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ORIGINAL RESEARCH

Historical shoreline analysis in selected areas on the east coast of Albay, Philippines

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ABSTRACT. Shoreline erosion in the Province of Albay, Philippines, remains unmonitored, creating significant vulnerability to natural and anthropogenic drivers. Effective monitoring of coastal integrity is crucial to provide valuable insights into shoreline alterations that can guide future adaptation measures and support climate resilience planning. This study aimed to assess shoreline alterations over the past 20 years by examining natural and anthropogenic drivers shaping these changes and their implications for coastal ecosystems. Erosive trends have resulted in the loss of up to 6 m of coastline in certain places in the cities of Santo Domingo, Bacacay, Malilipot, Legazpi, and Tabaco. Findings revealed that areas distant from river mouths exhibited severe erosion, while those near river mouths showed mixed erosion and deposition patterns. Natural processes, including storm surges and sediment transport, were compounded by human activities such as sand mining, urban expansion, and coastal road constructions, resulting in the degradation, fragmentation and loss of vital coastal ecosystems. These insights underscore the urgent need for systematic shoreline monitoring and the adoption of sustainable coastal management practices, as well as integrating environmental considerations into coastal development planning, enhancing community awareness, and leveraging monitoring data to inform climate resilience and adaptation strategies tailored to local contexts.

Key words: Coastal erosion monitoring, shoreline alterations, sustainable coastal development, climate resilience planning.

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Análisis histórico de la línea costera en áreas seleccionadas de la costa este de Albay, Filipinas

RESUMEN. La erosión de la costa en la Provincia de Albay, Filipinas, sigue sin ser monitoreada, lo que genera una vulnerabilidad significativa a los factores naturales y antropogénicos. El monitoreo efectivo de la integridad costera es crucial para proporcionar información valiosa sobre las alteraciones de la costa que puedan orientar las futuras medidas de adaptación y respaldar la planificación de la resiliencia climática. Este estudio tuvo como objetivo evaluar las alteraciones de la costa en los últimos 20 años, examinando los factores naturales y antropogénicos que dan forma a estos cambios y sus implicaciones para los ecosistemas costeros. Los resultados indicaron cambios significativos en la costa en las ciudades de Santo Domingo, Bacacay, Malilipot, Legazpi y Tabaco, donde las tendencias erosivas han resultado en una pérdida de hasta 6 m de costa en algunas áreas. Los hallazgos revelaron que las áreas distantes de las desembocaduras de los ríos exhibieron una erosión severa, mientras que las cercanas a las desembocaduras de los ríos mostraron patrones mixtos de erosión y deposición. Los procesos naturales, incluidas las mareas de tormenta y el transporte de sedimentos, se vieron agravados por actividades humanas como la extracción de arena, la expansión urbana y la construcción de carreteras costeras, lo que resultó en la degradación, fragmentación y pérdida de ecosistemas costeros vitales. Estos conocimientos subrayan la necesidad urgente de un monitoreo sistemático de las costas y la adopción de prácticas de gestión costera sostenible, así como de integrar

consideraciones ambientales en la planificación del desarrollo costero, mejorar la conciencia de la comunidad y aprovechar los datos de monitoreo para informar estrategias de resiliencia y adaptación climática adaptadas a los contextos locales.

Palabras clave: Monitoreo de la erosión costera, alteraciones de la línea de costa, desarrollo costero sostenible, planificación de la resiliencia climática.

INTRODUCTION

The beaches of Albay, Philippines, are predominantly composed of siliciclastic materials, largely supplied by deposits from Mount Mayon. In contrast, coasts of island areas or villages or barrios (*barangays*) are primarily composed of carbonate reef materials, except in areas near river mouths. Despite lava deposits from Mount Mayon and the unique climatic and monsoonal influences affecting the eastern and western coasts of Albay, the region generally benefits from an abundant supply of sediments (Arguden 1989; Rodolfo and Arguden 1991), which may exceed the capacity of waves and currents to transport and redistribute them. This natural surplus of sediments has also limited the formation of well-established fringing reefs along the mainland coastline of Albay (Risk and Edinger 2011). However, the ongoing development of coastal areas, driven by the expansion of housing, commercial establishments and road infrastructure, has disrupted natural coastal processes such as erosion and accretion (He et al. 2014; Huang 2022). These geomorphological processes, though constant, have been overlooked, particularly their potential impacts on built structures like dikes, seawalls, pavements, and residential and commercial buildings near the shore (Ismail and El-Sayed 2011; Hines et al. 2012; Huang 2022). Furthermore, coastal erosion remains poorly documented and monitored in Albay, leaving its implications for infrastructure and communities underexplored (Angnuureng et al. 2023; Siringan and Sta Maria 2024). This problem is exacerbated by the impact of intense quarrying activities in the region, which significantly impair the natural supply of sediments to coastal areas that would otherwise contribute to beach accretion, disrupting the delicate balance between sediment deposition and erosion. As sediment supply diminishes, coastal areas become more vulnerable to erosive forces, exacerbating shoreline retreat and threatening coastal habitats and infrastructure (Magooon et al. 2001; Preoteasa et al. 2016; Vousdoukas et al. 2020). This interplay between human activities and natural processes highlights the urgent need for effective sediment management and erosion monitoring to mitigate long-term impacts on the coastal stability of Albay. This lack of data hinders informed planning and climate change adaptation measures, which are critical in a region frequently impacted by typhoons and monsoonal. Addressing these gaps requires a comprehensive approach combining geomorphological data with sociological insights to capture the multifaceted impacts of coastal development. Effective monitoring of coastal integrity is essential, as it provides valuable data on shoreline dynamics that can inform future planning and the design of climate change adaptation strategies. The inclusion of surveys and interviews in this study allowed for integrating local perceptions and experiences, providing critical insights into how coastal changes and development are perceived and managed by communities. Previous studies underscore the importance of community engagement in coastal management to ensure effective and inclusive adaptation strategies (Roca and Villares 2012; Fletcher et al. 2014). Surveys and interviews offer a means to capture this human dimension, complementing physical data and enriching the overall analysis.

Thus, this study aimed to assess the geomorphological characteristics of the shoreline and sociological factors influencing the coastal development

of Albay. It also evaluated the impacts of infrastructure on erosion patterns, with the ultimate goal of contributing to climate change adaptation policies and the development of comprehensive coastal management plans tailored to the unique environmental and socioeconomic context of Albay.

MATERIALS AND METHODS

Study site

The east coast of Albay consists of two gulfs, the Lagonoy Gulf and the Albay Gulf, and comprises two cities and five municipalities. Study areas were Malinao, Tabaco city, Bacacay, Santo Domingo, and Legazpi city (Figure 1). These areas have different coastal types, such as cliff coast, intertidal/muddy coast, dune coast, and sandy coast, as well as extractive and development activities affecting the supply of sediment materials. Malinao coastline is situated on a narrow coastal plain, downstream from three active stratovolcanoes: Malinao, Masaraga, and Mayon, primarily composed of basaltic to andesitic materials. Volcaniclastic sediments, ranging from sand to gravel, are directly sourced from these volcanoes and transported downstream via the Quinale River to the coast. The southeastward alignment of the spit suggests a net southeastward longshore transport of quaternary alluvial sediments to the southern bank of the Quinale River (Dayao 2006; Soria et al. 2021). The spit measures approximately 150 m wide and stretches 7 km southeast toward Tabaco city. Tabaco city coast, on the other hand, is characterized by sand and gravel deposited from Malinao and several tributary rivers of Tabaco city (such as Bombon, Bacolod, and Pawa rivers). It is found inside Tabaco Bay, which stretches to-

