Adjustment of the mangrove forest to rising sea-levels caused by climate change

Mangroves are adapted to grow in ecosystems at the interface between marine and terrestrial environments. They are of essential importance for both humans and natural environment, although they are already strongly impacted by human activities[1]. Climate change adds yet another constraint: temperature increase, variations in precipitation, salt stress[2, 3], etc. We will be particularly interested in the impact of the rise in sea level. As one of the most certain outcomes of global warming, the rise of sea level is already visible (between 12 and 22 cm during the 20th century[4]) and countless climate model project an elevation increase, like Salomon *et al.* (2017)[5] who project a sea-level rise of 18 to 59 cm by the end of the 21st century.

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Mangroves in short[2, 6, 7]:

- 75% of inter- and tropical coasts
- Strong resilience
- Low plant diversity
- High adaptive power of mangroves tree
- Coastal protection
- Refuge for marine species
- Sediment retention
- Carbon sink

Fig. 1. Mangrove of 'Grand Cul de Sac marin' (Guadeloupe)

Process

Elevation change in mangrove forests typically occurs at very slow rates (mm/year)

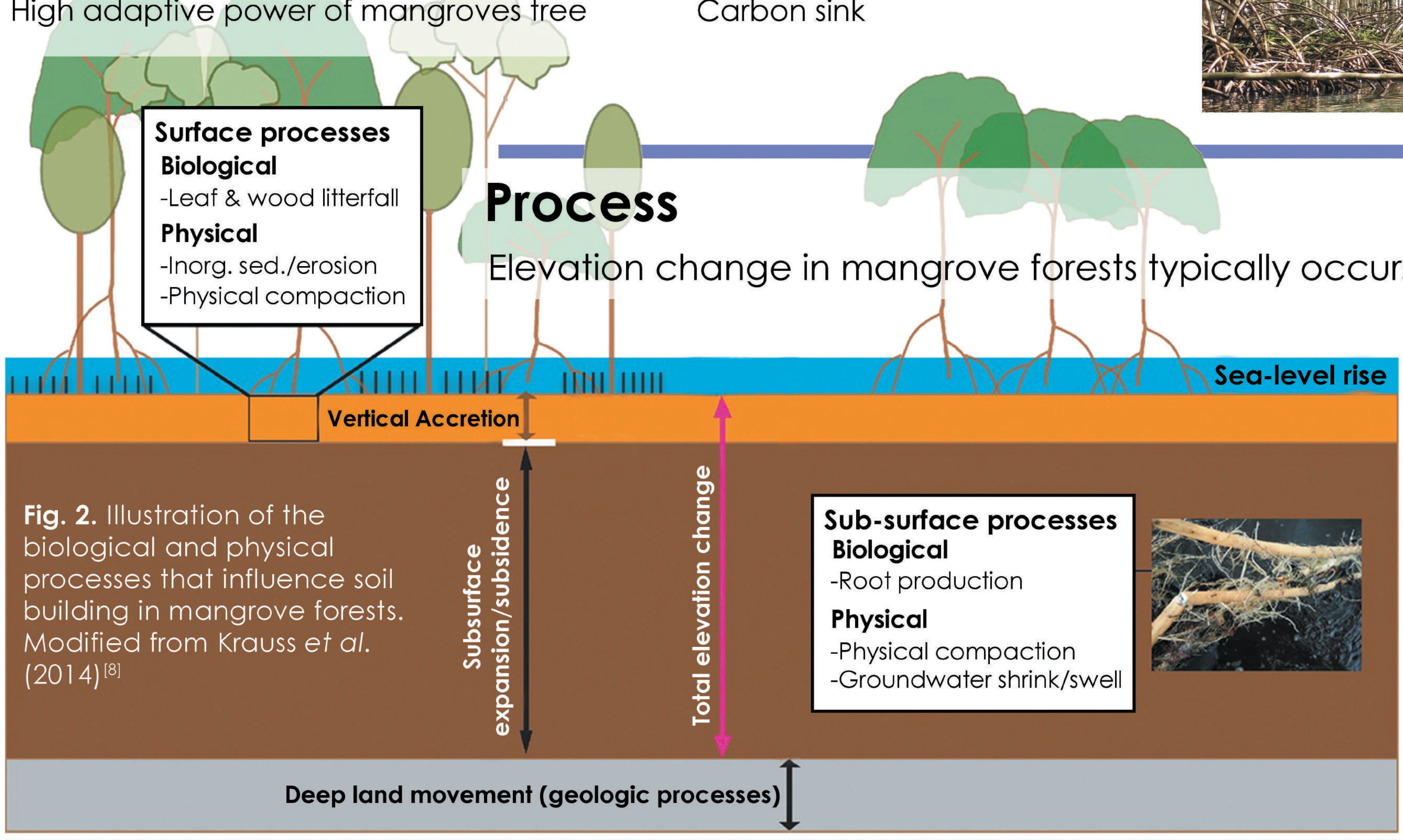


Fig. 2. Illustration of the biological and physical processes that influence soil building in mangrove forests. Modified from Krauss *et al.* (2014)[8]

To maintain mangroves, its sedimentary surface must follow the rise in sea level

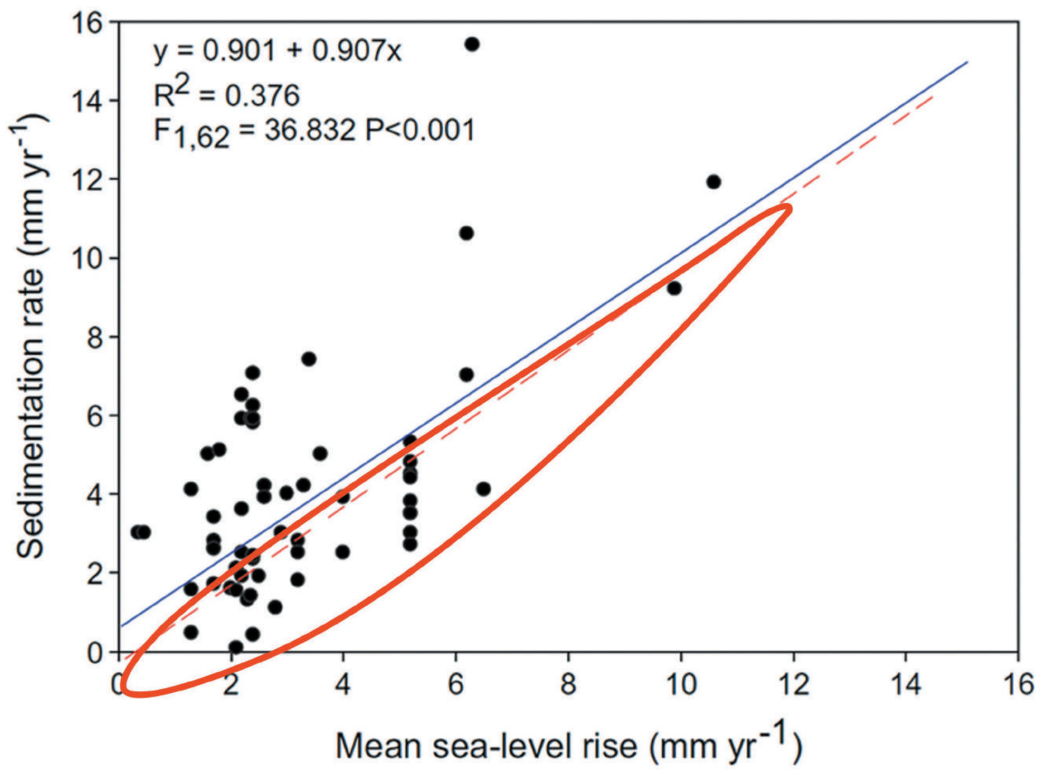
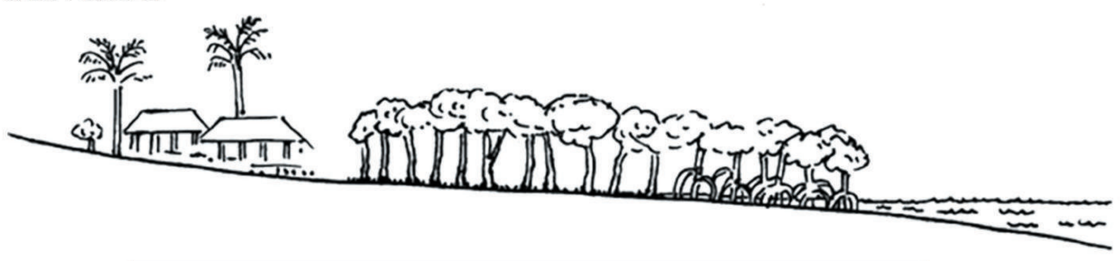


