UNIVERSIDADE FEDERAL DO ESPÍRITO SANTO
CENTRO DE CIÊNCIAS HUMANAS E NATURAIS
DEPARTAMENTO DE OCEANOGRAFIA E ECOLOGIA
PROGRAMA DE PÓS-GRADUAÇÃO EM OCEANOGRAFIA AMBIENTAL

UM PONTO DE ESPERANÇA NA CONSERVAÇÃO DOS PEIXES NO MONUMENTO NATURAL DAS ILHAS CAGARRAS E ÁGUAS DO ENTORNO/RJ

Augusto Alves Machado

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Tese apresentada ao Programa de Pós-Graduação em Oceanografia Ambiental da Universidade Federal do Espírito Santo, como requisito parcial para obtenção do título de Doutor em Oceanografia ambiental.

Orientador: Maurício Hostim-Silva
Coorientador: Áthila Bertoncini Andrade

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"Bem-aventurada aquela que acreditou, porque
será cumprido o que o senhor lhe prometeu"
(Lc 1,45)

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Resumo

Áreas marinhas protegidas são espaços delimitados por lei que visam a conservação dos ambientes marinhos e dos seus serviços ecossistêmicos. Nesse contexto, o Monumento Natural das Ilhas Cagarras (MONA Cagarras) é uma unidade de conservação de proteção integral localizada na cidade do Rio de Janeiro, RJ. Devido a sua valiosa riqueza de espécies e abundância, as Ilhas Cagarras e as águas do entorno foram reconhecidas como um *Hope Spot* (Ponto de Esperança) para a conservação marinha mundial. Dentre as formas de vida dessa região, os peixes são componentes essenciais nas cadeias tróficas marinhas tropicais, sendo importantes na dispersão de nutrientes e no provimento de alimento e renda para milhões de pessoas no mundo. Apesar da sua relevância, a fauna de peixes do MONA Cagarras vem sofrendo com severos impactos, como a poluição, sobrepesca, o lixo marinho, dispersão de espécies invasoras e outros. Diante disso, esta tese teve o objetivo de avaliar os efeitos do MONA Cagarras na conservação da fauna de peixes. Neste estudo, durante os anos de 2020 e 2022, foram realizadas amostragens das comunidades de peixes, o lixo marinho, e das espécies não nativas no MONA Cagarras e nas ilhas do entorno por meio de técnicas não destrutivas. Neste período, foram realizados 576 censos visuais (UVC) e 288 videos rotacionais subaquáticos (SRV) dentro e fora da área protegida. Deste modo, este estudo registrou por meio das amostragens em campo, revisão bibliográfica e dados de desembarque pesqueiro mais de 282 espécies de peixes, incluindo mais de 21 novos registros para a área. Desse total, cerca de 6% são endêmicas da província brasileira e 10,5% se encontram em alguma das categorias de ameaça da IUCN. Além disso, os resultados destacaram o plástico como uma das principais ameaças a saúde da fauna de peixes tendo sido a principal categoria encontrada na região. Esse estudo ainda levantou cerca de 15 espécies não nativas, incluindo quatro novos registros para a área de estudo. Dentre elas, o Coral-sol foi amplamente reportado nas ilhas amostradas e com indícios de estar causando efeitos negativos na comunidade de peixes recifais. No entanto, mesmo diante desse cenário, os valores medianos de riqueza de espécies (8,0 – SRV / 12,0 - UVC) e densidade (70,74 indivíduos por 100m² - SRV) de peixes dentro do MONA Cagarras foram superiores comparando com as ilhas do entorno. O reconhecimento como *Hope Spot* por si só, não será o suficiente para proteção dessa área, sendo necessário um trabalho em conjunto de gestores com os diferentes atores sociais visando a mitigação dos impactos negativos. Por fim, é esperado que os resultados dessa tese contribuam na melhoria da qualidade ambiental do MONA Cagarras e que este se torne mais conhecido e valorizado por todas e todos.

Palavras-chaves: Peixes recifais; Hope spots; área marinha protegida; MONA Cagarras; técnicas não-destrutivas;

Abstract

Marine protected areas are legally designated spaces that aim to conserve marine environment and its ecosystems services. In this context, the Cagarras Islands Natural Monument (MONA Cagarras) is a no-take zone located at Rio de Janeiro City, RJ. Due to their high species richness and abundance, the Cagarras Islands and the surrounding waters were recognized as a *Hope Spot* for global marine conservation. Among the forms of life in this region, fish are essential components in tropical marine trophic food web, being important in the dispersion of nutrients and providing food and income for millions of people worldwide. Despite its relevance, the fish fauna of MONA Cagarras has been suffering from severe impacts, such as pollution, overfishing, marine litter, dispersion of invasive species and others. In light of this, the present thesis aimed to evaluate the effects of MONA Cagarras on the conservation of fish fauna. In this study, during the years 2020 and 2022, were carried out samplings on fish communities, marine litter, and non-native species in MONA Cagarras and the surrounding islands using non-destructive techniques. During this period, 576 Underwater Visual Censuses (UVC) and 288 Submersible Rotating Videos (SRV) were carried out inside and outside of the protected areas. In this way, this study recorded through field sampling, bibliographic review and fishing landing data more than 282 fish species, including more than 21 new records for this area. From this total, about the 6% are endemic to the Brazilian province and 10.5% are in one of the IUCN threatened categories. Furthermore, the results highlighted plastic as one of the main threats to the health of fish fauna, being the main category encountered in the region. This study also identified about 15 non-native species, including four new records for the study area. Among them, the Sun Coral was widely reported on the sampled islands and with evidence of causing negative effects on the reef fish community. However, even in this scenario, the median values of fish richness (8,0 – SRV / 12,0 - UVC) and density (70,74 individuals per 100m² - SRV) within MONA Cagarras were higher when compared to the surrounding islands. The Hope Spot recognition itself will not be enough to protect this area, it is necessary to work together between the management of MONA Cagarras and different stakeholders to mitigate negative impacts. Finally, it is expected that the results of this thesis will contribute to improving the environmental quality of MONA Cagarras and that it will become better known and valued by everyone.

Keywords: reef fishes; Hope spots; marine protect area; MONA Cagarras; non-destructive techniques.