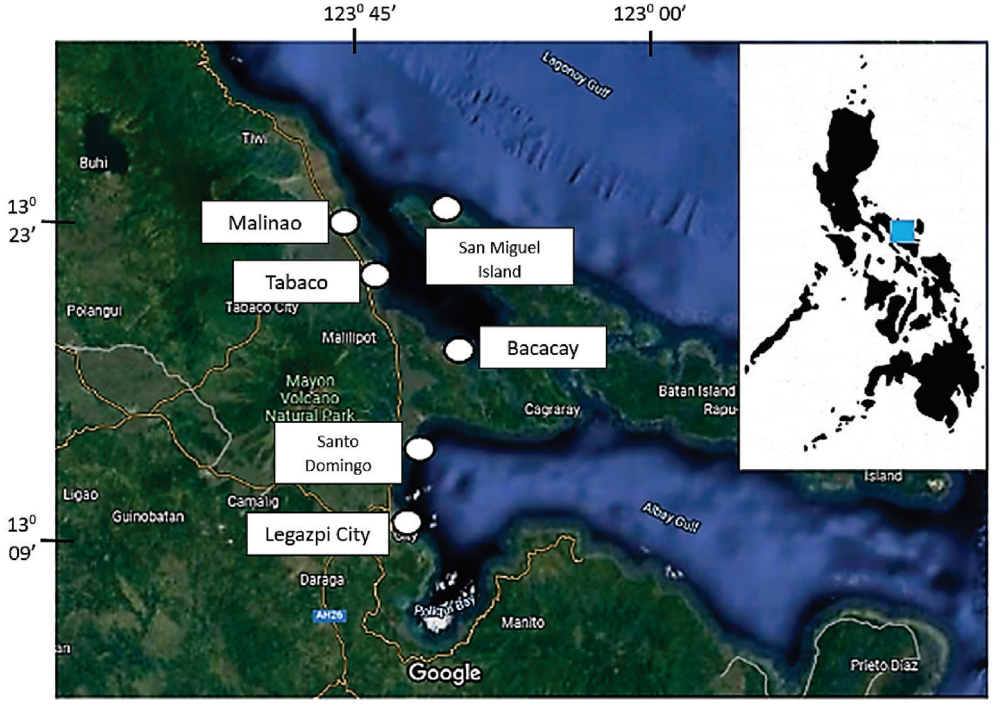

Figure 1. Location of study sites along the east coast of Albay, Philippines, including Malinao, Tabaco city, San Miguel Island, Bacacay, Santo Domingo, and Legazpi city.

wards the municipality of Malinao to the south. Extending further to the southeastern portion of the Bay is the coastline of the municipality of Bacacay, which is influenced by major tributaries of the municipalities of Malilipot and Bacacay. To the south are the coastal areas of the municipality of Santo Domingo and the city of Legazpi, both characterized and influenced by the discharge of basaltic and andesitic materials from the Mayon volcano (Soria et al. 2021). On the other hand, San Miguel Island is characterized by possessing carbonate sediments, which are primarily formed predominantly through the biological and chemical precipitation of calcium carbonate in marine environments (Pomar 2020).

These coastal areas support various socio-economic activities, such as agriculture, fisheries, sand and gravel quarrying, and small-scale tourism. For instance, Tabaco city is a hub for fishing and trade, while the island villages of Tabaco and Bacacay are popular destinations for beach tourism, particularly on San Miguel Island and Cagraray Island, which draw visitors for their white sand beaches and marine biodiversity (Bradecina et al. 2013). Meanwhile, Malinao and Santo Domingo have significant sand and gravel extraction industries (Arao 2020), vital for regional construction but often contributing to sediment depletion and coastal erosion (Paz-Alberto et al. 2016). The study area is critical for understanding how socio-economic activities interact with natural coastal processes.

Data collection

The method of Emery (1961) for beach profiling was applied to determine changes in elevation and length of the backshore of selected areas in Albay. This cost-effective and straightforward technique maps the cross-sectional elevation of beaches. This method consists of using two graduated rods of the same height and measuring the difference in elevation and distance between them, starting from an inland reference point and moving towards the sea. The horizon serves as the reference for determining relative elevation. Emery's method allowed us to record the cross-sectional shape of the beach and observe morphological changes over time. These measurements were used to quantify sediment volume fluctuations, indicating whether the beach experienced sediment loss (erosion) or gain (accretion) over different seasons (Jackson et al. 2002). This method was specifically applied to Lidong and San Isidro, both in Santo Domingo, from October 2020 to November 2021, because these two sites exhibited the most significant changes in shoreline morphology.

Google Earth satellite images from 2004, 2009, 2017, and 2021 were used to analyze changes in coastal morphology. These years were chosen because the images provided the clearest resolution for accurate shoreline outlining and tracing, enabling meaningful comparisons between historical and current shoreline positions. Digitized shorelines from selected sites –Malinao, Tabaco city, Bacacay, Santo Domingo, and Legazpi city– were analyzed to identify areas of erosion and accretion, offering a spatial and temporal perspective on coastal changes. This approach provided valuable insights into the dynamic patterns of shoreline evolution in these areas.

Photographic documentation was conducted to capture visible evidence of erosion and sediment deposition along the coastline. Secondary data played a critical role in supporting and complementing the analysis, encompassing various sources of information. Historical reports, including archival records, government publications, and technical documents, provided insights into past coastal changes, interventions, and management practices in the study areas. Related studies, such as research articles, theses, and surveys conducted within the region or on similar coastal systems, were used to validate findings and identify long-term trends in shoreline dynamics. Hydrometeorological data, including records of typhoon frequency, wave action, sea level rise and seasonal variations, provided insight into environmental drivers behind changes in coastal morphology.

Additionally, land use and infrastructure records highlighted human activities, such as urbanization and reclamation projects, which may have influenced shoreline behavior. Anecdotal accounts and observations from local residents contributed valuable qualitative insights into historical shoreline changes and coastal resource use, while historical maps, nautical charts, and older satellite imagery provided spatial references for tracking changes over extended periods. By integrating these diverse secondary data sources with satellite imagery, field surveys, and local knowledge, this study ensured a robust and multifaceted assessment of coastal morphological changes, enabling a comprehensive understanding of the natural and human-induced factors shaping the Albay shoreline.

Key informant interviews and community insights

Key informant interviews (KIIs) with local residents, fisherfolk, and community leaders provided additional qualitative insights, offering historical context and local observations about erosion patterns. A total of 144 respondents were surveyed across five municipalities and one city along the east coast of Albay to gather local insights regarding shoreline changes, coastal activities, and community observations of erosion and accretion. The term 'interviews' in this context refers to both structured surveys and KIIs, which were used to complement each other. Surveys aimed to collect quantitative data, while the KIIs provided qualitative, in-depth perspectives. The KIIs were conducted with individuals directly involved in fishing, tourism, aquaculture, coastal agriculture, mangrove harvesting, seaweed farming, shellfish gathering, beachcombing, boat building, and coastal trade, as well as community leaders and elders with historical knowledge of the area. These interviews focused on gathering detailed accounts of long-term shoreline dynamics, community coping strategies, and recommendations for coastal management. By engaging individuals from diverse coastal livelihood sectors, the study captured a more comprehensive understanding of human-environment interactions and the social and economic dimensions of shoreline changes and their impact on the local community.

Surveyed locations were selected based on their proximity to the coastline and the active involvement of residents in coastal-related livelihoods, such as fishing, tourism, and resource extraction. Legazpi city was excluded from the survey due to its predominantly commercial nature, minimal residential population along the coast, and limited direct engagement in coastal livelihoods.

Surveys consisted of structured questionnaires with a mix of closed and open-ended questions designed to achieve the following purposes:

- Shoreline changes: respondents were asked about observable changes in the coastline, including erosion, accretion, and the frequency of significant events such as storm surges or sediment deposition.
- Coastal activities: questions explored the types of livelihoods connected to the coast, such as fishing, tourism, or quarrying, and how these activities have been affected by shoreline changes.
- Perceptions of causes and impacts: respondents provided insights into their perceptions of the factors driving erosion and accretion and the social and economic impacts of these changes on their communities.

Ethical considerations

This study strictly adhered to established ethical guidelines, obtaining all necessary permits and approvals from relevant local authorities, including Municipal Mayors and Barangay Captains. Before data collection, respondents were thoroughly briefed on the research purpose, objectives, procedures, and potential risks or benefits. Participants were provided ample opportunity to ask questions and clarify concerns before proceeding. Informed consent was obtained in writing from

each respondent, ensuring their voluntary participation without coercion. Participants were explicitly informed that their involvement was entirely voluntary and that they had the right to withdraw from the study at any point without any adverse consequences. This open, transparent approach reinforced the commitment to ethical research practices.