Fig. 3. Relationship between sediment accretion rates and the current average rate of global sea level rise. The red circle correspond to mangroves that do not have a sufficient sediment supply [9]

Responses

Fig. 4. The four main scenarios (a, b, c, d) for mangrove responses to sea-levels trends [4,10]

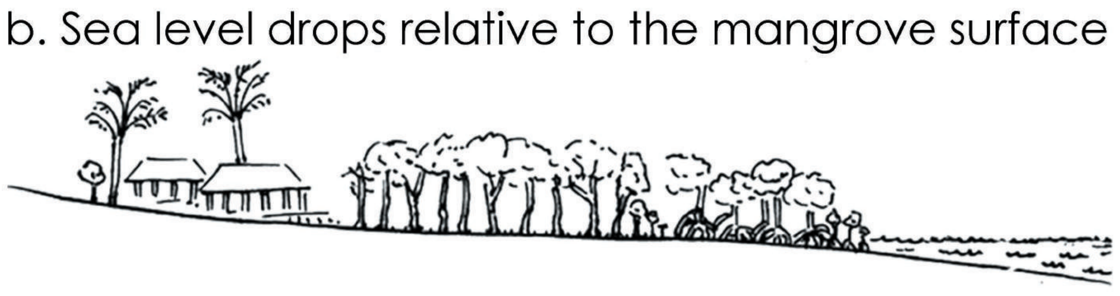
a. No change in sea level relative to mangrove surface



Mangrove position remains stable

- Factor of development stay constant (*e.g.* elevation, salinity, inundation)

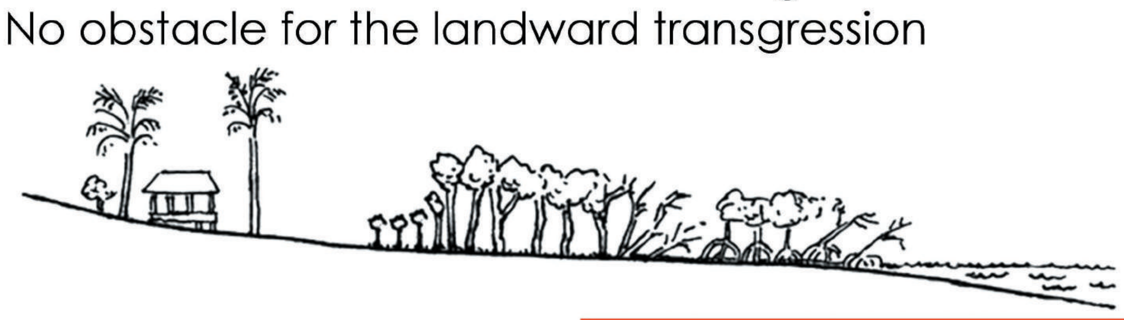
b. Sea level drops relative to the mangrove surface



Mangrove margins migrates seaward

- Development on emerged back reefs in Fiji islands
- Also latterally, if there is suitable conditions for establishment

c. Sea level rises relative to the mangrove surface. No obstacle for the landward transgression



d. Sea level rises relative to the mangrove surface and landward transgression is obstructed

Insufficient sediment supply to adjust. Mangrove migrates landward. Erosion of the mangrove [9, 11]

