
Journal of Maps

ISSN: (Print) 1744-5647 (Online) Journal homepage: https://www.tandfonline.com/loi/tjom20

# Geomorphology of the Caribbean coast of Costa Rica

Adolfo Quesada-Román & Paula M. Pérez-Briceño

**To cite this article:** Adolfo Quesada-Román & Paula M. Pérez-Briceño (2019) Geomorphology of the Caribbean coast of Costa Rica, Journal of Maps, 15:2, 363-371, DOI: 10.1080/17445647.2019.1600592

**To link to this article:** https://doi.org/10.1080/17445647.2019.1600592

JOURNAL OF MAPS
2019, VOL. 15, NO. 2, 363–371
https://doi.org/10.1080/17445647.2019.1600592

Science

OPEN ACCESS Check for updates

# Geomorphology of the Caribbean coast of Costa Rica

Adolfo Quesada-Román [a,b] and Paula M. Pérez-Briceño [b,c]

[a]Climate Change Impacts and Risks in the Anthropocene, Institute for Environmental Sciences, University of Geneva, Geneva, Switzerland; [b]School of Geography, University of Costa Rica, San Pedro, Costa Rica; [c]Center for Geophysical Research, University of Costa Rica, San Pedro, Costa Rica

**ABSTRACT**
Costa Rica's Caribbean coastline is the result of a complex tectonic setting coupled with dynamic geological, climatological, hydrological and ecological processes. Despite their importance in risk prevention and in land use planning, geomorphological maps at detailed scales are scarce in Costa Rica. A geomorphology map of 210 km of the Caribbean coastline was produced at a scale of 1: 25,000 with a 1: 50,000 scale output map. Eleven landforms were mapped and described based upon their morphogenesis (i.e. tectonic, volcanic, fluvial and/or coastal). This work is an important base for coastal management, and is a compilation of the best existing knowledge of the Caribbean coast of Costa Rica.

**ARTICLE HISTORY**
Received 7 February 2019
Revised 20 March 2019
Accepted 25 March 2019

**KEYWORDS**
Geomorphological mapping; coastal geomorphology; fluvial geomorphology; coastal management; Caribbean Sea; Central America

## 1. Introduction

The Costa Rican Caribbean coast is located on the eastern coast of the nation stretching from the geographic coordinates 9° 32′ 34.8″ to 10° 56′ 24″ N and −82° 33′ 14.4″ to −83° 41′ 52.8″ W. This territory forms an elongated depression that is approximately 50 km wide extending from marine carbonate platforms of the South East to the broad alluvial plains to the North. This, forms the morphotectonic unit of the volcanic backarc, which is a result of the subduction process between the Cocos and Caribbean plates, the Central Deformed Belt of Costa Rica, the Depression Belt of Northern Panama and the subsequent erosion-accumulation of sediments of the Cordillera de Talamanca and the Central Volcanic Cordillera (Marshall, 2007; Marshall, Fisher, & Gardner, 2000). The study area encompasses two geological regions: the Caribbean Basin and the Limón Basin. These regions are a result of the development of shallow deposits and turbidity environments generated around 65 Ma and a series of volcanic and sedimentary lithologies (Figure 1). According to Denyer and Alvarado (2007), the different geological formations of the Costa Rican Caribbean vary on their compositions and ages from Miocene shales and sandstones (Uscari), Mio-Pliocene sandstones (Río Banano, Quebrada Chocolate, and Moín), Plio-Pleistocene conglomerates and sandstones (Suretka).

Four climatic groups can be found on the Costa Rican Caribbean coast. Two of them very humid with hydric rates of 100-300% and the other two are wet ones with hydric rates of 60–100%. In the extreme north, the first climatic group is classified as G2a, followed by G7a, while in the south are the wet climatic groups of F6 and E6. Figure 1 shows the spatial distribution of the climatic groups and its characteristics: temperature ranges, and the annual precipitation parameters (Pérez-Briceño, Amador, & Alfaro, 2017).