Privacy and confidentiality were put at the forefront of the study. All personal data collected during interviews and surveys were anonymized or de-identified to protect the identity of participants. Information provided by respondents was treated with strict confidentiality and used solely for research purposes. Data was handled responsibly throughout the research process, and measures were taken to ensure accurate and objective reporting of findings. In all aspects, the privacy and anonymity of respondents were safeguarded, ensuring that ethical standards were maintained from data collection to dissemination.

RESULTS AND DISCUSSION

Historical changes in coastal morphology

Historically, the coastal sites of Tabaco city and Bacacay have been central to human activities, such as fishing and family recreation, such as swimming. These areas have faced increasing natural forces and pressures from human development. The construction of coastal roads, beach houses, and other infrastructure, combined with the regular impact of typhoons and monsoons, has significantly altered the coastal landscape (He et al. 2014; Huang 2022). In Tabaco city, approximately 1.5 ha of coastline has been eroded (Figure 2 A and 2 B). This same trend has been observed in Bacacay, where an average of 6 m of shoreline has receded over the years (Figure 2 C and 2 D). From 2004 to 2021, coastal areas in Tabaco and Bacacay

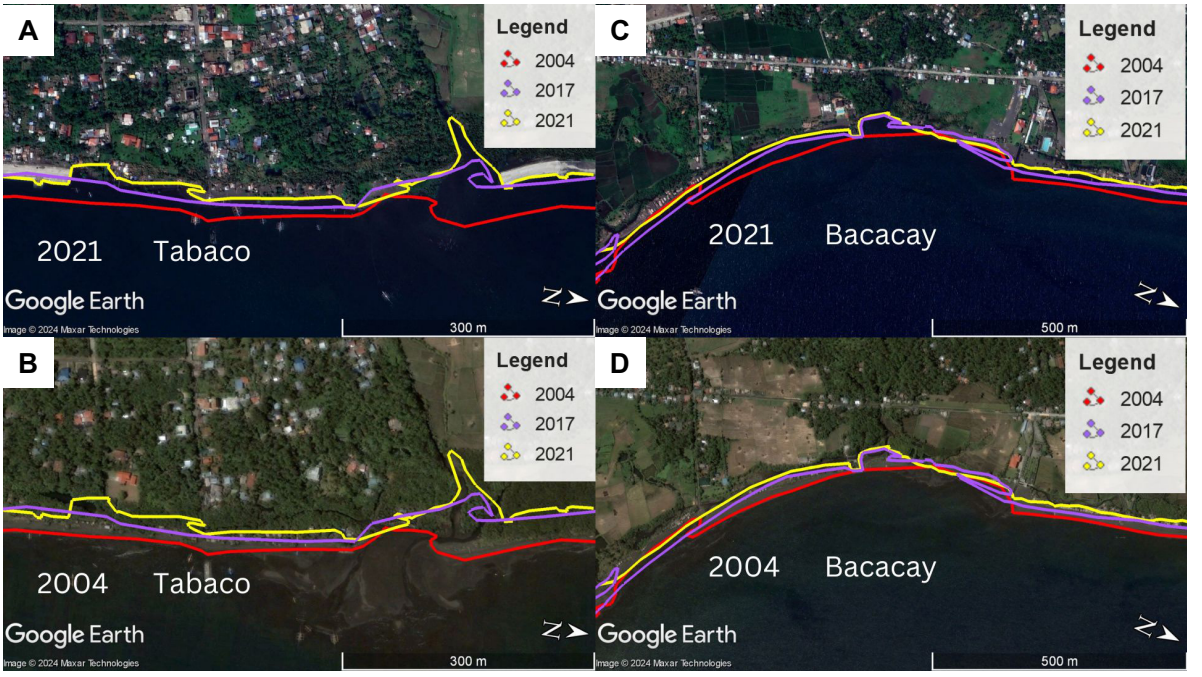

Figure 2. Historical changes in coastal morphology in Tabaco city (A-B) and Bacacay (C-D). Temporal line traces in yellow, violet, and red indicate shoreline positions for 2021, 2017, and 2004, respectively (source: Google Earth).

exhibited similarly dramatic changes. The continuous loss of shoreline in these regions reflects the combined effects of natural coastal processes and anthropogenic activities.

The observed coastal erosion in Tabaco city and Bacacay illustrates a broader shoreline retreat pattern driven by natural and human-induced factors. Frequent typhoons and monsoons exacerbate the natural erosional processes, leading to significant sediment displacement. Coastal infrastructure development, including roads and residential projects, disrupts natural sediment transport and deposition patterns, preventing the coastline from replenishing lost sediments and intensifying erosion (Huang 2022). This impact is especially noticeable in areas such as Tabaco city and Bacacay, where the construction of beach houses and coastal roads has significantly altered shoreline geomorphology. The loss of vegetation and natural barriers, such as mangroves and sand dunes, further contributes to the vulnerability of these areas (Feagin et al. 2005). Without these natural defenses, coastal zones are less resilient to storm surges and wave action, resulting in greater erosion (Delfino et al. 2015; Siringan and Sta Maria 2024). Moreover, data from 2004 to 2021 revealed that coastal changes in Tabaco and Bacacay were not isolated incidents but part of a long-term trend, highlighting the urgent need for sustainable coastal management. The retreat of shorelines in these areas underscores the importance of integrating climate change adaptation measures into coastal development planning. Strategies such as the construction of green infrastructure (e.g. mangrove reforestation), the creation of buffer zones, and the restriction of development in highly vulnerable areas could help mitigate future erosion.

Changes in river mouths, such as those observed in Malinao and Bacacay, accentuate their vital role in sediment transport (Figure 3). Historically, these areas acted as natural reservoirs, receiving volcanic sediments from Mayon volcano and facilitating their distribution to nearby beaches through coastal

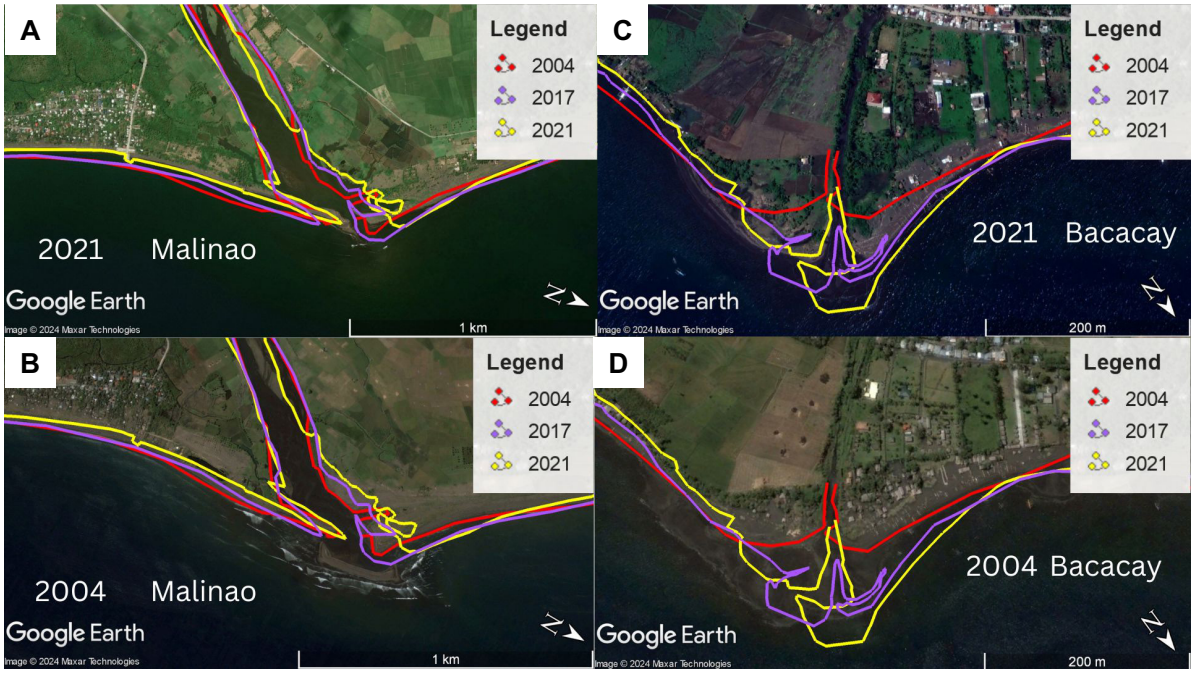

Figure 3. Historical changes in river mouths of Malinao (A-B) and Bacacay (C-D). Temporal line traces in yellow, violet, and red lines indicate shoreline positions for 2021, 2017, and 2004, respectively (source: Google Earth).

