Mesophotic ecosystems at Fernando de Noronha Archipelago, Brazil (South-western Atlantic), reveal unique ichthyofauna and need for conservation

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Although several studies on the ichthyofauna of the Fernando de Noronha Archipelago have been carried out, its mesophotic fish diversity has never been surveyed before. Here we used SCUBA and technical rebreather diving, baited remote underwater videos and remotely operated vehicle to record shallow (≤ 30 m depth) and mesophotic (31 to 150 m depth) fishes. Nineteen fish species belonging to 14 families are reported here as new records, representing an increase of 8.2% in marine fish richness for the region, which now has a total of 250 species and 77 families. These new records include four potential new species and highlight the importance of surveying mesophotic ecosystems, even in well studied sites. Our results also emphasize the need for protection and attention to the unique ichthyofauna found at mesophotic depths.

Keywords: BRUVS, Marine Protected Area, Oceanic Island, Rebreather, Remotely Operated Vehicle.

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Apesar de muitos estudos sobre a ictiofauna do Arquipélago de Fernando de Noronha terem sido realizados, sua diversidade de peixes mesofóticos nunca foi estudada antes. Neste estudo utilizamos mergulho autônomo e mergulho técnico, vídeos subaquáticos remotos com isca e veículo operado remotamente para registrar peixes de ecossistemas rasos (≤ 30 m de profundidade) e mesofóticos (31 a 150 m de profundidade). Dezenove espécies de peixes pertencentes a 14 famílias são apresentadas aqui como novos registros, representando um aumento de 8,2% na riqueza de peixes marinhos da região, que agora possui um total de 250 espécies e 77 famílias. Esses novos registros incluem quatro prováveis novas espécies e reforçam a importância de estudos em ecossistemas mesofóticos. Nossos resultados também enfatizam a necessidade de proteção e atenção à essa ictiofauna única encontrada nesses ecossistemas profundos.

Palavras-chave: Área Marinha Protegida, BRUVS, Ilha Oceânica, Rebreather, Veículo Operado Remotamente.

INTRODUCTION

Due to their geographical isolation, oceanic islands are often unique environments with biodiversity characterized by high endemism (Vaske Jr *et al*., 2005; Macieira *et al*., 2015; Kosaki *et al*., 2017; Pinheiro *et al*., 2018a). These environments function as true natural laboratories for evolutionary and ecological studies (Pinheiro *et al*., 2017) and are important for understanding patterns of species dispersal and establishment (Losos, Ricklefs, 2009). Recent studies are revealing many new species and new occurrences, filling gaps in the biodiversity knowledge and increasing our understanding about the biogeographic patterns of oceanic islands (*e.g*., Simon *et al*., 2013; Macieira *et al*., 2015; Carvalho-Filho *et al*., 2016; Pinheiro *et al*., 2018a).

Knowledge about reef fish biodiversity and biogeographic patterns of South Atlantic oceanic islands has steadily increased over the past two decades (*e.g*., Batista *et al*., 2012; Wirtz *et al*., 2017; Hachich *et al*., 2015; Pinheiro *et al*., 2015, 2018a; Quimbayo *et al*., 2019). However, mesophotic ecosystems (between 31 – 150 m depth) remain largely unknown and are only now receiving some scientific attention (*e.g*., Rocha *et al*., 2018). Even though these ecosystems have been recognized since the 19th century (Sinniger *et al*., 2016), the first studies in Brazil date back only to the 1960s (Francini-Filho *et al*., 2019). Systematic studies of the mesophotic ecosystems have however increased worldwide (*e.g*., Rosa *et al*., 2015; Andradi-Brown *et al*., 2016; Pyle *et al*., 2016; Simon *et al*., 2016; Rocha *et al*., 2018; Pinheiro *et al*., 2019; Pimentel *et al*., 2020). Such pioneer studies have provided important baseline information, such as richness and diversity of species, and form the basis for more complex ecological and evolutionary studies.

Fernando de Noronha Archipelago (FN) is the most accessible oceanic island in Brazil, as it is relatively close to the mainland and has an airport. It also offers logistical support due to the presence of a research station and several dive shops and boats. Part of the Archipelago comprises a no-take Marine Protected Area (MPA), the Fernando de

Noronha Marine National Park, which protects near-shore ecosystems (*e.g.*, tidepools, rocky shores, and reefs) to around 50 m depth. Most of the mesophotic ecosystems are located in a sustainable use MPA, the Fernando de Noronha – Rocas – São Pedro and São Paulo Environmental Protected Area, where fishing is allowed with some restrictions (ICMBio, 2017). Nearly all biodiversity and ecological studies of FN's ichthyofauna to date have been carried out in the intertidal (*e.g*., Andrades *et al*., 2018; Rodríguez-Rey *et al*., 2018) and shallow (≤ 20 m deep) environments (*e.g*., Krajewski, Floeter, 2011; Medeiros *et al*., 2011; Ilarri *et al*., 2017; Smith-Vaniz *et al*., 2018; but see Garla *et al*., 2006; Sazima *et al*., 2010; Afonso *et al*., 2017).

Therefore, to fill the knowledge gap about fish biodiversity from mesophotic ecosystems of the Fernando de Noronha Archipelago, we carried out a large-scale survey using sampling techniques including technical rebreather diving, baited remote underwater stereo-video systems (stereo-BRUVS) and remotely operated vehicles (ROVs). Here, we present new records and new species of fishes discovered during our expedition, discuss aspects related to the island's biodiversity and biogeography, and highlight the need to protect insular mesophotic ecosystems.

