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ORIGINAL ARTICLE

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Tropical Paleoglacial Geoheritage Inventory for Geotourism Management of Chirripó National Park, Costa Rica

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Abstract

Globally, most active tropical glacial landscapes are found at elevations above 4000 m. Nonetheless, the presence of paleoglacial landforms in low latitudes, especially those formed during the Last Glacial Maximum (LGM), persists in different tropical regions. Chirripó National Park, in central-south Costa Rica, is one of these particular examples. The glacial and periglacial landscape in the park are located over 3000 m, with landforms such as arêtes, glacial cirques, moraines, till deposits, and glacial lakes. We performed an integrated approach for the geoheritage inventory and geotourism management, crossing geomorphological and cultural information. A total of 14 geomorphosites were assessed and their management discussed. These geomorphosites achieved scientific scores between 0.5 (Valle Talari, Cerro Urán, and Cerro Terbi) and 0.88 (Cerro Chirripó and Los Crestones). The average scientific value of the geomorphosites is 0.75, since they are well preserved (0.75), rare (0.57) and representative (0.84) of the region's geomorphology. They also play an important role in the geographical history (0.62), as well as the significant use and management characteristics (0.8). Chirripó National Park has key importance both naturally and culturally for Costa Rica. Its geomorphosites assessment is of critical value for the Costa Rican Conservation Areas System in order to promote improved geotourism. Geoheritage mapping can offer more opportunities of transferring geoscience knowledge to a larger public and policy makers. Our study aims to improve and further the state of the art of tropical glacial geoheritage.

Keywords Tropical mountain · Glacial geomorphology · Geoheritage · Geotourism · Costa Rica

Introduction

Geoheritage studies around the world have presented a marked growth since the early 1990s (Reynard and Brilha 2018). Moreover, the International Union for the Conservation of Nature (IUCN) and the UN's Sustainable Development Goals recognize geoheritage and geoconservation importance (Gordon et al. 2018). This study is based on geomorphosites that are sites of geomorphological interest (Panizza 2001). Certainly, geomorphological interest considers different added values to characterize the relief, as scientific value for reconstructing the Earth's history (Clivaz and Reynard 2018). Therefore, economic, cultural, environmental, and aesthetic values are necessary to understand the relationship between the landforms with society and the meaning that they have with people (Comanescu and Nedelea 2010).

Geomorphosites are divided in active and inactive (Reynard, 2004). The former allows the visualization of geological and geomorphological processes in action. The latter are inherited landforms that testify past processes. Nevertheless, inactive glacial geomorphosites responded to climatic changes that reflect the intense dynamic of the past (Diolaiuti and Smiraglia 2010). There is also the category of passive geomorphosites, which are relevant when they are affected by different active processes changing their current conditions. They have a high educational value because they are linked to the concepts of hazard and risk (Pelfini and Bollati 2014). Geoheritage intrinsically has natural and cultural elements, and in this context, geomorphology has a cultural component known as cultural geomorphology (Panizza and

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Piacente 2003). The interactions between cultural components of a territory and the geomorphological context favor the geoheritage recognizance (Boukhchim et al., 2018).

Geoheritage needs to be appreciated by the wider regional, national, and international community through tourism. Geotourism is a form of tourism centered on some aspects of the Earth's geological and/or geomorphological heritage that can have beneficial or negative impacts on geoheritage (Newsome and Dowling 2018). Once geoheritage is widely understood and valued, a need of geoconservation begins. The geoconservation community must work to ensure geoheritage conservation in protected areas gains more significance in local, national, and international agendas for nature, sustainable development, and human well-being (Gordon et al. 2018).

Numerous quantitative and qualitative methodologies have been proposed to inventory geomorphosites during the last two decades (Zwoliński et al. 2018; Mucivuna et al. 2019). In Latin America, studies on geomorphosites have been increasing (Brilha 2018). However, in Central America and Costa Rica, they are scarce and focused on volcanic landscapes. For example, Pérez-Umaña (2017) and Pérez-Umaña and Quesada-Román (2018a) studied Poás Volcano National Park geomorphosites, the most visited volcano in Central America. Moreover, Pérez-Umaña et al. (2018) compared geomorphosites of Poás volcanoes in Costa Rica, Paricutin in Mexico, and Teide-Pico Viejo in the Canary Islands of Spain. Recently, Pérez-Umaña et al. (2019) presented an integrated approach for the inventory and management of the geomorphological heritage of the Irazú Volcano National Park.

Due to its geographical nature and discipline novelty, glacial geoheritage studies are more common in temperate than in tropical regions (Migoń, 2018). Chirripó National Park is located at central-south Costa Rica in the Cordillera de Talamanca at 9°30′N and 83°30′W and presents a group of glacial and periglacial landforms with great geodiversity (Quesada-Román et al. 2019). The Strategic Environmental Assessment of UNESCO mentioned the importance of the La Amistad Biosphere Reserve (in which the park belongs), especially due to the existence of a geopark proposal for the Chirripó National Park (UNESCO, 2018). In addition, Pérez-Umaña and Quesada-Román (2018b) suggested in their national proposal that this protected area has geophysical and cultural elements to be declared as a geopark. Therefore, we evaluate the geomorphosites of the Chirripó National Park using an integrated approach for the inventory and management of geomorphological heritage for the promotion of geotourism in a unique tropical paleoglacial geoheritage.

Methodology

This study was carried out in three stages: (1) an inventory of the landforms of Chirripó National Park to identify geosites with geomorphological interest inside of the protected area, (2) a cultural characterization of the historical geography of this national park, and (3) an assessment of the geomorphosites divided into four main stages (Fig. 1; see Reynard et al. 2016 for details). (a) Site description: For each inventoried site, we collected general data (coordinates, altitudes, etc.), a description, a simplified geomorphological map, and an explanation of the morphogenesis. (b) Intrinsic value assessment: We evaluate the central or scientific value and the additional values, including ecological, aesthetic, and cultural values. (c) Use and management characteristics: We documented the protection of the site (protection status, damages, and threats) and its promotion (visit conditions—accessibility, security, site context, tourism infrastructures—and educational facilities and interests). (d) Synthesis: it gives an overview of the intrinsic value, the use and management characteristics, and some protection or promotion measures are proposed.

