Tourist Carrying Capacity of Geological Sites of Interest on San Cristóbal Island for Land Management and Sustainable Tourism Development

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Abstract

The rapid growth of tourism in heritage destinations such as the Galapagos Is-lands (a UNESCO World Heritage Site) poses significant challenges for conservation and land management. Assessing the tourist carrying capacity of the islands' geological sites (geosites) is essential for preserving their natural and geomorphological heritage. This analysis allows for the regulation of visitor flows, minimizing environmental impacts, and promoting sustainable tourism that benefits local communities. This research aims to evaluate ten geosites on San Cristóbal Island using tourist carrying capacity (TCC) for their conservation and sustainable tourism development, in the context of a geopark. The methodology used was: i) review and collection of information on the ten geosites, ii) evaluation of the TCC, iii) proposal of management and conservation strategies. The number of visits, proposed by the carrying capacity assessment, ranged from 40 to 955 per day, with Playa Mann and Frigate Bird Hill standing out for their large size to accommodate tourists and adequate facilities adapted to tourism. This analysis made it possible to propose sustainable development strategies based on the pillars of geotourism, geoeducation, and geoconservation. A fundamental part of this is the participation of public, private, and government entities through programs that promote awareness and the spread of sustainable tourism, applying geocommunication of the unique values of each geosite. Future research should address issues of environmental, social, and cultural impact assessments at geosites using complementary methodologies to determine their influence on management.

Keywords

Geosites, Tourist carrying capacity, Geotourism, Ecosystem, Sustainable development, Galapagos

1. Introduction

Natural heritage is associated with geological heritage, as both focus on places where geological processes and landscapes characteristic of the area exist, uniquely promoting scientific, educational, and cultural interest in sites of geological interest (geosites) [1, 2]. Geotourism is a valuable tool that focuses on the knowledge, exploration, appreciation, and interpretation of the natural heritage provided by nature, facilitating the socio-economic growth of a region and helping us to understand the conservation of geological elements [3].

Volcanic islands demonstrate the importance of tourism in sites of geological interest, such as the Galapagos Islands (declared a World Heritage Site by UNESCO in 1978), due to their biodiversity and natural environments [4]. Another example is the volcanic island of Jeju in South Korea, which is well known for its lava tunnels and is the only site in the world classified as a Biosphere Reserve [5, 6]. Another example is the island of Tenerife (Canary Islands), which is home to unique volcanic features such as the caldera complex, volcanic strata, and volcanic chimneys [7, 8].

Geotourism is becoming increasingly popular as an alternative form of tourism that focuses on social, cultural, environmental, and economic sustainability criteria to benefit society and the environment [9]. The increase in tourism development at sites of geological interest generates significant economic benefits; however, it also puts considerable pressure on public resources, the cultural environment,

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and the ecological environment, jeopardizing the sustainability of the site. For an adequate tourism development strategy, academics and professionals propose calculating the CCT at sites of interest [10, 11].

The CCT refers to the maximum number of visitors that a site of geological interest can support without affecting its environment (physical, social, economic, and environmental). The CCT is a tool that helps us plan and maintain sustainable management, allowing us to make decisions regarding access regulation, tourism development, and ecosystem preservation [12]. The assessment of the CCT in the islands' geosites is essential for preserving their natural and geomorphological heritage. This analysis allows us to regulate the flow of visitors, minimizing environmental impacts and promoting sustainable tourism that benefits local communities [13]. The CCT will provide information on how many visitors the geological sites of interest can support, allowing us to identify potential tourist hazards arising from physical, biological, and human activities that affect the degradation of heritage [14].

The Galápagos Islands are located approximately 1,000 km off the mainland coast of Ecuador and are known for their biodiversity and natural environments. They consist of 13 main volcanic islands, six smaller islands, and 107 small islets [15, 16]. In addition, the islands have three of the four international designations promoted by UNESCO (World Heritage Site in 1978, Biosphere Reserve in 1984, and Ramsar Site in 2002) and have a geopark project idea in Ecuador [17]. The Galápagos Islands are recognized as a major tourist destination where the highest authorities are examining strategies to promote conservation and community interests through tourism [18].

San Cristóbal Island is located at the eastern end of the Galápagos archipelago and has an area of 558 km2 [19] (Figure 1). The island's population is 8,300 (7,290 urban and 1,010 rural), according to the Population and Housing Census conducted by the National Institute of Statistics and Census (INEC) in 2022[20]. The main economic activity is tourism, followed by agricultural production and fishing [21, 22].

