Mangrove Restoration Under Shifted Baselines and Future Uncertainty

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INTRODUCTION

Mangrove forests are inherently dynamic and are often regarded as complex social-ecological systems. Being located at the interface between the land and the sea, they need to keep up with changes in sea-level (Saintilan et al., 2020) and other gradual or extreme events to be successful, and so do mangrove rehabilitation and restoration (hereafter referred to as “R/R”) initiatives. However, both the starting condition before R/R activities and the evaluation of their success, may be subject to misconceptions or at least require special attention. We highlight three such points of attention that are seldomly, if ever, emphasised in the scientific literature: shifted baselines, faunal assemblages and human poverty and uncertainty.

SHIFTED BASELINES

Numerous R/R targets or mangrove health assessments, unfortunately, rely on the earliest remote sensing imagery available or on past vegetation data to establish which areas sustainably rejuvenate and which must be restored (Wang et al., 2019). Dated years to decades ago, the site conditions documented in these previous studies do not necessarily represent anymore a reliable baseline. A wide suite of anthropogenic impacts, including forest and beach encroachment and other forms of land reclamation (Richards and Friess, 2016; Goldberg et al., 2020) and river diversion (Dahdouh-Guebas et al., 2005), are known to affect mangroves to the extent that referring to historic mangrove cover or composition makes no sense.

Natural processes may also change the baselines for successful R/R initiatives. For example, gradual or abrupt sedimentary processes may have significantly changed the intertidal topography and the consequent inundation regime of the target sites. Subsequently, mangrove areas once dominated by mid-intertidal species could now only host species characteristic of the upper or lower intertidal zone (Nehru and Balasubramanian, 2018). Where tectonic events have subsided the entire coastal zone, terrestrial areas once uninhabitable for mangrove species would be frequently inundated and have become an ideal place to afforest mangroves. In contrast, reporting historic mangrove presence in areas that are emerged or submerged nowadays would constitute false pretence upon which to attempt successful R/R (Kodikara et al., 2017; Chakraborty et al., 2019).

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We recognise that in pathways of R/R a synergism exists between (i) mangrove vegetation succession, (ii) anthropogenic drivers of change, and (iii) shifted baselines. Vegetation succession...
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FIGURE 1 | The Sri Lankan tree climbing crab *Pentesarma dussumieri*, here on a *Rhizophora apiculata* mangrove tree. The invertebrate faunal community in Sri Lankan mangroves has an extremely high level of functional vulnerability, suggesting a potentially rapid decrease of functional diversity (Cannicci et al., 2021).

in mangroves involves rapid or slow changes from pioneering species to climax vegetation and their complex interactions with the natural environment (Berger et al., 2006). Biotic and abiotic drivers, including for example plant-animal interactions (Cannicci et al., 2008), changes in sea-level and geomorphology (Ellison, 2019; Rogers et al., 2019), or extreme events (Abhik et al., 2021) can return a mangrove forest back to a previous successional stage. In addition, anthropogenic drivers of rapid or gradual ongoing change can strongly interact with development, growth and succession of mangrove plant communities (Dahdouh-Guebas and Koedam, 2002). But we draw specific attention to the shifted baselines, which forms a third type of complexity. We advocate that mangrove R/R targets should rely on the local conditions at the time of restoration and should be planned with the intention to build resilience under certain and sometimes even imminent change. In addition to these shifted or shifting baselines, the complexity of mangroves warrants that R/R targets transcend mere numbers of seedlings planted in Guinness World Records style (Guinness World Records, 2012). Instead, they should integrate objectively verifiable indicators of ecosystem functioning and service provision, including proxies of thriving or deteriorating faunistic assemblages (e.g., macrobenthos) and human communities (e.g., poverty, land tenure conflicts).

CRABS CANNOT BE PLANTED

Mangroves do not only host a unique tree diversity but an equally unique set of resident and visiting faunal communities such as mangrove crab assemblages that are adapted to intertidal life. These macrobenthic communities act as ecosystem engineers and enhance the oxygenation and bioturbation of the soil, which in turn contributes to habitat creation through soil accretion, composition and biogeochemistry and to viability of mangrove trees and associated organisms. The faunal components are thus critical for mangrove ecosystem service provision.

We emphasise that the presence of viable faunistic assemblages, and by extension other biotic ecosystem components, is the result of a slow recruitment conditional of successful R/R of mangrove vegetation, i.e., they are not “planted” along with the trees. Considering their redundancy-vulnerability relationship (Figure 1), a lack of recruitment of invertebrate fauna, leading to
a low diversity, could result in significant negative consequences in the viability and resilience of rehabilitated mangrove forests, and cascading effects for adjacent ecosystems (Cannicci et al., 2021). Therefore, R/R targets should consider the selection of sites connected to healthy mangroves in which faunal communities can act as source populations. The latter is an example of panarchy, known to play an important role in the resilience of an ecosystem through the so-called “remember” process. This process enables undisturbed adjacent forest patches help a focal recovering patch “remember” what a functional mangrove forest is (Dahdouh-Guebas et al., 2021). However, shifted baselines could make it impossible to reach R/R targets in terms of macrobenthic recruitment, for example in areas that are continuously flooded (Nehru and Balasubramanian, 2018).