Due to the location of the Costa Rican Caribbean region, the climatic regime is formed in part by the recurrent impact of cold breaks (Alfaro & Pérez-Briceño, 2014; Campos-Durán & Quesada-Román, 2017a) and tropical cyclones (Alfaro & Quesada-Román, 2010; Alfaro, Quesada-Román, & Solano, 2010; Campos-Durán & Quesada-Román, 2017b; Pérez-Briceño, Alfaro, Hidalgo, & Jiménez, 2016). These same phenomena cause strong waves on the Caribbean coasts, where average wave heights of 1.37 m are reported with a maximum wave height of 3.87 m (Lizano, 2007). In terms of tidal behavior, the Caribbean coast has a mixed and sometimes semi-diurnal tide, with an intertidal range of 21 cm (Lizano, 2006).

The most common soil orders found here are Entisols in places of limited pedological development owing to the relative youth of the parent materials, Inceptisols where the soils have a more advanced B-horizon development, Histosols generally where there are periodic floods throughout the year, and Ultisols occurring in the most weathered profiles (Camacho, 2017). The tropical wet and moist forests dominate the Caribbean coast, together with extensive pastures for livestock

**CONTACT** Adolfo Quesada-Román adolfo.quesada@unige.ch Climate Change Impacts and Risks in the Anthropocene, Institute for Environmental Sciences, University of Geneva, Geneva, Switzerland School of Geography, University of Costa Rica, San Pedro, Costa Rica

