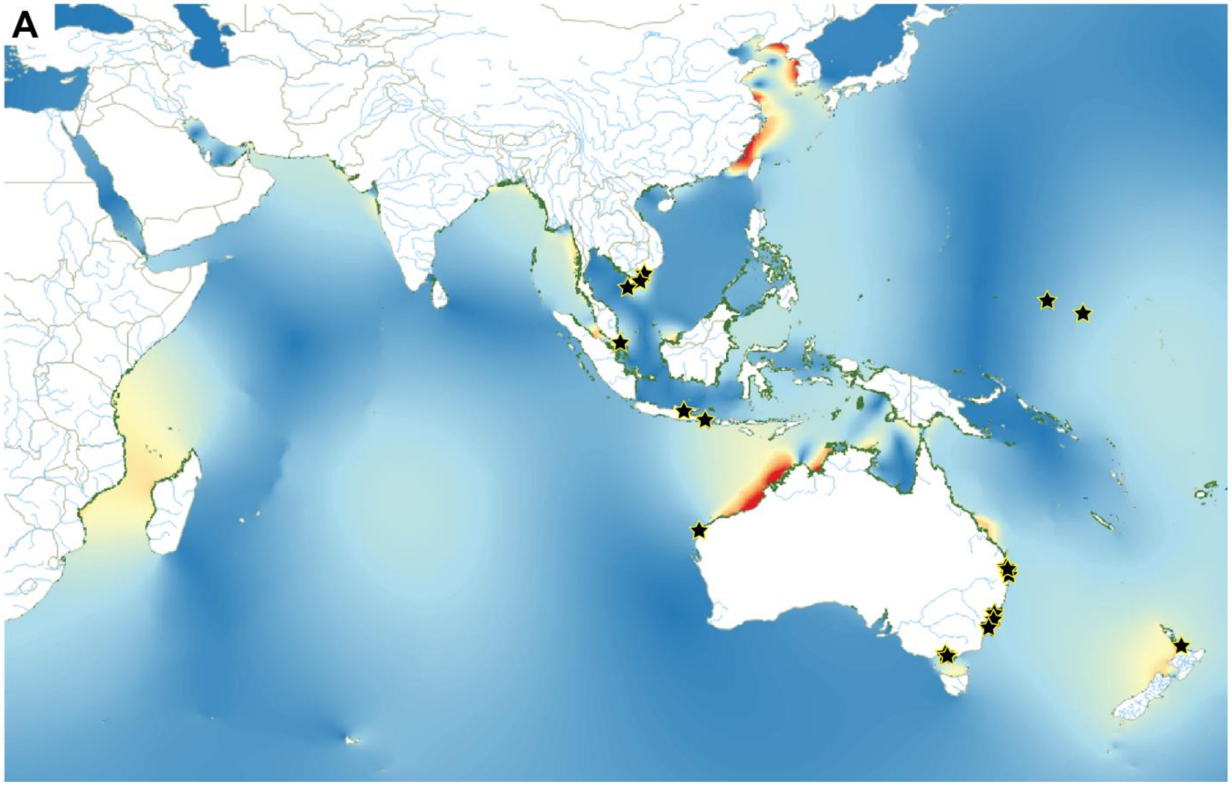
Lovelock et al. 2011

Lots of sediment

Very little sediment

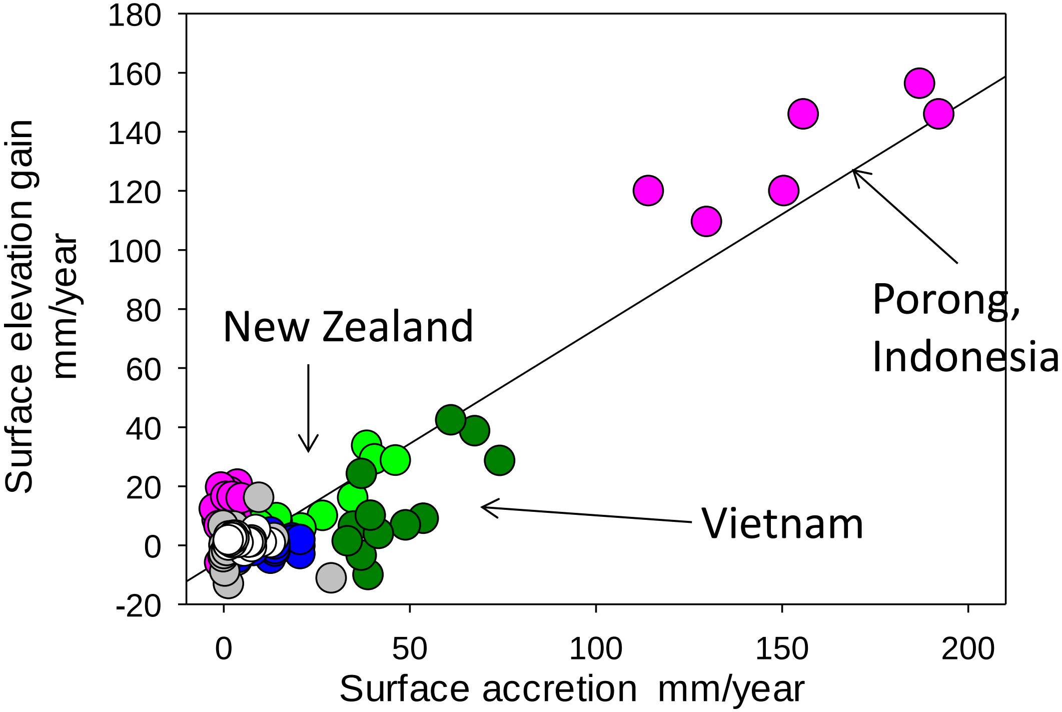
Study sites

153 installations over 27 sites



Lovelock et al. 2015, *Nature*

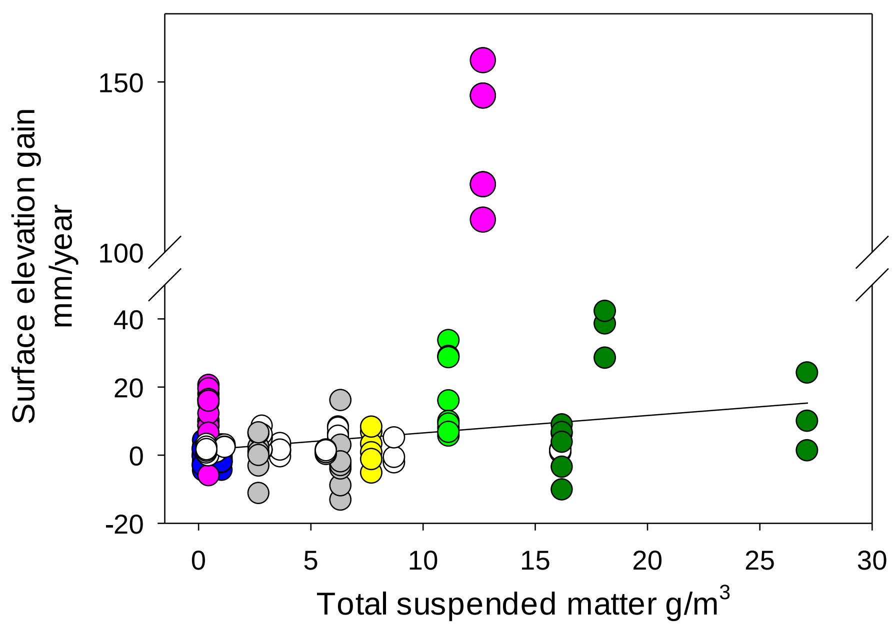
Sediment supply was key to surface elevation gains

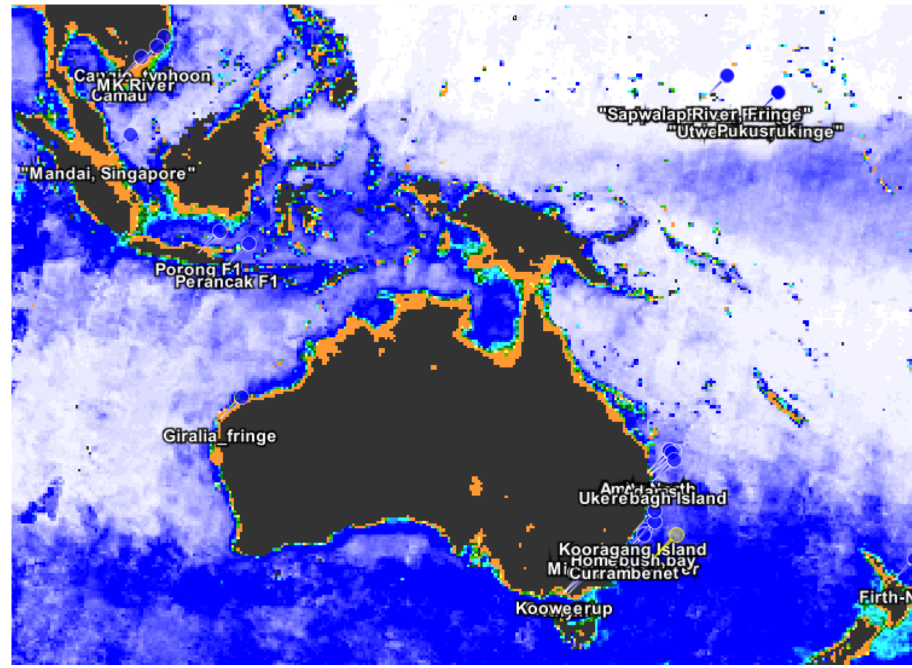


Slope = 0.78

- In contrast to previous analyses that found that surface sediment inputs were not good predictors of surface elevation gains

Surface elevation gain correlates with available sediment





Globcolour dataset. Medium Resolution Imaging Spectrometer (MERIS) instrument on the European Space Agency's (ESA) Envisat satellite (390 – 1040 nm). 4 km pixels.