currents. However, the balance has been disrupted by quarrying operations (Alfane 2023). While river mouths continue to receive sediment inflows, uncontrolled quarrying has significantly reduced the overall sediment supply, leading to erratic and chaotic sedimentation patterns (Figure 3 C and 3 D). This depletion has further exacerbated coastal erosion in downstream areas, despite the natural abundance of sedimentary materials from the volcano (Figure 3 A and 3 B).

Beach erosion occurs when the rate of sediment loss from longshore drift exceeds the supply of new material from updrift sources. Longshore drift, a process in which sand or gravel is transported along the coast by wave action, degrades beaches unless these losses are compensated by fresh sediments from the updrift (Komar 1998; Nordstrom 2014). Erosion becomes particularly severe when the sediment supply diminishes, such as when updrift sources are interrupted, either by the cliff stabilization that stops natural sediment production or by rivers with reduced fluvial sediment input (Bird 2008; McInnes et al. 2011; Hines et al. 2012). In some coastal areas, beaches develop sand or gravel lobes, which are pockets of sediment that gradually migrate along the coast following longshore drift (Ortega-Sánchez et al. 2017). These lobes can temporarily build up the beach as they arrive, resulting in accretion. However, as the lobe continues to move downdrift, the area it passes through is left vulnerable to erosion, leading to alternating periods of sediment gain and loss along the coastline (Wright and Short 1984; Preoteasa et al. 2016). This dynamic interaction between sediment transport and beach morphology highlights the importance of maintaining a balance between natural sediment sources and coastal processes to preserve beach stability over time (Dean and Dalrymple 2004).

In Legazpi city, land reclamation efforts initiated in 2007 have contributed to improving the stability of the coastline, as seen through the establishment of protective structures (Duvat 2013) (Figure 4). As a consequence of coastal development, the construction of Legazpi boulevard in the northern (Figure 4 A and 4 B) and southern parts of the harbor (Figure 4 C and 4 D) altered the morphology of the shoreline. A closer examination of changes in vegetation over time revealed significant changes. In 2004, there were trees, likely mangroves known for their role in coastal protection and sediment retention (Figure 4 B). However, by 2021 these trees had been replaced by shrubs and grasses, most likely as a result of urban development, including the construction of homes and businesses (Figure 4 A and 4 C). Although seawalls and boulders provided some degree of protection against coastal erosion, the constant action of waves and currents eroded the underlying substratum (Trenhaile 2016). This is largely attributed to the limited sediment supply for transport and reworking (Komar 1998; Dean and Dalrymple 2004). As a result, while reclamation structures have temporarily improved coastal stability, their long-term durability remains uncertain, especially considering the exposure to powerful northeast monsoons and frequent typhoons in the region (Bird 2008). Without a sustainable sediment supply, the reclaimed area may become vulnerable to future erosion (De Vente and Poesen 2005), highlighting the importance of continuous monitoring and adaptive management strategies (Birgé et al. 2016).

While coastal developments and resorts in Santo Domingo have boosted the local economy by creating jobs, income, and revenue (Arao 2020), they also pose long-term environmental risks that could eventually undermine the tourism sector of the local government (Alfane 2023). The shoreline of Santo Domingo underwent a striking transformation between 2009 and 2021, with over 50 m of retreat observed during that period (Figure 5 A and 5 B). This shoreline erosion is primarily due to reduced sediment availability for coastal reworking, leading to significant sand loss in front of resorts (Figure 5 C and 5 D). The limited sediment supply is largely a result of extensive quarrying activities in river channels and at the base of Mayon volcano, which have disrupted the natural sediment replenishment cycle. Consequently, beaches that once supported a vibrant tourism industry are now

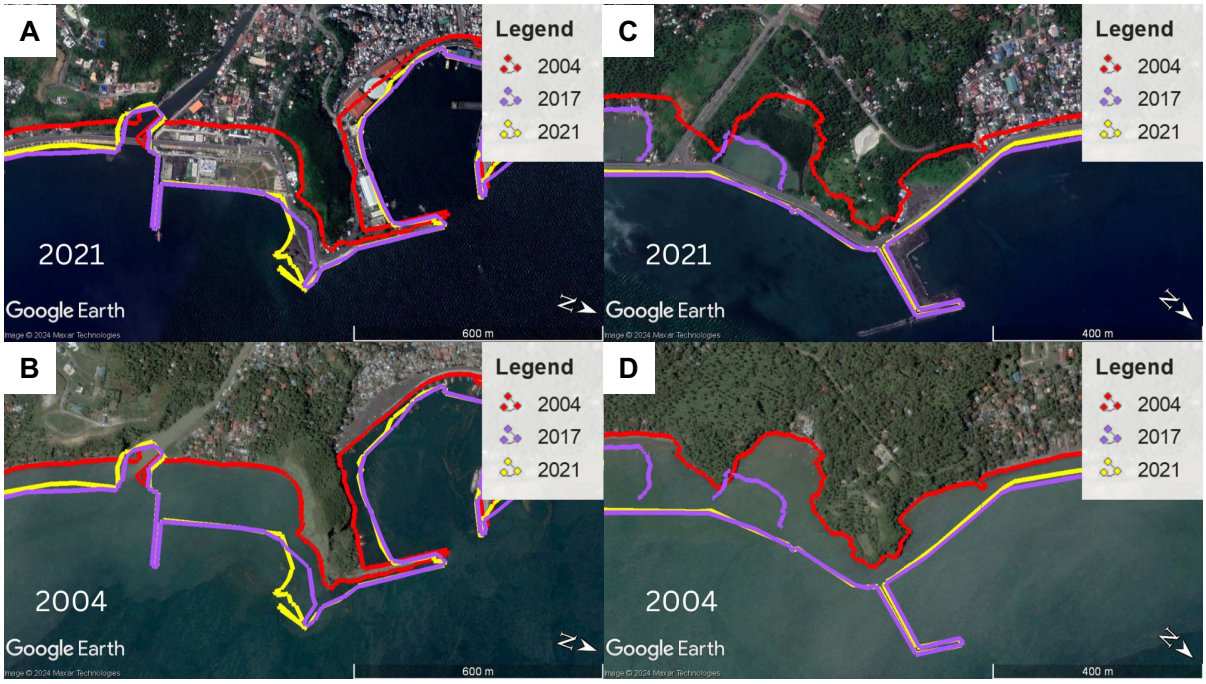

Figure 4. Historical changes in the coastal area of Legaspi (2004-2021). A-B) Legazpi boulevard north port. C-D) Legazpi boulevard southern port. Temporal line traces in yellow, violet, and red lines indicate shoreline positions for 2021, 2017, and 2004, respectively (source: Google Earth).

experiencing accelerated erosion. Without proper management and mitigation measures, such as regulating quarrying activities and enhancing sediment management, the continued shoreline degradation will harm the environment and jeopardize the future of the coastal tourism industry in the municipality of Santo Domingo.

The increasing frequency and intensity of storms in coastal areas have eroded previously stable beaches. This trend has been observed in parts of Albay, which is located on the eastern seaboard and was one of the first areas affected by tropical cyclones. Two powerful and catastrophic typhoons are among the 20 tropical storms that typically hit the Bicol region each year, particularly the Province of Albay. These storms, rising sea levels, and more frequent storm surges have accelerated coastal erosion, making the shoreline increasingly vulnerable to significant changes (Michener et al. 1997).

