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Nature-based coastal flood protection: Lessons from the Caribbean and the Philippines

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Abstract

This short communication examines four case studies from the Caribbean and the Philippines to summarize practical lessons on the implementation of nature-based solutions (NbS) for coastal flood protection. Each project, ranging from hybrid breakwaters to mangrove restoration, illustrates the benefits of integrating ecological restoration with participatory governance to enhance coastal resilience. Findings highlight that the effectiveness of NbS is highly site-specific, contingent upon local ecological conditions, governance structures, and socio-economic factors. While these interventions can offer significant co-benefits, including erosion control, biodiversity enrichment, and alternative livelihoods, challenges persist related to maintenance, funding, institutional coordination, and risk of maladaptation. This communication highlights the importance of integrating NbS into broader adaptation frameworks, which combines scientific knowledge with community engagement to achieve sustainable outcomes. These insights are particularly relevant for low-lying coastal regions and small island developing states (SIDS) facing rising sea levels and intensifying storm impacts.

Keywords

Coastal adaptation, Community-based, Low-lying coastal regions, Nature-based solutions (NbS), Small Island Developing States (SIDS)

1 Introduction

Nature-based solutions (NbS) are actions that use natural processes and ecosystems to address societal challenges, including climate change, disaster risk, and biodiversity loss (Cohen-Shacham et al., 2016; Seddon et al., 2020). In coastal settings, NbS typically involve the protection, conservation, and/or restoration of ecosystems such as mangroves, coral reefs, seagrasses, and coastal wetlands, and in some cases, their integration with gray infrastructure into hybrid systems (Reguero et al., 2018). NbS offer multiple co-benefits: ecologically, they sustain biodiversity and ecosystem services such as shoreline stabilization, carbon sequestration, and water purification (Temmerman et al., 2013); socially, they support livelihoods and foster participatory governance when communities are actively engaged; and economically, they can provide cost-effective, adaptive, and multifunctional alternatives to gray infrastructure, with additional value for fisheries, tourism, and recreation (Riera-Spiegelhalder et al., 2023; Suedel et al., 2023).

Despite their promise, NbS face some limitations. Their performance is highly context-dependent, often requiring time to deliver measurable flood protection outcomes, and they currently lack the standardized metrics and regulatory frameworks that govern gray infrastructure. Scaling NbS is also constrained by land-use competition, lack of supporting policies, funding gaps, and the complexity of multi-stakeholder coordination (Magnan et al., 2023; Seddon, 2022).

This communication distills key insights from four projects, two in the Caribbean and two in the Philippines, that illustrate the practical application of NbS in regions characterized by high climate risk and socio-ecological vulnerability. Both regions are recognized as biodiversity hotspots and are increasingly affected by the intensification of hurricanes and typhoons, rising sea levels, and coastal flooding. Sea-level rise projections underscore the scale of the challenge: in the Caribbean, mean sea levels are projected to increase by approximately 0.70 m under moderate emission scenarios and up to 1.10 m under high scenarios by 2100, while in the Philippines, regional projections indicate rises of 0.83 m under moderate scenarios and up to 1.36 m under high scenarios over the same period (Fox-Kemper et al., 2021; Kopp et al., 2023; Garner et al., 2021). These trends amplify the exposure of low-lying coastal communities to flooding and other coastal hazards.

The case studies presented here serve as empirical counterpoints to the legacy of Hurricane Katrina, a disaster that highlighted the limits of the existing protection system. Although marshes once played an important protective role in southeastern Louisiana, their rapid degradation, combined with failures in the gray infrastructure, particularly levees and floodwalls developed as discrete projects over several decades, ultimately compromised the system's integrity. The event exposed fundamental structural and governance weaknesses inherent in centralized and fragmented approaches to flood protection (Daniels et al., 2006; Delisi, 2006). In contrast, the interventions analyzed in this article explore more integrated, participatory, and adaptive pathways to coastal resilience but also the challenges often associated with NbS implementation. The information presented derives from a combination of published sources and direct insights provided by practitioners and co-authors with first-hand experience in the implementation of the projects described.

As the coastal adaptation enterprise scales interventions to maintain or enhance resilience, communities need sound analysis of all options on the table. The work here reflects the evolving contributions of the Practitioner Exchange for Effective Response to Sea Level Rise (PEERS), a global community of practice committed to advancing place-based strategies that combine scientific insight with local knowledge to adapt to long-term coastal hazards (www.peerscoastal.org). In practitioner-led global workshops that led to the formation of PEERS, greater understanding of the potential of – and limitations to – NbS was a high priority goal for coastal resilience practitioners (Boyle et al., 2022; Hirschfeld et al., 2024). These cases, in regions where PEERS is currently working, meet this demand and offer grounded and transferable lessons for similarly threatened low-lying and densely populated coastal areas worldwide.

2 Analytical Framework for Case Assessment

To enable systematic comparison and synthesis of lessons learned, each case is assessed using a set of six criteria adapted from literature, existing NbS frameworks, and practitioner insights drawn from the firsthand experience of the case implementers.