- Potential for using remotely sensed data for predicting surface elevation gains

Analysis of variation in surface elevation trends

- Used Boosted Regression Trees and fitted a range of models
- TSM and annual change in sea level account for ~60% of variation

Model predictor	Relative Influence (%)
Model 1	
Total Suspended Matter (annual mean) g m^{-3}	36.47
Sea level change at tide gauge (mm/year)	29.32
Longitude	8.81
Geomorphological setting	7.19
Ecological habitat	5.36
Latitude	5.20
Dominant tree genera	3.68
Annual rainfall (mm)	2.84
Tidal range (m)	1.12

Tidal marshes from the east coast of USA

AGU PUBLICATIONS

Earth's Future

RESEARCH ARTICLE
10.1002/2015EF000334

Special Section:
Integrated field analysis & modeling of the coastal

Contributions of organic and inorganic matter to sediment volume and accretion in tidal wetlands at steady state

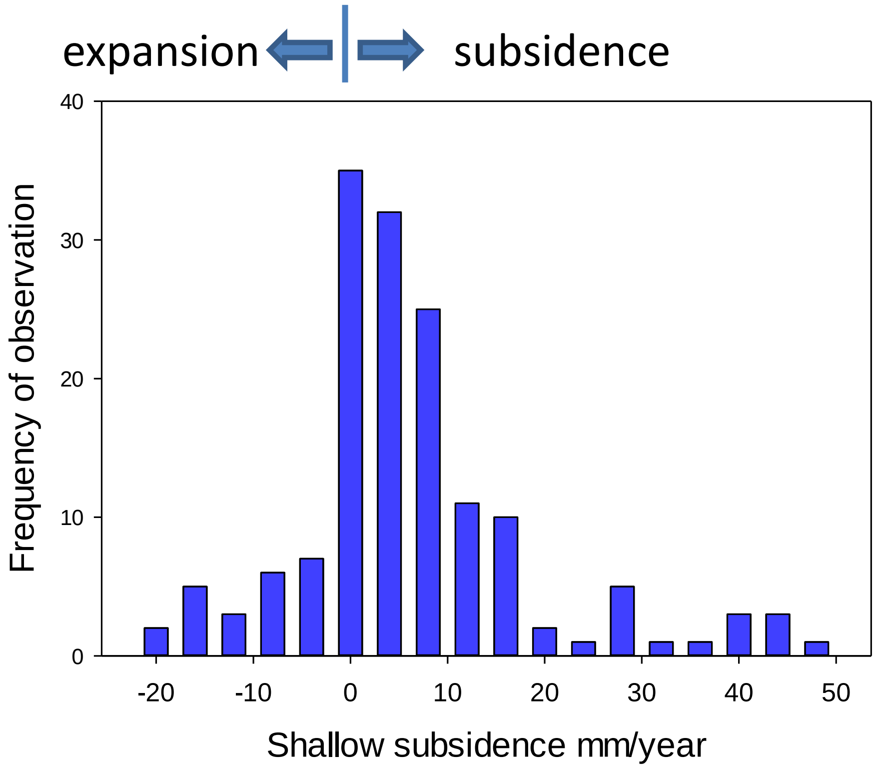
James T. Morris[1], Donald C. Barber[2], John C. Callaway[3], Randy Chambers[4], Scott C. Hagen[5], Charles S. Hopkinson[6], Beverly J. Johnson[7], Patrick Megonigal[8], Scott C. Neubauer[9], Tiffany Troxler[10], and Cathleen Wigand[11]

"Mass accretion rates of mineral and organic matter in tidal freshwater and salt water wetlands ….have been reported ……..these authors have advanced the argument that organic matter accretion is the principal means by which marshes accrete vertically. Our analysis supports this view, considering the low TSS concentrations typical of many estuaries, but we would argue that vertical accretion is limited by low availability of mineral sediment."

……..even current rates of SLR along the East Coast (mean=0.34 cm yr^{-1}, range=0.18–0.60 cm yr^{-1}) **are near the point that will lead to long-term elevation loss and eventual drowning of coastal wetlands.**

Subsidence - losing the game

- 88% of sites had evidence of shallow subsidence
- 69% of sites had an elevation deficit relative to regional sea level rise (whether tidal gauge record or satellite altimetry)
- Elevation deficits of ~6 mm/year where they occurred



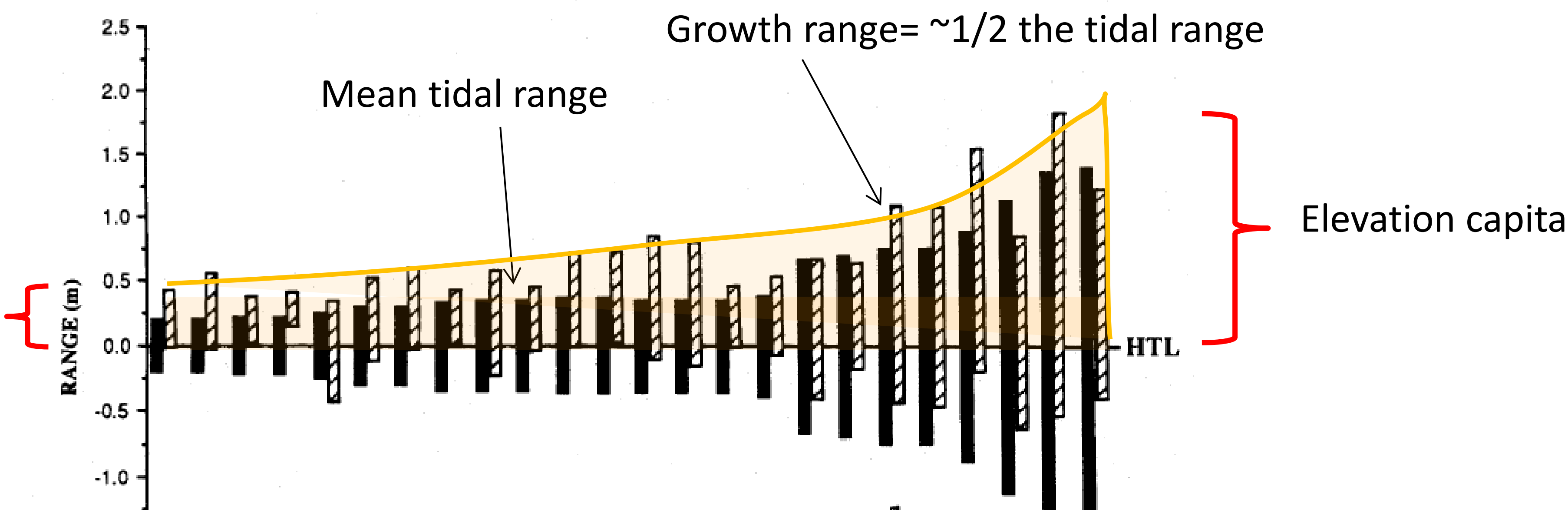
But does this indicate disaster for mangrove forests?

- The concept of elevation capital
- How much loss of elevation capital before the plants cannot grow/recruit (before they reach mean sea level)?
- Elevation capital is described by the depth of the sediment pile that is within the range that would support growth (tidal range and also where you are in the intertidal zone)