MATERIAL AND METHODS

Study area. Fernando de Noronha Archipelago is located 345 km off the north-eastern Brazilian coast (03°50'S 32°25'W), on the Fernando de Noronha Submarine Ridge (Fig. 1). It is the largest Brazilian oceanic archipelago, composed by a volcanic island (16.4 km^2) and 18 small islets (Almeida, 2006). The shallow reefs (≤ 30 m depth) are mainly composed by volcanic rocks predominantly covered by algal turfs and brown macroalgae, with low coral cover (Krajewski, Floeter, 2011). Following the pattern of low diversity typical of Atlantic oceanic islands (Ferreira *et al*., 2004; Floeter *et al*., 2008), the fish assemblages are dominated by a few very abundant species (Krajewski, Floeter, 2011; Ilarri *et al*., 2017). Compared to shallow reefs, the upper mesophotic reefs (31 to 60 m depth) show higher cover of sponges and the scleractinian coral *Montastraea cavernosa* (Linnaeus, 1767) (Matheus *et al*., 2019). A mosaic of habitats such as patch reefs, sand bottoms and rhodolith beds compose the middle mesophotic zone (61 to 90 m depth; Fig. 2). Below 90 m depth, the edge of the insular shelf followed by a steep wall characterizes the lower mesophotic zone (91 to 150 m; Fig. 3). A strong thermocline is found just below the shelf edge, where the temperature drops from ~27 to ~14 °C. The ecosystem at the lower mesophotic zone is highly complex, formed by rocky reefs covered mostly by crustose coralline algae, black corals and sponges.

Regarding environmental management, the Archipelago encompasses two different types of Marine Protected Areas, the no-take zone of the Fernando de Noronha Marine National Park (Brasil, 1988), and the sustainable use zone of the Fernando de Noronha – Rocas – São Pedro and São Paulo Environmental Protected Area (Brasil, 1986) (Fig. 1). The Marine National Park comprises about 70% of the main island (*i.e*., all the windward coast and part of the leeward coast), all smaller islands and extends to around the 50 m isobath, with fishing prohibited and tourism regulated (Brasil, 1988; Ibama, 1990). The area of sustainable use aims to make human occupation, tourism and fishing compatible with environmental protection and preservation of natural

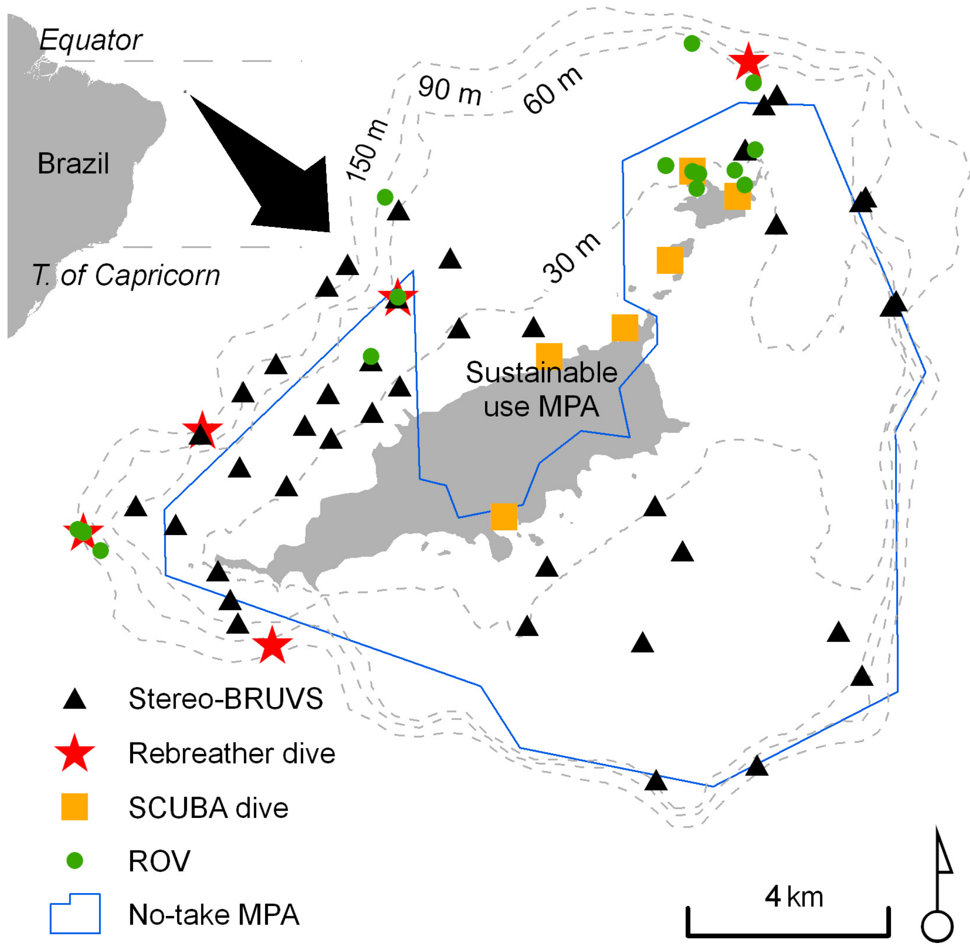

FIGURE 1 | Location of the Fernando de Noronha Archipelago, Brazil (South-western Atlantic). Blue line indicates the area of the Marine National Park of Fernando de Noronha (no-take MPA). Dashed lines indicate the 30, 60, 90 and 150 m isobaths. Black triangles, red stars, golden squares and green dots indicate the position of stereo-BRUVS deployments, rebreather dives, SCUBA dives and ROV footages, respectively.

resources (Brasil, 1986; ICMBio, 2017). The use of trawl nets, longlines, drift nets and spears, as well as the capture of sharks, rays and parrotfishes are not allowed (Brasil, 1986; ICMBio, 2017).