1. **Effectiveness in Risk Reduction:** Quantitative and qualitative evidence of hazard mitigation, including wave attenuation, flood peak reduction, shoreline stabilization, and reduction in erosion rates. The literature highlights the need to link hazard reduction not only to measurable physical processes and long-term resilience outcomes, but also to public perceptions of effectiveness (Louarn et al., 2025).
2. **Ecological Integrity:** The extent to which the intervention restores or maintains the structure, composition, and functioning of ecosystems, while sustaining biodiversity and ecosystem services. For coastal systems, this involves maintaining connectivity between habitats and supporting ecological processes such as sediment transport and nutrient cycling (Lacambra et al., 2024). Projects that successfully enhance biodiversity, such as

increases in mangrove species richness and coral recruitment, are more likely to sustain their protective functions over time (Seddon, 2022; Winterwerp et al., 2025).

3. **Socioeconomic Benefits:** Include improved livelihoods, public health, cultural values, and recreational opportunities. In many cases, NbS outperform gray infrastructure in terms of benefit–cost ratios, especially when long-term ecosystem service provision is included (Van Zanten et al., 2023). Cost-effectiveness and return on investment are methods commonly used here (Raymond et al., 2017; Riera-Spiegelhalder et al., 2023).
4. **Governance and Stakeholder Engagement:** Effective governance involves multilevel coordination between local, regional, and national authorities, strong legal frameworks, and clear allocation of rights and responsibilities. Indigenous and local knowledge, along with community engagement and co-creation are critical for ensuring local buy-in, integrating traditional and scientific knowledge, and sustaining interventions over time (Cottrell, 2022).
5. **Technical Feasibility:** Technical feasibility relates to the suitability of the NbS design to local biophysical and socio-economic conditions. This includes alignment with hydrodynamic, geomorphological, and sedimentary regimes, as well as the ability to operate in data-poor contexts (Winterwerp et al., 2025). Successful designs often emerge from a detailed understanding of site-specific processes, sometimes relying on conceptual models when data are scarce (Reguero et al., 2018; Temmerman et al., 2013).
6. **Sustainability and Scalability:** Sustainability involves the long-term maintenance of ecological functions and socio-economic benefits without causing harm to other areas. It requires adaptive management, secured financing, and institutional capacity for ongoing operation (Cohen-Shacham et al., 2016; IUCN, 2020; Raymond et al., 2017). Scalability refers to the potential for replication in other locations with similar conditions, considering transferability of techniques and governance arrangements.

Each case study is presented next following this structure. The Cross-Cutting Lessons section will synthesize findings along the same six criteria to support the conclusions.

3 Case snapshots

3.1 At the Water's Edge – Grenada

The At the Water's Edge (AWE) project, implemented in Grenada from 2013 to 2017, presents a model for integrating NbS with community engagement to address coastal hazards in vulnerable small island contexts (see Fig. 1). Located in Grenville Bay on the island's eastern coast (Fig. 2), directly exposed to intense wave action, AWE responded to escalating threats including coastal erosion and flooding, all intensified by long-term ecosystem degradation (Reguero et al., 2018; Suedel et al., 2023).

1. **Effectiveness in Risk Reduction**: The project built submerged hybrid breakwaters designed to reduce wave energy and facilitate coral recruitment (Fig. 3). Modelling results showed that healthy and well-developed reef systems in the southern part of Grenville Bay maintain shoreline stability, whereas reef degradation in the northern sector is linked to severe erosion. The study demonstrated that changes in wave propagation patterns induced by reef condition largely explain observed shoreline retreat, highlighting the role of reef restoration as a coastal protection measure (Reguero et al., 2018). The intervention was conceived to function under projected sea level rise scenarios, with reef crest heights and planting zones adapted to anticipated tidal changes.
2. **Ecological Integrity:** A participatory vulnerability assessment identified upstream pollution as a key driver of coastal ecosystem decline. Fertilizer runoff from farming areas, along with other stressors, contributed to coral reef degradation and poor nearshore water quality. In response, the project adopted a ridge-to-reef approach, an integrated land-to-sea management strategy recognizing the ecological connectivity between upland watersheds and coastal and marine ecosystems. Upland measures included the construction of retention ponds, developed in collaboration with local farmers, to reduce agricultural runoff. In the coastal zone, the project implemented a "living shoreline" that combined beach re-nourishment, revegetation and mangrove restoration. (Suedel et al., 2023). Within less than a year after the installation of the submerged breakwaters, coral reef recruitment was thriving.

3. **Socioeconomic Benefits:** The project generated local employment through the implementation of engineering and habitat restoration works, including building and installing breakwaters and planting mangroves. Hybrid breakwaters and vegetated shorelines enhanced habitat quality, supporting fisheries and strengthening the natural resource base that local livelihoods depend on. Monitoring recorded increases in fish biomass and species diversity within two years of breakwaters' installation (Beck et al., 2020). Community members were engaged in training and planning activities, building capacity to manage and maintain these nature-based interventions.

