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The opinion of divers on the interpretation of marine geology in the archipelago of Fernando de Noronha, Brazil

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Abstract

Environmental interpretation seeks to reveal meanings to provoke personal connections between the public and the protected heritage. In the specific case of geological heritage, it determines and communicates the meaning of a geological and geomorphological phenomenon, event or location. There is a range of nature tourism activities that can promote interpretation of this heritage. The practice of properly organized scuba diving can bring benefits both to conservation of the environment and to local communities. Fernando de Noronha is one of the best dive sites in Brazil and actions focused on aspects of marine geology add even more value to the activity. In this sense, we sought to investigate the opinion of divers about environmental interpretation and aspects of marine geology in the archipelago by applying a questionnaire. The questionnaire was applied online between April 2018 and May 2019, with 100 individuals who had practiced scuba diving in the archipelago at least once. Different data collection techniques were applied (convenience, purposive sampling, quota and snowball). The main results indicate that information on marine geology is relevant for the scuba diving activity, and this type of action can contribute to a more conscious attitude towards island sustainability.

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1. Introduction

The Fernando de Noronha archipelago is located in the South Atlantic Ocean, 345 km off the Brazilian coast. With a unique geological heritage, this territory highlights part of the geological history of oceanic islands of volcanic origin. Studies and actions are being carried out to recognize the area as a UNESCO Global Geopark (Wildner and Ferreira 2012, Moreira 2008, Vale 2017). In 2013, the Geopark Project Working Group was formed. Wildner and Ferreira (2012) identified 26 geosites in an inventory of the archipelago's geological heritage. This study, however, did not consider marine geosites, which were later suggested by Moreira and Silva Jr. (2016).

Moreira and Silva Jr. (2013) also collected information on the marine geology and geomorphology of diving sites, in a study on underwater trails aimed at interpretation. There is still little interpretation of aspects of marine geodiversity. In Brazil, this type of study is virtually non-existent, which shows the lack of initiatives in the field of teaching and dissemination of geoscientific information.

Environmental interpretation can be understood as "the set of communication strategies aimed at revealing the meanings of environmental, historical and cultural resources in order to provoke personal connections between the public and the protected heritage" (Caetano et al. 2018). Hose (2012, p.17) defined geo-interpretation as "the art or science of determining and then communicating the meaning or significance of a geological or geomorphological phenomenon, event or location." When considering environmental interpretation as a fundamental aspect for understanding the landscape, the objective of this research was to identify the perceptions of the visitors who scuba-dived in Fernando de Noronha, of aspects of interpretation of geodiversity.

2. Materials and methods

Data were collected using a structured questionnaire containing 13 closed-ended and multiple-choice questions. The first part of the questionnaire consists of questions about the profile of the visitors while the second part focuses on interpretation of aspects of geodiversity.

The survey was applied through the Google Forms online platform between April 2018 and May 2019. A total of 100 valid questionnaires were collected. Sampling was non-

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probabilistic and data collection techniques were based on quota, convenience, purposive sampling, and snowball. Thus, three steps were followed:

1. The first stage was the adoption of the quota technique, which, according to Mason (2002), defines categories and the minimum number of cases required for each category. Thus, people who had scuba-dived in Fernando de Noronha at least once were selected and distributed equally into groups of men and women.

2. In the second stage, techniques for convenience and judgment were adopted, with respondents who were accessible and willing to participate in the study, based on their qualities (Etikan et al. 2016). The form was targeted towards divers, according to previous knowledge on the activity in the archipelago, and sent online to diving groups.

3. In the final stage, the snowball technique was adopted. "A sampling procedure may be defined as snowball sampling when the researcher accesses informants through contact information that is provided by other informants" (Noy 2013, p. 330). It was more likely that interviewees knew other members who had visited volcanic areas; therefore, this technique made it possible to expand the sample.

This study used a mixed method of analysis in order to "answer research questions that address the relationships between variables" (Sandelowski et al. 2009). A descriptive statistical analysis was carried out to quantify the qualitative questions of the study.

