Integrating Geoheritage into the Management of Protected Areas: Proposal for the Itatiaia National Park, Brazil

Vanessa Costa Mucivuna (✉ vanessa.c.mucivuna@gmail.com)

University of Sao Paulo: Universidade de Sao Paulo <https://orcid.org/0000-0001-8931-9568>

Maria da Glória Motta Garcia

University of Sao Paulo: Universidade de Sao Paulo

Emmanuel Reynard

University of Lausanne: Universite de Lausanne

Pedro Augusto da Silva Rosa

Federal University of Minas Gerais: Universidade Federal de Minas Gerais

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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. Many protected areas, however, do not have an inventory of geoheritage sites. In view of this fact, this study aims to discuss the geoheritage inventory and to analyse, through a case study, how geodiversity is described in an existing management plan, prepared before IUCN included geoheritage in the Manual for the Management of Protected Areas. This study was conducted in the Itatiaia National Park, which has outstanding geological and geomorphological features. To ensure appropriate assessment of geological sites (including geomorphological, hydrological, petrological, sedimentary, structural sites, etc.), we took inventory of geoheritage and then analysed how the management plan addresses geodiversity. The geoheritage 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 geoheritage inventory would facilitate and support the exploration of management possibilities that range from protection to education. Therefore, we recommend the inclusion of geoheritage inventory in the management plans of protected areas because it is a valuable tool for the proper conservation and management of geoheritage.

1. Introduction

Since the International Conference on the Protection of Geological Heritage in 1991 (Martini 1994) and the Malvern Conference in 1993 (O'Halloran et al. 1994), initiatives and research focused on geodiversity and geoheritage have increased around the world (Reynard and Brilha 2018). In this context, geoconservation has emerged to prevent sites of geoscientific importance from being destroyed (Sharples 2002; Gray 2004, 2013; Henriques et al. 2011; Prosser 2013). 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 Organisation (UNESCO) (Crofts and Gordon 2015; Brilha 2018; Crofts 2018; Reynard and Brilha 2018; Crofts et al. 2020).

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

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 (Thomas, 2012; Bétard and Peulvast 2019). Another possible explanation could be the fact that international conventions and agreements have addressed it short until very recently, which made it 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 et al. 2021).

Recently, there has been a growing effort to integrate geoconservation into environmental and management policies (Crofts and Gordon 2014, 2015; Díaz-Martínez et al. 2016, 2017; Crofts 2018; Brilha et al. 2018; Gordon et al. 2018a, 2018b; Crofts et al. 2020). 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 and 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 and 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, <https://portals.iucn.org/library/resrec/search>).

Several authors (e.g. Matthews 2014; Crofts and Gordon 2014, 2015; Brilha and Reynard 2018; Crofts 2018; Gordon et al. 2018a, 2018b) have emphasised the challenges faced by geoconservation in protected areas (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 PAs 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 (MPs), either as a broader landscape element or their intrinsic features and scientific value (Dingwall 2000), could contribute to the appropriate management of abiotic aspects (Crofts et al. 2020), as well as promoting geodiversity, so that it causes the same level of concern that is currently shown about biodiversity (Crofts and Gordon 2015).

Considering the importance of geoconservation in PAs, the aims of this work are (i) to discuss the method and results of the inventory of geological sites (including geosites, geodiversity sites and viewpoints) 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 (USA) (Castro Júnior et al. 2009). The Yellowstone National Park in the US 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 (IUCN 2016).

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 No. 23,793/1934, amended by Law No. 4,771/1965 and No. 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 No. 6,902/1981), Ecological Reserves and Area of Relevant Ecological Interest (Decree No. 89,336/1984) and Private Natural Heritage Reserves (Law No. 1,922/1996) (Medeiros et al. 2004; Medeiros 2006).

One of the most important laws is the National System of Protected Areas (NSPA) (Law No. 9,985/2000), 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).

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, these elements are not satisfactorily elaborated in these documents (Garcia et al. 2019a), 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 No. 9,985/2000 reinforced it as a tool central 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 et al. 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 et al. 2018).

3. Study Area

3.1 General context

Located in Mantiqueira Mountain Range, in the southeast of Brazil, the INP has almost 280 Km² with altitudes ranging between 540 and 2791 m. (IBGE 2016). Its boundaries covers 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. 1).

The INP is part of the Atlantic Forest Biome, standing out as one of the 25 biodiversity hotspots in the world (Myers et al. 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 (MMA 2014), and its flora is classified into Vegetation Refuge, Dense High Ombrophilous Montane Forest, Dense Ombrophilous Montane Forest, Mixed Ombrophilous Montane Forest, and Semideciduous Montane Forest, highlighting endemic species such as *Fernesea itatiaiae*, *Piper itatiaianum*, *Itatiaia cleistopetala* and *Lycopodium jussiaei* (IBDF 1982; 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 *Malanophryniscus moreirae*, an endemic species chosen to be the symbol of the national park (IBAMA 1994; ICMBio 2013).

In hydrographic terms, the area is drained by Grande and Paraíba do Sul Basin Rivers, being the Itatiaia Alkaline Massif (IAM) its water divisor. 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). Its average temperature is 11.4° C, being January the warmest month (13.6° C) and July the coldest (8.2° C) (IBDF 1982; Tomzhinski 2012; ICMBio 2013).

Four soil classes were mapped by ICMBio (2013) dystic cambisol (humic), dystic litholic neosols, red-yellow dystic argisols, and latosols.

3.2 Geological and Geomorphological Setting

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

The study area is located in the interference zone between the structures related to two orogens, Brasília and Ribeira, in the Mantiqueira Province (Almeida et al. 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 et al. 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 and Ernesto 2004; Thiede and Vasconcelos 2010). During the Meso-Cenozoic, the development of the Continental Rift of Southeastern Brazil (Riccomini 1989; Riccomini et al. 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, 2005), including the intrusion of the IAM (e.g. Ribeiro Filho 1967; Penalva 1967; Brotzu et al. 1997; Enrich et al. 2005; Rosa 2017; Rosa and 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 (Modenesi and Toledo 1993; Trouw et al. 2003; Zalán and Oliveira 2005; Cogné et al. 2012; Heilbron et al. 2016; Rosa and Ruberti 2018).