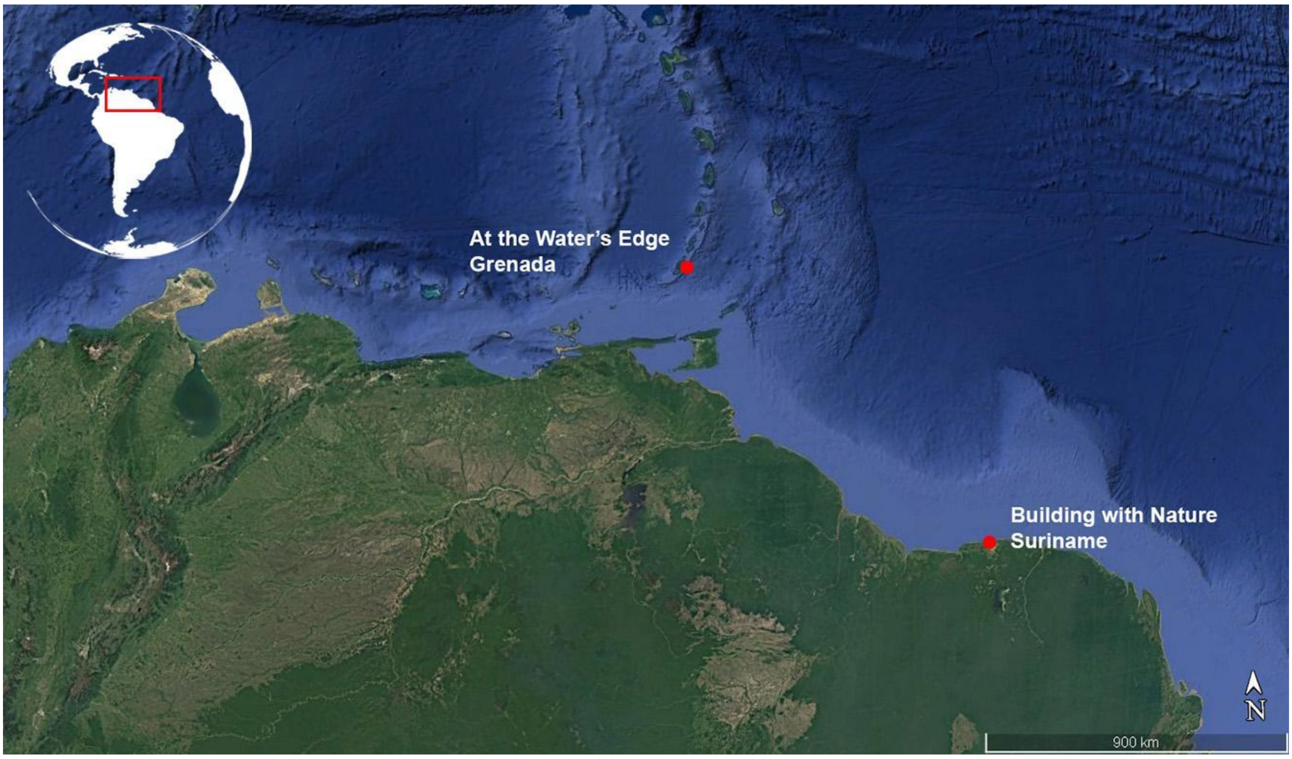

Figure 1. Location map of case studies in the Caribbean. Source: Google Earth.

Figure 2. Grenville Bay, Grenada. Source: Hunter Nichols/Courtesy TNC.

4. **Governance and Stakeholder Engagement:** The project's governance structure involved multi-actor coordination among the Grenadian government, The Nature Conservancy, the Grenada Red Cross Society, and

community groups. Community engagement was integral throughout. Fishers helped build the breakwaters and received training in coral restoration, while local knowledge informed decisions on site selection, resource use, and maintenance. Agreements were established with fishers for the ongoing maintenance of the breakwaters and the ensuing biodiversity benefits, thereby embedding the project within the local economy.

5. **Technical Feasibility:** The technical design was informed by hydrodynamic modeling and site-specific assessments of sediment transport and wave regimes. The configuration consists of an array of modular reef units, each approximately 8 meters long by 5 meters wide, for a total length of 350 meters. Each unit is built from interconnected gabion steel baskets and filled with cement blocks. This modular approach allows for flexibility in installation, maintenance, and potential scaling. Placement was optimized to maximize wave attenuation while minimizing ecological disturbance, and mangrove planting sites were selected according to tidal inundation modelling (Reguero et al., 2018). In September 2015, four pilot units were installed and monitored annually to test the design, construction methods, and implementation procedures before scaling up to the full design.

6. **Sustainability and Scalability:** The project provided a foundation for subsequent adaptation initiatives, most notably the Resilient Islands project, which expanded the AWE model to Jamaica and the Dominican Republic. AWE was funded through a mix of international grants and partnerships. While the design phase envisioned a full reef array of 350 meters, this was never completed. Long-term viability continues to depend on securing investments, supported by evidence of coastal protection and socioeconomic co-benefits such as sustainable livelihoods linked to tourism and fisheries.