Selection of Geomorphosites

For the selection of the geomorphosites evaluated in this work, a previous bibliographic review was carried out to identify sites that have been studied in the study area. Scientific studies as articles and dissertations were reviewed and taken into account to identify some of the geomorphosites of interest. Inventories with the main attractions were searched by the National System of Conservation Areas, which is the entity in charge of the administration of protected areas of Costa Rica. In addition, topographic maps with a scale of 1:50.000 were reviewed to identify particular landforms to investigate these locations. Finally, fieldwork was carried out over three campaigns between 2016 and 2018 with the objective to collect data and some photographs. These were then used to identify which sites to evaluate the Chirripó National Park.

Geomorphological Survey

The geomorphological survey was developed in three phases: pre-mapping, field work, and post-mapping (Otto and Smith 2013). During the pre-mapping, the morphogenetic map was generated based upon aerial photo interpretation (API) at 1:25,000 scale from the CARTA project (Costa Rica Airborne Research and Technology Applications), a NASA mission which mapped Costa Rica between 2003 and 2005. These aerial photographs were georeferenced and processed to accomplish the geomorphological mapping. The method allowed mapping the genesis, dynamics, morphology, evolution, and age of the different landforms and its processes using various manual and digital graphic techniques to develop the final cartographic product (Otto et al. 2018). The fieldwork was conducted during three ground checks between 2016 and 2018 to verify landform dynamics and limits using a preliminary morphogenetic map. During the post-mapping, a legend

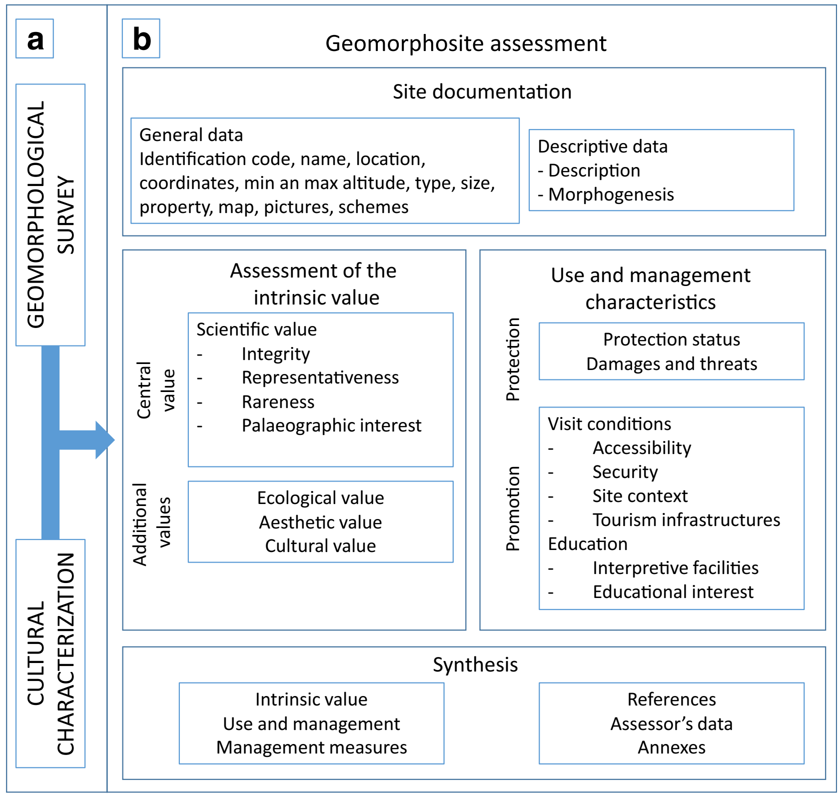

Fig. 1 Methodology in two steps: (a) geomorphological survey and cultural characterization; (b) geomorphosite assessment (based on Reynard et al. 2016). Modified from Boukhchim et al. (2018)

for the geomorphological map was developed, grouping the exogenic landforms by volcanic, fluvial, gravitational, and glacial genesis. Finally, the map was created within a Geographic Information System (ArcGIS 10.3).

Cultural Characterization

Chaverrí (2008) mentions that the name Chirripó probably has Quechua origin, which means "Land of Eternal Waters." Many visitors consider it as a place full of mysticism (Ross and Capelli 2014). Interestingly, Cerro Chirripó was mistaken as a volcano in the past (Alvarado 2011). In addition, Cerro Chirripó is located the tri-provincial point, where the boundary between the provinces of San José, Cartago, and Limón is located (Chaverrí, 2008).

The first documented expeditions of people who ascended Cerro Chirripó date back to the beginning of the twentieth century. Chaverrí (2008) described in detail expeditions to this peak. The first person to climb Cerro Chirripó was the German Agustin Blessing in 1904. He was helped by indigenous people who accompanied him until the middle of the mountain. The summit is a sacred place for natives and where their gods could punish them. The first Catholic Mass held at the top of Cerro Chirripó in 1957 by the priest of San Isidro de General. The ascent carried out in 1955 is one of the most important because the German geologist Richard Weyl and other Costa Rican scientists discovered evidence of glaciations during the Pleistocene in this massif. This marked the beginning of the ascent of many researchers to the Cerro Chirripó to carry out different geology and ecology studies.

Three lakes are located in Valle de los Lagos. The largest lake is named Lago Chirripó, also named San Juan Lagoon and Grande de Chirripó Lagoon. The latter is the most appropriate because it is the largest and deepest lake in the Chirripó massif (Horn et al. 2005). A group of people who climbed Cerro Chirripó reported the existence of this lagoon in 1905 (Chaverrí, 2008). The second lake in Valle de los Lagos is called by Horn et al. (2005) Lago Chirripó to differentiate it from Lago Chirripó. However, this lake was named Lago de las Damas in honor of the two first women to climb it during an expedition carried out in 1960 (Horn et al. 2005).