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LISTA DE SIGLAS

Águas Centrais do Atlântico Sul...ACAS

Áreas Marinhas Protegidas..AMP

Baited Remote Underwater Video – *Video Subaquático Remoto Iscado*…........................BRUV

Convenção da Diversidade Biológica ....CDB

Diver-operated vídeo – *Vídeo Operado por Mergulhador* ....DOV

Instituto Mar Adentro..IMA

International Union for Conservation of Nature..IUCN

Ministério do Meio Ambiente...MMA

Monumento Natural das Ilhas Cagarras...MONA Cagarras

Objetivos de Desenvolvimentos Sustentável...ODS

Organização das Nações Unidas...ONU

Parque Nacional Marinho...PANAMAR

Pesquisas Ecológicas de Longa Duração...PELD

Projeto Ilhas do Rio...PIR

Plano Nacional do Meio Ambiente..PNMA

Sistema Nacional do Meio Ambiente..SISNAMA

Sistema Nacional de Unidade de Conservação...SNUC

Submersible Rotating Video – *Video Rotacional Subaquático*...SRV

Underwater Visual Census - *Censo Visual Subaquático*..UVC

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1. Introdução Geral:

1.1. Conservação da biodiversidade

Durante os últimos dois séculos da vida no planeta Terra, os seres humanos têm acompanhado de perto as ações humanas tornando-se uma força global e atuando diretamente nas mudanças ambientais (Crutzen, 2002; Steffen et al., 2015). O debate científico acerca dos efeitos negativos sofridos pelo planeta no Antropoceno (desde 1800), em especial sobre a capacidade humana de causar impactos consideráveis na saúde ambiental (Dirzo et al., 2014), tem alertado os tomadores de decisão sobre a necessidade de mudanças urgentes na direção do desenvolvimento das nações. Nessa perspectiva, lideranças mundiais vêm se reunindo ao longo dos anos para avaliar as condições ambientais do planeta e elaborar acordos a serem seguidos pelos signatários nos anos seguintes (Kim, 2013; Gomar et al., 2016).

Dentre os acordos firmados, a Convenção da Diversidade Biológica (CDB) configurou-se como um dos mais importantes instrumentos internacionais criado pela Organização das Nações Unidas (ONU), assinado por mais de 160 países durante a ECO-92 - Conferência das Nações Unidas sobre Meio Ambiente e Desenvolvimento. Esse tratado se baseou na conservação da biodiversidade e na repartição justa e igualitária dos benefícios provenientes do uso dos recursos genéticos, levando em consideração a necessidade do seu uso sustentável (www.cbd.int). Além disso, no ano de 2015 a ONU propôs aos seus países membros uma nova agenda mundial (Agenda 2030) contendo 17 Objetivos de Desenvolvimento Sustentável (ODS). Essa iniciativa surge como um plano de ação que visa a melhoria da qualidade da vida humana e do planeta nos 15 anos subsequentes, tendo a conservação da vida na água (ODS 14) e na terra (15) dentro das prioridades globais a serem adotadas (https://www.pactoglobal.org.br/ods).

Diante dos desafios crescentes que ameaçam o oceano, a ONU, em consonância com seus países filiados, proclamou no ano de 2017 que o período entre 2021 e 2030, conhecido como a "Década do Oceano", seria destinado à construção de uma estrutura para fortalecer a ciência oceânica (https://www.unesco.org/en/decades/ocean-decade). Essa medida teve como finalidade oferecer apoio aos países no cumprimento dos objetivos estabelecidos pela Agenda 2030, proporcionando oportunidades para criar uma conexão entre a ciência e a política, a fim de fortalecer a gestão do oceano e proteger a diversidade da vida marinha (Diederichsen et al., 2024). A Década do Oceano emerge então como uma valiosa ferramenta para reforçar a importância do oceano para a vida no planeta, além de ressaltar a necessidade de intensificar a sua proteção. Atualmente, cerca de 8,16% do oceano tem algum nível de proteção de acordo com a Base de Dados Mundial sobre Áreas Protegidas (https://protectedplanet.net/) e apenas 2,9% é totalmente protegido das atividades extrativistas (https://mpatlas.org/).

Seguindo nessa direção, em 2021 o secretariado da CDB apresentou uma nova estrutura focada na proteção dos ambientes naturais e da sua biodiversidade, composta por 23 metas a serem alcançadas até 2030. Entre elas, está a necessidade de planejamento e gestão de todas as áreas para reduzir a perda da biodiversidade (Meta 1), incluindo uma maior atenção às espécies sob forte pressão antrópica e que se encontram ameaçadas (Meta 4), ou seja, com risco iminente de desaparecerem do planeta (https://www.cbd.int/gbf/targets/). Em suma, ao longo das últimas décadas, essas conferências internacionais têm proporcionado a formação de fóruns fundamentais para a discussão das políticas ambientais em escala global, potencializando a cooperação entre os países e o enfrentamento local através da criação de leis efetivas para orientar o desenvolvimento econômico, social e ambiental das nações.

1.2. Breve histórico da política ambiental brasileira na proteção da biodiversidade

A política ambiental brasileira começou a ganhar espaço, ainda que de forma tímida, em meados da década de 1930 com a elaboração dos instrumentos normativos "Códigos de Águas e do Código Florestal", ambos implementados em 1934. Nesse momento, o Brasil ainda não era dotado de uma instituição gestora do meio ambiente propriamente dita, mas apresentava políticas setoriais que abrangiam a sua proteção visando o uso controlado dos recursos naturais (De Moura, 2016). O "Código de Águas", instituído por meio do decreto nº 24.643 (1934), reforça no seu artigo 42 o papel dos entes da União de legislar sobre os bens de propriedade federal, incluindo a regulação das atividades extrativistas (e.g. Caça e Pesca).

A partir de 1937, o Brasil deu início à implementação de uma política para a criação de áreas ambientalmente protegidas, tendo como ponto de partida o estabelecimento do Parque Nacional de Itatiaia/RJ. Embora a iniciativa de delimitar áreas protegidas tenha se originado na primeira metade do século XX, somente 42 anos depois (1979) surgiu a primeira Unidade de Conservação (UC) marinha com a criação da Reserva Biológica Atol das Rocas. O primeiro Parque Nacional Marinho (PARNAMAR) foi estabelecido apenas em 1983, O PARNAMAR dos Abrolhos localizado no sul da Bahia que abriga o maior banco de corais do Atlântico Sul e serve de berçário para baleias Jubartes (https://www.icmbio.gov.br/parnaabrolhos/).