Figure 3. Submerged hybrid breakwater unit in Grenville Bay, Grenada. Source: Tim Calver/Courtesy TNC.

3.2 Building with Nature – Suriname

Suriname's low-lying Atlantic coast is one of the most dynamic and erosion-prone shorelines in the world, shaped by the westward migration of mud banks from the Amazon River. For decades, human interventions such as dike construction and mangrove clearance near urban centers like Paramaribo-Wanica have disrupted natural sedimentation processes, increasing vulnerability to flooding, storm surges, sea-level rise, and saline intrusion into agricultural lands. Since 2015, several pilot interventions have been launched to test sediment trapping units (STUs), low-cost, permeable wooden dams designed to dissipate wave energy and trap sediments (Fig. 4).

1. **Effectiveness in Risk Reduction:** The Building with Nature project aimed to reduce coastal hazards by building STUs along different sites to promote mud accretion and mangrove establishment (Winterwerp et al., 2020). Where sediment supply was adequate, these interventions attenuated wave energy and stabilized shorelines (Anthony, 2015; Winterwerp et al., 2020). Their effectiveness, however, was highly site-specific and closely linked to seasonal and interannual sediment dynamics. Along the Suriname coast, these dynamics are influenced by the migration of the Intertropical Convergence Zone (ITCZ). When the ITCZ shifts southward (November - April), strong winds and high waves suppress deposition and increase erosion in the

absence of mudbanks. In contrast, when the ITCZ is positioned northward, weaker winds create calmer conditions that favor sediment accretion.

2. **Ecological Integrity:** STUs helped restore natural sedimentation processes, facilitating mangrove recolonization and enhancing habitat quality and biodiversity (Anthony, 2015). Sediment deposition during the early stages of construction also attracted red ibises (Eudocimus ruber) and sandpipers (Calidris spp.), indicating positive ecological responses. As mangroves mature, they provide critical ecosystem services, including nursery grounds for marine species and coastal protection. However, dredging activities at the Suriname River mouth disrupted sediment flows, creating deficits that undermined outcomes at adjacent project sites located west, specifically at Weg Naar Zee.
3. **Socioeconomic Benefits:** By reinforcing natural defenses, the project reduces wave energy through the combined effect of STU structures and sediment deposition. This diminishes flood impacts on local communities and protects agricultural lands from salinization (Winterwerp et al., 2020). These benefits support livelihoods tied to farming and coastal resources. However, the unusually prolonged La Niña event (2020 - 2023), intensified waves and swell, causing more erosion and highlighting the influence of climate variability and climate change on long-term project outcomes.
4. **Governance and Stakeholder Engagement:** The project involved community participation in building and maintaining STUs, while collaboration with national ministries helped embed the approach within broader coastal management strategies. As a pilot initiative, it successfully generated and shared knowledge, leading other organizations to replicate STU construction. Yet, sustaining these efforts faced significant challenges, such as limited logistics for operating in soft mud environments, shortage of skilled personnel, and financial constraints for long-term maintenance.
5. **Technical Feasibility:** STUs are low-cost and constructed from local materials, making them viable in resource-constrained contexts. Their effectiveness, however, depended on precise siting in sediment-rich areas and regular maintenance to withstand wave action. Adequate sediment supply was a critical condition for success. Where sediment input was insufficient, vertical erosion deepened the seabed, reducing the stability of the STUs and making them more vulnerable to damage (Fig. 5). The government of Suriname has initiated the construction of a seawall at Weg Naar Zee to protect local residents and farmers from erosion and flooding during high tides, particularly spring tides, with the intent of combining this gray infrastructure with mangrove rehabilitation in front of it to enhance coastal protection (Fig. 6).
6. **Sustainability and Scalability:** The method showed promise for replication across the mud-bank coasts of the Guianas, but long-term sustainability was compromised by dredging activities and sediment supply variability. The contrast between the failed Weg Naar Zee site and more successful remote western sites underscored the importance of integrated, landscape-scale planning and strong policy frameworks to protect NbS from incompatible development pressures.

Figure 4. STUs built in Weg Naar Zee, Suriname. Source: Sieuwnath Naipal (2015).

Figure 5. Fluid mud covers young, planted mangroves behind STUs in Weg Naar Zee, Suriname. Source: Sieuwnath Naipal (2021).