Lago Ditkevi is located outside of Valle de los Lagos. It is considered a place for reconciliation with God. Even its name means "Place to be close to God" (Consorcio Aguas Eternas 2016a). An indigenous legend about Lago Ditkevi says that if a person is impure or commits a sin, a dragon will appear to eat that person. However, if the dragon considered that the person could be forgiven, he would let him leave the lake (Caminatas al Chirripó 2018). The name of Sabana de los Leones comes from the similarity of vegetation with a lion mane when it dries and blows in the wind (Consorcio Aguas Eternas 2016b). Furthermore, due to the coloring of the plants in dry season, this place is named golden valley (Chaverrí, 2008). Another story of the area's name claims that a group of tourists saw a puma and they confused it with a lion (Caminatas al Chirripó 2018). Valle de los Conejos receives its name from the rabbits that can be found there. Nevertheless, due to more frequent damage from human presence, it has become difficult to observe them during the day (Caminatas al Chirripó 2018).

Cerros Cuerici, located to the west of Cerro Chirripó, also has the name of Chirripocillo and Chirripó Pequeño (Gómez 2005; Chaverrí, 2008). Cerro Ventisqueros is another interesting hill whose name comes from the strong winds that hit this summit (Caminatas al Chirripó 2018). Los Crestones were declared national symbol by the law N°8943 of April 28, 2011 (Asamblea Legislativa 2011). A popular legend claims that near Los Crestones, the compasses do not work because of the existence of strong magnetic field. This is because the local rocks have a high content of magnetite that causes the compasses to point in other directions (Lachniet et al., 2005a).

Cabécar people (a native indigenous group in the Caribbean of Costa Rica) have a sacred history named “The mother of Surá Yaba.” It says that Namay Tamí (mother of Surá Yaba) was looking for her son who was working the land. Once she did not find him, she climbed the Cerro Chirripó to cry and her tears formed the rivers that now run down to the Caribbean (MEP 2017). The Chirripó River originates in the upper parts of Cerro Chirripó and has a very marked cultural connotation with the Cabécar people, because for them the Chirripó River is more important than Cerro Chirripó itself (Solís, 2016). For this reason, Cabécars call the Chirripó River Duchí (Solís 2016; MEP 2017), which means High Chirripó in Cabécar language (Salinas 2017). Even in the Cabécar language, they do not use the word Chirripó, but they mention Duchí when they refer to the Chirripó River, its territories, or any element that in Spanish relates to Chirripó.

Study Area

Chirripó National Park is located in the Talamanca Range, the most prominent mountain system in Central America. This range extends 175 km from the central-southern portion of Costa Rica to the eastern sector of Panama (Marshall 2007). Its landscape is the result of ~~a~~ complex tectonics. Its architecture has a direct relation to the subduction processes between the Cocos and Caribbean plates with has implications on regional volcanism and seismicity (DeMets et al. 2010). In SE Costa Rica, the collision of the Cocos Ridge, a sequence of an oceanic crust growth from the Galapagos hotspot, stopped volcanism in the Cordillera de Talamanca about 2 Ma ago (Morell et al. 2012). Geology includes plutonic rocks, granodiorites, and volcanic rocks that were exposed between 12 and 7.8 Ma ago, as well as andesites and basalts ranging in age from 29 to 7 Ma (Denyer and Alvarado 2007; Alfaro et al., 2018). Geomorphology of this territory is defined by a high uplift rates ranging from 1.7 to 8.5 m kyr^{-1} (Gardner et al. 2013), under the control of faulting with NW-SE and N-S orientations (Alvarado et al., 2017). Volcanic slopes shaped by glacial or periglacial action characterize the glacial landscape (Quesada-Román 2016). The results are well-preserved cirques, arêtes, moraines, till deposits, and glacial lakes above 3000 masl (Quesada-Román et al. 2019). The interrelated dynamics of tectonics, climate, geomorphological, and anthropic processes favor the occurrence of constant landslides and floods in the surrounding territory (Quesada-Román et al. 2018; Quesada-Román and Zamorano-Orozco, 2019b; Quesada-Román et al. 2020a).

During the LGM (~ 26.5–19 ka; Clark et al. 2009), several paleoglaciers advanced in tropical America (Mark et al. 2005; Vázquez-Selem and Lachniet 2017). Glacial landforms associated with these past cold climate episodes have persisted because glaciers effectively shaped the landscapes (Porter 2001; Lachniet and Vázquez-Selem 2005b). Different authors have studied glaciated landscapes in high elevations of Costa Rica since the late nineteenth century (Weyl 1955; Hastenrath 1973; Castillo-Muñoz 2010). In addition, geomorphological mappings have been made with different techniques and scales (Bergoeing 1977; Barquero and Ellenberg 1983; Lachniet and Seltzer 2002; Lachniet et al. 2005a; Quesada-Román 2016; Quesada-Román and Zamorano-Orozco 2019a; Li et al. 2019). Several studies have determined the glacial dynamics in Chirripó National Park over 3000 masl during the LGM (Horn 1990; Orvis and Horn 2000; Lachniet and Seltzer 2002; Cunningham et al. 2019; Potter et al. 2019; Quesada-Román et al. 2020b).

Climatic conditions are dominated by northeast trade winds, the latitudinal migration of the Intertropical Convergence Zone, cold fronts, and tropical cyclones (Campos-Durán and Quesada-Román 2017; Esquivel-Hernández et al. 2019). These circulation processes produce two rainfall maxima, one in May and another one in October, which are interrupted by a relative minimum between July and August known as the mid-summer drought (Maldonado et al. 2018). Historical records show that ~ 89% of the precipitation falls among May and November (wet season). As a result, a well-defined dry season is established from December to April with average precipitation of ~ 2000 mm and temperatures in the study area of 9.7 °C (Quesada-Román 2017).

Different types of mountainous forests and peatlands compose the vegetation of the Cordillera de Talamanca. At elevations exceeding 3000 m, páramo landscapes prevails, a grassy or shrub-dominated ecosystem typical of cool and wet upper hills of tropical mountains (Kappelle and Horn 2016). Along Costa Rican páramo, hundreds of palustrine and lacustrine wetlands have an important hydrological and ecological regional function (Esquivel-Hernández et al. 2018, Veas-Ayala et al., 2018).

