LEIBNIZ CENTRE
for Tropical Marine Research

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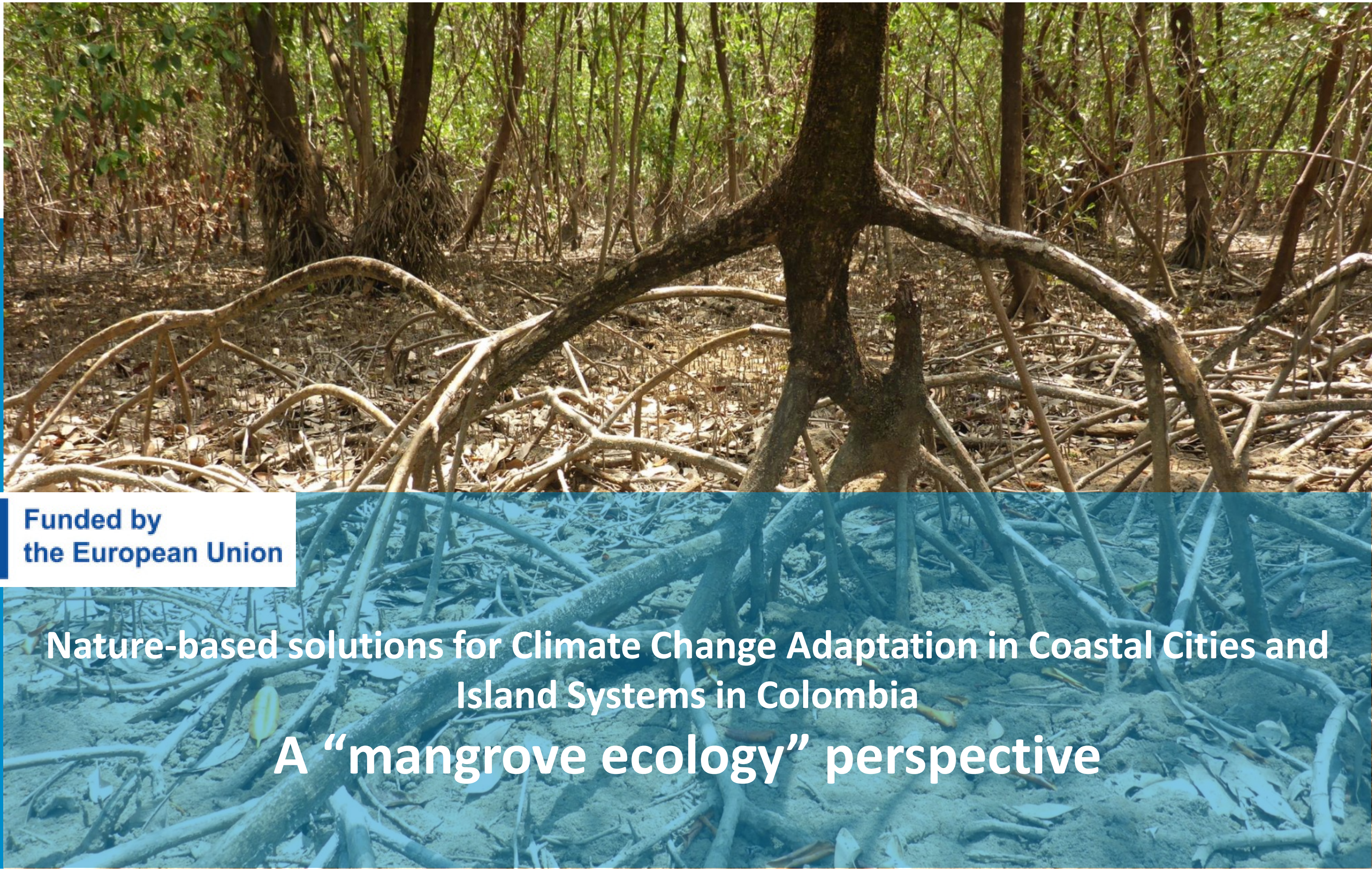


Funded by the European Union

Nature-based solutions for Climate Change Adaptation in Coastal Cities and Island Systems in Colombia

A “mangrove ecology” perspective

18th January 2024

Véronique Helfer

EUCDs COL01: Nature-based Solutions for Climate Change Adaptation in Coastal Cities and Island Systems in Colombia - *Workshop: Lessons Learned on NBS for Climate Change Adaptation in Coastal Cities and Island Systems.*
Cartagena, Colombia, 17-19 January 2024

CEMarin Corporation Center of Excellence in Marine Sciences

IH cantabria INSTITUTO DE HIDRÁULICA AMBIENTAL UNIVERSIDAD DE CANTABRIA

ZMT LEIBNIZ-ZENTRUM für Marine Tropenforschung

ZMT

The Leibniz Centre for Tropical Marine Research (ZMT), Bremen, DE

Only scientific institute in Germany that investigates **tropical and subtropical coastal ecosystems** and their importance for **nature** and **people**.

ZMT

Mission, approach and aim

Our mission

The mission of ZMT is to provide a **scientific basis** for the **protection** and **sustainable use** of **tropical coastal ecosystems** by conducting **research**, **capacity development** and **consulting activities** in close cooperation with international and national partners.

Our approach

Integration of **social** and **natural science** approaches, as well as transdisciplinary **stakeholder involvement** processes bridging the science-practice gap.

Our aim

A **socially** and **ecologically** possible planetary future.

Mangrove ecology Work Group

Aim and research questions

Provide a reliable scientific fundament for the protection, (re-)establishment and sustainable use of mangroves and other coastal vegetated ecosystems.

→ Guideline for stakeholders and decision-makers for the management and (re-)establishment of mangrove ecosystems.

Upon adequate sampling strategies and experimental design, we want to infer:

- which factors drive **community composition** in mangrove ecosystems;
- how this translates into **ecosystem processes and services;**
- how mangrove **ecosystem services** are or will be affected upon **global change**.

Nature-based solutions (NbS)

Definitions

"Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits." (Initial IUCN definition)

"Nature-based Solutions are actions to protect, conserve, restore, sustainably use and manage natural or 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." (Global definition adopted by the United Nations Environment Assembly at its fifth meeting (UNEA-5) providing an official reference to be used by Parties to the CBD and other international agreements)

Sources: Figure: Cohen-Shacham, E., Walters, G., Janzen, C. and Maginnis, S. (eds.) (2016). Nature-based Solutions to address global societal challenges. Gland, Switzerland: IUCN. xiii + 97pp. Quotes: nbs-in-gbf-targets-brief-november-2022.pdf

Nature-based solutions (NbS)

Definitions

“NbS encompasses a variety of approaches working with nature for societal benefit, including

Ecosystem-based adaptation (EbA);

Ecosystem-based Disaster Risk Reduction (DRR);

Ecosystem-based mitigation (EbM).“

Ecosystem-based Adaptation (EbA) is a **nature-based solution** that harnesses **biodiversity** and **ecosystem services** to **reduce vulnerability** and **build resilience** to **climate change** in a comprehensive adaptation strategy. It links **biodiversity** and ecosystem conservation approaches with sustainable socio-economic development for helping people adapt to shocks and risks associated with climate change.

EbA is defined as “an approach that **builds resilience** and **reduces the vulnerability** of **local communities** to **climate change**.”

Sources: nbs-in-gbf-targets-brief-november-2022.pdf;
https://www.iucn.org/sites/dev/files/feba_eba_qualification_and_quality_criteria_final_en.pdf,
https://www.iucn.org/sites/dev/files/import/downloads/ecosystem-based_adaptation_issues_brief_final.pdf,

Nature-based solutions (NbS)

Overarching goal

The goal of Nature-based Solutions is "to support the **achievement of society's development goals** and **safeguard human well-being** in ways that reflect cultural and societal values and **enhance the resilience of ecosystems**, their **capacity for renewal** and the **provision of services**; Nature-based Solutions are designed to address major societal challenges, such as food security, climate change, water security, human health, disaster risk, social and economic development".

Source: https://portals.iucn.org/library/sites/library/files/resrecfiles/WCC_2016_RES_069_EN.pdf

Nature-based solutions (NbS)

Definitions

Resilience (based on Delettre, 0. 2021)

“The concept of resilience is polysemic (i.e. has multiple definitions) in ecology.”

“[...] broad definition of resilience as **‘the capacity of an ecological system to maintain its identity in the face of disturbance’** [...] the polysemy of the concept is partly due to the **multiple meanings of the term ‘identity’**.”

“[...] we propose four definitions of resilience, each one referring to the maintenance of a different type of identity and thus to a different level of persistence of ecological systems.”

Quotes from Delettre O. 2021. Identity of ecological systems and the meaning of resilience. *Journal of Ecology* 109:3147–3156.

Nature-based solutions (NbS)

Definitions

Resilience

„Identity of ecological systems and the meaning of resilience“

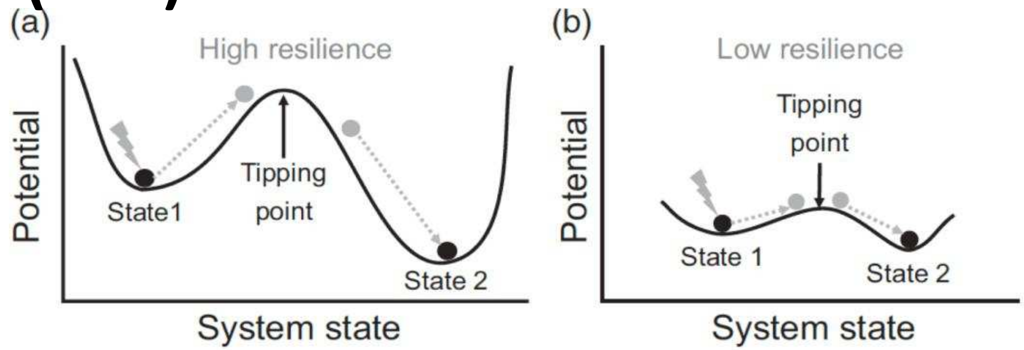
	Identity maintained	Conditions of maintenance	Process whereby the identity is maintained	Level of Persistence	Type of perturbation often associated
Typological resilience	Typological identity (represented by the whole phase space and dimensions of the stability landscape)	Maintenance of the nature of the key variables (chosen to account for the dynamics of the system)	Reorganization and renewal after destruction Adaptation	Low	Very strong and always destructive Periodic or permanent
Meta-regime resilience	Numerical identity (represented by the stability landscape itself and by all the shapes and limits it takes without discontinuity through time)	Maintenance of typological identity And Spatiotemporal continuity of the key components of the system	Extension of the stability landscape Increase in the number of attraction basins or trajectories Increase in option space		Very strong and potentially destructive Temporary or permanent
Ecological resilience	Global state identity (represented by a basin of attraction or a valley in a stability landscape)	Maintenance of numerical identity And Maintenance of the key variables values within an interval delimited by thresholds (which, if crossed, trigger an abrupt but continuous change in the system)	Enlargement of the basin of attraction (increase in latitude) Move away from the frontiers of the basin of attraction (decrease in precariousness)		Strong Temporary or permanent
Engineering resilience	Local state identity (represented by an area in the neighbourhood of equilibrium in a stability landscape)	Maintenance of global state identity And Maintenance of the key variables values within an interval close to an equilibrium point or trajectory	Rapid return to equilibrium after disturbance Permanent maintenance at the equilibrium despite disturbance (resistance)	High	Small Mostly temporary

Source: Delettre O. 2021. Identity of ecological systems and the meaning of resilience. *Journal of Ecology* 109:3147–3156.

Nature-based solutions (NbS)

Definitions

Resilience



"**In its broadest sense, resilience describes the ability of an ecosystem to resist, and recover from, a disturbance**. However, the application of such a concept in different subdisciplines of ecology and in different study systems has resulted in a **wide disparity of definitions and ways of quantifying resilience**."

"We identify four **key recommendations** to harmonize future efforts in resilience research:

(a) **define resilience** using existing theoretical frameworks;

(b) use **common and comparable metrics** to measure resilience;

(c) clearly contextualize and define the pre-and post-disturbance state of the ecological system

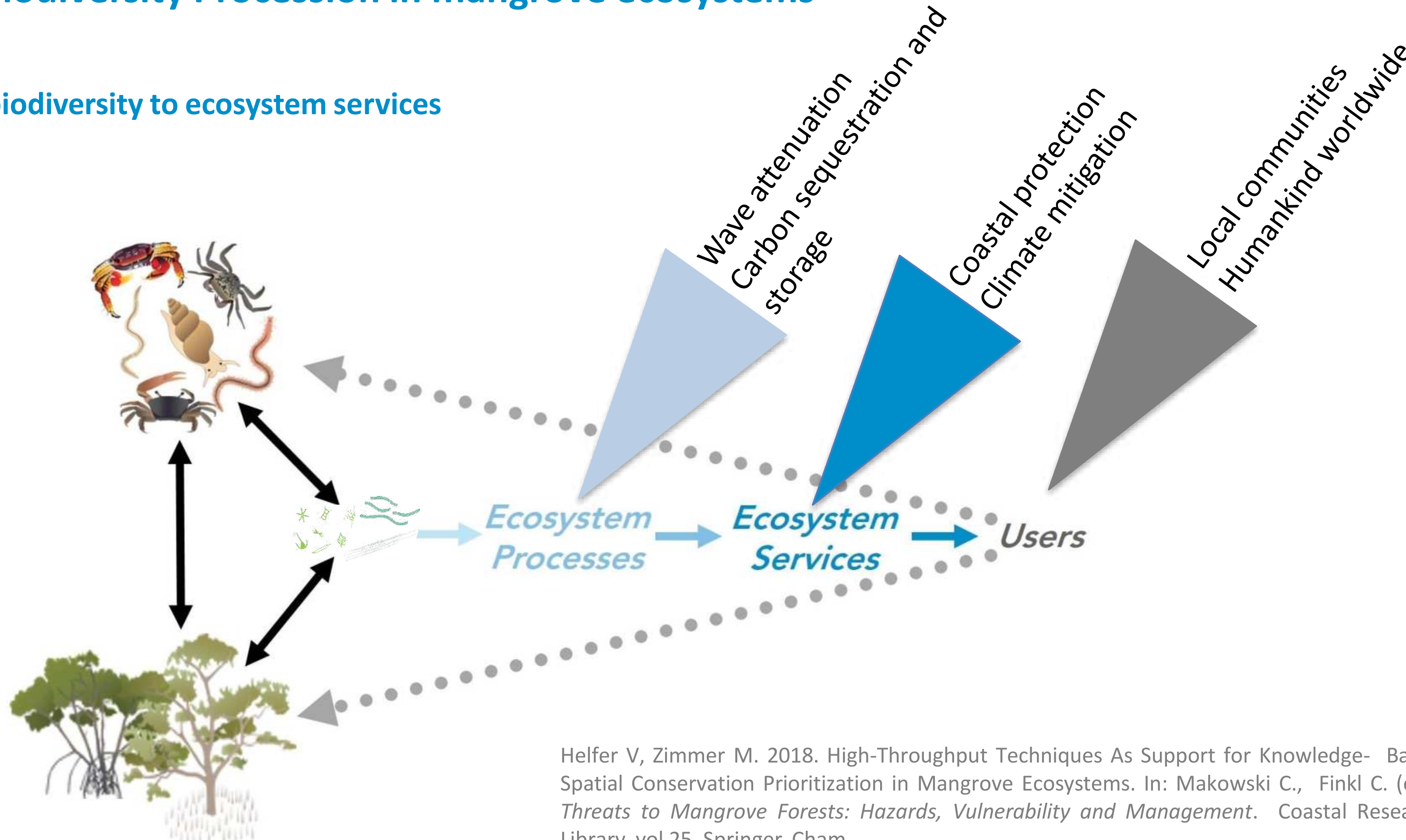
(d) consider explicitly the disturbance type and regime impacting the system."

