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Coastal Erosion Mitigation in Saint-Louis, Senegal: Evaluating the Effectiveness of "Typhavelles", a Nature-Based Solution

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Abstract

Coastal erosion poses a major threat to low-elevation coastal zones such as Saint-Louis in Senegal, where rapid shoreline retreat has led to community displacement and infrastructure degradation. To address this challenge, nature-based solutions (NbS) have been deployed within the Saint-Louis Marine Protected Area (MPA), notably the installation of "Typhavelles" structures made from *Typha australis* designed to promote dune formation and reduce erosion. This study assesses the effectiveness of "Typhavelles" using field data collected from 2019 to 2022, complemented by diachronic satellite imagery analysis. Results indicate a notable increase in beach width and dune development across the majority of monitored profiles. Shoreline change analysis reveals a dramatic shift from severe erosion (up to −94.5 m/year between 2017 and 2019) to significant accretion, reaching up to +136 m/year during the 2019-2021 period following the installation of the "Typhavelles". These findings demonstrate that "Typhavelles" are effective in trapping sediment and stabilizing the coastline. However, their long-term viability may be compromised by sea level rise, sediment supply limitations, maintenance needs, and material biodegradation. The study highlights the promise of bio-inspired NbS for coastal protection and recommends enhancing "Typhavelles" durability through protective treatments to support broader replication in similar vulnerable coastal zones.

Keywords

Costal Erosion, MPA, Nature-Based Solutions, "Typhavelles"

1. Introduction

Coastal erosion is a big concern in many parts of the world, particularly in coastal lowland regions that are vulnerable to sea-level rise, extreme weather events, and anthropogenic pressures. In West Africa, Senegal's coastline has been severely impacted by erosion, endangering marine ecosystems and the livelihoods of coastal communities (Diop et al., 2021; Diouf et al., 2025). The city of Saint-Louis, located at the mouth of the Senegal River, is particularly vulnerable due to its geographic position and the dynamic nature of its coastal environment. Over the past decades, shoreline retreat in the Saint-Louis region has accelerated, leading to the displacement of thousands of people and the loss of vital infrastructure (Sy et al., 2018).

In response to these challenges, nature-based solutions (NbS) have been increasingly recognized as effective and sustainable approaches to coastal protection (Narayan et al., 2016a). These solutions integrate natural processes and ecosystems to enhance coastal resilience while providing ecological and socio-economic benefits. In Saint-Louis, one such NbS involves the use of "Typhavelles", structures constructed from the invasive aquatic plant *Typha australis*. These structures function by trapping wind-blown sand, promoting dune stabilization, and acting as a natural buffer against coastal erosion (Fall et al., 2022).

The implementation of "Typhavelles" within the Saint-Louis Marine Protected Area (MPA) has been part of a broader strategy to restore coastal ecosystems and mitigate erosion. Studies indicate that these bio-structures not only help in dune formation but also contribute to biodiversity conservation by creating habitats for local flora and fauna (Rocle et al., 2020). Additionally, the integration of local communities in the construction and maintenance of "Typhavelles" has strengthened their resilience by providing employment opportunities and promoting sustainable coastal management practices (UNEP, 2021).

Recent research and initiatives, such as the Sustainable Ecosystem-Based Adaptation Solutions (SEDAD) project, have demonstrated the importance of knowledge exchange and collaborative efforts in enhancing the effectiveness of NbS (PRCM, 2023). Case studies from Senegal, The Gambia, and Mauritania have shown that well-managed NbS can provide long-term benefits in mitigating coastal erosion, improving ecosystem health, and strengthening local governance structures (FFEM, 2022).

This paper assesses the effectiveness of "Typhavelles" as a nature-based solution (NbS) for mitigating coastal erosion within the Saint-Louis Marine Protected Area (MPA). It evaluates their capacity to promote dune formation through the analysis of recent field data and satellite imagery. By contributing to the broader discourse on sustainable coastal management, we aim to discuss both the benefits and limitations of such bio-inspired approaches.

2. Material and Methods

2.1. Experimental Area

The experimental site is the Saint-Louis Marine Protected Area (MPA), located

on the northwestern coast of Senegal (Figure 1). This MPA is playing a vital role in the conservation of marine biodiversity and the sustainable development of local communities. Established in 2004, the MPA spans approximately 49,600 hectares and is managed under an ecosystem-based approach that seeks to balance environmental preservation with the improvement of socio-economic conditions for coastal populations. Despite its ecological and socio-economic significance, the MPA faces multiple pressures that compromise its long-term ability to maintain essential ecological and economic functions. One of the most critical threats is coastal erosion, exacerbated by rising sea levels and the increasing frequency of extreme storm events. In 2003, the creation of an artificial breach in the Langue de Barbarie, initially intended to mitigate flooding, significantly altered the region's coastal dynamics. Originally measuring just 4 meters wide, the breach has since expanded to over 6 kilometers, resulting in severe erosion of several fishing such as Doun Baba Dièye village and the destruction of key tourism infrastructure (Sagna et al., 2021; Sy et al., 2022).