Regarding geomorphological aspects, Mantiqueira Mountain Range represents one of the highest orographic features (above 2,000m a.s.l.) on the Atlantic edge of the South American continent (Hiruma et al. 2010; Marques Neto et al. 2015). 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 (Riccomini 1989; Almeida and Carneiro 1998; Zalán and Oliveira 2005; Marques Neto et al. 2015).

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 (RADAMBRASIL 1983; IBGE 2009, 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 (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 (IBGE 2009).

4. Methodological Procedures

The methodological procedures were structured into three main steps: the inventory of geosites, geodiversity sites and viewpoints, the analysis of the MP, and proposals for integrating the inventoried sites into the MP guidelines.

4.1 Inventory of geological sites

The inventory of geological sites (including geomorphological, hydrological, petrological, sedimentary, structural sites, etc.) was performed based on Brilha's (2016, 2018) concepts, which classifies as geosites only the high scientific relevance sites and as geodiversity sites the ones which relevance is mainly educational or recreative. It also included viewpoints, places that offer a view of rocks, structures, and landscapes with intrinsic value (Migoñ and Pijet-Migoñ 2017). It was carried out based on four steps:

(i) Definition of geological frameworks (GFs). This step was performed to identify and describe the main features related to the geology of the area. The GFs were defined based on the review of literature, interpretation of cartographic materials and suggestions of researchers who have conducted studies in the area.

(ii) Selection of potential sites. It was carried out based on Mucivuna and Garcia (2017), which includes (a) review of literature; (b) analysis of the MP (IBDF 1982; ICMBio 2013); (c) review of tourist advertisement materials; (d) interviews with researchers who have worked in the area; (e) analysis of cartographic materials (geological map (Trouw et al. 2003; Heilbron et al. 2016; Rosa and Ruberti 2018), geomorphological and pedological maps (ICMBio 2013), satellite images (Google Earth®, Global Digital Elevation Model) and Landsat 8 image (U.S. Geological Survey)), and (f) analysis of access routes and pathways.

(iii) Field evaluation. This step was performed intending to assess and describe potential sites, as well as identify new sites. Each of them was described in terms of its geological and geomorphological features, potential uses and threats.

(iv) Final list and characterisation of sites. Sites that (i) were not found in the fieldwork, (ii) were in inaccessible areas, or (iii) had no geoscientific importance were excluded from the final list. All potential geosites with scientific publications have been included in the final list because they are already recognised by the scientific community. As to those not mentioned in any publication, the criteria of representativeness, integrity and rarity were applied (Brilha 2016, 2018). Regarding geodiversity sites, the criteria of educational potential, variety of geological elements (educational value), scenery and interpretative potential (tourism value) were applied. The criteria of accessibility and safety (Brilha 2016, 2018) were not considered; since INP is a mountainous area, most sites are accessed only by hiking, and it has poor infrastructure.

4.2 Analysis of the management plan

In INP, two MP versions are available: the 1982 version covers its initial boundaries (IBDF 1982), and the current one includes the expanded area (ICMBio 2013). The analysis was performed based on the following aspects:

(i) Review of plans. This step was carried out in order to (i) identify potential sites that could be included in the inventory (item 4.1) and (ii) analyse the latest version (ICMBio 2013) considering the following questions:

- How are the elements of geodiversity described?
- Do geological and geomorphological maps show sites of geological interest?
- Is the physical characterisation of geological sites adequate?
- Do the proposals for public use cover sites of geological interest?

(ii) Diagnosis. All relevant information associated with geodiversity has been described and stored in a database.

(iii) Content analysis. The assessment was carried out based on how the information relating to geodiversity aspects was displayed in the MP.

4.3 Proposals for integrating the inventoried sites into the management plan

Based on the description of the previous steps, proposals to include geological sites in the management plan were performed based on the analysis of geodiversity content in the MP (item 5.2) and the inventory of geological sites (item 5.3).

5. Results

5.1 Inventory of geological sites

Six GF were defined (Table 1), represented by 17 geosites (Table 2 and Fig. 2). In addition, seven geodiversity sites (Table 3 and Fig. 3) and three viewpoints were also identified (Table 4 and Fig. 3). Figure 4 shows a map with the location of all inventoried sites.

The morphogenesis of the geosites are mainly associated with fluvial and mass movement processes (Quaternary deposits GL), tectonic reactivation (Cenozoic tectonism GF), intrusion and fracturing of alkaline rocks (first, second and third magmatic stages of alkaline intrusion GF), and metamorphic and ductile deformations (Proterozoic igneous and metamorphic rocks GF).

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. In the south region there are less inventoried sites because of the dense Atlantic Forest cover and lacks geoscientific publications. The reduced number of sites in the north region is a result of 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 deposits of Quaternary age, 60% of alkaline rocks of Meso-Cenozoic age, and 34% of igneous and metamorphic rocks of Proterozoic age (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.

Table 1

Description of the geological frameworks 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 and 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 and 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 and 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 and 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) Tectonics records of Rio Preto Waterfalls (16) Metagranitoid of Enamorados Peak (17) Mylonitic gneiss of Santa Clara Waterfall
* All geosites are also geomorphosites (Panizza 2001; Reynard et al. 2009) (excluding the Biotite monzonite quarry).		

Table 2

Geosites in the Itatiaia National Park. 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: Surface formations, TC: Tectonics (CPRM 2020).