Results

Geomorphological Characterization of Chirripó National Park

Fourteen geomorphosites were selected and are located inside of Chirripó National Park. Each geomorphosite is seen in different parts of the national park due to the altitude at which they are located, while for others it is necessary to walk some hours to observe them. The selected geomorphosites are described below. In addition, Table 1 shows the documentation data of these geomorphosites and Fig. 2 shows the geomorphology of Chirripó National Park and Fig. 3 illustrates some of the studied geomorphosites.

Valle Talari is a glacial valley molded during the LGM; an assumption made due to the location of clear lateral moraines in both of its slopes. Probably after the LGM terminus within deglaciation processes, periglacial activity was the dominant process in these high mountains. Eventually, paraglacial processes have favored the abrupt formation of fluvial knickpoints and mass movements just after the glacial/periglacial regions during the Holocene. Valle de los Conejos is composed of gentle slopes molded by glacial action that alternate with clear till deposit areas and riegels. Hundreds of palustrine wetlands represent the origin of several rivers that finally compose the bigger water basin of Costa Rica (Térraba River). Valle de los Lagos is a sequence of glacial lakes blocked by a frontal riegels (Fig. 3a). It was likely formed as a deposition of the progressive movement of paleoglaciers. Here, Lago Chirripó represents the deepest glacial lake of the national park with ~20 m and the second deepest natural lake of Costa Rica surpassed only by Río Cuarto Maar.

Cerro Chirripó is a glacial volcanic (plutonic) modeled mountain where sharp and convex arêtes converge (Fig. 3b). This summit represents the highest elevation in Costa Rica (3820 masl). It presents erosive morphology caused by glacial action. Valle de las Morrenas is a sequence of glacial lakes embedded in extensive till deposits due to the relative glacier movements during the LGM (Fig. 3c). Laguna Ditkevi was formed due to the formation of a riegel that blocked the river flows damming this glacial lake. The progressive movement of paleoglaciers likely formed it (Fig. 3d).

Loma Larga Moraine was formed due to the progressive movement of paleoglaciers along Chirripó River valley. It is the longest lateral moraine preserved in the national park with approximately 1.4 km long and 100 m wide. Cerro Ventisqueros is a glacial volcano-plutonic modeled mountain where sharp arêtes converge. This summit represents the second highest elevation of Costa Rica (3812 masl). Los Crestones (Fig. 3e) is a group of volcanic plugs molded by glacial action that acted as sharp arêtes during the LGM, reaching 3720 masl. These rocks have a height of 30 m. This formation has large concentrations of magnetite.

Sabana de los Leones (Fig. 3f) is a glaciofluvial origin subhorizontal slope where a Talari River tributary flows between 3000 and 3200 masl. It is not clear if the origin was developed during the LGM or even in a prior glaciation. This

Table 1 Documentation of selected geomorphosites in Chirripó National Park

Geomorphosite		Data					
Code	Name	Altitude (m)	Surface (m2)	Coordinates	Main geomorphological process	Characteristics	Type of geometry
CHIgla001	Valle Talari	3320	189,204	9°27′20″N–83°30′17″W	Glacial and fluvial	Natural	Areal
CHIgla002	Valle de los Conejos	3500	402,801	9°27′56″N–83°29′39″W	Glacial and fluvial	Natural	Areal
CHIgla003	Valle de los Lagos	3520	446,635	9°28′53″N–83°29′38″W	Glacial and fluvial	Natural	Areal
CHIgla004	Cerro Chirripó	3820	869,393	9°29′04″N–83°29′19″W	Glacial	Natural	Point
CHIgla005	Valle de las Morrenas	3520	1,624,563	9°29′28″N–83°29′14″W	Glacial and fluvial	Natural	Areal
CHIgla006	Laguna Ditkevi	3460	32,556	9°28′12″N–83°28′48″W	Glacial and fluvial	Natural	Areal
CHIgla007	Loma Larga Moraine	3400	74,022	9°30′30″N–83°29′47″W	Glacial	Natural	Areal
CHIgla008	Cerro Ventisqueros	3812	256,192	9°28′33″N–83°30′37″W	Glacial	Natural	Point
CHIvol009	Los Crestones	3715	26,274	9°27′05″N–83°29′54″W	Volcanic	Natural	Point
CHIgla010	Sabana de los Leones	3200	1,297,035	9°25′14″N–83°30′33″W	Glaciofluvial	Natural	Areal
CHIgla011	Cerros Cuericí	3345	3,353,761	9°34′52″N–83°38′07″W	Periglacial	Natural	Point
CHIgla012	Cerro Urán	3600	833,897	9°30′36″N–83°32′05″W	Glacial	Natural	Point
CHIgla013	Cerro Terbi	3765	104,554	9°27′19″N–83°29′41″W	Glacial	Natural	Point
CHIgla014	Cerro Chirripó Grande	3749	2,006,618	9°30′10″N–83°28′54″W	Glacial	Natural	Point

