International Journal of Geoheritage and Parks 10 (2022) 252–272

Contents lists available at ScienceDirect

International Journal of Geoheritage and Parks

journal homepage: http://www.keaipublishing.com/en/journals/international-journal-of-geoheritage-and-parks/

Integrating geoheritage into the management of protected areas: A case study of the Itatiaia National Park, Brazil

Vanessa Costa Mucivuna [a,*], Maria da Glória Motta Garcia [a], Emmanuel Reynard [b], Pedro Augusto da Silva Rosa [c]

[a] Centre for Research Support on Geological Heritage and Geotourism (GeoHereditas), Institute of Geosciences, University of São Paulo, Rua do Lago, 562, São Paulo, SP 05508-080, Brazil
[b] Institute of Geography and Sustainability and Interdisciplinary Centre for Mountain Research, University of Lausanne, Ch. de l'Institut 18, CH-1967 Bramois, Switzerland
[c] Manoel Teixeira da Costa Research Centre (CPMTC), Institute of Geosciences, Federal University of Minas Gerais, Av. Presidente Antônio Carlos, 6627, Belo Horizonte, MG 31270-901, Brazil

ARTICLE INFO

Article history:
Received 7 February 2022
Received in revised form 19 April 2022
Accepted 25 April 2022
Available online 01 May 2022

Keywords:
assessment
geoconservation
geodiversity
geological sites
inventory
management plan

ABSTRACT

The International Union for Conservation of Nature (IUCN) has created many initiatives to integrate geodiversity and geoheritage into the management of protected areas through a broader concept of nature. However, many protected areas do not have an inventory of geological sites. In view of this fact, this study aims to discuss the inventory of geological sites (including geomorphological, hydrological, petrological, sedimentological, and structural sites) and analyse, through a case study, how geodiversity is described in an existing management plan, prepared before IUCN included geoconservation in the *Manual for the Management of Protected Areas*. This study was conducted in the Itatiaia National Park, which has outstanding geomorphological and other geological features. To ensure appropriate assessment of geological sites, we carried out an inventory of geological sites and then we analysed how the management plan addressed geodiversity. The inventory includes 17 geosites (distributed in six geological frameworks), seven geodiversity sites and three viewpoints. We concluded that although geodiversity is mentioned in the plan, the inventory of geological sites would facilitate and support the exploration of management possibilities that range from conservation to education. Therefore, we recommend the inclusion of the inventoried sites in the management plan of protected areas because it is a valuable tool for the proper conservation and management of geoheritage.

Contents

* Corresponding author.
E-mail addresses: vanessa.c.mucivuna@gmail.com (V.C. Mucivuna), mgmgarcia@usp.br (M.G.M. Garcia), emmanuel.reynard@unil.ch (E. Reynard), pasrosa@ufmg.br (P.A.S. Rosa).

https://doi.org/10.1016/j.ijgeop.2022.04.004

1. Introduction

Since the International Conference on the Protection of Geological Heritage in 1991 (Martini, 1994) and the Malvern Conference in 1993 (O'Halloran, Green, Harley, Stanley, & Knill, 1994), initiatives and research focused on geodiversity and geoheritage have increased around the world (Reynard & Brilha, 2018). In this context, geoconservation has emerged to prevent sites of geoscientific importance from being destroyed (Gray, 2004, 2013; Henriques, Reis, Brilha, & Mota, 2011; Prosser, 2013; Sharples, 2002). After nearly 30 years of initial discussions, however, geodiversity does not cause the same level of concern that is expressed about biodiversity. For example, neither the Earth Summit in Rio de Janeiro (1992) nor the Millennium Declaration (2000) and the United Nations Sustainable Development Goals (SDGs) (2015) have included geoheritage as a central issue. Although geoconservation is not on the United Nations' main political agenda, geodiversity and geoheritage have recently been included on the agendas of the International Union for Conservation of Nature (IUCN) and United Nations, Scientific and Cultural Organization (UNESCO) (Brilha, 2018; Crofts, 2018; Crofts et al., 2020; Crofts & Gordon, 2015; Reynard & Brilha, 2018).

The fact that geodiversity and geoheritage are not mentioned in official documents is not a result of a lack of research on such topics. Brilha (2017) points out that the number of papers, dissertations, theses, and scientific conferences is growing worldwide (Németh, Németh, Procter, & Farrelly, 2021); however, most countries still do not have their geoheritage protected and/or included in nature conservation policies (Reynard & Brilha, 2018). On the other hand, some countries have developed geoconservation policies and measures to protect their geodiversity and geoheritage, such as Great Britain (England, Scotland, and Wales) (National Parks and Access to the Countryside Act - 1949), Tasmania State in Australia (Sharples, McIntosh, & Comfort, 2018), Spain (Law on Natural Heritage and Biodiversity - 2007) and Norway (Nature Diversity Act - 2009) (Gordon, Crofts, & Díaz-Martínez, 2018).

One of the reasons that could explain why geodiversity and geoheritage are usually not officially protected is the widespread idea that geodiversity is resistant and durable (Gray, 2013), unlike biodiversity, an assumption that has proved to be wrong. Geodiversity is actually a non-renewable resource, has finite extensions and can be affected by natural or human threats (Bétard & Peulvast, 2019; Thomas, 2012). Another possible explanation could be the fact that international conventions and agreements have addressed geodiversity and geoheritage superficially until very recently. Thus, it was challenging to prioritise geodiversity and geoheritage in public policies, as there is a lack of statutory protection tools to be used by national nature conservation agencies and managers (Crofts, Tormey, & Gordon, 2021).

Recently, there has been a growing effort to integrate geoconservation into environmental and management policies (Brilha, Gray, Pereira, & Pereira, 2018; Crofts, 2018; Crofts et al., 2020; Crofts & Gordon, 2014, 2015; Díaz-Martínez et al., 2016, 2017; Gordon, Crofts, & Díaz-Martínez, 2018; Gordon, Crofts, Díaz-Martínez, & Woo, 2018). The IUCN has put several issues related to geoconservation on its agenda, strongly influenced by new board members who represent institutions that are related to this theme. Geodiversity has been recognised as an integral part of nature and geoheritage as part of the natural heritage (Crofts & Gordon, 2015). A Geoheritage Specialist Group has been created in the World Commission on Protected Areas (WCPA) (Woo, 2017), a chapter on *Geoconservation* has been included in the *Manual for the Management of Protected Areas* published by IUCN (Crofts & Gordon, 2015), and specific Best Practice Guidelines on Geoconservation in Protected and Conserved Areas have been recently published (Crofts et al., 2020). Also, since 2008 almost 20 resolutions have been adopted by the IUCN (e.g., 4.040/2008, 048/2012, 091/2016, 089/2020) to include geoconservation in the international legal framework (Díaz-Martínez et al., 2017, International Union for Conservation of Nature (IUCN), 2021). Furthermore, some protected areas (PAs) have successfully included geological site inventories into PA management plans (MPs) in Brazil. For example, some geosites of the geoheritage inventory of the state of São Paulo, Brazil (Garcia, Brilha, Lima, et al., 2018) were integrated into the Geobiodiversity Protection Zone of the Central Coast Marine Environmental Protection Area MP (Garcia et al., 2019; MA, 2019) and all geological sites of the municipality of Bertioga-SP, Brazil (Mucivuna, 2016; Mucivuna, Garcia, & Del Lama, 2017) were included into the Restinga de Bertioga State Park MP (Fundação Florestal, 2019).

Several authors (e.g., Brilha & Reynard, 2018; Crofts, 2018; Crofts & Gordon, 2014, 2015; Gordon, Crofts, & Díaz-Martínez, 2018; Gordon, Crofts, Díaz-Martínez, & Woo, 2018; Matthews, 2014) have emphasised the challenges faced by geoconservation in PAs, highlighting that the integration of abiotic aspects into their management remains a crucial unresolved issue for nature conservation. For example, Brilha (2002) stated that in the 20th century, geoconservation was not a priority for PA's managers, as many of them were not geoscientists nor had a good knowledge of abiotic aspects. Therefore, the geology and geomorphology of these areas have only been indirectly conserved due to biological, aesthetic, and cultural values (Dingwall, 2000).

In this context, the appropriate recognition of geoheritage in PAs is essential for its conservation and management. A systematic inventory, based on a reliable method of identification and assessment and solid criteria, could guarantee a clear diagnosis of potentialities and threats, and avoid the partial or total loss of records of the Earth's geological history.

Including inventoried sites in PAs management plans could contribute to the adequate management and promotion of abiotic aspects (Crofts et al., 2020). Moreover, geodiversity would be at the same level of concern that is currently shown about biodiversity (Crofts & Gordon, 2015).

Although some significant advances have happened in recent years, there is still a need to discuss and improve how geological sites could be better recognised in nature conservation in worldwide PAs. Considering these issues, this study aims (i) to discuss the results of the inventory of geological sites in the Itatiaia National Park (INP), (ii) to analyse how geodiversity is addressed in the MP and (iii) to evaluate the possibilities of including the inventoried sites in the MP guidelines in order to ensure their effective management.

2. Nature conservation and the role of Protected Areas

2.1. The protection of nature in the global context

At the turn of the 20th century, the growth in agricultural and industrial activities was responsible for a change in nature conservation paradigm. At that time, nature conservation and management were focused on (i) landscape conservation by land-use policies and laws (Europe) and (ii) wilderness protection (United States) (Castro Júnior, Coutinho, & Freitas, 2009). The Yellowstone National Park in the United States is considered the first PA established in 1872. Later, others were created in Canada (1885), New Zealand (1894), Australia, South Africa, Mexico (1898), Argentina (1903), Sweden (1909), Switzerland (1914), Chile (1926), Ecuador (1934), Brazil and Venezuela (1937) (Medeiros, 2003). This movement fostered the creation of IUCN in 1948, aiming at the conservation and sustainable use of nature. IUCN defines PA as "*a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values*" and classifies them into: (Ia) strict nature reserve and (Ib) wilderness area, (II) national park, (III) natural monument, (IV) habitat/species management area, (V) protected landscape/seascape, (VI) protected area with sustainable use of natural resources (Dudley, 2008).

The growing concern for nature conservation has contributed to the creation of PAs around the world. The global network of PAs covers 14.7% of land area and 10% of territorial waters under protection (International Union for Conservation of Nature (IUCN), 2016). However, recent studies have highlighted that the global area protected is insufficient to halt the loss of biodiversity and important ecosystem services, making it necessary to increase nature conservation efforts to mitigate the effects of climate change (Dinerstein et al., 2019). Given this fact, the 30 by 30 target has emerged as a global initiative that aims to designate 30% of Earth's terrestrial areas and inland waters as PAs by 2030 (International Union for Conservation of Nature (IUCN), 2021a).

2.2. Brazilian protected areas

The first mention of nature conservation in the Brazilian Constitution was in 1934. In that same year, the Forest Code (Decree 23,793/1934, amended by Law 4771/1965 and 12,651/2012) established the rules for protecting Permanent Protect Areas (Medeiros, 2003), and three years later, the INP was created.

After these initiatives and following global trends, several policies were developed to protect and maintain the environment's integrity. These include the rules for creating Ecological Stations and Environmental Protection Areas (Law 6902/1981), Ecological Reserves and Area of Relevant Ecological Interest (Decree 89,336/1984) and Private Natural Heritage Reserves (Law 1922/1996) (Medeiros, 2006; Medeiros, Irving, & Garay, 2004).

One of the most important laws is the National System of Protected Areas (NSPA) (Law 9985/2000), which was adopted to guarantee PAs' creation, management, and consolidation (Brasil, 2000). According to the NSPA, PAs are classified into strictly protected areas, in which only the indirect use of natural resources is allowed (ecological station, biological reserve, national park, natural monument, and wildlife refuge) and sustainable-use protected areas, in which the controlled exploitation of some natural resources is allowed (environmental protection area, area of relevant ecological interest, national forest, extractive reserve, fauna reserve, sustainable development reserve, and private natural heritage reserve).

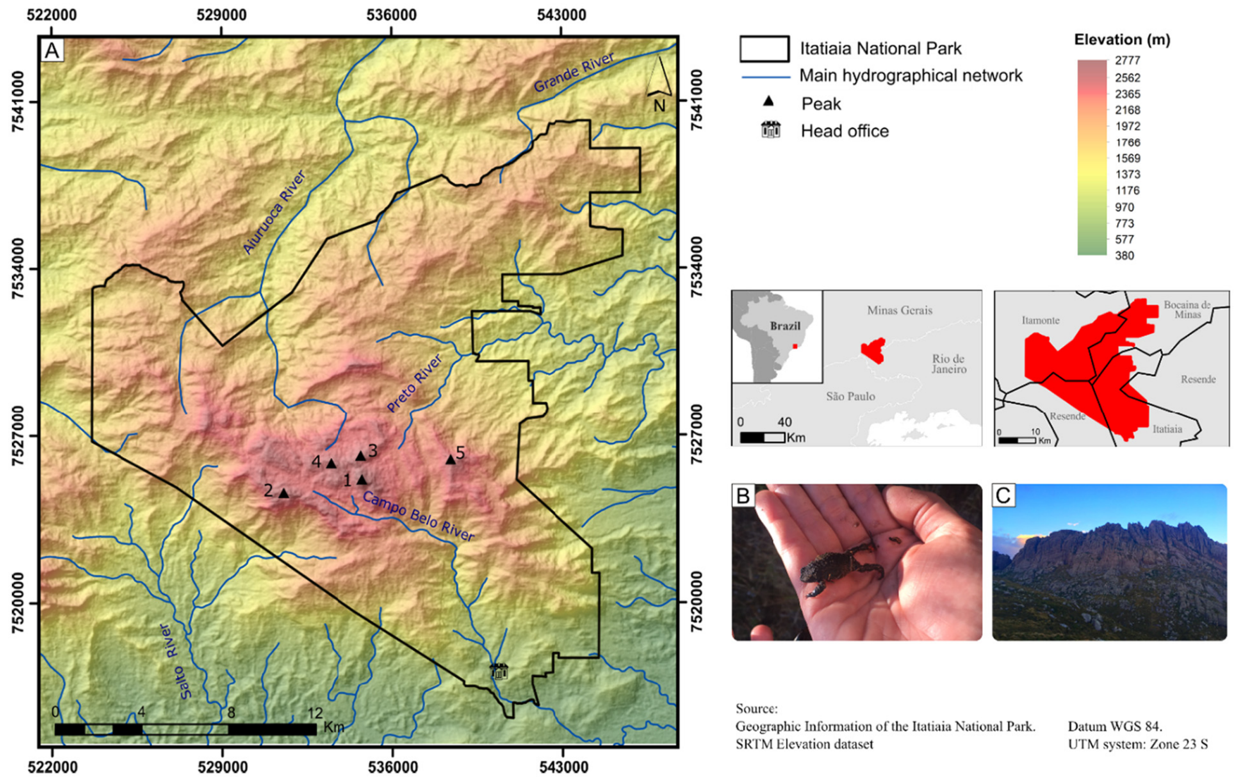

Fig. 1. A. Location map of the Itatiaia National Park with the main hydrographical network and the five highest peaks where 1 is Agulhas Negras Peak, 2 is Pedra do Couto Hill, 3 is Pedra do Sino Hill, 4 is Pedra do Altar Hill, 5 is Maromba Hill. B. *Melanophryniscus moreirae* is an endemic species and symbol of the Itatiaia National Park. C. The highest point of the Agulhas Negras Hill is associated with the park's name. Its origin is inspired by the local geodiversity, characterised by very sharp peaks in alkaline rocks.