3. Geodiversity

Geodiversity can be understood as the abiotic part of nature. It was conceptualized by Gray (2013) as the abiotic equivalent of biodiversity, which includes rocks, minerals, fossils, landscapes, topography, and physical processes.

3.1 Geodiversity in Fernando de Noronha

The origin of the Fernando de Noronha archipelago is related to successive volcanic eruptions resulting from the separation of the African and South American continents, which originated the Atlantic Ocean. The passage of the South American plate through a hotspot may have been the reason for the emergence of the archipelago (Wildner and Ferreira 2012). The volcanic events that gave rise to the islands began about 12 million years ago. The base of the volcanic mountain that houses the archipelago is 74 km in diameter and 4,000 m in depth, and it is located in the fracture zone of Fernando de Noronha (Almeida 1958, 2006).

According to Almeida (1958), the archipelago has volcanic and sub-volcanic subsaturated rocks, especially sodium-alkaline ones. The geological structure has rocks dating from the Quaternary, Upper and Lower Pliocene and Upper Miocene periods. Almeida (1958) identified distinct rock formations, e.g., Remédios, Quixaba, São José and Caracas. There are controversies about the São José Formation, as recent studies indicate that the rocks found in this formation are part of the Remédios Formation (Perlingeiro et al. 2013, Lopes and Ulbrich 2015).

The topography is related to the nature and geological history of the rocks. The main island has an irregular outline with recesses and protrusions and wavy surfaces. At 323 meters, Morro do Pico is the highest point of the archipelago (Teixeira et al. 2003).

The morphological composition is divided into eight units: hills, plateaus, low plateaus, slopes, beaches, dune fields, mangroves, and rocks (Wildner and Ferreira 2012).

The sand on the beaches is different from that of the continent, as it does not have quartz-rich rocks; rather, it is formed by bioclastic materials such as shells, remains of marine animals, and rock fragments (Teixeira et al. 2003).

Most of the soils are young and shallow, and were influenced by the generalized phosphatization of birds that led to the formation of a Latosol. This unusual soil is sandy, and is composed of bioclastic and carbonate material in dunes and emerged marine platforms (Schaefer et al. 2017, Silveira et al. 2020).

The Geological Survey of Brazil – CPRM carried out a technical study that supports the creation of the Fernando de Noronha Geopark, recognizing its importance for geoconservation. A total of 26 geosites of scientific, educational and tourist importance have been identified, 8 of which are of international relevance (Wildner and Ferreira 2012).

It can be said that Fernando de Noronha's international relevance is due to the fact that the islands represent a unique example of volcanic oceanic islands west of the Mesoatlantic Dorsal Volcanic Mountain Range, associated with tectonic structures (e.g., transforming faults) of the MAR (Middle Atlantic Region) itself (Vale 2017).

Fernando de Noronha is the top of an underwater volcano and represents the last volcanic events that occurred in Brazil. Wildner and Ferreira (2012) pointed out that one can directly observe rocks from the Earth's mantle with xenoliths.

4. Scuba diving

Diving is a practice that has occurred since the dawn of humanity as a strategy for obtaining food (Cousteau 1979). Since the 1930s, equipment has improved to enable longer submersion time (Cunha 2018). With this technological advance, the practice of diving tourism began to occur more frequently as of the 1950s (Musa and Dimmock 2013).

According to the Professional Association of Diving Instructors (PADI, 2020), there are three types of diving:

- Discover scuba diving: known in Brazil as 'baptism', this modality introduces people to scuba diving under supervision. Participants learn the basic concepts of safety and the correct use of equipment to swim underwater under the supervision of a professional.
- Accredited diving: in this modality, the person who has already completed the course and has a diving certification contacts a diving operator who takes them to the place to be visited. Before starting the dive, information is passed on (briefing) by a local diving guide and, during the activity, this professional draws a route to be followed in order to ensure the safety of divers. For the Open Water Diver certification, maximum depth is 18 meters, while for Advanced Open Water Diver, it is 40 meters.
- Course: courses are based on progressive training that includes diving skills, equipment handling, safety procedures and knowledge of the underwater environment.