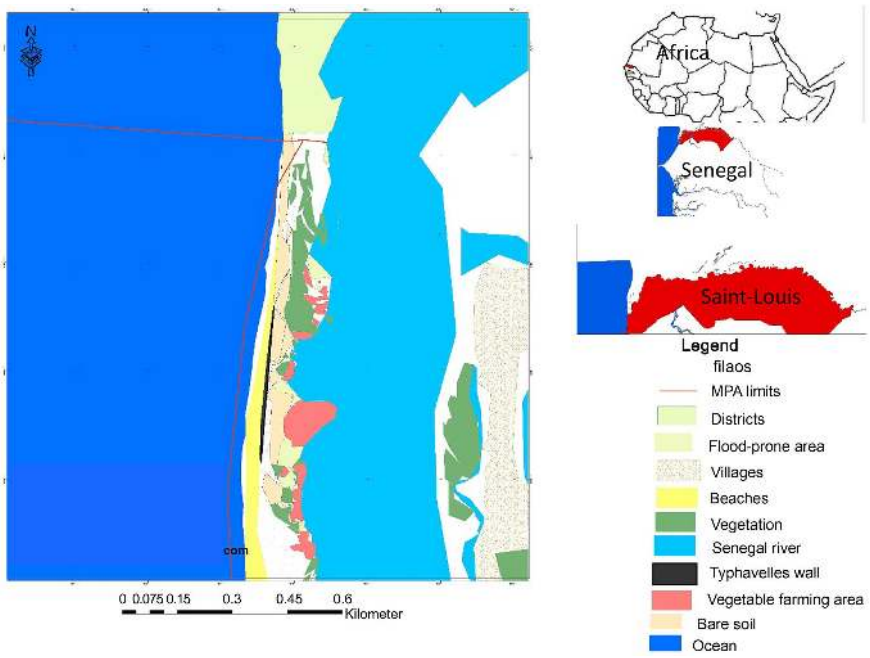


Figure 1. Localisation the Saint-Louis MPA.

2.2. Experimental Setup

"Typhavelles" are plant-based structures used as a nature-based solution to combat coastal erosion, particularly in sandy areas. They are made from *Typha australis*, an invasive aquatic plant that is abundant in Senegal's wetlands. As part of this study, the construction of the "Typhavelles" followed a number of specific steps. This experiment was funded by the FFEM (French Fund for Environment) as part of a project aimed at combating coastal erosion in Senegal. The word "Typhavelles" was inspired by the term "Ganivelle" which refers to a traditional fence made of vertical wooden slats connected by galvanized wire.

2.2.1. Harvesting of Typha (*Typha australis*)

The process begins with the manual harvesting of the typha plant in the Senegal River Delta. This operation is generally carried out by local communities using machetes or sickles. Only the longest and most resilient stems are selected.

2.2.2. Drying of the Stems

The harvested stems are then sun-dried for several days to reduce their moisture content, which improves their durability and resistance to decomposition. This drying process is essential to ensure the stability of the structures once installed in coastal environments.

2.2.3. Construction of the "Typhavelles"

Once the stems are dried, they are assembled into fascines, bundles of typha tied together using ropes. These fascines typically measure 2 meters in length, 1 meter in height, and 25 centimeters in diameter (**Figure 2**).



Figure 2. Structure of the "Typhavelles".

2.2.4. Installation of the "Typhavelles"

The "Typhavelles" were positioned in a northwest direction, 60 meters from the sea. Rectangular enclosures measuring 8 meters in length and 2 meters in width were installed over a distance of 1.5 km (**Figure 1** and **Figure 3**). For each "Typhavelles" enclosure, 10 typha fences and 10 wooden stakes were required. It's worth to highlight that the "Typhavelles" were installed in the most vulnerable part of the MPA.

2.2.5. Monitoring System

After the installation of the "Typhavelles" in June 2019, a monitoring system was set up. This system involved measuring a number of parameters along eight profiles positioned along the "Typhavelles" barrier, over the period from June 2019 to August 2022 (**Figure 4**). It is important to emphasize that monitoring commenced in June for Profile 1 through 4, whereas for the remaining, it began in November. The parameters measured in metric units were: beach width (W_b), free height without sand behind the "Typhavelles" (H_{fwsb}) and free height without sand in front of the "Typhavelles" (H_{fwsf}).

In addition to these data, satellite imagery was used to monitor shoreline changes over time. Landsat images with a spatial resolution of 30 meters were an-

alyzed, focusing on two distinct timeframes: two years before (2017-2019) and two years after (2019-2021) the installation of the "Typhavelles". To determine shoreline evolution, the ArcGIS software and its Digital Shoreline Analysis System (DSAS 5.2) extension were employed. This tool enabled the calculation of shoreline change metrics such as End Point Rate (EPR) and Net Shoreline Movement (NSM), helping to evaluate the impact of the "Typhavelles" on coastal dynamics (Thior et al., 2019).



Figure 3. "Typhavelles" wall.



Figure 4. Monitoring stations along the "Typhavelles" in the Saint-Louis MPA.

3. Results

3.1. Evolution of "Typhavelles" Height

Figure 5 shows the temporal evolution of the free height in front (H_{fwsf}) and be-

hind (H_{fwsb}) the "Typhavelles", across eight monitored profiles.