These areas must prepare a MP within five years from the date of their creation in order to regulate and guide the general objectives, zoning, rules, and restrictions of use (Brasil, 2000). However, despite the importance of geological and geomorphological aspects for maintaining ecosystems, geodiversity is not satisfactorily elaborated in these documents (Garcia et al., 2019), which hinders the integrated management of biodiversity and geodiversity, reducing the potential for geoheritage conservation and promotion.

Management plans were officially established in Brazil in 1979, aiming to guide national parks' management (Brasil, 1979). The enactment of Law 9985/2000 reinforced it as a central tool to the management process for all categories of PAs (Brasil, 2000). According to the NSPA, a MP is a technical document that, based on the general objectives of a PA, defines its zoning and the rules that should regulate the use and management of natural resources, including the installation of the physical structures required for its management (Brasil, 2000). It must cover not only the core zone but also its buffer zone and wildlife corridors.

Among the goals of the MP, the following stand out: i) meeting the objectives established when the PA was created; ii) defining the management objectives, guiding its management, iii) describing the guidelines for its development, iv) defining the specific management actions, v) establishing the zoning for the protection of natural and cultural resources, vi) promoting the social and economic integration of the surrounding communities, and vii) guiding the use of the financial resources allocated to the PA (Galante, Beserra, & Menezes, 2002).

There are different guidelines for the preparation of MPs according to the category of PAs. These guidelines must be followed in order to standardise these documents and guarantee systematic planning. Therefore, to integrate the different existing documents for preparing MPs, the ICMBio published new methodological guidelines for preparing and revising MPs at the federal level, aiming to standardise planning across their different categories (D'Amico, Coutinho, & Moraes, 2018).

3. Study ara

3.1. General context

Located in Mantiqueira Mountain Range, in the southeast of Brazil, the INP has almost 280 km^2 with altitudes ranging between 540 and 2791 m. (Brasileiro de Geografia e Estatística (IBGE), 2016). Its boundaries cover the municipalities of Itatiaia and Resende, in the state of Rio de Janeiro, and Bocaina de Minas and Itamonte, in the state of Minas Gerais (Fig. 1A).

The INP is part of the Atlantic Forest Biome, standing out as one of the 25 biodiversity hotspots in the world (Myers, Mittermeier, Mittermeier, Fonseca, & Kent, 2000), and is recognised as a Biosphere Reserve by UNESCO since 1991 and as natural heritage by the Brazilian Constitution (Brasil, 1988). It is also classified as a priority area for biodiversity conservation (Ministério do Meio Ambiente (MMA), 2004), and its flora is classified into Vegetation Refuge, Dense High Ombrophilous Montane Forest, Dense Ombrophilous Montane Forest, Mixed Ombrophilous Montane Forest, and Semideciduos Montane Forest, highlighting endemic species such as *Ferneseea itatiaiae*, *Piper itatiaianum*, *Itatiaia cleistopetala* and *Lycopodium jussiaei* (Instituto Brasileiro de Desenvolvimento Florestal (IBDF), 1982; Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), 2013). The fauna is diverse, with over 50,000 species of insects, 320 species of birds, 15 species of mammals, and 60 species of amphibians, including the *Melanophryniscus moreirae,* an endemic species chosen to be the symbol of the park (Fig. 1B) (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA), 1994; Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), 2013).

In hydrographic terms, the area is drained by Grande and Paraíba do Sul Basin Rivers, and the Itatiaia Alkaline Massif (IAM) is its water divisor. Twelve springs are located in the park, in which the Campo Belo River, Preto River, Aiuruoca River and Grande River stand out (Tomzhinski, 2012). According to the Köppen-Geiger climate classification, INP has the Cwb climate (mesothermic, mild summer and rainy season in summer) and Cpb climate (mesothermic, mild summer without dry season). The average annual precipitation is 2400 mm, with heavy rainfall in summer. In contrast, the dry season is very distinctive between June and mid-September, and temperatures below zero are expected. Its average temperature is 11.4 °C, where January is the warmest month (13.6 °C) and July the coldest (8.2 °C) (Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), 2013; Instituto Brasileiro de Desenvolvimento Florestal (IBDF), 1982; Tomzhinski, 2012). Four soil classes were mapped by Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), 2013 from the area: dystric cambisol (humic), dystric litholic neosols, red-yellow dystric argisols, and latosols.

The INP stands out as one of the most visited national parks in Brazil and has recorded over 127,000 visitors per year in the past few years (Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), 2019). The park offers visitors a range of recreational activities through ecotourism, leisure, adventure, and contemplative tourism. These activities include rock climbing, bird watching, rappelling, crossing, hiking, and trekking (Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), 2013). In addition, the park also provides educational activities for around 18,000 students on school trips (Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), 2021). Such activities include guided tours and environmental education programmes that take place mainly at the visitor centre and attractions near the park headquarter. Students range from preschool to university, but the most significant are middle school students from the states of Rio de Janeiro, Minas Gerais, and São Paulo (Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), 2013).

Access to most tourist attractions is made through trails or crossings with scarce or no infrastructure around them. The Último Adeus Viewpoint is the main park attraction accessible by car. The other attractions are accessed by trails with an easy difficulty level: Lago Azul (1 km from the Visitor Centre), Maromba Pool, Véu de Noiva and Itaporani Waterfalls (340 m, 760 m and 1280 m from the Maromba bridge), Poranga waterfall (800 m from the BR-485), Camelo Hill (500 m from the BR-485), Escorrega and Macacos waterfalls (500 m the from Escorrega Road) and Santa Clara waterfall (500 m from the Santa Clara Road); moderate difficult level: Couto-Prateleiras Hills (12,5 km from the Marcão station), Pedra do Altar Hill. (6 km from the Marcão station) and Aiuruoca Waterfall (11 km from the Marcão station); and hard difficult level: Agulhas Negras Peak (11 km from the Marcão station) (Fig. 1C), Pedra do Sino Hill (24 km from the Marcão station) and Três Picos Hill (14 km from the Marcão station).

3.2. Geological and geomorphological setting

The INP has been the subject of geological and geomorphological research for decades (e.g., Ab'Saber & Bernardes, 1958; Brotzu et al., 1997; Lamego, 1936; Lasaulx, 1885; Melluso, Guarino, Lustrino, Morra, & De' Gennaro, 2017; Modenesi & Melhem, 1986; Penalva, 1967; Rosa & Ruberti, 2018; Silva, 1876).

The study area is located in the interference zone between the structures related to two orogens, Brasília and Ribeira, in the Mantiqueira Province (Almeida, Hasui, Brito Neves, & Fuck, 1977, 1981), developed during the Brasiliano Pan-African Orogeny (~670–480 Ma) as a result of the amalgamation of the West Gondwana Supercontinent (Heilbron et al., 2004). This period is also associated with large volumes of pre-, *syn*- and post-tectonic calcium-alkaline granites emplaced into the basement rocks (Trouw, Ribeiro, & Paciullo, 2003).

In the Upper Jurassic, the extensional tectonics, resulting from the South Atlantic Ocean's opening, allowed the reactivation of ancient faults and generation of tholeiitic basaltic magmatism (~134 Ma) in the Paraná basin (Marques & Ernesto, 2004; Thiede & Vasconcelos, 2010). During the Meso-Cenozoic, the development of the Continental Rift of Southeastern Brazil (Riccomini, 1989; Riccomini, Sant'Anna, & Ferrari, 2004) reactivated the Brasiliano shear zones and allowed the intense alkaline magmatism of Serra do Mar Province and Cabo Frio Magmatic Lineament (Almeida, 1983, 1991; Riccomini et al., 2004; Riccomini, Velázquez, & Gomes, 2005), including the intrusion of the IAM (e.g. Brotzu et al., 1997; Enrich, Azzone, Ruberti, Gomes, & Comin-Chiaramonti, 2005; Penalva, 1967; Ribeiro Filho, 1967; Rosa, 2017; Rosa & Ruberti, 2018) and about 30 others alkaline bodies. During the Cenozoic, intense uplift, weathering, and erosion processes occurred in the region, exposing outcrops of deep rocks, sculpting the landscape, and generating sediments that accumulated in the base of slopes, such as talus deposits, and depressed areas, such as alluvial deposits (Cogné, Gallagher, Cobbold, Riccomini, & Gautheron, 2012; Heilbron, Eirado, & Almeida, 2016; Modenesi & Toledo, 1993; Rosa & Ruberti, 2018; Trouw et al., 2003; Zalán & Oliveira, 2005).

Regarding geomorphological aspects, Mantiqueira Mountain Range represents one of the highest orographic features (above 2000 m above sea level) on the Atlantic edge of the South American continent (Hiruma et al., 2010; Marques Neto, Perez Filho, & Oliveira, 2015). Consequently, its evolution is linked to the uplift that culminated in the formation of the Serra do Mar and Mantiqueira horsts; to the rifting processes that gave rise to the graben of Paraíba do Sul; and to the emplacement of alkaline rocks (Almeida & Carneiro, 1998; Marques Neto et al., 2015; Riccomini, 1989; Zalán & Oliveira, 2005).

The INP is inserted in the morphostructural domain of the Neoproterozoic Mobile Belts and the geomorphological regions of the Paraíba do Sul Depression and Mantiqueira/Itatiaia Mountain Ranges (Projeto RADAMBRASIL, 1983; Instituto de Geografia e Estatística (IBGE), 2009, Instituto Brasileiro de Geografia e Estatística (IBGE), 2019). The first is within the Middle Paraíba do Sul Depression unit, linked to the readjustment of regional tectonic movements and successive erosive and depositional phases. It is characterised by ridges, erosive scarps, and valleys (Projeto RADAMBRASIL, 1983). The latter is inserted in the Itatiaia Plateau unit, associated with tectonic activities, uplift and block failure in the NE-SW direction, represented by structural valleys, scarps, symmetrical ridges, and circular structures (Instituto de Geografia e Estatística (IBGE), 2009).

4. Methodological procedures

The methodological procedures of this study follow three main approaches: (i) the inventory of geological sites of the INP, (ii) the analysis of the MP of the INP, and (iii) the discussion of the importance of integrating the inventory data into the MP.

4.1. Inventory of geological sites

Given the strong relationship of geomorphological and other geological features and processes in the INP, the inventory of geological sites (including geomorphological, hydrological, petrological, sedimentological, and structural sites) was carried out according to the guidelines for geoconservation in protected areas (Crofts et al., 2020).

Methods for assessing geomorphological heritage have been reviewed by Mucivuna, Reynard, and Garcia (2019). Most of the analysed methods were designed considering the specificities of the geomorphosites, i.e., the aesthetic dimension, the dynamic dimension, and the imbrication of scales (Coratza & Hobléa, 2018; Reynard, 2009) and the scientific and additional values (Reynard, 2005), such as aesthetic (e.g., Reynard, Perret, Bussard, Grangier, & Martin, 2016), cultural (e.g., Reynard & Giusti, 2018) and ecological (e.g., Bollati, Leonelli, Vezzola, & Pelfini, 2015; Bussard & Giaccone, 2021) values. Despite the wide range of geomorphosites' assessment methods, none of them was applied in this work because the INP inventory aimed to include all geological sites and not only the geomorphosites.

Based on that, the method of Brilha (2016, 2018) was selected to be applied in this study because (i) it can select sites with geomorphological and other geological interests; (ii) it allows making a comparative assessment based on an unbiased selection of sites with the lowest degree of subjectivity possible; and (iii) it proposes the quantitative assessment of scientific value, degradation risk, potential educational and touristic uses (step to be applied later - not covered in this work).

This method proposes the inventory of geosites (in situ occurrences of geodiversity elements with high scientific value) and geodiversity sites (in situ occurrences of geodiversity elements that do not have a particular scientific value, but which are still important resources for education, tourism, or cultural identity of communities) with scientific, educational, and touristic values. It includes (i) the definition of the topic, the value, the scale and the aim; (ii) review of literature and consultation with experts who have worked in the area; (iii) definition of geological frameworks (when applicable); (iv) review of sites used in educational activities (when applicable); (v) review of touristic advertisement materials (when applicable); (vi) list of potential sites; (vii) fieldwork and qualitative assessment based on defined criteria, and (viii) final list with complete characterisation (Brilha, 2016, 2018). In this work, steps (ii), (iv), (v) and (vi) were grouped into a step called "selection of potential sites". It also included the analysis of the MPs, cartographic materials, access routes and pathways (Mucivuna & Garcia, 2017).

Given these issues, the inventory of geological sites was carried out based on five steps and considering both geomorphological and other geological features:

(i) Definition of the topic, the value, the scale, and the aim. This step was carried out to define the inventory objectives and ensure the site selection under the same criteria. According to Lima, Brilha, and Salamuni (2010), the objective of the inventory must be clear and consider four issues: the topic (subject or theme to be inventoried, the whole geoheritage or just a partial component of it), the value (related to the potential use of the sites), the scale (geographical area covered by the inventory), and the use (purpose of the inventory).

(ii) Definition of geological frameworks (GFs). This step was carried out to identify and describe the main geological and geomorphological features and processes representing the park's geological history. The definition of GFs instead of geomorphological contexts was due to its broader approach, as GFs included both geological and geomorphological settings of the INP. In contrast, geomorphological contexts would be more focused on geomorphological processes and not on the specificities of the park's outcropping rocks. They were defined based on: (a) review of literature, (b) analysis of cartographic materials, and (c) suggestions of researchers who have conducted studies in the area.

(iii) Selection of potential sites. In order to select sites that would represent the geomorphological and other geological features and processes that compound the registers of the park's geological history, the following steps were carried out using published geological and geomorphological data (a) review of literature; (b) analysis of the MPs (Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), 2013; Instituto Brasileiro de Desenvolvimento Florestal (IBDF), 1982); (c) review of sites used in educational activities; (d) review of tourist advertisement materials; (e) interviews with researchers who have worked in the area; (f) analysis of cartographic materials (geological map (Heilbron et al., 2016; Rosa & Ruberti, 2018; Trouw et al., 2003), geomorphological and pedological maps (Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), 2013), satellite images (Google Earth®, Global Digital Elevation Model) and Landsat 8 image (U.S. Geological Survey)) to identify the main rocks, structures, features and processes, and (g) analysis of access routes and pathways.