The tourist dive is performed on a trip away from the diver's place of residence. This trip can be planned specifically for scuba diving, or the activity can be done at the destination (Musa and Dimmock 2013). With the growing demand of practitioners of the activity, regulations are required for

conservation of the marine environment and diver safety. Discussions on the impact on biodiversity are common; however, when it comes to marine geodiversity, the topic remains little debated.

Burek et al. (2013) and Gordon et al. (2016) highlighted the work on marine geoconservation being done in the United Kingdom. Regarding geoparks, there are few initiatives that mention marine geosites, and two examples are the Azores Geopark (Portugal) (Lima et al. 2018) and the Lanzarote and Chinijo Islands UNESCO Global Geopark, in the Canary Islands (Spain) (Galindo et al. 2019).

Diving in Conservation Units must follow ICMBio guidelines. The Normative Instruction of April 24, 2020 states the procedures for carrying out the activity. According to article 4, scuba diving, free diving or floating can be considered as an activity for educational purposes, and the operator can develop informative and interpretive activities on the natural and cultural environment being visited (Brasil 2020). For Moreira and Silva Jr. (2013), the training of operators who conduct underwater trails should include elements of geodiversity.

Human activities have the potential to impact both geomorphological and geological features on the seabed. (Gordon and Barron 2012). In scuba diving, divers try to minimize the impact of the activity; however, inexperienced people may negatively affect geodiversity owing to the lack of buoyancy control, and may touch and damage rock formations.

4.1 Scuba diving in Fernando de Noronha

Fernando de Noronha has 25 diving sites, four in the Environmental Protection Area of Fernando de Noronha - São Pedro and São Paulo (APA) and twenty-one in the Fernando de Noronha National Marine Park (PARNAMAR) (Figure 1).

The following sites are located in the Park area: Ilha do Meio (Figure 2A), Ressurreta, Cagarras Rasa, Cagarras Fundas, Buraco do Inferno, Cordilheira, Cordas, Pontal do Norte, Macaxeira, Buraco das Cabras, Cabritos, Caieiras (Figure 2B), Pedras Secas, (Figures 2C and 2D), Frade, Trinta Réis, Cabeço Submarino, Iuias, Navio do Leão, Capim Açu, Cabeço da Sapata (Figure 2E) and Caverna da Sapata (Figure 2E). In the APA area are Corveta Ipiranga - V 17 (Figure 2F), Laje Dois Irmãos, Cabeço Dois Irmãos and Naufrágio do Porto. The modalities offered by four companies are baptism, accredited diving and courses.

For Teixeira et al. (2003), what makes Fernando de Noronha one of the best diving sites in Brazil are the convenience and the ease of observing biodiversity, whether waist deep in water or at a depth of a hundred meters. The underwater landscape, with