Sampling procedures. The data presented here were obtained during a 15-day expedition in October 2019. Fish were recorded with SCUBA (*ca.* 30 h sampling in the euphotic zone) and technical rebreather diving (*ca.* 6 h sampling in the upper and 2 h in the lower mesophotic zone), remotely operated vehicle (ROV – *ca.* 8 h of footage) and baited remote underwater stereo-video systems (stereo-BRUVS – 42 deployments of 1 h footage each). Some fishes were collected using hand-nets and pole-spears, and voucher specimens were deposited in the ichthyological collection of the Universidade Federal do Espírito Santo (CIUFES; see Tab. 1 for catalogue numbers).

Data analysis. Species identification was performed using taxonomic keys (*e.g.*,

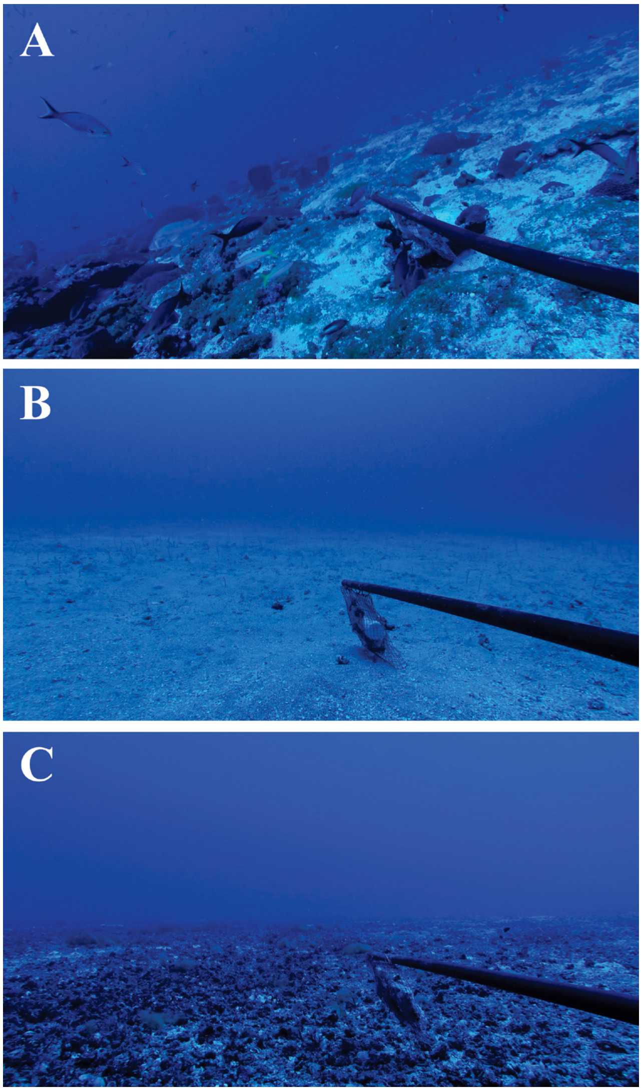

FIGURE 2 | Middle mesophotic (61 to 90 m depth) mosaic of habitats sampled with stereo-BRUVS around the Fernando de Noronha Archipelago. **A.** Patch reefs; **B.** Sand bottoms; and **C.** Rhodoliths beds.

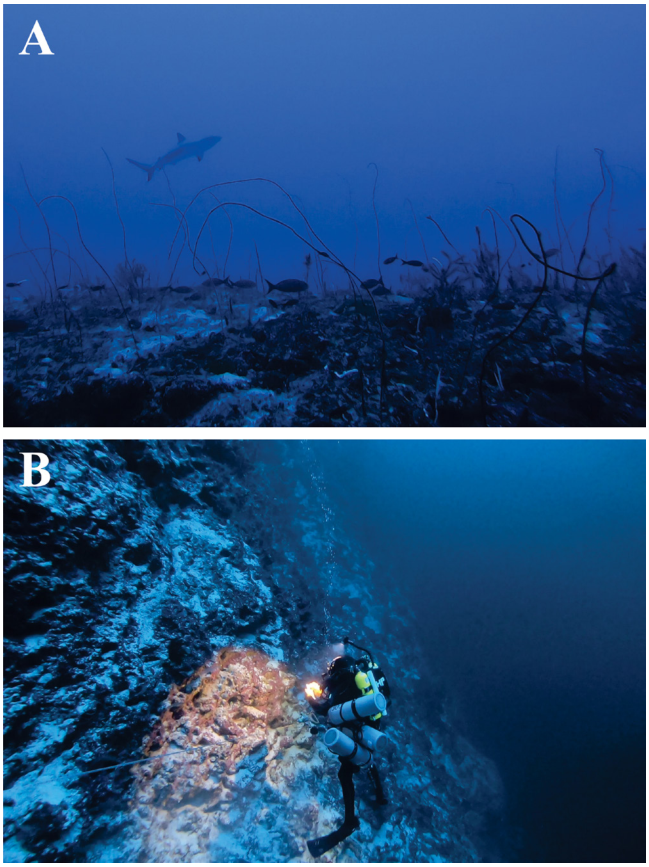

FIGURE 3 | Lower mesophotic (below 90 m depth) ecosystems explored through technical rebreather diving around the Fernando de Noronha Archipelago. **A.** The insular shelf edge; and **B.** The steep wall.