Not much elevation capital

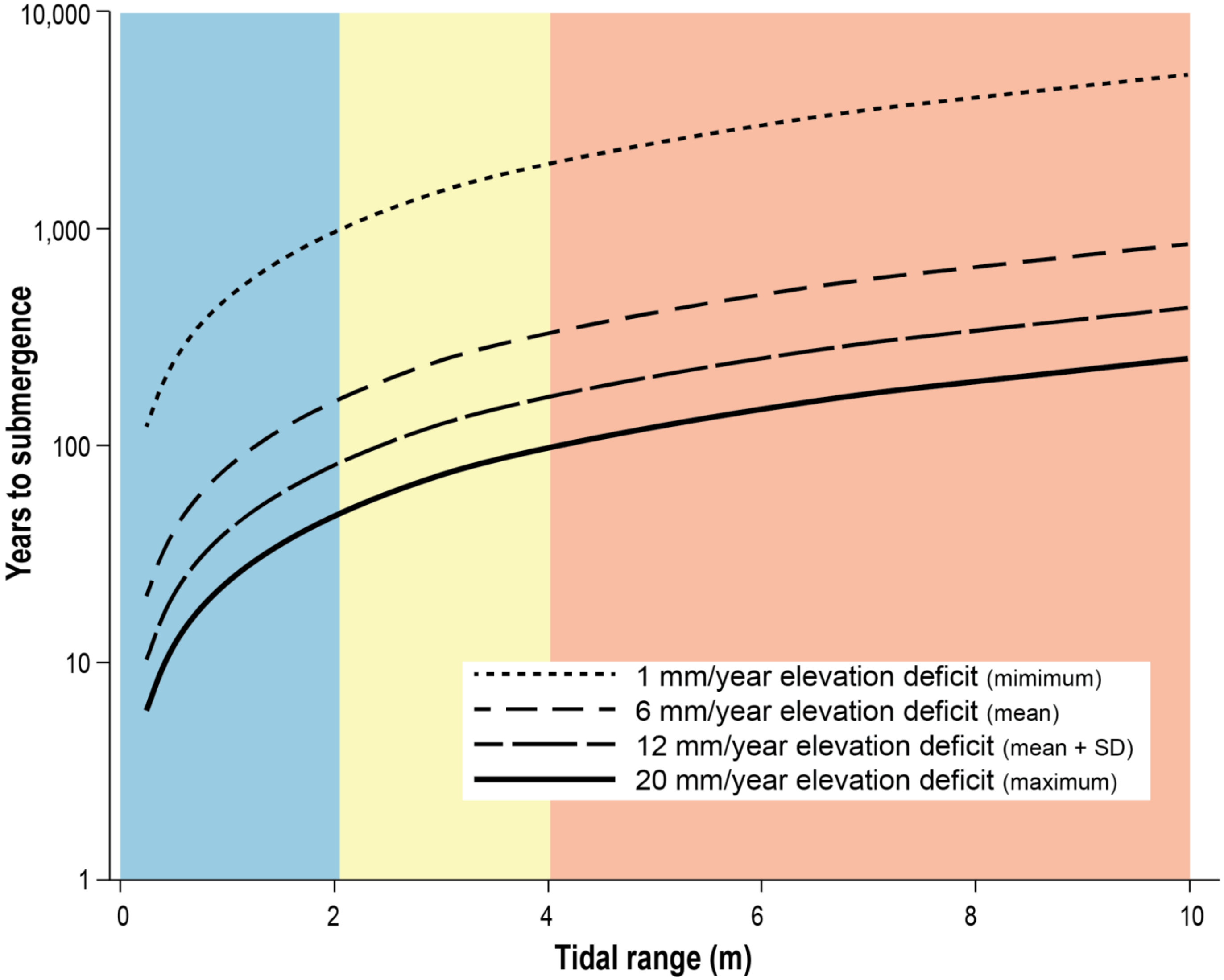
Lots of elevation capital


Elevation capital and tidal range

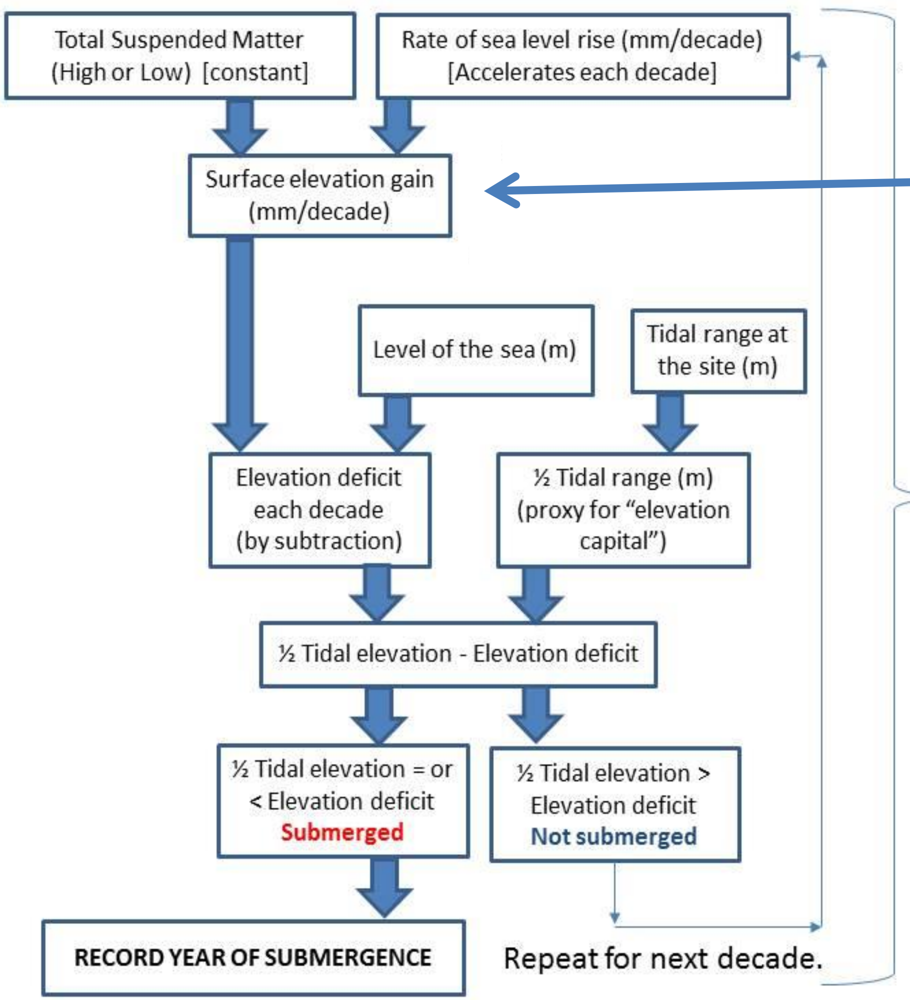


McKee and Patrick 1988

How long can a habitat be suitable?

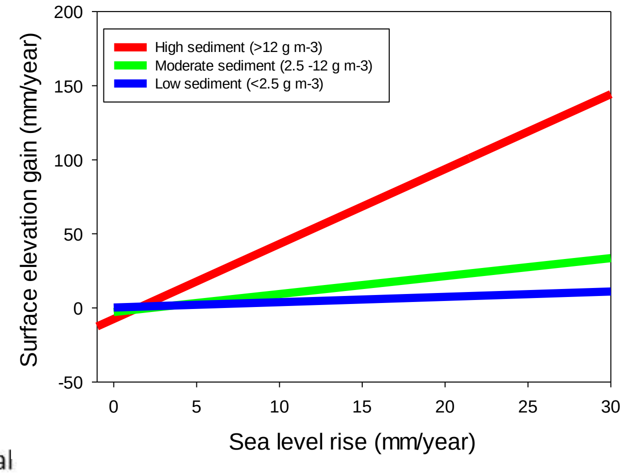


A simple model



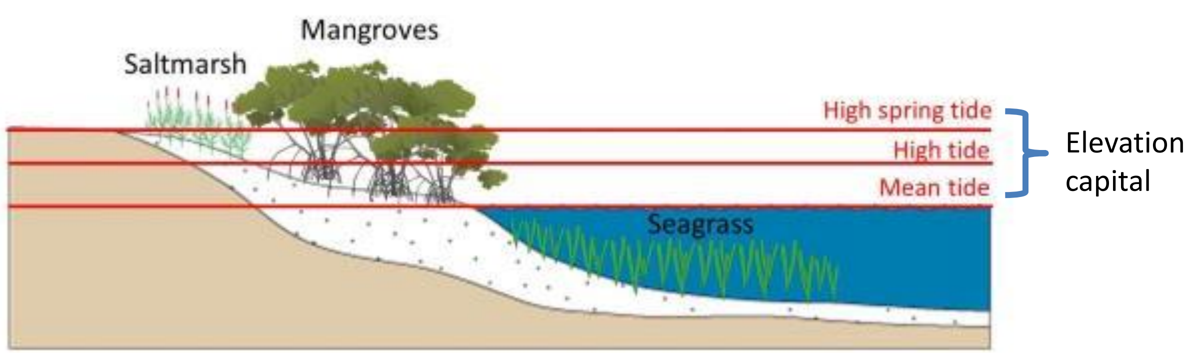
Repeat for different tidal Ranges

Repeat for different accelerating SLR trajectories (0.45 – 1.35 m by 2100)



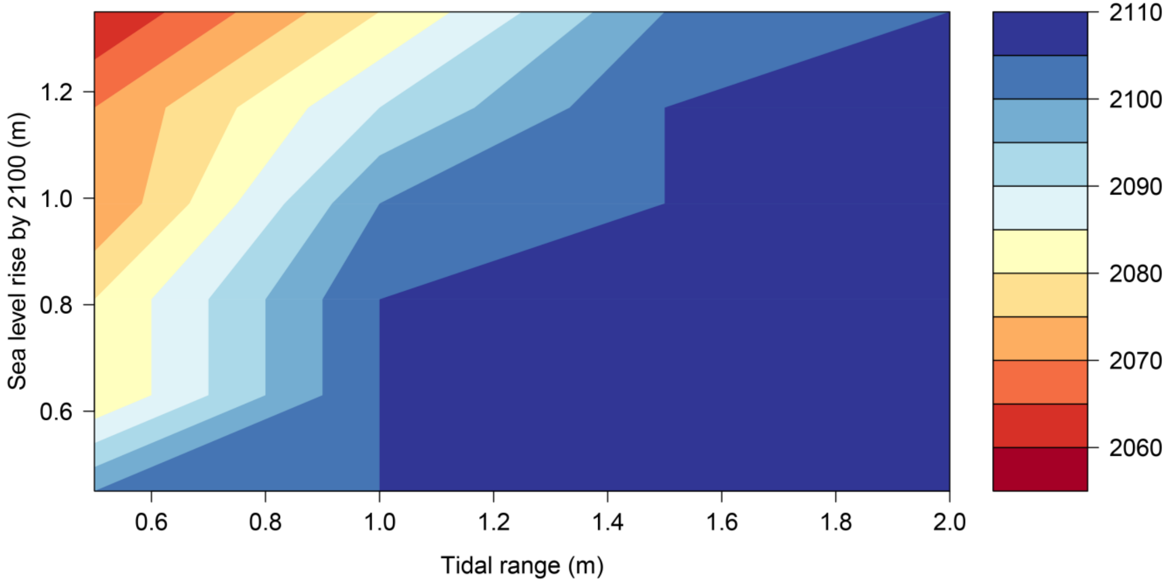
Estimating time to submergence

- Used a range of rates of sea level rise comparable to IPCC scenarios and a 1.4 m “extreme” scenario
- Calculated elevation deficit relative to sea level and subtracted from the elevation capital
- Assumed no horizontal migration (barriers up-slope – no capital for migration)
- Conservative: assumed the forest is not lost until all the elevation capital is gone (this is not change in forested area)
- 192 simulations