Anthropogenic pressures and shoreline morphological changes

In addition to these natural factors, human activities further exacerbate the problem. In island areas, sand and gravel used for constructing houses are often extracted directly from the beaches. This unsustainable practice depletes sediment reserves, leading to the gradual erosion of foreshore areas. Over time, this erosion exposes the roots of trees and damages concrete structures (Figure 6 A-D). The removal of sediment not only weakens natural coastal defenses but also increases shoreline susceptibility to further degradation (Nordstrom 2014). The combined intensified storm activity (Soria et al. 2021) and unsustainable extraction of beach materials (Rangel-Buitrago and Neal 2023) highlight the urgent need for comprehensive coastal management strategies. These should focus on regulating resource extraction, reinforcing natural

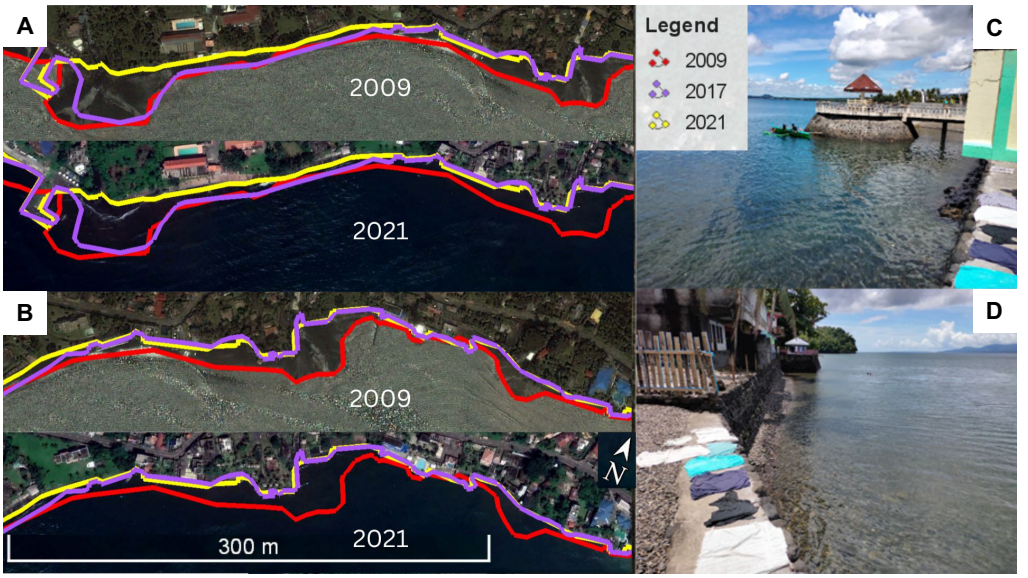

Figure 5. Historical changes in coastal morphology (2009, 2017, and 2021) in Santo Domingo. Temporal line traces in yellow, violet, and red lines indicate shoreline positions for 2021, 2017, and 2004, respectively. A) Northern beach area. B) Southern beach area. C-D) Beach resort frontage showing an eroded portion of the beachfront (source: Google Earth).

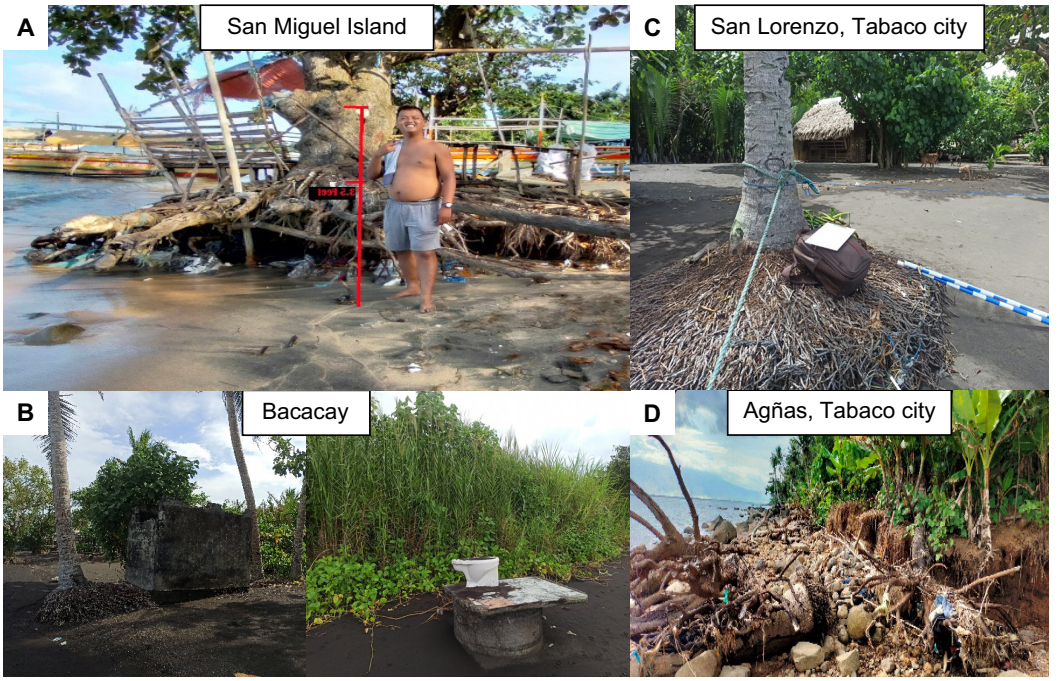

Figure 6. Evidence of shoreline erosion on the east coast of Albay. A) Erosion in San Miguel Island exposing tree roots. B) Exposed tree roots and abandoned concrete parts of a house and a well in Bacacay. C) Exposed tree roots in Tabaco city. D) Eroded coastline in Agñas, Tabaco city.

sediment cycles, and implementing adaptive measures to mitigate the impacts of climate change and human activities on coastal environments.

Beach profiling using the Emery approach was conducted to assess the cross-sectional outline of the beach and track its evolution over time. In the municipality of Santo Domingo, data from San Isidro and Lidong revealed distinct patterns of shoreline change. Both areas experienced erosion, but the nature of the erosion varied between the two sites. In San Isidro, erosion affected the entire beach profile, extending from the backshore to the foreshore (Figure 7). In contrast, Lidong primarily experienced erosion in the foreshore area (Figure 8). Notably, between October 2020 and November 2021, the vertical shore distance in Lidong decreased by approximately 7 m, accompanied by an elevation reduction of about 60 cm. In San Isidro, however, the vertical length of the shore remained relatively unchanged over the same period. However, the elevation dropped by an average of 65 cm from the back to the front along the beach profile

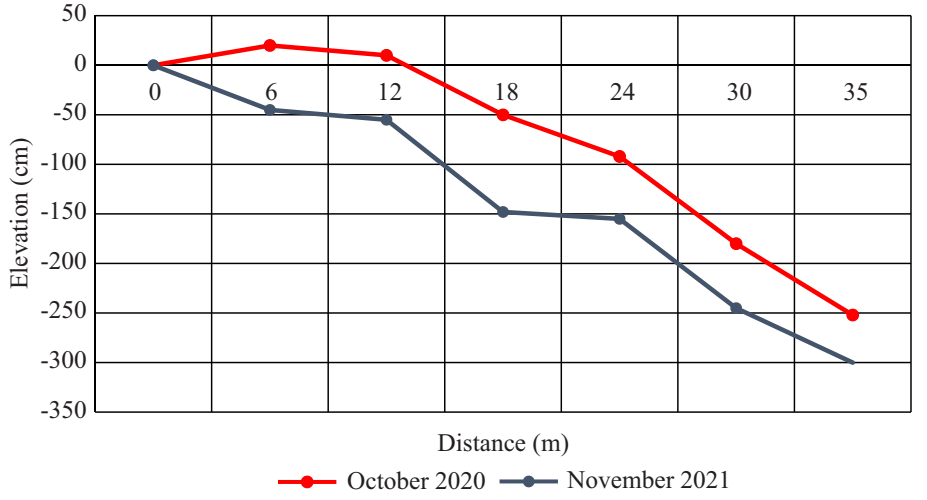

Figure 7. Changes in the coastal profile of Santo Domingo at San Isidro, from October 2020 to November 2021.