All steps except (b), (f) and (g) were described by Brilha (2016). Steps (a) and (b) consisted of a review of literature of geological and geomorphological data published about the park in papers, theses, dissertations, books, technical reports, and MPs. Steps (c) and (d) consisted of the review of sites used in educational and touristic activities in the MPs, INP leaflet and website, advertisement materials available online and websites of the Tourism Department of the cities within the study area. Step (e) involved asking researchers who carry out studies in the area for advice on potential sites with scientific, educational and tourism values. Step (f) consisted of analysing geological, geomorphological and pedological maps as well as satellite and Landsat images to identify the main lithostratigraphic units, regional structures, geomorphological units, and soils (Mucivuna, Garcia, & Del Lama, 2015). Finally, step (g) consisted of finding the shortest access routes to the potential sites (Mucivuna & Garcia, 2017).

(iv) Fieldwork and qualitative assessment. This step was carried out to identify and characterise all potential sites and new ones concerning geomorphological and other geological features and processes and links with aesthetic, cultural, and ecological values. All potential geosites referred previously in scientific publications have been included in the final list because the scientific community already recognises them and their relevance. As to those not mentioned in any publication, they were qualitatively assessed considering the criteria of representativeness, integrity, and rarity (Brilha, 2016, 2018). The representativeness criterion considered not only "*the appropriateness of the geosite to illustrate a geological process or feature that brings a meaningful contribution to the understanding of the geological topic, process, feature, or geological framework*" (Brilha, 2016), but also the observation of representative inherited and active geomorphological processes (dynamic dimension and spatial and temporal scales). The integrity criterion assessed not only "*the present conservation status of the geosite, taking into account both natural processes and human actions*" (Brilha, 2016), but also the forms and process (dynamic dimension) (Santos, Reynard, Mansur, & Seoane, 2019). Finally, the rarity criterion considered both the "*number of geosites in the study area presenting similar geological features*" and the rare forms representative of the regional geomorphological diversity of the park (spatial scale). Regarding geodiversity sites, they were qualitatively assessed considering the criteria of didactic potential, variety of geological elements (educational value), scenery and interpretative potential (tourism value) (Brilha, 2016, 2018). The scenery criterion is strongly related to the aesthetic dimension of geomorphosites due to the visual appeal that landscapes have to attract people's attention and the potential to improve understanding of geoscientific knowledge (Santos et al., 2019). On the other hand, accessibility, and safety (Brilha, 2016, 2018) were not considered as key criteria to include or not geological sites in the final list (Mucivuna, Garcia, & Reynard, 2022), as these issues involve measures that can be modified by building infrastructure.
(v) Final list and characterisation of sites. Sites that (a) were not found in the fieldwork, (b) were in inaccessible areas, or (c) had no geoscientific importance were excluded from the final list. Each geological site was characterised by considering the following data: name of the geological site, geological framework (when applicable), geographical location, interests (Serviço Geológico do Brasil, 2020), and description of the most remarkable geomorphological and other geological features and processes.

4.2. Analysis of the management plan

In INP, two MP versions are available: the 1982 version covers its initial boundaries (Instituto Brasileiro de Desenvolvimento Florestal (IBDF), 1982), and the current one includes the expanded area (Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), 2013). Therefore, the analysis was performed based on the following aspects:

(i) Review of plans. This step was carried out to (i) identify potential sites that could be included in the inventory (Section 4.1) and (ii) analyse the latest version (Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), 2013) considering the following questions:

- How is geodiversity described?
- Do geological and geomorphological maps show sites associated with geodiversity?
- Is the physical characterisation of geological sites adequate?
- Do the proposals for public use cover sites associated with geodiversity?

(ii) Diagnosis. This step was carried out to (i) store all relevant information on abiotic aspects in a database and (ii) identify which chapters of the MP can potentially integrate geological sites directly or indirectly.
(iii) Content analysis. This step was carried out to (i) describe how information on abiotic aspects was displayed in the MP and (ii) analyse such information to relate how geodiversity could be better addressed in the MP.

Table 1
Geological frameworks and geosites of the Itatiaia National Park, Brazil.

Geological framework	Brief description	Geosites*
Quaternary deposits	It represents the geological, geomorphological, and climatic processes that have controlled the evolution of the study area's recent landforms.	(1) Bog of Aiuruoca River (2) Bog of Preto River (3) Fluvial deposits of Lago Azul (4) Talus deposits of Serra Negra village
Cenozoic tectonism	It includes the Cenozoic tectonism records represented by the following structures: (i) NW-SE, corresponding to the elongation of the massif; (ii) ENE-WSW, following the basement and the arrangement of the Continental Rift of Southeast Brazil (CRSB); and (iii) W-E, more perceptible in the central sector of the IAM (Rosa & Ruberti, 2018).	(5) Structural valley of Campo Belo River (6) Fault escarpment of Couto-Prateleiras Hills
Third magmatic stage of alkaline intrusion	It includes nepheline syenite to trachyte, trachyte and two small bodies of basic rocks from the last magmatic intrusion of the IAM, 67.5 Ma (Rosa, 2017; Rosa & Ruberti, 2018).	(7) Biotite monzonite quarry (8) Breccia of Pedra Furada Hill
Second magmatic stage of alkaline intrusion	It represents nepheline syenite to quartz syenite, trachyte and a small granite body formed during the second magmatic intrusion between 69.65 and 68.65 Ma (Rosa, 2017; Rosa & Ruberti, 2018). It also covers the peralkaline facies, symbolised by the circular ridge, one of the most outlined geomorphological features on the Itatiaia Plateau.	(9) Fracture planes of Pedra do Altar Hill (10) Fluted erosion of Agulhas Negras Hill (11) Ovos da Galinha boulders and trachyte dyke swarm (12) Ring-dyke on Itatiaia Plateau
First magmatic stage of alkaline intrusion	This framework includes records of nepheline syenite rocks from the first magmatic intrusion, aged 71.26 Ma (Rosa, 2017) and mostly embedded in the CRSB (Riccomini, 1989), but not strongly affected or deformed by its evolution (Rosa & Ruberti, 2018).	(13) Waterfalls of Campo Belo River Basin
Proterozoic igneous and metamorphic rocks	Basement composes the Paleoproterozoic rocks of Juiz de Fora Domain and Neoproterozoic rocks of Andrelândia Sequence (Occidental Terrane), related to the Trans-Amazonian Orogenic Cycle and the Brasiliano Pan-African Cycle.	(14) Leucogranite of Pedra Grande Hill (15) Tectonic records of Rio Preto Waterfalls (16) Metagranitoid of Enamorados Peak (17) Mylonitic gneiss of Santa Clara Waterfall

Note: * All geosites are also geomorphosites (Panizza, 2001; Reynard, Coratza, & Regolini-Bissig, 2009) (excluding the Biotite monzonite quarry). Geosites are described in more details in Table 2.

4.3. Proposals for integrating the inventoried sites into the management plan

Based on the results of the inventory of geological sites (Section 5.1) and the MP analysis (Section 5.2), proposals were performed to suggest the inclusion of geological sites directly or indirectly in some chapters and in the zoning of the MP.

5. Results

5.1. Inventory of geological sites

In this work, the topic included the whole geoheritage, emphasising geomorphological heritage; the value considered the scientific, educational and tourism interests; the scale covered the boundaries of the Itatiaia National Park, and; the aim was to contribute with geoconservation strategies through geological site interpretation.

Based on these objectives, six GFs were defined (Table 1). Subsequently, these GFs were associated with morphogenesis, which was mainly related to fluvial and mass movement processes, rock formation processes, tectonic processes, and rock erosion and weathering processes.

During fieldwork, some potential sites selected in the review of sites used in educational activities and touristic advertisement materials (Último Adeus Viewpoint, Flores Viewpoint and Altos dos Brejos Hill) were assessed. However, they showed no geological or geomorphological interest in the site itself (one is an artificial belvedere and the other a road cut), but they allowed panoramic views to rocks, structures, and processes with intrinsic values. Based on this, they were included in the inventory, since viewpoints can play na essential role in comprehending geodiversity and geoheritage (Migoń & Pijet-Migoń, 2017).

After the qualitative assessment, 17 representative geosites of the park's geological history were included in the inventory and characterised by considering geomorphological and other geological features and processes (Table 2). In addition, seven geodiversity sites (Table 3) and three viewpoints were also identified (Table 4). The park's geological map was compiled using three other maps (Heilbron et al., 2016; Rosa & Ruberti, 2018; Trouw et al., 2003). Fig. 2 shows all inventoried sites' locations, examples of representative geosites within each geological framework, geodiversity sites, and viewpoints with education and tourism values.

The distribution of these sites is not uniform in the territory; most of the inventoried sites are concentrated in the central region due to a high number of scientific publications, detailed mapping (scale 1:50.000), and excellent exposure of rock outcrops and relief features. There are fewer inventoried sites in the South region because of the dense Atlantic Forest cover and the lack of

Table 2
Geosites in the Itatiaia National Park.

Geosite	Coordinates 23 K (UTM WGS-84)	Interests	Brief description
Quaternary deposits			
(1) Bog of Aiuruoca River	534,151 / 7,527,107	SF, SD, HD, GM	Floodplain filled with peat sediments and one of the highest springs in Brazil (Teixeira & Linsker, 2007). On its Western side, alluvial deposits with granules and pebbles are observed in the central and upper portion of the profile.
(2) Bog of Preto River	536,460 / 7,526,460	SF, SD, HD, GM	Depressive area filled with alluvial deposits and the Spring of Preto River. A few metres from its left bank, alluvial deposits of up to one-metre high were observed, with sub-rounded granules at the top of the profile.
(3) Fluvial deposits of Lago Azul	539,736 / 7,517,208	HD, SD, GM	Natural pool inserted in an incised valley (middle course of Campo Belo River), filled with boulders and cobbles along the riverbank, as well as pebbles, granules and sand deposited on its left bank.
(4) Talus deposits of Serra Negra VVillage	530,929 / 7,532,340	GM, SF	Talus deposits composed of large rock fragments in clay to a sand-clay matrix (Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), 2013) with convex tops and slopes. In lower regions, the exposed boulders are related to slope erosion.
Cenozoic tectonism			
(5) Structural valley of Campo Belo River	532,716 / 7,524,651	GM, TC, SF, SD, HD, PE, PL	Structural valley oriented in the NW-SE direction and segmented into six sub-areas including spring, peat, talus and colluvium deposits, linear concentration of boulders, waterfall and a microalaskite outcrop.
(6) Fault escarpment of Couto-Prateleiras Hills	532,843 / 7,524,000	GM, TC, PL	Fault scarp oriented towards N70W (Penalva, 1967) with rounded tops and straight slopes. It comprises four sub-areas on Itatiaia Plateau such as Índio cave, hills (Couto and Prateleiras) and boulders (Pedra da Maçã and Pedra da Tartaruga).
Third magmatic stage of alkaline intrusion			
(7) Biotite monzonite quarry	526,016 / 7,526,458	PT, PL	Quarry composed of greenish-gray with medium-grained massive crystals, a significant amount of poikilitic biotite, cleavage planes and no preferential orientation (Rosa & Ruberti, 2018).
(8) Breccia of Pedra Furada Hill	528,365 / 7,527,402	PT, PL, GM	Trachyte hill marked by fracture planes, top and smooth convex slopes. Some outcrops have fluidal textures with deformed fragments along the trail to reach it, suggesting subvolcanic conduct magmatism with intense activity.
Second magmatic stage of alkaline intrusion			
(9) Fracture planes of Pedra do Altar Hill	533,539 / 7,525,715	TC, PL, GM	Intensely fractured hill, with uneven surfaces, smooth convex top and straight slopes. Vertical and sub-vertical fracture planes are arranged on slopes and pitted erosion is observed on the ridge.
(10) Fluted erosion of Agulhas Negras Hill	534,818 / 7,525,059	PT, TC, GM	Deeply dissected hill with uneven surfaces, sharp peaks, and straight slopes. There are fluted and pitted erosion on fracture planes in the *E*-W direction formed by chemical dissolution due to microorganisms associated with water.
(11) Ovos da Galinha boulders and trachyte dyke swarm	535,060 / 7,526,810 534,929 / 7,526,795	PL, TC, GM	It includes two sub-areas: (i) five boulders arranged on a hill and aligned in the NW-SE direction, and (ii) biotite hornblende pulaskite slab crosscut by trachyte dykes.
(12) Ring-dyke on Itatiaia Plateau	536,870 / 7,528,573	PT, PL, GM	Circular crest marked by water gaps developed by river erosion. Maromba and Aiuruoca Rivers are the most outstanding examples of these features (Teixeira, 1961).
First magmatic stage of alkaline intrusion			
(13) Waterfalls of Campo Belo River Basin	538,868 / 7,520,001 539,302 / 7,519,893 539,161 / 7,519,592 539,774 / 7,518,369	HD, SF, TC, GM	Waterfalls located in the Campo Belo and Maromba rivers with straight to convex slopes and fragments of rocks deposited along their valleys.
Proterozoic igneous and metamorphic rocks			
(14) Leucogranite of Pedra Grande Hill	529,562 / 7,529,067	PL, TC, GM	Convex top and slopes hill marked by stretched K-feldspar crystals and intrusions of quartz veins discordant with foliation.
(15) Tectonic records of Rio Preto Waterfalls	539,405 / 7,530,390 539,420 / 7,530,346	TC, MT, HD, GM	It includes two sub-areas: (i) slide waterfall composed of locally garnet-bearing banded paragneiss, showing axial plane foliation to isoclinal to tight folds, and (ii) cascade marked by banded paragneiss with moderate to high dip angle.
(16) Metagranitoid of Enamorados Peak	526,108 / 7,525,221	MT, GM, TC	Hill marked by an outcrop of about 30 m at its top, with uneven surfaces and straight slopes. Its foliation is oriented in the NW-SE direction, and the fracture planes are concordant with a moderate dip angle.
(17) Mylonitic gneiss of Santa Clara Waterfall	541,600 / 7,532,273	MT, TC, HD, GM	Slide waterfall characterised by mylonitic gneiss with horizontal fracture planes, deformed feldspar crystals and foliation orientated in the NW-SE direction.

Note: Interests are based on the categories adopted at the Brazilian scale and visible on GEOSSIT platform. GM: geomorphological, HD: hydrological, MT: metamorphism, PE: paleoenvironmental, PL: plutonism, PT: petrological, SD: sedimentary, SF: furface formations, TC: tectonics (Serviço Geológico do Brasil, 2020).

geoscientific publications. The reduced number of sites in the North region results from the absence of rock outcrops since the igneous and metamorphic ones are quite weathered; therefore, the inventoried sites are only represented by waterfalls and hilltops. These are also a result of the distribution of the rocks in the park, since about 6% of the area is made up of alluvial and talus

Table 3
Geodiversity sites in the Itatiaia National Park.