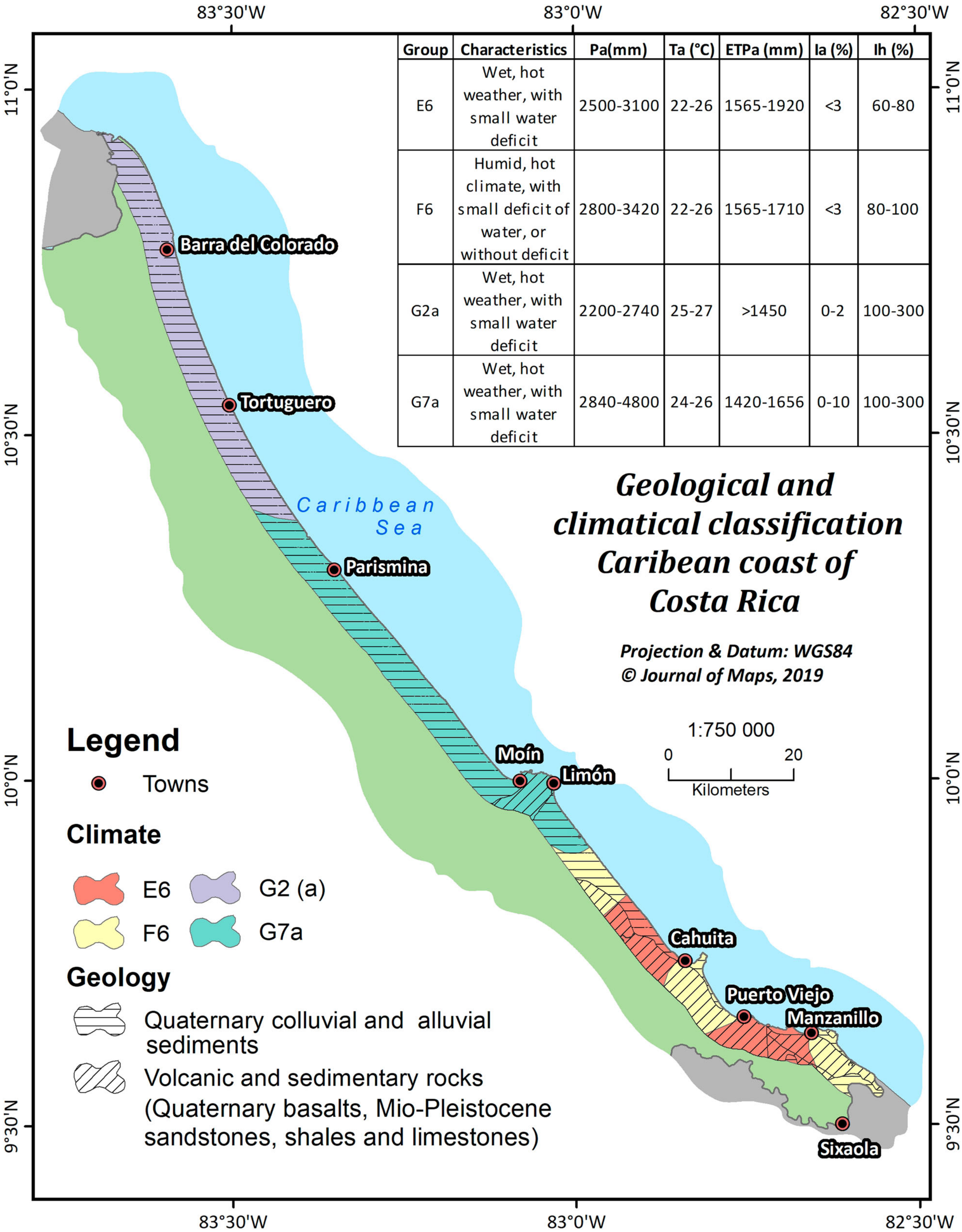


**Figure 1.** Geology and coastal climatic groups of the Caribbean of Costa Rica. $P_a$: Mean annual rainfall; $T_a$: Mean annual temperature; $ETP_a$: Annual potential evapotranspiration; Ia: Drought index; Ih: Hydric index

and banana fields that form the agricultural landscape (McClearn et al., 2016).

## 2. Materials and methods

The Main Map of the Caribbean coast geomorphology of Costa Rica was developed in three phases: pre-mapping, fieldwork, and post-mapping (Otto & Smith, 2013). Initially, 5 km strip was defined from the coastline to help to define the transitional fluvial and coastal processes. To determine the landforms of the coastal strip, we utilized aerial photography from the CARTA 2005 project at a scale of 1: 25,000 (last national cadastral survey), as well as Copernicus

Sentinel and Landsat 8 satellite images from March 2018 to determine the recent landform variations. As a historical base and a toponymic, the following topographic sheets of the National Geographic Institute were consulted at a scale of 1: 50,000: Punta Castilla, Colorado, Tortuguero, California, Parismina, Matina, Moín, Agua Fría, San Andrés, Río Banano, Cahuita, Sixaola, and Amubri. An initial legend was prepared based on a morphogenetic classification (Gustavsson, Kolstrup, & Seijmonsbergen, 2006), which separates landforms according to their origin into endogenic (i.e. formed beneath the Earth's surface) and exogenic (i.e. occurring at the surface). A description of each landform starts from the morphogenetic classification carried out in the first preliminary legend. This description is based on the characteristics of its morphology (shape), genetics (process), composition and structure, chronology, as well as its associations with the environmental system including land use, soils, and ecology (Bishop, James, Shroder, & Walsh, 2012).

In the fieldwork phase, visits were made to the Caribbean coastline between 2015 and 2018 to verify the limits and dynamics of the proposed landforms. Once the final geomorphological map was finished it was accompanied by a legend that correlates the colors according to their genesis (Hernández-Santana, Méndez-Linares, López-Portillo, & Preciado-López, 2016; Quesada-Román, 2018; Quesada-Román & Zamorano-Orozco, 2018). As the coastline of the Costa Rican Caribbean is about 210 km, it was decided that the optimal output scale given the extension of the basin would be 1:50,000.

## 3. Results

### 3.1. Endogenic landforms

#### 3.1.1. Tectonic landforms

The sedimentary hills are small elevations, with smooth and elongated slopes and relative heights that do not exceed 300 m. They are located between Moín and Sixaola and are composed of sandstones, shales and conglomerates with carbonaceous intercalations of turbidites. The turbidites are coastal and fluvial origin dating from the Miocene epoch to Quaternary period. The evolution of this region is controlled by regional tectonics and seismicity generated by the Central Deformed Belt of Costa Rica and the Depression Belt of Northern Panama. These processes favor the development of sedimentary hills aligned to a series of inverse faults with preferential South West trending, strike-slip faults with North East-South West orientation, syncline folds with North–South orientation and are characterized by tectonic uplift (Denyer & Alvarado, 2007; Marshall et al., 2000). Incessant uplifts due to positive neotectonics coupled with an intense erosive dynamics were the prevalent geomorphic processes that explain its present height and smooth relief. The sedimentary hills act like a pre-mountain between the coastal plains and the Cordillera de Talamanca and are dissected by the rivers Limoncito, Banano, Vizcaya, Bananito, San Andrés, Estrella, Coal, Cocles, as well as other minor streams.