Sources: Figure and quotes from Capdevila, P., Stott, I., Oliveras Menor, I., Stouffer, D. B., Raimundo, R. L. G., White, H., Barbour, M., & Salguero-Gómez, R. (2021). Reconciling resilience across ecological systems, species and subdisciplines. *Journal of Ecology*, 109, 3102–3113. https://doi.org/10.1111/1365-2745.13775

Biodiversity and resilience

The Biodiversity Procession in mangrove ecosystems

From biodiversity to ecosystem services



Helfer V, Zimmer M. 2018. High-Throughput Techniques As Support for Knowledge- Based Spatial Conservation Prioritization in Mangrove Ecosystems. In: Makowski C., Finkl C. (eds) *Threats to Mangrove Forests: Hazards, Vulnerability and Management*. Coastal Research Library, vol 25. Springer, Cham.

Biodiversity and resilience

The Biodiversity Procession in mangrove ecosystems

Floral communities

Foundation species

dominant species that, through their

considerable abundance and biomass,

have a strong effect on other species, by creating

conditions and stabilizing fundamental

ecosystem processes, and

thus community composition and biodiversity

(Dayton 1972; Whitham et al. 2006).

Helfer V & Zimmer M 2018. High-Throughput Techniques as support for Knowledge-Based Spatial Conservation Prioritization in Mangrove Ecosystems. In: Makowski C., Finkl C. (eds) *Threats to Mangrove Forests: Hazards, Vulnerability and Management*. Coastal Research Library, vol 25. Springer, Cham.

Mangrove root architecture: pneumatophores ("finger-roots" or "pencil-roots") of *Avicennia germinans* in Brazil (upper left; © V. Helfer); prop roots of *Rhizophora mangle* in Brazil (upper right; © V. Helfer); "knee-roots" of *Bruguiera gymnorhiza* in Fiji (lower left; © M. Zimmer); buttress- or plank-roots of *Xylocarpus granatum* in Fiji (lower right; © M. Zimmer).

Biodiversity and resilience

The Biodiversity Procession in mangrove ecosystems

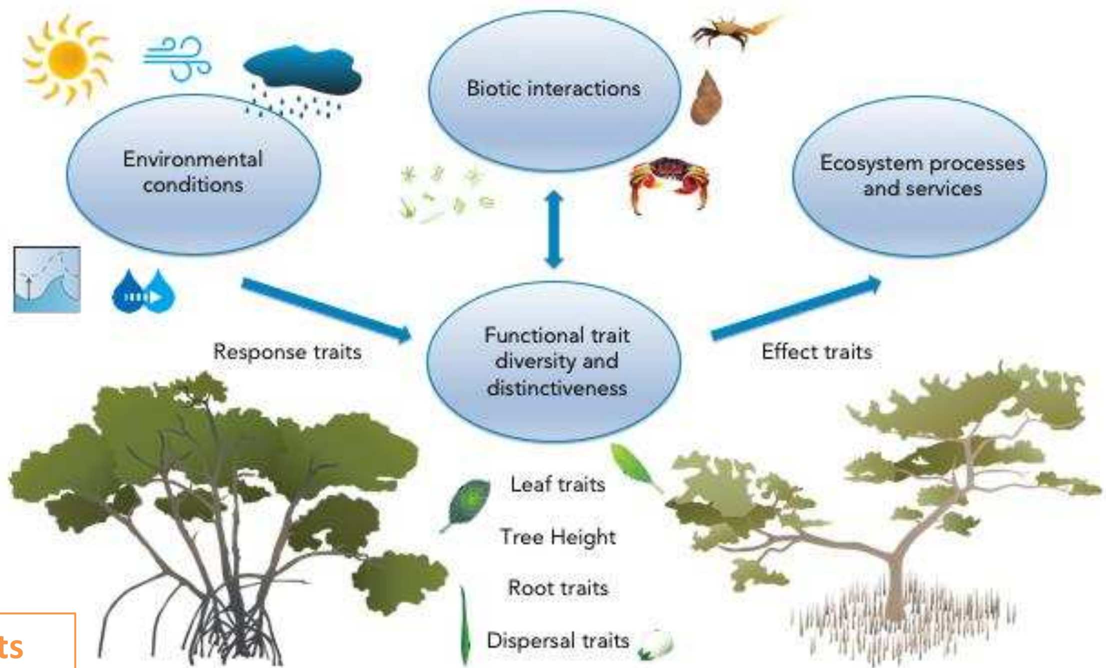
Floral communities – Plant functional traits

Response traits:

will affect the response of the plant to changes in biotic or abiotic conditions

Effect traits:

will influence ecosystem processes



The genetic basis of plant functional traits and plasticity in trait expression is still understudied in mangroves.

Global initiative launched by
V. Helfer, CY Cheung, & M. Zimmer; unpublished.

Biodiversity and resilience

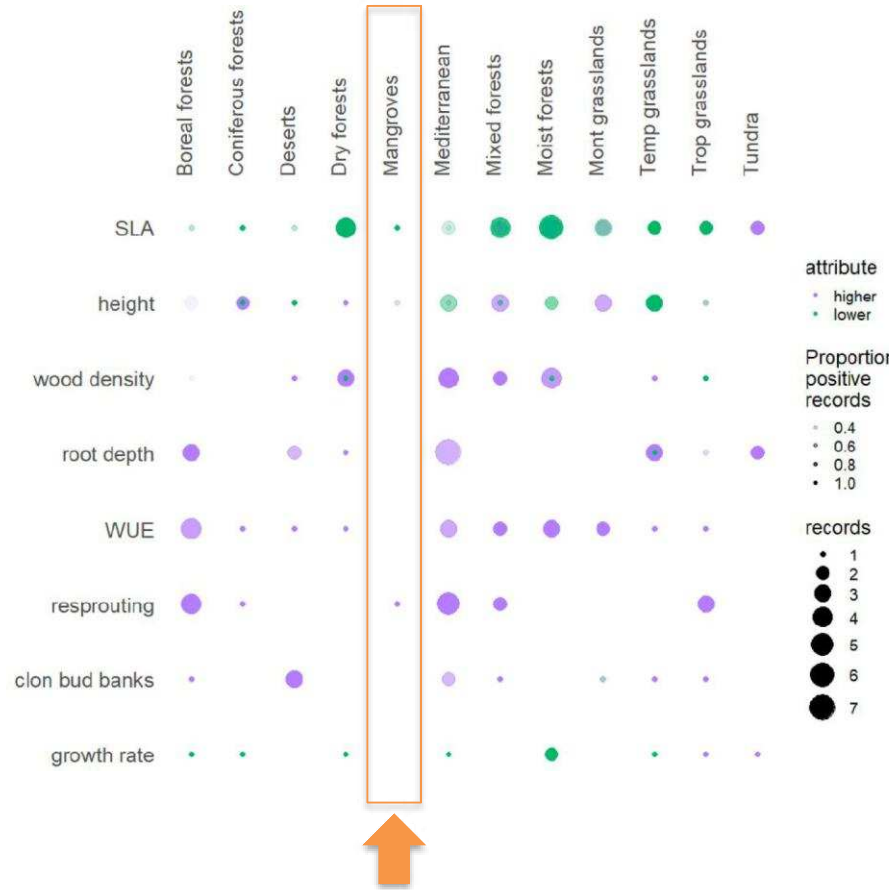
The Biodiversity Procession in mangrove ecosystems

Floral communities – Plant functional traits

Response traits:

“[...] identifying whether there are general patterns of plant functional traits that are associated with positive plant responses (ability to cope or thrive) under predicted climate and associated environmental changes, across biomes.“

Note: overrepresentation of studies focusing on leaf traits; all biomes not equally investigated; climate effects also investigated unequally (overrepresentation of studies on decreased precipitation/drought compared to other changes)



Data deficiency for mangrove ecosystems.

Kühn N, Tovar C, Carretero J, [...], Willis K J (2021) Globally important plant functional traits for coping with climate change. *Frontiers of Biogeography*

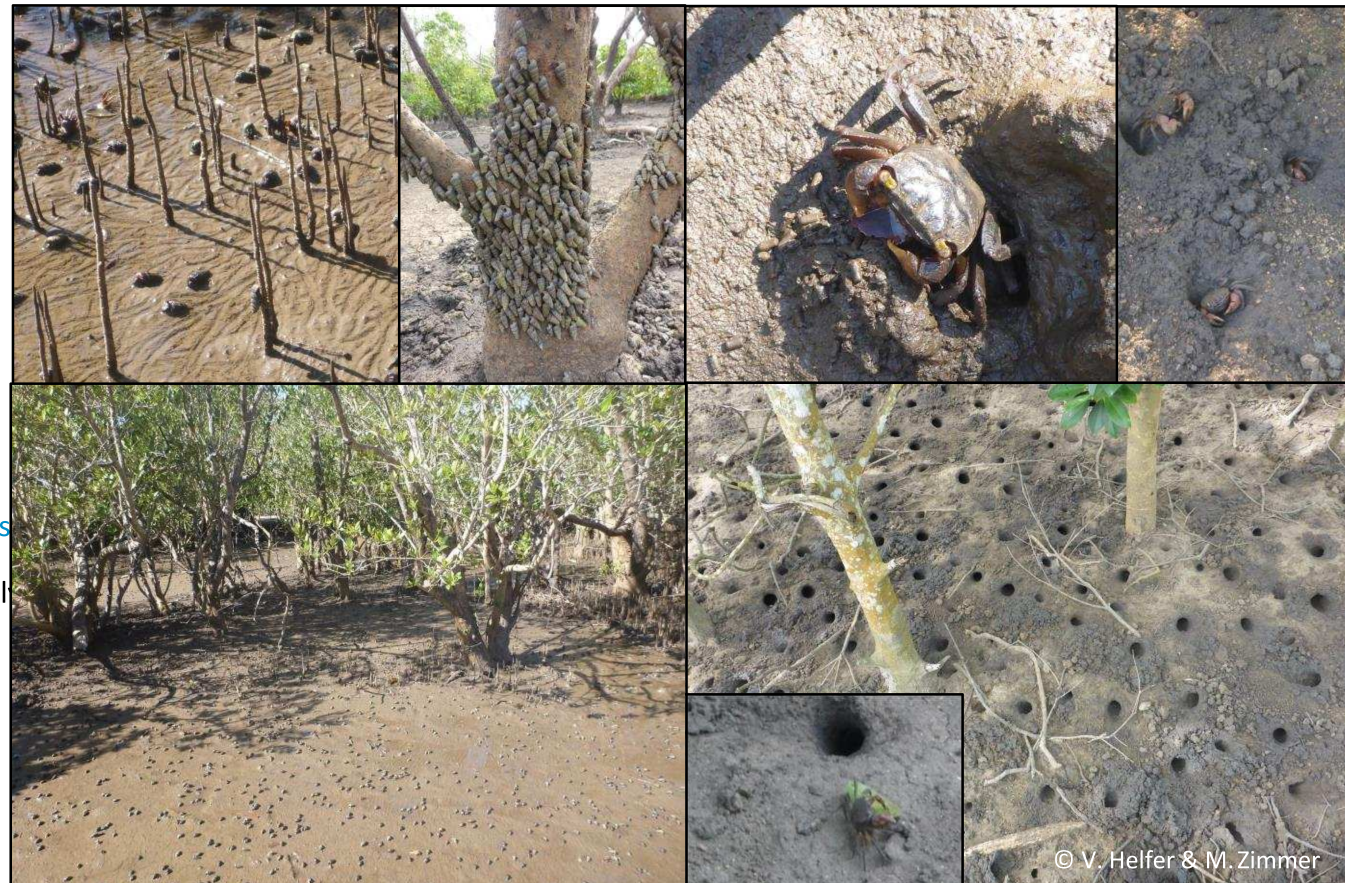
Biodiversity and resilience

The Biodiversity Procession in mangrove ecosystems

Faunal communities

Snails (left)

and crabs (right)



Ecosystem engineers

species that are able to create, modify or maintain physical habitat for them- selves and other species by significantl changing abiotic environmental conditions (Jones et al. 1994).

Biodiversity and resilience

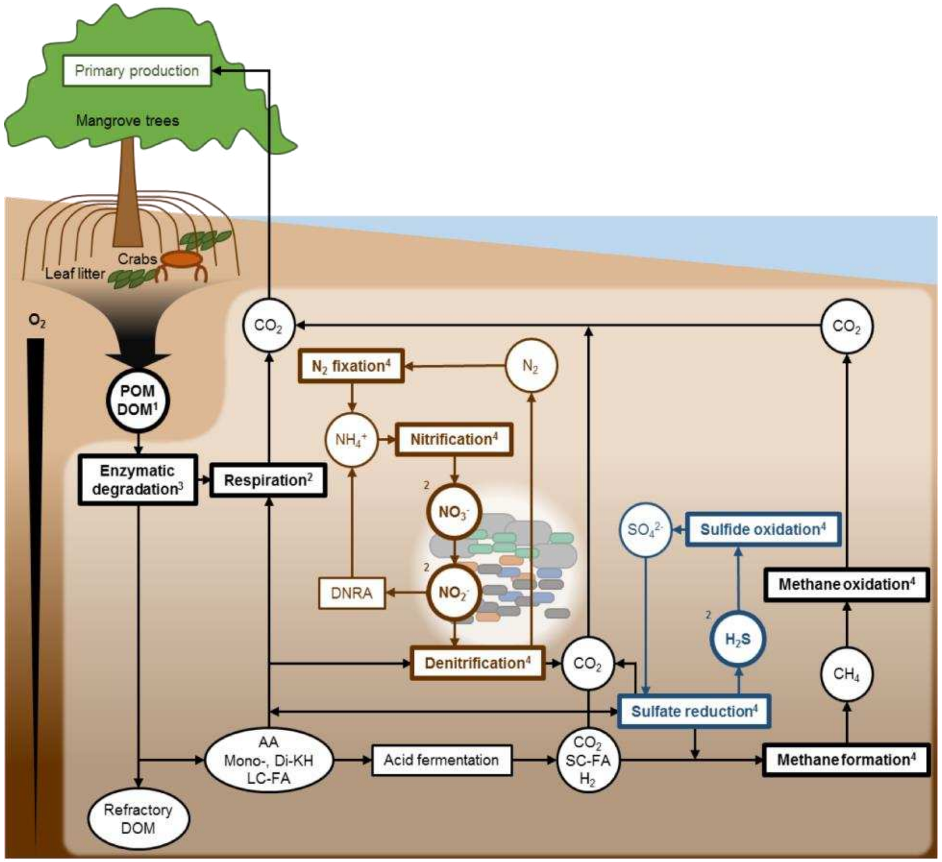
The Biodiversity Procession in mangrove ecosystems

Microbial communities

Microbial communities = basis of numerous ecosystem processes and services of mangroves