Geodiversity site	Coordinates 23 K (UTM WGS-84)	Interests	Brief description
(18) Lakes and wetlands with peat deposits	531,616 / 7,526,418	SF, SD, HG, GM	Wetland filled with peat deposits and shallow lakes surrounded by steep hills and rocky peaks.
(19) Breccia of Camelo Hill	529,874 / 7,526,124	PT, PL, GM	Intensely dissected hill, with irregular surfaces, smooth convex top, straight slopes, and alveolar hollows.
(20) Pitted erosion of Pedra do Sino Hill	534,737 / 7,526,045	PL, GM, TC	Hill marked by uneven surfaces, smooth convex top, straight slopes, and chemical dissolution in the fracture planes.
(21) Aiuruoca Waterfall	534,128 / 7,527,224	PL, TC, HD, GM	Cascade characterised by horizontal fracture planes and natural pool filled with rock fragments.
(22) Nepheline syenite of Três Picos Hill	542,910 / 7,519,982	GM, PL	Hill marked by convex top and slopes and an outcrop of about two metres long by one metre wide on its ridge.
(23) Granitic gneiss of Alcantilado Waterfall	545,202 / 7,534,632	PL, TC, HD, GM	Cascade characterised by foliation in the NW-SE direction and moderate dip angle.
(24) Gneiss of Cristais Waterfall	540,397 / 7,528,736	MT, TC, HD, GM	Tiered waterfall and a natural pool marked by locally folded rocks, foliation in the NW-SE direction and low dip angle.

Note: Interests are based on the categories adopted at the Brazilian scale and visible on GEOSSIT platform. GM: geomorphological, HD: hydrological, HG: hydrogeological, MT: metamorphism, PL: plutonism, PT: petrological, SD: sedimentary, SF: surface formations, TC: tectonics (Serviço Geológico do Brasil, 2020).

deposits of Quaternary age, 60% of alkaline rocks of Meso-Cenozoic age, and 34% of igneous and metamorphic rocks of Proterozoic age (Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), 2013).

As for access, 82% of the sites are reached only by trails and their difficulty levels are considered moderate to high. Among them, 27% have a length of up to 2 km, 27% between 2.1 and 6.0 km, 9% between 6.1 and 10.0 km, 23% between 10.1 and 20.0 km and 14% over 20 km.

5.2. Analysis of the management plan

The main differences between the 1982 and 2013 plans are the covered area, as previously mentioned, and the applied methodological guidelines. The plan review was carried out to contemplate the expanded area, add new information, and readjust the actions since the planning process must be flexible and continuous (Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), 2013).

5.2.1. 1982 plan

Although the scope of this study's analysis is the latest version of the MP (Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), 2013), some aspects of the 1982 version are worth mentioning.

The 1982 version was developed by the Brazilian Institute for Forest Development, the institution that used to be responsible for park management, according to Decree 84,017/1979 (Brasil, 1979). This Decree established general rules, which contained suggestions on the information that should be included in the MP, not imposing a specific technical requirement about its structure and writing. In this context, the 1982 plan has 207 pages and is divided in four chapters (i: national and regional context; ii: analysis of the protected area; iii: management and development, and; iv: implementing) that contains the area's description, zoning, and proposal for management actions (Instituto Brasileiro de Desenvolvimento Florestal (IBDF), 1982). This plan is no longer used by park managers.

Table 4
Viewpoints in the Itatiaia National Park.

Viewpoint	Coordinates 23 K (UTM WGS-84)	Interests	Brief description
(25) Viewpoint Flores Highway	528,107 / 7,526,791	GM, TC	Visualisation of the Bocaina, Mantiqueira and Fina mountain ranges and Paraiba do Sul river valley.
(26) Viewpoint Último Adeus	540,414 / 7,516,328	GM, TC, HD	Panoramic view of the Campo Belo river's incised valley, Paraíba do Sul river valley, dam of Funil hydroelectric power plant and Bocaina mountain range.
(27) Viewpoint Alto dos Brejos Hill	539,869 / 7,535,397	GM, TC	Panoramic view of the Bocaina mountain range, Paraíba do Sul river valley, talus deposits, asymmetric slopes, convex section slopes, Gavião peak and Pedra Selada protected area.

Note: Interests are based on the categories adopted at the Brazilian scale and visible on GEOSSIT platform. GM: geomorphological, HD – Hydrological, TC – Tectonics (Serviço Geológico do Brasil, 2020).

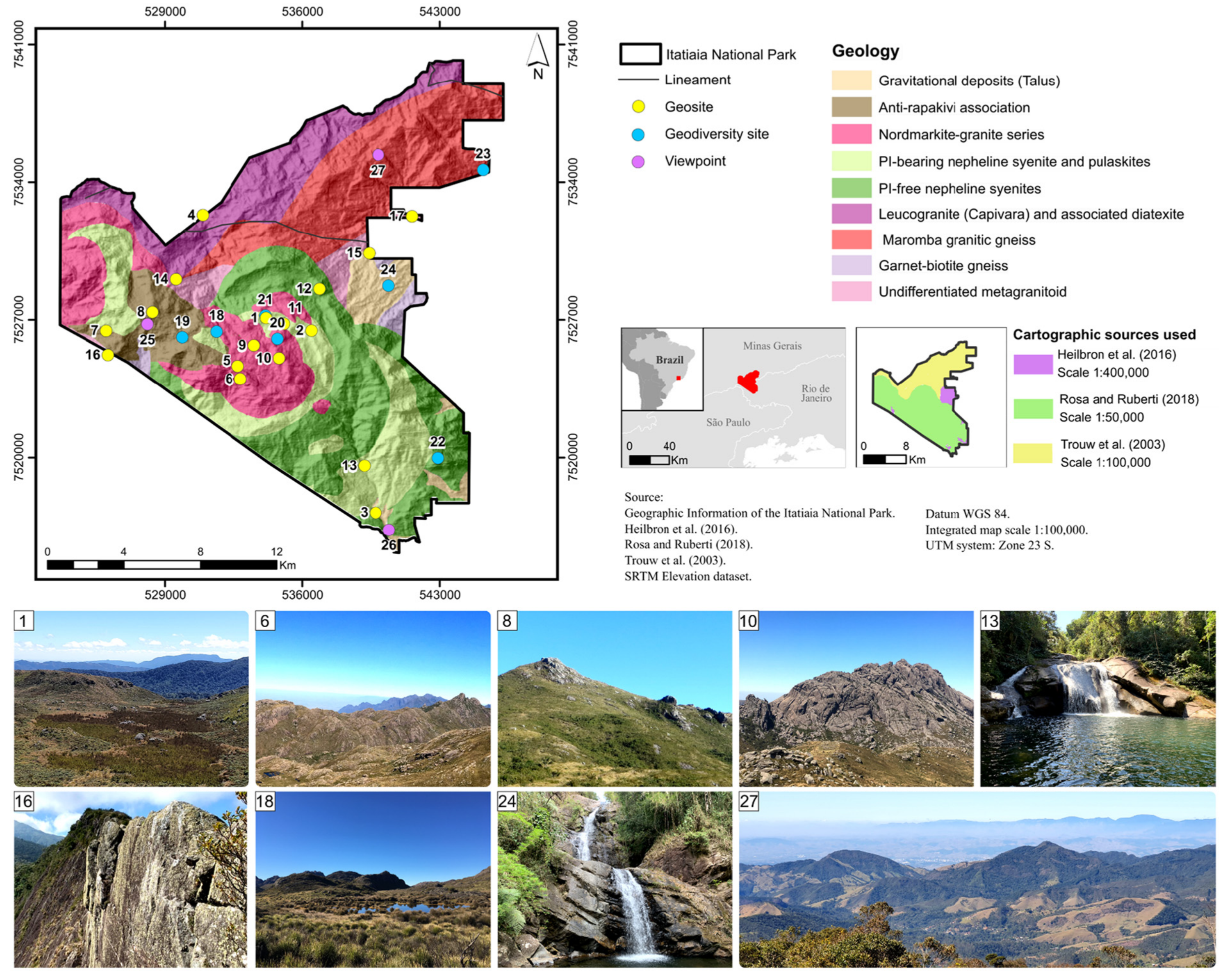

Fig. 2. Inventoried sites in the Itatiaia National Park. Geosites of the quaternary deposits geological framework: (1) bog of Aiuruoca River; (2) bog of Preto River; (3) fluvial deposits of Lago Azul; (4) talus deposits of Serra Negra village. Geosites of the Cenozoic tectonism geological framework: (5) structural valley of Campo Belo River; (6) fault escarpment of Couto-Prateleiras Hills. Geosites of the third magmatic stage of alkaline intrusion geological framework: (7) biotite monzonite quarry; (8) breccia of Pedra Furada Hill. Geosites of the Second magmatic stage of alkaline intrusion geological framework: (9) fracture planes of Pedra do Altar Hill; (10) fluted erosion of Agulhas Negras Hill; (11) ovos da Galinha boulders and trachyte dyke swarm; (12) ring-dyke on Itatiaia Plateau. Geosite of the First magmatic stage of alkaline intrusion geological framework: (13) waterfalls of Campo Belo River Basin. Geosites of the Proterozoic igneous and metamorphic rocks geological framework: (14) leucogranite of Pedra Grande Hill; (15) tectonic records of Rio Preto Waterfalls; (16) metagranitoid of Enamorados Peak; (17) mylonitic gneiss of Santa Clara Waterfall. Geodiversity sites: (18) lakes and wetlands with peat deposits; (19) breccia of Camelo Hill; (20) pitted erosion of Pedra do Sino Hill; (21) Aiuruoca Waterfall; (22) nepheline syenite of Três Picos Hill; (23) granitic gneiss of Alcantilado Waterfall; (24) gneiss of Cristais Waterfall. Viewpoints: (25) Flores Highway (26) Último Adeus; and (27) Alto dos Brejos Hill. The pictures show representative geosites within each geological framework and geodiversity sites and viewpoints with education and recreative values.
Note: photo (16) by Jobson Pereira; all other photos byVanessa C. Mucivuna.

The plan details the aspects of regional and local geological and geomorphological features. In addition, some sites are emphasised (Viewpoint of Último Adeus, Lago Azul, Maromba Waterfall, Agulhas Negras Hill, Pedra do Altar Hill, and Bog of Aiuruoca River) regarding the analysis of the landscape.

The document presents some management objectives directly associated with geodiversity, such as: (i) protect the springs; (ii) conserve areas of natural beauty in the Serra da Mantiqueira, and; (iii) provide visitors with environmental education and interpretation associated with high altitude grasslands, rivers, slopes, and valleys. Moreover, it stresses that the most significant aspects of the Park's fauna, flora and geology must be considered in the development of interpretative trails. It also highlights that the geology and tectonics featured in the park represent an important heritage to be interpreted. Unfortunately, there are no photos or local maps included in the plan.

5.2.2. 2013 plan

The latest version (Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), 2013) was designed to guide the management and operation of public visitation activities, environmental management, and monitoring. It was prepared by ECOMEK

Table 5
Reports and chapters of the Itatiaia National Park Management Plan (Instituto Chico Mendes de Conservação da Biodiversidade (CMBio), 2013).

Report	Chapter
1. Contextualisation of the Itatiaia National Park	1.1 International context
	1.2 Federal context
	1.3 State context
2. Analysis of the region of the protected area	2.1 Description of the Itatiaia National Park region
	2.2 Physical environment
	2.3 Cultural and historical aspects
	2.4 Land use and occupation and environmental issues
	2.5 Population characteristics
	2.6 Community view on the protected area
	2.7 Opportunities to sustainable economic development
	2.8 Relevant environmental law
	2.9 Potential to support the protected area
3. Analysis of Itatiaia National Park	3.1 General information
	3.2 Characterisation of abiotic and biotic aspects
	3.3 Cultural, material, and immaterial heritage
	3.4 Socioeconomy
	3.5 Property situation
	3.6 Fire and other unusual occurrences
	3.7 Developed activities
	3.8 Institutional issues
	3.9 Statement of significance
4. Itatiaia National Park Planning	4.1 Overview of the planning process
	4.2 History of planning in Itatiaia National Park
	4.3 Specific management goals of Itatiaia National Park
	4.4 Strategic evaluation of Itatiaia National Park
	4.5 Zoning
	4.6 General management regulations of the Itatiaia National Park
	4.7 Management programmes

Business Consulting and Environment, a company commissioned by Chico Mendes Institute for Biodiversity Conservation (ICMBio) (Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), 2013).

The INP management plan was elaborated based on the methodological planning guidelines of Galante et al. (2002), i.e., planning is a continuous and collaborative process. These guidelines are adjusted to the rules of NSPA and set out that an MP must be organised in four reports, including (i) contextualisation of the protected area (three chapters); (ii) regional analysis of the municipalities covered by its boundaries (nine chapters); (iii) analysis of the Itatiaia National Park (nine chapters), and; (iv) planning strategies and its relation with the surroundings (seven chapters) (Table 5).

The first report contextualises the park regarding international agreements and relates it with federal and state levels. In addition, it addresses possible cooperation initiatives that could assist in its conservation. The second report describes both opportunities and threats as well as information for planning and management. The third report describes the general data, abiotic and biotic aspects, and human activities. Moreover, it indicates the activities and infrastructure available. Finally, the last report presents its planning and zoning (Table 5). The INP's MP characterises the area, draws and describes each zone's activities, and plans the management over 487 pages. Moreover, the plan is well illustrated with several regional and local maps.

Several chapters describe aspects of geodiversity that deserve attention (column 3: Table 6). In some of them, abiotic aspects are clearly mentioned, such as “to conserve areas of natural beauty representing Serra da Mantiqueira” and “provide visitors with environmental education and interpretation, such as high-altitude grasslands, rivers, slopes and valleys”. In contrast, others are only indirectly mentioned (Table 6) or not even described (Visconde de Mauá region).

Several sites that have been inventoried in this work are mentioned in the document; however, only their potential for tourism use is mentioned, with no consideration for their geomorphological or other geological features and processes.

6. Proposals for integrating the inventoried sites into the management plan

All INP's MP reports have geodiversity aspects that require attention (Table 6). However, there is no concrete proposal for conserving or monitoring these aspects. In this context, a rigorous selection of geological sites is essential to propose their inclusion in the MP. The characterisation and potential use data would support conservation and management planning and ensure that geoheritage features and processes are protected.

In the following, we propose how geological sites could be further included in the MP guidelines by integrating them into general and specific aspects, ongoing activities, and zoning. The proposals are presented in a broader approach, i.e., presenting general discussions on the subject, and in a narrower approach, i.e., focusing on integrating geological sites in the INP's MP.

Concerning general aspects, in the “contextualisation of the park” report, many universities, research groups and companies dedicated to studies on geoconservation could be scientific partners to develop research through systematic inventories of

Table 6
Analysis of the Itatiaia National Park Management Plan (Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), 2013).