Ainda na Década de 1980, ocorreu o estabelecimento da Política Nacional do Meio Ambiente (PNMA) por meio da lei nº 6.938/81. Esse dispositivo legal foi responsável pela criação do Sistema Nacional do Meio Ambiente (SISNAMA) promovendo diretrizes e atribuições para os entes da federação na gestão de políticas ambientais no território brasileiro. Dentre as normas aprovadas por esta lei, a organização institucional, o controle da degradação ambiental e a necessidade de fortalecimento da participação da sociedade surgiram como pontos chaves na construção dessa política pública (Araújo, 2013). No final da década de 1980, o movimento ambiental ganhou mais força com a inclusão do capítulo VI (art. 225) sobre o Meio Ambiente na Constituição Federal de 1988. Em meio às atribuições do poder público conforme este capítulo, destacam-se os papéis de 'preservar e restaurar os processos ecológicos essenciais' (Inciso I), bem como a preservação da diversidade, incluindo a integridade do patrimônio genético (Inciso II), e a proteção da fauna e flora, impedindo qualquer atividade que coloque em risco a extinção de espécies (Inciso VII). Esses aspectos emergiram como cruciais na conservação dos ambientes naturais e na promoção da manutenção da diversidade biológica.

No final do século XX, o Brasil se torna um dos poucos países no mundo a instituir um direito penal ambiental (De Moura, 2016), por meio da criação e da implementação da Lei de Crimes Ambientais (Lei nº 9.605/98). Esse instrumento legal dispõe sobre as punições penais e/ou administrativas aplicáveis a condutas lesivas ao meio ambiente, como o lançamento de resíduos ou detritos de qualquer natureza que possam causar dano à fauna e flora (art. 54), abrangendo também a introdução de espécies não nativas (art. 31). Além disso, estão incluídas a realização de atividades extrativistas em ambientes aquáticos não autorizadas ou com técnicas insustentáveis (art. 34 e 35). Outro avanço desse período, foi a regulamentação das UCs com a criação do Sistema Nacional de Unidade de Conservação (SNUC) por meio da Lei 9.985 de 2000.

O SNUC veio abranger um conjunto de categorias de áreas protegidas que podem ser classificadas como UC de Proteção Integral ou de Uso sustentável (https://www.planalto.gov.br/ccivil_03/leis/l9985.htm). Destacam-se entre as primeiras a Estação Ecológica, Reserva Biológica, Parque Nacional, Monumento Natural e o Refúgio de Vida Silvestre, que têm o objetivo de preservar a natureza, permitindo uso indireto dos recursos naturais e, dessa forma, apresentam regras restritivas. Já as UCs de Uso Sustentável têm como propósito conciliar a conservação da natureza com o uso moderado de parte dos recursos naturais (e.g. Área de Proteção Ambiental, Reserva Extrativista, Floresta Nacional, entre outras). Dessa forma, a regulamentação das UCs, aliada à integração na política de proteção tanto para áreas terrestres quanto marinhas, tem proporcionado a criação de estratégias de conservação da biodiversidade, resguardando ecossistemas fundamentais para o equilibro ecológico global.

1.3. Áreas Marinhas Protegidas

Ao longo das últimas décadas, os efeitos das atividades antrópicas têm se tornado cada vez mais evidentes em todo o mundo, especialmente nas áreas costeiras próximas a grandes centros urbanos (Halpern et al., 2008; Carneiro et al., 2021). Com o objetivo de mitigar os efeitos negativos causados pelos seres humanos nos ecossistemas marinhos (e.g. Pesca e turismo desordenado) e proteger a sua biodiversidade, os tomadores de decisão têm utilizado a implementação de Áreas Marinhas Protegidas (AMPs) como uma ferramenta estratégica para salvaguardar os recursos marinhos (Edgar et al., 2014; Blowes et al., 2020).

As AMPs são espaços delimitados por lei e que têm adotado uma estratégia de proteção focada na eliminação total ou restrição parcial das atividades com potencial para causar danos aos ecossistemas (Fenberg et al., 2012; Mumby and Harborne, 2010). Estudos anteriores evidenciam diversos benefícios associados à implementação de AMPs, como a crescente produção de ovos e larvas de organismos (Félix-Hackradt et al., 2018), o aumento da biomassa e abundância (Claudet et al., 2010; Rolim et al., 2022), o transbordamento (*Spillover*) da biomassa para áreas adjacentes (Harmelin-Vivien et al., 2008) e a melhoria da resiliência ecológica dentro dos seus limites (Barnett e Baskett, 2015). Ademais, as AMPs são locais valiosos para o desenvolvimento de pesquisa cientifica, auxiliando os tomadores de decisão na formulação de medidas de conservação e de promoção de atividades de educação ambiental que destaquem a importância desses ambientes para a saúde do planeta (Abbad et al., 2022).

No Brasil, as AMPs vêm sendo implementadas desde o final do Século XX e, desde então, têm se expandido ao longo do litoral brasileiro. Atualmente, as áreas marinhas brasileiras contam com 190 unidades de conservação, protegendo cerca de 26,5% do bioma marinho, sendo apenas 2,5% de proteção integral (MMA, 2021). Apesar desse expressivo percentual de proteção dentro das suas zonas marinhas, ainda persistem consideráveis desafios na preservação das espécies ameaçadas de extinção (Vilar e Joyeux, 2021). Diante disso, a cooperação entre os gestores ambientais das AMPs junto a outras partes interessadas, através da formação dos conselhos consultivos, tem se mostrado uma estratégia de gestão positiva em UCs brasileiras (Laurino et al., 2024). Dentre as competências dos gestores ambientais, inclui-se o acompanhamento da elaboração, implementação e revisão do plano de manejo, bem como a busca por compatibilizar os diferentes interesses levando em consideração a conservação do meio ambiente, sobretudo em UCs de proteção integral, como tem sido o caso do Monumento Natural das Ilhas Cagarras.