Geosite	Coordinates 23 K (UTM WGS-84)	Interests	Brief description
Quaternary deposits			
(1) Bog of Aiuruoca River	534151 / 7527107	SF, SD, HD, GM	Floodplain filled with peat sediments and one of the highest springs in Brazil (Teixeira and 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	536460 / 7526460	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	539736 / 7517208	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 village	530929 / 7532340	GM, SF	Talus deposits composed of large rock fragments in clay to a sand-clay matrix (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	532716 / 7524651	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	532843 / 7524000	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	526016 / 7526458	PT, PL	Quarry composed of greenish-grey with medium-grained massive crystals, a significant amount of poikilitic biotite, cleavage planes and no preferential orientation (Rosa and Ruberti 2018).
(8) Breccia of Pedra Furada Hill	528365 / 7527402	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	533539 / 7525715	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	534818 / 7525059	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	535060 / 7526810 534929 / 7526795	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	536870 / 7528573	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	538868 / 7520001 539302 / 7519893 539161 / 7519592 539774 / 7518369	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	529562 / 7529067	PL, TC, GM	Convex top and slopes hill marked by stretched K-feldspar crystals and intrusions of quartz veins discordant with foliation.
(15) Tectonics records of Rio Preto Waterfalls	539405 / 7530390 539420 / 7530346	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	526108 / 7525221	MT, GM, TC	Hill marked by an outcrop of about 30 metres 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	541600 / 7532273	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.

Table 3

Geodiversity sites in the Itatiaia National Park. 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 (CPRM 2020).

Geodiversity site	Coordinates 23 K (UTM WGS-84)	Interests	Brief description
(18) Lakes and wetlands with peat deposits	531616 / 7526418	SF, SD, HG, GM	Wetland filled with peat deposits and shallow lakes surrounded by steep hills and rocky peaks.
(19) Breccia of Camelo Hill	529874 / 7526124	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	534737 / 7526045	PL, GM, TC	Hill marked by uneven surfaces, smooth convex top, straight slopes and chemical dissolution in the fracture planes.
(21) Aiuruoca Waterfall	534128 / 7527224	PL, TC, HD, GM	Cascade characterised by horizontal fracture planes and natural pool filled with rock fragments.
(22) Nepheline syenite of Três Picos Hill	542910 / 7519982	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	545202 / 7534632	PL, TC, HD, GM	Cascade characterised by foliation in the NW-SE direction and moderate dip angle.
(24) Gneiss of Cristais Waterfall	540397 / 7528736	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.

Table 4

Viewpoints in the Itatiaia National Park. Interests are based on the categories adopted at the Brazilian scale and visible on GEOSSIT platform: GM – Geomorphological, HD – Hydrological, TC – Tectonics (CPRM 2020).

Viewpoint	Coordinates 23 K (UTM WGS-84)	Interests	Brief description
(25) Viewpoint Flores Highway	528107 / 7526791	GM, TC	Visualisation of the Bocaina, Mantiqueira and Fina mountain ranges and Paraíba do Sul river valley.
(26) Viewpoint Último Adeus	540414 / 7516328	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	539869 / 7535397	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.

5.2 Analysis of the management plan

The main differences between the 1982 and 2013 plans are the size, as previously mentioned, and the applied methodological guidelines.

5.2.1 1982 plan

Although the scope of this study's analysis is the latest version of the MP (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 No. 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 (IBDF, 1982). This plan is no longer used by park managers.

The plan details the aspects of regional and local geological and geomorphological features. Some sites are emphasised (Viewpoint of Último Adeus, Lago Azul, Maromba Waterfall, Agulhas Negras Hill, Pedra do Altar Hill, 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 is not any photo or local maps.

5.2.2 2013 plan

The latest version (ICMBio 2013) was prepared by ECOMEX Business Consulting and Environment, a company commissioned by Chico Mendes Institute for Biodiversity Conservation (ICMBio). It was prepared 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 sets out that an MP must be organised in four reports, including (i) contextualisation of the protected area in the international, federal and state levels (three chapters); (ii) regional analysis of the municipalities covered by its boundaries (nine chapters); (iii) analysis of the biotic and abiotic characteristics, and the anthropic, cultural and institutional factors (nine chapters), and; (iv) planning strategies and its relation with the surroundings (seven chapters). 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 5). 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 5) 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 potentials for tourism use are mentioned, with no consideration for their geological or geomorphological features.

Table 5

Analysis of the Itatiaia National Park management plan (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, eco-tourism activities, and tourist routes.	It does not mention the conservation of abiotic aspects, nor describe sites of geological interest 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 abiotic (Geology, Geomorphology, Soil, Climate, Hydrography) and biotic (vegetation and fauna) characteristics.	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 eco-tourism, 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 Paraíba do Sul's 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 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

6. Proposals For Integrating The Inventoried Sites Into The Management Plan

All INP's MP reports have geodiversity aspects that require attention. However, there is no concrete proposal for conserving or monitoring these aspects. In this context, the first step to be taken should be including the diagnosis in the MP (inventory of geological sites) to characterise and evaluate geological site values and potential uses. This data would support the planning of conservation and management actions to ensure that the geoheritage features and the processes that form them are protected.

Proposals were made to include geological sites in the MP guidelines, considering the MP chapters that describe geodiversity directly or indirectly (item 5.2.2).

In the "contextualisation of the park" report, many universities, research groups, and companies dedicated to studies on geoconservation could contribute to research development through systematic geoheritage inventories. These actions could bring significant contributions since many PAs lack these data. In INP, the chapter "state approach" should include geoconservation projects like they do for biodiversity. In addition, the inclusion of inventoried sites would ensure that geodiversity and biodiversity conservation are linked for nature conservation; it would enrich the content of environmental education programmes through a systemic approach to the environment.

In the "analysis of the region of the protected area" report, tourism activities could address the conservation of the environment as a whole. In INP, the chapter "physical environment" could include some key geosites, such as the Fluted erosion of Agulhas Negras Hill (10) and Tectonic records of Rio Preto Waterfalls (15), in order to illustrate the geological history of the region. The chapter "cultural and historical aspects" should include geological sites linked with other aspects of the region. The chapter "opportunities to sustainable economic development" should associate geoconservation with tourism activities to contribute to the achievement of the SDGs. The dissemination of geoscientific content through Geotourism would be an excellent opportunity to contribute to the sustainable economic development of the region.