Important role in organic matter decay and element cycling

Influence on ecosystem productivity and blue carbon dynamics



Organic matter dynamics in marine sediments
Adapted from Fenchel and Jørgensen, 1977

Biodiversity and resilience

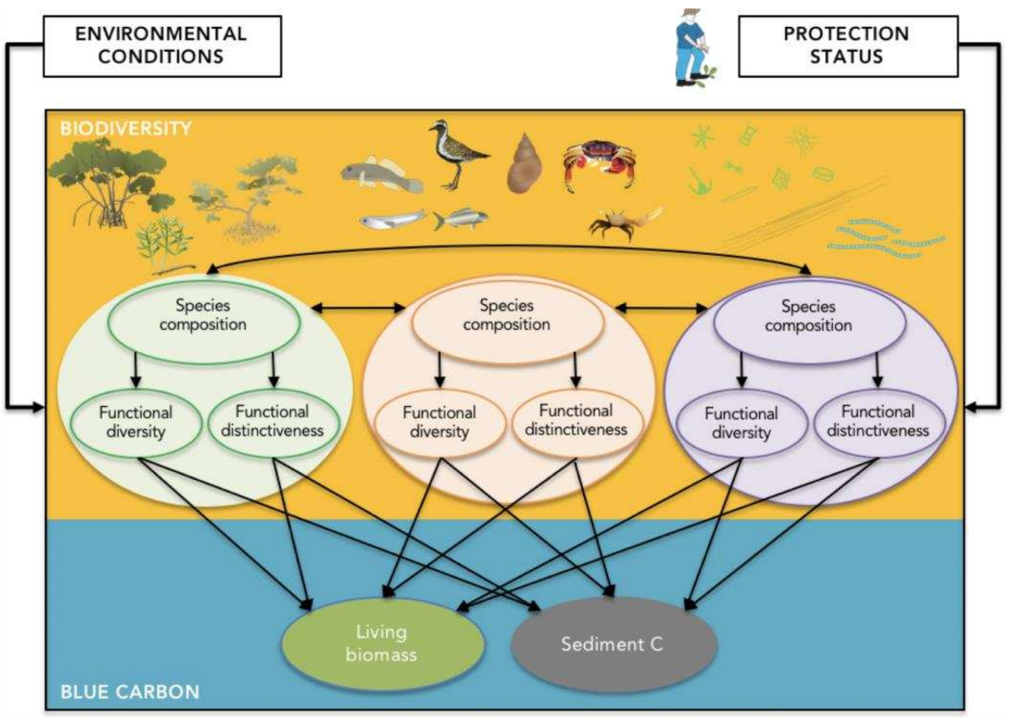
The Biodiversity Procession in mangrove ecosystems

The Role of Biodiversity in Ecosystem Resilience (ER)

“[...] that **biodiversity mechanisms contributing to ER at all levels are interlinked.** This has important practical implications **requiring a holistic approach to biodiversity conservation to secure ER** instead of focusing on selected species conservation.“

Quote from Denis Vasiliev 2022. The Role of Biodiversity in Ecosystem Resilience. IOP Conf. Ser.: Earth Environ. Sci. 1072 012012

Biodiversity and blue carbon



Biodiversity and Blue Carbon – A Conceptual framework
V. Helfer, J. Geburzi, & M. Zimmer; unpublished

Biodiversity and resilience

The more species the better?

The Role of Biodiversity in Ecosystem Resilience (ER)

“Controversial evidence is presented in scientific literature regarding the role of species richness in ensuring ER [...].“

Quotes from Denis Vasiliev 2022. The Role of Biodiversity in Ecosystem Resilience. IOP Conf. Ser.: Earth Environ. Sci. 1072 012012

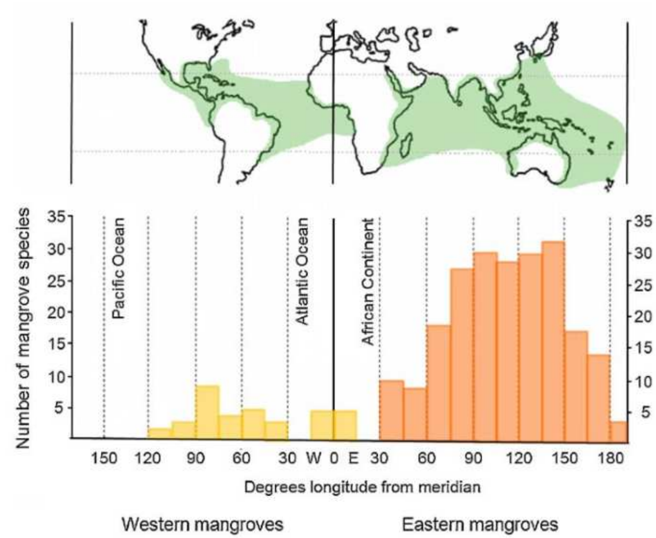
“[...] majority of authors [...] agree that **functional diversity** is more important than species richness, and that response diversity and functional redundancy are the most important species level mechanisms determining ER.“

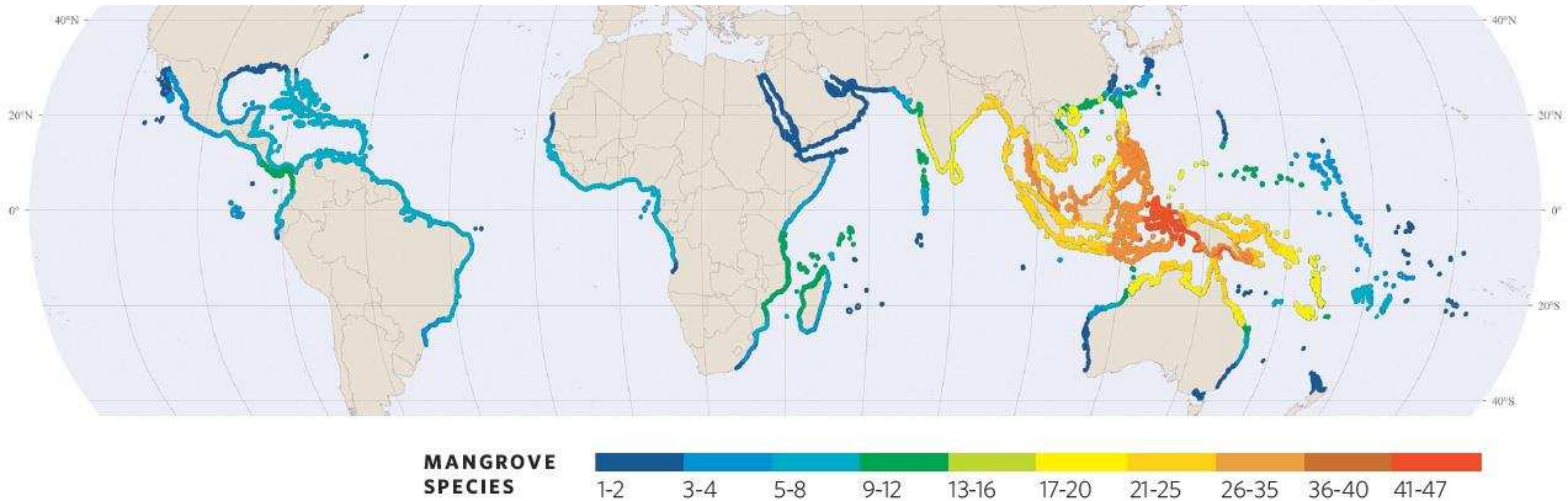
Functional distinctiveness (not diversity) is the main driver of mangrove productivity and carbon storage.

Rahman MM, Zimmer M, Ahmed I, [...], Xu M (2021) Co-benefits of protecting mangroves for biodiversity conservation and carbon storage. *Nature Communications*

Biodiversity and resilience

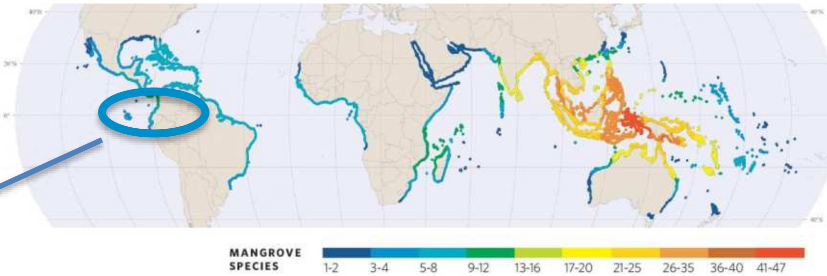
The more species the better?

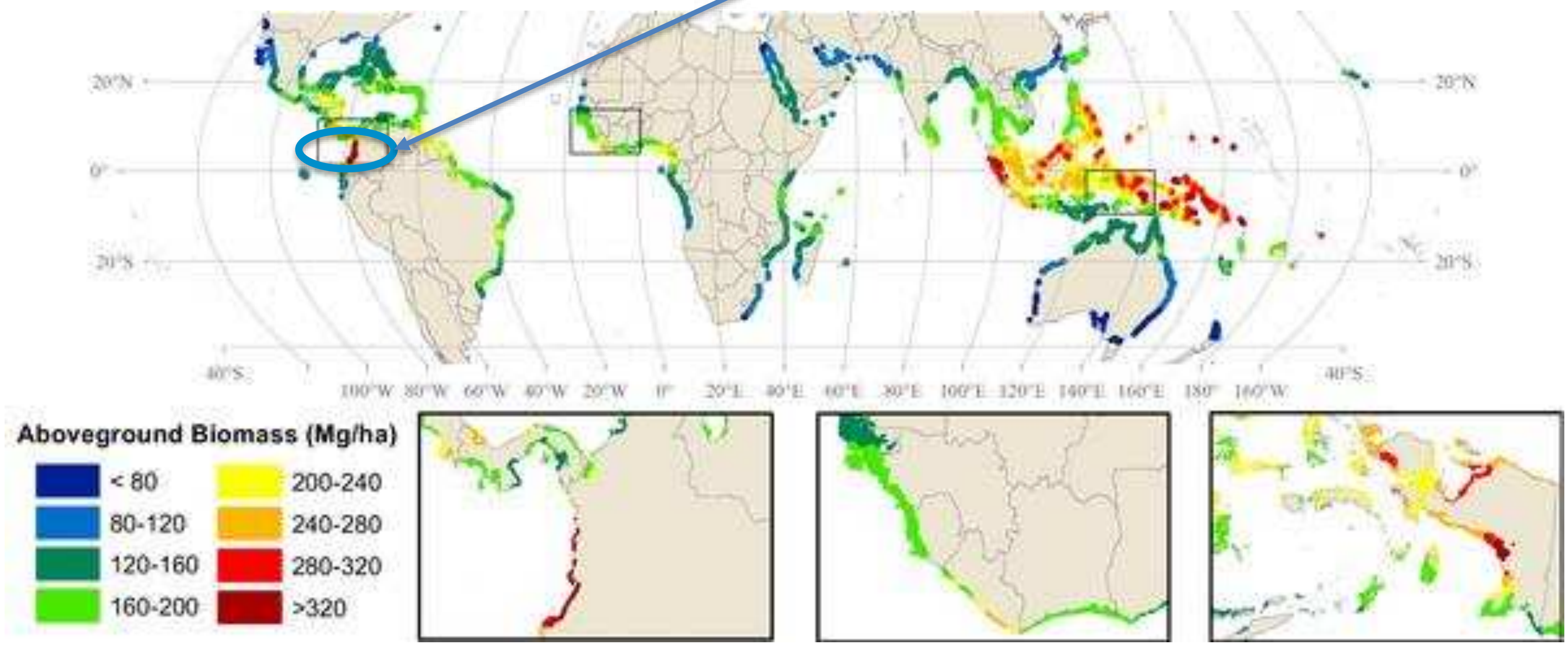




Biodiversity and resilience

The more species the better?





Conservation Letters

Volume 7, Issue 3, pages 233-240, 20 SEP 2013 DOI: 10.1111/conl.12060

http://onlinelibrary.wiley.com/doi/10.1111/conl.12060/full#conl12060-fig-0002

Mangrove ecosystems

Mangroves worldwide – alike but distinct

1

2

3

4

5

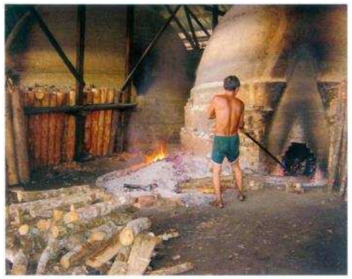
6

1. Mixed stands of *Rhizophora mangle*, *Laguncularia racemosa* and *Avicennia germinans* in direct vicinity to desert vegetation in the arid zone of Baja California, Mexico. 2. Dense riverine stands of stunted *Rhizophora mangle* on the edge of the African savannah of Senegal. 3. Dense inland stand of *Rhizophora mangle* on San Andrés Island (Caribbean Colombia). 4. M. Zimmer getting prepared for taking deep sediment cores in an old-grown stand of *Rhizophora mangle* in North Brazil. 5. Old-grown estuarine stand of *Avicennia marina* in South Africa. 6. Dense stands of *Rhizophora stylosa*, mixed with some *Bruguiera gymnorhiza*, on the southern coast of the main island of Fiji, Viti Levu.

Mangrove ecosystems

Mangroves worldwide – alike but distinct

Mangrove ecosystem services



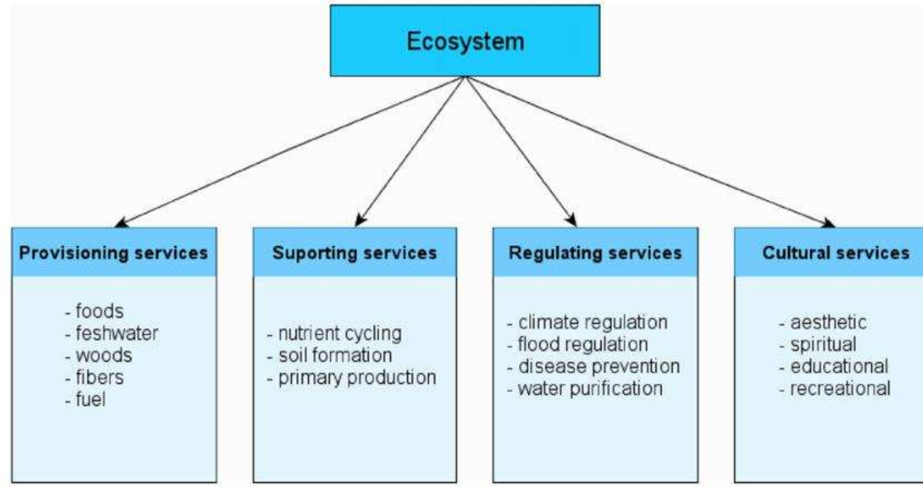
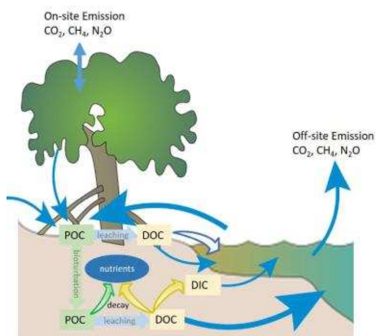
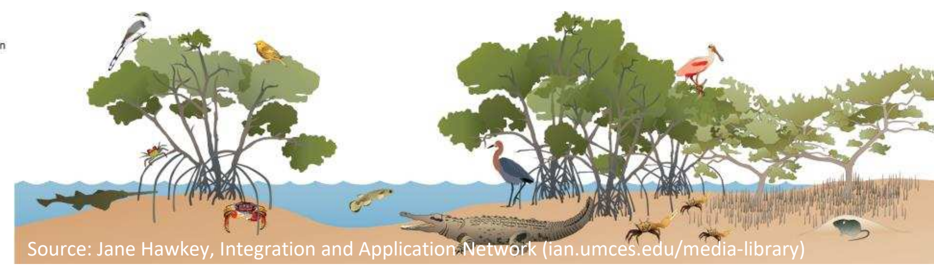


Fig. 1. Ecosystem services (adapted from MA, 2005a,b), modified.