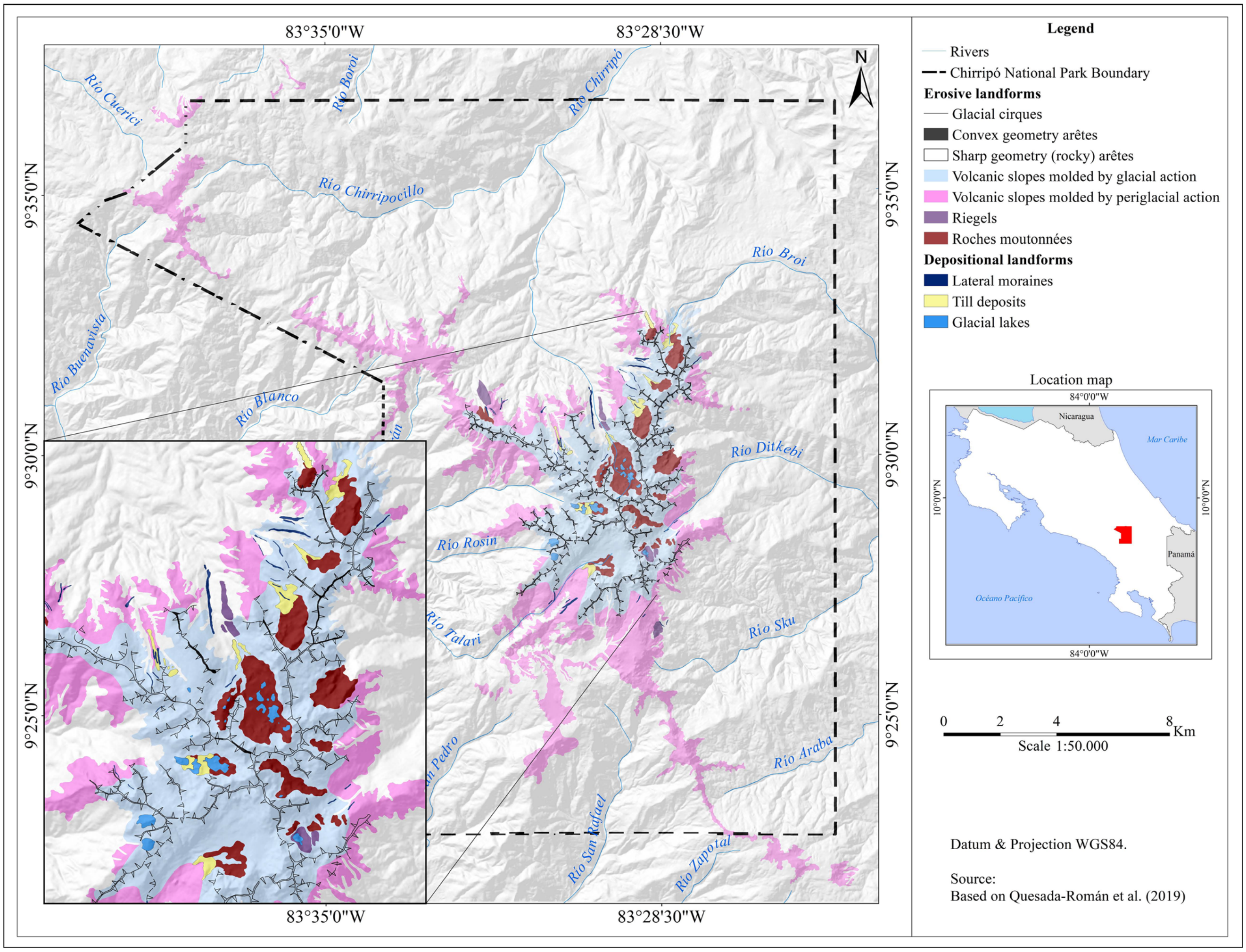

Fig. 2 Glacial geomorphology of Chirripó National Park

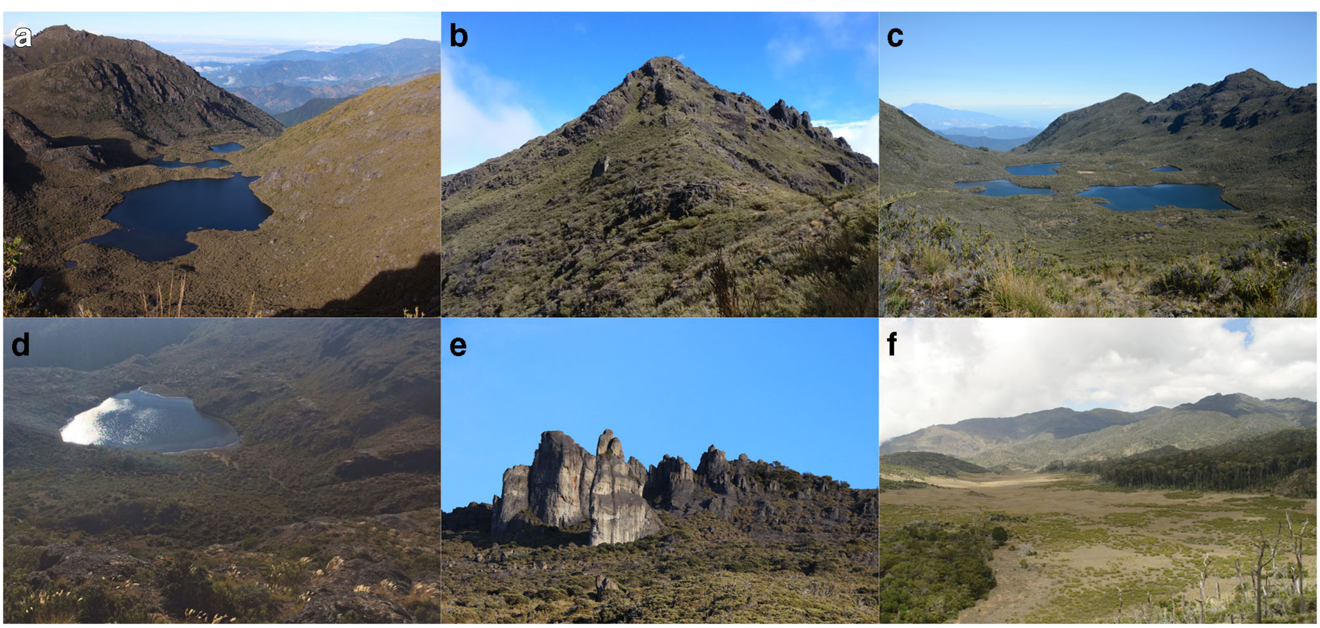

Fig. 3 Some geomorphosites of Chirripó National Park. **a** Valle de los Lagos, **b** Cerro Chirripó, **c** Valle de las Morrenas, **d** Laguna Ditkevi, **e** Los Crestones, **f** Sabana de los Leones

uncertainty is due to its morphology, the absence of absolute dating, and its relative position on a periglacial domain. Cerros Cuerici is a group of volcanic mountain hills in the upper western part of the national park at 3360 masl. Periglacial processes such as weathering, frost action, mass movement, nivation, and frozen ground have modeled them.

Cerro Urán is a glacial volcanic modeled mountain where sharp arêtes converge at 3213 masl. This summit is surrounded by volcanic slopes molded by periglacial action and heavily eroded glacial cirques. Cerro Terbi is a glacial volcano-plutonic modeled mountain where sharp arêtes converge at 3720 masl. Cerro Chirripó Grande is a glacial volcano-plutonic modeled mountain where sharp arêtes converge at 3760 masl representing the third highest elevation of Costa Rica. Volcanic slopes molded by glacial action, as well as preserved glacial cirques and valleys, surround this summit.