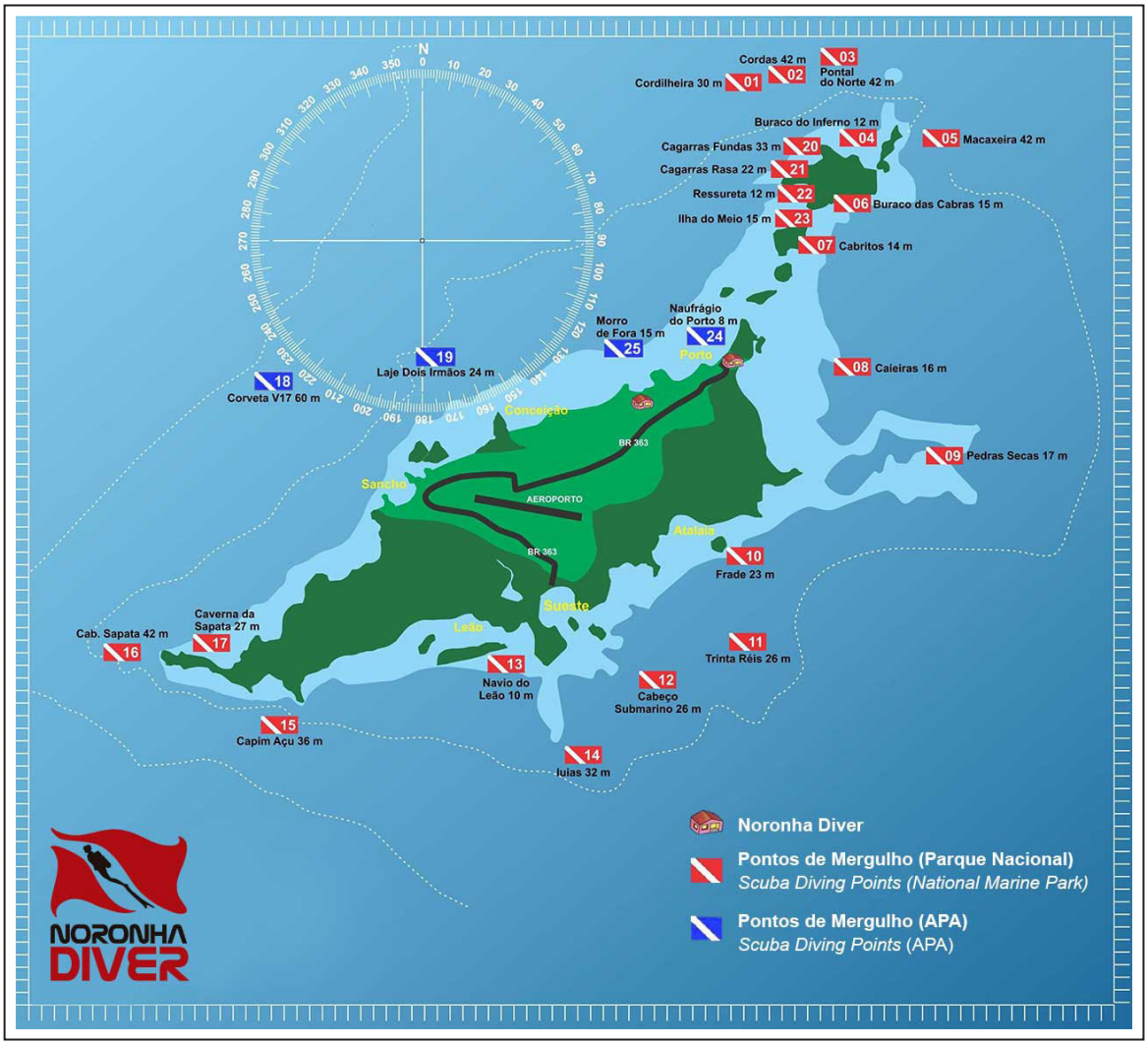

FIGURE 1. Diving sites in the Fernando de Noronha National Marine Park (PARNAMAR), and Environmental Protection Area of Fernando de Noronha - São Pedro and São Paulo (APA) (Source: http://www.noronhadiver.com.br/).