The carbonate platforms are segments of marine origin, formed by relatively stable, low inclination Plio-Pleistocene reef limestone rocks that have been gradually raised by slow uplift punctuated by sudden vertical movements due to regional tectonic activity. The progressive uplift of old coral reefs due to continuous or sudden earthquakes, such as the San Estanislao in 1822 or the Limón earthquake in 1991, have formed coastal plains adjacent to the coast in the principal cities and towns of Limón, Cahuita, Puerto Viejo and Manzanillo (Cortés, Soto, & Jiménez, 1994; Quesada-Román, 2016). These zones coincide with the outcrops of the Portete Formation, which is composed of very altered Pleistocene coral reefs (Bergoeing, 2017). Despite their endogenic origin, at present the marine abrasion is the prevalent modeling process of these landforms. The postseismic relaxation of this region favor a rapid karstification and could generate problems by subsidence with the formation of dolines or sinkholes (Figure 2).

#### 3.1.2. Volcanic landforms

The volcanic cones are concentrated in Cerro Tortuguero, an ancient and extinct volcanic edifice of 119 m height composed of pyroclasts and potassium basalts of the Quaternary period less than 1 Ma (Gazel et al., 2011). It exhibits distinct volcanic origins and morphological characteristics and it is being dismantled by fluvial erosion, the construction of artificial channels and the extraction of pyroclastic materials from its flanks. Three cones have been recognized in this unit, Cerro Tortuguero of 119 m height, and two minor cones: San Francisco of 20 m height and Tortuguerito of 40 m height. These last two very abraded by the marine action, while Cerro Tortuguero has been cut for the construction of the canal. It should be noted that the Caribbean coast exhibits other examples of this intragraben volcanism, such as the Lomas del Colorado, the Lomas Azules, the hills of Aguas Zarcas and the Mercedes hills (Alvarado, 2011). The mapping of this morphological units is consistent with other works including Denyer and Alvarado (2007), Bergoeing (2017), and Bergoeing and Brenes (2017).

### 3.2. Exogenic landforms

#### 3.2.1. Fluvial landforms

The fluvial morphologies include rivers, abandoned meanders, alluvial plains and fluvial islands. Along these lowlands a complex system of channels exhibit the transitions of large rivers from the Central Volcanic

**Figure 2.** Marine abrasive platforms in Puerto Viejo.

Cordillera to wide plains. They exhibit extensive systems of natural and artificial channels ending in estuaries in the northern part of the Caribbean. These systems include the Colorado, La Suerte, Parismina, Pacuare, Madre de Dios and Matina rivers. The Caribbean northern coastal plains were submerged up to the level of 10 m by the Flandrian transgression until 6 ka and since then emerged due by positive neotectonics (Bergoeing, 2017). In the Southern Caribbean, the rivers tend to form rapid transitions between the Cordillera de Talamanca, the sedimentary hills, and the alluvial plains. These alluvial plains, occupied by Limoncito, Banano, Vizcaya, Bananito, San Andrés, Coal and Cocles rivers are no larger than 4 km wide and empty into the Caribbean Sea. In the case of the channels that cross through the Valle de la Estrella, the Valle de Talamanca and the Sixaola river, these rivers form meanders due to the width of their floodplains and the shallow gradient of the channel before reaching their mouths. Abandoned meanders form as isolated parts of a river in the shape of an arc that form by cutting the end of a meander and forming a marshy hollow known as an ox-bow lake. They occur where the floodplains are wide and dynamic, such as the Colorado and Parismina rivers.