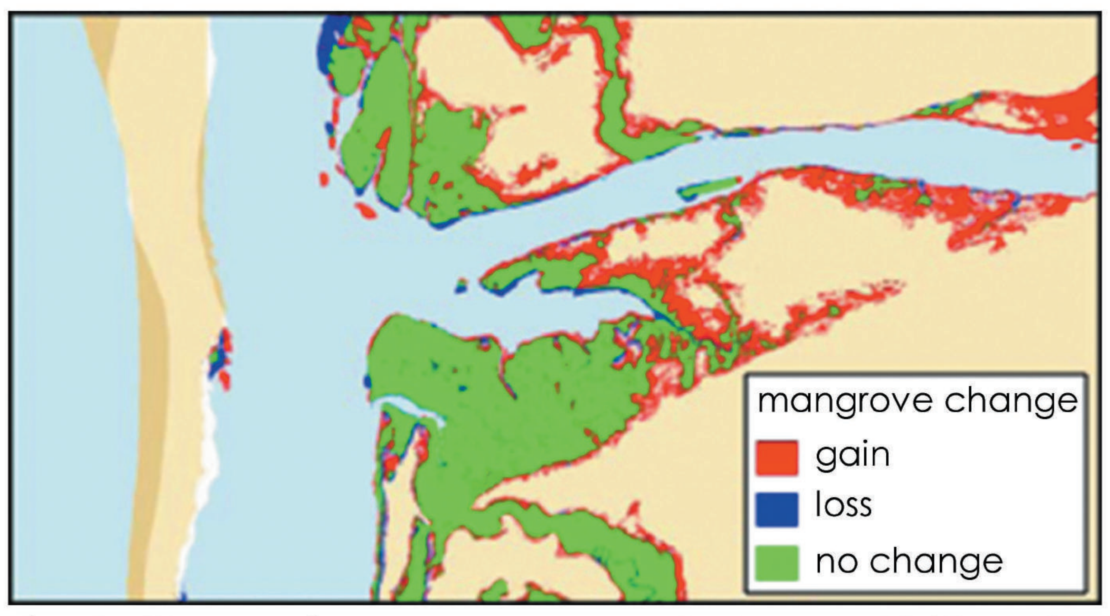


Fig. 5. Change in mangrove area between 1960 and 2001 near Boca de Santo Domingo region (pacific coast of Mexico)[12]

- **20 % increase in surface area**. Past empty area are now colonized by saplings

➡ More gain than loss BUT **seaward side provide most of environmental services** like fisheries and coastal protection[12, 13, 14]

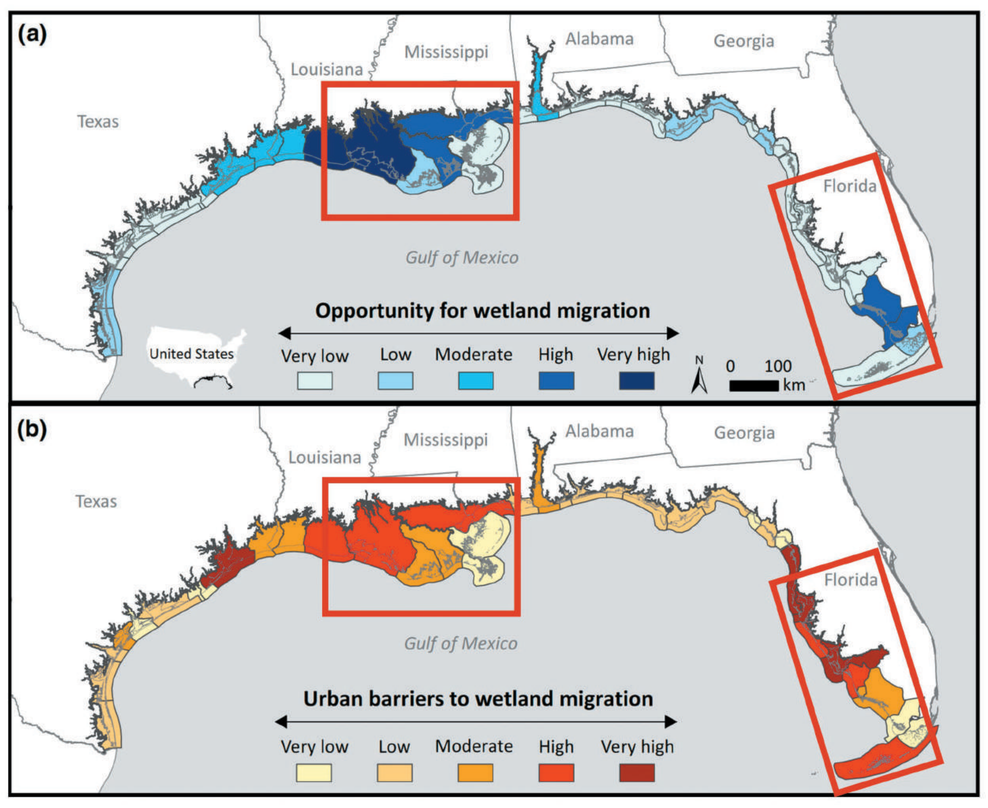


Fig. 6. 1-m sea level rise "by 2100" scenario with the representation of **(a)** area available for landward migration and **(b)** area with urban lands that are expected to prevent migration. Red square represent mangrove [14]