Report	Chapter	Description of the management plan	Analysis of the description of geodiversity
Contextualisation of the Itatiaia National Park	State context	Most management programmes and projects are focused on (i) conservation of biological aspects, (ii) environmental education programmes, (iii) infrastructure building, and (iv) support for creating protected areas within buffer zones. In addition, partner institutions can contribute to research, environmental education and awareness projects, ecotourism activities, and tourist routes.	It does not mention the conservation of abiotic aspects, nor describe sites associated with geodiversity that could be included in environmental education and awareness programmes.
Analysis of the region of the protected area	Physical environment	Regional physical aspects are described based on characteristics of abiotic (geology, geomorphology, soil, climate, hydrography) and biotic (vegetation and fauna).	The description is focused on regional aspects.
	Cultural and historical aspects	Cultural and environmental heritages are described based on general aspects, location, and current uses.	It includes sites linked to geodiversity, such as peaks and waterfalls. However, they are described only in relation to tourism potential.
	Opportunities to sustainable economic development	The possibilities for strengthening the region are described through (i) infrastructure construction, (ii) reforestation and (iii) tourism, mainly ecotourism, involving local communities.	It does not offer opportunities for linking environmental aspects to local communities.
Analysis of Itatiaia National Park	Characterisation of abiotic and biotic aspects	Specific abiotic (Climate, Geology, Geomorphology, Pedology, Hydrography) and biotic (Fauna and Flora) aspects are highlighted through detailed descriptions, maps, and figures.	It describes the main physical aspects but does not assess the threats and degradation risk.
	Statement of significance	Eleven aspects of relevance to protection are described, highlighting: (i) protect the watersheds of the main hydrographic basins; (ii) enable scientific research focused on the management of the area; (iii) conserve areas of natural beauty in Serra da Mantiqueira; (iv) recover, preserve and protect the Itatiaia Plateau; (v) provide visitors with environmental education and interpretation information, associated with high altitude grasslands, rivers, slopes, and valleys.	Geodiversity is not highlighted concerning its importance for research.
Itatiaia National Park planning	Specific management goals of Itatiaia National Park	Three pillars support the park's objectives: (i) the NSPA; (ii) the specific objectives of its creation; and; (iii) its specific knowledge. The latter stands out because rare species, historical, archaeological or paleontological sites, ecosystems, geological and geomorphological formations of scenic beauty are essential for management. The management plan has 20 management goals, of which we highlight: (i) protection of the landscape and scenic beauty of Paraiba do Sul Valley and Serra da Mantiqueira; (ii) protection of springs; (iii) provision of activities for the public use, education and environmental interpretation of the natural environment; (iv) promote visits to the population of the surrounding area to raise environmental awareness of the importance of preserving the region; and (v) encouragement and development of visiting and tourism activities as an opportunity to local economic development.	Despite mentioning the promotion of abiotic elements through public use, environmental education and interpretation activities, there is no project in progress.
	Strategic evaluation of Itatiaia National Park	It is necessary to implement environmental education and awareness programmes targeted at visitors and neighbours, as natural resources, historical-cultural and environmental values are largely unknown.	It has no action in practice that includes abiotic aspects in environmental education and awareness programmes.
	Zoning	Eight zones were mapped and described based on biotic, abiotic, land use and occupation characteristics, as well as allowed or forbidden activities.	There is no clear definition of the rules and activities regarding the use and management of biotic and abiotic elements.

geological sites. These actions could bring significant contributions, as they could contribute to the adequate assessment of geological sites and the integration of such data in the PA's MP. In INP, the chapter “state context” should include geoconservation projects like they do for biodiversity.

Regional information on abiotic aspects is described without correlating with INP geological sites (analysis of the region of the protected area report). Based on that, including some geological sites in the chapter “physical environment” is essential to illustrate the characteristics described and correlate them to the park's GFs. For example, the Metagranitoid of Enamorados Peak (16) could integrate the MP as a representative site of the Paleoproterozoic crystalline basement, the Fluted erosion of Agulhas Negras Hill (10) of the Meso-Cenozoic alkaline rocks, and the Talus deposits of Serra Negra village (4) of the Quaternary deposits.

Table 7
Proposals for including the inventoried sites into the management plan based on the zoning and allowed activities.

Zoning	Allowed activities	Inventoried sites (Fig. 2)	Possibilities to include the inventoried sites into the management plan
Primitive zone: slight or minimal human intervention, containing fauna and flora species or natural phenomena of great scientific value.	Research, traditional climbing, low impact visits, hiking, management, and environmental interpretation.	1, 2, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21 and 24	Visiting geological sites can be an opportunity for developing tourism in the region (Opportunities for sustainable economic development). In this sense, the geosite Fluted erosion of Agulhas Negras Hill is an excellent venue for understanding the physical environment, as it is already widely used in traditional climbing.
Temporary occupation zone: area with a concentration of residences and areas of use.	Protection, environmental interpretation, and awareness of the local population.	4 and 23	Projects aiming to promote environmental awareness and spread the importance of preserving the region to neighbouring populations could be included in specific management goals. Therefore, inventoried sites close to the park boundaries are in a privileged location for the dialogue between the park management and the local people.
Recovery zone: areas with considerable human impact.	Protection, environmental interpretation, and awareness of the local population, visiting and research.	27	Historical and geological values could be integrated into the strategic evaluation section. In addition, the viewpoint has a good potential for interpretation and environmental awareness of the local population since residents use its path to transport local handmade products.
Extensive use zone: mostly comprised of natural areas, it may have signs of anthropic activities.	Visiting, research, protection, monitoring, environmental education, and awareness.	1, 2, 3, 5, 6, 9, 10, 11, 12, 13, 14, 16, 18, 20, 21, 22, 26 and 27	An integrated environmental education programme, including biological and geological aspects, could be included in the management plan (State approach). The geosite Fluvial deposits of Lago Azul could contribute to a better visitor experience.
Intensive use zone: comprised of natural or anthropic areas, with the environment maintained as close as possible to nature. Infrastructures, other facilities, and services support public use.	Protection, research, visiting, and permanent environmental education activities.	5, 7, 8, 13, 25 and 26	Stimulating scientific research could contribute to manage geological and biological aspects (Statement of significance). The geosite Structural valley of Campo Belo River is an excellent example of scientific research on geological and biological aspects.

Furthermore, the Flores Highway (25) and Alto dos Brejos Hill Viewpoints (27) are excellent examples of sites that allow observing the regional geomorphological regions (Paraíba do Sul River depression, and Mantiqueira Mountain Range).

Regarding specific aspects, systematic inventory methods are strongly recommended by the IUCN guidelines (Crofts et al., 2020), as it allows recreating the local geological history through the link between intrinsic and additional values. In INP, the links between abiotic and cultural (e.g., Biotite monzonite quarry (7)) and ecological values (e.g., Lakes and wetlands with peat deposits (18)) should be prioritised in the MP to contribute to the integrated management of nature (analysis of the region of the protected area report: chapter cultural and historical aspects). Furthermore, the description of the Granitic gneiss of Alcantilado Waterfall (23), Tectonic records of Rio Preto Waterfalls (15), and Mylonitic gneiss of Santa Clara Waterfall (17), besides the touristic aspects, is essential to approach abiotic aspects of the Visconde de Mauá region in the INP's MP.

In the “analysis of the protected area” report, all geological sites must be described and illustrated using photographs and maps in a specific subchapter focused on geoconservation of the park or throughout chapter “characterising the abiotic and biotic aspects”. In the chapter “characterising the abiotic and biotic aspects”, geological sites should be described regarding their geomorphological and other geological features and processes and their potential uses to prioritise conservation actions, environmental education and interpretation, and visiting. The chapter “Cultural, material and immaterial heritage” should correlate information on historical aspects of the Viewpoint Último Adeus (26) with abiotic aspects, as it is an excellent site to observe different geomorphological regions (Paraíba do Sul River Depression and Mantiqueira Mountain Ranges). In addition, the Nepheline syenite of Três Picos Hill (22) should integrate their geological-historical potential, as depicted in Alberto da Veiga Guignard paintings. The chapter “Fire and other unusual occurrences” should highlight the potential risk of forest fire in the Bogs of Aiuruoca and Preto Rivers (1 and 2), Breccia of Pedra Furada Hill (8), Aiuruoca Waterfall (21) and Viewpoint Alto dos Brejos Hill (27) in order to measure threats and mitigate possible damage. The chapter “Developed activities” focus on environmental education, visiting and climbing activities. Although climbing activities in the Breccia of Camelo Hill (19), Fault escarpment of Couto-Prateleiras Hills (6) and Fluted erosion of Agulhas Negras Hill (10) are entirely associated with abiotic aspects, no information is provided. Therefore, identifying the potential impacts of this activity on geological-geomorphological features and processes is essential for the conservation and use of these sites. In the chapter “statement of significance”, geosites that have watersheds, such as Bogs of Aiuruoca and Preto Rivers (1 and 2), should be included in the plan due to their essential role to the protection of local freshwater.

Ongoing activities are mainly associated with environmental education, public use, and monitoring. Therefore, integrating geological sites related to the MP objectives could increase awareness of the importance of conservation among visitors and the population of the surrounding areas; interpretation and education could contribute to the sustainable management of resources and raise awareness of the importance of PAs, in addition to highlighting the fundamental role of geological sites in the maintenance of ecosystems and the benefits provided by nature to society and developing a more sustainable future.

Environmental education activities are mainly performed in the Fluvial deposits of Lago Azul (3), Waterfalls of Campo Belo River Basin (13), and indoor activities in the Visitor centre. Considering that, the inclusion of such sites in the "contextualisation of the park" and "analysis of the protected area" reports would ensure that geodiversity and biodiversity conservation are linked for nature conservation; it would enrich the content of environmental education and interpretation programmes through a systemic approach to the environment (Potential for cooperation and Statement of significance).

The most visited sites in the South of the park are the Fluvial deposits of Lago Azul (3), the Waterfalls of Campo Belo River Basin (13) and the Viewpoint Último Adeus (26). They are accessed by trails with an easy difficulty level and some infrastructure. On the contrary, the most visited sites of the upper region are the Fault escarpment of Couto-Prateleiras Hills (6), the Fluted erosion of Agulhas Negras Hill (10), and the Fracture planes of Pedra do Altar Hill (9). They are accessed by trails with moderate to high difficulty levels and no safety measures. Given these aspects and some types of danger to reach the sites (6) and (10), the association of geoconservation with tourism activities are essential to contribute to the opportunities to sustainable economic development (analysis of the region of the protected area" report). Therefore, if such aspects are appropriately addressed by management staff, the achievement of the SDGs can be accomplished. Furthermore, the dissemination of geoscientific content through geotourism would be an excellent opportunity to contribute to geoconservation and stimulate the sustainable economic development of the region. Thus, contributing to achieving the SDGs, notably SDG1 (no poverty) and SDG8 (decent work and economic growth).

In the "analysis of the protected area" report, geoscientific content targeted at the general public and the population of the surrounding areas could be inserted to raise awareness of the role of geodiversity and geoconservation, to help reduce the negative aspects of biodiversity loss and to mitigate and adapt to climate change (Crofts et al., 2021). Furthermore, including such content in interpretation and environmental educational activities would contribute to the management and popularisation of geological sites. Such actions could be implemented through leaflets, digital media, interpretative panels, etc. (Mucivuna & Garcia, 2018). The development of Geoscience courses for environmental guides could be an opportunity for the economic development of the region and contribute to the dissemination of scientific knowledge, as proposed in the MP.

In the "Itatiaia National Park planning", geological sites located in zones that allow environmental interpretation, visiting and research should be assessed to check their potential use. In INP, the chapter "specific goals of management" should include the inventoried sites in the interpretation and environmental education projects to disseminate their importance for the management and conservation of the park. In the chapter "strategic evaluation", activities focused on disseminating abiotic aspects could be combined with other values. For example, the geosite Biotite monzonite quarry (7) shows a significant relationship with the historical value, as the quarry rocks were used as raw material for the building of the Casa de Pedra (lodging used by the ex-president Getúlio Vargas during his visits to the INP). In the chapter "zoning", the assessment of the use of inventoried sites was performed to help their management in their respective park areas (Table 7).

Therefore, as the MP is both a source of data and a tool for managers, integrating geological sites into PA management would help managers ensure that important geological and geomorphological features are included in key nature management decisions, including biotic and abiotic aspects.

7. Discussion

7.1. Inventory of geological sites

The inventory of geological sites is the initial step to prepare the support material for their inclusion in the MP in worldwide PAs. Based on that, the inventoried geological sites of the INP took into account the scientific, educational, and touristic values to contribute to geoconservation strategies through geological site interpretation. Therefore, the method of Brilha (2016, 2018) was applied since it is a systematic method with transparent criteria that meet the purpose of this inventory.

Although the method applied (Brilha, 2016, 2018) is not focused on the specificities of geomorphosites (Coratza & Hobléa, 2018; Reynard, 2009), such characteristics were considered in selecting sites fieldwork, qualitative assessment, and characterisation. For example, representativeness, integrity, and rarity criteria covered the dynamic dimension and the imbrication of scales in the qualitative assessment. However, the aesthetic dimension was only partially considered in assessing educational and touristic values. Given the importance of assessing additional values of geomorphosites (Santos et al., 2019), they were identified during fieldwork to make links with geodiversity and analyse the potential for integrating them into conservation, management, and dissemination actions in the park (Mucivuna et al., 2022).

Protected areas have among their objectives scientific research, educational and recreational activities. Because of this fact, the selection of geological sites with a narrow purpose focused on the conservation of special scientific features and multi-purpose based on scientific and other values (Crofts et al., 2020) are essential to achieve the objectives of these areas. For this purpose, systematic inventories encompassing different values are widely encouraged to include geoconservation in the PAs national system.

The number of tourists has increased exponentially in Brazilian PAs. In 2019, they received over 15.3 million visitors, the National Park and the National Forest categories being the most prominent (ICMBio. Instituto Chico Mendes de Conservação da Biodiversidade, 2019). However, although many Brazilian PAs are nationally or internationally recognised for their geoheritage (Mucivuna et al., 2022), there is not yet any systematic government action to conserve and manage abiotic aspects in these areas. Therefore, using systematic inventory methods based on international selection criteria (Crofts et al., 2020) is essential in both existing and potential PAs (Mucivuna et al., 2022).

In this context, the INP inventory comprises the key localities and best representative records of the past and present features and processes. Moreover, most inventoried sites are already used as tourist attractions and educational resources, receiving over 127,000 visitors and nearly 18,000 students on school trips in 2019 (ICMBio. Instituto Chico Mendes de Conservação da Biodiversidade, 2019, 2021).