Geoheritage Inventory and Management

Scientific Value Assessment

The compilation of the assessment of scientific values of selected geomorphosites in Chirripó National Park is presented in Table 2.

The integrity of each geomorphosite remains intact. The location of these geomorphosites, in addition to their difficult access, ensures that there are no strong impacts caused by visitors. The LGM molded the shape of these geomorphosites and there have been no similar events that modify them, so historically each landform has remained intact. Nine geomorphosites are highly representative and are the main attractions of this protected area. One of these is Cerro Chirripó, which is the main symbol of this national park and one of the sites that many visitors wish to climb to reach the highest peak in the country. Similar case to Los Crestones, as a relict evidence of volcanic activity in the Talamanca Range.

Ten geomorphosites present a unique rarity because they are the only landforms with evidence of the LGM in Costa Rica. Nonetheless, there are other possible highlands molded during the LGM in Costa Rica, but only the Chirripó National Park glacial landforms have been clearly identified and dated. Therefore, these geomorphosites are unique and generate national and international scientific interest. Sabana de los Leones is unique due to its periglacial and glaciofluvial origin and flat morphology. Also, Loma Larga Moraine is an important place to study because it is a well conserved moraine. Cerro Urán, Cerro Terbi, and Cerro Chirripó Grande have a medium rarity because they are hills that mix with the landscape and at first sight are confused with other nearby hills. Although, they present glacial actions, they do not have a rarity as significant as the other geomorphosites. Likewise, Valle Talari does not have a significant rarity, as they are abundant landforms in the national park.

Paleographic interest shows that eleven of the geomorphosites have very high value because they are the remnants of the LGM. The other geomorphosites get a medium value, but still show an interest in being linked to the other geomorphosites and the glacial period that molded them into their current morphology. The average of the scientific assessment is 0.88, which means that the geomorphosites of Chirripó National Park have a high scientific interest because they are rare and unique landforms for Costa Rica, Central America, and the tropical region. In addition, this national park is an object of study for several researchers to understand the geological and climatic history of this region of the world.

Additional Value Assessment

The geomorphosites of Chirripó National Park represent the very specific ecosystem of páramo. Despite páramo being a common highland~~s~~ grass and shrublands in Andes, Chirripó National Park is an endemic well-developed case for Central America (Fig. 4a). Chirripó National Park was declared a protected area in 1975 in order to protect their pristine oak forests, its unique páramo ecosystem, and strategic water springs with a regional importance (Fig. 4b). Geological and climatic dynamics through thousands of years have favored the conditions to develop a unique páramo ecosystem in Central America. The protection of this ecosystem is crucial to protect hundreds of highland wetlands, fauna, and flora endemism (Fig. 4c), and provide potable water to dozens of rural communities.

All considered and evaluated geomorphosites can be visited all year long. Visits require time and physical effort. Different walking trails have difficulties and can sometimes take hours to reach the geomorphosites or their viewpoints. Glacial and periglacial dynamic during the LGM developed an intricate landscape from flat surfaces to steep walls. The impressive isolated mountains such as Cerro Chirripó, Cerro Ventisqueros, or Los Crestones contrast with a diverse rich landscape in colors and hues. The landscapes vary from gray sharp mountains modeled by ancient glaciers to vast green páramo shrubs, yellow grasslands, and transparent pristine freshwaters (Fig. 5). Chirripó National Park breaks any conformity with other landscape in Costa Rica. Its geological and climatological dynamics have molded a unique mélange of glacial landforms with rich ecosystems that draw a set of morphologies, colors, and hues exceptionally distinctive.

Cultural value present in Chirripó National is very significant (Table 3). Its name is derived from an indigenous language. Cerro Chirripó is present in indigenous narratives and legends due to this site having high religious value for indigenous communities as Cabécars. The first registered ascent of this mountain was in 1904, with a catholic mass being held in gratitude, showing the geomorphosites importance at a religious level for the population. The ascents of Cerro Chirripó

Table 2 Assessment of the scientific values of geomorphosites in Chirripó National Park

Geomorphosite		Criteria				Scientific values
Code	Name	Integrity	Representativeness	Rareness	Paleographic value	
CHIgla001	Valle Talari	0.75	0.5	0.25	0.5	0.5
CHIgla002	Valle de los Conejos	0.75	0.5	1	0.5	0.69
CHIgla003	Valle de los Lagos	0.75	0.75	1	0.75	0.81
CHIgla004	Cerro Chirripó	0.75	1	1	0.75	0.88
CHIgla005	Valle de las Morrenas	0.75	0.75	1	0.75	0.81
CHIgla006	Laguna Ditkevi	0.75	0.25	1	0.75	0.69
CHIgla007	Loma Larga Moraine	0.75	0.5	1	0.75	0.75
CHIgla008	Cerro Ventisqueros	0.75	0.75	1	0.5	0.75
CHIvol009	Los Crestones	0.75	1	1	0.75	0.88
CHIgla010	Sabana de los Leones	0.75	0.5	1	0.75	0.75
CHIgla011	Cerros Cuerici	0.75	0.5	1	0.5	0.69
CHIgla012	Cerro Urán	0.75	0.25	0.5	0.5	0.5
CHIgla013	Cerro Terbi	0.75	0.25	0.5	0.5	0.5
CHIgla014	Cerro Chirripó Grande	0.75	0.5	0.5	0.5	0.56
Average		0.75	0.57	0.84	0.62	0.7

have been well documented throughout history. These ascents have historical and scientific importance because it was when the existence of lakes at these altitudes was documented and recorded evidence of glaciations in these mountains, being a finding of great geohistorical importance for Costa Rica.

Another cultural aspect is its toponym, as the names of the geomorphosites such as Sabana de los Leones and Valle de los Conejos have mostly symbolic names for some animal sightings. Others relate their names to some climatic factor such as Cerro Ventisqueros (strong winds hill). Cerros Cuericí is also known as Chirripocillo due to its resemblance with Cerro Chirripó. The geomorphosite with the most representative cultural level is Los Crestones, which was declared national symbol of Costa Rica representing the geodiversity of the country. Therefore, the geomorphosites of Chirripó National Park have a very high cultural value. Costa Rican population identifies with this massif and has a curiosity to explore their mountains and its secrets that science is still revealing.