Menezes, 1971; Knudsen, Clements, 2013) and, when necessary, comparing our collected specimens with others available at the ichthyological collection of CIUFES. We then classified the species according to: 1) depth zone of the record, *i.e.*, euphotic (≤ 30 m) or mesophotic (> 30 – 150 m), 2) habitat (reef or rhodolith), 3) the type of the record (collected, photographed or filmed with ROV or stereo–BRUVS), 4) geographic range (following Pinheiro *et al.*, 2018a), and 5) conservation status, following the International Union for Conservation of Nature's (IUCN) Red List of Threatened Species (https://www.iucnredlist.org).

RESULTS

Nineteen fish species belonging to 14 families are reported here as new records for FN (Tab. 1). The most speciose families were Kyphosidae and Serranidae, with three new records each, followed by Pomacentridae, with two new records. Fourteen new records (74% of total) were from the mesophotic ecosystems (Figs. 4–5; Tab. 1) and five (26%) from the euphotic zone (Fig. 6; Tab. 1). Seven species are distributed throughout the Western Atlantic, and the three Kyphosidae are circumtropical species. Three other species are amphi-Atlantic, one of which also occurs in the Mediterranean (*Balistes capriscus* Gmelin, 1789). *Aulotrachichthys argyrophanus* (Woods, 1961) occurs only in the South-western Atlantic and *Chromis scotti* Emery, 1968 is found in the Caribbean Sea and Northern Brazil (Moura *et al*., 1999). Four new records are probable new species (*Synodus* sp., *Scorpaena* sp., *Psilotris* sp., and *Tosanoides* sp.) with unknown geographic range (Fig. 4E–G; Tab. 1). In terms of conservation status, only *B. capriscus* is listed as threatened, being currently classified as vulnerable in the IUCN Red List (Liu *et al*., 2015).

TABLE 1 | New records of fishes from Fernando de Noronha Archipelago, north-eastern Brazil. Families are presented in phylogenetic order according to Nelson *et al.* (2016). Information about depth zone, habitat, record type and voucher of the new records, as well as distribution and conservation status of the species are presented. Depth zone of the record: euphotic (≤ 30 m deep) and mesophotic (31 to 150 m deep). Geographic range: amphi-Atlantic (AA), Caribbean Sea (CS), Circumtropical (CT), Mediterranean (M), Northern Brazil (NB), South-western Atlantic (SW) and Western Atlantic (WA). International Union for Conservation of Nature and Natural Resources (IUCN) conservation status: data deficient (DD), least concern (LC), and vulnerable (VU); N/A: not applicable.

Family	Species	Depth zone	Habitat	Record type	Voucher	Geographic range	Conservation status
Synodontidae	*Synodus* sp.	Mesophotic	Reef	Photo	Fig. 4	Unknown	N/A
Holocentridae	*Corniger spinosus* Agassiz, 1831	Mesophotic	Reef	Collected / Photo	CIUFES 3922 / Fig. 5	AA	LC
Trachichthyidae	*Aulotrachichthys argyrophanus* (Woods, 1961)	Mesophotic	Reef	Collected / Photo	CIUFES 3909 / Fig. 5	SW	DD
Apogonidae	*Apogon pseudomaculatus* Longley, 1932	Euphotic	Reef	Collected	CIUFES 3957	WA	LC
Gobiidae	*Psilotris* sp.	Mesophotic	Reef	Photo	Fig. 4	Unknown	N/A
Pomacentridae	*Chromis enchrysura* Jordan & Gilbert, 1882	Mesophotic	Reef	Collected / Photo	CIUFES 3902 / Fig. 4	AA	LC
Pomacentridae	*Chromis scotti* Emery, 1968	Mesophotic	Reef	Photo	Fig. 4	CS / NB	LC
Syngnathidae	*Cosmocampus profundus* (Herald, 1965)	Mesophotic	Rhodolith	Stereo-BRUVS	Fig. 4	WA	DD
Labridae	*Decodon puellaris* (Poey, 1860)	Mesophotic	Reef	Collected	CIUFES 3914 / Fig. 5	WA	LC
Kyphosidae	*Kyphosus bigibbus* Lacepède, 1801	Euphotic	Reef	Photo	Fig. 6	CT	LC
Kyphosidae	*Kyphosus cinerascens* (Forsskål, 1775)	Euphotic	Reef	Photo	Fig. 6	CT	LC
Kyphosidae	*Kyphosus vaigiensis* (Quoy & Gaimard, 1825)	Euphotic	Reef	Collected / Photo	CIUFES 4050 / Fig. 6	CT	LC
Serranidae	*Pronotogrammus martinicensis* (Guichenot, 1868)	Mesophotic	Reef	Collected / Photo	CIUFES 3939 / 3960 / Fig. 5	WA	LC
Serranidae	*Pseudogramma gregoryi* (Breder, 1927)	Euphotic	Rhodolith	Collected / Photo	CIUFES 4029 / Fig. 6	WA	LC
Serranidae	*Tosanoides* sp.	Mesophotic	Reef	Collected	CIUFES 3892 / 3893 / 3894 / 3912 / 3913 / 3952	Unknown	N/A
Chaetodontidae	*Prognathodes guyanensis* (Durand, 1960)	Mesophotic	Reef	Collected / Photo / ROV	CIUFES 3959 / Fig. 4	WA	LC
Lutjanidae	*Lutjanus buccanella* (Cuvier, 1828)	Mesophotic	Rhodolith	Stereo-BRUVS	Fig. 4	WA	DD
Scorpaenidae	*Scorpaena* sp.	Mesophotic	Reef	Photo	Fig. 4	Unknown	N/A
Balistidae	*Balistes capriscus* Gmelin, 1789	Mesophotic	Rhodolith	Stereo-BRUVS	Fig. 3	AA / M	VU