Carrión-Mero et. al. [20] qualitatively explored the ecological heritage and geodiversity of the island, encompassing its origin, geological context, and conservation. These authors proposed a study covering the selection of ten geosites on San Cristóbal Island, with Laguna El Junco being the most prominent site, obtaining two of the three highest values (tourism and education). The Galapagos National Park Directorate reveals that San Cristóbal Island received 274,000 visits in 2024, reflecting a 4% increase in visitors compared to 2022 [23]. There has been an 11% increase in population (825 inhabitants) compared to the 2010 INEC Population and Housing Census [21]. K. Brown [24] highlights that the increase in tourists and population growth affects the Galápagos Islands in terms of the generation of waste (plastics) and wastewater found in tourist sites. This excess has caused deterioration and degradation in the geological tourist sites visited. Therefore, how can tourist visits to sites of geological interest on San Cristóbal Island be regulated for their preservation and proper management?

The aim of this study is to evaluate the TCC of ten geosites on San Cristóbal Island by calculating the physical, actual, and effective TCC for the development of conservation and sustainable tourism strategies in the context of a geopark, allowing for the proper management of the sites. This study will provide a better overview of the number of visitors that geological sites of interest can support, enabling better control of visitor numbers, protecting the ecosystem, reducing environmental impact, and fostering an efficient social culture of site preservation.

2. Materials and Methods

Determining the TCC at geosites is a fundamental step for the effective and efficient management of these sites. In addition, this study contributes to strengthening the definition of sustainable tourism in the preservation of sites of geological interest. In this study, the methodology used was carried out in three phases: i) review and collection of information on the ten geosites, ii) assessment of carrying capacity, iii) proposal of management and conservation strategies (SWOT analysis) (Figure 2).

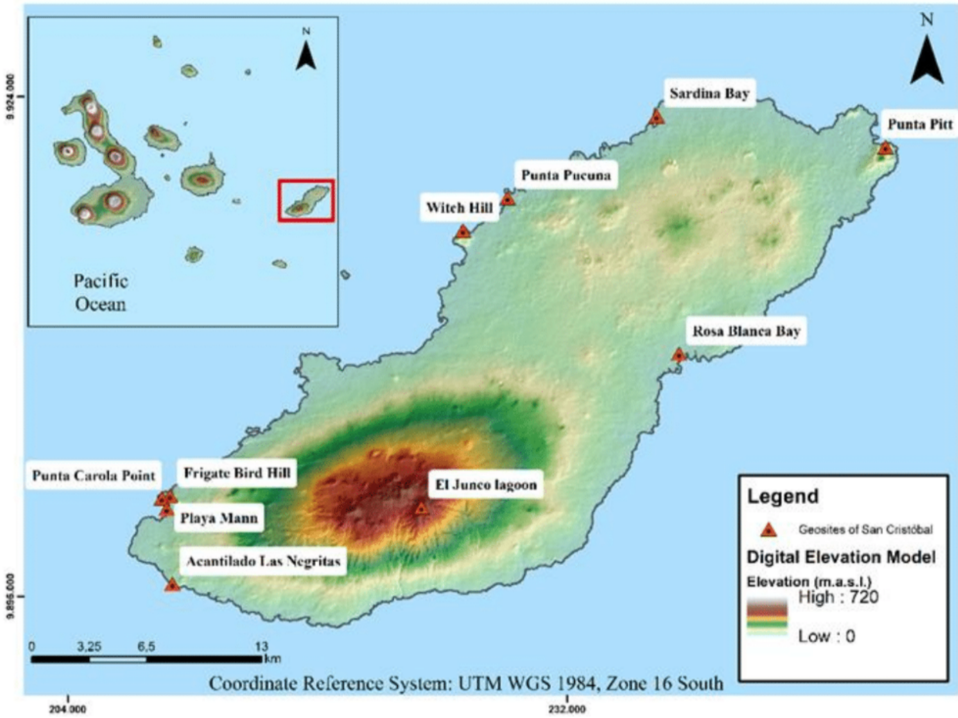

Figure 1: Map showing the location of San Cristóbal Island, Galápagos, and its sites of geological interest.