Use and Management Characteristics

All of the geomorphosites are located within Chirripó National Park, which has a very high management category value aimed at ecosystem conservation and tourism (Table 3). Therefore, the studied geomorphosites are well protected and conserved within the La Amistad Biosphere Reserve since 1982. This protected area is composed of the Chirripó National Park, seven other protected areas, and eleven indigenous territories. Due to its wide coverage of forest, water production, biodiversity, and variety of ecosystems that provide various environmental services to the citizens of Costa Rica and Panamá, it was declared World Heritage Site.

The main threats facing Chirripó National Park are wildfires, wastewater use and discharge, agricultural, livestock expansion, climate change, and tourist visits. Wildfires could reach areas where some geomorphosites are located, leaving them vulnerable. Climate change represents a threat if rainfall

Fig. 4 Some photographs illustrating the ecology of Chirripó National Park. **a** Community of Chusquea near to Cerro Chirripó. **b** River in the páramo surrounded by *Chusquea subtessellata*. **c** *Sceloporus malachiticus*, a salamander commonly seen in the protected area

Fig. 5 Some landscapes seen in the Chirripó National Park

and temperature patterns change eroding the morphology of geomorphosites and endangering several species.

Visit Conditions

Chirripó National Park is accessible only by land, about 3 h from the capital of the country, San José. The entrance to the national park can be reached from San Gerardo de Rivas, Herradura de Rivas, or San Jerónimo de Cajón without a guide. In addition, another longer route close to the Inter-American Highway allows access the national park with a local guide. The location of public transport and parking lots is several kilometers away. Figure 6 shows that these trails can take from 3 to 5 days to complete a circuit where you can see much of the National Park. An extensive network of trails exists for visitors to access the geomorphosites (Fig. 6). Although some sites are close to each other, it can take hours from one point to another. This is due to the rugged terrain with rocky and muddy trails in the middle of the forests.

Visitors can walk the trails safely but should be vigilant to avoid injuries. Wet conditions during rainy season should be considered the trails become slippery. In the Chirripó National Park, there are some shelters where visitors can rest during their stay. Base Crestones is the most recognized and serves as a reference for the rest of the attraction sites. This hut provides services and comfort to visitors, from a restaurant to information for tourists. The National Park administration office is located in San Gerardo de Rivas. Within the national park, there is no other infrastructure like these shelters. During the last 3 years with the private concession of the reservations, accommodation, and restaurant services of the principal shelter in Base Crestones, the visitation has increased from a mean of 8000 visitors to more than 20,000 annually.

Educational Interest

Many signposts of the trails and the main attractions of the Chirripó National Park are in Base Crestones. Only in Cerro Chirripó, a sign indicates the maximum altitude (3820 m) but

Table 3 Assessment of the additional values, use, and management characteristics of geomorphosites in Chirripó National Park

Geomorphosite		Additional values	Use and management characteristics
Code	Name		
CHIgla001	Valle Talari	0.25	0.75
CHIgla002	Valle de los Conejos	0.5	0.75
CHIgla003	Valle de los Lagos	0.75	0.75
CHIgla004	Cerro Chirripó	1	0.75
CHIgla005	Valle de las Morrenas	0.75	0.75
CHIgla006	Laguna Ditkevi	0.5	0.75
CHIgla007	Loma Larga Moraine	0.5	1
CHIgla008	Cerro Ventisqueros	0.75	0.75
CHIvol009	Los Crestones	1	0.75
CHIgla010	Sabana de los Leones	0.75	0.75
CHIgla011	Cerros Cuerici	0.25	1
CHIgla012	Cerro Urán	0.25	1
CHIgla013	Cerro Terbi	0.25	0.75
CHIgla014	Cerro Chirripó Grande	0.25	1
Average		0.6	0.8