Estimating when we might lose mangroves – loss of elevation capital

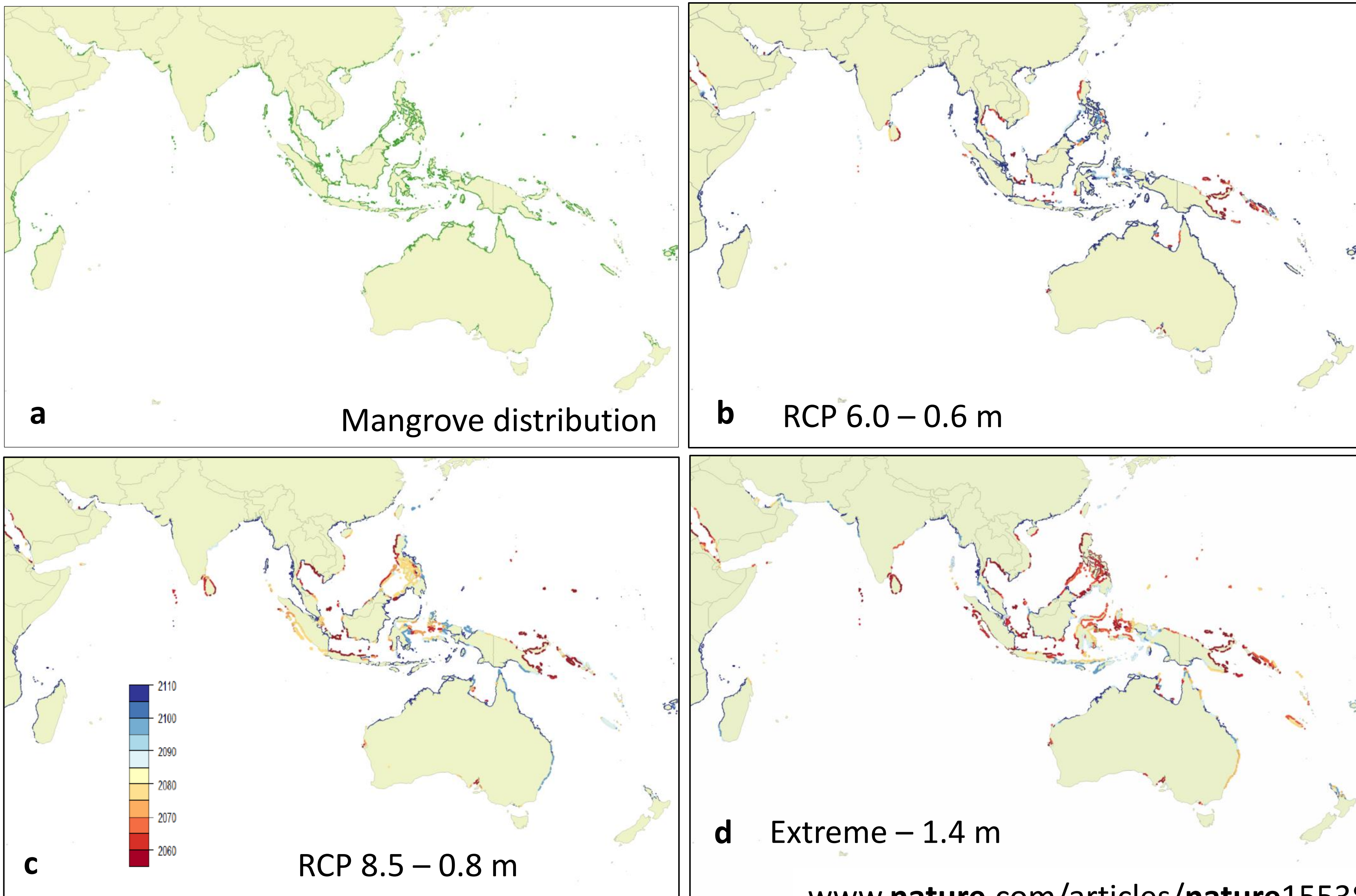
TSM < 2.5 g m^{-3}



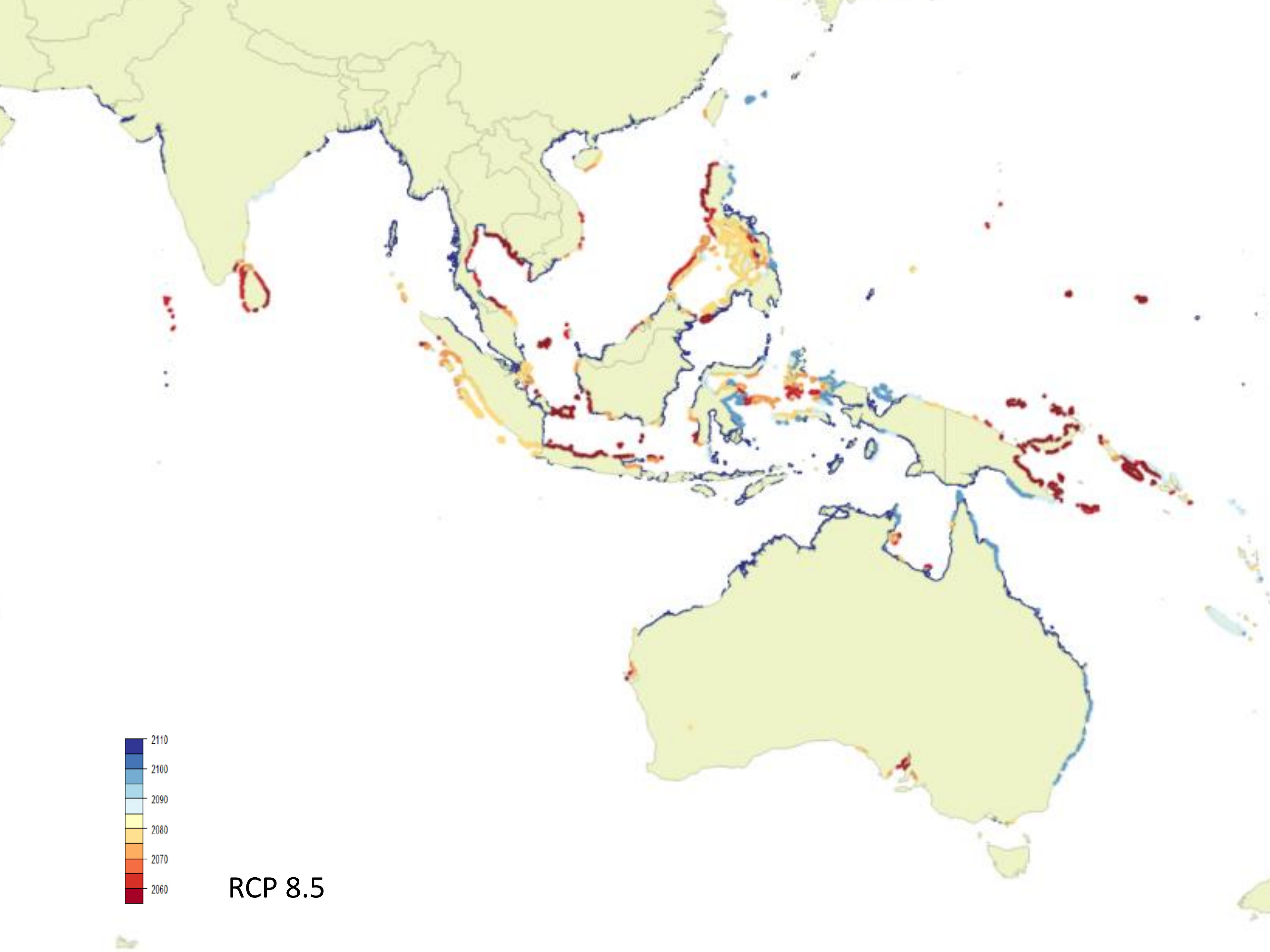
- Low sediment supply, low elevation capital and high SLR – loss by 2060
- High rates of sediment supply (TSM>2.5 g m^{-3}) no losses predicted by 2100

- Going spatial uses Aviso+ FES2012 tide model as an estimate of elevation capital
- TSM concentration was derived from the Medium Resolution Imaging Spectrometer (MERIS) instrument on the European Space Agency's (ESA) Envisat satellite (390 – 1040 nm) (4 km resolution).