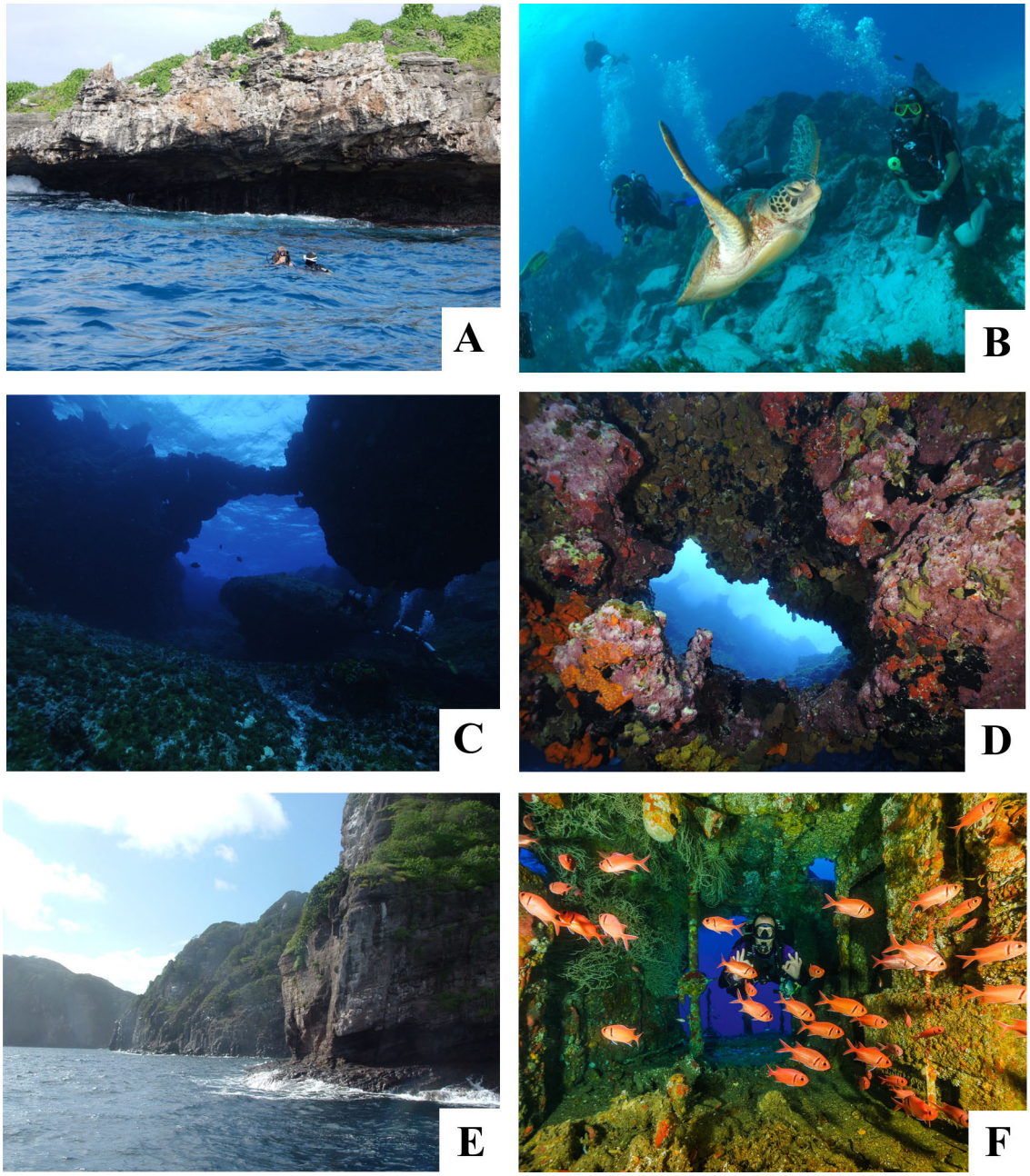

FIGURE 2. Diving sites in the Fernando de Noronha archipelago. (A) The Caracas sandstone, near Ilha do Meio. (B) Caieiras is composed of pyroclastic rocks. (C and D) Pedras Secas is considered as one of the best diving sites in Fernando de Noronha. (E) Caverna da Sapata area, where the diving boats stay anchored. (F) Corveta Ipiranga – V 17 is a shipwreck and has rich marine life. Sources: 2A, Tatiane Ferrari do Vale (2016); 2B, Jasmine Cardozo Moreira (2010); 2C and 2D, Marcos Tanner de Abreu (2019); 2E, Jasmine Cardozo Moreira (2007); 2F, Augusto Mano (2019).

emphasis on the geological formations, can be as attractive as the aspects of biodiversity if it is properly interpreted.

The APA Management Plan presents the necessary procedures for performing scuba diving activities. There is no specific mention of marine geology, however, as the document intends “to disseminate scientific knowledge about fauna, flora and geology, among other topics researched, with the valorization of local knowledge.” (ICMBIO 2017).

The Study of Carrying Capacity and Operationalization of Nautical Tourism Activities of the National Marine Park of Fernando de Noronha, carried out by Luiz Jr. (2009), analyzed how the activity can cause damage to the marine environment. The author considers that “the intervention of the diving guide is one of the most effective strategies for reducing the physical impact of divers with reefs”. In other words, it is essential to train these guides, who can explain the importance of these places, as they are the ones who monitor and provide instruction on the activity.