- Timber and forest products
  Wood products / Fuelwood / Roofing / Tannins / Medicine / Food (*Sonneratia*) /Fodder
- Fisheries
- Recreation
- Biofiltration
- Coastal protection
- Carbon sequestration
- Habitat provision



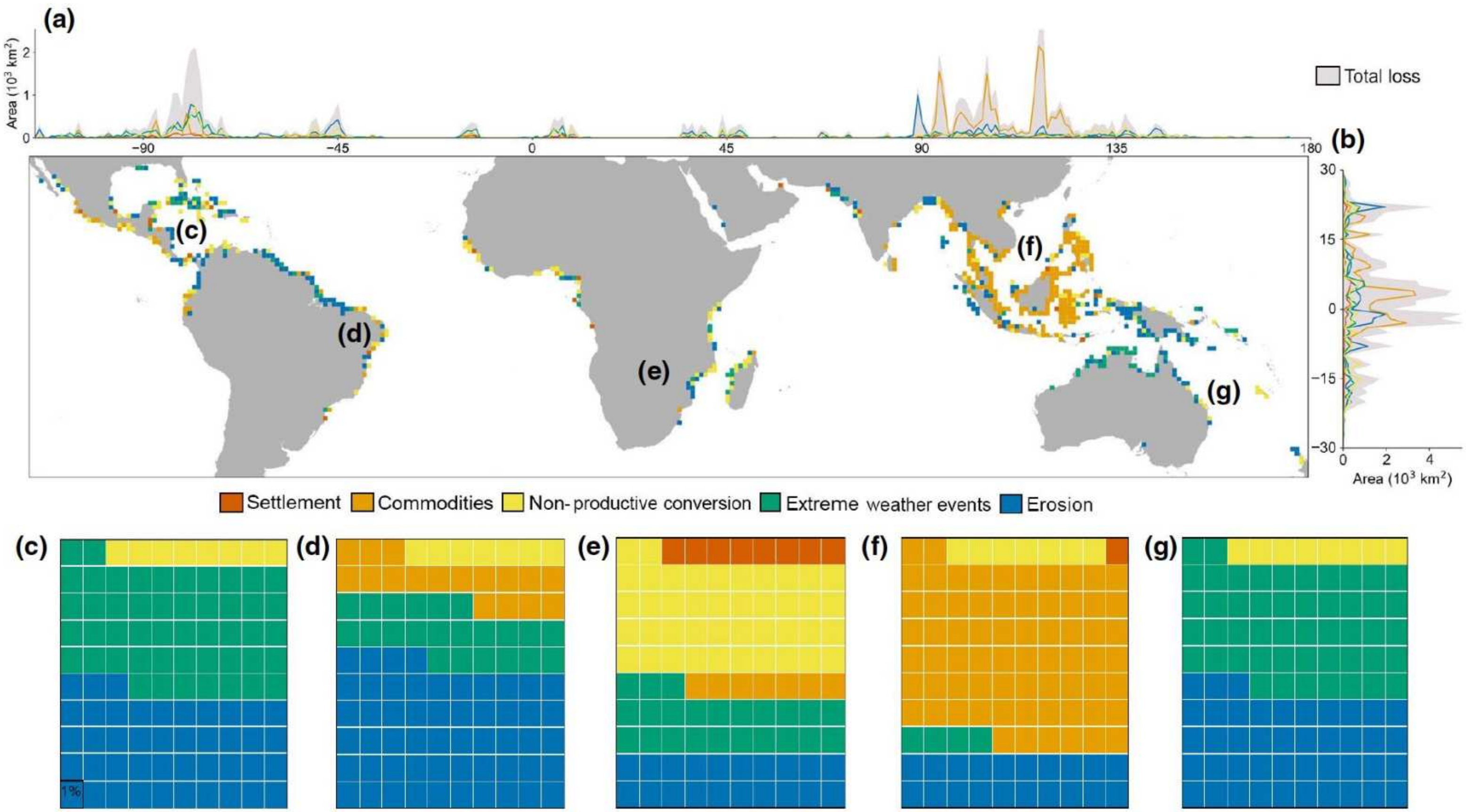


Source: Jane Hawkey, Integration and Application Network (ian.umces.edu/media-library)

Mangrove ecosystems

Mangroves worldwide – alike but distinct

Threats to mangroves



Source: Goldberg, L, Lagomasino, D, Thomas, N, Fatoyinbo, T. Global declines in human-driven mangrove loss. *Glob Change Biol.* 2020; 26: 5844– 5855. https://doi.org/10.1111/gcb.15275

Mangrove ecosystems

Mangroves worldwide – alike but distinct

GOOD NEWS: mangrove losses declined **but slower decline in natural losses**

Threats to mangroves

Land-use change:

62%

Aquaculture (e.g. shrimp)

Agriculture (e.g. rice – China, Myanmar, Madagascar)

Urban development (population increase by 35–102% between 2000 and 2030**)**

Extractive activities:

Forest products (e.g. timber & fuelwood)

Other drivers:

Conversion to salt ponds

Oil and gaz extraction...

Natural processes (e.g. erosion, extreme weather events)

Sources:
Friess DA, Rogers K, Lovelock CE, Krauss KW, Hamilton SE, Lee SY, Lucas R, Primavera J, Rajkaran A, Shi S. The State of the World's Mangrove Forests: Past, Present, and Future. *Annual Review of Environment and Resources* 2019 44:1, 89-115
Goldberg, L, Lagomasino, D, Thomas, N, Fatoyinbo, T. Global declines in human-driven mangrove loss. *Glob Change Biol.* 2020; 26: 5844– 5855. https://doi.org/10.1111/gcb.15275

Mangroves

And climate change

Climate change effects

Sea-level rise

Extreme high water events

Storms

Precipitation

Temperature

Atmospheric CO_2 concentration

Source: Gilman, E.L., Ellison, J., Duke, N.C. and Field, C. (2008) Threats to Mangroves from Climate Change and Adaptation Options: A Review. *Aquatic Botany*, 89, 237-250. https://doi.org/10.1016/j.aquabot.2007.12.009

Mangroves

And climate change

Climate change consequences

Good news: Future Sea-Level Rise ➔ Increasing Mangrove Area

(poleward expansion)

Bad news: Future Sea-Level Rise ➔ Reducing Mangrove Area and Health

(increased hydroperiod, salinization...)

Complex processes...

Source: Friess DA, Rogers K, Lovelock CE, Krauss KW, Hamilton SE, Lee SY, Lucas R, Primavera J, Rajkaran A, Shi S. The State of the World's Mangrove Forests: Past, Present, and Future. *Annual Review of Environment and Resources* 2019 44:1, 89-115

Mangroves

And climate change

Resilience to sea-level rise

resilience

capacity for maintained areal coverage [e.g. through landward migration]

resistance

capacity to maintain functionality within existing distributions [e.g. maintained productivity

Effect of species composition not considered!

Site	Capacity for resilience	Capacity for resistance	Migration availability (topographic; % [radians])	Potential change (anthropogenic; %)	Potential change (sediment; *tau* TSM)
Saloum Delta, Senegal	Stable area (−0.09%) Landward migration < Seaward loss (0.00% L; −2.81% S)	Marginal biomass loss (−2.04%)	82.92 (θ = 0.098)	−4.07	−0.02
Sherbro Bay, Sierra Leone	Decreasing area (−2.46%) Landward migration ≈ Seaward loss (0.00% L; −0.60% S)	Stable biomass (−0.62%)	63.07 (θ = 0.123)	3.09	0.006
Save River Delta, Mozambique	Increasing area (4.55%) Landward migration > Seaward loss (20.98% L; −5.54% S)	Biomass loss (−5.33%)	93.82 (θ = 0.064)	0.015	-
Ruvuma Estuary, Tanzania	Stable area (0.64%) Landward migration > Seaward loss (6.54% L; −5.57% S)	Marginal biomass loss (−3.96%)	87.22 (θ = 0.066)	0.38	-
Rufiji Delta, Tanzania	Stable area (0.36%) Landward migration < Seaward loss (1.85% L; −5.62% S)	Biomass loss (−5.34%)	47.18 (θ = 0.086)	6.34	−0.04
Mahajamba, Madagascar	Increasing area (12.09%) Landward & Seaward increasing (31.11% L; 3.13% S)	Biomass gain (1.56%)	94.12 (θ = 0.082)	0.00	−0.005
Sundarbans, India and Bangladesh	Stable area (0.21%) Landward migration > Seaward loss (11.49% L; −4.48% S)	Stable biomass (−0.66%)	89.94 (θ = 0.066)	0.13	−0.004
Categorisation	High: increasing/stable area [<4% loss]; landward migration > seaward biomass loss Medium: stable area [<4% loss]; landward migration ≈ seaward biomass loss Low: stable [<4% loss]/decreasing area; landward migration < seaward biomass loss	High: increasing/stable biomass [<1% loss] Medium: marginal biomass loss [<5% loss] Low: >5% biomass loss	Low [concern]: >70% non-anthropogenic landward pixels with SRTM DEM slope ≤θ Medium: 50–70% ≤θ High: <50% ≤θ	Low [concern]: decreasing/stable % change in anthropogenic landward pixel land cover [<0.5%] Medium: 0.5–5% increase High: >5% increase	Low [concern]: increasing/stable mean Kendall's *tau* TSM concentration [>-0.01] Medium: marginal decrease [>−0.04] High: decreasing [≤-0.04]

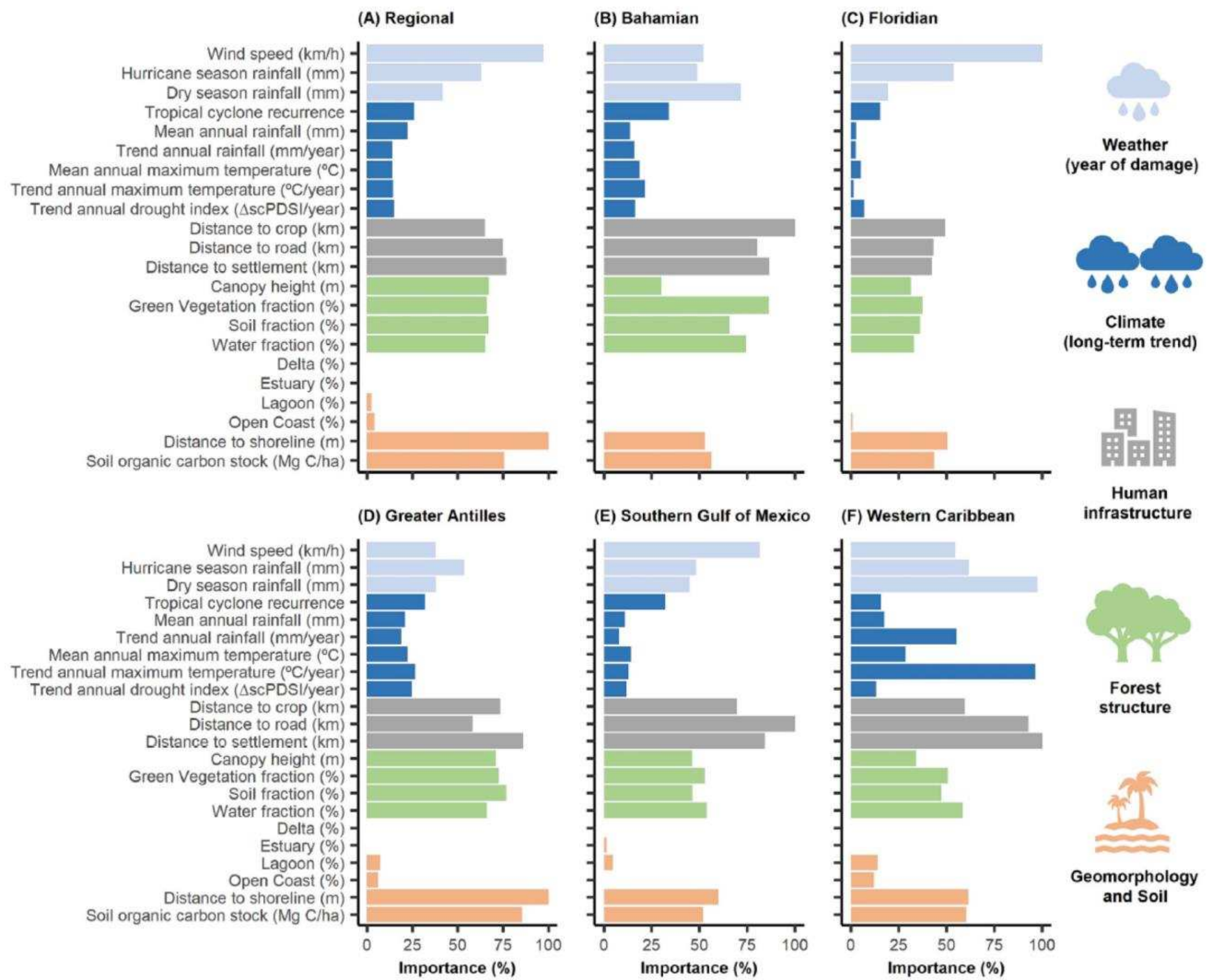
Source: Duncan C et al. 2018. Satellite remote sensing to monitor mangrove forest resilience and resistance to sea level rise. *Methods Ecol Evol.* 9:1837–1852.

Mangroves

And climate change

Resilience to tropical cyclone

„Bars are proportional to the variable importance from mangrove recovery vs. loss classification trees (n = 700).“



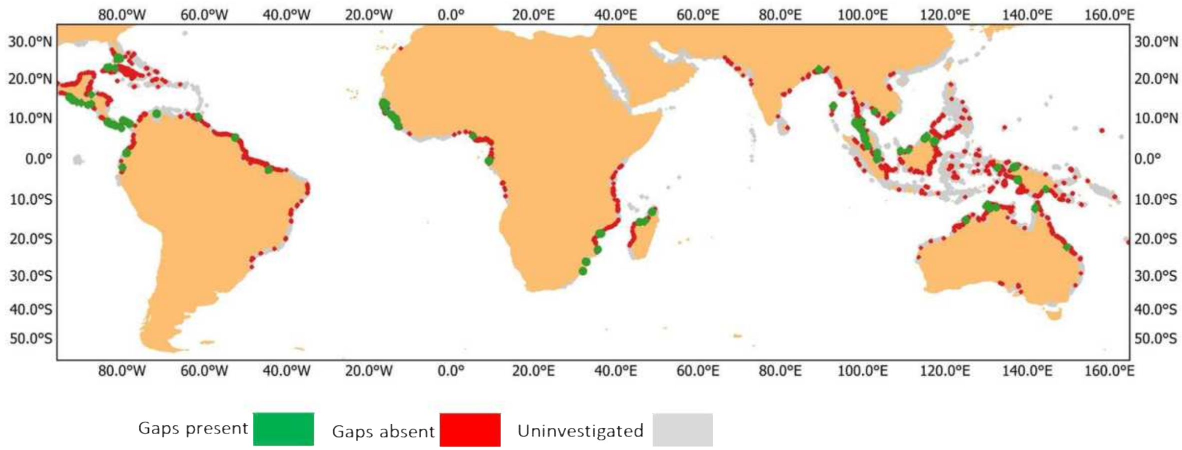
Effect of species composition not considered!