The alluvial plains range from a shallow gradient to nearly flat and form large extensions in the Northern Caribbean. These alluvial plains serve as the coastal plains in the South Caribbean. These landforms have their origin in the deposition of sediments produced by the erosion of the Central Volcanic Cordillera and Cordillera de Talamanca. Based upon their locations these can be divided into five sections: from the mouth of the San Juan River and Tortuguero, between Tortuguero and Limón, from Limón to Cahuita, between Cahuita and Manzanillo, and finally near the mouth of the Sixaola River. Between the mouth of the Colorado and Tortuguero rivers these plains are drained by a dense system of natural and artificial fluvial channels in a matrix of wooded swamps or *yolillales*. From Tortuguero to Limón, these plains have similar dynamics associated with canals along swamps that in some cases have been drained for the cultivation of bananas. In addition, they are bounded by a series of natural or artificial coastal bars that connect with different mouths such as those of the rivers Parismina, Madre de Dios and Matina. In the case of the section between Limón and Cahuita, these alluvial plains are narrow, with a maximum width of 4 km, in their transition between the sedimentary hills and the Caribbean Sea. They are dominated by agricultural land uses principally banana production and pastures. Between Cahuita and Manzanillo the alluvial plain is narrow with no more than 2 km between the sedimentary hills and/or the carbonate platforms of the Caribbean Sea. A last segment of the alluvial plains is located in the proximity of the mouth of the Sixaola River, where a marked meandric drainage dominates the landscape (Figure 3).

In the northernmost sector of the Caribbean coast of Costa Rica two segments of the fluvial islands of Portillos and Calero are found. These are composed of portions of the mainland surrounded by rivers or the sea. In the case of Portillos Island, it is ringed to the north and east by the Caribbean Sea, to the west by the San Juan River and to the south with by Taura River. In

**Figure 3.** Sixaola River in the Costa Rica-Panama boundary.

the case of Calero Island, it is bounded on the north with the Taura River, on the east with the Caribbean Sea, on the west with the San Juan River and on the south with the Colorado River. In addition, other small fluvial islands are located on the Colorado River and Tortuguero lagoon. The constant sediment deposition that has occurred since the Miocene coupled with the consequent formation of large channels and wetlands in the Tortuguero National Park and the Wildlife Refuge Barra del Colorado in the North Caribbean have paramount ecosystemic and hydrological functions. These features act as large reservoirs of carbon, niches of wide biodiversity, temperature regulators and they protect the coasts from the impact of tropical storms (Sasmito, Murdiyarso, Friess, & Kurnianto, 2016). In the case of the southern Caribbean,with a few notable exceptions, the rivers travel less than 4 km in the alluvial plain. Among these exceptions are the Valle de la Estrella, Valle de Talamanca and the Sixaola rivers who developed meander patterns in their journey between the Cordillera de Talamanca and Caribbean Sea.

### 3.2.2. Coastal landforms

Coastal landforms are created by the action of the waves and the oceanic processes as exemplified by the coastal drift of the littoral currents. In this region the coral reefs, coastal lagoons, coastal bars, at least one blind estuary, and beaches dominate the area. The coral reefs are found in shallow waters and generate platforms between the coast and the barrier reef. This is common in Cahuita, Uvita island in front of Limón, and amid Puerto Viejo and Manzanillo and to a lesser extent in the coasts among Limón and Moín. These coral reefs are classified as fringing and patch reefs as well as carbonate banks and algal ridges (Cortés & Jiménez, 2003).

The coastal lagoons of the Caribbean coast exhibit characteristics of estuaries or coastal bars that have been enclosed by sedimentation. These lagoons are subject to the ebb and flow of tides and as a result they contain brackish water. These units maintain an important ecosystem function as valuable wetlands. In the sector of Calero Island, these landforms appear as elongated lagoons of up to 10 km long and 250 m wide. Examples include the Pereira, Atrás, Enmedio, and Agua Dulce lagoons. Other smaller coastal lagoons stand out to the south of the Colorado river, including Laguna Samay, Nine, Eight, Six and Four. In the vicinity of Tortuguero, the Penitencia lagoon and Tortuguero lagoon are found, which are approximately 25 km long and can be up to 350 m wide.

**Figure 4.** Coastal lagoon, coastal bar and fluvial plains from Cerro Tortuguero (volcanic cone).

Coastal bars are accumulative banks near the coast with a slight elevation above sea level. These bars extend parallel to the coast and are separated from the mainland by coastal lagoons. They originated from the saturation of sediments in the coastal zone due to the action of the waves and the deposition by the coastal currents in surfaces of the very shallow slope. The fluctuation of tides, the action of low energy waves and the abundant presence of sand contribute to this process. These bars are located between Tortuguero and Moín, with natural coastal lagoons amid Tortuguero and the estuary of the Parismina River. In certain segments among the mouth of the Parismina river and the Moín artificial channels were built to connect the estuaries of the Pacuare, Madre de Dios, Matina, Vueltas and Moín rivers. These channels reach 30 km long and 1.5 km wide, from Tortuguero to Moín and are 82 km long. The blind estuary of the Taura River connects the San Juan River with the Taura coastal lagoon and divides the island of Portillos from Calero Island. They are closed by an ephemeral baymouth and are stagnant during the dry season.