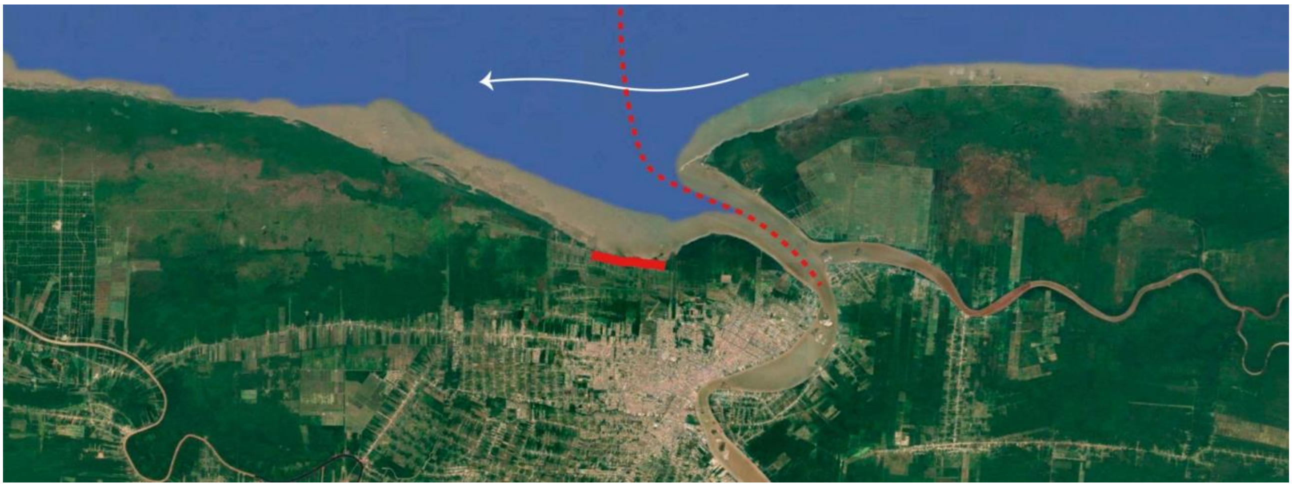

Figure 6. The dredging line (dashed red line). The Guiana Current (white arrow) and in the same direction the movement of the mudbank. Please note that the movement of the mudbank might follow a complex path, but the direction is westwards. Weg Naar Zee planned seawall (thick red line). Source: Sieuwnath Naipal (2025).

3.3 Danajon Bank Double Barrier Reef – Philippines

Danajon Bank is a double-barrier reef (Fig. 7), a very rare geological formation of which there are only six in the world; it is one of the primary geological sites of the Bohol UNESCO Global Geopark. Danajon Bank consists of large reefs and numerous islets that span across the provinces of Bohol, Cebu, Leyte, and Southern Leyte in the Philippines (Fig. 8).

Tidal flooding is one of the earliest impacts of sea level rise. Today, the small island communities of Danajon Bank are experiencing some of the most extreme cases of tidal flooding in the world, with spring tides partially or completely inundating the islands each month (Jamero et al, 2017) (Fig. 9). Danajon Bank lay directly in the path of Typhoon Odette, which in December 2021 caused many small island communities to suffer storm surge damage (Esteban et al, 2023) (Fig. 10).