➡ Mangrove **will decline if no space is available** for colonization [9, 14]

Conclusions

- **Already visible impacts** of sea level rise even if lesser than anthropogenic stressors [10]
- But sea level rise may account in the future for **a significant part of the losses as many** mangrove sites have **not kept pace with the rise** (10–20% of total estimated losses) [9]
- **Mangroves will adapt** but are likely to be more negatively than positively impacted [9]
- **Loss of multiple ecosystem services** (e.g. water quality, decrease of biodiversity, loss of fish nursery and stabilization of coastal land) [10, 15, 16]

Solutions ? [2, 9, 14, 17]

- Protected area network
- Mangrove rehabilitation
- Establishment of landward migration corridors
- Limit the coastal development
- Preservation of environments in contact with mangroves

[1] Joseph, C., Dolique, F. & Saffache, P. Impacts des activités anthropiques sur les écosystèmes littoraux et marins : les mangroves du parc national des trois baies étudiées à partir d'images landsat. *Les cahiers d'outre-mer* 72, 69–95 (2019) ; **[2]** Fromard, F. & Gardel, A. Mangrove, pressions anthropiques et climatiques. In *Les mécanismes d'adaptation de la biodiversité aux changements climatiques et leurs limites*, 105–109 (Académie des Sciences, 2017) ; **[3]** Bompy, F., Lequeue, G., Imbert, D. & Dulormne, M. Increasing fluctuations of soil salinity affect seedling growth performances and physiology in three neotropical mangrove species. *Plant and Soil* 380, 399–413 (2014) ; **[4]** Gilman, E., Ellison, J. & Coleman, R. Assessment of mangrove response to projected relative sea-level rise and recent historical reconstruction of shoreline position. *Environmental Monitoring and Assessment* 124, 105–30 (2007) ; **[5]** Solomon, S., Manning, M., Marquis, M. & Qin, D. *Climate change 2007-the physical science basis : Working group I contribution to the fourth assessment report of the IPCC*, vol. 4 (Cambridge university press, 2007) ; **[6]** Lee, S. Y. et al. Ecological role and services of tropical mangrove ecosystems : a reassessment. *Global Ecology and Biogeography* 23, 726–743 (2014) ; **[7]** Alongi, D. M. Carbon sequestration in mangrove forests. *Carbon management* 3, 313–322 (2012) ; **[8]** Krauss, K. W. et al. How mangrove forests adjust to rising sea level. *New Phytologist* 202, 19–34 (2014) ; **[9]** Alongi, D. M. The impact of climate change on mangrove forests. *Current Climate Change Reports* 1, 30–39 (2015) ; **[10]** Gilman, E. L., Ellison, J., Duke, N. C. & Field, C. Threats to mangroves from climate change and adaptation options : a review. *Aquatic botany* 89, 237–250 (2008) ; **[11]** Lovelock, C. E. et al. The vulnerability of indo-pacific mangrove forests to sea-level rise. *Nature* 526, 559–563 (2015) ; **[12]** Lopez-Medellin, X. et al. Oceanographic anomalies and sea-level rise drive mangroves inland in the pacific coast of mexico. *Journal of Vegetation Science* 22, 143–151 (2011) ; **[13]** Koch, E. W. et al. Non-linearity in ecosystem services : temporal and spatial variability in coastal protection. *Frontiers in Ecology and the Environment* 7, 29–37 (2009) ; **[14]** Borchert, S. M., Osland, M. J., Enwright, N. M. & Griffith, K. T. Coastal wetland adaptation to sea level rise : Quantifying potential for landward migration and coastal squeeze. *Journal of Applied Ecology* 55, 2876–2887 (2018) ; **[15]** Vuik, V., Jonkman, S. N., Borsje, B. W. & Suzuki, T. Nature-based flood protection : The efficiency of vegetated foreshores for reducing wave loads on coastal dikes. *Coastal engineering* 116, 42–56 (2016) ; **[16]** Mumby, P. J. et al. Mangroves enhance the biomass of coral reef fish communities in the caribbean. *Nature* 427, 533–536 (2004) ; **[17]** Enwright, N. M., Griffith, K. T. & Osland, M. J. Barriers to and opportunities for landward migration of coastal wetlands with sea-level rise. *Frontiers in Ecology and the Environment* 14, 307–316 (2016).