1.4. Monumento Natural das Ilhas Cagarras

O Monumento Natural das Ilhas Cagarras (MONA Cagarras) é uma UC de proteção integral, instituída pela Lei 12.229/2010, com o propósito de “preservar remanescentes do ecossistema insular do domínio da Mata Atlântica; as belezas cênicas e servir como área de refúgio e nidificação de aves marinhas”. O MONA Cagarras está localizado na cidade do Rio de Janeiro, a cerca de 5km da praia de Ipanema, e abrange uma área de 91,23 hectares, onde estão inseridas as Ilhas Cagarra, Palmas, Comprida, Redonda e duas ilhotas (Filhotes da Cagarra e da Redonda), além da área marinha de 10 metros (m) no entorno de cada ilha (ICMBio, 2020).

O MONA Cagarras conta com o apoio de um Conselho Consultivo composto por diferentes atores sociais, tais como pesquisadores, representantes de associações locais, agentes do governo, membros de instituições não governamentais, entre outros que auxiliam a gestão nas tomadas de decisão (ICMBio, 2020). A partir das oficinas organizadas pelos gestores, foram elaborados diversos instrumentos normativos visando ordenar, informar e direcionar as atividades dentro e no entorno do MONA Cagarras, como os Planos de Manejo, Uso Público, Pesquisa, e o plano de Prevenção, Controle, Erradicação e Monitoramento de Espécies Exóticas Invasoras e outros (ICMBio, 2020, 2021a,b,c). Atualmente, toda atividade extrativista biológica está proibida dentro do limite de 10 m de cada uma das ilhas, bem como a pesca industrial ou artesanal com rede de arrasto, emalhe ou cerco em um raio de 200 m das ilhas protegidas (Fig.1). Outras restrições incluem a proibição do fundeio até uma distância de 30 m, o tráfego de embarcações de grande porte (>24 m) e todo tipo de molestamento à fauna em toda a UC.

Figura 1. Infográfico apresentando algumas restrições dentro e no entorno do MONA Cagarras. Fonte: IMA, 2022.

O litoral fluminense onde estão inseridos o MONA Cagarras e ilhas do entorno (entre 43º35'W - 42º09'W; 23º01'S - 22º09'S) está localizado em uma região sob forte influência de duas importantes massas de água. A Corrente do Brasil, que está associada ao giro subtropical do Atlântico Sul, é formada a 10ºS da linha do Equador e segue margeando na plataforma continental brasileira para o sul até a região de convergência subtropical (33-38ºS), onde encontra a corrente das Malvinas e se separa da costa (Silveira et al., 2000). A Corrente do Brasil é formada por meio do empilhamento de massas de água características do Atlântico Sul, como as Águas Tropicais que apresentam aproximadamente temperaturas maiores que 20ºC e salinidade acima de 36 no sudeste brasileiro (Emilson, 1961).

Somando a isso, o MONA Cagarras recebe, principalmente entre setembro e março, a influência das Águas Centrais do Atlântico Sul (ACAS) formada na região de convergência subtropical que é caracterizada com temperaturas variando de 6-20ºC e salinidade 34,6-36

(Silveira et al., 2000). No Rio de Janeiro, a ACAS surge como resultado da ressurgência costeira, atribuída à intensidade e ao padrão dos ventos regionais (e.g. nordeste e leste) em direção à linha da costa (Oliveira, et al., 2015). Esse fenômeno resulta no aumento da estratificação na coluna d'água e da diversidade biológica local (Castro et al., 2005; Villac e Tenenbaum, 2010).

1.5. Biodiversidade marinha do MONA Cagarras e das águas do entorno

Os recifes rochosos presentes no MONA Cagarras apresentam regiões de alta, média e baixa declividade, variando principalmente entre 20º e 50º (De Araujo et al., 2019). Essa região abriga uma ampla diversidade de fauna e flora marinha (Moraes et al., 2013), que inclui grupos de invertebrados, tais como esponjas-marinhas, corais, moluscos, crustáceos e equinodermos, bem como vertebrados, como os peixes, as tartarugas e as aves-marinhas, que encontram neste ecossistema uma área para refúgio, nidificação e alimentação (Bertoncini et al., 2019; ICMBio, 2021a). Além disso, as águas do entorno do MONA Cagarras frequentemente recebem a visita de golfinhos e baleias, que utilizam essa região para socialização, rota de passagem, abrigo e alimentação (Lodi e Tardin, 2018; ICMBio, 2020).

Nas comunidades marinhas presentes no MONA Cagarras, a ictiofauna representa o grupo de vertebrados mais biodiverso, incluindo uma elevada riqueza de espécies associadas aos substratos rochosos ou arenosos, como também à coluna d'água (Monteiro-Neto et al., 2013; Bertoncini et al., 2019). Os peixes são elementos cruciais das comunidades marinhas tropicais, fornecendo alimento e fonte de renda para milhares de pessoas ao redor do mundo (Pauly et al., 2002; Nelson et al., 2016). Muitos desses organismos apresentam uma ampla interação com os ambientes recifais, especialmente em locais com alta complexidade e heterogeneidade, os quais fornecem áreas para refúgio e reprodução das espécies (Graham e Nash, 2013).

1.6. Peixes recifais

Os peixes recifais desempenham um papel fundamental nas teias tróficas tropicais marinhas, contribuindo para a ciclagem e dispersão de nutrientes ao longo dos recifes (Nunes et al., 2023). As comunidades de peixes recifais estão distribuídas sob a influência de múltiplos fatores, como a temperatura, profundidade, exposição às ondas e a complexidade bentônica (Gibran e Moura, 2012; Pinheiro et al., 2018). Além disso, a ictiofauna recifal tem sofrido com diversos efeitos negativos causados pelos seres humanos em todo o mundo (Kennedy et al., 2013), incluindo as mudanças climáticas que já tem contribuído para a perda da sua biodiversidade e redução da sua resiliência (Pandolfi et al., 2011; Hughes et al., 2017).