Teixeira et al. (2003) reported data on dive sites in the archipelago; however, they do not characterize the geology and geomorphology of these sites. Moreira and Silva Jr. (2013) collected geological and geomorphological information at 21 dive sites in Fernando de Noronha to assist in the environmental interpretation of these aspects, as it had been found that the operators only passed on information about the local biodiversity.

These dive sites were considered to be geosites by Moreira and Silva Jr. (2013) and their characteristics are shown in Table 1, with their Geological Formation (Quixaba, Remédios or Caracas) and the type of the dive that can be done (baptism or advanced).

Sea turtles, spinner dolphins, sharks, rays and fish can be seen in the sea. In addition to rich biodiversity, visitors who do scuba diving get to know a unique environment, with shipwrecks, caves, and marine canyons.

During night dives, animals sighted during the day are resting, and the marine fauna is different. In this type of diving, aspects of geodiversity can be hardly observed, since light is limited and divers only have the range of the light beams from the lanterns.

The Fernando de Noronha archipelago has ample potential to attract divers for the reasons listed by Davis and Tisdell (1995): interest in marine ecology or other characteristics of the submerged environment, such as geology and archeology; the search for experiences close to nature; or for the feeling of adventure and excitement.

An alternative that can help people gain knowledge of Fernando de Noronha's geodiversity and marine geosites is Google Street View, which has mapped the archipelago. Through 360º images, it allows anyone with internet access to get to know it. In addition to the images, there is also some information about each location.

5. Results

In this study, 100 people who had performed the dive in Fernando de Noronha at least once were interviewed. Of the 100 respondents, 50% were female and 50% were male. Regarding age groups, most of them were aged between 26 and 35 years old (51%), followed by 36-45 years old (22%), 18-25 years old (17%), and 46-55 years old (10%). As for level of education, they have postgraduate studies (46%), complete higher education (27%), incomplete higher education (13%), and a high school diploma (5%).

Regarding origin, 98% are Brazilian, from Pernambuco (22%), Paraná (21%), São Paulo (14%), Rio de Janeiro (11%), Minas Gerais (6%), Rio Grande do Norte (5 %), Santa Catarina (5%), and Bahia (4%), with the others add up to 9%. The origin of one of the respondents could not be detected. The foreign participants accounted for 2% and came from the countries of El Salvador and Portugal.

Of the visitors who did scuba diving, 44% practiced it more than 8 times, while 23% from 1 to 4 times, 23% only once (baptism) and 10%, 5 to 8 times. (Figure 3A). As for the year of the first dive, most were done in 2018, 2016, 2015 and 2013.

The main motivation for carrying out the activity was recreation, tourism and/or adventure (73%), followed by science, study and/or research (17%), work (7%) and other activities (3%) (Figure 3B).

Of the respondents, 83% said they had received information about marine flora and fauna, 30% about marine geology, 11% had not received any information and 5% could not remember if they had (Figure 3C). Regarding this issue, 85,7% of those who said they had received some type of information indicated that this was easily identified during the activity, while 14,3% said it was not (n = 91) (Figure 3D).

Divers were asked if they felt any information was lacking, and 26% indicated marine fauna and flora, 60% marine geology, while 11% reported not having missed any specific information (Figure 3E). Regarding the information made available, 87.1% (n = 91) said it had been provided by briefing before the dive; 34.1%, in conversation after the dive, and other responses corresponded to 11% (Figure 3F).

The last question asked about the opinion of divers on environmental interpretation and aspects of marine geology, and 98% believe that this subject is a relevant aspect for carrying out the activity.

TABLE 1. Geological characteristics of dive sites in Fernando de Noronha (After Moreira and Silva Jr. 2013).