Most of the park's attractions can be accessed independently, and there is no limit to the number of visits per day; however, several sites have a time limit to start the trail due to the park's opening hours. Nevertheless, hiring environmental monitors is highly recommended for groups and sites that require safety measures, such as ropes (e.g., Fault escarpment of Couto-Prateleiras Hills (6) and Fluted erosion of Agulhas Negras Hill (10)). In contrast, there is a limit of visitors per day to the following attractions: 120 at the base of Prateleiras Hill and Pedra da Maçã e Pedra da Tartaruga boulders, 80 on the summit of Prateleiras and Agulhas Negras Hills, 60 in the Chapada da Lua, 40 in the Serra Negra Crossing, 30 on the Southern summit of Agulhas Negras Hill and 26 in the Rancho Caído and Rui Braga Crossings. In addition, to access the Três Picos trail, visitors must fill out and sign a Waiver of Liability Agreement.

The inventoried sites are already visited by a wide range of audiences, from those who appreciate long walks and climbing activities to reach the sites (e.g. Pitted erosion of Pedra do Sino Hill (20), Fault escarpment of Couto-Prateleiras Hills (6) and Fluted erosion of Agulhas Negras Hill (10)), to those who prefer shorter walks for contemplative and leisure activities (e.g., Structural valley of Campo Belo River (5), Waterfalls of Campo Belo River Basin (13) and Granitic gneiss of Alcantilado Waterfall (23)). On the other hand, teachers with a group of young students usually look for sites with easy access (e.g., Fluvial deposits of Lago Azul (4) and Breccia of Camelo Hill (19)). In contrast, this criterion usually is not considered a concern for university students (e.g., Breccia of Pedra Furada Hill (8), Tectonic records of Rio Preto Waterfalls (15) and Nepheline syenite of Três Picos Hill (22)).

Although most geological sites are already included in educational and touristic programmes, it was noted that most do not have a high degradation risk associated with anthropic activities. It may be explained by the sites' intrinsic characteristics, the visitation conducted by environmental monitors and the visitors' compliance with the codes of conduct inside the park. However, some geological sites may have degradation risks due to their intrinsic fragility (e.g., Bog of Aiuruoca River (1), Bog of Preto River (2) and Lakes and wetlands with peat deposits (18)) and natural vulnerability (e.g., Talus deposits of Serra Negra village (4) and Biotite monzonite quarry (7)).

For these reasons, it is recommended to assess further the degradation risk of geological sites regarding their role in conserving abiotic features and processes, supporting biodiversity and ecosystem services, and the impact of use for tourism and educational activities. Given these issues, Pica, Luberti, Vergari, Fredi, and Del Monte (2017), Clivaz and Reynard (2018), Queiroz, Garcia, and Del Lama (2019) and Reverte, Garcia, Brilha, & Moura, 2019 highlight that natural processes and/or anthropogenic activities can destroy not-sufficiently protected or known geosites. Thus, assessing the physical environment's potential and restrictions and the impacts from its inappropriate use (Pfaltzgraff & Peixoto, 2010) is fundamental to the conservation and integration of abiotic aspects in nature conservation policies (Garcia, Del Lama, Martins, Mazoca, & Bourotte, 2019). Therefore, the assessment of degradation risk should also consider the use and management proposals, as the results of the degradation risk without the implementation of mitigation and management measures do not contribute to the effective geoconservation of the inventoried sites.

Since INP is a mountainous area, most inventoried sites can only be reached by long trails with high to moderate difficulty levels. Fortunately, there is no link between access difficulty and the potential for using the site in the educational programme. For example, some sites such as the viewpoints Flowers Highway (25) and Último Adeus (26) are not only accessible by climbers, hikers, and trekking specialists; they can be accessed by motorised vehicles. Furthermore, viewpoints offer a view to areas with exceptional geological and geomorphological features and processes and are excellent candidates for educational resources (Mucivuna & Garcia, 2018), as they play an essential role in comprehending geodiversity and geoheritage (Migoń & Pijet-Migoń, 2017). In contrast, some sites that are difficult to access may limit obtaining geological information for research or dissemination of content. In this sense, virtual products could be excellent tools in the scientific study of relevant geosites and provide new opportunities to experience and reveal the values of geodiversity by promoting geoheritage (Gordon, Crofts, Gray, & Tormey, 2021; Ibanez, Garcia, & Mazoca, 2021; Santos, Henriques, Mariano, & Pereira, 2018).

Furthermore, virtual products such as those developed for the Jaraguá State Park (Brazil) can be used as a model to promote geological sites in Brazilian and worldwide PAs (https://geohereditas.igc.usp.br/passeio-virtual-PEJ/passeio-virtual_PEJ.html).

7.2. Analysis of the management plan and proposals for integrating the inventoried sites into its guidelines

The review of MPs showed how these documents had been prepared over the years. The 1982 version was prepared directly by the institution responsible for managing the INP and written in a context when geoheritage was not a topic of discussion at the international level. Despite this, a concern was noted for describing the geodiversity and their importance for landscape analysis (even briefly), highlighting the importance of interpreting the park's geoheritage (even though not using the current concept).

The 2013 version was developed by an outsourced company that is not responsible for its management and written in a period when the interest in geodiversity and geoconservation had grown in Brazil and around the world. However, the sites that had their features described were mostly those already widely visited and mainly referred to their potential for public use. Although research on geoconservation had already been published at that time, the INP MP did not address the conservation of abiotic elements.

The fact that the geodiversity in the study area's MP is addressed only briefly is not restricted only to the INP. Although the Ministry of Environment encourages the inclusion of geodiversity and geological settings (Meira, Nascimento, & Silva, 2018), the chapters that address them in Brazilian MPs are not very elaborated (Garcia, Reverte, et al., 2019). Based on that, guidelines for the elaboration of MPs should also include criteria and parameters for assessing and managing geological sites, as many PA managers are not geoscientists nor have a good knowledge of abiotic aspects. The recent guidelines for geoconservation in protected areas published by IUCN (Crofts et al. 2020) are very helpful in this context.

Considering these facts, a systematic inventory of geological sites is the crucial database for including geological sites into the PA management strategies in order to prevent significant geoscientific sites from being degraded due to the lack of knowledge by managers and visitors and to plan adequate geoconservation actions. However, after analysing the MP, not much geoheritage content was found; therefore, this gap should be filled. Furthermore, as the MP is a document that must be revised every five years, or even when new and relevant facts require it (Galante et al., 2002), the integration of the geological sites and geodiversity, as a whole, could be performed gradually according to the recommendation proposed herein.

In this way, the results of this research can be applied to the integrated management of PA and should be included in the next version of the MP. For example, geological sites can be included in chapters dealing with the regional geological and geomorphological settings and the specific geological and geomorphological aspects (Sallun & Sallun Filho, 2009). In addition, they can be integrated into the description of public use attractions, the correlation between geological sites and conservation (Fundação Florestal, 2019), specific zoning (Garcia, Lanza, et al., 2019; MA, 2019) and trough a new section on the links between geodiversity and biodiversity.

8. Conclusions

This work was carried out in the Itatiaia National Park, presenting an inventory of geosites, geodiversity sites and viewpoints, analysing how geodiversity is addressed in the MP and discussing the importance of integrating geological sites inventory into the park's MP.

Applying a systematic method (Brilha, 2016) based on the park's values activities (scientific, educational and tourism) and in line with the guidelines for geoconservation in protected areas (Crofts et al., 2020) proved helpful, as the set of geosites includes all events of local geological history.

Despite the challenges of including geoconservation in PAs, this work has shown that the MP has an essential role because it is a source of park-specific data. In addition, the INP has an approach strongly associated with geodiversity. However, the results showed that although geodiversity is mentioned in the MP, abiotic aspects do not receive the same attention as biodiversity.

Therefore, more than just recognising the geological sites in the PA, the proposal to integrate them into the general and specific descriptions, ongoing activities and zoning of the MP proved to be very promising for providing conservation possibilities to managers. In addition to benefing the local population through geotourism and contributing to the integrated management of biotic and abiotic aspects in the protected areas.

The integration of geological sites into local policies is in line with conservation and management policies proposed by IUCN. In protected areas, the inclusion of inventoried sites in PAs management plans could contribute to the adequate management of abiotic aspects, ranging from conservation to promotion (Crofts et al., 2020). We think that the proposed approach can be used not only in the MP of other Brazilian protected areas, but also in MP in other countries even if the specific institutional context would change. The main objective is to integrate more broadly the recognition of geodiversity and geoheritage in the conservation structures and processes, as stressed by Brilha et al. (2018) and Crofts (2018).

The approach focused on the inventory of geological sites and its application to the PA's MP can therefore be applied as a roadmap for other Brazilian and worldwide protected areas, as this approach allows for better recognition of geological sites in these areas. We expect that protected areas will better integrate geodiversity, biodiversity, and landscape management into their MP contents during their preparation or revision.

Funding information

This work was supported by the National Council for Scientific and Technological Development-CNPq [PhD scholarship no. 141970/2017-0] and the Coordination for the Improvement of Higher Education Personnel- CAPES [mobility scholarship no. 88881.189352/2018-0] granted to the first author. M. G. Garcia thanks the National Council for Scientific and Technological (CNPq), Grant 309964/2018-0.

Conflicts of interest/competing interests

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Acknowledgements

We thank Debora S. Queiroz, Eliana Mazzucato, Raquel M. M. Romão for their help during fieldwork and the Itatiaia National Park for logistical support and research permissions. We are also grateful to the four anonymous referees for their very useful comments that improved the paper's quality, and to Guangyu Wang who handled the edition process.

References

Ab'Saber, A. N., & Bernardes, N. (1958). Vale do Paraíba, Serra da Mantiqueira e arredores de São Paulo [Vale do Paraíba, Serra da Mantiqueira and surroundings of São Paulo]. *International Congress of Geography*, *18*, 284–292.

Almeida, F. F. M. (1983). Relações tectônicas das rochas alcalinas mesozoicas da região meridional da Plataforma Sul-Americana [Tectonic relations of mesozoic alkaline rocks of the south American platform]. *Revista Brasileira de Geociencias*, *13*(3), 139–158.

Almeida, F. F. M. (1991). O Alinhamento Magmático de Cabo Frio [The cold cape magmatic alignment]. *Proceedings of the Southeast Geology Symposium*, *2*, 423–428.

Almeida, F. F. M., & Carneiro, C. D. R. (1998). Origem e evolução da Serra Do Mar [Origin and evolution of the Serra Do Mar]. *Revista Brasileira de Geociencias*, *28*(2), 135–150.

Almeida, F. F. M., Hasui, Y., Brito Neves, B. B., & Fuck, R. A. (1977). Províncias estruturais brasileiras [Brazilian structural provinces]. *Proceedings of the Northeast Geology Symposium*, *8*, 363–391.

Almeida, F. F. M., Hasui, Y., Brito Neves, B. B., & Fuck, R. A. (1981). Brazilian structural provinces: An introduction. *Earth-Science Reviews*, *17*(1–2), 1–29. https://doi.org/10.1016/0012-8252(81)90003-9.

Bétard, F., & Peulvast, J. P. (2019). Geodiversity hotspots: Concept, method and cartographic application for geoconservation purposes at regional scale. *Environmental Management*, *63*, 822–834. https://doi.org/10.1007/s00267-019-01168-5.

Bollati, I., Leonelli, G., Vezzola, L., & Pelfini, M. (2015). The role of ecological value in geomorphosite assessment for the debris-covered Miage glacier (Western Italian Alps) based on a review of 2.5 centuries of scientific study. *Geoheritage.*, *7*(2), 119–135. https://doi.org/10.1007/s12371-014-0111-2.

Brasil. (1979). Decreto n° 84.071 de 21 de setembro de 1979 [Decree No. 84.071 of 21 September 1979]. Retrieved from http://www.planalto.gov.br/ccivil_03/Atos/decretos/1979/D84017.html

Brasil. (1988). Constituição da República Federativa do Brasil [Constitution of the Federative Republic of Brazil]. Retrieved from http://www.planalto.gov.br/ccivil_03/constituicao/constituicaocompilado.htm

Brasil. (2000). Lei n° 9.985 de 18 de julho de 2000 [Law No. 9,985 of July 18, 2000]. Retrieved from http://www.planalto.gov.br/ccivil_03/leis/L9985.htm

Brasileiro de Geografia e Estatística (IBGE) (2016). *Anuário estatístico do Brasil [statistical yearbook of Brazil].* Rio de Janeiro: IBGE.

Brilha, J. (2002). Geoconservation and protected areas. *Environmental Conservation*, *29*(3), 273–276.

Brilha, J. (2016). Inventory and quantitative assessment of geosites and geodiversity sites: A review. *Geoheritage.*, *8*(2), 119–134. https://doi.org/10.1007/s12371-014-0139-3.

Brilha, J. (2017). Trends and challenges for geoconservation. *Geophysical Research Abstracts*, *19*, 8626.

Brilha, J. (2018). Geoheritage: Inventories and evaluation. In E. Reynard, & J. Brilha (Eds.), *Geoheritage: Assessment, protection and management* (pp. 69–85). Amsterdam: Elsevier.

Brilha, J., Gray, M., Pereira, D. I., & Pereira, P. (2018). Geodiversity: An integrative review as a contribution to the sustainable management of the whole of nature. *Environmental Science & Policy*, *86*, 19–28. https://doi.org/10.1016/j.envsci.2018.05.001.

Brilha, J., & Reynard, E. (2018). Geoheritage and geoconservation: The challenges. In E. Reynard, & J. Brilha (Eds.), *Geoheritage: Assessment, protection and management* (pp. 433–438). Amsterdam: Elsevier.

Brotzu, P., Gomes, C. B., Melluso, L., Morbidelli, L., Morra, V., & Ruberti, E. (1997). Petrogenesis of coexisting SiO_2-undersaturated to SiO_2-oversaturated felsic igneous rocks: The alkaline complex of Itatiaia, southeastern Brazil. *Lithos.*, *40*(2–4), 133–156. https://doi.org/10.1016/S0024-4937(97)00007-8.

Bussard, J., & Giaccone, E. (2021). Assessing the ecological value of dynamic mountain geomorphosites. *Geographica Helvetica*, *76*, 385–399. https://doi.org/10.5194/gh-76-385-2021.

Castro Júnior, E., Coutinho, B. H., & Freitas, L. E. (2009). Gestão da Biodiversidade e áreas protegidas [*Gestão da Biodiversidade e áreas protegidas*]. In A. J. T. Guerra, & M. C. N. Coelho (Eds.), *Unidades de Conservação: abordagens e características geográficas [Conservation units: Geographical approaches and characteristics]* (pp. 25–65). Rio de Janeiro: Bertrand.

Clivaz, M., & Reynard, E. (2018). How to integrate invisible geomorphosites in an inventory: A case study in the Rhone River valley (Switzerland). *Geoheritage*, *10*(4), 527–541. https://doi.org/10.1007/s12371-017-0222-7.

Cogné, N., Gallagher, K., Cobbold, P. R., Riccomini, C., & Gautheron, C. (2012). Post-breakup tectonics in Southeast Brazil from thermochronological data and combined inverse-forward thermal history modelling. *Journal of Geophysical Research*, *117*, Article B11413. https://doi.org/10.1029/2012JB009340.