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 popularization of geological sites. Such actions could be implemented through leaflets, digital media, interpretative panels, etc. (Mucivuna and 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 INP, the chapter "characterising the abiotic and biotic aspects" should integrate geological sites to identify the priority of conservation actions and guarantee their conservation and management. In the chapter "statement of significance", geosites that have watersheds, such as Bogs of Aiuruoca and Preto Rivers (1 and 2), are essential to the protection of local freshwater. Viewpoints (25-27) and geodiversity sites (18-24) would allow a more integrated approach to environmental education and interpretation.

In the "planning" report, the geological sites located in zones that allow environmental interpretation, visiting, research, etc. 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 the dissemination of abiotic aspects could be carried out combined with other values, such as the geosite Biotite monzonite quarry (7), which shows a significant relationship with the historical value, as the quarry rocks were used for the construction of some buildings. In the chapter "zoning", the assessment of the use of inventoried sites was performed to help their management in their respective park areas (Table 6).

Furthermore, the inventoried sites are related to some of the objectives described in the MP, as they could be used to 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.

Since most of the inventoried sites are already used as a tourism attraction, their integration into the MP must be appropriately addressed by management staff in order to contribute to the development of geotourism and thus achieve the SDGs, notably SDG1 (no poverty) and SDG8 (decent work and economic growth).

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.

Table 6

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

Zoning	Allowed activities	Inventoried sites (Fig. 4)	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	The integration of 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.

7. Discussion

7.1 Inventory of geological sites

Protected areas have among their objectives scientific research, educational and recreational activities. The INP stands out for the large amount of research and visits, receiving nearly 18,000 students on school trips and over 127,000 visitors in 2019 (ICMBio 2019, 2021).

Most of its tourist attractions have geodiversity elements of interest. Therefore, the development of a systematic inventory was considered an tool essential to support conservation and improve the way people are introduced to geodiversity elements.

Pica et al. (2017), Clivaz and Reynard (2018), Queiroz et al. (2019) and Reverte et al. (2019) highlight that natural processes or anthropogenic activities can destroy not-sufficiently protected or known geosites due to farming, quarrying, infrastructure construction, urbanisation, vandalism, weathering and others. Thus, assessing the physical environment's potential and restrictions and the impacts from its inappropriate use (Pfaltzgraff and Peixoto 2010) is fundamental to the conservation and integration of abiotic aspects in nature conservation policies (Garcia et al. 2019b).

Most of the INP's inventoried sites can only be reached by long trails that have high to moderate difficulty levels. Fortunately, there is no link between access difficulty and potential for using the site in educational programme. For example, mountainous areas are not only accessible by climbers, hikers, and trekking specialists, as the viewpoints Último Adeus and Flowers Highway can be accessed by motorised vehicles, offer a view to areas with exceptional geomorphological features and are excellent candidates to be used as educational resources (Mucivuna and Garcia 2018). In contrast, some sites that are difficult to access may limit the obtaining of geological information for research or dissemination of content. In this sense, virtual products could be excellent tools in the scientific study of relevant geosites as well as in providing new opportunities to experience and reveal the values of geodiversity by promoting geoheritage (Santos et al. 2018; Gordon et al. 2021; Ibanez et al. 2021). Furthermore, virtual products such as those developed for the Jaraguá State Park can be used as a model to promote geological sites in Brazilian PAs (https://geohereditas.igc.usp.br/passeio-virtual-PEJ/passeio-virtual_PEJ.html).

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. However, although many Brazilian PAs are nationally or internationally recognised for their geoheritage, there is not yet any systematic government action to conserve and manage abiotic aspects.

Taking an inventory of geological sites could be the initial step towards the preparation of the material to support the inclusion of geological sites in the MP.

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

The MPs review showed how these documents have 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 elements of 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 context that the interest in geodiversity and geoconservation had grown in Brazil and around the world. The sites which had their geodiversity elements described were mostly those that are 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 elements in the study area's MP are addressed only briefly is not restricted only to the INP. Although the inclusion of geodiversity and geological setting is encouraged by the Ministry of Environment (Meira et al. 2018), the items that address them in Brazilian MPs are not very elaborated (Garcia et al. 2019a). Therefore, integrating these sites into the PA management is crucial to prevent significant geoscientific sites from being degraded due to the lack of knowledge by managers and visitors and to plan adequate geoconservation actions.

A systematic inventory of geological sites would be a reliable source for including and managing these sites. After analyzing the MP, not much geoheritage content was found; therefore, this gap should be filled. 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.

Similar actions have achieved significant results in state-level PA along the coast of the state of São Paulo State, Brazil. Based on the geoheritage inventory of the state of São Paulo (Garcia et al. 2018), the inventoried geosites were integrated into the MP of the Central Coast Marine Environmental Protection Area, in the Geobiodiversity Protection Zone (Garcia et al. 2019c; MA 2019), demonstrating the crucial role of the geoheritage inventory to include geosites in local environmental policies. In addition, the geoheritage inventory of the municipality of Bertioga-SP (Mucivuna 2016) was also used as a basis for the inclusion of geosites and geodiversity sites in the MP of the Restinga de Bertioga State Park.

8. Conclusions

Many geoheritage inventories have been conducted in Brazilian PA in recent years (Meira et al. 2018; Mucivuna et al. 2021) and are evidences of the growth and development in geoconservation research. However, actions to ensure their conservation, management and use are still scarce.

The application of a systematic method and the evaluation of values according to park activities are helpful, as the set of geosites includes all events of local geological history. The MP has an essential role because it is a source of park-specific data and shows the possibilities of a direct tool for conserving and managing geological sites.

The INP has an approach strongly associated with geodiversity, being a key place for mountaineering activities. However, abiotic aspects do not receive the same attention as biodiversity, as shown by the MP analysis. More than just recognising the geological sites in the PA, the proposal to integrate them into the MP proved to be very promising for providing conservation possibilities to managers.

The integration of geological sites into local policies is in line with conservation and management policies proposed by IUCN (Crofts et al. 2020).

Finally, this work is aimed to support the analysis of other MPs. We expect that future Brazilian MPs include a better integration of geodiversity, biodiversity and landscape management into their contents during their preparation or revision.