The coastal landforms of the northern Caribbean tend to be units of larger sizes such as the coastal bars along the shoreline between Tortuguero and Moín. These stretch 82 km in length with widths of 1.5 km on average and also include wetlands according to the last national wetlands inventory (SINAC-PNUD-GEF, 2018). The islands of Portillo and Calero, despite their fluvial origin, are intensely influenced by coastal dynamics due to the action of the marine currents, the coastal drift, and occasional erosion during storms. The different coastal landforms are affected by the tectonic uplift especially in the South Caribbean (Alvarado et al., 2017), and by the rise in sea level as a result of climate variability in the Caribbean Sea during the Holocene (Khan et al., 2017), and global warming (Cronin, 2012; Losada et al., 2013). Coral reefs in the Caribbean have been devastated by a number of processes including the drastic reduction in the population of spatially dominant species and construction of primary structures during the Pleistocene and Holocene, and their loss represents a great ecological impact (Carpenter et al., 2008) (Figure 4).

Besides the described landforms, important but smaller and not mapped features are the beaches. They can be long (kilometers) and normally narrow (less than 50 m), even with two berms. These morphologies can be characterized by their origin with white sand owing to the coastal erosion of coral reefs, such as Cahuita and Manzanillo; or beaches with dark sand due to the fluvial erosion from the Cordillera

**Figure 5.** Eroded beaches in Cahuita National Park, Southern Caribbean coast.

de Talamanca (Puerto Viejo and Playa Negra), and the Cordillera Volcánica Central (Parismina, Barra del Colorado and Matina Beach). Some of these beaches have experienced intense erosion during the last years possibly due to the post-seismic relaxation or sea level rise (Quesada-Román, 2016). In addition, Moín beach is been affected by intense erosion due to the construction of a new container terminal (Vargas & Barrantes, 2018) (Figure 5).

## 4. Conclusions

Here we present the geomorphological map of the 210 km Caribbean coastline of Costa Rica. This study resulted in the production of the first geomorphological product made at a scale of 1: 25,000 on the Caribbean coast with the output of a 1:50,000 scale map. The legend was classified according to its genesis on two tectonic landforms (sedimentary hills and carbonate platforms), one volcanic landform (volcanic cones), four fluvial landforms (rivers, abandoned meanders, alluvial plains and fluvial islands), and four coastal landforms (coral reef, coastal lagoon, coastal bars and a blind estuary). These types of geomorphological maps can also be used for studies of landform evolution, detailed morphogenetic maps, natural hazards as well as land use planning cartography.

## Software

The software used was ESRI ArcGIS 10.3 to georeference, digitize, and visualize the aerial photographs and generate the geomorphological map.


## Acknowledgements

The final version of the manuscript and the map benefits from the observations of D. Chavarría, M. Alas, R. L. Losco, J. A. Rodríguez, J. L. Gutiérrez. We greatly thank to reviewers H. Apps, P. E. Orrù, J. R. Hernández and W. Stephenson for their useful corrections and suggestions that highly improved the manuscript and the Main Map.


## Disclosure statement

No potential conflict of interest was reported by the authors.


## Funding

The authors were partially supported by 805-B7-286 (Vicepresidency of Research UCREA) and B8-766 (Vicepresidency of Research-Redes) projects of the University of Costa Rica.

## ORCID

*Adolfo Quesada-Román* http://orcid.org/0000-0001-6601-5254
*Paula M. Pérez-Briceño* http://orcid.org/0000-0002-7217-8495

## References

Alfaro, E., & Pérez-Briceño, P. M. (2014). Análisis del impacto de fenómenos meteorológicos en Costa Rica, América Central, originados en los mares circundantes. *Revista de Climatología*, *14*, 1–11.