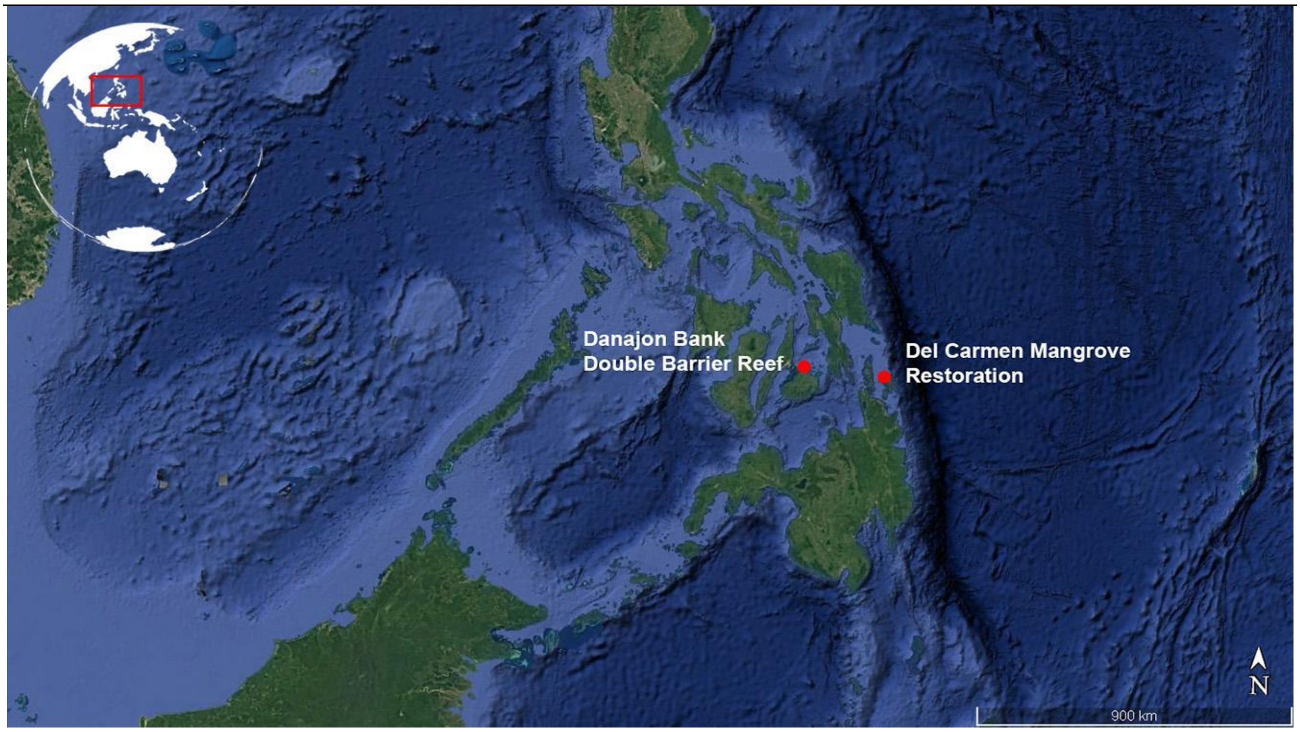

Figure 7. Location map of case studies in the Philippines. Source: Google Earth.

Through a broad array of NbS, the newly established Bohol Danajon Bank Double Barrier Reef Management Council is promoting the protection and conservation of coral reefs and mangroves to adapt to the adverse impacts of climate change. These NbS include strengthening of community-based Marine Protected Areas within Danajon, establishing mangrove nurseries, creating and implementing a management plan for Bohol's coastal greenbelt, and building capacity of local leaders and various stakeholders (including the youth) through training, among others.

1. **Effectiveness in Risk Reduction:** Mangroves perceived by small islanders as being effective as wave barriers; they often hide their boats (and sometimes their families) within mangrove forests during strong typhoons. For this reason, small islanders often engage in mangrove planting. Meanwhile, coral reef's role and effectiveness as the first line of defense during storm surges, is not as appreciated by small islanders (likely because they are underwater and their effect on reducing wave energy is not as apparent). Their role is often associated with protecting fishes rather than homes, and they are instead often harvested to build make-shift seawalls along coastlines. There is a need to raise more awareness on the important role that corals play, and how this ecosystem works hand-in-hand with mangroves.
2. **Ecological Integrity:** Mangrove forests helped restore fish stocks in Danajon Bank, aside from offering coastal protection. In the past, a single species of mangrove has been planted by small islanders (the national greening program focused more on quantity). With this, local conservation groups have questioned its appropriateness for the local environment. In more recent years, these groups have started to educate the communities on the various mangrove species available, which types are appropriate for which areas, and established mangrove nurseries where the small islanders can get seedlings. They also raised awareness about coastal zones, establishing the link and importance of both mangrove and seagrass, as overly aggressive mangrove planting (often driven by the desire to protect their homes from storm surges) tend to encroach on seagrass areas.
3. **Socioeconomic Benefits:** Mangrove forests and coral reefs (particularly inside Marine Protected Areas or MPAs) help maintain fish stocks through serving as nurseries. Rabbitfish, which used to be available seasonally, can now be fished throughout the year. Rabbitfish is a fish commonly eaten by Filipinos and is easily sellable on the market for a good price. In the past couple of years, mangrove forests and MPAs in Danajon Bank have also become eco-tourism attractions, drawing in mainly local tourists.
4. **Governance and Stakeholder Engagement:** While NbS paints a promising future for Danajon Bank, several challenges remain. Ecosystem-wide governance of Danajon is still nascent, with the capacity building

activities of the Bohol Council having been severely limited by the cancellation of the USAID-funded Protect Danajon Project which provided support especially for organizing training events and convening council meetings. Representatives of the Council emphasize the need for continuous capacity building as well as the guidance of experts with proper technical know-how of the local ecosystem to prevent the risk of maladaptation which could inadvertently lead to biodiversity loss. There is also a lack of an integrated approach to managing Danajon Bank across the provinces of Bohol, Leyte, Southern Leyte, and Cebu. This has led to a "tragedy of the commons" where the problems of overfishing, illegal fishing and decreasing fish stocks persist (Ortiz et al, 2023).

5. **Technical Feasibility:** The Bohol Provincial Environment Management Office as well as the Bohol Island State University, regularly monitor existing mangroves/corals and provide technical advice for new initiatives planned (e.g. artificial reefs) that support the decision-making of the Bohol Danajon Bank Management Council.

6. **Sustainability and Scalability:** For coral reefs, community-based marine protected areas (although pioneered and popularized by the Philippines) face growing resistance among small-scale fishing communities who are living in poverty, and who therefore could not afford to give up valuable fishing grounds. Recent monitoring results show coral reefs in many of the MPAs within Danajon Bank are now degraded. Meanwhile, for mangroves, the local government has recently passed the Provincial Ordinance No. 2025-005: Coastal Greenbelts of Bohol (with management plan and funding), which provides the institutional support for the expansion and maintenance of mangrove forests.

Figure 8. Batasan Island sits on a large reef in Danajon Bank. Batasan residents have been planting mangroves for decades used for, among other things, hiding their boats during storms. Source: Ervin Brian Sumalinog (2025).