Coratza, P., & Hobléa, F. (2018). The specificities of geomorphological heritage. In E. Reynard, & J. Brilha (Eds.), *Geoheritage: Assessment, protection and management* (pp. 87–106). Amsterdam: Elsevier.

Serviço Geológico do Brasil. (2020). GEOSSIT: Cadastro de sítios geológicos [GEOSSIT: Register of geological sites]. Retrieved from https://www.cprm.gov.br/geossit/geossitios

Crofts, R. (2018). Putting geoheritage conservation on all agendas. *Geoheritage.*, *10*, 231–238. https://doi.org/10.1007/s12371-017-0239-y.

Crofts, R., & Gordon, J. E. (2014). Geoconservation in protected areas. *Parks*, *20*(2), 61–76. https://doi.org/10.2305/IUCN.CH.2014.PARKS-20-2.RC.en.

Crofts, R., & Gordon, J. E. (2015). Geoconservation in protected areas. In G. L. Worboys, M. Lockwood, A. Kothari, S. Feary, & I. Pulsford (Eds.), *Protected area governance and management* (pp. 531–568). Canberra: ANU Press.

Crofts, R., Gordon, J. E., Brilha, J., Gray, M., Gunn, J., Larwood, J., & Worboys, G. L. (2020). *Guidelines for geoconservation in protected and conserved areas: Best practice protected area guidelines.* Gland: IUCN.

Crofts, R., Tormey, D., & Gordon, J. E. (2021). Introducing new guidelines on geoheritage conservation in protected and conserved areas. *Geoheritage*, *13*, 33. https://doi.org/10.1007/s12371-021-00552-0.

D'Amico, A. R., Coutinho, E. O., & Moraes, L. F. P. (2018). *Roteiro metodológico para elaboração e revisão de planos de manejo das unidades de conservação federais* [Methodological guide for elaboration and review of management plans of federal conservation units]. Brasília: ICMBio - Instituto Chico Mendes de Conservação da Biodiversidade.

Díaz-Martínez, E., Brilha, J., Brocx, M., Erikstad, L., García-Cortés, A., & Wimbledon, W. A. P. (2016). Global Geosites: An active and partially achieved geoheritage inventory initiative, waiting to regain official recognition. In A. Cornée, G. Egoroff, P. Wever, A. Lalanne, & F. Duranthon (Eds.), *Actes du congrès international "Les inventaires du géopatrimoine" [Proceedings of the International Conference on "geographical Heritage List"]* (pp. 103–108). Toulouse: Mémoire hors-série de la Société géologique de France.

Díaz-Martínez, E., Guillén-Mondéjar, F., Brilha, J., Monge-Ganuzas, M., Herrero Martínez, N., Hilario, A., ... Utiel, J. C. (2017). Nuevas resoluciones y avances de la UICN para la geoconservación [new resolution and progress of the world conservation union on earth protection]. In L. Carcavilla, J. Duque-Macías, J. Giménez, A. Hilario, M. Monge-Ganuzas, J. Vegas, & A. Rodríguez (Eds.), *Patrimonio geológico, gestionando la parte abiótica del patrimonio natural [Geological heritage, abiotic part, natural heritage management]* (pp. 247–252). Madrid: Cuadernos del Museo Geominero.

Dinerstein, E., Vynne, C., Sala, E., Joshi, A. R., Fernando, S., Lovejoy, T. E., & Wikramanayake, E. (2019). A global deal for nature: Guiding principles, milestones, and targets. *Science Advances*, *5*(4), Article eaaw2869. https://doi.org/10.1126/sciadv.aaw2869.
Dingwall, P. R. (2000). Legislation and international agreements: The integration of the geological heritage in nature conservation policies. In D. Barrentino, W. A. P. Wimbledon, & E. Gallego (Eds.), *Geological heritage: Its conservation and management* (pp. 15–28). Madrid: IGME.
Dudley, N. (2008). *Guidelines for applying protected area management categories*. Gland: IUCN.
Enrich, G. E. R., Azzone, R. G., Ruberti, E., Gomes, C. B., & Comin-Chiaramonti, P. (2005). Itatiaia, Passa Quatro and São Sebastião Island, the major alkaline syenitic complex from the Serra do Mar region. In P. Comin-Chiaramonti, & C. B. Gomes (Eds.), *Mesozoic to Cenozoic alkaline magmatism in the Brazilian platform* (pp. 419–441). São Paulo: EDUSP/FAPESP.
Fundação Florestal (2019). *Plano de Manejo: Parque Estadual Restinga de Bertioga* [Management plan: Retinga de Bertioga National Park]. São Paulo: Fundação Florestal Retrieved fromhttp://arquivos.ambiente.sp.gov.br/fundacaoflorestal/2019/01/plano-de-manejo-pe-restinga-de-bertioga.pdf.
Galante, M. L. V., Beserra, M. M. L., & Menezes, E. O. (2002). *Roteiro metodológico de planejamento: Parque Nacional, Reserva Biológica, Estação Ecológica* [Methodological planning roadmap: national park, biological reserve, ecological station]. Brasília: IBAMA - Instituto Brasileiro de Meio Ambiente e Recursos Naturais Renováveis.
Garcia, M. G. M., Brilha, J., Lima, F. F., et al. (2018). The inventory of geological heritage of the state of São Paulo, Brazil: Methodological basis, results and perspectives. *Geoheritage*, *10*(2), 239–258. https://doi.org/10.1007/s12371-016-0215-y.
Garcia, M. G. M., Del Lama, E., Martins, L., Mazoca, C. E. M., & Bourotte, C. L. M. (2019). Inventory and assessment of geosites to stimulate regional sustainable management: The northern coast of the state of São Paulo, Brazil. *An. Acad. Brasil. Ciênc*, *91*(2), Article e20180514. https://doi.org/10.1590/0001-3765201920180514.
Garcia, M. G. M., Lanza, M. C. T., Silva, I. L., Mucivuna, V. C., Costa, J. A., & Queiroz, D. S. (2019). Geossítios como áreas de interesse em planos de manejo de unidades de conservação: exemplo da APA Marinha Litoral Centro, estado de São Paulo [Geosites as areas of interest in conservation unit management plans: example of APA Marinha Litoral Centro, State of São Paulo]. *Simpósio Brasileiro de Patrimônio Geológico*, *5*, 40–41.
Garcia, M. G. M., Reverte, F. C., Mucivuna, V. C., Arruda, K. E. C., Prochoroff, R., Santos, P. L. A., & Romão, R. M. M. (2019). Geoconservação em áreas protegidas: contribuição de cursos para monitores ambientais no litoral norte do estado de São Paulo, Brasil [Geoconservation in protected areas: Contribution of courses for environmental monitors on the northern coast of the state of São Paulo, Brazil]. *Terrae Didática*, *15*, Article e19028. https://doi.org/10.20396/td.v15i0.8652390.
Gordon, J. E., Crofts, R., & Díaz-Martínez, E. (2018). Geoheritage conservation and environmental policies: Retrospect and prospect. In E. Reynard, & J. Brilha (Eds.), *Geoheritage: Assessment, protection and management* (pp. 213–235). Amsterdam: Elsevier.
Gordon, J. E., Crofts, R., Díaz-Martínez, E., & Woo, K. S. (2018). Enhancing the role of geoconservation in protected area management and nature conservation. *Geoheritage*, *10*, 191–203. https://doi.org/10.1007/s12371-017-0240-5.
Gordon, J. E., Crofts, R., Gray, M., & Tormey, D. (2021). Including geoconservation in the management of protected and conserved areas matters for all of nature and people. *International Journal of Geoheritage and Parks*, *9*(3), 323–334. https://doi.org/10.1016/j.ijgeop.2021.05.003.
Gray, M. (2004). *Geodiversity: Valuing and conserving abiotic nature*. Londres: John Wiley & Sons.
Gray, M. (2013). *Geodiversity: Valuing and conserving abiotic nature*. Londres: John Wiley & Sons.
Heilbron, M., Eirado, L. G., & Almeida, J. (2016). *Mapa Geológico e de Recursos Minerais do Estado do Rio de Janeiro* [Geological and mineral resources map of the state of Rio de Janeiro (scale 1:400, 000)]. Brasil: Serviço Geológico do Brasil.
Heilbron, M., Pedrosa-Soares, A. C., Campos Neto, M. C., Silva, L. C., Trouw, R. A. J., & Janasi, V. A. (2004). Província Mantiqueira [Mantiqueira Province]. In V. Mantesso-Neto, A. Bartorelli, C. D. R. Carneiro, & B. B. Brito-Neves (Eds.), *Geologia do Continente Sul-Americano: evolução da obra de Fernando Flávio Marques de Almeida [Geology of the South American Continent: evolution of the work of Fernando Flávio Marques de Almeida]* (pp. 203–234). São Paulo: Beca.
Henriques, M. H., Reis, R. P., Brilha, J., & Mota, T. (2011). Geoconservation as an emerging geoscience. *Geoheritage*, *3*, 117–128. https://doi.org/10.1007/s12371-011-0039-8.
Hiruma, S. T., Riccomini, C., Modenesi-Gauttieri, M. C., Hackspacher, P. C., Hadler-Neto, J. C., & Franco-Magalhães, A. O. B. (2010). Denudation history of the Bocaina Plateau, Serra do Mar, Southeastern Brazil: Relationships to Gondwana breakup and passive margin development. *Gondwana Research*, *8*(4), 674–687. https://doi.org/10.1016/j.gr.2010.03.001.
Ibanez, K., Garcia, M. G. M., & Mazoca, C. E. M. (2021). Tectonic geoheritage as records of Western Gondwana history: A study based on a geosite's potential in the Central Ribeira Belt, Southeastern Brazil. *Geoheritage*, *13*, 9. https://doi.org/10.1007/s12371-021-00533-3.
Instituto Brasileiro de Geografia e Estatística (IBGE). (2019). Base Vetorial Geomorfologia do Brasil [Vector base geomorphology of Brazil]. https://www.ibge.gov.br/geociencias/downloads-geociencias.html
(ICMBio). (2019). Monitoramento da visitação em Unidades de Conservação Federais: resultados de 2019 e breve panorâmica histórico [Visitation monitoring in Federal Conservation Units: results of 2019 and brief historical overview]. Retrieved from https://www.icmbio.gov.br/portal/images/stories/comunicacao/publicacoes/monitoramento_visitacao_em_ucs_federais_resultados_2019_breve_panorama_historico.pdf
Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio). (2021). Notas de pesquisa [Research notes]. Retrieved from https://www.icmbio.gov.br/parnaitatiaia/images/stories/2021/o-que-fazemos/notas-de-pesquisa/433.pdf
Instituto Brasileiro de Desenvolvimento Florestal (IBDF) (1982). *Plano de manejo do Parque Nacional do Itatiaia [management plan of the Itatiaia National Park]*. Brasília: IBDF.
Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA) (1994). *Plano Emergencial para o Parque Nacional do Itatiaia [Emergency Plan for the Itatiaia National Park]*. Brasília: Diretoria de Ecossistemas, Departamento de Unidades de conservação.
Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) (2013). *Plano de Manejo: Parque Nacional do Itatiaia* [Management plan: Itatiaia National Park]. Brasília: ICMBio.
Instituto de Geografia e Estatística (IBGE) (2009). *Manual técnico de Geomorfologia* [Geomorphology technical manual]. Rio de Janeiro: IBGE.
International Union for Conservation of Nature (IUCN). (2016). The world now protects 15% of its land, but crucial biodiversity zones left out. Retrieved from https://www.iucn.org/news/secretariat/201609/world-now-protects-15-its-land-crucial-biodiversity-zones-left-out
International Union for Conservation of Nature (IUCN). (2021). IUCN Resolutions and recommendations. Retrieved from https://portals.iucn.org/library/resrec/search
International Union for Conservation of Nature (IUCN). (2021). Setting area-based conservation targets based on evidence of what nature and people need to thrive. Retrieved from https://www.iucncongress2020.org/motion/101
Lamego, A. R. (1936). O massiço de Itatiaya e regiões circumdantes [The massif of Itatiaya and surrounding regions]. *Boletim do Serviço Geológico e Mineralógico do*, *88*, 1–93.
Lasaulx, A. (1885). Üeber das Vorkommen von Eläeolith-Syeniten und echten zu diesen gehörigen Eläeolith-porphyren aus der Serra d'Itatiaia westlich von Rio de Janeiro, Brasilien [On the occurrence of eläeolithic syenites and real eläeolithic porphyries from the Serra d'Itatiaia west of Rio de Janeiro, Brazil]. *Sitzungsberichte Der Niederrheinischen Gesellschaft Für Natur*, 231–232.
Lima, F. F., Brilha, J. B., & Salamuni, E. (2010). Inventory of geological heritage in large territories: A methodological proposal applied to Brazil. *Geoheritage*, *2*(3), 91–99. https://doi.org/10.1007/s12371-010-0014-9.
MA. (2019). Minuta em aprovação do plano de manejo da APA Marinha Litoral Centro [Minute in approval of APA Marine Litoral Center management plan]. Retrieved from http://sigam.ambiente.sp.gov.br
Marques, L. S., & Ernesto, M. (2004). O magmatismo toleítico da Bacia do Paraná [The toleitic magmatism of the Paraná Basin]. In V. Mantesso Neto, A. Bartorelli, C. D. R. Carneiro, & B. B. Brito-Neves (Eds.), *Geologia do Continente Sul-Americano: Evolução da Obra de Fernando Flávio Marques de Almeida [Geology of the south American continent: Evolution of the work of Fernando Flávio Marques de Almeida]* (pp. 245–263). São Paulo: Beca.
Marques Neto, R., Perez Filho, A., & Oliveira, T. A. (2015). Itatiaia massif: Morphogenesis of Southeastern Brazilian highlands. In B. C. Vieira, A. A. R. Salgado, & L. J. C. Santos (Eds.), *Landscapes and landforms of Brazil* (pp. 299–308). Berlin: Springer.
Martini, G. (1994). *Actes du premier symposium international Sur la protection du patrimoine géologique* [Proceedings of the First International Symposium on Geological Heritage Protection]. Paris: Société Géologique de France.
Matthews, T. J. (2014). Integrating Geoconservation and biodiversity conservation: Theoretical foundation and conservation recommendations in a European Union context. *Geoheritage*, *6*, 57–70. https://doi.org/10.1007/s12371-013-0092-6.

Medeiros, R. (2003). *Proteção da natureza: das estratégias internacionais e nacionais às demandas locais* [Nature protection: From international and national strategies to local demands] (Doctoral dissertation). Federal University of Rio de Janeiro, Rio de Janeiro, Brazil.

Medeiros, R. (2006). Evolução das tipologias de áreas protegidas no Brasil [Evolution of the typologies of protected areas in Brazil]. *Ambiente & Sociedade*, *9*(1), 41–64. https://doi.org/10.1590/S1414-753X2006000100003.