Spatial variation in vulnerability



www.**nature**.com/articles/**nature**15538


2110
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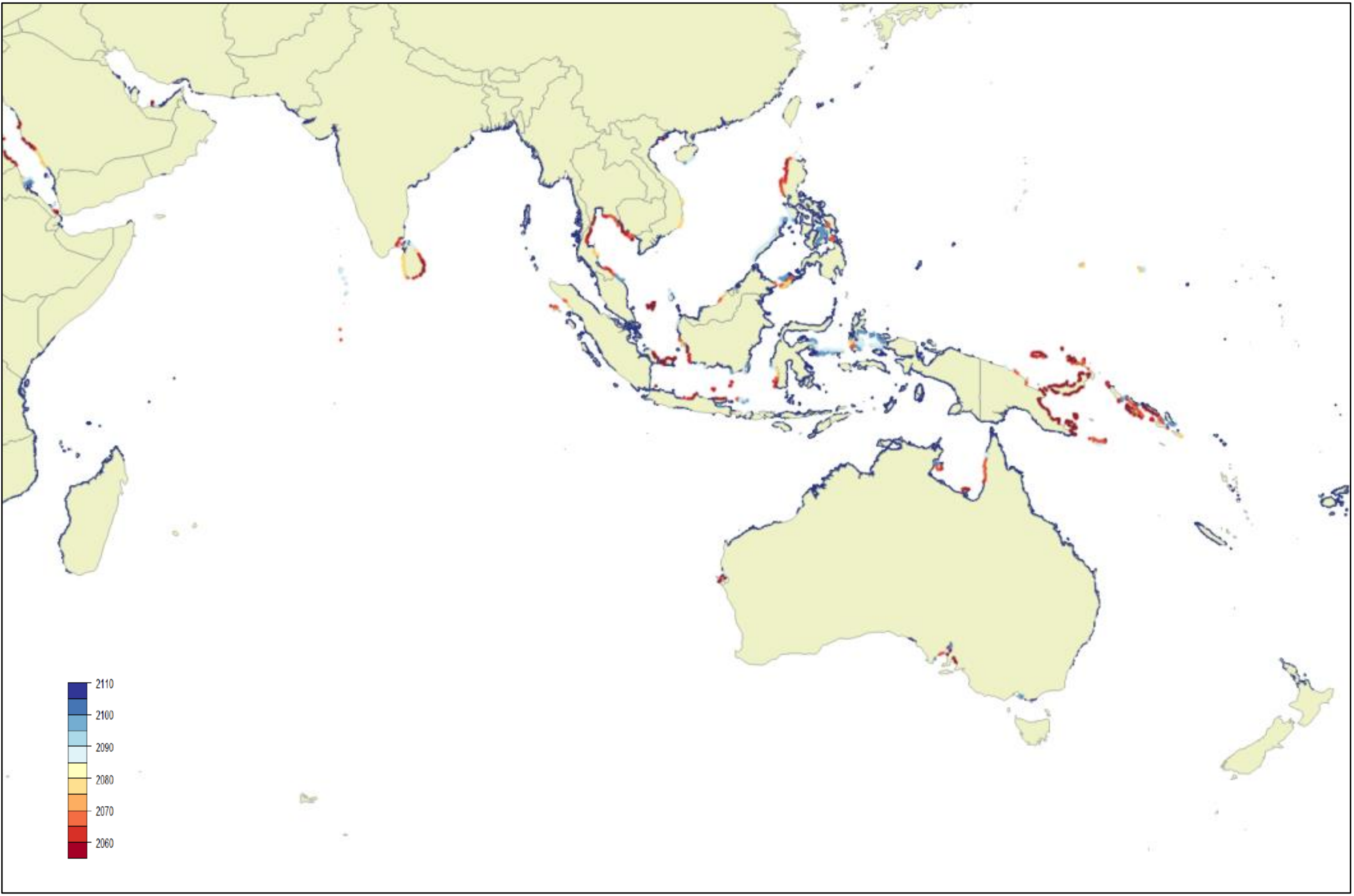
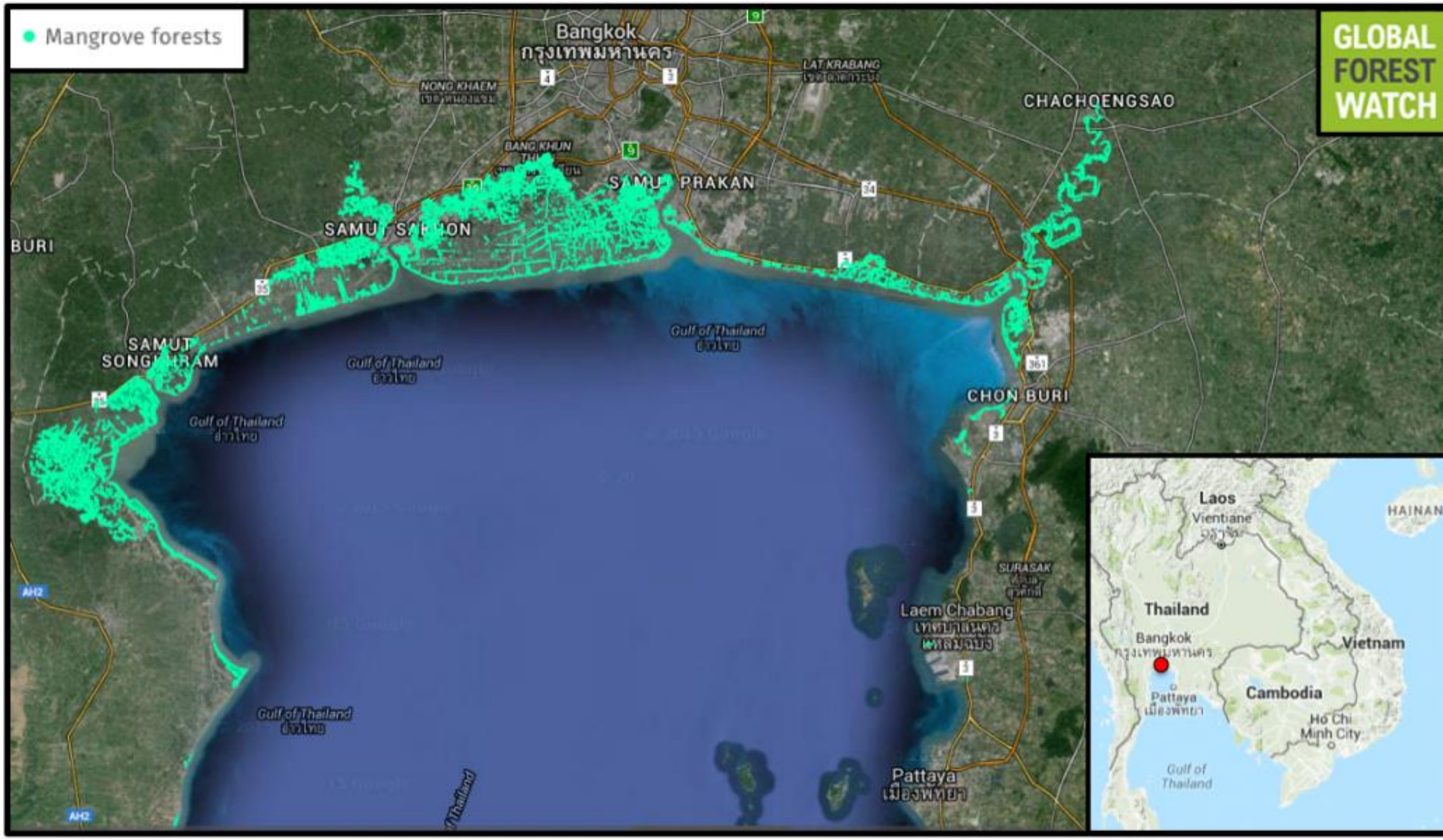
RCP 8.5



RCP – 6.0



The Chao Phraya River enters the ocean near Bangkok. According to Global Forest Watch, the area's mangroves lost nearly 8 percent of their tree cover from 2001 through 2014.

http://news.mongabay.com/2015/10/new-research-sets-doomsday-for-indo-pacific-mangroves/

Overly optimistic?

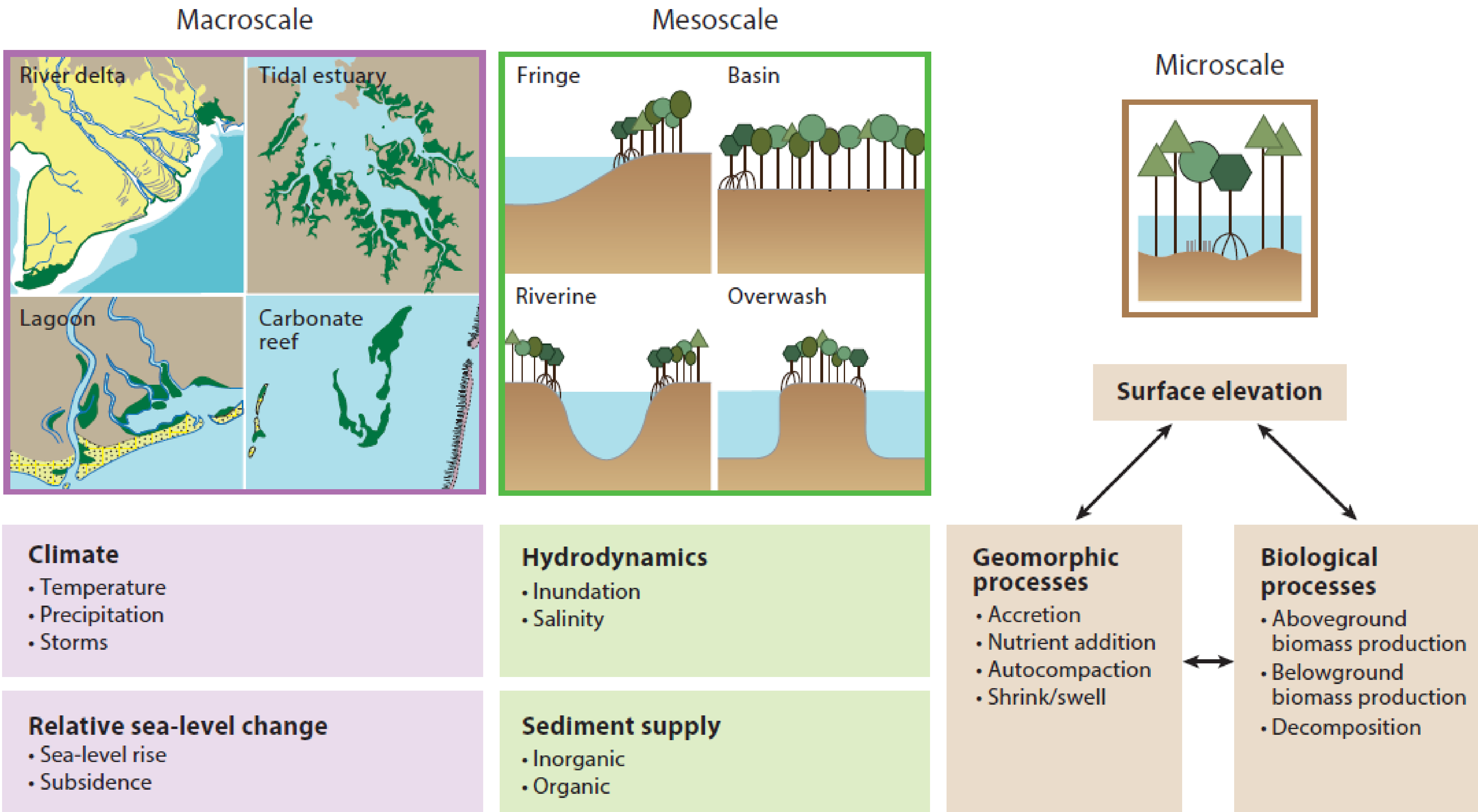
Table 1: Island area and loss over time. Area (edge of vegetation) of islands with greater than 20% change from 1947-2014 based on aerial and satellite imagery.*Partial Island - only village area assessed, nd=no data.

Site	Island area (m^2) 1947	1962	2002	2011	2014	Area lost since 1947 (m^2)	Overall loss (%)
Kale	48,893	43,073	12,572	509	0	48,893	100
Rapita	45,695	21,245	0	0	0	45,695	100
Rehana	38,329	21,798	0	0	0	38,329	100
Kakatina	15,148	3,576	nd	0	0	15,148	100
Zollies	12,236	4,982	0	0	0	12,236	100
Hetaheta	251,701	239,375	nd	104,302	95,910	155,791	62
Sogomou	203,254	199,666	120,072	98,213	92,321	110,933	55
Nuatambu*	28,664	30,084	nd	20,518	13,979	14,685	51
Sogomou Ite	139,655	132,954	115,966	nd	107,296	43,477	23
Sasahura Ite	47,040	48,322	40,006	36,670	36,125	10,915	23
Sasahura Fa	162,766	174,776	152,960	135,863	130,036	32,730	20

Interactions between sea-level rise and wave exposure on reef island dynamics in Solomon Islands

Simon Albert[1*], Javier X. Leon[1, 2], Alistair R. Grinham[1], John A. Church[3], Badin R. Gibbes[1], Colin D. Woodroffe[4]