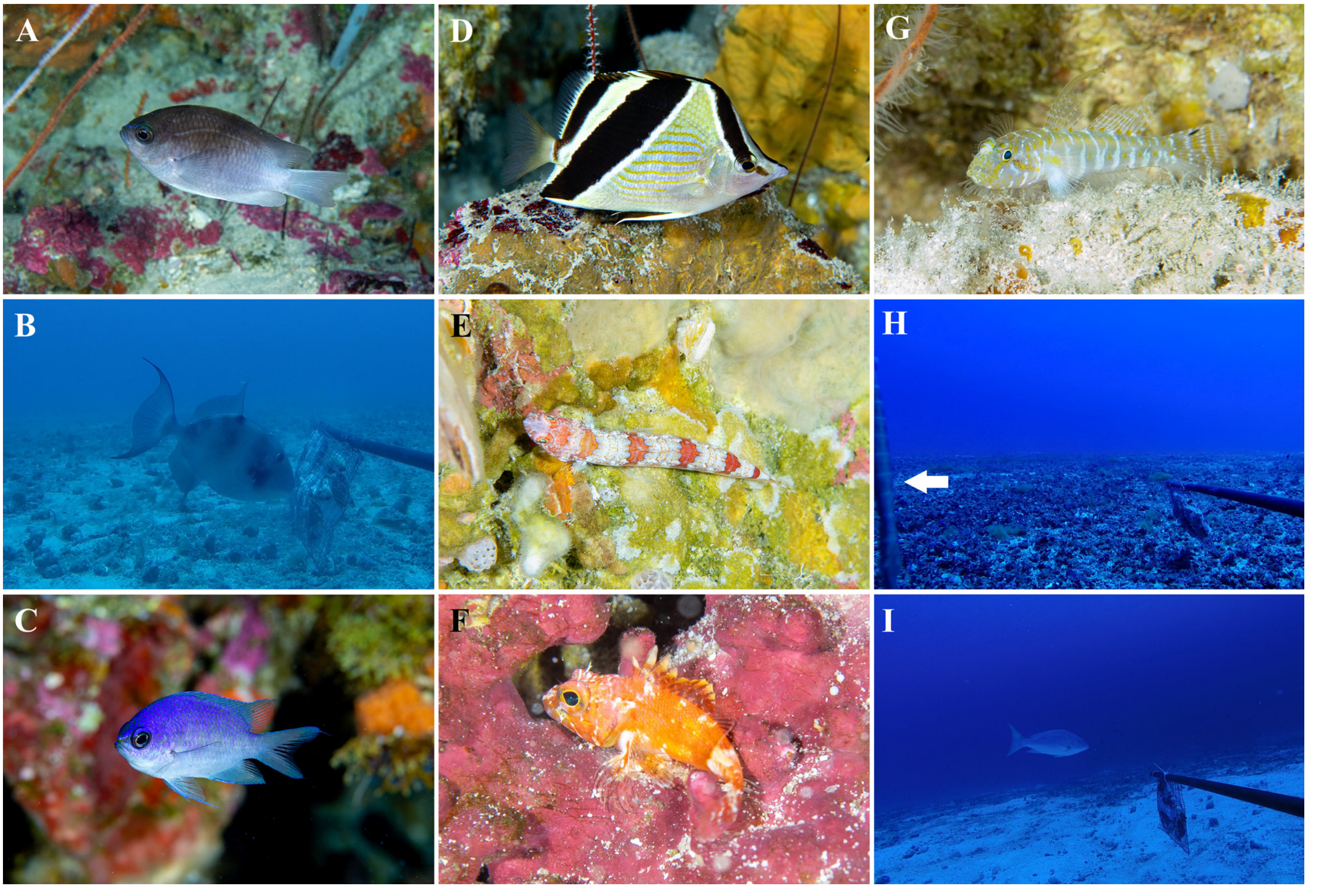

FIGURE 4 | New records of fishes at the mesophotic ecosystems. **A.** *Chromis enchrysura* (~ 10 cm total length); **B.** *Balistes capriscus* (~ 30 cm total length); **C.** *Chromis scotti* (~ 7.5 cm total length); **D.** *Prognathodes guyanensis* (~ 15 cm total length); **E.** *Synodus* sp. (~ 15 cm total length); **F.** *Scorpaena* sp. (~ 7.5 cm total length); **G.** *Psilotris* sp. (~ 5 cm total length); and **H.** *Cosmocampus profundus* (white arrow; ~ 15 cm total; *I. Lutjanus buccanella* (~ 50 cm total length). Photos by L. A. Rocha (**A**, **C**-**G**) and stereo-BRUVS (**B**, **H** and **I**). *Tosanoides* sp. is under description and its picture is not shown.