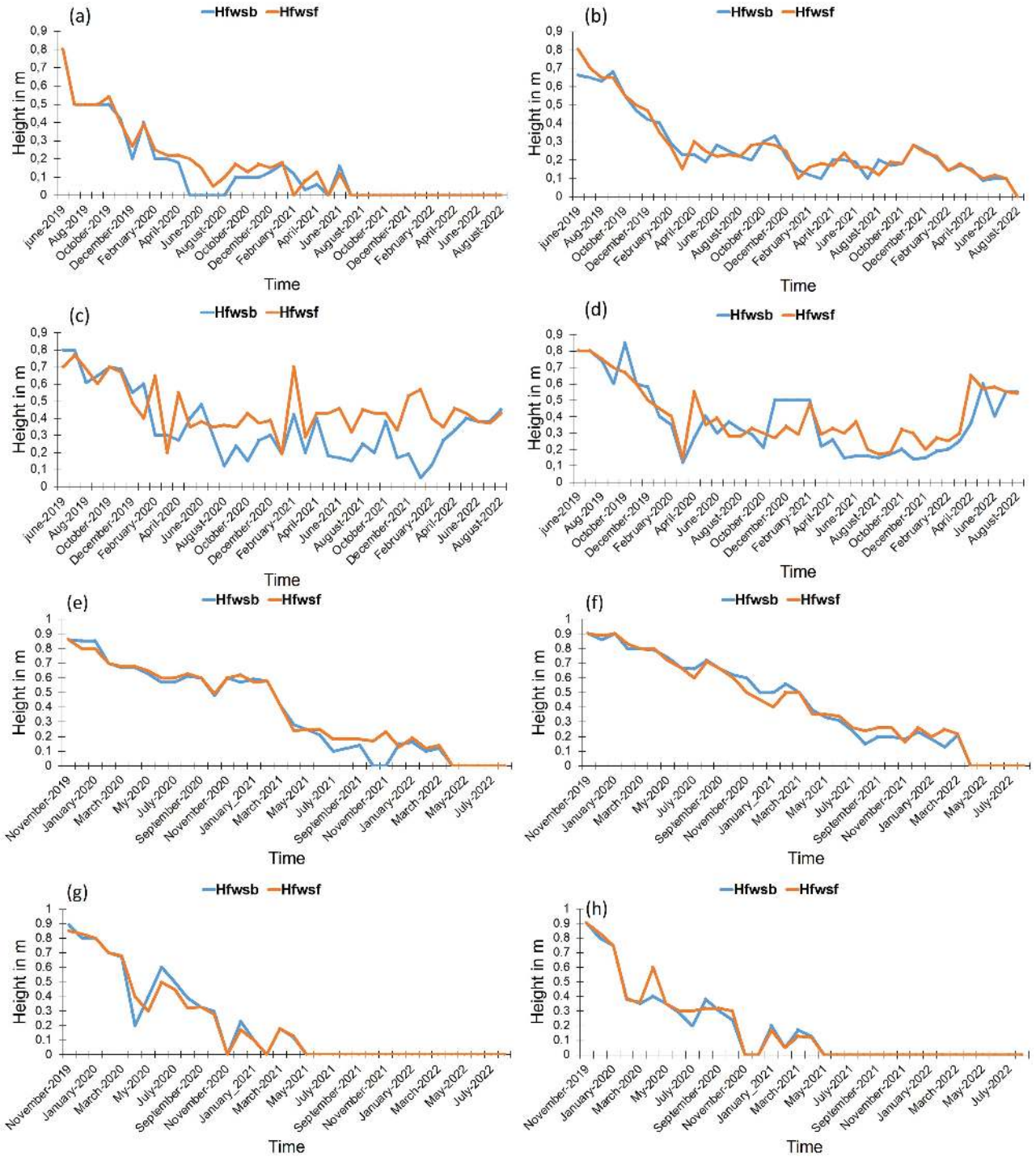


Figure 5. Temporal evolution of free height in front (Hfwsb) and behind (Hfwsf) the "Typhavelles" across eight monitoring profiles in the Saint-Louis Marine Protected Area (MPA): (a) Profile 1, (b) Profile 2, (c) Profile 3, (d) Profile 4, (e) Profile 5, (f) Profile 6, (g) Profile 7 and (h) Profile 8.

Profiles 1, 2, 5, 6, 7, and 8 exhibit a clear trend of progressive reduction in both H_{fwsf} and H_{fwsb}, reaching values close to or equal to zero by the end of 2021. This

pattern indicates a complete sediment infill of the compartments. In contrast, Profiles 3 and 4 are characterized by irregular fluctuations in free water heights over time, with no clear trend toward full infill. Notably, H_{fwsf} and H_{fwsb} in these profiles sometimes show opposing variations. Profiles 7 and 8 achieved full infill in record time, within less than one year, compared to the other profiles.