Source: Amaral G et al. 2023. Drivers of mangrove vulnerability and resilience to tropical cyclones in the North Atlantic Basin. *Science of the Total Environment* 898.

Mangroves

And climate change

Resilience – the example of mangrove canopy gaps



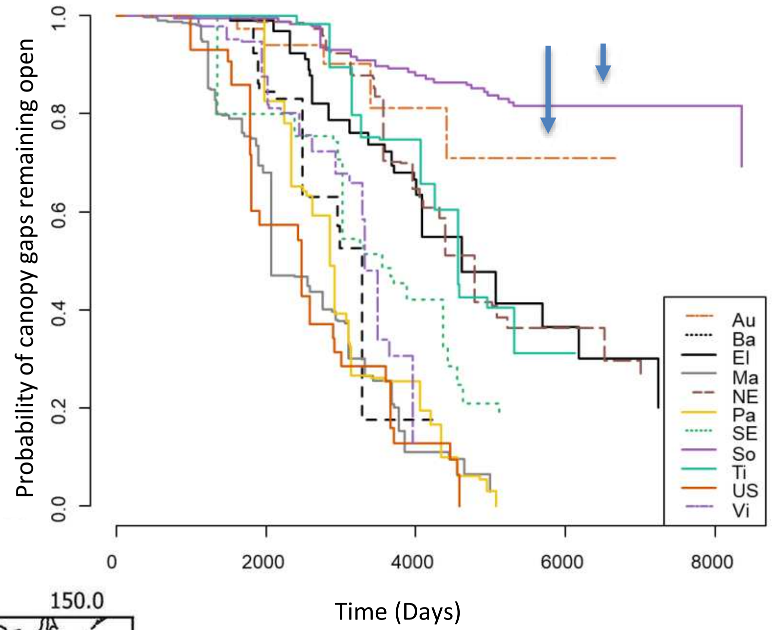
Doctoral project of Michael Kyei Agyekum
https://www.leibniz-zmt.de/en/research/research-projects/remainman.html

Mangroves

And climate change

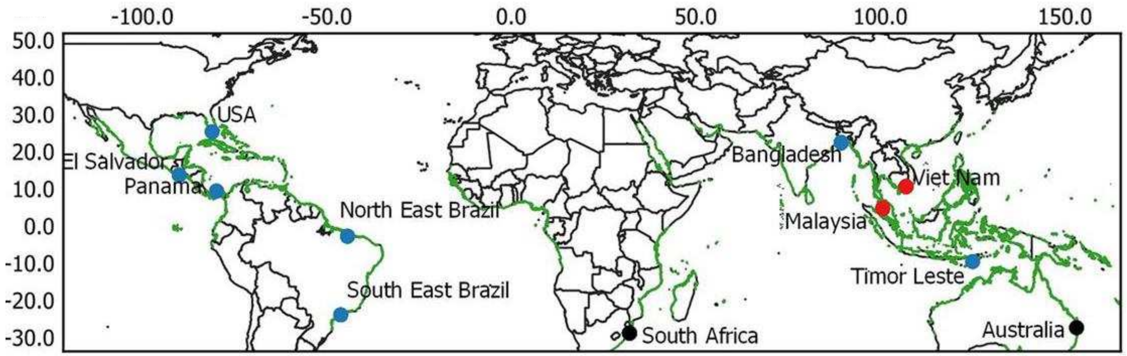
Resilience – the example of mangrove canopy gaps

Gaps remaining open for a longer time in Australia and South Africa



Important variation among regions in estimated duration of canopy gap closure

Australia (Au), Bangladesh (Ba), El Salvador (El), Malaysia (Ma), North East Brazil (NE), Panama (Pa), South East Brazil (SE), South Africa (So), Timor Leste (Ti), United States America (US), Viet Nam (Vi).



Black dots: *Avicennia marina*-domined stands ; Blue dots: mixed stands; Red dots: *Rhizophora*-domined stands; Mangrove extent (Global Mangrove Watch datasets version 3; Bunting et al., 2022) in green.

Doctoral project of Michael Kyei Agyekum
https://www.leibniz-zmt.de/en/research/research-projects/remainman.html

Mangroves

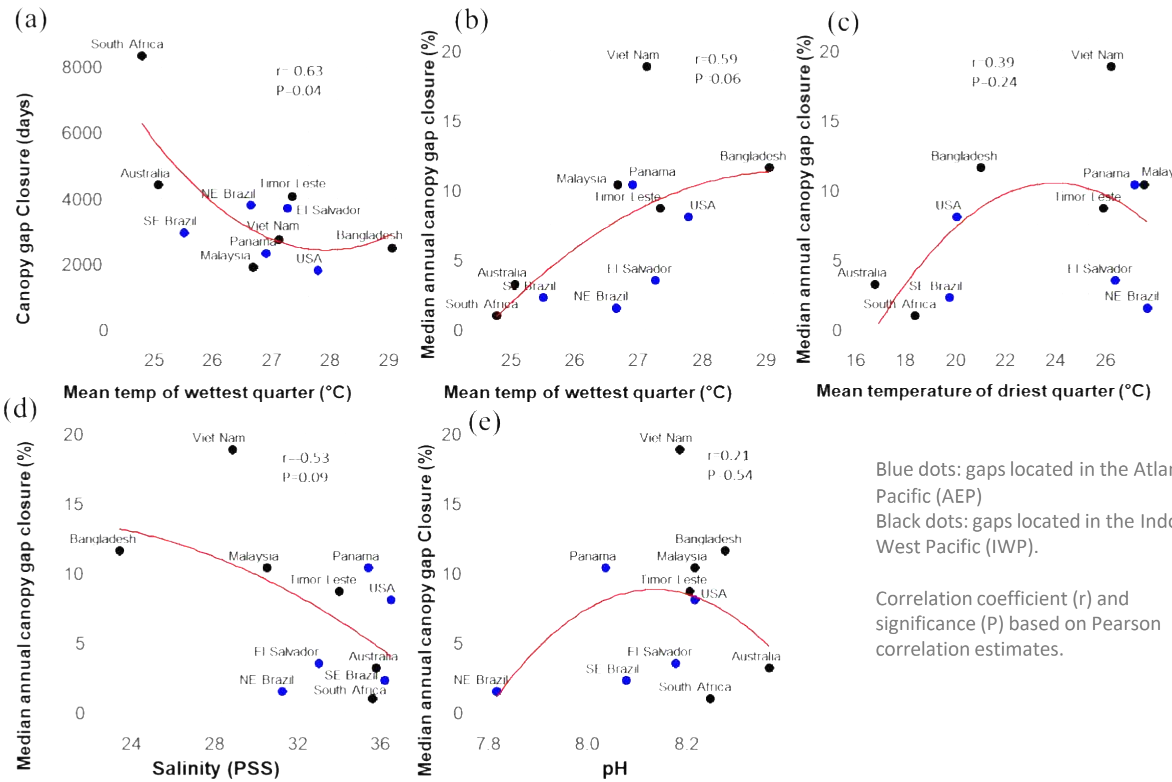
And climate change

Resilience – the example of mangrove canopy gaps

Effect of environmental conditions on

Gap Closure (time in days for 30% canopy gaps closure)

Median Annual Gap Closure



Blue dots: gaps located in the Atlantic East Pacific (AEP)
Black dots: gaps located in the Indo-West Pacific (IWP).

Correlation coefficient (r) and significance (P) based on Pearson correlation estimates.

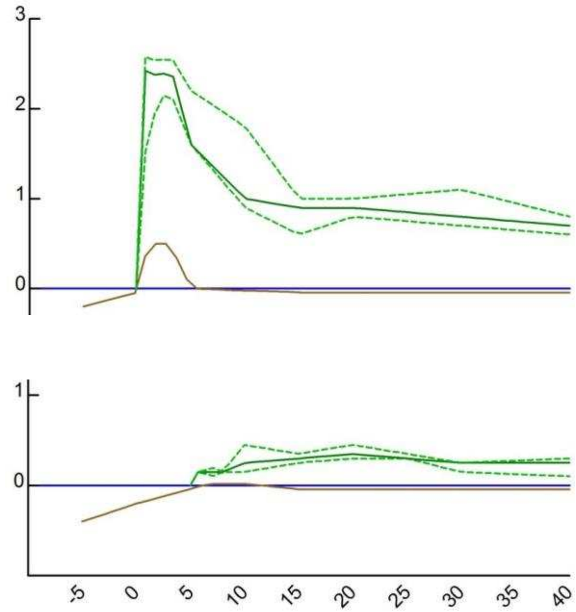
Doctoral project of Michael Kyei Agyekum
https://www.leibniz-zmt.de/en/research/research-projects/remainman.html

WORK IN PROGRESS...

Mangrove ecosystems for coastal resilience

Nature-based solutions for climate change mitigation and adaptation

Protection against erosion



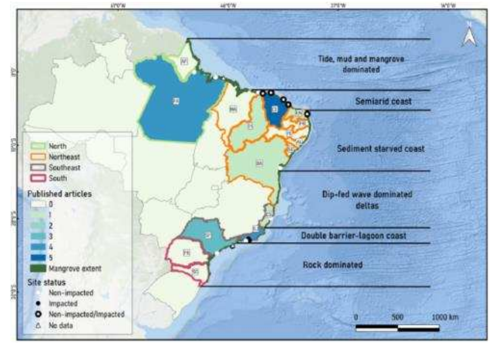
Green: vegetation height
Brown: terrain elevation

Strong erosion upon 100% mangrove cutting with ca. 5 meter coastline retreat within 5 years.

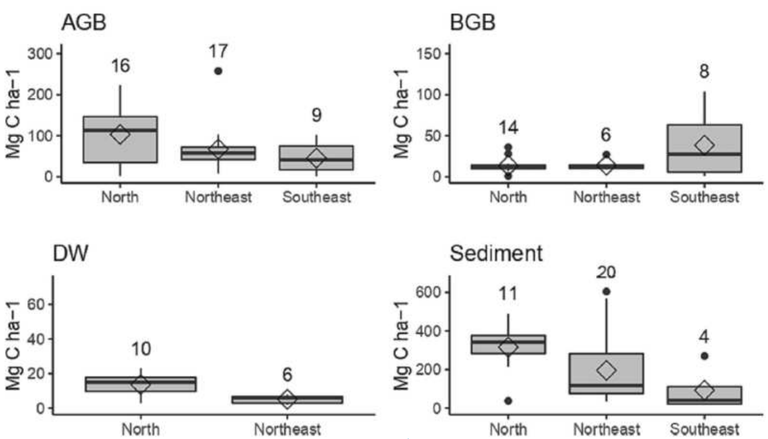
Collaborative project with University of Houston
V. Helfer, M. Zimmer & S.C. Pennings, unpubl.

Mangrove ecosystems for coastal resilience

Nature-based solutions for climate change mitigation and adaptation

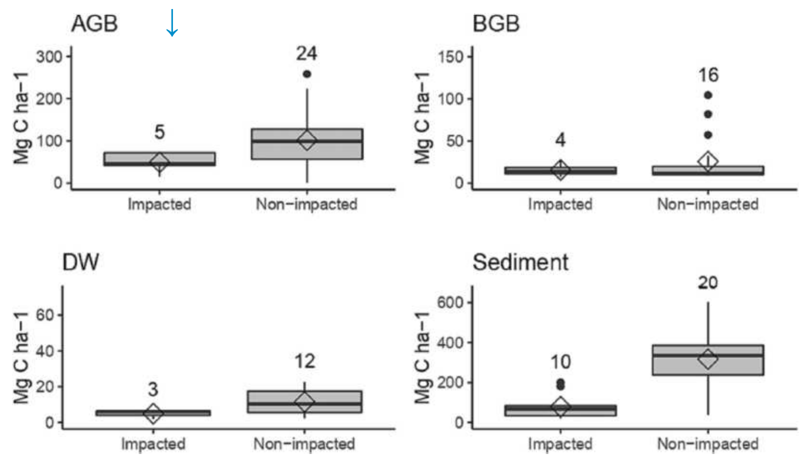


Carbon sequestration and storage



Geographic variability

Effect of site status



Brazilian mangroves store ~0.44 PgC

≈ 10–12 % of the world TECS.

Brazilian mangroves = a global blue carbon hotspot

⟶ efficient nature-based solution for carbon dioxide removal

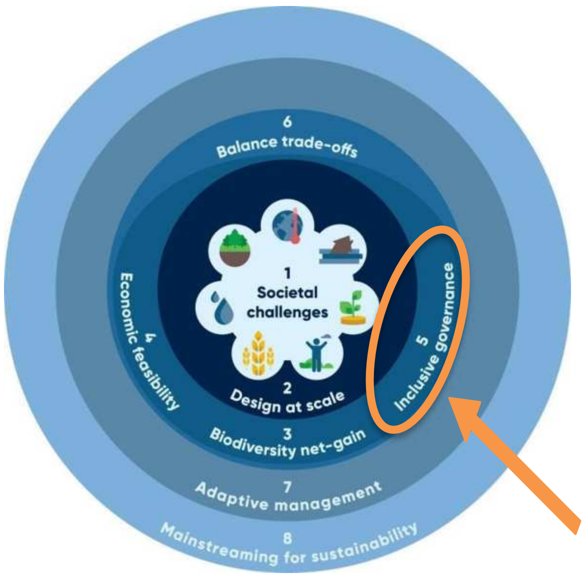
Beloto N et al 2023. Blue carbon stock heterogeneity in Brazilian mangrove forests: A systematic review. *Marine Pollution Bulletin* 197 (2023) 115694

Mangrove ecosystems for coastal resilience

Maximizing chances of success

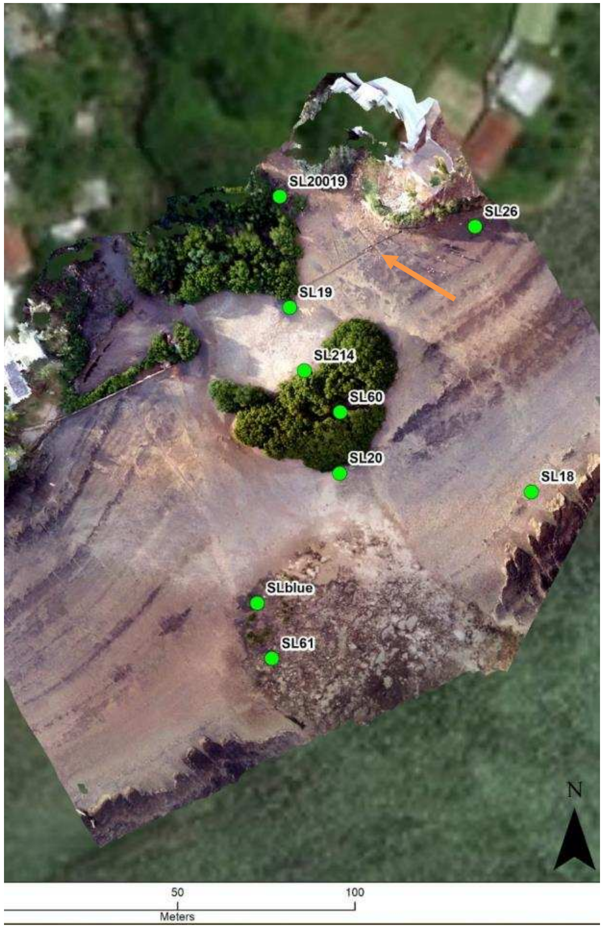
Beside technical and ecological feasibility,

societal acceptance and **desirability** are key!