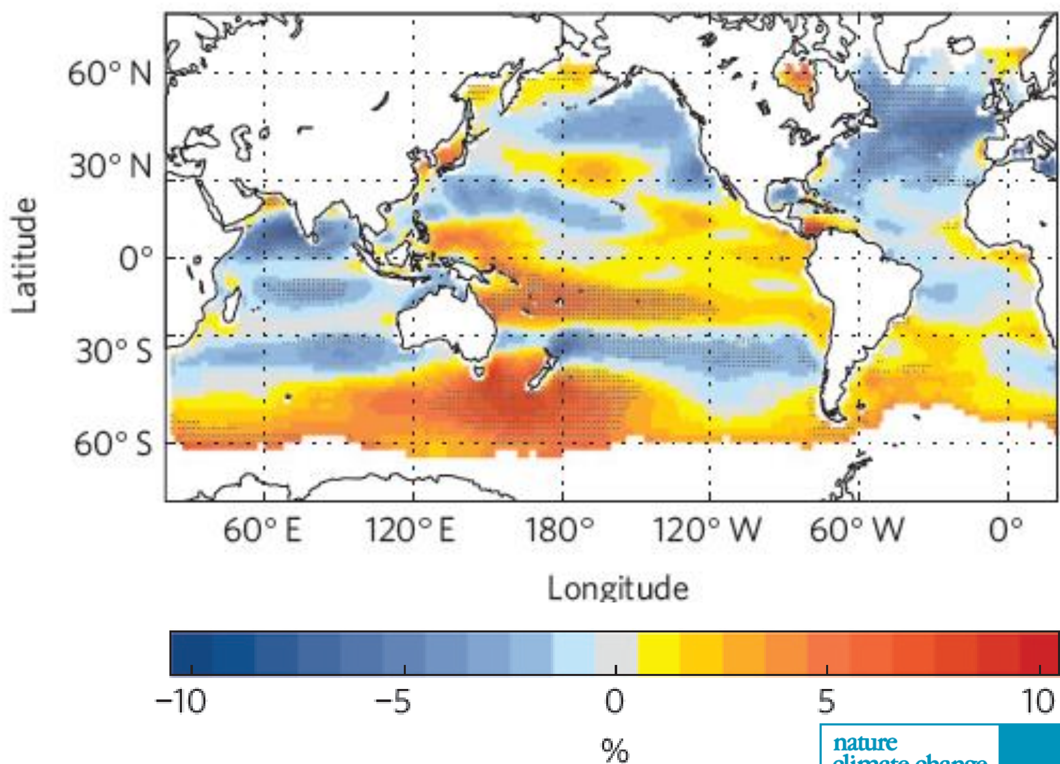
Environmental Research Letters, 2016



Woodroffe et al. 2016 *Annual Review in Marine Science*

Other environmental factors: Waves

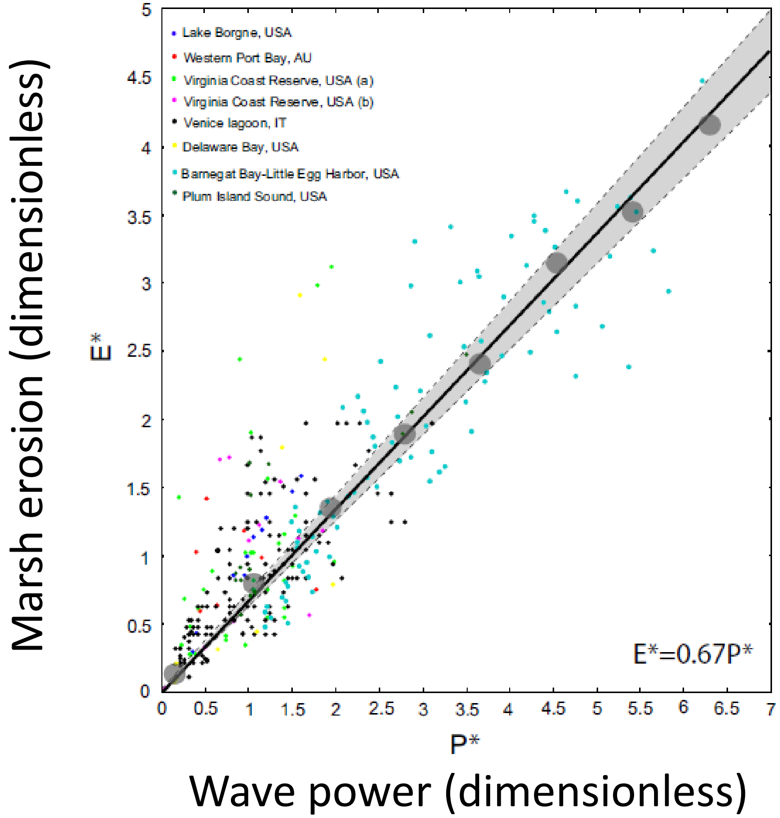
- Increases in wind-driven wave heights in austral winter months (Hemer et al. 2013)
- Increases in wind-driven waves with intensification of ENSO (Barnard et al. 2015)
- Variation in north Atlantic waves influence mangrove distribution (Walcker et al. 2016)
- Sensitivity of recruitment to waves (Balke et al. 2015)



nature climate change
LETTERS
PUBLISHED ONLINE: 13 JANUARY 2013 | DOI: 10.1038/NCLIMATE1791

Projected changes in wave climate from a multi-model ensemble

Mark A. Hemer[1]*, Yalin Fan[2], Nobuhito Mori[3], Alvaro Semedo[4,5] and Xiaolan L. Wang[6]



"Our result clearly shows that long-term salt marsh deterioration is dictated by average wave conditions, and it is, therefore, predictable."

A linear relationship between wave power and erosion determines salt-marsh resilience to violent storms and hurricanes

(2016)

Nicoletta Leonardi[a,1], Neil K. Ganju[b], and Sergio Fagherazzi[a]

[a]Department of Earth and Environment, Boston University, Boston, MA 02215; and [b]US Geological Survey, Woods Hole Coastal and Marine Science Center, Woods Hole, MA 02543-1598

Edited by Andrea Rinaldo, Laboratory of Ecohydrology, Ecole Polytechnique Federale Lausanne, Lausanne, Switzerland, and approved November 12, 2015 (received for review May 22, 2015)

Other factors: extreme events

Photo-Norm Duke

Other direct human influences: Dams

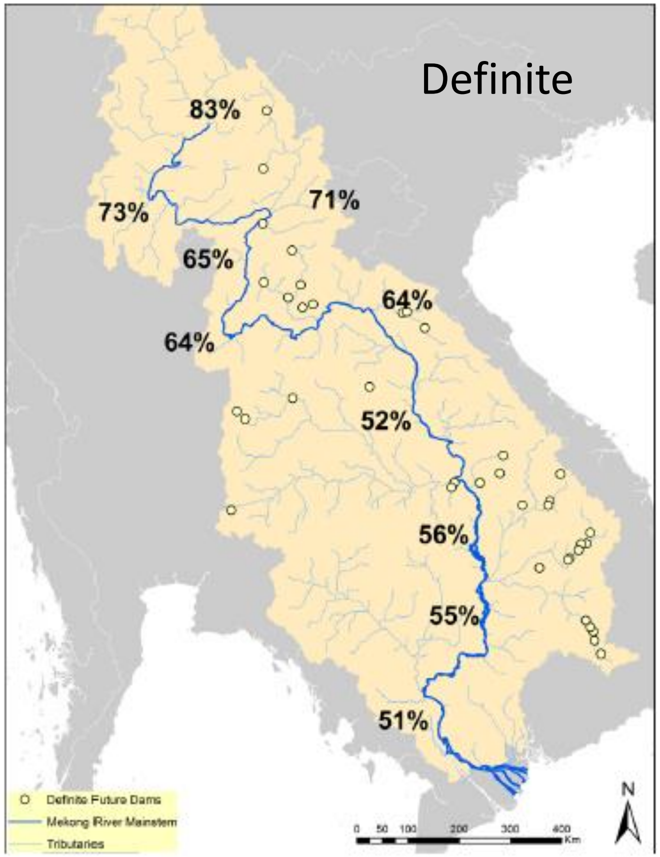


Figure 2. Cumulative sediment starvation effects of the definite-future dams. 51% of the total sediment load of the river would be trapped before reaching the delta.

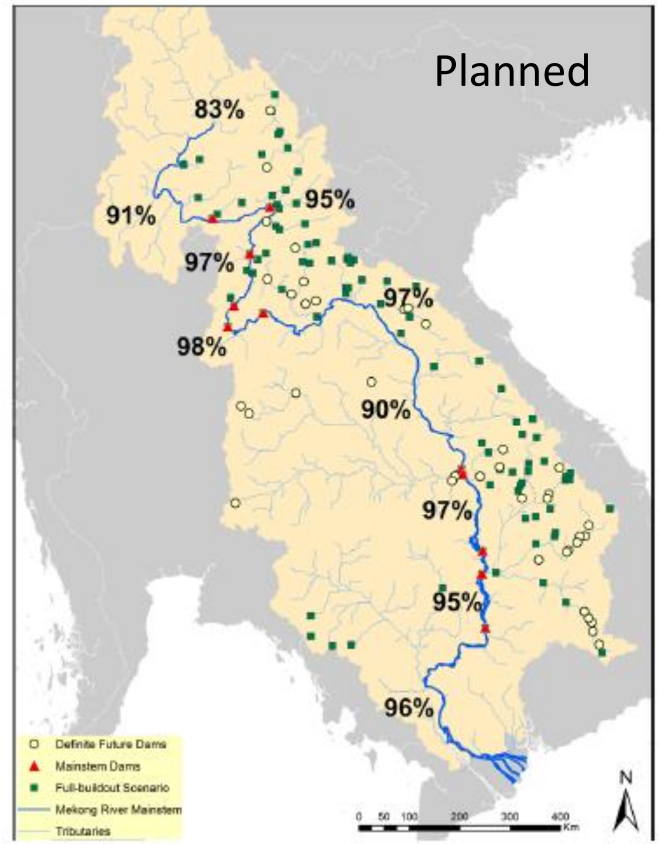


Figure 3. Cumulative sediment starvation effects of full buildout of all proposed dams. 96% of the total sediment load of the river would be trapped before reaching the delta.