DISCUSSION AND CONCLUSION

Mangrove shorelines are essential for human well-being, but despite conservation optimism (Friess et al., 2020), efforts to restore them in a holistic framework have been largely unsuccessful. We emphasise that “before and after”-assessments are paramount in the success of R/R initiatives, yet they often remain disregarded. We advocate that R/R projects should always include the following prior assessments:

- a thorough assessment of current ecological and environmental conditions that enable mangrove trees to grow in the R/R sites selected for (re)afforestation;
- a nearby source site from which newly planted mangroves can recruit associated invertebrates, but also micro-organisms and even mangrove propagules from non-planted species;
- a social, human and financial capital aimed at medium to long-term resilience.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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REFERENCES

Abhik, S., Hope, P., Hendon, H. H., Hutley, L. B., Johnson, S., Drosdowsky, W., et al. (2021). Influence of the 2015–2016 El Niño on the record-breaking mangrove dieback along northern Australia coast. Sci. Rep. 11:20411. doi: 10.1038/s41598-021-99313-w

Boongaling Agaton, C., and Azcuna Collera, A. (2022). Now or later? Optimal timing of mangrove rehabilitation under climate change uncertainty. For. Ecol. Manag. 503:119739. doi: 10.1016/j.foreco.2021.119739

Berger, U., Adams, M., Grimm, V., and Hildenbrandt, H. (2006). Modelling secondary succession of neotropical mangroves: Causes and consequences of growth reduction in pioneer species. Perspect. Plant Ecol. Evol. Syst. 7, 243–252. doi: 10.1016/j.ppees.2005.08.001

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Cannicci, S., Burrows, D., Fratini, S., Lee, S. Y., Smith, T. J. III, Offenberg, J., et al. (2008). Faunal impact on vegetation structure and ecosystem function in mangrove forests: a review. *Aquat. Bot.* 89, 186–200. doi: 10.1016/j.aquabot.2008.10.009

Cannicci, S., Lee, S. Y., Bravo, H., Cantera-Kinta, J. R., Dahdouh-Guebas, F., Fratini, S., et al. (2021). A functional analysis reveals extremely low redundancy in global mangrove invertebrate fauna. *Proc. Natl. Acad. Sci. U. S. A.* 118, 2016913118. doi: 10.1073/pnas.2016913118

Chakraborty, S., Sahoo, S., Majumdar, D., Saha, S., and Roy, S. (2019). Future mangrove suitability assessment of Andaman to strengthen sustainable development. *J. Clean. Prod.* 234, 597–614. doi: 10.1016/j.jclepro.2019.06.257

Dahdouh-Guebas, F., Hettiarachchi, S., Sooriyarachchi, S., Lo Seen, D., Batelaan, O., Jayatissa, L. P., et al. (2005). Transitions in ancient inland freshwater resource management in Sri Lanka affect biota and human populations in and around coastal lagoons. *Curr. Biol.* 15, 579–586. doi: 10.1016/j.cub.2005.01.053

Dahdouh-Guebas, F., Hugé, J., Abuchahla, G. M. O., Cannicci, S., Jayatissa, L. P., Kairo, J. G., et al. (2021). Reconciling nature, people and policy in the mangrove social-ecological system through the adaptive cycle heuristic. *Estuar. Coast. Shelf Sci.* 248, 106942. doi: 10.1016/j.ecss.2020.106942

Dahdouh-Guebas, F., and Koedam, N. (2002). A synthesis of existing and potential mangrove vegetation structure dynamics from Kenyan, Sri Lankan and Mauritanian case-studies. *Proc. R. Acad. Overseas Sci. Sect. A.* 48, 487–511. Available online at: http://www.koawarsom.be/documents/BULLETINS_MEDEDELINGEN/2002-4.pdf

Dahdouh-Guebas, F., Zetterström, T., Rönnbäck, P., Troell, M., Wickramasinghe, A., and Koedam, N. (2002). Recent changes in land-use in the Pambala-Chilaw Lagoon complex (Sri Lanka) investigated using remote sensing and GIS: conservation of mangroves vs. development of shrimp farming. *Environ. Dev. Sustain.* 4, 185–200. doi: 10.1023/A:1020854413866