Declarations

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References

1. Ab'Saber AN, Bernardes N (1958) Vale do Paraíba, Serra da Mantiqueira e arredores de São Paulo. *International Congress of Geography* 18:284–292
2. Almeida FFM (1983) Relações tectônicas das rochas alcalinas mesozoicas da região meridional da Plataforma Sul-Americana. *Revista Brasileira de Geociências* 13(3):139–158
3. Almeida FFM (1991) O Alinhamento Magmático de Cabo Frio. *Proceedings of the Southeast Geology Symposium* 2, 423–428
4. Almeida FFM, Carneiro CDR (1998) Origem e evolução da Serra do Mar. *Revista Brasileira de Geociências* 28(2):135–150
5. Almeida FFM, Hasui Y, Neves B, Fuck BB, R.A., 1977. Províncias estruturais brasileiras. *Proceedings of the Northeast Geology Symposium* 8, 363–391
6. Almeida FFM, Hasui Y, Neves B, Fuck BB, 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](https://doi.org/10.1016/0012-8252(81)90003-9)
7. Bétard F, Peulvast JP (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>
8. Brasil (1979) Decreto nº 84.071 de 21 de setembro de 1979. http://www.planalto.gov.br/ccivil_03/Atos/decretos/1979/D84017.html (Accessed 15 jan 2021)
9. Brasil (1988) Constituição da República Federativa do Brasil. http://www.planalto.gov.br/ccivil_03/constituicao/constituicaocompilado.htm (Accessed 10 March 2017)
10. Brasil (2000) Lei nº 9.985 de 18 de julho de 2000. http://www.planalto.gov.br/ccivil_03/leis/L9985.htm (accessed 25 November 2015)
11. Brilha J (2002) Geoconservation and protected areas. *Environ Conserv* 29(3):273–276
12. 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>
13. Brilha J (2017) Trends and challenges for geoconservation. *Geophysical Research Abstract* 19:8626
14. Brilha J (2018) Geoheritage: inventories and evaluation. In: Reynard E, Brilha J (eds) *Geoheritage: assessment, protection and management*. Elsevier, Amsterdam, pp 69–85
15. Brilha J, Reynard E (2018) Geoheritage and Geoconservation: the challenges. In: Reynard E, Brilha J (eds) *Geoheritage: assessment, protection and management*. Elsevier, Amsterdam, pp 433–438
16. Brilha J, Gray M, Pereira DI, 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>
17. Brotzu P, Gomes CB, Melluso L, Morbidelli L, Morra V, Ruberti E (1997) Petrogenesis of coexisting SiO₂-undersaturated to SiO₂-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](https://doi.org/10.1016/S0024-4937(97)00007-8)
18. Castro Júnior E, Coutinho BH, Freitas LE (2009) Gestão da Biodiversidade e áreas protegidas. In: Guerra AJT, Coelho MCN (Orgs.) *Unidades de Conservação: abordagens e características geográficas*. Bertrand, Rio de Janeiro, pp 25–65