No Brasil, as comunidades de peixes recifais podem ser encontradas ao longo da costa, desde a foz do rio Amazonas, na região norte, até o litoral do estado de Santa Catarina, no Sul do país (Hostim-Silva et al., 2005; Moura et al., 2016), estendendo-se às ilhas oceânicas (Quimbayo et al., 2019; Pinheiro et al., 2020). Apesar disso, a estrutura trófica das assembleias de peixes recifais brasileiros varia de acordo com a latitude, podendo ser influenciada pela filogenia, características fisiológicas (e.g. temperatura) e impactos antrópicos (Ferreira et al., 2004; Floeter et al., 2007). Nesse contexto, ao longo dos últimos anos o número de estudos relacionados aos peixes recifais brasileiros vem aumentando, contribuindo com a identificação de novas espécies (Carvalho-Filho et al., 2020), as relações ecológicas entre as comunidades e os fatores ambientais (Gibran e Moura, 2019), efeitos da pesca e as mudanças no comportamento em virtude de ações humanas (Rolim et al., 2019; Pereira et al., 2020).

Os peixes recifais do MONA Cagarras e das águas do entorno têm sido amplamente estudados há quase duas décadas (Rangel et al., 2007; Monteiro-Neto et al., 2013; Bertoncini et al., 2019). Desde então, o número de novos registros tem aumentado significativamente ao longo dos anos, contando atualmente com mais de 280 espécies de peixes, incluindo um nível moderado de espécies endêmicas e espécies em categorias de ameaça de acordo com a lista vermelha da IUCN. Devido a sua diversidade biológica, bem como à sua importância cultural e histórica, o MONA Cagarras e as águas do entorno foram reconhecidos em 2021 como um *Hope Spot* (Ponto de esperança) para a conservação da biodiversidade marinha.

1.7. *Hope Spots* (Pontos de Esperança)

Os '*Hope spots*' são áreas singulares identificadas cientificamente como essenciais para a saúde dos Oceanos e reconhecidas pela organização internacional sem fins lucrativos Mission Blue. Esse reconhecimento é concedido a locais com uma considerável riqueza e abundância de espécies, presença de espécies raras, endêmicas ou ameaçadas de extinção, além de possuírem valores históricos, culturais ou espirituais (https://missionblue.org/hope-spots/). Esses locais despertam a atenção sobre a necessidade de ampliar a proteção dos oceanos e permitem planejar o futuro para além das atuais AMPs existentes e suas singelas medidas restritivas delimitadas.

Os pontos de esperança são locais que requerem uma proteção especial, embora em alguns deles ela já exista por meio de AMPs implementadas, mas que necessitam de mais ações de defesa desses ambientes. A organização Mission Blue tem o objetivo de inspirar ações de proteção aos oceanos, promovendo uma onda de conscientização que alcança a sociedade por meio de campanhas de comunicação, documentários e mídias sociais (https://missionblue.org/about/). Atualmente, existem no mundo 161 *Hope Spots*, distribuídos ao redor de todos os continentes e cobrindo mais de 57 milhões de km² de Oceano (https://missionblue.org/hope-spots/).

No Brasil, o reconhecimento 'Hope Spot' foi estabelecido pela primeira vez em 2017 no sul da Bahia, especificamente no banco dos Abrolhos. Essa região apresenta um mosaico de ecossistemas marinhos e costeiro, abrigando a maior biodiversidade marinha do Atlântico Sul.

Em 2021, os *Hope Spots* chegam ao litoral da cidade do Rio de Janeiro, abrangendo as Ilhas Cagarras e as águas do entorno (https://missionblue.org/hope-spots/). O mais recente '*Ponto de Esperança*' brasileiro enfrenta diversas ameaças que os ecossistemas marinhos frequentemente enfrentam quando localizados próximos a grandes centros urbanos densamente povoados, como a região metropolitana do Rio de Janeiro que concentra uma população de mais de 6,2 milhões de habitantes (IBGE, 2022). A área do Hope Spot localizado no Rio de Janeiro compreende uma pequena parte marinha protegida, enquanto as águas do entorno não apresentam ainda qualquer tipo de proteção, onde ocorrem livremente tráfego de embarcações, liberação de esgoto, atividades de pesca, entre outras atividades.

1.8. Desafios enfrentados pela vida marinha do MONA Cagarras

Devido à sua proximidade da costa e à beleza cênica que inclui uma variedade de atrativos naturais, o MONA Cagarras e as águas adjacentes são procurados por diferentes usuários que encontram nessa área um maior contato com a natureza (ICMBio, 2020). Essa região recebe regularmente uma ampla variedade de atividades de recreação e lazer, tais como natação, banho de mar, mergulho autônomo recreativo e livre, passeio embarcado, canoagem, *stand-up paddle* e escalada (ICMBio, 2021a). Além disso, nos arredores dos limites da AMP são realizadas atividades extrativistas, que envolvem a pesca amadora (recreativa e esportiva), a pesca artesanal e a industrial com redes de arrasto, emalhe e cerco (Moraes et al., 2013).

Apesar de toda a importância desta região, há desafios enfrentados diariamente devido à sua proximidade a uma grande metrópole, como a cidade do Rio de Janeiro. O MONA Cagarras e as águas do entorno estão sob forte influência dos impactos antrópicos, tanto terrestres quanto marinhos, tais como o lixo marinho, a visitação desordenada, a introdução de espécies alienígenas invasoras, a pesca indiscriminada, entre outros (ICMBio, 2020). Estudos que forneçam um diagnóstico dos efeitos causados por essas atividades já vêm sendo apontados como prioritários nos Planos de Manejo e Pesquisa do MONA Cagarras (ICMBio, 2020; ICMBio, 2021b). Dessa forma, é necessário fornecer dados que permitam aos tomadores de decisão elaborarem medidas que mitiguem as ações insustentáveis, visando à conservação marinha local.

O termo "lixo marinho" tem sido utilizado para qualquer material sólido persistente, fabricado ou processado que foi abandonado no ambiente costeiro e marinho (UNEP, 2021). Estudos anteriores têm relatado diferentes impactos negativos nas comunidades marinhas associados ao lixo mal descartado, como o emaranhamento e ingestão de detritos (Adimey et al., 2014), pesca fantasma (Link et al., 2019), danos ao habitat (Lewis et al., 2009) e dispersão de espécies invasoras (Mantelatto et al., 2020). A gestão do MONA Cagarras carece de iniciativas que promovam um diagnóstico do lixo e os seus impactos e reforça no Plano de Pesquisa a importância de pesquisas que revelem o panorama dos impactos sobre as comunidades marinhas, em especial os efeitos do lixo marinho e espécies invasoras na região.

