Geotourism and Geoconservation Strategies through Carrying Capacity Analysis: Case Study of Floreana Island, Galápagos

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Abstract

Galápagos was declared a protected area (1959), as well as a cultural heritage site (1978) and a UNESCO biosphere reserve (1984) due to the uniqueness of the flora and fauna that inhabit the area, and as a source of inspiration for scientific advances. These factors have contributed to an increase in tourism in the region, with a total of 279,277 visitors to the Galápagos Islands in 2024 (a 4% increase compared to 2022). However, the increase in tourism can have negative impacts, such as overexploitation of resources and pollution/degradation of the site of interest (tourist or geological). This study aimed to evaluate the tourist carrying capacity of sites of geological interest (geosites) on Floreana Island (Galápagos) through the analysis of qualitative and quantitative information to propose management strategies in the areas of geotourism, geoconservation, and geoeducation. The methodology includes: i) field visits to collect information on the geosites, ii) calculation of tourist carrying capacity, and iii) development of management strategies for the three proposed areas. In assessing carrying capacity, daily visitor numbers ranging from 181 to 1,406 were identified, with Basaltic Black Beach standing out, as well as the volcanic spring "Asilo de la Paz", the island's only source of fresh water. This analysis enabled the formulation of strategies aimed at promoting the use of geosites based on the pillars of geotourism, geoeducation, and geoconservation.

Keywords

Geosite, geotourism, Geoconservation, Geoeducation, Geocommunication, Sustainable tourism

1. Introduction

Geosites are sites of scientific interest because of their geology and geomorphology. They serve as a source for research in conservation, education, and tourism development, where fundamental factors in the cultural relations of the place are involved [1]. Geosites have been proposed as a means to contribute to the sustainable development of urban sites by helping to strengthen the culture of an area [2]. One way to select a geosite is by examining the biodiversity and habitat protected by a conservation agency, such as the European Directives on Special Areas of Conservation (SAC), which safeguard geosites located in European Union member countries [3]. The purpose of a geosite is to enable geotourism to occur.

Geotourism is a natural form of tourism that promotes tourist access without damaging geodiversity and encourages geoconservation. Geotourism seeks to develop strategies to increase the number of people in the tourism sector without involving local ethnic groups. These strategies can be developed based on quantitative data related to the maximum tourist load [4]. Geoconservation seeks to find methods for the conservation of specimens and geological features in an area so that they can benefit [5]. Geoconservation requires the involvement of practitioners, academics, amateurs, and volunteers to make decisions that will last for an extended period and do not harm the geology of the area [6].

Tourism plays a crucial role in island development, as it has a socioeconomic impact on the community and geological sites with tourism potential [7]. Thanks to tourism, cultural exchanges can be achieved even if the place is relatively unknown. Tourism creates many job opportunities over time, provides a

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significant source of income, and can help local ethnic groups. An example of this can be found on one of the Pacific Islands, where an ethnic group called the i-Taukei proved capable of taking on business roles, something that was unknown before visiting the area [8].

Although geotourism has become popular and contributes to environmental and community sustainability through geoconservation efforts, if left uncontrolled, it can harm the area. An excessive increase in the number of people in an area can cause environmental damage, such as the deterioration of the geological layers of the site and loss of vegetation. In the social sphere, the ethnic groups present in that area can be overwhelmed by a high number of people. Sites such as Sangkulirang-Mangkalihat in Indonesia, which has several geosites, limit the number of people to 108 per day in one of them (Bloyot Cave). This calculation was made using the tourist carrying capacity, and therefore its importance [9].

Ecuador ranks 17th globally in terms of biodiversity, boasting a wide variety of ecosystems and species. Protected areas have been established in specific zones, such as national parks and geological reserves (geoparks), to preserve biodiversity and geodiversity within the Convention on Biological Diversity (CBD) [10]. Geoparks such as the Santa Elena Peninsula, which are classified as having a history and being geologically attractive, have had an 89.20% satisfaction rating from their communities, with 9.20% rating the area as peaceful and 27.20% rating the tourist services as good [11]. In 2023, the country registered 1,426,725 foreign tourists, generating more than one million US dollars [12].