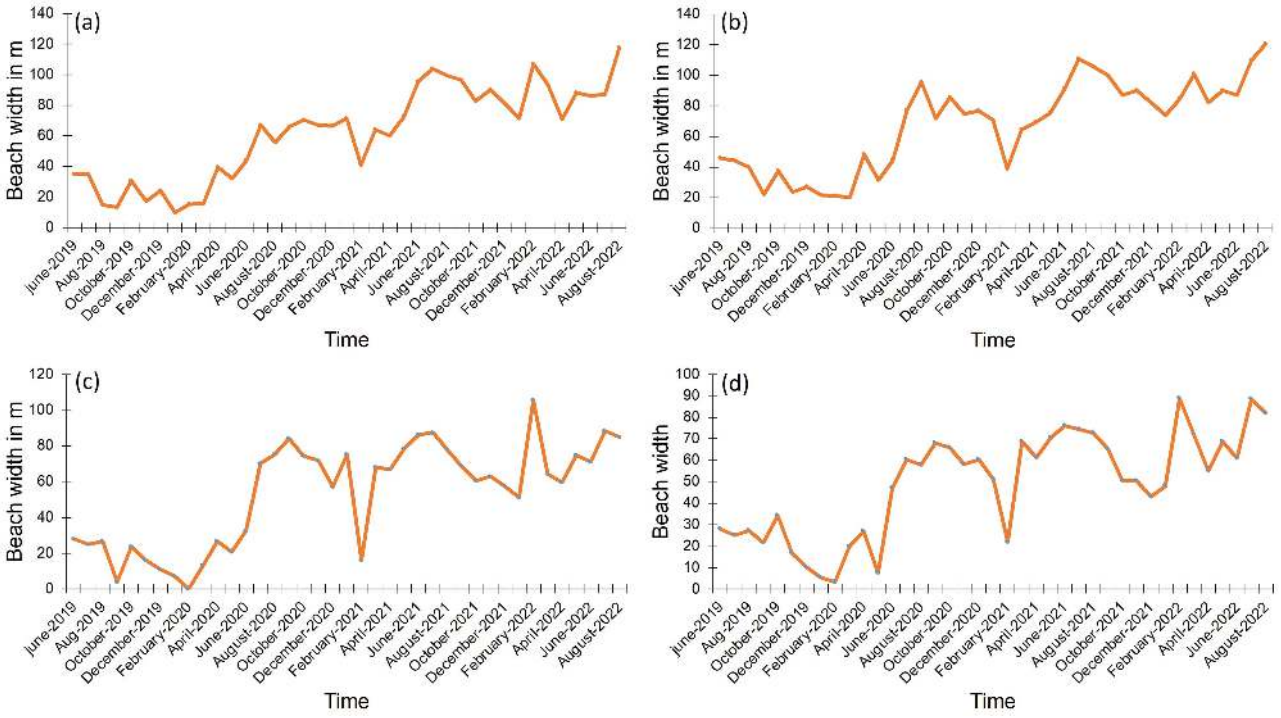
3.2. Evolution of Beach Width

Figure 6 illustrates the variations in beach width across all profiles between June 2019 and August 2022. It reveals a general trend of increasing beach width, particularly pronounced from 2020 onward, with values reaching or exceeding 120 meters for the majority of profiles. Profiles 1, 2, 7, and 8 stand out with a steady and sustained increase in beach width. Profile 8, in particular, reached values close to 160 meters by 2022. In contrast, Profiles 3 and 6 display greater temporal variability, while Profiles 4 and 5 show alternating phases of expansion and regression.

3.3. Evolution of Beach Width before and after "Typhavelles" Installation

3.3.1. Upstream of the "Typhavelles" Area

The area located upstream of the "Typhavelles" exhibited a general trend of erosion during the 2017-2019 period (Figure 7). This erosion was particularly pronounced near the "Typhavelles", where shoreline retreat reached approximately 80 meters. However, in the two years following the installation of the "Typhavelles" (2019-2021), this erosive trend appears to have diminished, with accretion observed in the vicinity of the structures (Figure 8).