A introdução de espécies não nativas e o descarte de lixo nos oceanos representam grandes ameaças para os ecossistemas marinhos (Bax, 2003; UNEP, 2011). As espécies invasoras, após se estabelecerem, apresentam capacidade de alterar a estrutura e o funcionamento dos ecossistemas, podendo causar a extinção de espécies nativas (Ruiz et al., 1997; Jeschke et al., 2012). No Brasil, o gênero *Tubastraea* spp., conhecido popularmente como Coral-sol, representa um exemplo de invasão biológica marinha bem-sucedida e está amplamente distribuído no sudeste brasileiro (Creed et al., 2017; Machado et al., 2021), incluindo no MONA Cagarras (Silva et al., 2022). Dentre os efeitos negativos que esse coral invasor tem ocasionado, destacam-se a necrose de corais endêmicos (e.g. *Mussismilia hispida*) e os danos causados nas comunidades de peixes (Creed, 2006; Lages et al., 2011; Miranda et al., 2018). Diante desse cenário, o monitoramento das comunidades marinhas sob essas ameaças, por meio de metodologias não letais, é crucial para a conservação da biodiversidade e fornecimento de informações que permitam elaborar medidas que levem a redução dos impactos.

1.9. Técnicas de amostragens não-destrutivas

Em busca de atenuar os danos ao meio ambiente, as metodologias de pesquisa não-letais têm sido mundialmente empregadas nas comunidades marinhas recifais, especialmente dentro de AMPs (Schmid et al., 2020; Rolim et al., 2022; Nalmpanti, et al., 2023). O Censo Visual Subaquático (UVC – *Underwater visual census*) representa um conjunto de técnicas amplamente utilizadas por pesquisadores em estudos ecológicos com peixes que não são afetados pela presença do mergulhador (Barneche et al., 2018; Motta et al., 2021). O UVC pode ser realizado por meio do censo estacionário (Bohnsack e Bannerot, 1986), através de transectos (Brock, 1954; Kimmel, 1985) ou com a busca intensiva (Jones e Thompson, 1978; Thompson e Mapstone, 1997). Esses métodos permitem realizar o levantamento da biodiversidade, estimar a densidade de peixes e detectar espécies não nativas (Willis, 2001; Adelir-Alves, 2018; Pereira et al., 2021).

De forma complementar ao UVC, o advento tecnológico das câmeras subaquáticas tem se mostrado uma ferramenta valiosa capaz registrar vídeos com alta definição, que podem ser armazenados por tempo indeterminado. Os vídeos subaquáticos têm sido empregados extensivamente nos estudos com peixes recifais (Mallet e Pelletier, 2014; Pinheiro et al., 2020), permitindo estimar a riqueza e a abundância da ictiofauna. Nesse contexto, o Vídeo Operado Por Mergulhador (DOV – *Diver-operated vídeo*) representa uma técnica eficaz contendo um sistema de vídeo (Alevizon e Brooks, 1975) guiado por mergulhador em uma determinada área, simulando um UVC, porém com capacidade de armazenar os registros para análises futuras.

Além disso, foram desenvolvidos aparatos de amostragem cabeados a uma boia na superfície, os quais são liberados de uma embarcação e permanecem submersos por um tempo definido, registrando imagens na ausência do mergulhador e, dessa forma, eliminando seus efeitos na fauna de peixes (Dickens et al., 2011). Os Vídeos Subaquáticos Remotos (RUV - *Remote Underwater Vídeo*) têm sido empregados com maior frequência nos estudos marinhos desde 1961, quando foram coletados os primeiros dados sobre o comportamento de peixes na ausência dos seres humanos (LaFond et al., 1961; Mallet e Pelletier, 2014). Desde então, o desenvolvimento tecnológico dos vídeos remotos tem visado atender as demandas científicas e de segurança dos pesquisadores, incluindo técnicas iscadas (BRUV - *Baited remote underwater vídeo*), com o objetivo de atrair determinados grupos tróficos (Ellis e DeMartini, 1995) e não iscadas por meio de câmeras fixas ou técnicas com vídeos rotacionais (LaFond et al., 1961; Koenig e Stallings, 2015).

O Vídeo Rotacional Subaquático (SRV - *submersible rotating video*) desenvolvido por Koenig e Stallings (2015), simula o renomado censo estacionário (Bohnsack e Bannerot, 1986). Essa técnica compreende um cilindro estanque que abriga internamente uma bateria ligada a um motor que realiza duas rotações por minuto (2-rpm). Uma câmera de alta definição (e.g. GoPro) é acoplada a esse sistema e liberado da embarcação para que atinja o fundo e permaneça gravando por um tempo determinado. Por fim, o equipamento é recolhido e, posteriormente, os vídeos são analisados no computador, fornecendo dados sobre a riqueza, abundância (incluindo o número máximo de indivíduos de uma mesma espécie por frame – Nmax). A técnica visual, permite ainda observar o comportamento das espécies, sem a interferência do mergulhador. O uso de metodologias não-letais, que incluem o censo visual realizado por mergulhadores ou por meio de vídeos, é ideal para o levantamento da biodiversidade e permite amostragens com uma redução na perturbação dos ecossistemas marinhos, em particular nas AMPs.

1.10. Organização da tese

O presente documento contém as seções fundamentais para a elaboração deste trabalho de finalização da pós-graduação em Oceanografia Ambiental – Nível doutorado – da Universidade Federal do Espírito Santo (UFES). A tese aqui apresentada está dividida em: Introdução geral (em português visando contextualizar o leitor sobre o tema abordado), seguida de três Capítulos em inglês no formato de artigos científicos (caps. 1 e 2 – já publicados em periódicos) e o terceiro a ser submetido à revista "*Biological Conservation*", considerações gerais relacionando os capítulos, e por fim, as conclusões obtidas através da elaboração dessa tese. Os capítulos encontrados no corpo do documento foram pensados buscando atender aos objetivos específicos expostos nos tópicos a seguir (pág. 12) e formatados nos padrões estabelecidos pelas revistas.