Floreana Island (also known as Santa María Island), located in the south of the Galápagos, has an area of 173 km2 and a maximum altitude of 640 meters above sea level (m.a.s.l.) (Figure 1). It originated from a volcanic eruption more than 2 million years ago and is considered the first island in the Galapagos to be colonized [13]. In 2017, a species of bird called the "medium tree finch" was discovered to be confined to an area of 24 km2 [14, 15]. Its geological features have led to its nomination as a cultural heritage site. One of the characteristics of this island is that its lava contains elements such as barium (Ba), strontium (Sr), lead (Pb), niobium (Nb), thallium (Ta), and thorium (Th), which are unique compared to other islands. This characteristic demonstrates that this island has a unique magmatic composition, which influences the physical (geological) characteristics of Floreana, making it an attractive geotourism destination [16, 17, 18, 19].

Although studies on tourist carrying capacity have been conducted on the larger islands of the Galapagos Archipelago (e.g. Santa Cruz [20]), Floreana Island remains without a specific analysis that incorporates the vulnerability of its geosites, interactions with the associated biodiversity, and the role of community-based tourism. The absence of these assessments limits the sustainable management and protection of a unique geological and cultural heritage, which faces the risks of tourist overload, environmental degradation, and loss of educational value. Consequently, there is a research gap in defining a comprehensive tourism carrying capacity model adapted to Floreana that would harmonise conservation, visitor experience, and local development.

This raises the following question: What is the tourist carrying capacity of the geological sites of interest (geosites) on Floreana Island, considering the fragility of its volcanic geosites and associated biodiversity, and how can this assessment contribute to the sustainable management of the island's geological and cultural heritage? Therefore, the aim of this study was to evaluate the tourist carrying capacity of Floreana Island, integrating geological, social, and physical criteria to propose sustainable management strategies that balance the conservation of natural and geocultural heritage.

2. Materials and Methods

The search for strategies to obtain the tourist carrying capacity (TCC) of geological sites is vital to understanding how the flow of people to a geosite is managed in a study area. This study analysed sites of geological interest (SGI) to contribute to tourism by applying TCC and its derivatives. This study also emphasises the cultural importance of Floreana Island using sustainable strategies. The present research was developed in three phases (Figure 2): (i) field observation and analysis of collected information; (ii) calculation of tourist carrying capacity; and (iii) proposal of sustainable development strategies.

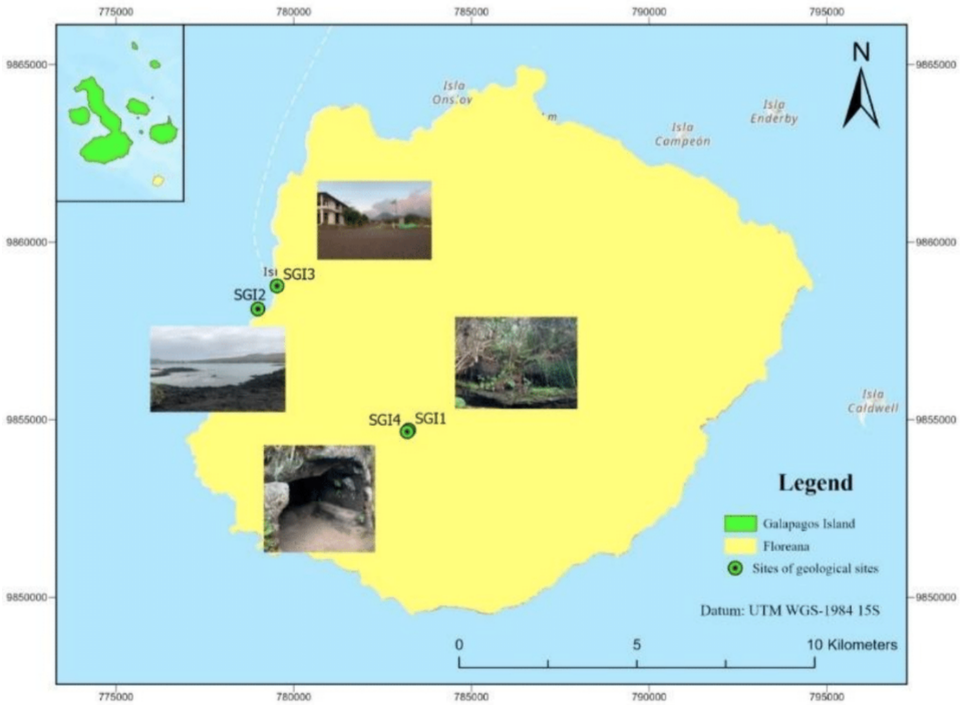

Figure 1: The geographical location of the study area, together with the four Sites of Geological Interest (SGI) visited, is shown. SGI1: Volcanic Waterhole "Asilo de la Paz"; SGI2: Basaltic Cove of Lobería de Floreana; SGI3: Black Basaltic Beach; SGI4: Trail of Caves, Magmatics, and Leg-ends "Upper Part".