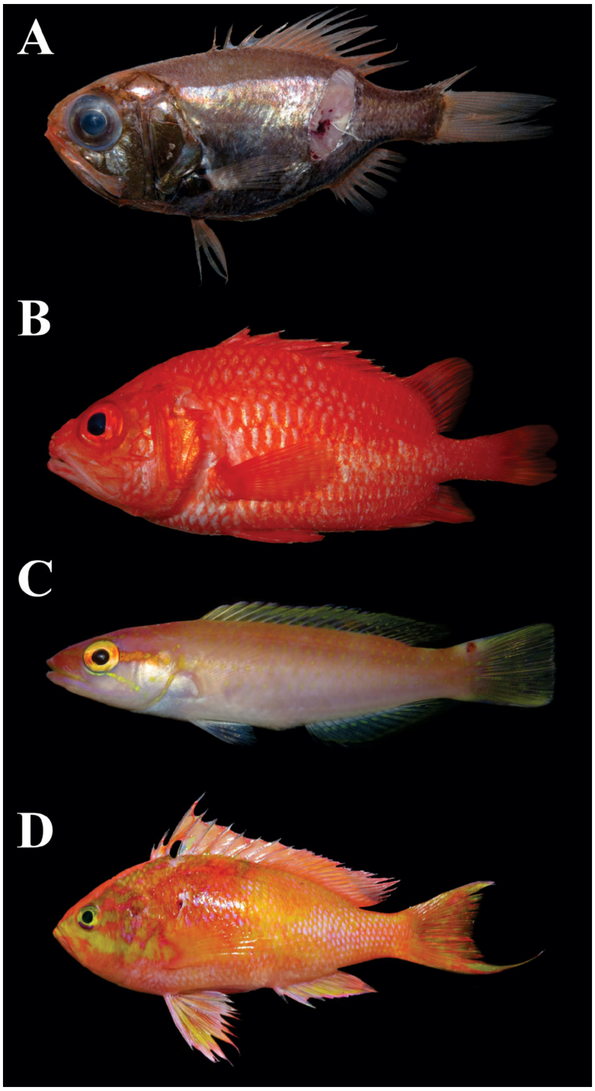

FIGURE 5 | New records of fishes from the mesophotic ecosystems collected and photographed in aquarium. **A.** *Aulotrachichthys argyrophanus* (~ 6.5 cm total length; CIUFES 3909); **B.** *Corniger spinosus* (~ 15 cm total length; CIUFES 3922); **C.** *Decodon puellaris* (~ 7.5 cm total length; CIUFES 3914); and **D.** *Pronotogrammus martinicensis* (~ 20 cm total length; CIUFES 3939 / 3960). Photos by J. L. Gasparini.

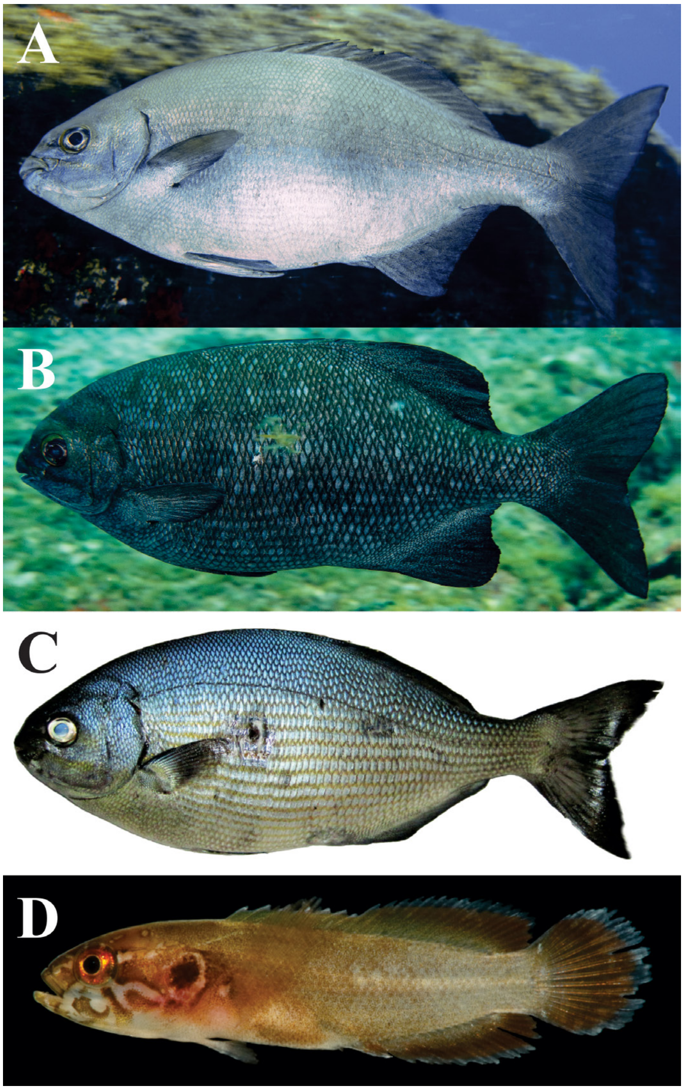

FIGURE 6 | New records of fishes from the euphotic ecosystems. **A.** *Kyphosus bigibbus* (~ 25 cm total length); **B.** *Kyphosus cinerascens* (~ 25 cm total length); **C.** *Kyphosus vaigiensis* (~ 25 cm total length; CIUFES 4050); and **D.** *Pseudogramma gregoryi* (~ 6.5 cm total length; CIUFES 4029). Photos **A**, **B** and **C** by J. L. Gasparini and photo **D** by R. M. Macieira. *Apogon pseudomaculatus* (CIUFES 3957) is not shown.