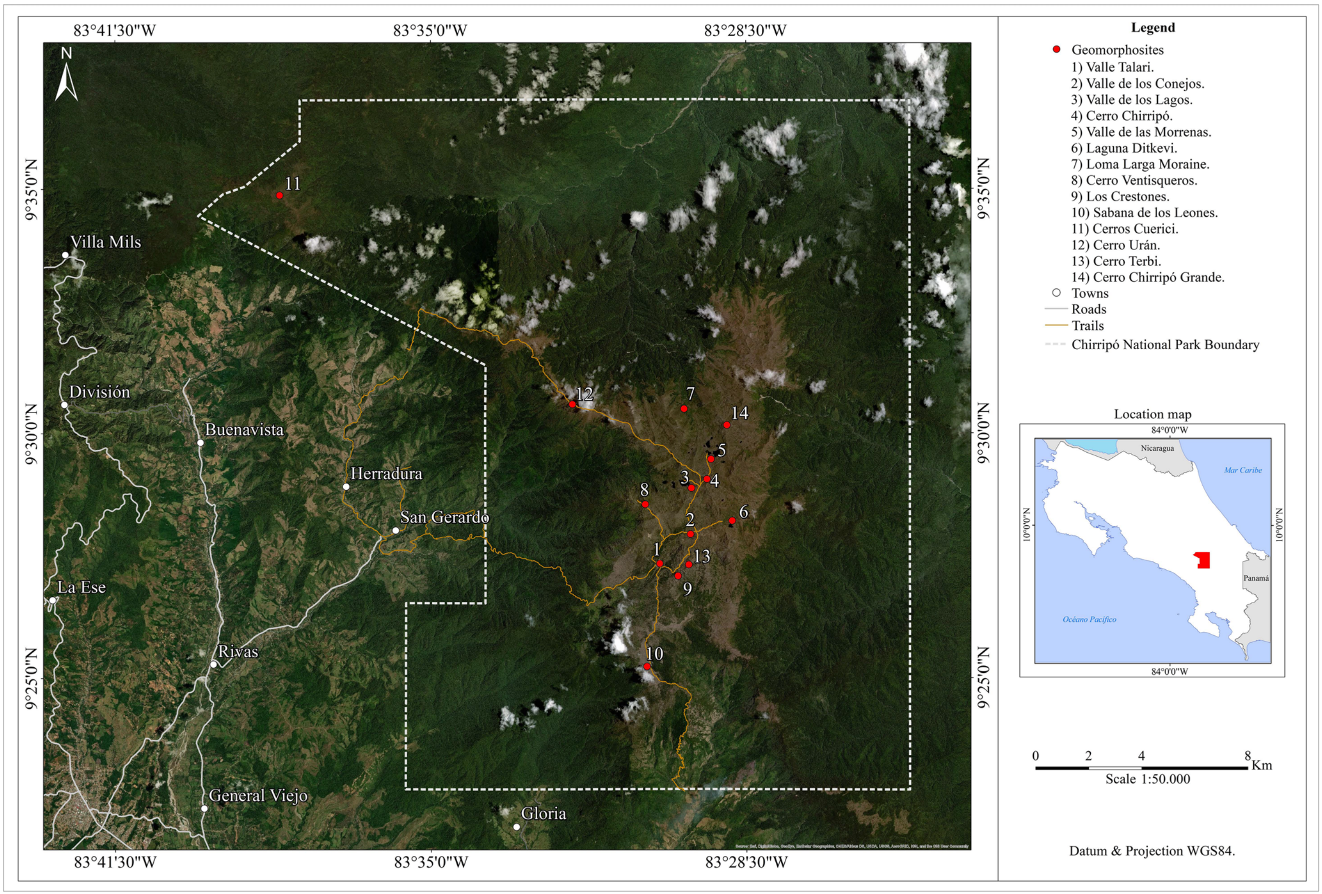

Fig. 6 Trails and location of geomorphosites in Chirripó National Park

in other places, this information is not available. Neither general nor scientific informative signs are common in the protected area viewpoints. In the Base Crestones shelter, there is a topographic map of the national park, being the only element facilitated to promote the attractiveness of the place. However, La Amistad Pacífico Conservation Area disseminates digital material on the attractions of Chirripó National Park. In addition, multiple websites provide touristic information. Many of people who visit Chirripó National Park are hikers, both national and from abroad, for whom this site represented a challenge due to these steep slopes. Scientists ascend to study the glacial landscape dynamics during the LGM, páramo ecosystem, hydrological, climatological, and soil aspects of a paleoglacial tropical environment. While the motivation for most tourists is trying to reach—and keep in their memories—the top of Costa Rica.

Discussion

Tropical Geoheritage Studies on Glacial Environments

Geoheritage studies in glacial and periglacial environments have been broad in temperate regions but scarce in tropical regions (Migoń, 2018). During the LGM, numerous valley glaciers advanced above 3000 masl in tropical mountain regions of America (Mexico, Guatemala, Costa Rica, and along the Andes), Africa (Morocco, Kenya, Ethiopia, and Uganda), Asia (Taiwan, Indonesia, and Malaysia), and Papua New Guinea in Oceania (Porter 2001; Mark et al. 2005). At present, tropical glaciers are located on the three highest East African Mountains, the Indonesian Puncak Jaya, and the Andes from Chile-Argentina to Venezuela (Kaser and Osmaston 2002). Tropical paleoglacial geoheritage studies have been made in Ethiopia (Asrat 2018), Colombia (Tavera-Escobar et al. 2017), Peru (Seijmonsbergen et al. 2010; Gałaś et al. 2018), and Malaysia (Hussain et al. 2008). On the other hand, present tropical glacial geoheritage studies were recently made in Chile (Benado et al. 2019), Indonesia (Kusumahbrata 2008), and Colombia (Tavera-Escobar et al. 2017).

Despite all of the glacial and paleoglacial geoheritage studies made, only a few works have geomorphosite evaluation and can be compared. In order to stimulate discussions around to the methodological approaches used for the evaluation of the geomorphological heritage, it is important that researchers critically evaluate their results and the criteria they used (Mucivuna et al. 2019). Other glacial geomorphosites have been evaluated according the integrated approach for the inventory and management of geomorphological geoheritage (Reynard et al. 2016). Our results in Chirripó National Park indicate an average integrity values of 0.75, representativeness (0.84), rareness (0.57), paleographic values (0.62), and scientific values of 0.75. Similar values to our results have been reported in Morocco (Bouzekraoui et al. 2018), Colombia (Tavera-Escobar et al. 2017), Ethiopia (Mauerhofer et al. 2018), Romania (Ovreiu et al. 2019), and Czech Republic (Kubalíková 2019). Therefore, we can now start to talk about a worldwide glacial geomorphological heritage assessment. Geoconservation now has opportunities to enhance its global impact under the new focus on "people and nature" and the "conserving nature's stage" using protected areas (Gordon et al. 2018).

Conclusions

We performed an integrated geomorphological approach for the inventory and management of Chirripó National Park geoheritage. We evaluated 14 geomorphosites of mainly glacial morphogenesis formed during the Last Glacial Maximum. The average scientific value of the geomorphosites is 0.75. This geoheritage is well preserved (0.75), rare (0.57), and representative (0.84). In addition, it plays an important role in the paleographic value (0.62), and has significant additional values (0.6) as well as use and management characteristics (0.8). In this context, the most important geomorphosites with the highest average (0.88) in this assessment are Cerro Chirripó and Los Crestones. These landforms have an important scientific value and different cultural values with interest to the population. Certainly, this information is critical for the promotion of geoscience knowledge to the larger public (through geotourism) and conservation decision makers. The use of protected areas for geoconservation is critical worldwide. The methodology used proves to be a useful tool to evaluate geomorphological heritage in tropical and paleoglacial environments. Therefore, we recommend its use in different tropical geomorphic environments. Our results have demonstrated the need of more geoheritage studies on tropical glacial environments. The extent of paleoglacial geoheritage studies in Central America can be done in dated spots, such as Sierra de los Cuchumatanes in Guatemala, and locations where dating is needed to be confirmed in Costa Rica (e.g., Cerro Buenavista, Cerro Dúrika, and Kámuk) and Panama (e.g., Cerro Fábrega and Barú volcano). Due to the specific geomorphological conditions of low latitudes with intense precipitation and weathering rates, it is important to define the concept of tropical geoheritage and promote its study.

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