▸ **Capítulo 1 - Rocky reef fish biodiversity and conservation in a Brazilian Hope Spot region**
Publicado em: 14/Out/2022 no periódico **Neotropical Ichthyology**. https://doi.org/10.1590/1982-0224-2022-0032.

Neste trabalho foi realizado o levantamento da fauna de peixes das Ilhas costeiras do Rio de Janeiro, por meio de múltiplas fontes e técnicas (e.g. Revisão bibliográfica, Desembarque pesqueiro, Amostragens através de Censo visual subaquático, busca intensiva e vídeo rotacional subaquático, dentre outras...), bem como reportou a distribuição das espécies ao longo dos costões rochosos insulares costeiros da cidade do Rio de Janeiro e das ilhas do entorno.

▸ **Capítulo 2 - Rocky reef incursions: challenges faced by reef fishes in a Brazilian Hope Spot region.** Publicado em: 08/Jul/2023 na **Marine Pollution Bulletin**. https://doi.org/10.1016/j.marpolbul.2023.115240.

O presente capítulo/artigo buscou compreender os desafios enfrentados pela fauna de peixes das Ilhas costeiras do Rio de Janeiro e entorno. O esforço amostral foi realizado por meio de mergulho autônomo (SCUBA diving) em dois níveis de profundidade: Raso (0-10 m) e Fundo (> 10m). Foram identificados e categorizados o lixo marinho, e classificadas a abundância de *Tubastraea* spp. (Coral-sol) de acordo com a escala DAFOR (Sutherland, 2006), buscando compreender os seus efeitos sobre a fauna de peixes. Além disso, foram registradas a ocorrência e distribuição de espécies não-nativas na área de estudo, revelando três novos registros de espécies não nativas para a região.

▸ **Capítulo 3 - No-take zone in check: an ecological assessment of the management role in reef fish conservation in a Brazilian Hope Spot region.** A ser submetido ao periódico "Ocean and Coastal Management".

Este estudo buscou realizar o comparativo dos descritores ecológicos da ictiofauna (e.g. Riqueza e Densidade) entre as ilhas protegidas, próximas (< 10 km) e as ilhas distantes (> 10 km). Para realização deste trabalho foram levantados os dados de peixes por meio de duas técnicas, o Censo Visual Subaquático e o Vídeo Rotacional Subaquático em dois estratos de profundidade, o Raso (< 10 m) e o fundo (> 10 m). Além disso, a partir dos dados coletados foi registrada a distribuição das espécies ameaçadas ao longo das áreas amostrais, bem como espécies de interesse da pesca, reforçando a necessidade da proteção da fauna de peixes.

1.11. Objetivo geral

- Avaliar a estrutura da assembleia de peixes recifais, bem como analisar as ameaças e o efeito de proteção na ictiofauna da Unidade de Conservação insular de proteção integral, Monumento Natural das Ilhas Cagarras localizada na Cidade do Rio de Janeiro.

1.12. Objetivos específicos

- Realizar o levantamento da estrutura e composição da ictiofauna recifal utilizando métodos não destrutivos;
- Investigar e classificar a distribuição do lixo marinho e espécies não nativas ao longo das ilhas, bem como correlacionar com dados de riqueza da fauna de peixes;
- Comparar descritores ecológicos da ictiofauna, como: densidade e riqueza entre diferentes comunidades marinhas de áreas protegidas e não protegidas nas ilhas;

1.13. Hipótese

- O Monumento Natural das Ilhas Cagarras cumpre seu papel como Unidade de Conservação de proteção integral na conservação dos peixes dentro dos seus limites.

1.14. Referências

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Capitulo 1: Rocky reef fish biodiversity and conservation in a Brazilian Hope Spot region

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Rocky reef fish biodiversity and conservation in a Brazilian Hope Spot region

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Coastal islands of Grande Rio, located south Rio de Janeiro and Maricá cities have been under multiple anthropogenic impacts. Despite these problems, these insular systems shelter a high diversity of fish species. Reef fishes are essential components of tropical marine coastal communities, also providing food and income for millions of people around the world. In this work, we generated an updated checklist from Cagarras Islands Natural Monument and surrounding areas based on fisheries data, literature records and multiple sampling techniques, including the Submersible Rotating Video technique, used for the first time in Brazil. We present an inventory of 282 fish species representing 91 different families, with 21 new records for the study area, including a non-native species (*Heniochus acuminatus*). In addition, our results show a moderate endemism level for the Brazilian province (approximately 6.0%), while 10.5% of species are assigned to one of IUCN's threatened categories. Our efforts show the fish biodiversity scenario and their distribution on coastal islands more than 10 years after the Cagarras Islands Natural Monument establishment, reinforcing the importance of monitoring research programs for the management of this Marine Protected Area and surrounding waters, that play a key role for artisanal fisheries.

Keywords: Checklist, Marine Protected Areas, Non-destructive techniques, Richness, South Atlantic.

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As ilhas costeiras do Grande Rio, ao sul das cidades do Rio de Janeiro e Maricá, têm sofrido múltiplos impactos antrópicos. Apesar destes problemas, esses sistemas insulares abrigam uma grande diversidade de espécies de peixes. Os peixes recifais são componentes essenciais das comunidades costeiras marinhas tropicais, fornecendo alimento e fonte de renda para milhões de pessoas em todo o mundo. Neste trabalho, geramos uma lista de verificação atualizada do Monumento Natural das Ilhas Cagarras e áreas do entorno com base em dados de pesca, registros da literatura e múltiplas técnicas de amostragem, incluindo a técnica de vídeo rotacional subaquático usada pela primeira vez no Brasil. Apresentamos um inventário de 282 espécies de peixes representando 91 famílias, com 21 novos registros para área de estudo, incluindo uma espécie não nativa (*Heniochus acuminatus*). Além disso, nossos resultados mostram um nível de endemismo moderado da província brasileira (aproximadamente 6,0%), sendo 10,5% das espécies classificadas em uma das categorias ameaçadas da IUCN. Nossos esforços mostram o cenário da biodiversidade de peixes e sua distribuição nas ilhas costeiras mais de 10 anos após o estabelecimento do Monumento Natural das Ilhas Cagarras, reforçando a importância de programas de pesquisa de monitoramento para a gestão desta Área Marinha Protegida e suas águas adjacentes, que desempenham papel fundamental para a pesca artesanal.