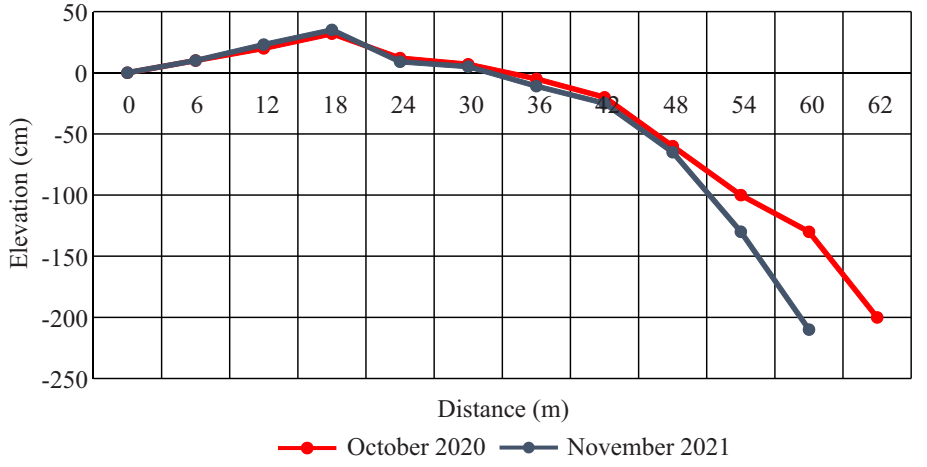

Figure 8. Changes in the coastal profile of Santo Domingo at Lidong, from October 2020 to November 2021.

in comparison to 2020 measurements. These variations highlight the differential impacts of coastal processes on each site, likely influenced by localized factors such as wave energy, sediment supply, and human activities.

The rapidly changing profile of the coastline of Albay underscores its vulnerability to natural and physical processes, compounded by human activities and ongoing coastal development. Destructive practices such as sand extraction, alongside the pressure of coastal infrastructure, contribute to the instability of the shoreline, emphasizing the need for sustainable coastal management and erosion mitigation strategies.

Erosion has significantly impacted many of the world's beaches over the past century (Vousdoukas et al. 2020). Coastal environments are severely threatened by the natural process of beach erosion (Bird 2014). Beach erosion is expected to worsen as a result of rising sea levels, stronger storms, and changes in the global climate (Bilan 1993; Zhang et al. 2004). However, the growing expansion of development into coastal areas has raised concerns about its impact on natural ecosystems and the need for sustainable coastal development that balances ecological preservation with economic growth (He et al. 2014). Coastal areas, home to rich biodiversity and sensitive ecosystems, are especially vulnerable to the consequences of development, which threaten habitats, biodiversity, and overall environmental health (He et al. 2014; Huang 2022). In Albay, coastal development has surged significantly, driving a heightened demand for gravel and sand to support infrastructure projects (MGB 2022). Consequently, extensive quarry operations near the Mayon volcano have risen sharply, extracting hundreds of thousands of cubic meters of sand and gravel annually (Figure 9). This widespread extraction has led to a substantial reduction in sediment supply to coastal zones, which depend on river-carried materials for nourishment (Bird and Lewis 2014). The analysis of coastline changes by Google Earth time slider showed the coastal erosion in eastern areas of Albay as a result of the reduction in sediment supply. Similar patterns of coastline alteration due to development were observed in Taiwan, where rapid coastal expansion during the 1970s substantially impacted coastal morphology (Huang 2022). In response, Taiwan has proposed countermeasures to restore longshore drift and reduce environmental degradation (Zhang and Hou 2020). Those authors observed significant spatial variations in the southeastern of Asia, with natural coastlines decreasing and artificial coastlines increasing by 11%. These changes, often due to interactions between natural processes and human activities, highlight the delicate balance between erosion and coastal expansion. In the Philippines, Paz-Alberto et al. (2016) found that quarrying and human interventions along riverbanks of Dagupan led to an increase in river width and a reduction in nearby coastline size. This finding is consistent with the situation in Albay, where quarry activities and coastal developments have altered the coastline and reduced sediment supply, exacerbating coastal erosion.

The construction of coastal roads in Albay has further disrupted the dynamics of sediments (Huang 2022). As concluded previously, reclamation of the foreshore area in Legazpi city has expanded the coastal surface, while coastal roads and seawalls have accelerated erosion and threatening infrastructure in other municipalities such as Bacacay, Santo Domingo, Malilipot, and Tabaco. Ismail and El-Sayed (2011) demonstrated that seawalls can lower beach profiles and increase longshore sediment transport rates near the structures, followed by sediment accumulation further down the coast. Along Albay coast, the reflected energy from waves striking seawalls creates seaward currents that erode material at the base. These same authors concluded that altered wave patterns and longshore currents were responsible for changes in sediment transport rates. When waves strike a sturdy coastal structure, such as a concrete seawall or stone blocks, they are reflected, leading to seaward currents that carry material away from the base of the wall. This reflection washout is typically avoided

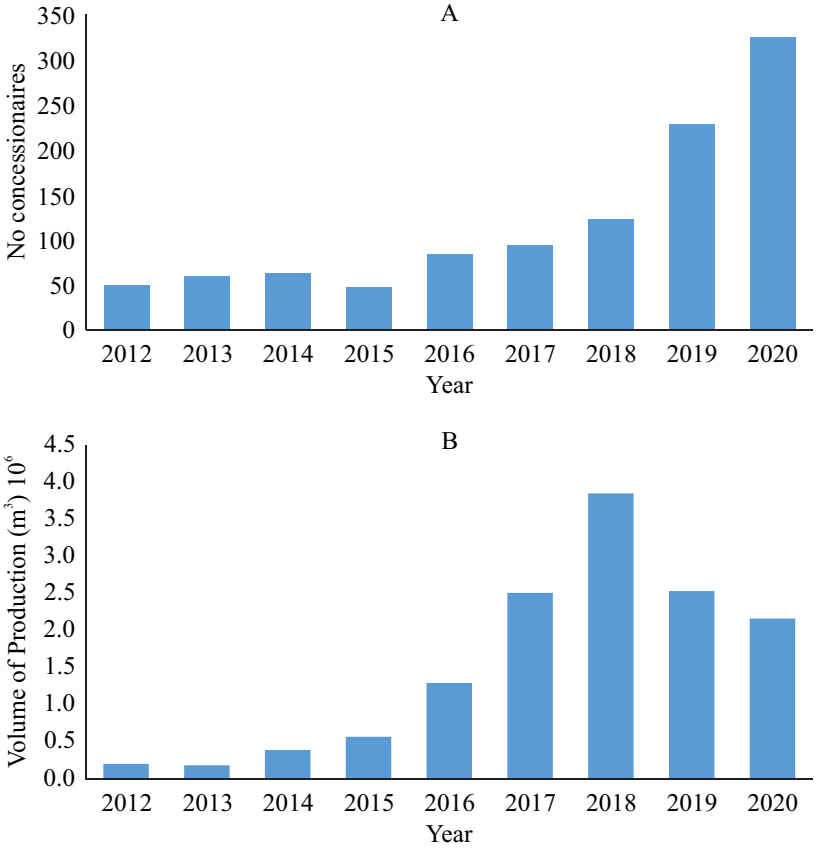

Figure 9. Annual trends (2012-2020) in the number of quarry concessioners (A), and the aggregate extraction volume in Mt. Mayon (B) (MGB 2022).

when a beach is sufficiently broad and elevated to prevent waves from reaching and rebounding off the solid structure. However, if waves reach the seawall, beach erosion occurs rapidly, which is the situation of the coastal roads and seawalls throughout Albay. Moreover, other potential impacts of these structures include visual disruption, loss of habitat, reduced beach access, sediment supply alteration, and exacerbation of erosion.