19. 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>
20. Cogné N, Gallagher K, Cobbold PR, Riccomini C, Gautheron C (2012) Post-breakup tectonics in southeast Brazil from thermochronological data and combined inverse-forward thermal history modeling. *Journal of Geophysical Research* 117:B11413. <https://doi.org/10.1029/2012JB009340>
21. CPRM. Serviço Geológico do Brasil, 2020. GEOSSIT: cadastro de sítios geológicos. <https://www.cprm.gov.br/geossit/geossitios> (accessed May 2020)
22. Crofts R (2018) Putting geoheritage conservation on all agendas. *Geoheritage* 10:231–238. <https://doi.org/10.1007/s12371-017-0239-y>
23. Crofts R, Gordon JE (2014) Geoconservation in protected areas. *Parks* 20(2):61–76. <https://doi.org/10.2305/IUCN.CH.2014.PARKS-20-2.RC.en>
24. Crofts R, Gordon JE (2015) Geoconservation in protected areas. In: Worboys GL, Lockwood M, Kothari A, Feary S, Pulsford I (eds) *Protected area governance and management*. ANU Press, Canberra, pp 531–568
25. Crofts R, Gordon JE, Brilha J, Gray M, Gunn J, Larwood J, Santucci VL, Tormey D, Worboys GL (2020) Guidelines for geoconservation in protected and conserved areas: best practice protected area guidelines, series n. 31. IUCN, Gland
26. Crofts R, Tormey D, Gordon JE (2021) Introducing New Guidelines on Geoheritage Conservation in Protected and Conserved Areas. *Geoheritage* 13:33. <https://doi.org/10.1007/s12371-021-00552-0>
27. D'amico AR, Coutinho EO, Moraes LFP (2018) Roteiro metodológico para elaboração e revisão de planos de manejo das unidades de conservação federais. ICMBio - Instituto Chico Mendes de Conservação da Biodiversidade: Brasília
28. Díaz-Martínez E, Brilha J, Brocx M, Erikstad L, García-Cortés A, Wimbledon WAP (2016) Global Geosites: an active and partially achieved geoheritage inventory initiative, waiting to regain official recognition. In: Cornée A, Egoroff G, Wever P, Lalanne A, Duranthon F (eds) *Actes du congrès international "Les inventaires du géopatrimoine"*. Mémoire hors-série de la Société géologique de France, Toulouse, pp 103–108
29. Díaz-Martínez E, Guillén-Mondéjar F, Brilha J, Monge-Ganuzas M, Herrero Martínez N, Hilario A, Mata-Perelló JM, Meléndez G, Utiel JC (2017) Nuevas resoluciones y avances de la UICN para la geoconservación. In: Carcavilla L, Duque-Macías J, Giménez J, Hilario A, Monge-Ganuzas M, Vegas J, Rodríguez A (eds) *Patrimonio geológico, gestionando la parte abiótica del patrimonio natural*. Cuadernos del Museo Geominero, Madrid, pp 247–252
30. Dingwall PR (2000) Legislation and international agreements: the integration of the geological heritage in nature conservation policies. In: Barrentino D, Wimbledon WAP, Gallego E (eds) *Geological heritage: its conservation and management*. IGME, Madrid, pp 15–28
31. Dudley N (2008) Guidelines for applying protected area management categories. IUCN, Gland
32. Enrich GER, Azzone RG, Ruberti E, Gomes CB, Comin-Chiaramonti P (2005) Itatiaia, Passa Quatro and São Sebastião Island, the major alkaline syenitic complex from the Serra do Mar region. In: Comin-Chiaramonti P, Gomes CB (eds) *Mesozoic to Cenozoic alkaline magmatism in the Brazilian Platform*. EDUSP/FAPESP, São Paulo, pp 419–441
33. Galante MLV, Beserra MML, Menezes EO (2002) Roteiro metodológico de planejamento: Parque Nacional, Reserva Biológica, Estação Ecológica. IBAMA - Instituto Brasileiro de Meio Ambiente e Recursos Naturais Renováveis, Brasília
34. Garcia MGM, Brilha J, Lima FF 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>
35. Garcia MGM, Reverte FC, Mucivuna VC, Arruda KEC, Prochoroff R, Santos PLA, Romão RMM (2019a) Geoconservação em áreas protegidas: contribuição de cursos para monitores ambientais no litoral norte do estado de São Paulo, Brasil. *Terrae Didactica* 15:e19028. <https://doi.org/10.20396/td.v15i0.8652390>
36. Garcia MGM, Del Lama E, Martins L, Mazoca CEM, Bourotte CLM (2019b) Inventory and assessment of geosites to stimulate regional sustainable management: the northern coast of the state of São Paulo, Brazil. *Anais da Academia Brasileira de Ciências*. 91(2), e20180514. <https://doi.org/10.1590/0001-3765201920180514>
37. Garcia MGM, Lanza MCT, Silva IL, Mucivuna VC, Costa JA, Queiroz DS (2019c) Geossítios como áreas de interesse em planos de manejo de unidades de conservação: exemplo da APA Marinha Litoral Centro, estado de São Paulo. *Simpósio Brasileiro de Patrimônio Geológico* 5:40–41
38. Gordon JE, Crofts R, Díaz-Martínez E (2018a) Geoheritage conservation and environmental policies: retrospect and prospect. In: Reynard E, Brilha J (eds) *Geoheritage: assessment, protection and management*. Elsevier, Amsterdam, pp 213–235
39. Gordon JE, Crofts R, Díaz-Martínez E, Woo KS (2018b) 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>
40. Gordon JE, 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 Parks*. <https://doi.org/10.1016/j.ijgeop.2021.05.003>
41. Gray M (2004) *Geodiversity: valuing and conserving abiotic nature*. John Wiley & Sons, Londres
42. Gray M (2013) *Geodiversity: valuing and conserving abiotic nature*. John Wiley & Sons, Londres
43. Heilbron M, Pedrosa-Soares AC, Campos Neto MC, Silva LC, Trouw RAJ, Janasi VA (2004) Província Mantiqueira. In: Mantesso-Neto V, Bartorelli A, Carneiro CDR, Brito-Neves BB (eds) *Geologia do Continente Sul-Americano: evolução da obra de Fernando Flávio Marques de Almeida*. Beca, São Paulo, pp 203–234
44. Heilbron M, Eirado LG, Almeida J (2016) Mapa Geológico e de Recursos Minerais do Estado do Rio de Janeiro. Serviço Geológico do Brasil, scale 1:400.000
45. Henriques MH, Reis RP, Brilha J, Mota T (2011) Geoconservation as an emerging geoscience. *Geoheritage* 3:117–128. <https://doi.org/10.1007/s12371-011-0039-8>
46. Hiruma ST, Riccomini C, Modenesi-Gauttieri MC, Hackspacher PC, Hadler-Neto JC, Franco-Magalhães AOB (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.