Alfaro, E., & Quesada-Román, A. (2010). Ocurrencia de ciclones tropicales en el Mar Caribe y sus impactos sobre Centroamérica. *Revista InterSedes*, *11*(22), 136–153. doi:10.15517/isucr.v11i22.991

Alfaro, E., Quesada-Román, A., & Solano, F. J. (2010). Análisis del impacto en Costa Rica de los ciclones tropicales ocurridos en el Mar Caribe desde 1968 al 2007. *Revista Diálogos*, *11*(2), 25–38. doi:10.15517/dre.v11i2.578

Alvarado, G. E. (2011). *Los volcanes de Costa Rica: Geología, historia y riqueza natural*. San José: EUNED.

Alvarado, G. E., Benito, B., Staller, A., Climent, Á, Camacho, E., Rojas, W., … Lindholm, C. (2017). The new Central American seismic hazard zonation: Mutual consensus based on up to day seismotectonic framework. *Tectonophysics*, *721*, 462–476. doi:10.1016/j.tecto.2017.10.013

Bergoeing, J. P. (2017). *Geomorphology and Volcanology of Costa Rica*. p. 280. Amsterdam: Elsevier.

Bergoeing, J. P., & Brenes, L. G. (2017). *Atlas geomorfológico de Costa Rica*. Escala 1:100,000. Editorial Universidad Nacional. p. 72.

Bishop, M., James, A., Shroder, J., & Walsh, S. J. (2012). Geospatial technologies and digital geomorphological mapping: Concepts, issues and research. *Geomorphology*, *137*, 5–26. doi:10.1016/j.geomorph.2011.06.027

Camacho, M. E. (2017). *Génesis y clasificación de algunos ultisoles y oxisoles de Costa Rica*. Tesis de Maestría Académica en Ciencias Agrícolas y Recursos Naturales con énfasis en Suelos. Universidad de Costa Rica. p. 180.

Campos-Durán, D., & Quesada-Román, A. (2017a). Impacto de los eventos hidrometeorológicos en Costa Rica, periodo 2000-2015. *Revista Geo UERJ*, *30*, 440–465. doi:10.12957/geouerj.2017.26116

Campos-Durán, D., & Quesada-Román, A. (2017b). Riesgos Intensivos y Extensivos en América Central entre 1990 y 2015. *Anuário do Instituto de Geociências*, *40*(2), 234–249. doi:10.11137/2017_2_234_249

Carpenter, K. E., Abrar, M., Aeby, G., Aronson, R. B., Banks, S., Bruckner, A., … Edgar, G. J. (2008). One-third of reef-building corals face elevated extinction risk from climate change and local impacts. *Science*, *321*, 560–563. doi:10.1126/science.1159196

Cortés, J., & Jiménez, C. (2003). Past, present and future of the coral reefs of the Caribbean coast of Costa Rica. In J. Cortés (Ed.), *Latin American coral reefs* (pp. 223–239). Amsterdam: Elsevier Science.

Cortés, J., Soto, R., & Jiménez, C. (1994). Efectos ecológicos del terremoto de Limón. *Revista Geológica de América Central, Volumen Especial del Terremoto de Limón*, 187-192.

Cronin, T. M. (2012). Rapid sea-level rise. *Quaternary Science Reviews*, *56*, 11–30. doi:10.1016/j.quascirev.2012.08.021

Denyer, P., & Alvarado G. E. (2007). *Mapa geológico de Costa Rica*. San José: Librería Francesa. Escala 1:400 000.

Gazel, E., Hoernle, K., Carr, M. J., Herzberg, C., Saginor, I., Van den Bogaard, P., … Swisher III, C. (2011). Plume–subduction interaction in southern Central America: Mantle upwelling and slab melting. *Lithos*, *121*, 117–134. doi:10.1016/j.lithos.2010.10.008

Gustavsson, M., Kolstrup, E., & Seijmonsbergen, A. C. (2006). A new symbol-and-GIS based detailed geomorphological mapping system: Renewal of a scientific discipline for understanding landscape development. *Geomorphology*, *77*, 90–111. doi:10.1016/j.geomorph.2006.01.026