Figure 9. Tidal flooding event during a king tide in July 2024 which completely inundated a small island in Danajon Bank. Source: Ervin Brian Sumalinog (2025)

Figure 10: Aftermath of Typhoon Odette in Pangapasan Island. Houses made of light materials have been swept away by storm surges. Source: Ervin Brian Sumalinog (2025).

3.4 Del Carmen Mangrove Restoration – Philippines

The Municipality of Del Carmen, located in Siargao Island, is a local leader in climate action (Fig. 11). In 2013 Del Carmen became one of the pilot sites of the Philippines Climate Change Commission's Ecotown Program, and in 2016 became one of the earliest to receive support from the People's Survival Fund for implementing the "Siargao Climate Field School for Farmers and Fisherfolks." It is also home to the Del Carmen Mangrove Reserve, the largest contiguous mangrove forest in the Philippines, with local communities proudly leading its protection and restoration.

Figure 11. The Municipality of Del Carmen in Siargao Island surrounded by large mangrove forests. Source: Ervin Brian Sumalinog (2025).

Still, in December 2021, Del Carmen suffered tremendously from strong storm surges generated by Typhoon Odette which made its first landfall in Siargao Island at category 5 super typhoon strength: thousands of families lost their homes and livelihoods, and all infrastructure was partially/completely damaged (Fig. 12). By 2100 sea level rise is projected to reach up to 1.36m under a very high emissions scenario (Fox-Kemper et al, 2021; Kopp et al, 2023; Garner et al 2021), drastically increasing storm surge risk. Considering the combined threat of sea level rise and storm surge in the future, the Municipality of Del Carmen committed to further improving mangrove protection and restoration along its coasts.

At the same time, the Municipality of Del Carmen is also driving up its mitigation efforts by exploring the possibility of participating in the carbon trading scheme through its mangrove forests. Recently, the local government launched its flagship program called the Blue Carbon Development Strategy which aims to increase carbon sequestration to engage in carbon trading and achieve zero emissions.

1. **Effectiveness in Risk Reduction:** The citizens of Del Carmen understand that the co-benefits of protecting their mangrove forests do not only extend to improving their livelihoods alone, but also to protecting their homes from the worst impacts of typhoons and storm surges. In the aftermath of Typhoon Odette, local communities shared how the mangrove forests noticeably reduced the strength of storm surges (Segales et al, 2024, Mangadlao, 2025).

2. **Ecological Integrity:** The Del Carmen Mangrove Reserve spans 4,871 hectares and hosts 27 out of 70 mangrove species. During World Wetlands Day in 2023, the Del Carmen Mangrove Reserve was recognized as a Wetland of International Importance and became part of the Ramsar List, an international registry of wetlands of global importance designated under the Ramsar Convention (1971).

3. **Socioeconomic Benefits:** In 2010, Del Carmen became known informally as the illegal mangrove cutting capital of the Philippines, where thousands of families living in extreme poverty have resorted to cutting mangroves and selling them as firewood to earn an income. Today, illegal loggers have now transitioned to become eco-tourism guides, boat operators, fishers, and forest caretakers. Local communities now also take charge of growing seedlings, planting mangroves and maintaining upkeep of the forests.

4. **Governance and Stakeholder Management:** To encourage behavior change and promote conservation over exploitation, the local government of Del Carmen used the bridging leadership framework (Garilao, 2007), which encouraged the community to own the issues and potential impact that come along with mangrove exploitation (ownership), helped the people understand that it is both the government's and the communities' responsibility to restore and protect the mangroves (co-ownership), and consequently strengthened their capacity to co-create the solutions in the pursuit of mangrove protection and conservation (co-creation).

5. **Technical Feasibility:** The Municipality of Del Carmen works with various organizations including the International Council for Local Environmental Initiatives (ICLEI) Southeast Asia in monitoring existing mangrove forests and guiding the planning/planting of additional hectares. The municipality’s Environment and

Natural Resources Office in particular has established partnerships with various NGOs and is driving local advocacy campaigns and implementing participatory conservation approaches.

6. **Sustainability and Scalability:** Local Government Unit Del Carmen is harmonizing its Local Climate Change Action Plan as well as Climate and Disaster Risk Assessment, with its Disaster Risk Reduction/Climate Change Adaptation-enhanced Comprehensive Land Use Plan and Comprehensive Development Plan, to ensure the sustainability of mangrove protection and restoration efforts amidst climate change threats.

Figure 12. Del Carmen before and after Typhoon Odette. Source: Philippine Space Agency.

4 Cross-Cutting Lessons

The four case studies presented in this communication reveal a set of recurring lessons that highlight both the potential and limitations of NbS for coastal flood protection. First and foremost, context matters. The effectiveness of NbS is deeply dependent on site-specific ecological and socio-economic conditions. The lessons learned are the following:

1. **Effectiveness in Risk Reduction:** Across the four cases, NbS demonstrated measurable contributions to reducing coastal hazards, but effectiveness was uneven and context dependent. In Grenada, hybrid breakwaters exhibited potential in attenuating wave energy and mitigating shoreline erosion, while in Suriname, sediment trapping units were only effective where natural sediment supply was sufficient. In the Philippines, mangroves offered locally perceived storm protection, whereas coral reefs, though crucial both ecologically and for wave attenuation, were less recognized by communities as protective. These differences highlight the importance of tailoring interventions to site-specific hazard dynamics and ensuring that ecological functions are translated into tangible risk reduction outcomes for local populations.