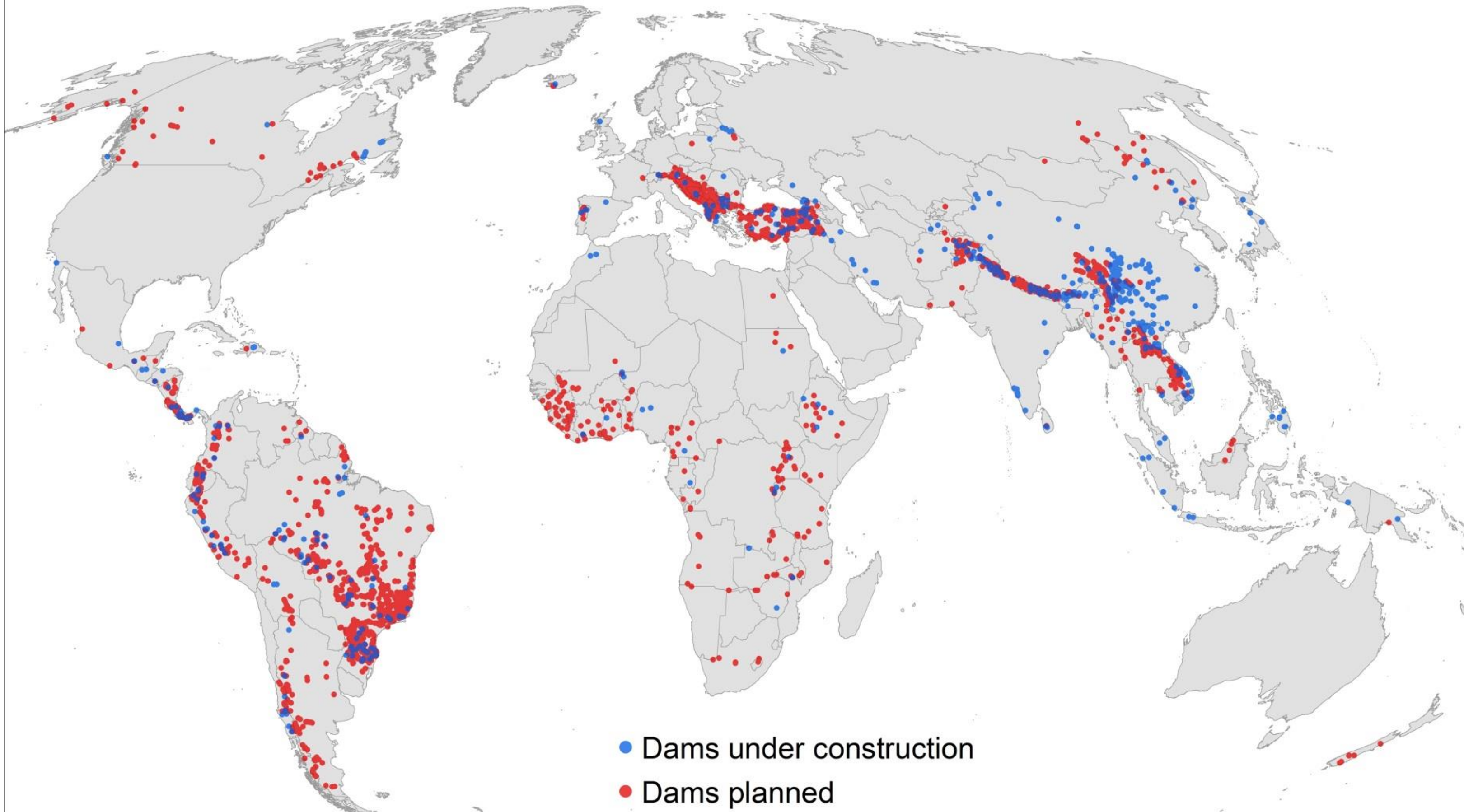
Water Resources Research

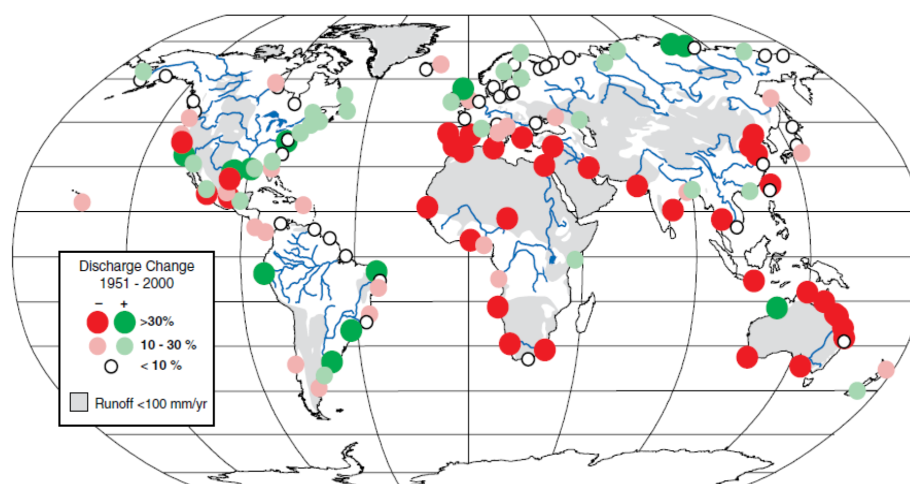
RESEARCH ARTICLE

10.1002/2013WR014651

Dams on the Mekong: Cumulative sediment starvation

G. M. Kondolf[1], Z. K. Rubin[1], and J. T. Minear[1]



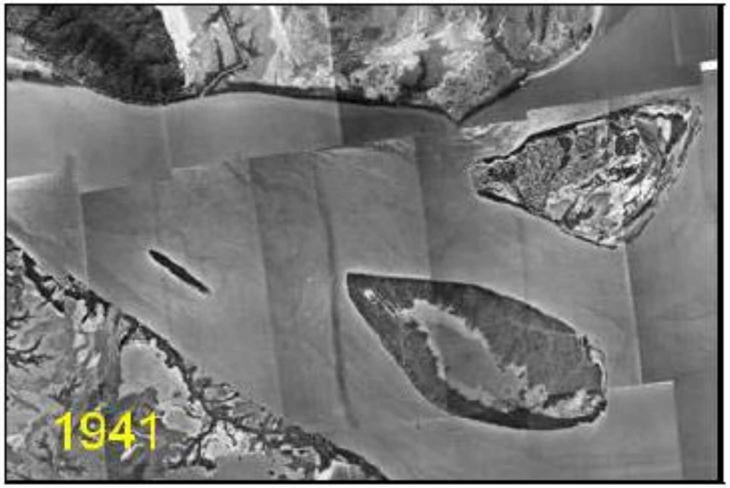


Milliman and Farnsworth 2011

Australia – Dams on the drawing board

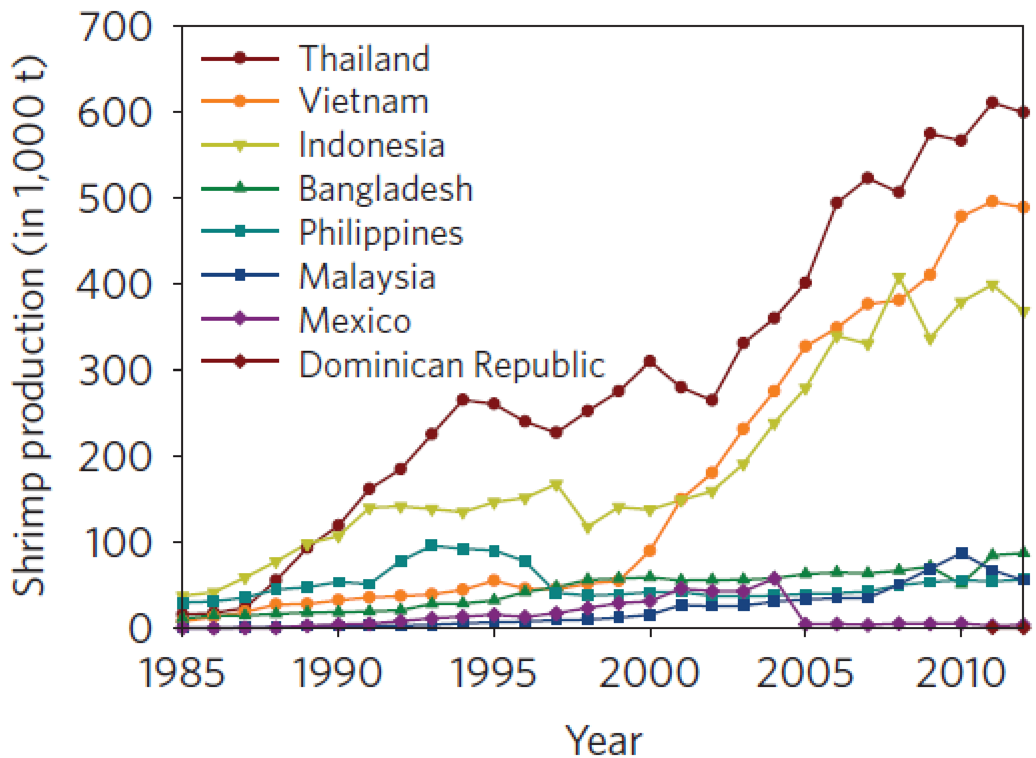
- Reversal of past declines in water quality?
- Interactions with changing rainfall

Fitzroy River



https://theconversation.com/dam-hard-water-storage-is-a-historic-headache-for-australia-33397