47. IBAMA. Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (1994) Plano Emergencial para o Parque Nacional do Itatiaia. Diretoria de Ecossistemas, departamento de unidades de conservação, Brasília
48. Ibanez K, Garcia MGM, Mazoca CEM (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>
49. IBDF. Instituto Brasileiro de Desenvolvimento Florestal (1982) Plano de manejo do Parque Nacional do Itatiaia. IBDF, Brasília
50. IBGE. Instituto de Geografia e Estatística, 2009. Manual técnico de Geomorfologia. IBGE, Rio de Janeiro
51. IBGE. Instituto Brasileiro de Geografia e Estatística, 2016. Anuário estatístico do Brasil. IBGE, Rio de Janeiro
52. IBGE. Instituto Brasileiro de Geografia e Estatística (2019) Base Vetorial Geomorfologia do Brasil. <https://www.ibge.gov.br/geociencias/downloads-geociencias.html> (accessed January 2020)
53. ICMBio. Instituto Chico Mendes de Conservação da Biodiversidade, 2013. Plano de Manejo: Parque Nacional do Itatiaia. ICMBio, Brasília
54. ICMBio. Instituto Chico Mendes de Conservação da Biodiversidade, 2019. Monitoramento da visitação em Unidades de Conservação Federais: resultados de 2019 e breve panorâmica histórico. https://www.icmbio.gov.br/portal/images/stories/comunicacao/publicacoes/monitoramento_visitacao_em_ucs_federais_resultados_2019_breve_panora (accessed 03 jan 2021)
55. ICMBio (2021) Instituto Chico Mendes de Conservação da Biodiversidade, Notas de pesquisa. <https://www.icmbio.gov.br/parnaaitatiaia/images/stories/2021/o-que-fazemos/notas-de-pesquisa/433.pdf> (accessed 20 feb 2021)
56. IUCN, International Union for Conservation of Nature (2016) The world now protects 15% of its land, but crucial biodiversity zones left out. <https://www.iucn.org/news/secretariat/201609/world-now-protects-15-its-land-crucial-biodiversity-zones-left-out> (accessed 18 August 2019)
57. Lamego AR (1936) O massiço de Itatiaia e regiões circundantes. *Boletim do Serviço Geológico e Mineralógico do.* v. 88, 1–93
58. Lasaulx A, 1885. Über das Vorkommen von Eläolith-Syeniten und editeri zu diesen gehöriigen Eläolith-porphyrn aus der Serra d'Itatiaia westlich von Rio de Janeiro, Brasilien. *Sitzungsberichte Der Niederrheinischen Gesellschaft Für Natur*, 231–232
59. MA (2019) Minuta em aprovação do plano de manejo da APA Marinha Litoral Centro. <http://sigam.ambiente.sp.gov.br> (accessed 11 July 2019)
60. Marques LS, Ernesto M (2004) O magmatismo toleítico da Bacia do Paraná. In: Neto M, Bartorelli V, Carneiro A, Brito-Neves CDR, B.B. (eds) *Geologia do Continente Sul-Americano: Evolução da Obra de Fernando Flávio Marques de Almeida*. Beca, São Paulo, pp 245–263
61. Marques Neto R, Perez Filho A, Oliveira TA (2015) Itatiaia Massif: morphogenesis of Southeastern Brazilian highlands. In: Vieira BC, Salgado AAR, Santos LJC (eds) *Landscapes and landforms of Brazil*. Springer, Berlin, pp 299–308
62. Martini G (1994) Actes du premier symposium international sur la protection du patrimoine géologique. Société Géologique de France, Paris
63. Matthews TJ (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>
64. Medeiros R (2003) Proteção da natureza: das estratégias internacionais e nacionais às demandas locais. PhD Thesis, Federal University of Rio de Janeiro
65. Medeiros R (2006) Evolução das tipologias de áreas protegidas no Brasil. *Ambiente sociedade* 9(1):41–64. <https://doi.org/10.1590/S1414-753X2006000100003>
66. Medeiros R, Irving M, Garay I (2004) A proteção da natureza no Brasil: evolução e conflitos de um modelo em construção. *Revista de Desenvolvimento Econômico* 9:83–93
67. Meira SA, Nascimento MAL, Silva EV (2018) Unidades de Conservação e geodiversidade: uma breve discussão. *Terr@Plural*. 12(2), 166–187. <https://doi.org/10.5212/TerraPlural.v.12i2.0002>
68. 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. *Mineral Mag* 81(2):217–250. <https://doi.org/10.1180/minmag.2016.080.122>
69. Migoñ P, Pijet-Migoñ 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>
70. MMA. Ministério do Meio, Ambiente (2004) Portaria nº 126, de 27 de maio de 2004. <http://www.mma.gov.br/biodiversidade/biodiversidade-brasileira/areas-prioritarias> (accessed 10 March 2017)
71. Modenesi MC, Melhem TS (1986) Primeiros resultados da palinologia dos sedimentos turfosos da várzea do Ribeirão das Flores, Itatiaia–Rio de Janeiro. *Revista do Instituto Geológico* 7(1–2):35–38. <http://dx.doi.org/10.5935/0100-929X.19860005>
72. Modenesi MC, Toledo MCM (1993) Morfogênese quaternária e intemperismo: colúvios do Planalto do Itatiaia. *Revista do Instituto Geológico* 14(1):45–53. <http://dx.doi.org/10.5935/0100-929X.19930004>
73. Mucivuna VC (2016) Estratégias de geoconservação aplicadas à geodiversidade do município de Bertioga-SP e às fortificações do litoral paulista. Master's Dissertation, University of São Paulo
74. Mucivuna VC, Garcia MGM (2017) Método para seleção de potenciais geossítios e geomorfossítios do inventário do Parque Nacional de Itatiaia. *Simpósio Brasileiro de Patrimônio Geológico* 4:367–371
75. Mucivuna VC, Garcia MGM (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
76. Mucivuna VC, Garcia MGM, Reynard E (2021) Criteria for assessing geological sites in national parks: a study in the Itatiaia National Park, Brazil. Manuscript submitted to *Geoheritage*