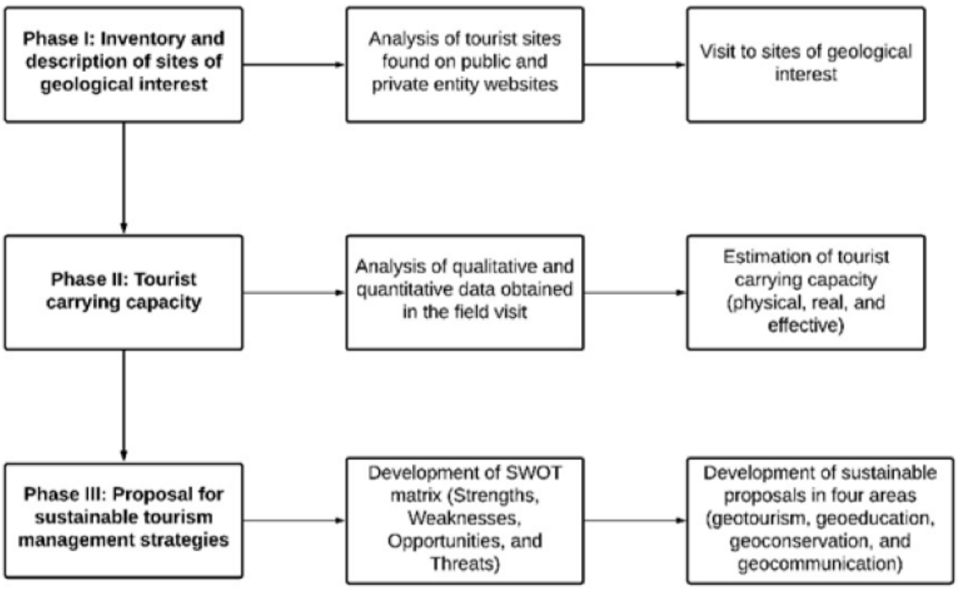

Figure 2: Methodological framework used to calculate tourist carrying capacity in Floreana, Galápagos.

2.1. Phase I: Sites of geological interest in Floreana

This phase is based on two main parts. The first is the collection of information outside the field, where preliminary information is obtained about the study area (Floreana Island), such as iconic sites, attractions for tourism, and the island's geology. After identifying this area, the SGI was analysed as the point of analysis for the article. Information is analysed and gathered, and research is conducted on the number of tourists visiting the sites in the study area. The second part focuses on the field, where field researchers visit these sites.

2.2. Phase II: Tourist carrying capacity assessment

A methodology was applied to obtain the tourist carrying capacity of people present in an SGI. The assessment consists of three types: physical carrying capacity (PCC), actual carrying capacity (RCC), and effective carrying capacity (ECC) [21, 22, 23]. This assessment seeks to correct and approximate the number of people/tourists that an SGI can accommodate in the area. Table 1 presents a description and the formulas for calculating the tourist carrying capacity.

Table 1
Explanation and determination of PCC, RCC, and ECC capacity.

	PCC	RCC	ECC
Description	Maximum number of visits that can take place at the site during a specific time in a given space.	CCF correction factors that directly or indirectly affect the site.	Maximum number of visits that each geological site of interest can allow based on the analysis of certain variables.
Considerations	PCC = (V/a)*S*t V/a: visitors/occupied area • S: area available for visitor access. • t: time required for the visit.	• Social factor. • Solar factor. • Precipitation factor. • Erodibility factor. • Accessibility factor. • Temporary closure factor. • Waterlogging factor.	• Staff (guides). • Infrastructure.