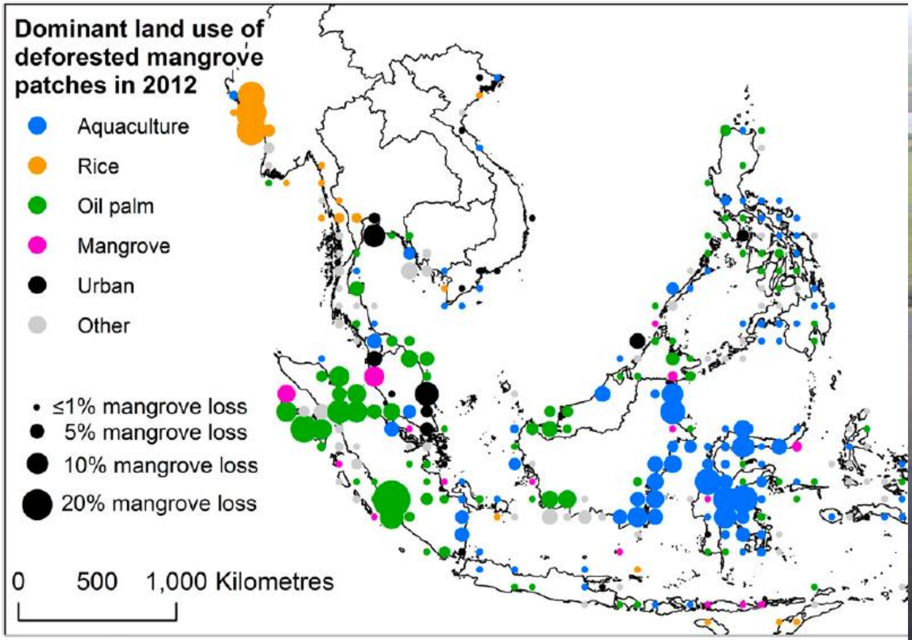
Other factors: Aquaculture



Kennedy Warren

Murdiyarso et al. 2015

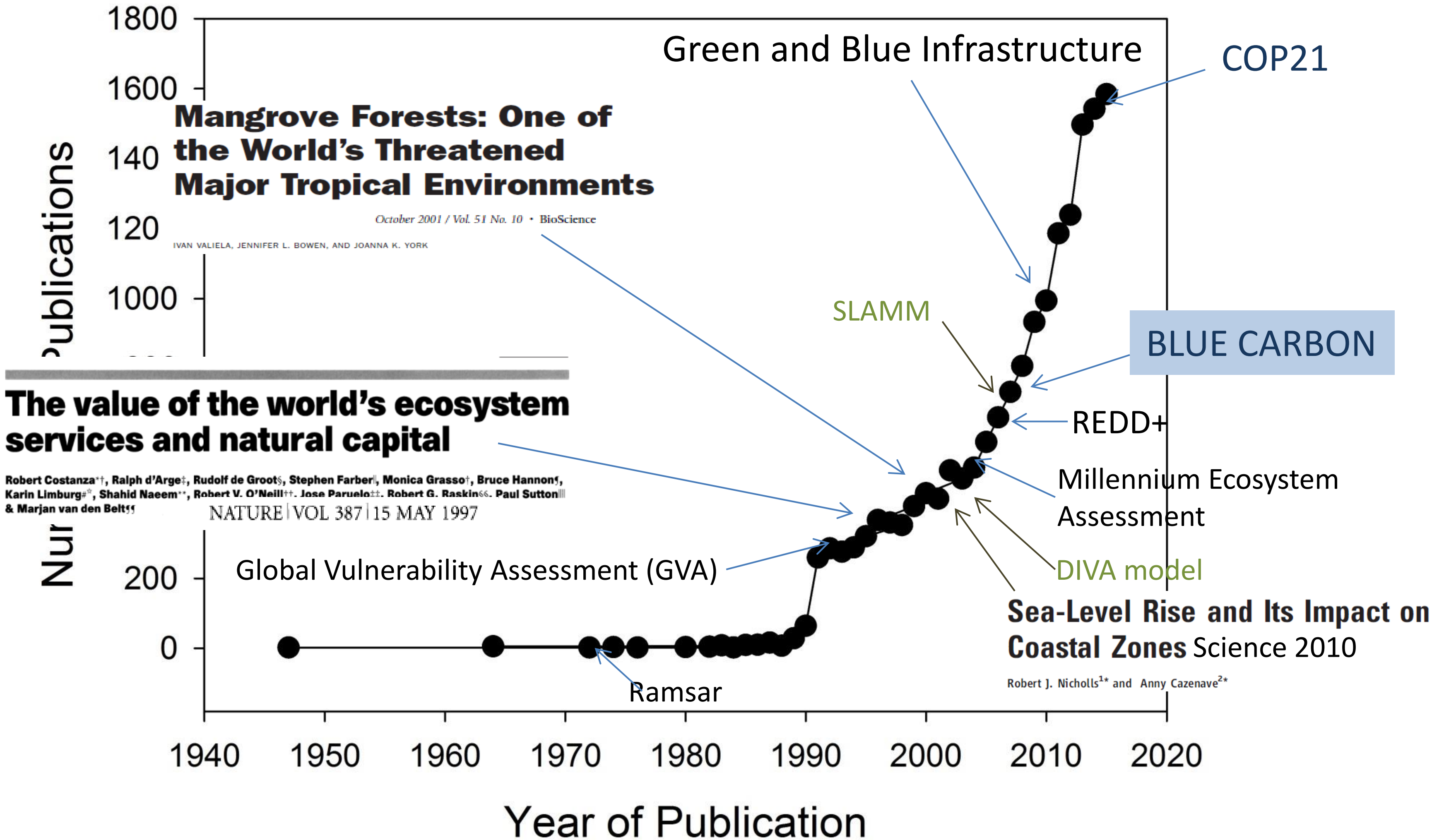
Other factors: Agriculture



Richards and Friess 2016, *PNAS*

Holmes et al. 2013, *GBRMPA*

Pathways: the future



Improve the tools

- Improved modelling approaches would open up opportunities –
  - modelling CO_2 emissions or C burial (blue carbon);
  - optimisation of coastal wetlands vs. hard infrastructure (Mills et al. *Conservation letters* 2015)

Some current options:

- Dynamic Interactive Vulnerability Assessment Wetland Change Model (DIVA_WCM) (e.g. Spencer et al. 2016)
  - 85 km segments – missing a lot of detail
  - Scores and weightings (expert opinion)
- Smaller scale modelling using tools like SLAMM (e.g. Traill et al. 2011)
  - Not easily used by land-sea managers (needs experts)
  - Elevation models of much of the coasts of the region are not available

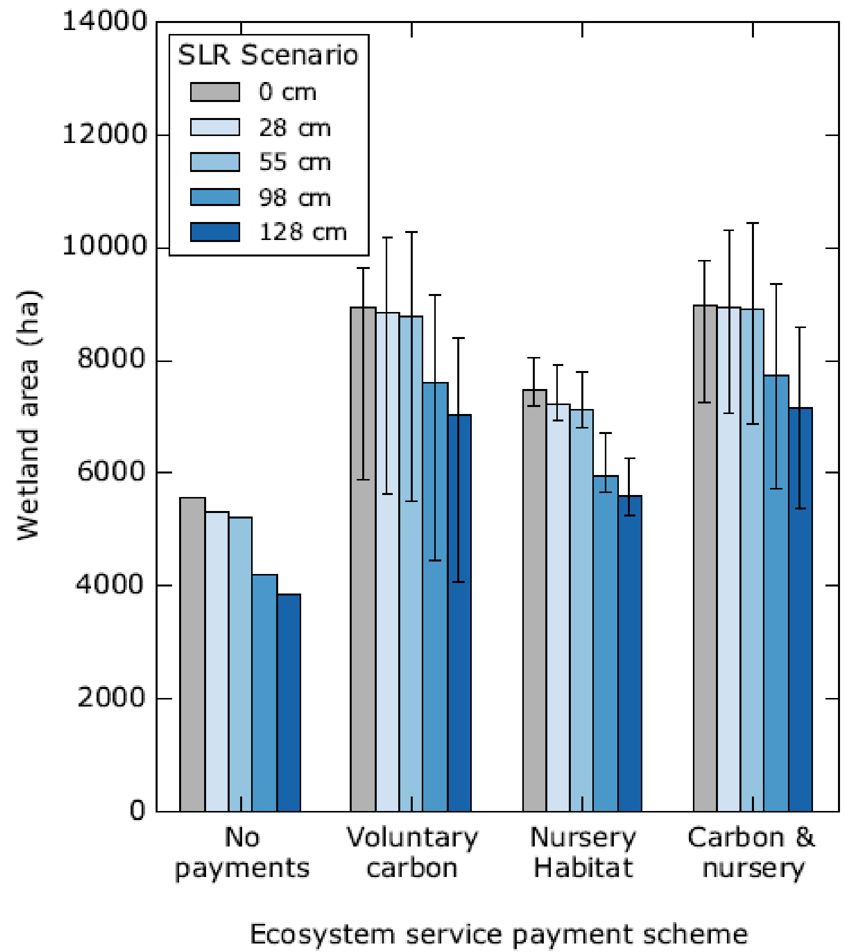
- If we want to make better decisions for future of coastal wetlands we need better tools

Can carbon value of coastal wetlands compensate for the cost of extending reserve network to accommodate sea level rise?

- Amount of land that can be preserved and still "break-even"

Details:

- Modest payments for carbon ($20/MgCO2)
- Cost of land increases with elevation
- SLAMM model
- Connectivity
- Land already conserved is no cost



Runting et al. *Conservation Letters* 2016

“Working with nature”
Adaptation and mitigation

- Conservation and <u>restoration</u> of tidal marshes and mangrove forests
  - Avoided GHG emissions and enhanced carbon sequestration
  - Restore and maintain for ecosystem services (fisheries, fuel, coastal protection, flood protection, biodiversity)
  - Support local economies through restoration (Edwards et al. 2013)
- Planning for reserving ‘new’ space

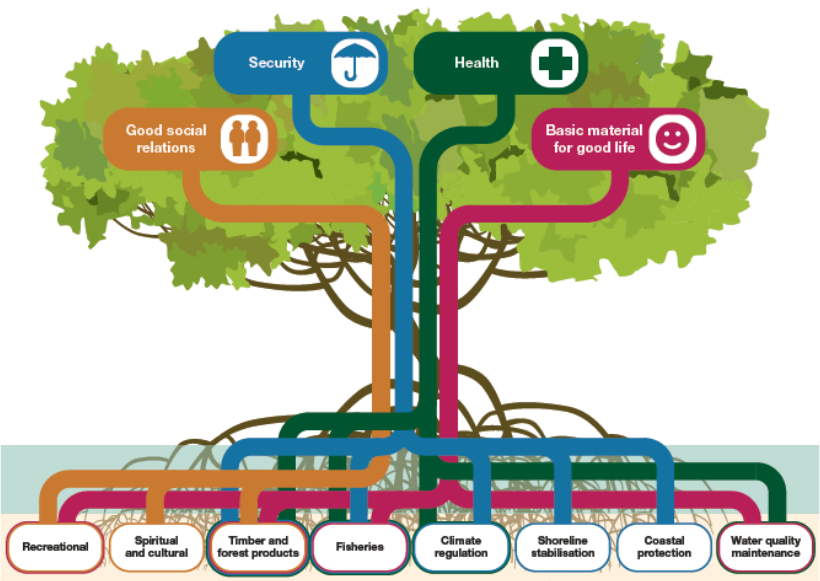


Figure 2.2 Mangrove ecosystem services support human well-being.

Conclusions

- Sediment is important to surface elevation gains; maintaining sediment supply is important
- Subsidence reduces resilience
- A range of other environmental factors interact with rising sea level
- Development of tools
- Restoration and planning provides opportunities for ‘adaptation’

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