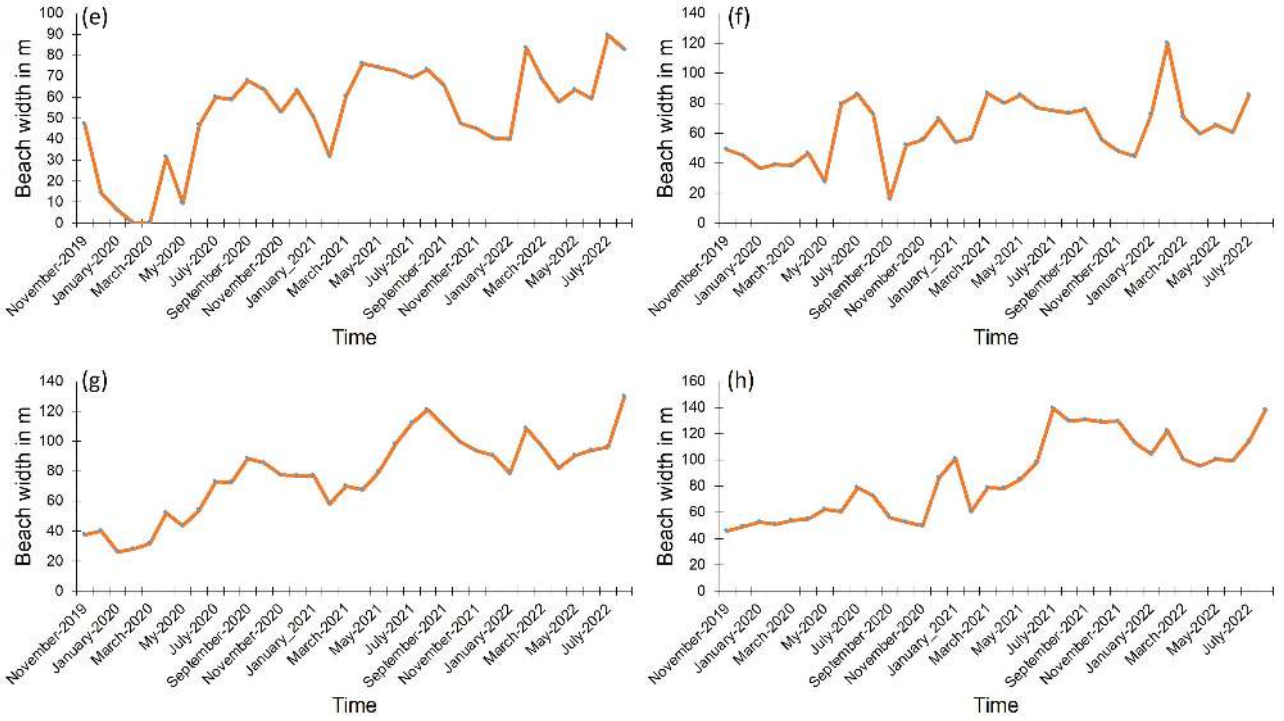


Figure 6. Temporal evolution of beach width across eight monitoring profiles in the Saint-Louis Marine Protected Area (MPA): (a) Profile 1, (b) Profile 2, (c) Profile 3, (d) Profile 4, (e) Profile 5, (f) Profile 6, (g) Profile 7 and (h) Profile 8.

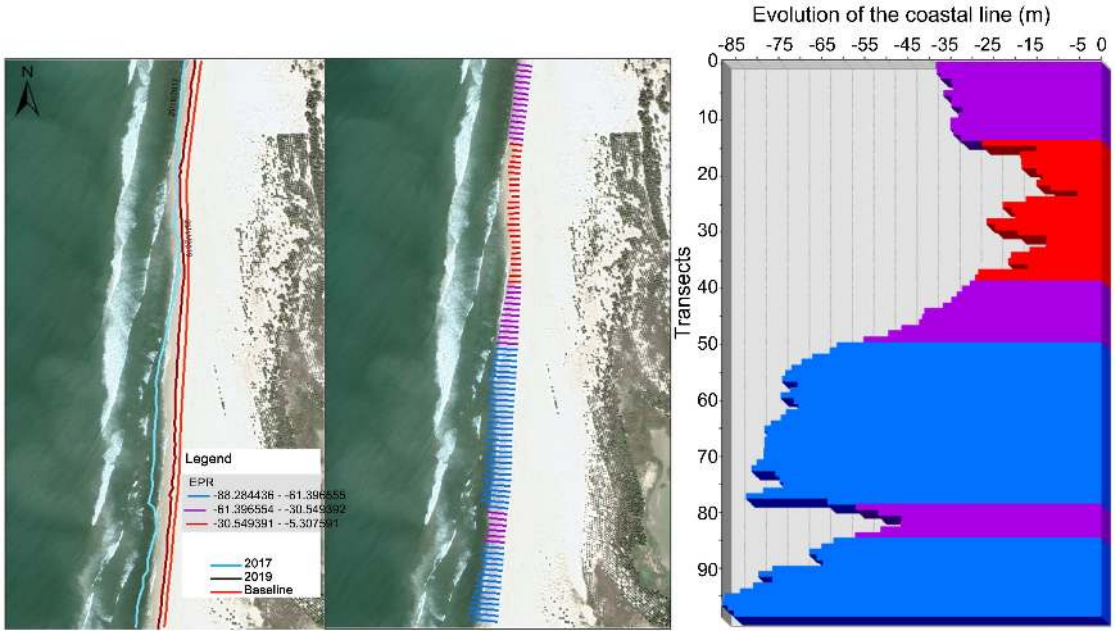


Figure 7. Shoreline evolution in the upstream area two years (2017-2019) before the installation of "Typhavelles".

3.3.2. Within the "Typhavelles" Area

Between 2017 and 2019, two years prior to the installation of the "Typhavelles", the study area experienced intense and widespread erosion, with retreat rates reaching up to −189 meters over two years (i.e., an average annual rate of −94.5 m/year) (**Figure 9**). The erosion was most severe in the northern sector (up to 94

m/year), moderate to high in the central part, and relatively less pronounced in the south, where retreat averaged around 44 m/year.