Community perceptions and adaptive strategies for shoreline management

One of the most profound consequences of coastal erosion is its impact on local communities, particularly through displacement. A study in riverine and deltaic regions of Bangladesh found that erosion exacerbated displacement, poverty, and social stigma (Barua et al. 2019). In Albay, coastal communities face similar challenges, with erosion damaging property and infrastructure, affecting livelihoods and employment. Residents are also concerned about saltwater intrusion into potable water sources (Figure 10).

Despite these challenges, coastal communities are highly aware of the causes of coastal erosion. Combest-Friedman et al. (2012) found that communities in the central Philippines recognize the role of rainfall variability, storm intensity, and sea level rise in driving coastal hazard risks. Similarly, Alcantara et al. (2022) reported that residents of Palawan identified sea level rise as a key factor in

erosion. Residents of Albay, particularly in Santo Domingo, attribute erosion to sand and gravel quarrying (Figure 11). These findings demonstrate the diversity of local perceptions about the causes of erosion, which are influenced by coastal activities, livelihoods, and the impacts of natural disasters.

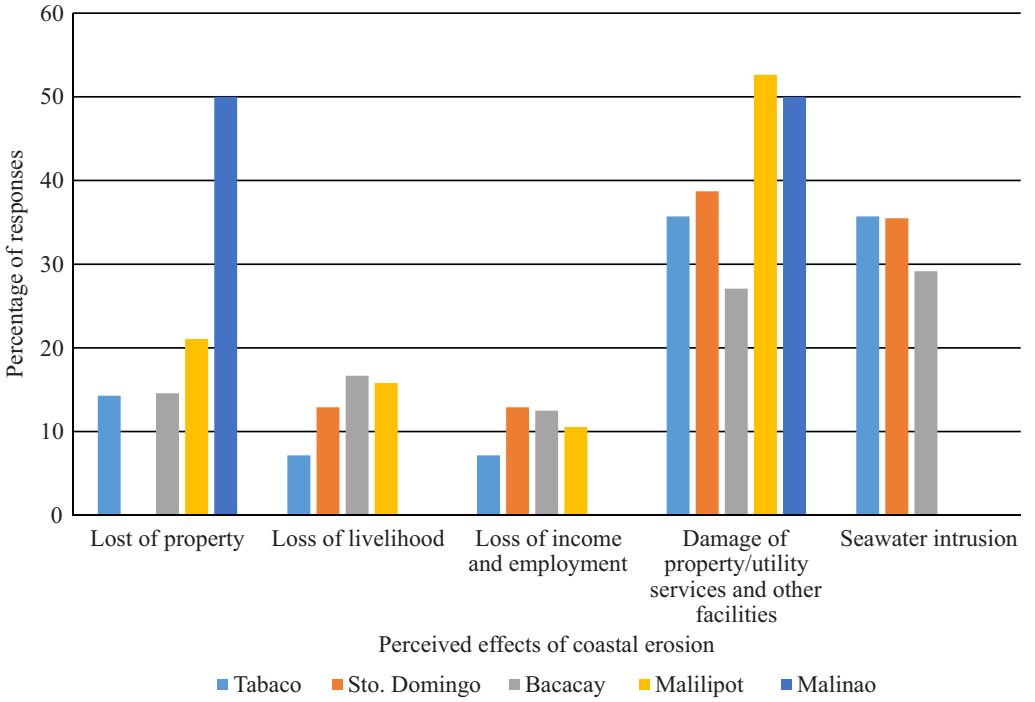

Figure 10. Perceived direct and indirect effects (%) of coastal erosion in coastal communities in Albay.

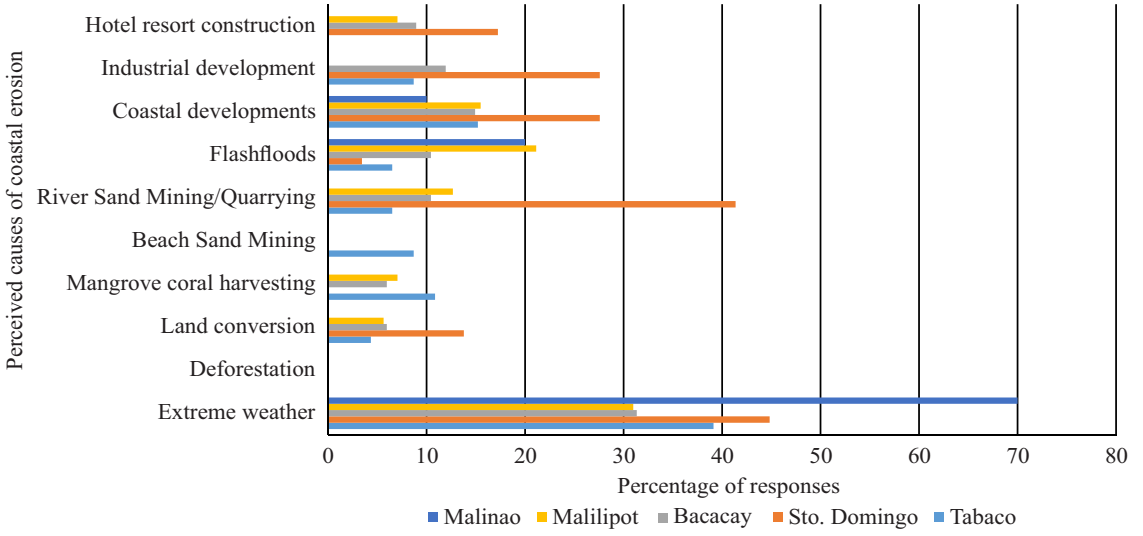

Figure 11. Perceived causes (%) of coastal erosion in coastal communities in Albay.

Depending on the municipality, residents noted changes in their coastal areas, ranging from new infrastructure developments to shrinking beach areas and rising sea levels (Figure 12). Some respondents also observed accretion in certain locations, which was consistent with the findings of Berdin et al. (2004) regarding simultaneous erosion and accretion along the coastline. Changes in river mouth morphology were particularly noticeable near large rivers, while municipalities such as Bacacay reported no significant coastal changes. Additionally, three sites noted an increased coastal population, likely driven by development expansion towards coastal areas.

All respondents demonstrated a comprehensive awareness of both preventive (Figure 13) and corrective (Figure 14) measures regarding the impacts of coastal erosion and alterations in coastal areas. Participants from various municipalities unanimously agreed on the necessity of effective planning for coastal projects and developments. This planning must adhere to environmental laws, ensuring continuous monitoring and evaluation of coastal areas to mitigate erosion effects (Alves et al. 2020).

Respondents emphasized the importance of employing soft measures, such as enhancing vegetation and stabilizing dunes, as vital strategies to combat accelerated coastal erosion. In line with the comprehensive land use plans of Local Government Units (LGUs), the development of hazard maps was highlighted as a crucial preventive and corrective action (Maralli et al. 2014). These strategies protect coastal ecosystems and foster resilience against the adverse effects of climate change and human activities (Birgé et al. 2016). Interestingly, the regulation of quarry activities (Figure 14) received notably low responses from participants as a corrective measure to minimize coastal erosion, particularly in the municipality of Santo Domingo, where most commercial quarry operators are located. This trend can be interpreted as a normal response, as many community members rely on quarrying as their primary source of livelihood (Arao 2020). The apparent reluctance to prioritize quarry regulation may reflect a conflict between economic dependence and the need for environmental protection (He et al. 2014), highlighting the complex dynamics of coastal resource management of the region.