DISCUSSION

Fernando de Noronha Archipelago harbours the greatest richness of marine fish among the oceanic islands of the South Atlantic (Floeter *et al*., 2008; Pinheiro *et al*., 2018a). The 19 new records presented here represent an increase of 8.2% in its marine ichthyofauna, now composed of 250 species and 77 families. Fernando de Noronha Archipelago is now between 22% and 36% richer, in fishes, than Trindade Island, Santa Helena Island, Ascension Island, Rocas Atoll and St. Paul's Archipelago (see Wirtz *et al*., 2017; Pinheiro *et al*., 2018a, 2020; Brown *et al*., 2019). This higher fish richness is probably related to FN being the largest and oldest island, situated relatively close to the continental shore, and being the most studied oceanic island in Brazil.

Even though we have also explored shallow ecosystems, this is the first systematic survey of the fish biodiversity of FN mesophotic ecosystems. Despite the logistical difficulties and risks associated with this type of exploration, our effort was rewarded as most of the new records (74%) came from the mesophotic ecosystems. In fact, we still know very little about mesophotic reefs in comparison to shallow ones, albeit they represent about 80% of the potential reef habitat worldwide (Pyle, Copus, 2019). Although they have been considered potential refuges for shallow water organisms and less susceptible to human and natural impacts, mesophotic reefs are increasingly being recognized as unique ecosystems, home to largely distinct and independent communities that are also impacted and in need of protection as much as shallow reefs (Rocha *et al*., 2018; Pyle, Copus, 2019). As reported elsewhere (Rocha *et al*., 2018), we found plastic trash and fishing debris (in 6% and 18% of the visual censuses, respectively) in mesophotic ecosystems explored around FN (Fig. 7), evidence of human impacts, which are even more noticeable in the intertidal and shallow ecosystems. Despite an island-wide ban on single use plastics (Pernambuco, 2018) and the presence of a program to eliminate plastic bags from the island, most of the goods that can be obtained in stores come wrapped in plastic.

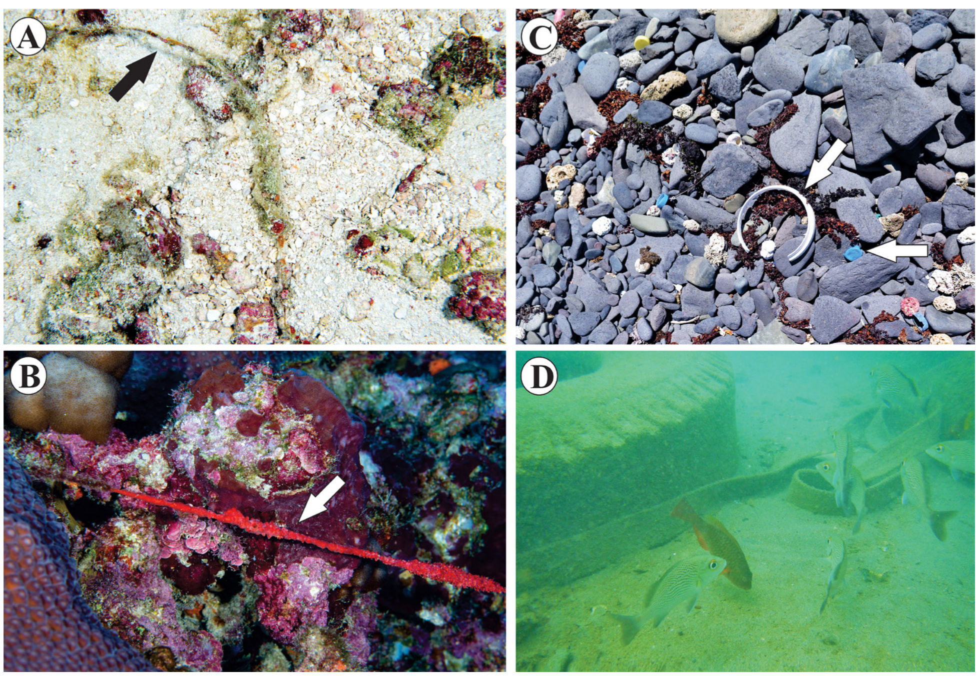

FIGURE 7 | Evidence of human impacts (arrows) by fishing debris, plastics and other trash found in the ecosystems explored around the Fernando de Noronha Archipelago. **A.** and **B.** Mesophotic (> 30 m deep); **C.** Intertidal; and **D.** Shallow ecosystems (≤ 30 m deep). Photos **A** and **B** by L. A. Rocha and photos **C** and **D** by J. L. Gasparini.

Several studies addressing the diversity, biology and ecology of the shallow water fish assemblages of FN have been carried out (*e.g*., Krajewski, Floeter, 2011; Ilarri *et al*., 2017). However, even for the relatively well explored euphotic zone, we obtained new records such as *Apogon pseudomaculatus* Longley, 1932 and *Pseudogramma gregoryi* (Breder, 1927) (Tab. 1), reinforcing the need for further studies and a better understanding of the local cryptobenthic fish diversity. Currently, the cryptobenthic fishes represent only about 17% (~ 42 species) of the ichthyofauna of FN. Due to its small size and cryptic behaviour, most cryptobenthic fishes cannot be properly accessed by standard technics (*e.g*., underwater visual censuses and videos). Thus, in order to increase our knowledge of this hidden fish diversity, the scientific use of anaesthetics to collect specimens should be promoted (Collette *et al*., 2003; Williams *et al*., 2010). The importance of these underestimated assemblages of cryptobenthic fishes goes far beyond diversity. In a recent study, Brandl *et al.* (2019) showed that through their extraordinary larval dynamics, rapid growth, and extreme mortality, the hyperdiverse assemblages of abundant, small, and short-lived cryptobenthic species appear to be a critical functional group on the trophodynamics of coral reefs.