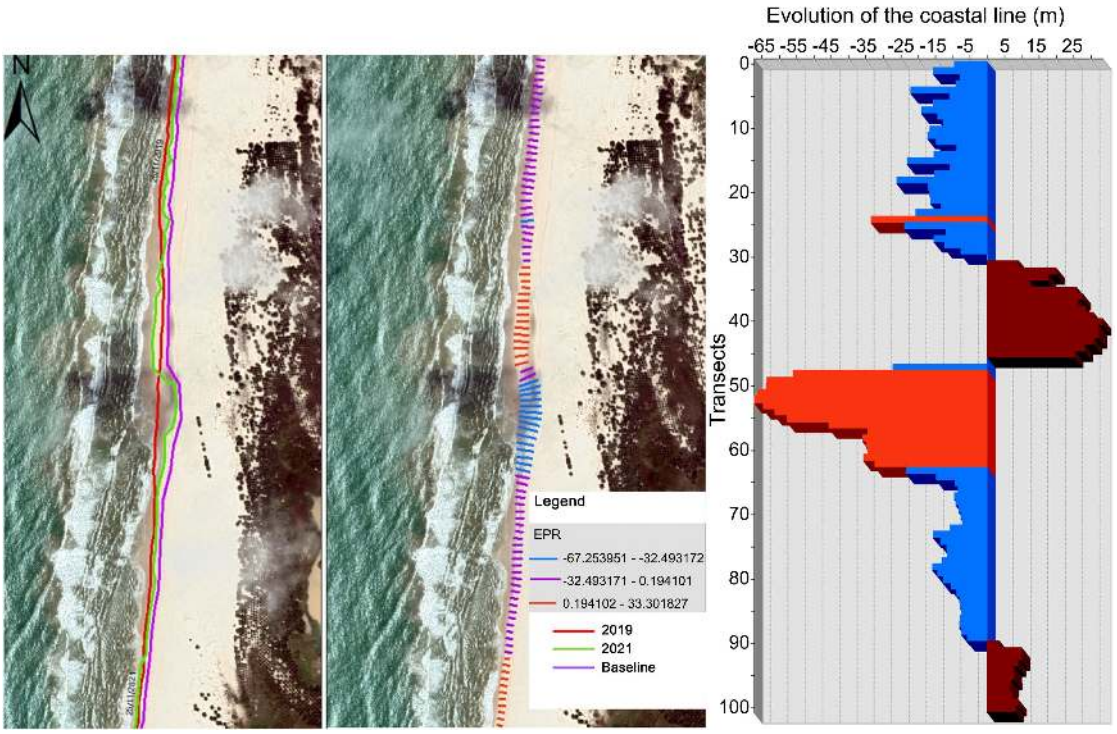


Figure 8. Shoreline evolution in the upstream area two years (2019-2021) after the installation of "Typhavelles".

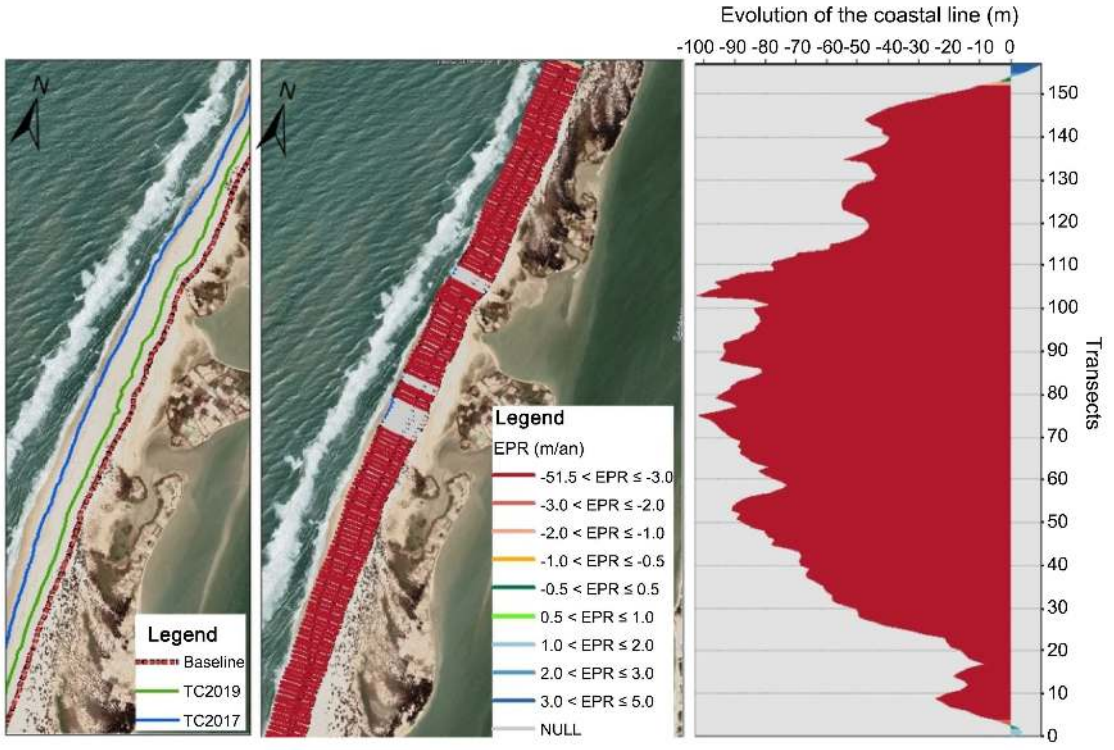


Figure 9. Shoreline evolution two years (2017-2019) before installation of "Typhavelles".

In contrast, the 2019-2021 period, two years after the installation of the "Typhavelles", reveals a clear reversal of the previous trend observed between 2017-2019 two prior the "Typhavelles" installation (Figure 10). A generalized accretion is observed throughout the "Typhavelles" zone, with the southern sector showing the most pronounced growth, recording sediment gains exceeding 136 m/year.