Geosite	Geological Formation	Characteristics	Diving modalities
Pontal do Norte	Quixaba	Ankaratrite flow	Advanced
Buraco do Inferno	Quixaba	Ankaratrite flow	Basic / Baptism
Buraco das Cabras	Quixaba	Organogenic Phosphates	Basic
Cagarras Rasa e Funda	Quixaba	Ankaratrite flow	Basic / Baptism
Laje Dois Irmãos	Quixaba	Ankaratrite flow	Basic / Advanced
Caverna da Sapata	Quixaba	Ankaratrite flow / Underwater Cave	Advanced
Cabeço da Sapata	Quixaba	Ankaratrite flow	Advanced
Iuias	Quixaba	Ankaratrite flow	Advanced
Cordilheira	Quixaba	Modern Sediments / conglomerates	Basic / Advanced
Cabeço das Cordas	Quixaba	Ankaratrite flow	Advanced
Ponta da Macaxeira	Quixaba	Ankaratrite flow	Advanced
Caieiras	Remédios	Pyroclastic Material	Basic
Cabeço Submarino	Remédios	Pyroclastic Material	Advanced
Ilha do Frade	Remédios	Phonolite Rocks Island	Basic / Advanced
Trinta Reis	Remédios	Phonolite Rocks island / Underwater “canyon”	Advanced
Ilha do Meio	Caracas	Modern Sediments / conglomerates	Basic / Baptism
Ressurreta	Caracas	Modern Sediments / conglomerates	Basic /Baptism
Pedras Secas	Caracas	Calcarenite / Underwater Cave	Advanced