2.3. Phase III: Proposal for geotourism sustainability strategies

The results of Phases I and II provided a diagnosis of the current state of each geosite, assessing the effects of tourism and other human activities on it. Based on this analysis, the aim is to propose strategies that promote sustainable tourism of geosites and facilitate orderly geotourism development on Floreana Island. To this end, the application of the Strengths, Opportunities, Weaknesses, and Threats (SWOT) matrix and the modified 4G model allows for the structuring of strategies in three fundamental areas of sustainable tourism: geotourism, geoeducation, and geoconservation, and geocommunication [24, 25, 26].

3. Results and Discussion

3.1. Inventory and description of geosites

The inventory of geosites forms the basis for geotourism management and planning, as it allows for the identification, classification, and description of areas of geological interest with tourism, education, and conservation potential [27, 28]. A survey was conducted on the island that included field visits, a literature review, and consultations with local stakeholders, which made it possible to record and characterise four geosites according to their geological characteristics, historical and cultural value, and photographic records (Table 2). This process not only facilitates the development of comparative diagnoses but also provides input for defining sustainable management strategies aimed at promoting their use for tourism without compromising the integrity of the associated natural and cultural resources of the region.

Table 2
Geological, tourist, and historical description of the inventoried geosites.

Geosites	Geological and tourist description	Historical background	Image
Volcanic Waterhole "Asilo de la Paz"	Formation of lava tunnels, caves, and freshwater springs on the eroded slopes of the shield volcano. Geological hiking, observation of volcanic formations, and interior landscapes are also included.	It was a refuge for pirates and settlers, including the Wittmer family, pioneers in the Galapagos. The site is associated with the history of human survival and adaptation to a hostile volcanic environment.	
Floreana Lobería Basaltic Cove	The coastline with basalt flows was eroded by marine action, forming beaches and coastal habitats. Sea lion watching, snorkelling, coastal walks, and interacting with geology and wildlife are also popular activities.	A space where the local community promotes sustainable tourism is created. This reflects the islanders' historical connections to fishing, the sea, and wildlife conservation.	
Black Basaltic Beach	Volcanic sand is formed by basalts rich in mafic minerals, which give it a dark colour. Photographic and scientific attraction due to the uniqueness of its sand. Sun and sea tourism with a geological focus.	It is a destination for visitors and fishermen. Historically used as a natural landing place, it now represents the interaction between geodiversity, biodiversity, and tourism.	
Trail of Caves, Magmatics, and Legends "Upper Part"	A network of cracks, tunnels, and lava cavities is formed by the cooling and fracturing of lava flows. Geological exploration, adventure trails, and mystery tourism are also popular.	Associated with the enigmatic story of Baroness Eloise Wagner de Bousquet in the 1930s, the protagonist of the "mysteries of Floreana." The place reinforces the cultural appeal linked to legends, colonisation, and disappearances on the islands.	

3.2. Analysis of physical, real, and effective tourism carrying capacity

Tourist carrying capacity is a widely used tool in tourism management, as it determines the maximum number of visitors that a site can sustainably receive without compromising its integrity or causing its degradation. Table 3 presents estimate of the number of people per day who can access sites of geological interest.

The Black Basalt Beach recorded the highest physical carrying capacity (PCC) of 4,430 visitors/day; however, when correction factors were considered, this was reduced to an effective carrying capacity (ECC) of 1,406 visitors/day. This decrease is mainly explained by environmental variables such as precipitation and solar radiation (as it is an outdoor geosite, adverse weather conditions reduce tourist numbers).

Geosites such as Volcanic Waterhole "Asilo de la Paz" and Trail of Caves, Magmatics, and Legends "Upper Part" have areas that are conducive to tourism. However, specific sectors have slopes between 10% and 20%, as well as sections with limited access for vulnerable groups (people with reduced mobility and older adults).

3.3. Analysis of physical, real, and effective tourism carrying capacity

Table 4 presents the SWOT analysis derived from the analysis carried out by the authors on Floreana Island, where the main internal and external factors were identified. This diagnosis made it possible to define priority strategies aimed at promoting sustainable tourism for the sustainable management of geosites, which are summarised below:

Geotourism

- **Design of integrated thematic routes:** Map priority geosites by developing differentiated routes according to interest (volcanic geology, marine fauna, and historical-cultural heritage) and

Table 3
Carrying capacity values (PCC, RCC, ECC) (visits/day) of the evaluated SGIs.