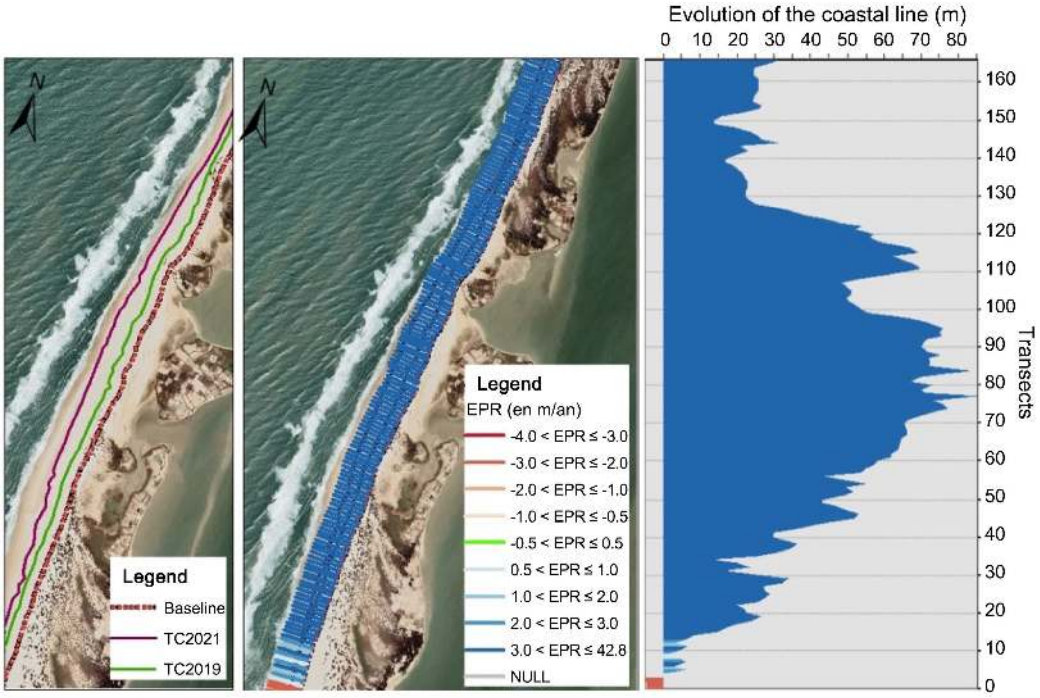


Figure 10. Shoreline evolution two years (2019-2021) after installation of "Typhavelles".

3.3.3. Downstream of the "Typhavelles" Area

Two years prior to the installation of the "Typhavelles" (2017-2019), the downstream area was marked by a regressive trend in its northern part, while accretion occurred in the southern sector (Figure 11). In contrast, this pattern reversed during the 2019-2021 period, two years (2019-2021) after the "Typhavelles" were implemented (Figure 12). In other words, accretion is now observed in the area adjacent to the "Typhavelles", whereas erosion is affecting the more distant sections.

4. Discussion

4.1. Effectiveness of the "Typhavelles"

This study clearly demonstrates the effectiveness of the "Typhavelles" as a nature-based coastal protection solution. Their implementation aligns with global efforts to promote nature-based solutions (NbS) in climate adaptation strategies (Seddon et al., 2020). The progressive reduction in free height in front and behind the "Typhavelles" is indicative of active sediment trapping and gradual infill of the compartments (Figure 13). This dynamic aligns with the principles of low-crested, porous structures, which aim to dissipate wave energy while allowing for sediment deposition (Burcharth et al., 2007; Zanuttigh & van der Meer, 2008).

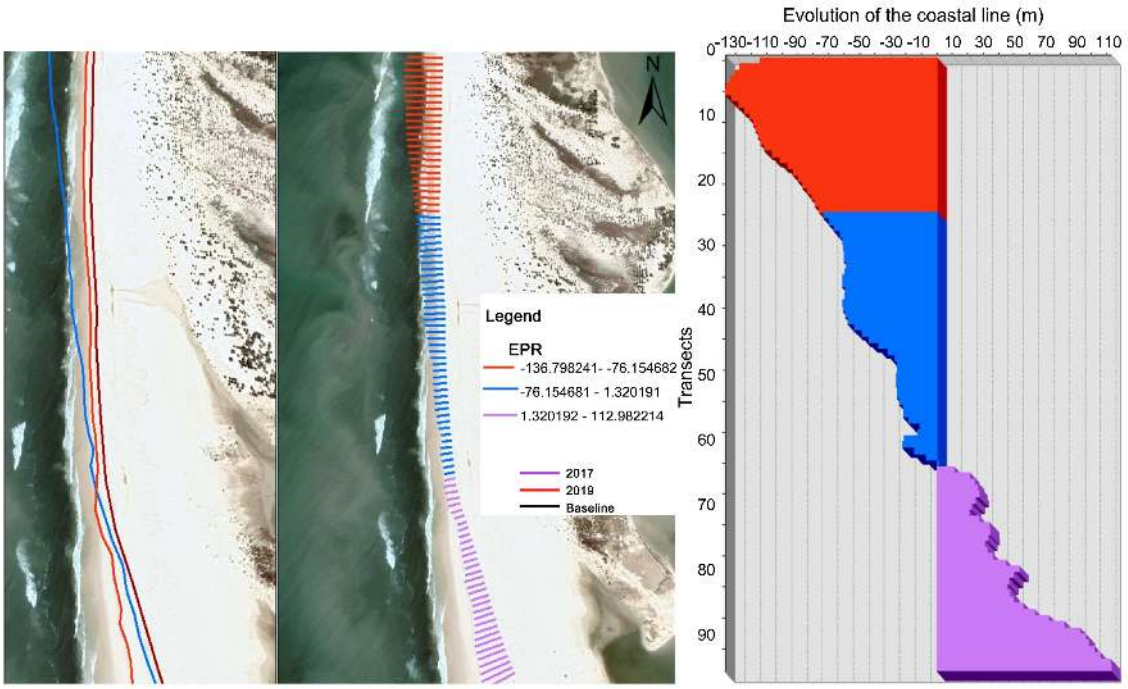


Figure 11. Shoreline evolution in the downstream area two years (2017-2019) before the installation of "Typhavelles".