© IUCN

Mangroves instead of concrete **seawall** against erosion; Fiji, near Suva.



A. Rovere, E. Casella, V. Helfer & M. Zimmer, unpubl.

Mangrove ecosystems for coastal resilience

Maximizing chances of success

Beside technical and ecological feasibility,

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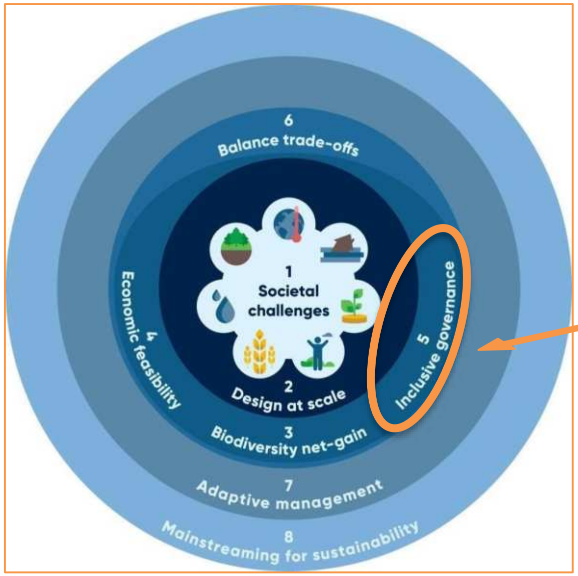

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„In 2020, IUCN launched the IUCN Global Standard for NbS, which provides an internationally recognized framework to:

i) effectively design NbS,

ii) ensure and respond to stakeholders' rights, particularly upholding the rights of indigenous peoples and local communities (IPLCs)

iii) increase the scale and impact of NbS,

iv) prevent unanticipated negative outcomes or misuse of NbS, and

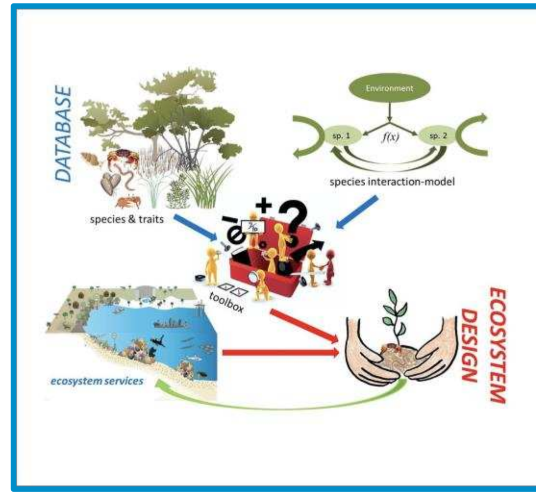
v) help funding agencies, policymakers, and other stakeholders assess the effectiveness of NbS implementation4.“

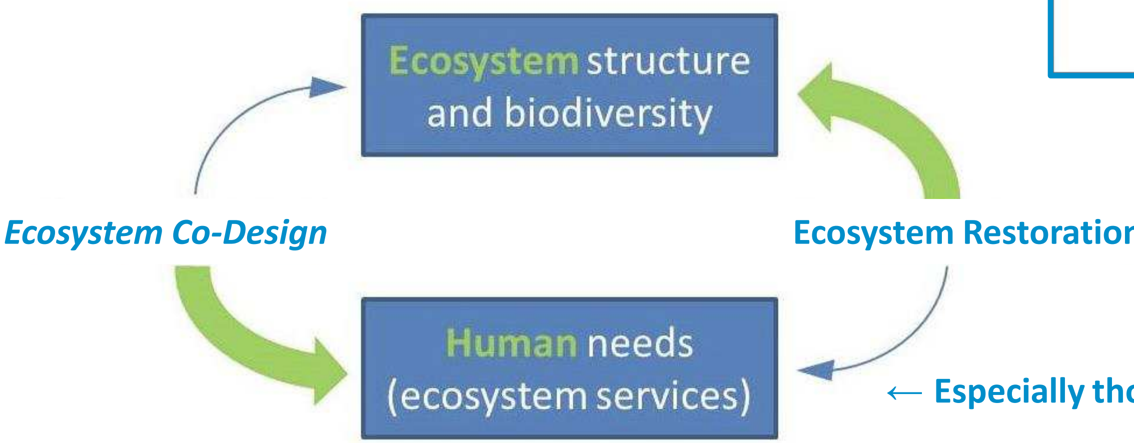
Source: nbs-in-gbf-targets-brief-november-2022.pdf

Mangrove ecosystems for coastal resilience

Maximizing chances of success

Ecosystem Co-Design



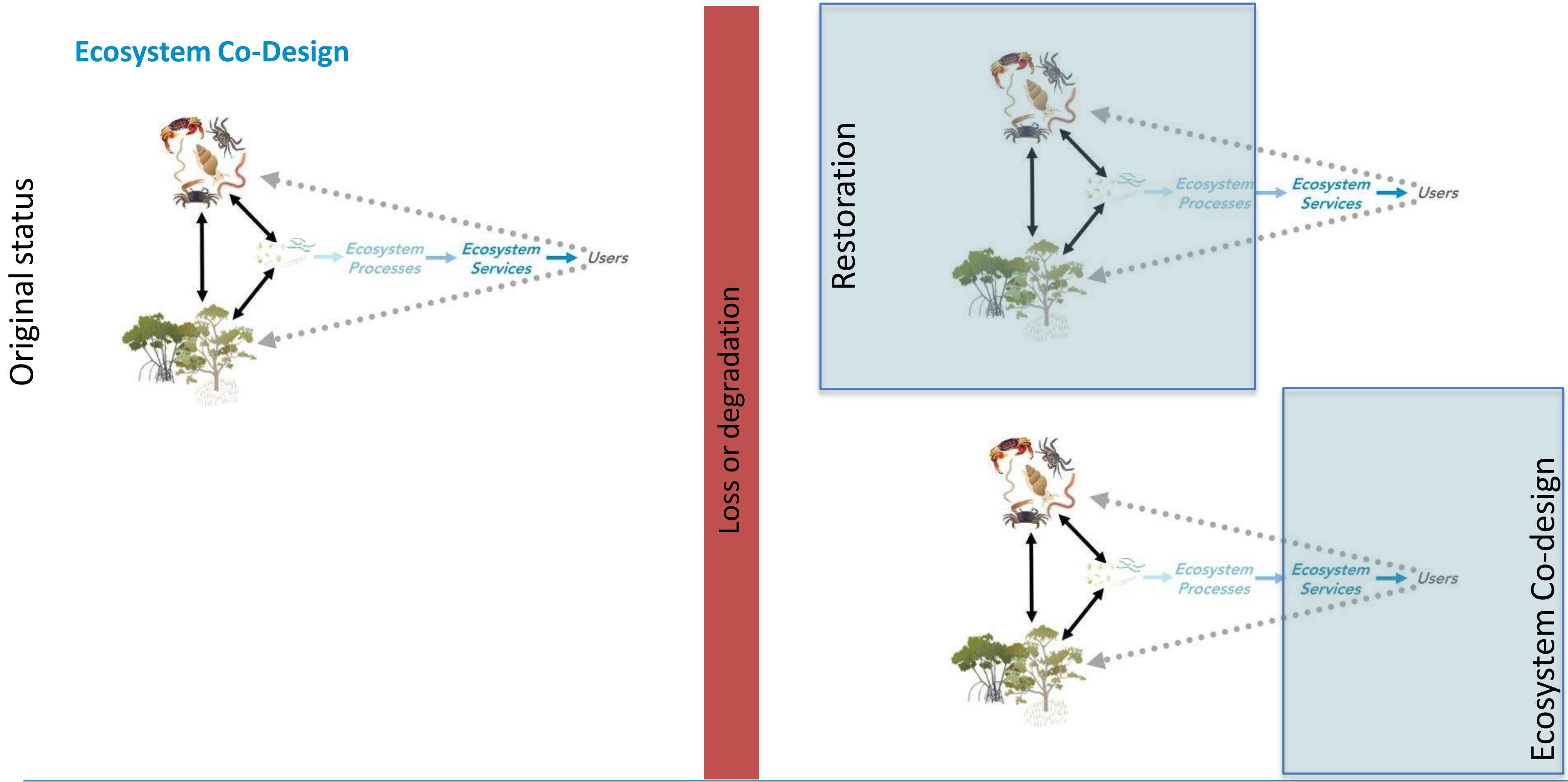


← **Especially those of local actors!**

Zimmer M. 2018. Ecosystem Design: when mangrove ecology meets human needs. In: Makowski C, Finkl CW (eds). *Threats to Mangrove Forests: Hazards, Vulnerability and Management*. Coastal Research Library, vol 25. Springer, Cham.

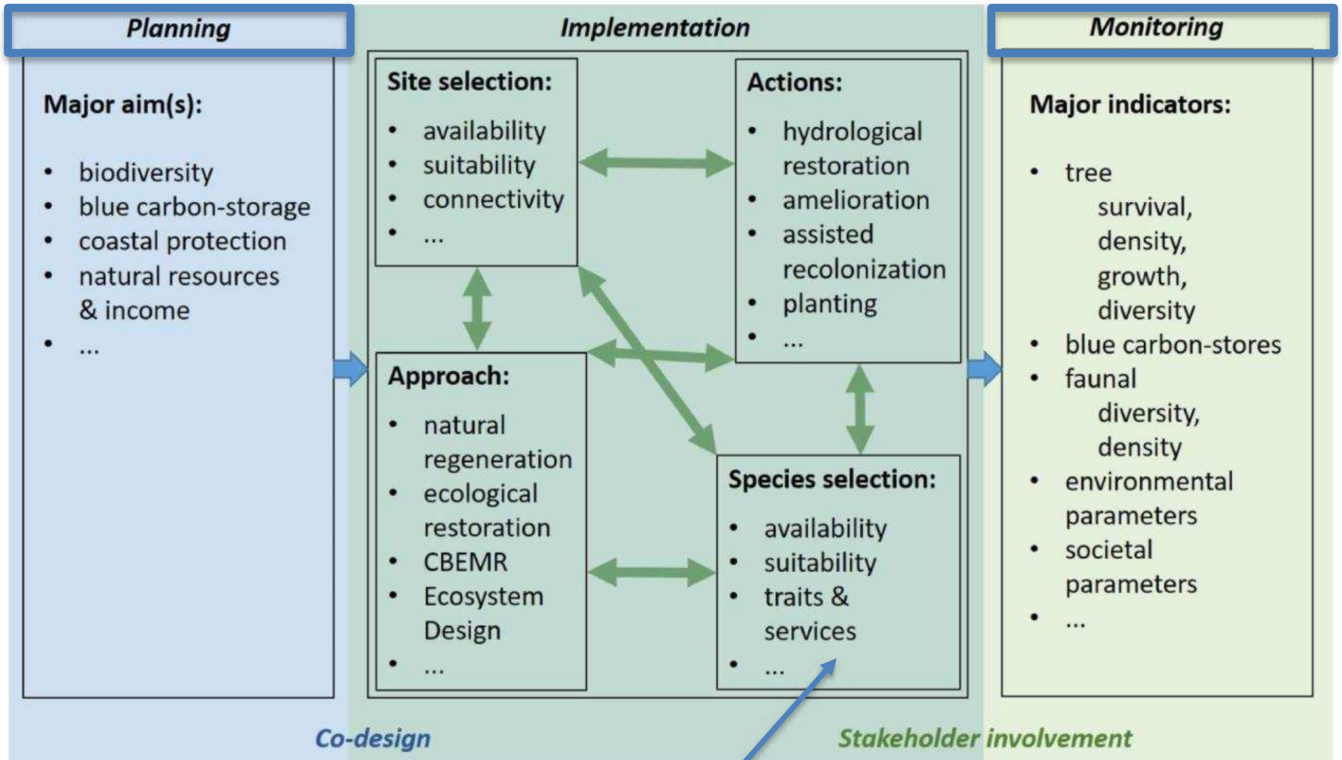
Mangrove ecosystems for coastal resilience

Maximizing chances of success



Mangrove ecosystems for coastal resilience

Maximizing chances of success



Conceptual scheme of major steps and decisions during planning, implementing, and monitoring the success of, **mangrove (re-)establishment**.

Blue arrows depict the progress of action, green arrows show dependencies of decisions.

Importance of good planning and monitoring often neglected!

Take also into consideration the genetic diversity, and characteristics and origin of the propagules

Zimmer M et al. 2022. When nature needs a helping hand: Different levels of human intervention for mangrove (re-)establishment. *Front. For. Glob. Change* 5:784322.