2. **Ecological Integrity:** Maintaining or restoring ecological processes was central to long-term project success. Grenada's ridge-to-reef approach addressed land-sea ecological linkages, while Suriname's interventions promoted mangrove recolonization. In Del Carmen, protecting one of the country's largest mangrove reserves safeguarded species diversity and earned international recognition. However, cases also revealed risks of maladaptation, such as limited understanding of how local ecosystems function. These examples underscore that NbS must be grounded in sound ecological science, with careful attention to species selection, ecological connectivity, and cumulative impacts.

3. **Socioeconomic Benefits:** All projects generated socioeconomic co-benefits, although their distribution varied. In Grenada and Del Carmen, NbS created jobs, supported fisheries, and stimulated ecotourism. In Danajon Bank, mangrove and reef restoration contributed to food security by sustaining fish stocks and enabling year-round harvests. In Suriname, NbS interventions protected agricultural lands from salinization, although climate variability challenged these benefits. Collectively, these cases confirm that NbS can strengthen livelihoods, but outcomes depend on sustained management and alignment with community needs.

4. **Governance and Stakeholder Engagement:** Effective governance and inclusive participation emerged as decisive factors. Grenada integrated national agencies, NGOs, and fishers into decision-making and maintenance, while Del Carmen adopted a co-creation model that transformed loggers into stewards. In contrast, Danajon Bank revealed persistent governance gaps, with fragmented jurisdiction across provinces limiting ecosystem-scale management. These experiences demonstrate that besides local ownership, durable governance frameworks and alignment of legal mandates are essential for ensuring legitimacy and continuity of NbS.
5. **Technical Feasibility:** Projects confirmed that feasibility relies on design suitability and local capacity. Modular breakwater units in Grenada and low-cost sediment traps in Suriname illustrate technically adaptable solutions that respond to local hydrodynamics and resource constraints. In the Philippines, continuous technical support from universities and government agencies strengthened implementation. However, site-specific limitations such as insufficient sediment supply in Suriname and limited enforcement in community-based marine protected areas in Danajon Bank illustrate the risks of inadequate technical fit. Feasibility therefore requires both robust site assessments and sustained technical capacity.
6. **Sustainability and Scalability:** Long-term sustainability remained a challenge across all sites. In Grenada and Suriname, projects stalled or remained at pilot scale due to funding gaps and political discontinuities. In contrast, Del Carmen leveraged strong local leadership to harmonize mangrove protection with land-use planning and climate policies, and to secure financing through blue carbon initiatives. Experiences in Danajon Bank also show that scaling NbS requires overcoming community resistance where poverty limits conservation trade-offs. The lessons indicate that sustainability depends on continuous financing, adaptive management, and embedding NbS in formal policy and planning frameworks, while scalability requires transferability of both ecological techniques and governance models.

5 Conclusion and Global Relevance

The case studies examined in this communication demonstrate that NbS can deliver meaningful contributions to reduce coastal hazards and generate co-benefits for biodiversity and livelihoods when designed with sensitivity to local ecologies and social and institutional capacities. However, their ability to prevent coastal flooding outright is context-dependent and, in some settings, inherently limited. The performance of the four case studies illustrates that NbS are highly site-specific and vulnerable to external stressors such as ecological disruption, governance fragmentation, and inconsistent funding.

Across all cases, success was most evident where:

1. Ecological suitability was matched with targeted interventions.
2. Governance arrangements provided continuity and cross-sector coordination.
3. Community participation ensured local ownership and maintenance capacity.
4. Hybrid designs balanced immediate physical protection with long-term ecosystem recovery.
5. Sustainability measures secured financing and institutional mandates beyond pilot phases.
6. Risk management accounted for both ecological and socio-economic dimensions of vulnerability.

Globally, these insights are especially relevant for low-lying coastal regions and SIDS facing intensified climate risks and growing pressure to adopt more sustainable and inclusive adaptation strategies. The lessons from the Caribbean and the Philippines underscore the necessity of integrating NbS into broader regional and national adaptation frameworks, supported by participatory governance, long-term financing, and scientific monitoring, to ensure long-term resilience outcomes.

As climate change accelerates, the global adaptation agenda must move beyond showcasing pilot projects toward scaling NbS. The experiences documented here provide practical reference points for practitioners, policymakers, and funders seeking to operationalize climate resilience at the interface of land and sea. They reaffirm the potential of NbS not as stand-alone fixes but as components of adaptive and context-responsive strategies for coastal protection in a rapidly changing world.

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Data access statement

Data will be made available on reasonable request.

Declaration of interests

The author reports no conflict of interest.

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