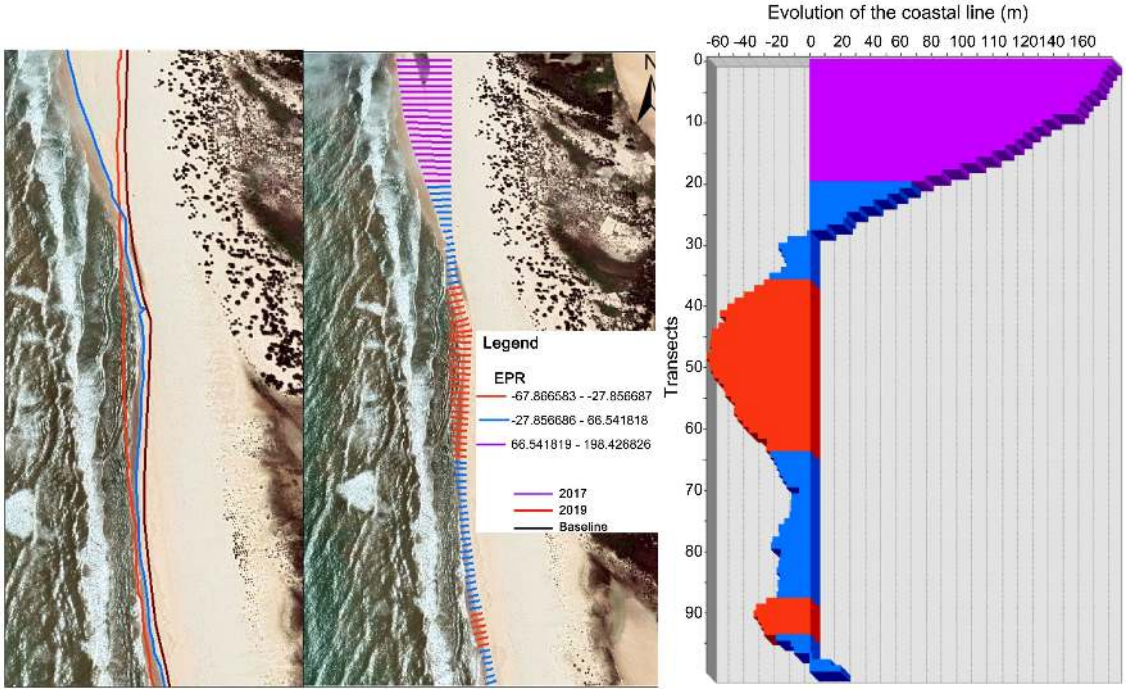


Figure 12. Shoreline evolution in the downstream area two years (2017-2019) before the installation of "Typhavelles".

The expansion of beach width observed between 2019 and 2022 confirms the success of the "Typhavelles". This extension is not only indicative of accretion but also provides critical ecosystem and socio-economic co-benefits, such as increased

storm-buffering capacity and improved conditions for local livelihoods (Arkema et al., 2013; Narayan et al., 2016b).



Figure 13. Image showing "Typhavelles" traps filled with sediment.

Importantly, the comparison of pre-installation and post-installation shoreline dynamics provides compelling evidence. The study area experienced severe erosion between 2017 and 2019, with rates exceeding −94 m/year in some sectors before implementation of the "Typhavelles". Two years after the deployment of the "Typhavelles", the trend reversed dramatically, with accretion surpassing 136 m/year in the most dynamic zones. Such a shift over a short period strongly supports the hypothesis that well-designed, bio-inspired coastal infrastructure can rapidly stabilize eroding shorelines (Pontee et al., 2016; Firth et al., 2020).

4.2. Limitations of "Typhavelles" as a Nature-Based Solution

While the "Typhavelles" demonstrate significant potential as a nature-based solution (NbS) for shoreline stabilization and sediment retention, several limitations must be considered to fully assess their effectiveness. In fact, the "Typhavelles", even if effective at trapping sediments do not eliminate the root causes of erosion, such as coastal squeeze, relative sea-level rise, or upstream sediment disruption (Schuerch et al., 2018). Their functionality could therefore be compromised in the long term if broader sedimentary inputs continue to decline or if sea-level rise outpaces their accretion capacity. Although designed to be permeable and biocompatible, they remain artificial structures that may interfere with natural coastal dynamics over time. For instance, they may redirect flows, creating unintended erosion zones downstream or altering sediment budgets along adjacent coastlines (Pontee et al., 2016). Moreover, as with many NbS, maintenance and adaptive management are often underprioritized. The longevity and continued effectiveness of "Typhavelles" may require periodic repositioning, reinforcement, or even removal in case of system failure or ecological conflict. This can challenge the notion that NbS are inherently low-maintenance solutions (Seddon et al., 2020). An important characteristic of the "Typhavelles" is their biodegradable

character, which aligns with the core principles of nature-based solutions by minimizing long-term environmental footprints. Constructed from natural fibers and materials, these structures are designed to gradually decompose within the environment (Firth et al., 2020; Seddon et al., 2020).

5. Conclusion

This study shows that "Typhavelles", as nature-based solutions to combat coastal erosion, have a positive impact in Saint-Louis MPA, Senegal. They promote sand accumulation and dune stabilization, leading to beach widening and a reduction in erosion. However, these structures need to be accompanied by proper maintenance and management to remain effective, especially in the face of sea-level rise and other environmental pressures. "Typhavelles" offer a sustainable and innovative approach to coastal protection in an ecological manner, but their long-term success depends on their improvement and collaboration with local communities. This initiative could serve as a model for other vulnerable regions in West Africa.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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