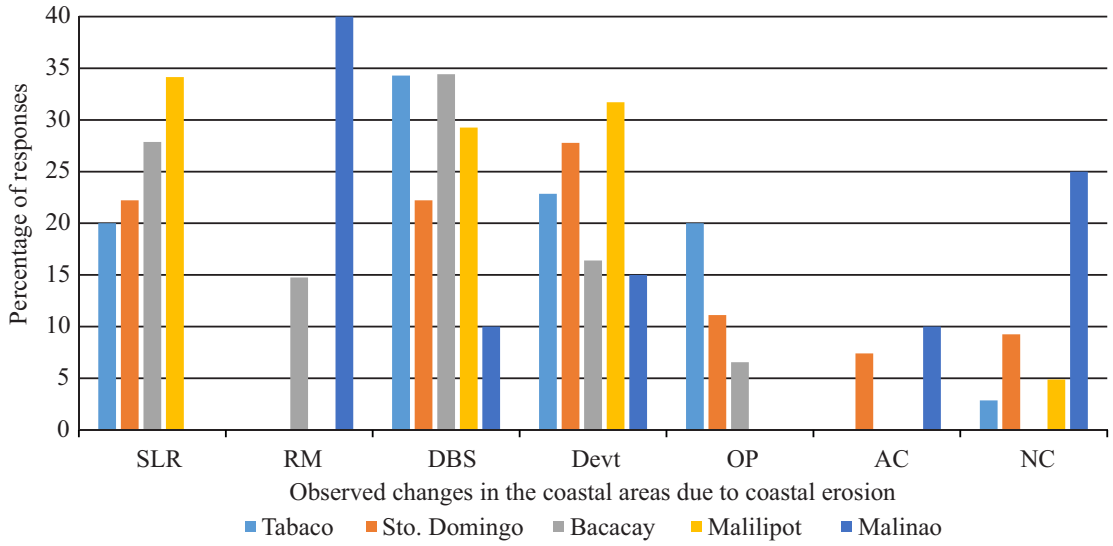

Figure 12. Observed changes (%) in the coastal area by coastal communities in Albay. SLR: sea level rise. RM: river mouth. DBS: decrease beach sand. Devt: development. OP: overpopulation. AC: accretion. NC: no change.

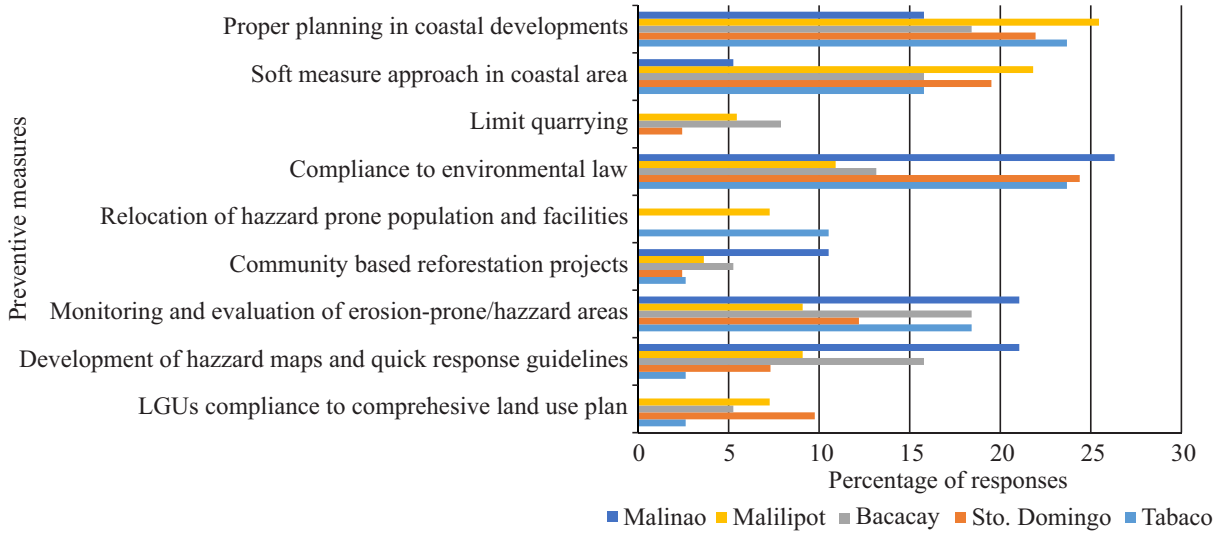

Figure 13. Perceived preventive measures to control erosion in the future by coastal communities in Albay.

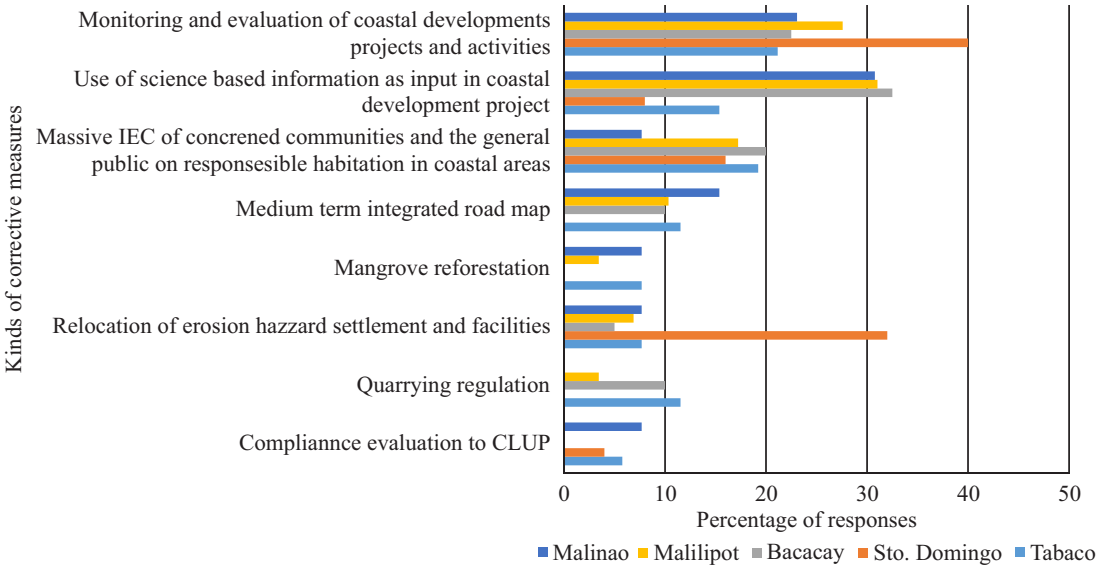

Figure 14. Perceived corrective measures to control erosion in the future by coastal communities in Albay.

CONCLUSIONS

The findings of this study highlight the complex interplay between natural processes, human activities, and community dynamics in shaping the shoreline changes along the east coast of Albay. Coastal erosion, driven by factors such as sand and gravel quarrying, climate variability, and rising sea levels, poses a significant threat to the coastal ecosystems, livelihoods, and infrastructure. While the physical impacts of erosion are evident in the changing shoreline profiles of areas like Santo Domingo, the per-

ceptions and responses of local communities offer valuable insights into potential adaptive strategies. Despite their awareness of the drivers of erosion, communities face challenges in balancing economic dependence on unsustainable practices, such as quarrying, with the urgent need for environmental protection. The limited prioritization of quarry regulation, particularly in economically dependent areas, underscores the necessity of implementing inclusive and context-sensitive management strategies. This study emphasizes the importance of integrating soft measures, such as vegetation restoration and dune stabilization, into comprehensive coastal management plans. The alignment of these measures with LGU hazard mapping and land use planning can enhance the resilience of coastal areas against the compounded effects of climate change and human activities. Moreover, fostering community participation and ensuring the enforcement of environmental regulations are critical for achieving long-term sustainability in shoreline management. Addressing shoreline erosion in Albay requires a multifaceted approach that combines scientific analysis, regulatory enforcement, and community-driven solutions. By striking a balance between ecological preservation and economic development, the region can mitigate the impacts of erosion while safeguarding its coastal resources for future generations.

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Conflict of interest

The author declares no conflicts of interest or competing interests regarding the publication of this study.

Availability of data and materials

The data used in this study, including satellite imagery and beach profiling records, are available from the corresponding author upon reasonable request.

Author contributions

Antonino B. Mendoza, Jr.: conceptualizing the research; conducting the data analysis; writing the manuscript; field observations. Joshua K. B. Bista: conceptualizing the research; conducting the data analysis; writing the manuscript; field observations. Skorzeny C. De Jesus: conceptualizing the research; conducting the data analysis; writing the manuscript; field observations. María Luisa U. Tango: conceptualizing the research; conducting the data analysis; writing the manuscript; field observations.

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