Hernández-Santana, J. R., Méndez-Linares, A. P., López-Portillo, J. A., & Preciado-López, J. C. (2016). Coastal geomorphological cartography of Veracruz State, Mexico. *Journal of Maps*, *12*(2), 316–323. doi:10.1080/17445647.2015.1016128

Khan, N. S., Ashe, E., Horton, B. P., Dutton, A., Kopp, R. E., Brocard, G., … Scatena, F. N. (2017). Drivers of Holocene sea-level change in the Caribbean. *Quaternary Science Reviews*, *155*, 13–36. doi:10.1016/j.quascirev.2016.08.032

Lizano, O. (2006). Algunas características de las mareas de la costa pacífica y caribe en Centroamérica. *Ciencia y Tecnología*, *24*(1), 51–64.

Lizano, O. (2007). Climatología del viento y oleaje frente a las costas de Costa Rica. *Ciencia y Tecnología*, *25*(1–2), 43–56.

Losada, I. J., Reguero, B. G., Méndez, F. J., Castanedo, S., Abascal, A. J., & Mínguez, R. (2013). Long-term changes in sea-level components in Latin America and the Caribbean. *Global and Planetary Change*, *104*, 34–50. doi:10.1016/j.gloplacha.2013.02.006

Marshall, J. (2007). The geomorphology and physiographic provinces of Central America. In Bundschuc and Alvarado (Eds.), *Central America: Geology, Resources and hazards* (p. 1436). London: Taylor & Francis.

Marshall, J., Fisher, D. M., & Gardner, T. W. (2000). Central Costa Rica deformed belt: Kinematics of diffuse faulting across the western Panama block. *Tectonics*, *19*(3), 468–492. doi:10.1029/1999TC001136

McClearn, D., Arroyo-Mora, J. P., Castro, E., Coleman, R. C., Espeleta, J. F., García-Robledo, C., … Timm, R. M. (2016). The Caribbean lowland evergreen moist and wet forests. In M. Kappelle (Ed.), *Costa Rican Ecosystems* (p. 744). Chicago, IL: University of Chicago Press.

Otto, J. C., & Smith, M. J. (2013). Geomorphological mapping. In Chap. 2, Sec. 6. L. Clarke, y J. Nield (Eds.), *Geomorphological Techniques* (pp. 1–10). London: British Society for Geomorphology. ISSN: 2047-0371.

Pérez-Briceño, P. M., Alfaro, E., Hidalgo, H., & Jiménez, F. (2016). Distribución espacial de impactos de eventos hidrometeorológicos en América Central. *Revista de Climatología*, *16*, 63–75.

Pérez-Briceño, P. M., Amador, J., & Alfaro, E. (2017). Dos propuestas de clasificación climática para la vertiente Caribe costarricense según el sistema de Thornthwaite. *Revista de Climatología*, *17*, 1–16.

Quesada-Román, A. (2016). Impactos geomorfológicos del Terremoto de Limón (1991; ms = 7.5) y consideraciones para la prevención de riesgos asociados en Costa Rica. *Revista Geográfica de América Central*, *56*, 93–111. doi:10.15359/rgac.1-56.4

Quesada-Román, A. (2018). Cartografía geomorfológica de la cuenca del río Guacimal, Costa Rica. *Revista Geográfica Venezolana*, *59*(1), 12–27.

Quesada-Román, A., & Zamorano-Orozco, J. J. (2018). Geomorphology of the Upper General River Basin, Costa Rica. *Journal of Maps*, *15*, 95–101. doi:10.1080/17445647.2018.1548384

Sasmito, S. D., Murdiyarso, D., Friess, D. A., & Kurnianto, S. (2016). Can mangroves keep pace with contemporary sea level rise? A global data review. *Wetlands Ecology and*

*Management*, *24*(2), 263–278. doi:10.1007/s11273-015-9466-7

SINAC-PNUD-GEF. (2018). *Inventario Nacional de Humedales*. SINAC/PNUD/GEF. 172 pp.

Vargas, A., & Barrantes, G. (2018). Impacto de la construcción de la Terminal de Contenedores (APM Terminals) en Playa de Moín, Costa Rica. *Revista Geográfica de América Central*, *61E*(3), 583–595. doi:10.15359/rgac.Esp-3.31