Current project and perspectives

sea4society – searching for solutions for C-sequestration in coastal ecosystems

CDR mare

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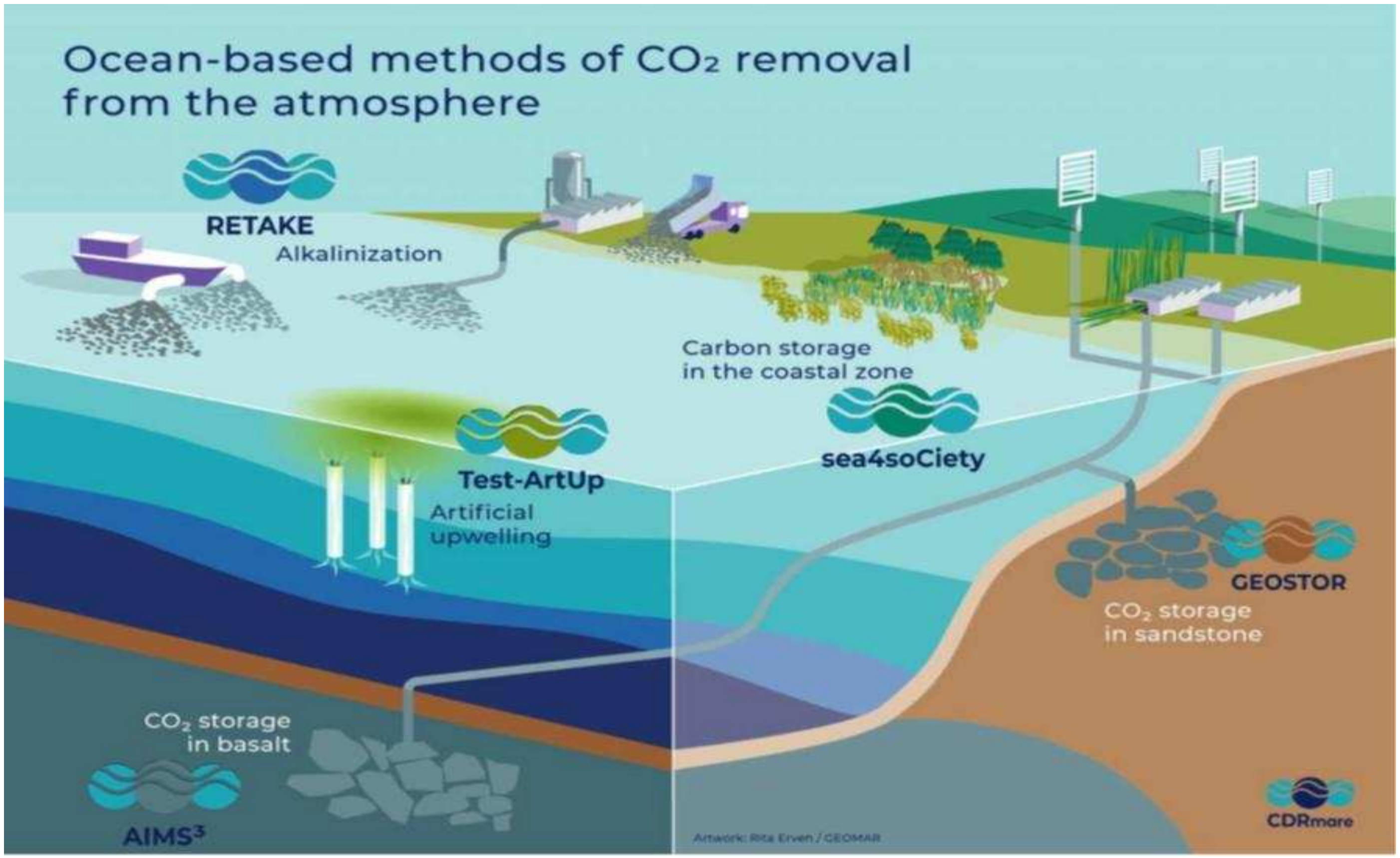
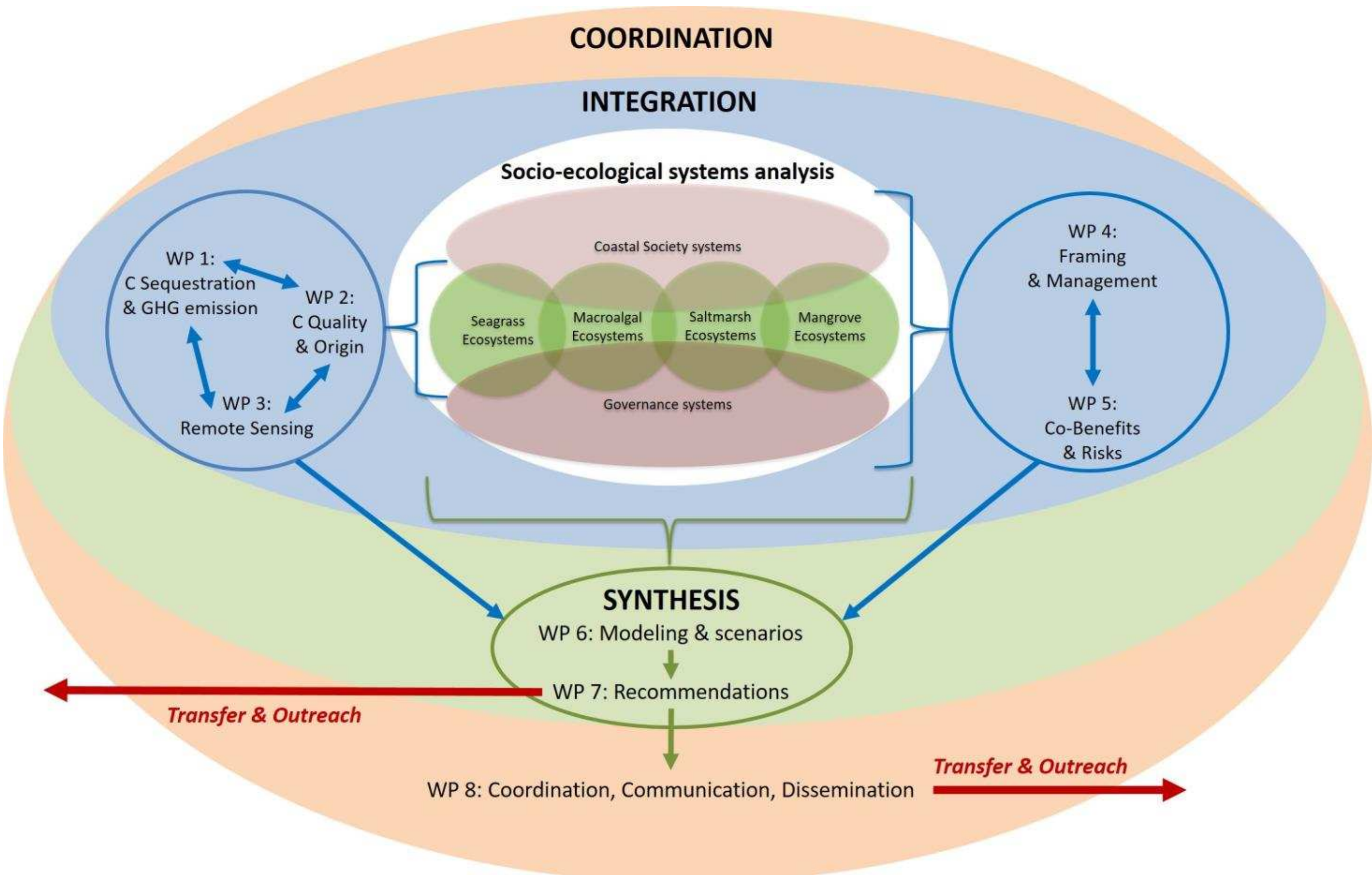


Current project and perspectives

sea4society – searching for solutions for C-sequestration in coastal ecosystems



Current project and perspectives

sea4society – searching for solutions for C-sequestration in coastal ecosystems

CDR mare
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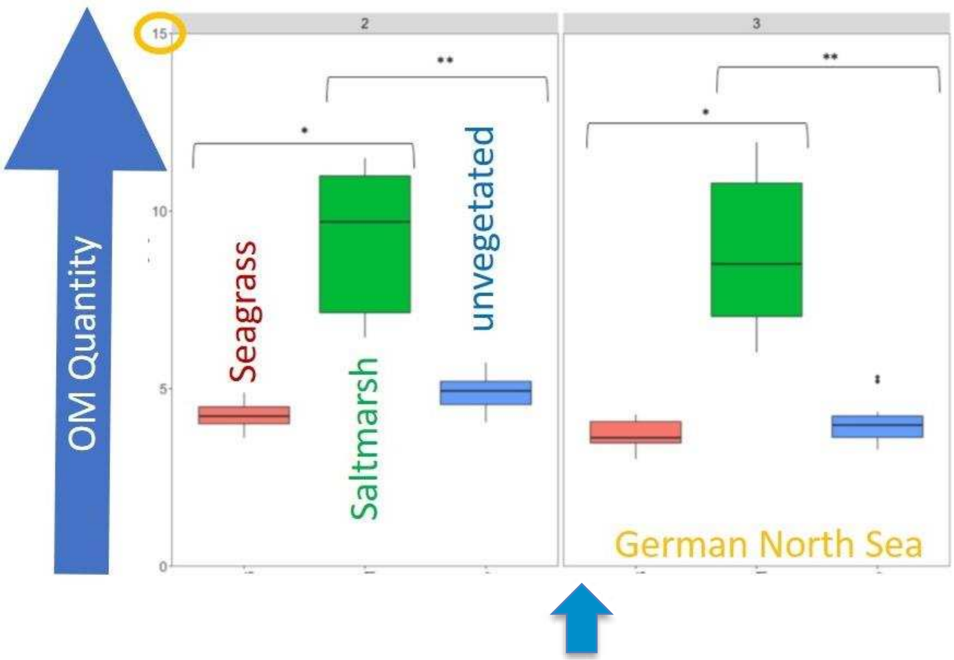
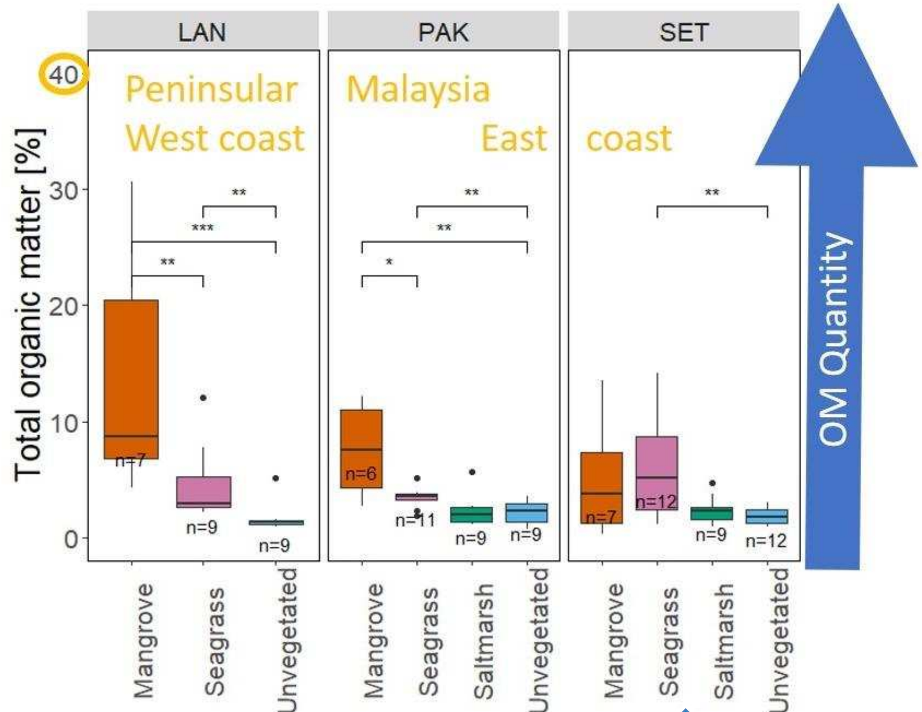
Germany: little difference between sediment layers



Germany: higher OM content in saltmarshes

Malaysia: only upper layer



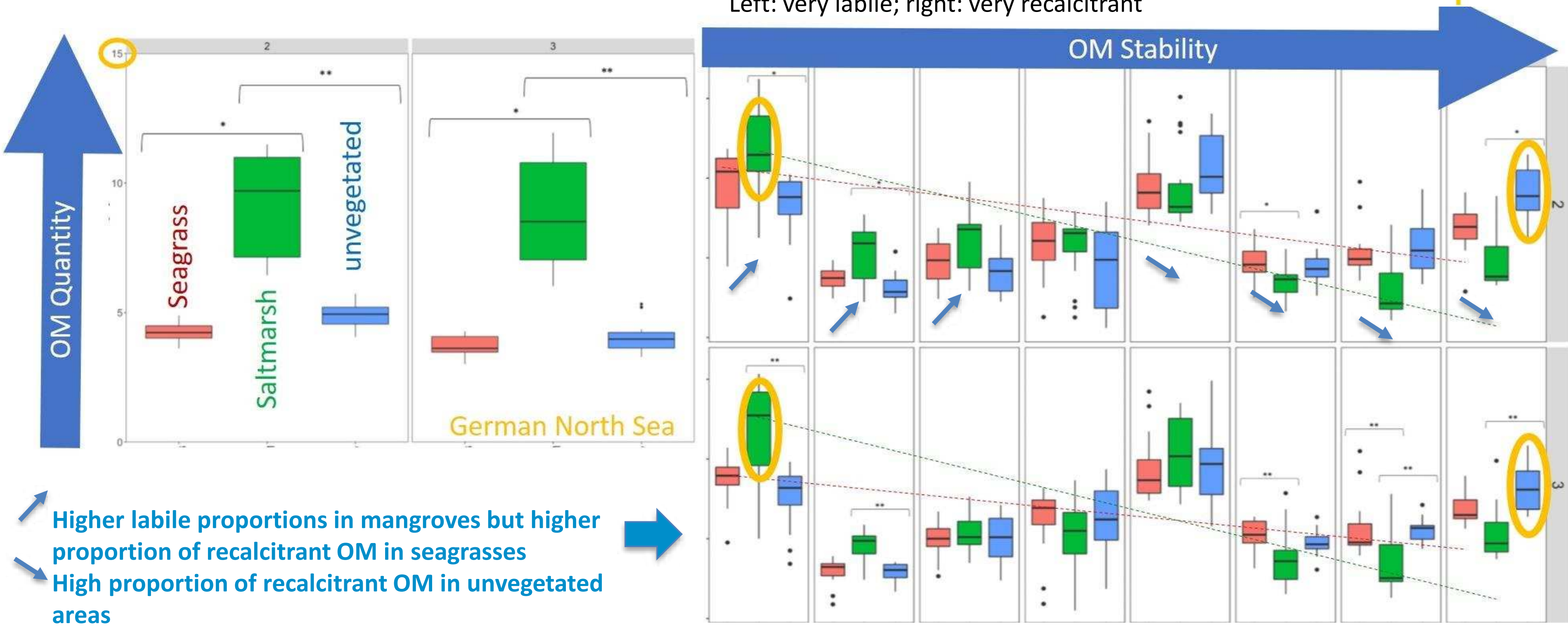
sea4soCiety, unpublished data

Malaysia: higher OM content in mangroves – except SET with similar content in mangroves and seagrasses