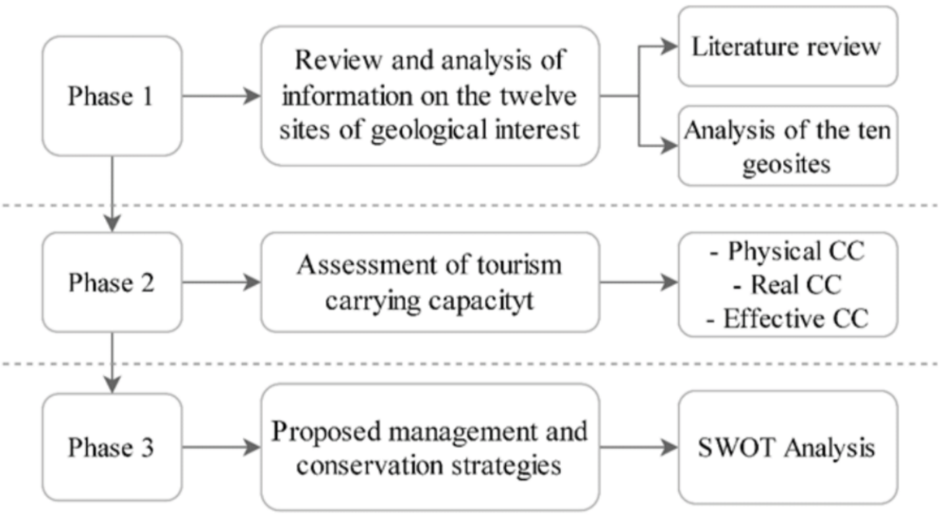

Figure 2: Diagram of the methodology used.

2.1. Selection of sites of geological interest

Phase 1 consisted of reviewing and analyzing bibliographic information that was evaluated in the study area, considering its geological importance in scientific dissemination. For this study, ten of the sites assessed by Carrión-Mero et al. [20] were selected as sites of geological interest (Table 1).

Table 1
Selection of sites of geological interest on San Cristóbal Island.

Code	SGI Name	X (east), Y (north)	General characteristics	Image

SGI-1	Frigate Bird Hill	209757, 9901621	• It is a cone-shaped hill eroded by the waves. • Observation of frigatebirds, sea lions, pelicans, and seagulls. • Access is by land. • Activities include hiking, bird watching, photography, flora sighting, and snorkeling.	
SGI-2	Witch Hill	226208, 9916476	• It is a cone-shaped hill of tuff eroded by the waves. • Gas bubbles formed in low-viscosity lava. • Different species can be found here, such as Darwin's finches, blue-footed boobies, green turtles, and Galápagos marine iguanas. • It is one of the first sites visited by Charles Darwin. • Access is by sea.	
SGI-3	Punta Pitt	249912, 9921133	• It has the largest tuff cone on the island. • Its proximity to the sea has caused erosion of the vertical walls where pyroclastic material is found. • Blue-footed and red-footed boobies can be seen, as well as masked boobies. • It is located at the eastern end and can only be accessed by sea. • Snorkeling, photography, sport fishing, hiking, and flora and fauna observation are popular activities.	
SGI-4	Mann Beach	209583, 9900870	• t is a white sand beach due to the fragmentation of shells. • Sea lions, frigatebirds, iguanas, seagulls, and pelicans can be seen. • Access is by land.	
SGI-5	Punta Carola	209292, 9901481	• It is a horseshoe-shaped white sand bay with large basalt lava flows. • It has dry forest vegetation. • Access is by land. Frigatebirds, iguanas, seagulls, pelicans, and sea lions can be observed.	
SGI-6	Punta Pucuna	228707, 9918300	• It is a small bay with access to caves formed by the solidification of lava flows. • Galapagos green turtles and land finches can be observed. • Access is by sea.	

SGI-7	Rosa Blanca Bay	238311, 9909545	• It is a beach with a variety of dunes and natural pools due to the weathering of basaltic lava. • Species such as white and black tip sharks, moray eels, and green turtles can be observed. • Basaltic rocks cover the coastal lagoons, providing natural shelter for species (birds).	
SGI-8	Sardina Bay	237075, 9922880	• It is a mangrove bay with a coral beach and volcanic rocks. • Species such as manta rays, turtles, and sea lions can be observed. • Sport fishing, photography, bird watching, and turtle and sea lion watching are popular activities. • Access is by sea.	
SGI-9	Las Negritas Cliff	209882, 9896683	• It is a basalt lava cliff in the surrounding area. • Species such as Galapagos lava lizards, blue-footed boobies, frigatebirds, and pelicans can be observed. • Access is by land.	
SGI-10	El Junco lagoon	223860, 9900951	• It is a lagoon located within the caldera (collapsed cone) of an inactive volcano. • It is located at an altitude of 500 m. • Junco (plant species), frigatebirds, and white-tailed ducks can be observed. • It has a surface area of 6 ha and a volume equivalent to 35 million liters of water.	