Regarding the species registered in the mesophotic ecosystems, we emphasize that this is only the second record of the genus *Tosanoides* for the Atlantic Ocean, with a new species previously recorded on mesophotic reefs of St. Paul's Archipelago (Pinheiro *et al*., 2018b). The present record corroborates the hypothesis that this genus is probably widely distributed in peripheral Atlantic sites (Pinheiro *et al*., 2018b). Differences in colour pattern suggest *Tosanoides* sp. from FN might be a new species, different from *Tosanoides aphrodite* Pinheiro, Rocha & Rocha, 2018, and genetic analyses are being carried out to confirm the species identity. Similarly, *Aulotrachichthys argyrophanus* (Woods, 1961) was previously known only from the type locality in the Southwest Atlantic, on the continental shelf slope off the Amazon River mouth, northern Brazil (Froese, Pauly, 2019; Moore, 2019). Finally, *Cosmocampus profundus* (Herald, 1965) is for the first time recorded in Brazil, previously known to occur only from eastern Florida to south Caribbean (Robertson, Van Tassell, 2019).

Another curious new record is the common *B. capriscus*, an amphi-Atlantic species widespread in the Atlantic Ocean (Liu *et al*., 2015; Froese, Pauly, 2019), which is also present at Trindade Island (Miranda Ribeiro, 1919) and St. Paul's Archipelago (Pinheiro *et al*., 2020). At FN and St. Paul's Archipelago, the species has been observed several times in groups of up to four individuals. In contrast, the only record of this species on Trindade Island dates from 1916, when one individual was collected during a scientific expedition by the National Museum of Rio de Janeiro (Miranda-Ribeiro, 1919). All recent extensive samplings around Trindade, in both euphotic and mesophotic ecosystems, including the use of technical dive (Pereira-Filho *et al*., 2011) and BRUVS (Pimentel *et al*., 2020), yielded no record for this species. New records of common and large fishes such as *B. capriscus* may result from the attractiveness of the BRUVS bait and sampling in the mesophotic ecosystems, however this does not appear to be the case here. Alternatively, this could represent a recent colonization and successful establishment in these oceanic islands (*e.g*., Mazzei *et al*., 2019). These observations involving colonization, establishment and extinction are in accordance with the Theory of Island Biogeography (*e.g*., Pinheiro *et al*., 2017), representing the main drivers balancing island diversity.

Other probable new species include *Psilotris* sp., *Scorpaena* sp. and *Synodus* sp., which have been only photographed. The goby resembles a *Psilotris* species (Luke Tornabene, 2020, pers. comm.), both in colour/appearance and in meristics: VII, 10 dorsal fin spines, with no visible scales and split pelvic fins. *Psilotris* sp. is closest in appearance to *Psilotris kaufmani* Greenfield, Findley & Johnson, 1993, but differs from it in having a unique body coloration, and not having a dark upper pectoral fin. The scorpaenid seems to belong to the genus *Scorpaena* (Alfredo Carvalho-Filho, 2020, pers. comm.) because the specimen has several pectoral fin rays well branched, especially the lower ones, whereas species of *Pontinus* have all rays unbranched. This *Scorpaena* sp. is different from the undescribed St. Paul's Archipelago species (Feitoza *et al*., 2003; CIUFES 0349), which has a snout larger than the eye. The synodontid is different from all other species occurring in Brazil (Alfredo Carvalho-Filho, 2020, pers. comm.). It differs from *Synodus synodus* (Linnaeus, 1758) in not having a characteristic black spot at the tip of the snout; from *Synodus intermedius* (Spix & Agassiz, 1829) and *Synodus macrostigmus* Frable, Luther & Baldwin, 2013 in not having a dark spot at upper right corner of the operculum; and from *Synodus poeyi* Jordan, 1887 in overall coloration, the latter being bluish. Therefore, these three species are likely undescribed. Considering that four possible new species were disclosed in two hours of exploration of the lower mesophotic ecosystems (four divers with an average of 30 min each), the discovery rate herein reported is of two new species per hour, which is consistent with recent findings in other unexplored mesophotic ecosystems of the world (Pinheiro *et al*., 2019; Pyle *et al*., 2019).

Here we have shown that the mesophotic ecosystems and the shallow cryptobenthic ichthyofauna need to be better studied, even in well-studied oceanic islands such as FN. We emphasize the need for protection of the mesophotic ecosystems of FN, looking for ways to conciliate activities such as fishing and tourism, with the preservation of the unique biodiversity and ecosystems found at mesophotic depths. As with shallow reefs, significant progress in the conservation of mesophotic ecosystems of FN could be reached by expanding the no-take zone of the Marine National Park beyond the 50 m isobath, or by creating some fishing exclusion zones inside the sustainable use MPA (Araújo, Bernard, 2016).

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ETHICAL STATEMENT

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COMPETING INTERESTS

The authors declare no competing interests.

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