77. Myers N, Mittermeier RA, Mittermeier CG, Fonseca GAB, Kent J (2000) Biodiversity hotspots for conservation priorities. *Nature* 403:853–858. <https://doi.org/10.1038/35002501>
78. O'Halloran D, Green C, Harley M, Stanley M, Knill. J (1994) Geological and landscape conservation. The Geological Society, London
79. Panizza M (2001) Geomorphosites: concepts, methods and examples of geomorphological survey. *Chin Sci Bull (suppl Bd)* 46:4–6
80. Penalva F (1967) Geologia e Tectônica da Região do Itatiaia (Sudeste do Brasil). *Boletim da Faculdade de Filosofia. Ciências e Letras* 22:99–193. <http://dx.doi.org/10.11606/issn.2526-3862.bffcluspgeologia.1967.121904>
81. Pica A, Luberti GM, 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>
82. Pfaltzgraff PAS, Peixoto CAB (2010) Introdução. In: Peixoto AB (Org.) *Geodiversidade do Estado de São Paulo*. CPRM, São Paulo, pp 9–4
83. Prosser CD (2013) Our rich and varied geoconservation portfolio: the foundation for the future. *Proceedings of the Geologists' Association*. 124(4), 568–580. <http://dx.doi.org/10.1016/j.pgeola.2012.06.001>
84. Queiroz DS, Garcia MGM, Del Lama E (2019) Desafios para a avaliação de locais de interesse geológico em áreas urbanizadas: Baixada Santista, litoral do estado de São Paulo. *Anuário do Instituto de Geociências–UFRJ*. 42(3), 129–144. http://dx.doi.org/10.11137/2019_3_129_144
85. Projeto RADAMBRASIL RADAMBRASIL (1983) Levantamento de Recursos Naturais. In: Folha SF.23/24 Rio de Janeiro/Vitória: Geologia, Geomorfologia, Pedologia, Vegetação e Uso Potencial da Terra. Ministério de Minas e Energia, Rio de Janeiro
86. Reverte FC, Garcia MGM, Brilha J, Moura TT (2018) Inventário como instrumento de gestão e preservação da memória geológica: exemplo dos geossítios vulneráveis da Bacia de Taubaté–SP. *Pesquisas em Geociências* 46(1):e0779. <https://doi.org/10.22456/1807-9806.93252>
87. Reynard E, Brilha J (2018) Geoheritage: a multidisciplinary and applied research topic. In: Reynard E, Brilha J (eds) *Geoheritage: assessment, protection and management*. Elsevier, Amsterdam, pp 3–9
88. Reynard E, Coratza P, Regolini-Bissig G (eds) (2009) *Geomorphosites*. Pfeil, München
89. Ribeiro Filho E (1967) Geologia e Petrologia dos Maciços Alcalinos do Itatiaia e Passa-Quatro (Sudeste do Brasil). *Boletim da Faculdade de Filosofia. Ciências e Letras* 22:9–89. <http://dx.doi.org/10.11606/issn.2526-3862.bffcluspgeologia.1967.121901>
90. Riccomini C (1989) O Rift Continental do Sudeste do Brasil. PhD Thesis, University of São Paulo
91. Riccomini C, Sant'Anna LG, Ferrari AL (2004) Evolução geológica do Rift Continental do Sudeste do Brasil. In: Neto M, Bartorelli V, Carneiro A, Brito-Neves CDR, B.B. (eds) *Geologia do Continente Sul-Americano. Evolução da Obra de Fernando Flávio Marques de Almeida*. Beca, São Paulo, pp 383–405
92. Riccomini C, Velázquez VF, Gomes CB (2005) Tectonic controls of the Mesozoic and Cenozoic alkaline magmatism in Central-Southeastern Brazilian Platform. In: Comin-Chiaramonti P, Gomes CB (eds) *Mesozoic to Cenozoic alkaline magmatism in the Brazilian Platform*. EDUSP/FAPESP, Sao Paulo, pp 31–55
93. Rosa PAS (2017) Geologia e evolução petrogenética do maciço alcalino de Itatiaia, MG-RJ. PhD Thesis, University of São Paulo
94. Rosa PAS, 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>
95. Santos I, Henriques R, Mariano G, Pereira DI (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>
96. Silva JF (1876) Descrição do Itatiaia ou Itatiaio. *Revista do Instituto Histórico e Geográfico Brasileiro* 39:413–418
97. Sharples C (2002) Concepts and principles of Geoconservation. <http://www.parks.tas.gov.au/geo/conprin/define.html> (accessed 10 March 2019)
98. Teixeira D (1961) Relevo e padrões de drenagem na chaminé vulcânica do Itatiaia. *Boletim Paulista de Geografia* 37:3–12
99. Teixeira W, Linsker R (2007) *Itatiaia: Sentinela das Alturas*. Terra Virgem, São Paulo
100. Thiede DS, Vasconcelos PM (2010) Paraná flood basalts: rapid extrusion hypothesis confirmed by new ⁴⁰Ar/³⁹Ar results. *Geology* 2010. 38 (8), 747–750. <https://doi.org/10.1130/G30919.1>
101. Thomas MF (2012) Geodiversity and landscape sensitivity: a geomorphological perspective. *Scottish Geographical Journal* 128(3–4):195–210. <https://doi.org/10.1080/14702541.2012.725863>
102. Tomzhinski GW (2012) Análise geoecológica dos incêndios florestais no Parque Nacional do Itatiaia. Master's Dissertation, Federal University of Rio de Janeiro
103. Trouw RAJ, Ribeiro A, Paciullo FVP (2003) Geologia da Folha Pouso Alto 1:100.000. In: Soares P, Noce CA, Trouw MA, Heilbron RAJ, M. (eds) *Geologia e Recursos Minerais do Sudeste Mineiro, Projeto Sul de Minas-Etapa I*. Companhia Mineradora de Minas Gerais, Belo Horizonte
104. Woo KS (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
105. Zalán PV, Oliveira JAB (2005) Origem e evolução estrutural do Sistema de Riftes Cenozoicos do Sudeste do Brasil. *Boletim de Geociências da Petrobras* 13(2):296–300

Figures

Figure 1

Location map of the Itatiaia National Park with the main hydrographical network and the five highest peaks 1: Agulhas Negras Peak. 2: Pedra do Couto Hill. 3: Pedra do Sino Hill. 4: Pedra do Altar Hill. 5: Maromba Hill.

Figure 2

Representative geosites of the Itatiaia National Park according to the geological frameworks. (A) Bog of Aiuruoca River (1) (Quaternary deposits). (B) Fault Escarpment of Couto-Prateleiras Hills (6) (Cenozoic tectonism). (C) Breccia of Pedra Furada Hill (8) (Third magmatic stage of alkaline intrusion). (D) Fluted erosion of Agulhas Negras Hill (10) (Second magmatic stage of alkaline intrusion). (E) Waterfalls of Campo Belo River Basin (13) (Third magmatic stage of alkaline intrusion). (F) Metagranitoid of Enamorados Peak (16) (Proterozoic igneous and metamorphic rocks). (Figures A, B, C, D and E: photos by Vanessa C. Mucivuna and Figure F: photo by Jobson Pereira).

Figure 3

Representative sites with educational and recreative values of the Itatiaia National Park. (A) Geodiversity site Lakes and wetlands with peat deposits (18) (educational value). (B) Geodiversity site Gneiss of Cristais Waterfall (24) (recreative value). (C) Viewpoint Alto dos Brejos Hill (27) (educational and recreative values). (Figures A, B and C: photos by Vanessa C. Mucivuna).

Figure 4

Inventoried sites in the Itatiaia National Park. (1) Bog of Aiuruoca River; (2) Bog of Preto River; (3) Fluvial deposits of Lago Azul; (4) Talus deposits of Serra Negra village; (5) Structural valley of Campo Belo River; (6) Fault Escarpment of Couto-Prateleiras Hills; (7) Biotite monzonite quarry; (8) Breccia of Pedra Furada Hill; (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; (13) Waterfalls of Campo Belo River Basin; (14) Leucogranite of Pedra Grande Hill; (15) Tectonics records of Rio Preto Waterfalls; (16) Metagranitoid of Enamorados Peak; (17) Mylonitic gneiss of Santa Clara Waterfall; (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; (25); Flores Highway (26) Último Adeus; and (27) Alto dos Brejos Hill.