2.2. Assessment of carrying capacity

Some authors have proposed methodologies for evaluating TCC. Cifuentes discusses the calculation of TCC in tourist areas [25]. The methodology focuses on calculating TCC using three components: i) Physical carrying capacity (PCC), which is the maximum number of visits that an area of the site can support during a set period; ii) Real carrying capacity (RCC), which is obtained from the site's PCC through factors that directly or indirectly affect it (environmental, physical, social, ecological, management); iii) Effective carrying capacity (ECC), which is the maximum number of visits allowed at sites for the analysis of certain variables (equipment, personnel, infrastructure). Some authors have used Cifuentes' methodology to evaluate the TCC and adapt it to the geosites under study, as in the case of Carrión-Mero et al., who described an environmental assessment and carrying capacity in geosites of the Ruta del Oro Geopark Project [1]. Jaya-Montalvo et al. conducted a carrying capacity analysis of geosites on Santa Cruz Island, Galapagos [12].

2.3. Proposed management and conservation strategies

In this phase, strategies will be proposed using a strengths, weaknesses, opportunities, and threats (SWOT) analysis matrix [26] with the participation of academics and researchers. This analysis will contribute to the management of geosites focused on three main areas (geotourism, geoeducation, and geoconservation) that contribute to sustainable tourism and the care of geosites [27, 28].

3. Results and Discussion

3.1. Evaluation of Tourist Carrying Capacity

The TCC at the islands' geosites is essential for the conservation of natural and geomorphological heritage. Calculating the TCC will make it easier to obtain information on how many visits the geological sites of interest can withstand, allowing us to identify potential hazards (physical, biological, and human activities) that affect the degradation of the heritage. Table 2 shows the TCC values for the 10 geosites.

Table 2
TCC results for sites of geological interest on San Cristóbal Island (visits per day).

Code	Sites of geological interest	PCC	RCC	ECC
SGI-1	Frigate Bird Hill	4,325	177	87
SGI-2	Witch Hill	7,270	79	49
SGI-3	Punta Pitt	5,450	74	42
SGI-4	Mann Beach	5,333	2,690	807
SGI-5	Punta Carola	5,216	2,631	658
SGI-6	Punta Pucuna	3,362	1,696	814
SGI-7	Rosa Blanca Bay	3,051	1,540	740
SGI-8	Sardina Bay	6,281	3,168	951
SGI-9	Las Negritas Cliff	8,765	160	90
SGI-10	El Junco lagoon	7,725	114	92

Acantilado Las Negritas was the geosite with a high PCC value (8,765 visits per day); however, it dropped to 90 visitors per day in ECC. El Junco follows with 7,725 visits per day in PCC, and its value in ECC is reduced to 92 visits per day. These reductions are mainly due to the correction factors stipulated, such as the social factor (group visits), rainfall, and solar conditions (as it is a trail in an open area, there are days with higher solar radiation or rainfall, which influences visits to the site), and the maintenance factor (the site needs cleaning days). Frigate Bird Hill has a lower number of visits per year (31,755) compared to the 2024 annual visitor report for the Galápagos National Park (66,000) [29], so there may be overcrowding at the site.

Geosites such as Punta Pitt, Witch Hill, and Frigate Bird Hill offer a large area for visitors, but they have the disadvantage of having sections with slopes between 10% and 20% and sections with slopes greater than 20%, which makes access difficult for vulnerable groups (older people). A similar case occurs in the study by Jaya-Montalvo et al., who propose the TCC on Santa Cruz Island and use correction factors to establish the ECC of the geosites on the island [12]. In addition, another study by Amador et al. determines the TCC at visitor sites in Galápagos National Park [25].

Punta Carola Point, Punta Pucuna, Rosa Blanca Bay, and Sardina Bay are geosites that have a higher ECC value due to their large areas. These geosites can only be reached by boat, making access difficult and hindering tourists from fully exploring them.

3.2. Proposed management and conservation strategies

With the information obtained from the previous points, an analysis is carried out using a SWOT matrix (Table 3). This study focuses on proposing strategies aimed at geotourism, geoeducation, and geoconservation. These strategies will contribute to the management and conservation of geosites.