Geosites	PCC	RCC	ECC	Image
Volcanic Waterhole “Asilo de la Paz”.	744	202	181	
Floreana Lobería Basaltic Cove.	1,016	288	260	
Black Basaltic Beach.	4,430	1,563	1,406	
Trail of Caves, Magmatics, and Legends “Upper Part”.	2,072	662	595	

establish time limits and daily visitor limits per route.

Geoeducation

- **Workshops and educational programs for visitors and the community:** Organise workshops on geosite and biodiversity conservation during visits by coordinating educational programs with local schools and tour operators to promote community participation and environmental education in geotourism.

Geoconservation

- **Load capacity control and impact management:** Minimise the impact of tourism on fragile geosites and biodiversity by implementing periodic monitoring of erosion, waste, and alterations to the environment to conserve ecosystems and prevent irreversible deterioration of the environment.

Table 4
SWOT analysis for the proposed 4G strategies.

Internal factors		Strengths (S)	Weaknesses (W)
External factors		• **S1.**Unique geological. • **S2.**Emblematic biodiversity. • **S3.**Historical and cultural value. • **S4.**Local community with experience in community-based tourism. • **S5.**Limited accessibility that allows for control of tourist flows.	• **W1.**Lack of studies on geosite inventory and tourist carrying capacity. • **W2.**Lack of educational signage and adequate interpretive material. • **W3.**Limited human and technical resources for comprehensive local management. • **W4.**Little research on visitor perception and acceptance of regulations.
Opportunities (O)	• **O1.**Global interest in sustainable tourism and geotourism. **O2.**Institutional support from the Galápagos National Park and international organisations. **O3.**Development of educational and geocultural interpretation programs for visitors. **O4.**Possibility of creating thematic routes for geotourism, geoeducation and conservation.	• Develop integrated geotourism routes that highlight geology, biodiversity, and culture (S1+S2+S3), leveraging the demand for sustainable tourism (O1). • Implement educational programs and geoeducation workshops aimed at tourists and the community (S4+S3+O3).	• Generate applied research on carrying capacity and geosites to guide sustainable management (W1+O1+O5). • Integrating community tourism with educational experiences strengthens positive perceptions of regulations (W4+O3+O5).
Threats (T)	• **T1.**Increasing tourist pressure may affect geosites and the biodiversity. • **T2.**Risk of loss of historical and cultural value due to tourist overexposure. • **T3.**Potential conflicts between local economic development and conservation.	• Train the local community in sustainable management and conservation protocols to prevent adverse impacts (S4+T1+T2). • Establish visitor limits and educational signage to protect geosites and biodiversity (S1+S2+T3).	• Technical training for local staff in comprehensive geotourism management and conservation (W2+W3+T1+T3). • Continuous monitoring of tourism and cultural impacts to prevent heritage loss (W1+W2+T2).

Geocommunication

- **Training and strengthening of the local community:** Integrate the community into the management and operation of sustainable geotourism by training local guides and operators in tourism management, environmental education, and conservation for greater community participation, sustainable income generation, and strengthening the responsible tourism model.

4. Conclusions

This study conducted a comprehensive assessment of the tourist carrying capacity (TCC) at four geosites on Floreana Island (Galápagos). The results obtained constitute a key tool for the sustainable management of these areas, providing guidelines that promote conservation and ensure the optimal use of geotourism attractions.

Black Basalt Beach had the highest effective carrying capacity (ECC), reaching 1,406 visitors per day. Other geosites, such as Trail of Caves, Magmatics, and Legends "Upper Part" (595), Floreana Lobería Basaltic Cove (260), and the Volcanic Waterhole "Asilo de la Paz" (181), have the potential for increased visitor numbers. However, their ECC is reduced by factors associated with climate, accessibility, and limited availability of tour guides.

This study proposes an integrated 4G model (geotourism, geoconservation, geoeducation, and geocommunication) as a tool for sustainable development and management of geosites. The relevance of this approach lies in its holistic vision, which links tourist appeal to environmental and cultural preservation. The geotourism axis highlights the need to design integrated thematic routes with an inventory of new geosites beyond the four evaluated. The geoconservation axis emphasises load capacity control and impact management, whereas the geocommunication axis indicates the need for training and strengthening of the local community. Finally, the geo-education axis underscores the role of education and communication between local populations, visitors, and authorities as key tools for promoting sustainable geotourism practices.

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Declaration on Generative AI

The authors have not employed any Generative AI tools.

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