Medeiros, R., Irving, M., & Garay, I. (2004). A proteção da natureza no Brasil: evolução e conflitos de um modelo em construção [Nature protection in Brazil: Evolution and conflicts of a model under construction]. *Revista de Desenvolvimento Econômico*, *9*, 83–93.

Meira, S. A., Nascimento, M. A. L., & Silva, E. V. (2018). Unidades de Conservação e geodiversidade: uma breve discussão [Conservation units and geodiversity: A brief discussion]. *Terr@Plural.*, *12*(2), 166–187. https://doi.org/10.5212/TerraPlural.v.12i2.0002.

Melluso, L., Guarino, V., Lustrino, M., Morra, V., & De' Gennaro, R. (2017). The REE- and HFSE-bearing phases in the Itatiaia alkaline complex (Brazil), and geochemical evolution of feldspar-rich felsic melts. *Mineralogical Magazine*, *81*(2), 217–250. https://doi.org/10.1180/minmag.2016.080.122.

Migoń, P., & Pijet-Migoń, E. (2017). Viewpoint geosites: Values, conservation and management issues. *Proceedings of the Geologists' Association*, *128*(4), 511–522. https://doi.org/10.1016/j.pgeola.2017.05.007.

Ministério do Meio Ambiente (MMA). (2004). Portaria n° 126, de 27 de maio de 2004 [Portal No. 126 of 27 May 2004]. Retrieved from http://www.mma.gov.br/biodiversidade/biodiversidade-brasileira/áreas-prioritárias

Modenesi, M. C., & Melhem, T. S. (1986). Primeiros resultados da palinologia dos sedimentos turfosos da várzea do Ribeirão das Flores, Itatiaia–Rio de Janeiro [First results of palynology of peat sediments from Ribeirão das Flores floodplain, Itatiaia–Rio de Janeiro]. *Revista do Instituto Geológico*, *7*(1–2), 35–38. https://doi.org/10.5935/0100-929X.19860005.

Modenesi, M. C., & Toledo, M. C. M. (1993). Morfogênese quaternária e intemperismo: colúvios do Planalto do Itatiaia [Quaternary morphogenesis and weathering: Collúvios do Planalto do Itatiaia]. *Revista do Instituto Geológico*, *14*(1), 45–53. https://doi.org/10.5935/0100-929X.19930004.

Mucivuna, V. C. (2016). *Estratégias de geoconservação aplicadas à geodiversidade do município de Bertioga-SP e às fortificações do Litoral Paulista* [Geoconservation strategies applied to the geodiversity of the municipality of Bertioga-SP and the fortifications of the coast of São Paulo] (Master's theis). University of São Paulo, São Paulo.

Mucivuna, V. C., & Garcia, M. G. M. (2017). Método para seleção de potenciais geossítios e geomorfossítios do inventário do Parque Nacional de Itatiaia [method for selection of potential geosites and geomorphosites from the inventory of Itatiaia National Park]. *Simpósio Brasileiro de Patrimônio Geológico*, *4*, 367–371.

Mucivuna, V. C., & Garcia, M. G. M. (2018). Educational and tourism use of easy-access viewpoints: A study in the Itatiaia National Park, Brazil. *Proceedings of the Quadrennial Conference of the International Geoscience Education Organisation*, *8*, 202–207.

Mucivuna, V. C., Garcia, M. G. M., & Del Lama, E. A. (2015). A seleção de geossítios no inventário do município de Bertioga - SP: critérios e metodologias [the selection of geosites in the inventory of the municipality of Bertioga - SP: Criteria and methodologies]. *Anais do Simpósio Brasileiro de Patrimônio Geológico*, *8*, 446–449.

Mucivuna, V. C., Garcia, M. G. M., & Del Lama, E. A. (2017). Inventário e avaliação quantitativa do patrimônio geológico de Bertioga (SP, Brasil) [inventory and quantitative evaluation of the geological heritage of Bertioga (SP, Brazil)]. *Pesquisas em Geociências*, *44*(2), 293–321. https://doi.org/10.22456/1807-9806.78281.

Mucivuna, V. C., Garcia, M. G. M., & Reynard, E. (2022). Criteria for assessing geological sites in National Parks: A study in the Itatiaia National Park, Brazil. *Geoheritage*, *14*, 1. https://doi.org/10.1007/s12371-021-00633-0.

Mucivuna, V. C., Reynard, E., & Garcia, M. G. M. (2019). Geomorphosites assessment methods: Comparative analysis and typology. *Geoheritage*, *11*(4), 1799–1815. https://doi.org/10.1007/s12371-019-00394-x.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., Fonseca, G. A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, *403*, 853–858. https://doi.org/10.1038/35002501.

Németh, B., Németh, K., Procter, J. N., & Farrelly, T. (2021). Geoheritage conservation: Systematic mapping study for conceptual synthesis. *Geoheritage*, *13*, 45. https://doi.org/10.1007/s12371-021-00561-z.

O'Halloran, D., Green, C., Harley, M., Stanley, M., & Knill, J. (1994). *Geological and landscape conservation*. London: The Geological Society.

Panizza, M. (2001). Geomorphosites: Concepts, methods and examples of geomorphological survey. *Chinese Science Bulletin*, *46*, 4–6.

Penalva, F. (1967). Geologia e Tectônica da Região do Itatiaia (Sudeste do Brasil) [Geology and tectonics of the Itatiaia Region (Southeast of Brazil)]. *Boletim da Faculdade de Filosofia, Ciências e Letras*, *22*, 99–193. https://doi.org/10.11606/issn.2526-3862.bffcluspgeologia.1967.121904.

Pfaltzgraff, P. A. S., & Peixoto, C. A. B. (2010). Introdução [Introduction]. In A. B. Peixoto (Ed.), *Geodiversidade do Estado de São Paulo [Geodiversity of the State of São Paulo]* (pp. 4–9). São Paulo: CPRM.

Pica, A., Luberti, G. M., Vergari, F., Fredi, P., & Del Monte, M. (2017). Contribution for an urban geomorphoheritage assessment method: Proposal from three geomorphosites in Rome (Italy). *Quaestiones Geographicae*, *36*(3), 21–36. https://doi.org/10.1515/quageo-2017-0030.

Projeto RADAMBRASIL (1983). *Levantamento de Recursos Naturais, Folha SF.23/24 Rio de Janeiro/Vitória: Geologia, Geomorfologia, Pedologia, Vegetação e Uso Potencial da Terra [Natural resources survey, SF sheet. 23/24 Rio de Janeiro/Vitória: Geology, geomorphology, pedology, vegetation and potential land use]*. Rio de Janeiro: Ministério de Minas e Energia.

Prosser, C. D. (2013). Our rich and varied geoconservation portfolio: The foundation for the future. *Proceedings of the Geologists Association*, *124*(4), 568–580. https://doi.org/10.1016/j.pgeola.2012.06.001.

Queiroz, D. S., Garcia, M. G. M., & Del Lama, E. (2019). Desafios para a avaliação de locais de interesse geológico em áreas urbanizadas: Baixada Santista, litoral do estado de São Paulo [Challenges for the evaluation of geological sites in urbanized areas: Baixada Santista, coast of the state of São Paulo]. *Anuário do Instituto de Geociências–UFRJ*, *42*(3), 129–144. https://doi.org/10.11137/2019_3_129_144.

Reverte, F. C., Garcia, M. G. M., Brilha, J., & Moura, T. T. (2019). Inventário como instrumento de gestão e preservação da memória geológica: exemplo dos geossítios vulneráveis da Bacia de Taubaté–SP [Inventory as an instrument of management and preservation of geological memory: Example of vulnerable geosites of Taubaté Basin–SP.]. *Pesquisas em Geociências*, *46*(1), Article e0779. https://doi.org/10.22456/1807-9806.93252.

Reynard, E. (2005). Géomorphosites et paysages [Geomorphology and landscape]. *Géomorphologie Relief Process Environ*, *3*, 181–188. https://doi.org/10.4000/geomorphologie.338.

Reynard, E. (2009). The assessment of geomorphosites. In E. Reynard, P. Coratza, & G. Regolini-Bissig (Eds.), *Geomorphosites* (pp. 63–71). München: Pfeil.

Reynard, E., & Brilha, J. (2018). Geoheritage: A multidisciplinary and applied research topic. In E. Reynard, & J. Brilha (Eds.), *Geoheritage: Assessment, protection and management* (pp. 3–9). Amsterdam: Elsevier.

Reynard, E., Coratza, P., & Regolini-Bissig, G. (Eds.). (2009). *Geomorphosites*. München: Pfeil.

Reynard, E., & Giusti, C. (2018). The landscape and the cultural value of geoheritage. In E. Reynard, & J. Brilha (Eds.), *Geoheritage: Assessment, protection and management* (pp. 147–166). Amsterdam: Elsevier.

Reynard, E., Perret, A., Bussard, J., Grangier, L., & Martin, S. (2016). Integrated approach for the inventory and management of geomorphological heritage at the regional scale. *Geoheritage*, *8*(1), 43–60. https://doi.org/10.1007/s12371-015-0153-0.

Ribeiro Filho, E. (1967). Geologia e Petrologia dos Maciços Alcalinos do Itatiaia e Passa-Quatro (Sudeste do Brasil) [Geology and petrology of the alkaline massif of Itatiaia and Passa-Quatro (southeast of Brazil)]. *Boletim da Faculdade de Filosofia, Ciências e Letras*, *22*, 9–89. https://doi.org/10.11606/issn.2526-3862.bffcluspgeologia.1967.121901.

Riccomini, C. (1989). *O rift continental do Sudeste do Brasil* [The continental rift of Southeast Brazil] (Doctoral dissertation). University of São Paulo, São Paulo.

Riccomini, C., Sant'Anna, L. G., & Ferrari, A. L. (2004). Evolução geológica do rift continental do Sudeste do Brasil [Geological evolution of the continental rift of Southeast Brazil]. In V. Mantesso Neto, A. Bartorelli, C. D. R. Carneiro, & B. B. Brito-Neves (Eds.), *Geologia do Continente Sul-Americano: Evolução da Obra de Fernando Flávio Marques de Almeida [Geology of the south American continent: Evolution of the work of Fernando Flávio Marques de Almeida]* (pp. 383–405). São Paulo: Beca.

Riccomini, C., Velázquez, V. F., & Gomes, C. B. (2005). Tectonic controls of the Mesozoic and Cenozoic alkaline magmatism in central-southeastern Brazilian platform. In P. Comin-Chiaramonti, & C. B. Gomes (Eds.), *Mesozoic to Cenozoic alkaline magmatism in the Brazilian platform* (pp. 31–55). São Paulo: EDUSP/FAPESP.

Rosa, P. A. S. (2017). *Geologia e evolução petrogenética do maciço alcalino de Itatiaia, MG-RJ* [Geology and petrogenetic evolution of the alkaline mass of Itatiaia, MG-RJ] (Doctoral dissertation). University of São Paulo, São Paulo.

Rosa, P. A. S., & Ruberti, E. (2018). Nepheline syenites to syenites and granitic rocks of the Itatiaia alkaline massif, southeastern Brazil: New geological insights into a migratory ring complex. *Brazilian Journal of Geology*, *48*(2), 347–372. https://doi.org/10.1590/2317-4889201820170092.

Sallun, A. E. M., & Sallun Filho, W. (2009). Geologia em planos de manejo: subsídios para zoneamento ambiental do Parque Estadual Intervales (PEI), estado de São Paulo [Geology in management plans: subsidies for environmental zoning of Intervales State Park (PEI), State of São Paulo]. *Geociências UNESP*, *28*(1), 91–107.

Santos, D. S., Reynard, E., Mansur, K. L., & Seoane, J. C. S. (2019). The specificities of geomorphosites and their influence on assessment procedures: A comparative analysis. *Geoheritage*, *11*(4), 2045–2064. https://doi.org/10.1007/s12371-019-00411-z.

Santos, I., Henriques, R., Mariano, G., & Pereira, D. I. (2018). Methodologies to represent and promote the geoheritage using unmanned aerial vehicles, multimedia technologies, and augmented reality. *Geoheritage*, *10*, 143–155. https://doi.org/10.1007/s12371-018-0305-0.

Sharples, C. (2002). Concepts and principles of geoconservation. Retrieved from http://www.parks.tas.gov.au/geo/conprin/define.html

Sharples, C., McIntosh, P., & Comfort, M. (2018). Geodiversity and geoconservation in land management in Tasmania - A top-down approach. In E. Reynard, & J. Brilha (Eds.), *Geoheritage: Assessment, protection and management* (pp. 355–371). Amsterdam: Elsevier.

Silva, J. F. (1876). Descripção do Itatiaia ou Itatiaio [Description of Itatiaia or Itatiaio]. *Revista do Instituto Histórico e Geográfico Brasileiro*, *39*, 413–418.

Teixeira, D. (1961). Relevo e padrões de drenagem na chaminé vulcânica do Itatiaia [Relief and drainage patterns in the volcanic chimney of Itatiaia]. *Boletim Paulista de Geografia.*, *37*, 3–12.

Teixeira, W., & Linsker, R. (2007). *Itatiaia: Sentinela das Alturas*. São Paulo: Terra Virgem.

Thiede, D. S., & Vasconcelos, P. M. (2010). Paraná flood basalts: Rapid extrusion hypothesis confirmed by new $^{40}Ar/^{39}Ar$ results. *Geology*, *38*(8), 747–750. https://doi.org/10.1130/G30919.1.

Thomas, M. F. (2012). Geodiversity and landscape sensitivity: A geomorphological perspective. *Scottish Geographical Journal*, *128*(3–4), 195–210. https://doi.org/10.1080/14702541.2012.725863.

Tomzhinski, G. W. (2012). *Análise geoecológica dos incêndios florestais no Parque Nacional do Itatiaia [Geoecological analysis of forest fires in Itatiaia National Park] (Master's thesis)*. Federal University of Rio de Janeiro, Rio de Janeiro.

Trouw, R. A. J., Ribeiro, A., & Paciullo, F. V. P. (2003). Geologia da Folha Pouso Alto 1:100, 000. In C. A. Pedrosa Soares, M. A. Noce, R. A. J. Trouw, & M. Heilbron (Eds.), *Geologia e Recursos Minerais do Sudeste Mineiro, Projeto Sul de Minas-Etapa I [Geology and mineral resources of the southeast miner, southern Minas project-stage I]*. Belo Horizonte: Companhia Mineradora de Minas Gerais.

Woo, K. S. (2017). Role of IUCN WCPA Geoheritage specialist group for geoheritage conservation and recognition of world heritage sites, global Geoparks and other protected areas. *Geophysical Research Abstracts*, *19*, 1137.

Zalán, P. V., & Oliveira, J. A. B. (2005). Origem e evolução estrutural do Sistema de Riftes Cenozoicos do Sudeste do Brasil [Origin and structural evolution of the Cenozoic rift system of Southeast Brazil]. *Boletim de Geociências da Petrobras*, *13*(2), 296–300.