Ellison, J. C. (2019). “Biogeomorphology of mangroves,” in *Coastal Wetlands: an Ecosystem Integrated Approach*, eds G. M. E. Perillo, E. Wolanski, and D. R. Cahoon, C. S. Hopkinson (Amsterdam: Elsevier Science), 687–715. doi: 10.1016/B978-0-444-63893-9.00020-4

Faridah-Hanum, I., Yusoff, F. M., Fitrianto, A., Ainuddin, N. A., Gandaseca, S., Zaiton, S., et al. (2019). Development of a comprehensive mangrove quality index (MQI) in Matang Mangrove: Assessing mangrove ecosystem health. *Ecol. Ind.* 102, 103–17. doi: 10.1016/j.ecolind.2019.02.030

Foell, J., Harrison, E., and Stirrat, R. L. (1999). *Participatory Approaches to Natural Resource Management - The Case of Coastal Zone Management in the Puttalam District*. Summary findings of DFID-funded research ‘participatory mechanisms for sustainable development of coastal ecosystems’ (Project R6977), School of African and Asian studies, University of Sussex, Falmer, Brighton, U.K. 48 p.

Friess, D., Yando, E. S., Abuchahla, G. M. O., Adams, J. B., Cannicci, S., Canty, S. W. J., et al. (2020). Mangroves give cause for conservation optimism, for now. *Curr. Biol.* 30, R135–R158. doi: 10.1016/j.cub.2019.12.054

Goldberg, L., Logamisino, D., Thomas, N., and Fatoynho, T. (2020). Global declines in human-driven mangrove loss. *Glob. Change Biol.* 26, 5844–5855. doi: 10.1111/gcb.15275

Guinness World Records. (2012). *Most Mangrove Trees Planted Within One Hour*. Available online at: https://www.guinnessworldrecords.com/world-records/101647-most-mangrove-trees-planted-within-one-hour-team/ (accessed 9 June 2021).

Kibrìa, A. S. M. G., Costanza, R., Groves, C., and Behie, A. M. (2019). Does higher access ensure greater wellbeing? In: *The Perspective of Forest Ecosystem Services of the Sundarbans mangrove forest*, Bangladesh. *Ocean Coast. Manag.* 177, 22–30. doi: 10.1016/j.ocecoaman.2019.04.019

Kodikara, K. A. S., Mukherjee, N., Jayatissa, L. P., Dahdouh-Guebas, F., and Koedam, N. (2017). Have mangrove restoration projects worked? An in-depth study in Sri Lanka. *Restorat. Ecol.* 25, 705–716. doi: 10.1111/rec.12492

Lovelock, C. E., and Brown, B. M. (2019). Land tenure considerations are key to successful mangrove restoration. *Nat. Ecol. Evol.* 3, 1135–1135. doi: 10.1038/s41559-019-0942-y

Nehru, P., and Balasubramanian, P. (2018). Mangrove species diversity and composition in the successional habitats of Nicobar Islands, India: a post-tsunami and subsidence scenario. *For. Ecol. Manag.* 427, 70–77. doi: 10.1016/j.foreco.2018.05.063

Richards, D. R., and Friess, D. A. (2016). Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012. *Proc. Natl. Acad. Sci. U. S. A.* 113, 344–349. doi: 10.1073/pnas.1510272113

Rogers, K., Kelleway, J. I., Saintilan, N., Megonigal, J. P., Adams, J. B., Holmquist, J. R., et al. (2019). Wetland carbon storage controlled by millennial scale variation in relative sea-level rise. *Nature* 567, 91–95. doi: 10.1038/s41586-019-0951-7

Saintilan, N., Khan, N. S., Ashe, E., Kelleway, J. I., Rogers, K., Woodroffe, C. D., et al. (2020). Thresholds of mangrove survival under rapid sea level rise. *Science* 368, 1118–1121. doi: 10.1126/science.ab2636

Satyanarayana, B., Quispe-Zuniga, M. R., Hugé, J., Sulong, I., Mohd-Lokman, H., and Dahdouh-Guebas, F. (2021). Mangroves fueling livelihoods: A socio-economic stakeholder analysis of the charcoal and pole production systems in the world’s longest managed mangrove forest. *Front. Ecol. Evol.* 9:621721. doi: 10.3389/fevo.2021.621721

Vandervoort, I., Pionier, A., Stepp, J., Hanazaki, N., Ladio, A., Nóbrega Alves, R. R., et al. (2020). Reshaping the future of ethnobiology research after the Covid-19 pandemic. *Nat. Plants* 6, 723–730. doi: 10.1038/s41477-020-0691-6

Wang, L., Jia, M., Yin, D., and Tian, J. (2019). A review of remote sensing for mangrove forests: 1956–2018. *Remote Sens. Environ.* 231:111223. doi: 10.1016/j.rse.2019.111223

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