Current project and perspectives

sea4society – searching for solutions for C-sequestration in coastal ecosystems

Left: very labile; right: very recalcitrant



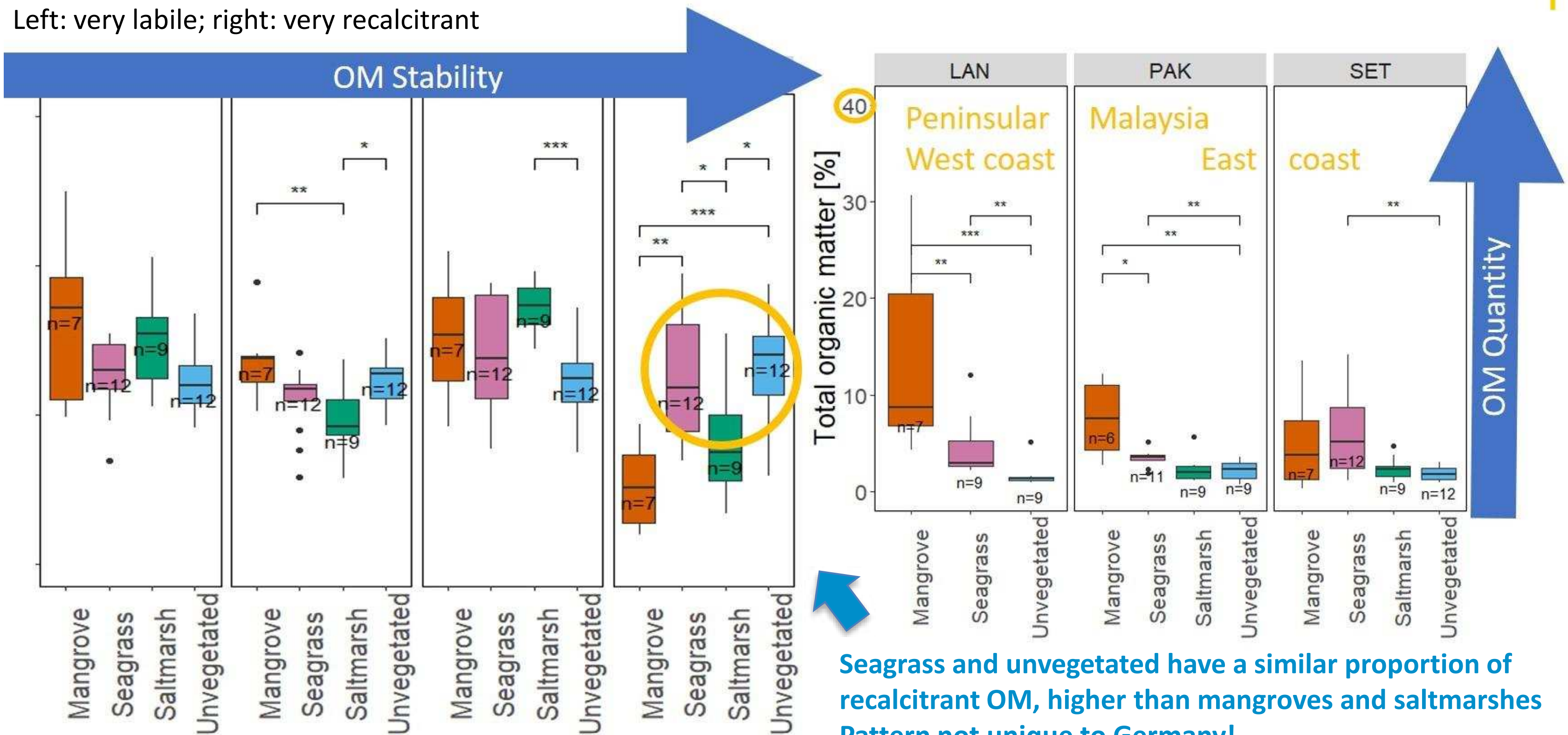
Higher labile proportions in mangroves but higher proportion of recalcitrant OM in seagrasses
High proportion of recalcitrant OM in unvegetated areas

sea4soCiety, unpublished data

Current project and perspectives

sea4society – searching for solutions for C-sequestration in coastal ecosystems

Left: very labile; right: very recalcitrant



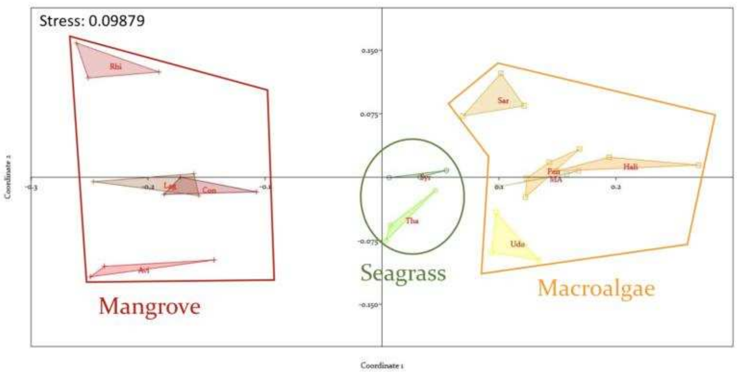
Seagrass and unvegetated have a similar proportion of recalcitrant OM, higher than mangroves and saltmarshes
Pattern not unique to Germany!
Waiting for the results from Colombia.

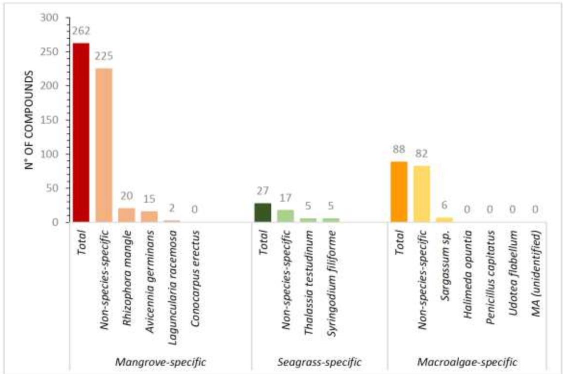
sea4soCiety, unpublished data

Current project and perspectives

sea4society – searching for solutions for C-sequestration in coastal ecosystems

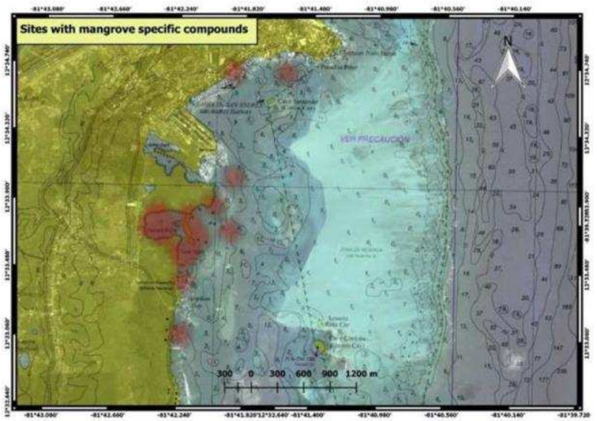
Untargeted sediment metabolomics

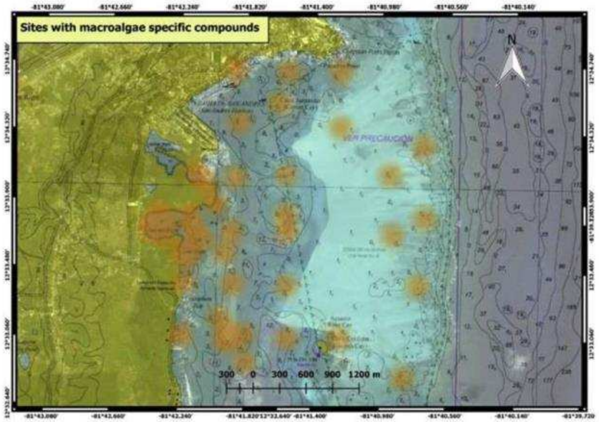




Bakkar T, Helfer V, Mancera Pineda J E & Zimmer M, *in prep*

Master study of Tarek Bakkar





Current project and perspectives

sea4society – searching for solutions for C-sequestration in coastal ecosystems

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Societal acceptance and **desirability – case studies in Colombia and Malaysia**

Perception

- Local people in COL & MY perceive "climate change" (the fish are moving from shallow bays into deeper water etc...) and "sea-level rise" (along with heavy erosion).

- They have no perception of "blue carbon" or what blue carbon ecosystems (or CVE) could contribute to climate change-mitigation.

Valuation

- They value CVE and the ecosystem services, but mostly in the context of (small-scale) fisheries (COL) and coastal protection (MY), i.e., rather in the context of climate change-adaptation

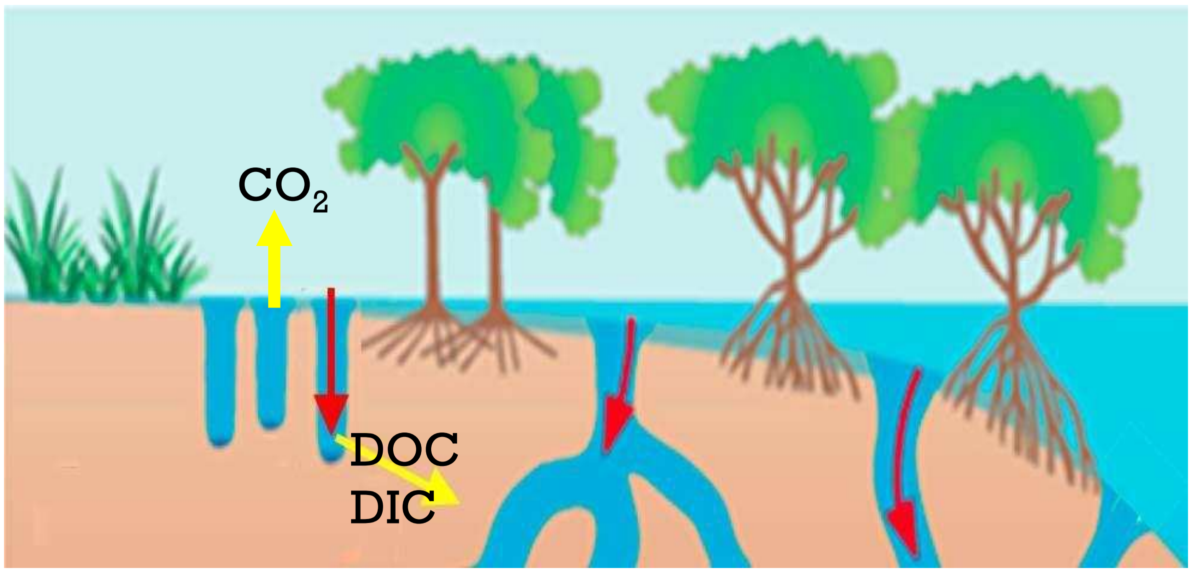
- They (re-)establish mangrove stands but not as CDR measure...

Doctoral project of Mondane Fouqueray
sea4soCiety, unpublished data

Current project and perspectives

sea4society – side projects

Effects of burrowing crustaceans on Blue Carbon dynamics and sediment characteristics



-organic matter content & stability

-microbiome metabolism

-sediment grain size

Master study of Nadim Katzer: *Ucides cordatus* in COL
Master study of Moritz Nusser: *Thalassina anomala* in MY

Current project and perspectives

sea4society – searching for solutions for C-sequestration in coastal ecosystems – PHASE II

CDR mare
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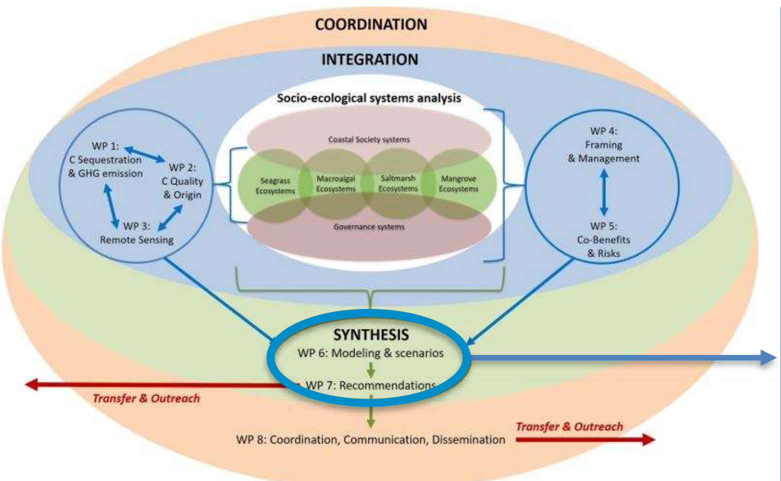
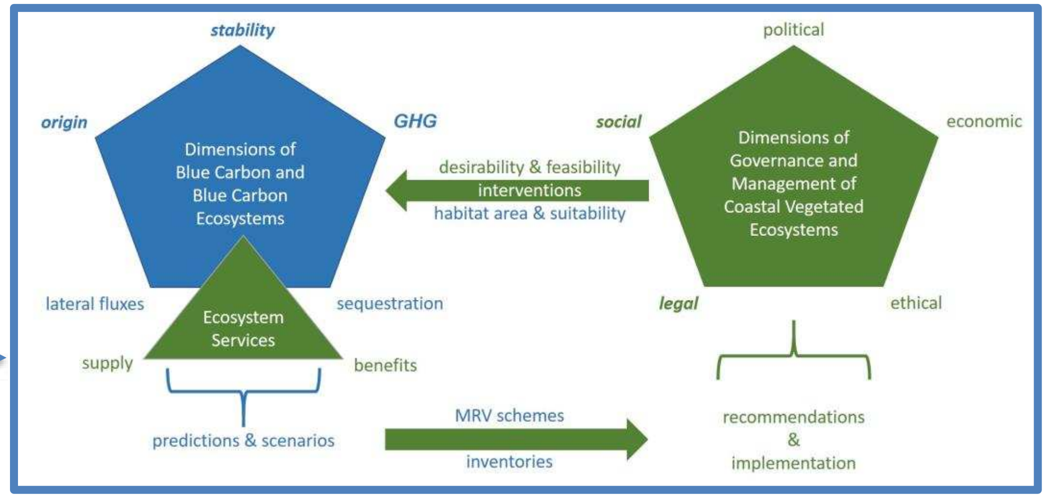
Phase I



Phase II



Current project and perspectives

sea4society – searching for solutions for C-sequestration in coastal ecosystems

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Building on outcomes of phase I, phase II of sea4soCiety will:

-implement first region-specific recommendations regarding the most efficient and societally accepted contribution of CVE to CDR and long-term storage of organic carbon upon areal extension;

-provide a proof of concept of CVE extension as measure of marine CDR through enhanced sequestration and storage of "blue carbon";

-accurately budget sequestration and storage rates by, as well as **GHG emissions** and **lateral losses** from, CVE;

-refine schemes for monitoring, reporting and verification (MRV) of CDR, carbon storage and its additivity, including co-benefits, risks of CVE extension and societal aspects.

To follow the development of the project:

Summary

NbS for climate change adaptation - A mangrove ecology perspective

Implementation Experience in NbS ➔ **Good planning is key, including definition of aims and metrics!**

Stakeholder Involvement in NbS ➔ **Crucial for long-term sustainability of actions.**

Monitoring and Evaluation in NbS ➔ **Need for common metrics and definitions. Essential for "lessons learned".**

Challenges and Barriers in NbS ➔ **Mangroves worldwide – alike but distinct! & Societal acceptance and desirability.**

Resource Allocation and Economic Impact in NbS ➔ **Resources for proper monitoring are needed.**

Environmental Impact, Adaptability and Resilience in NbS ➔ **Understanding resilience of ecosystems needs further scientific research.**

Community Impact in NbS ➔ **Societal acceptance and desirability are crucial.**

Education and Awareness in NbS ➔ **Understanding the perception of local actors is important.**

Government, Policy Support and Policy Integration in NbS ➔ **Consider needs of local users/actors.**

Long-Term Sustainability of NbS ➔ **Consider local conditions & needs of local users/actors.**

Future Recommendations for in NbS in Colombia (Coastal areas and islands) ➔ **Let's discuss this together!**

Dr Véronique Helfer
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Email: veronique.helfer@leibniz-zmt.de
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The Mangrove Ecology Group
https://www.leibniz-zmt.de/en/Mangrove_Ecology.html

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Funded by the European Union

A few words about me

Véronique Helfer, Senior scientist

Scientific background

- Molecular ecology including population genetics, landscape genetics, eDNA metabarcoding.
- Chemical ecology and environmental metabolomics.
- GIS, species distribution modelling, remote-sensing.

Research interests

- Understanding of the drivers of mangrove communities distribution through time (eDNA metabarcoding);
- Forecasting mangrove communities and ecosystem processes in space and time;
- **Spatial conservation prioritization**: defining the most suitable protected areas network, to ensure on-going ecosystem service provisioning by mangroves, while supporting sustainable use by local populations.