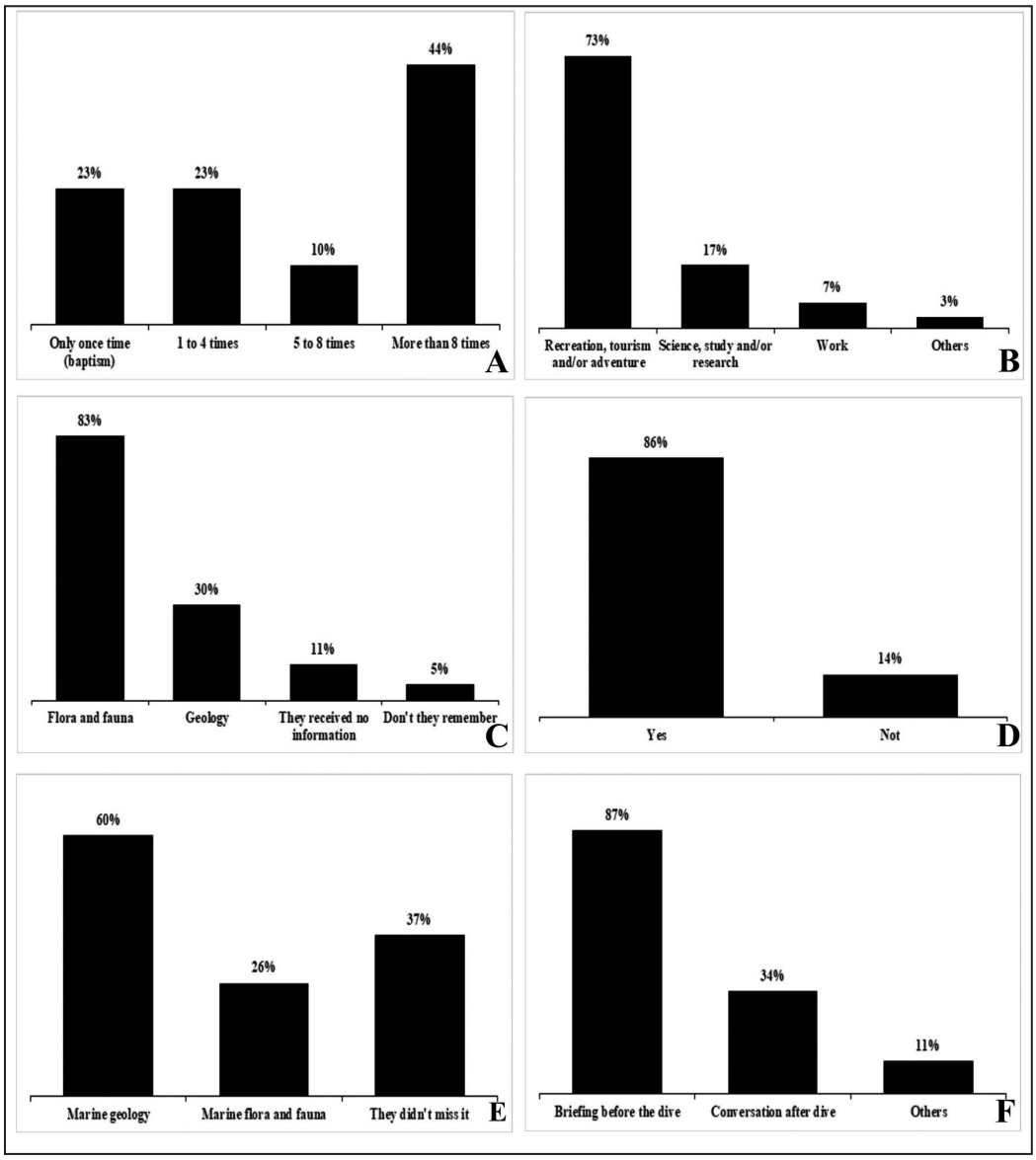

FIGURE 3. Histograms showing the frequency of answers from interviewed persons who did scuba diving in Fernando de Noronha. (A) Number of times they performed the dive (n=100). (B) Divers' main motivation (n=100). (C) Themes that received information (n=100). (D) Ease of observation of the information provided during the activity (n=91). (E) Need for information about marine geology or marine flora and fauna (n=100). (F) Time when information was provided (n=91).

6. Discussions

As indicated by previous studies, the interpretation of marine geodiversity can be important for scuba diving. It is common for practitioners of this activity, especially those less familiar with the marine environment, to identify biodiversity more easily, as dolphins and sea turtles are more commonly sighted than an underwater ankaratrite flow. Raising the awareness of visitors to biodiversity conservation is still a challenge, but such theme has the advantage of having been widely debated for much longer than geodiversity.

Importantly, despite the benefits provided by this practice to environmental conservation and to communities, it must occur in a controlled manner, as studies have shown that the excess number of vessels in the archipelago has threatened spinner dolphins (Stenella longirostris) (Silva et al. 2018).

Most respondents made the dive more than 8 times, which means that for this portion of visitors, the activity is interesting. The divers indicated that they felt they lacked information about marine geology, which means there is room for the development of actions in this regard. Almost three quarters of the respondents dove for the purposes of recreation, tourism and/or adventure, which demonstrates the attractiveness of the archipelago for this type of tourism.

The divers showed that the information had been provided before the dive. A more in-depth study of the effectiveness of these communicative strategies before and after the activity should be carried out. Virtually everyone responded that they believed marine geology to be a relevant subject for carrying out the activity.

Interpretative means are resources that can be used by guides to facilitate the recognition of elements of marine geodiversity. During the briefing, explanations about the geological context and the rocks that can be observed at the dive site may be accompanied by illustrated panels and mini-guides, or more advanced resources such as 3D models and simulations.

It is worth highlighting the importance of the operators for the success of interpretation, as they are the main channels of communication capable of revealing the meanings of the geological marine landscape. Establishing relationships between aspects of biodiversity and geodiversity would make the divers' experience more satisfying, as they would shift from being mere lovers of the landscape to agents of change, more committed to the sustainability of Fernando de Noronha and the oceans.

In Fernando de Noronha, a preliminary study was carried out to identify marine geosites; however, a methodology for assessing geological heritage should be applied to quantify and appreciate the relevance of these sites. As highlighted by Galindo et al. (2019), identifying and valuing shallow underwater geological heritage is crucial for the development of underwater and diving geotourism. The diving areas are already protected by the Conservation Units; however, when taking the necessary steps to value each site, monitoring actions can be better targeted, with the aim of reducing the impact of the activity in areas which are relevant for conservation.

7. Conclusions

This study showed that given the geological relevance of Fernando de Noronha, approaches that involve the interpretation of geodiversity could improve the visitor experience, since they believe that information about marine geology is relevant for the practice of scuba diving.

Fernando de Noronha is one of the tourist destinations most sought after by Brazilians, and the protection of this unique territory is essential. The implementation of an underwater trail and approaches to marine geology can reveal the meaning of the landscape and create connections between visitors and the geological heritage. This type of action helps to raise awareness of the importance of geoconservation and contributes to a more conscious attitude towards island sustainability.

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