The strategies will help us develop sustainable tourism and preserve geosites. Based on the analysis carried out, proposals for a strategy focused on geotourism, geoeducation, and geoconservation are established.

1. Geotourism: i) Implementation of activities that promote the growth of geotourism, adapting it to the community, ii) Improvement of the infrastructure and safety of geosites.

Table 3
Analysis using a SWOT matrix.

Strengths	Opportunities
• There is much diversity (flora and fauna). • It has high potential for research interest. • It has great geodiversity. • It has a high demand for tourist interest. • It has many geosites that contribute to history, culture, and landscaping.	• Good management of tourist sites. • Recognition as a UNESCO geopark. • Strengthening of educational, cultural, and knowledge values, focusing on geosites. • Training campaigns for residents on the care and preservation of their environment. • An entity to manage geosites in tourism development.
Weaknesses	**Threats**
• Lack of authorized guides and safety at the sites. • Most sites are visited by boat, and there is little awareness of them. • Guides and administrators lack adequate geological knowledge of the sites. • They focus only on the natural aspects. • The infrastructure of the sites needs improvement.	• Uncontrolled tourism. • An excess of tourists could lead to the spread of disease (as happened with COVID-19). • Lack of safety for tourists at sites and due care. • Food shortages due to an excess of tourists. • Degradation of sites of geological interest due to neglect in the maintenance and control of tourists.

2. Geoeducation: i) Develop training campaigns for tour operators (guides and administrators) on geotourism issues applied to sites of geological interest, ii) Strengthen ties between institutions (public, private, and governmental) that contribute to research, educational, and cultural growth.
3. Geoconservation: i) Manage the care and conservation of geosites through multidisciplinary projects to enhance sustainability, ii) Invite entities to invest financially in the promotion and conservation of geodiversity.

The consolidation of geotourism in the aforementioned geosites allows us to continue improving conservation management and sustainable tourism. This can be of great help in the Galapagos Geopark proposal, which boasts incredible diversity and already has two UNESCO designations. By presenting this plan for the geosites, the relevant authorities will take action to improve infrastructure, diversify tourist services, and provide greater security for the sites.

In geoeducation, there should be greater participation from the political, public, and private sectors in introducing geotourism education programs in educational institutions. This will help strengthen relations between the community, government, and academia. The academic industry can collaborate in the development of geotourism management tactics through research and scientific dissemination that contribute to knowledge of geological heritage and improve the quality of tourism. An example of scientific contribution is the study by Kelly and Salazar, who mention the geosites in the Galapagos Islands that are used for geological education programs for university students in the US [30].

4. Conclusions

This study determines the TCC of the 10 geosites located on San Cristóbal Island, Galápagos. The data obtained provides us with valuable guidance for the sustainable management of geosites, thereby strengthening conservation for the proper use of the sites. Acantilado Las Negritas a trail that obtained the highest PCC value with 8,765 visits per day, followed by El Junco (7,725) and Witch Hill (7,270). In open areas (i.e., beaches), sites such as Punta Carola Point, Punta Pucuna, Rosa Blanca Bay, and Sardina Bay attract visitors, but their ECC value is reduced due to factors such as accessibility (by boat), weather, and maintenance days. Sites such as Punta Pitt, Witch Hill and Frigates Bird Hill are trails with a large area available for visitors, but they have the disadvantage of having sections with slopes between 10% and 20% and sections with slopes greater than 20%, which makes access difficult for vulnerable groups (older people), reducing their ECC value.

This study proposes strategies focused on three main areas: geotourism, geoeducation, and geoconservation, which contribute to sustainable tourism and the care of geosites. The importance of these strategies highlights the need to expand tourism activities, increase awareness of geosites, generate interest, and boost economic activity in local communities. In geoeducation, the importance of education and communication between the local and tourist communities and the government in power is highlighted for the dissemination of sustainable geotourism and research growth. And in the field of geoconservation, the importance of caring for biodiversity and geological heritage is highlighted. This is vitally important for preserving geosites so that future generations can enjoy them.

Future research should address issues of environmental, social, and cultural impact assessments at geosites using complementary methodologies to determine their influence on management. This will give us a better scientific understanding of geosites, contributing to the efficient and effective management of geotourism for the benefit of the population, and in turn promoting the Geopark project.

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Declaration on Generative AI

The authors have not employed any Generative AI tools.

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