Palavras-chave: Áreas Marinhas Protegidas, Atlântico Sul, Lista de espécies, Riqueza, Técnicas não-destrutivas.

INTRODUCTION

Rocky reefs are among the most important marine ecosystems in the world, due to their importance in providing livelihood services for millions of people, such as fishing, medicinal compounds, and tourism (Pereira, Soares-Gomes, 2009; Laport *et al*., 2016; Riofrío-Lazo *et al*., 2022). Despite all their importance, many forms of life that inhabit rocky shore ecosystems are critically endangered by human actions (Benedetti-Cecchi *et al*., 2001; Pereira, Soares-Gomes, 2009; Mendez *et al*., 2019). Coastal development, urbanization and overfishing are amongst the main activities that exert pressure on coastal marine ecosystems (Elliott, 2014; Alves *et al*., 2019; Figueroa-Pico *et al*., 2021), currently occurring so fast that they generally surpass our ability to understand the surrounding ecosystem functioning. In order to reduce these impacts caused by human activities, Marine Protected Areas (MPAs) have been created as an important management tool, aiming to provide protection for local marine biodiversity (Lester *et al*., 2009; Miller, Russ, 2014), especially minimizing impacts on fish assemblages and improving/preserving the essential habitats on which species depend (Gaines *et al*., 2010; Sciberras *et al*., 2015).

As reef environments, reef fishes are important components of tropical marine communities, serving as food and income source for millions of people (Munro, 1996; Pauly *et al*., 2002; Nelson *et al*., 2016). In Brazil, reef fish communities are distributed along the coast, from off the mouth of the Amazon River, and the Manuel Luiz reefs (Northern Brazil) to coastal regions of Santa Catarina State in Southern Brazil (Rocha, Rosa, 2001; Hostim-Silva *et al*., 2005; Moura *et al*., 2016), including oceanic islands (Quimbayo *et al*., 2019; Pinheiro *et al*., 2020). However, the rocky shore ichthyofauna on coastal regions has been under increasing human pressure, ranging from the degradation by pollution, to extractive activities, such as fishing (recreational and commercial), which can lead some species to high extinction risks (Quaas *et al*., 2019). Additionally, the introduction/arrival of invasive species can pose a significant threat to local biodiversity, and may cause changes in the structure of communities, resulting in the exclusion of native species (Ruiz *et al*., 1997; Bax *et al*., 2003). These facts contribute to the reduction of the environment quality, directly impacting the associated ichthyofauna, which demands a better understanding of the dynamics of the reef fish communities in these regions, especially within MPAs.

Along the Southeastern Brazilian coastline, the complex structure of rocky reefs is associated with a valuable diversity of fish species and other organisms, even overcoming the number of species present on other marine ecosystems (Floeter *et al*., 2004; Souza *et al*., 2018). The Grande Rio region shelters our studied islands. They are precisely located from the Guanabara Bay entrance to both sides of the E-W coastline orientation, encompassing Rio de Janeiro and Maricá municipalities, in Southeastern Brazil. These islands and surrounding waters shelter a high biodiversity of marine and terrestrial fauna and flora, and even stand out as a singular archeological site, being commonly visited by tourists, fishermen, military activities, and the general public (details in Moraes *et al*., 2013; Bertoncini *et al*., 2019). Part of these islands form an important Marine Protected Area (MPA) in Rio de Janeiro City, The Cagarras Islands Natural Monument (MONA Cagarras). Despite its importance and proximity to a highly populated Brazilian metropolis, the ichthyofauna of these coastal islands and surrounding waters are still poorly known. Nonetheless, MONA Cagarras, together with its surrounding areas (including Rasa and Cotunduba islands) was, in 2021, recognized as a Hope Spot for conservation of marine biodiversity by the international nonprofit organization Mission Blue.

The survey of biodiversity appears as a key tool in studies of fish communities (Mora *et al*., 2008; Guabiroba *et al*., 2020; Pereira *et al*., 2021). Non-destructive techniques have been widely employed in marine ecosystems, especially in MPAs (Andradi-Brown *et al*., 2016; Bayley *et al*., 2019; Quaas *et al*., 2019, Schmid *et al*., 2020). The Underwater Visual Census (UVC) is frequently used in ecological studies of reef fish communities (Chaves, Monteiro-Neto, 2009; Daros *et al*., 2018; Motta *et al*., 2021; Pereira *et al*., 2021), allowing the identification of species and the monitoring of the behavior of organisms that especially, are not affected by the presence of divers (Sale, 1997; Beck *et al*., 2014). In parallel, the evolution of non-destructive techniques through remote videos, have been employed as important complementary tools, to carry out more accurate sampling of the ichthyofauna (Mallet, Pelletier, 2014; Koenig, Stallings, 2015; Pimentel *et al*., 2020; Pinheiro *et al*., 2020; Rolim *et al*., 2022). Such instruments allow to estimate the abundance and diversity of reef fishes, providing relevant information on the health of local marine communities, with minimum impacts.

In the present work, we revisited and updated the checklist of fish species from Rio de Janeiro coastal islands and surrounding waters, based on a decade of field surveys, published scientific articles and fisheries records. In addition, we report the first record of the non-native species *Heniochus acuminatus* (Linnaeus, 1758) in Rio de

Janeiro. Furthermore, we provide data of species richness on several coastal islands and surroundings by different sampling methods, improving the knowledge on the marine fish species of the state of Rio de Janeiro.

MATERIAL AND METHODS

Sampling sites. The present study was conducted at the coastal islands of Rio de Janeiro and Maricá cities (between 43º35'W - 42º09'W; 23º01'S - 22º09'S) (Fig. 1): from West to East, Tijucas Archipelago is located 1.7 km off Barra da Tijuca Beach and comprises Pontuda, Alfavaca, and Meio Islands; the Cagarras Archipelago is about 4 km southwards off Ipanema Beach, formed by Palmas, Cagarra, Comprida islands plus Filhote da Cagarra Islet; and along with Redonda Island and Filhote da Redonda Islet, which lie 4 km southwards the Cagarra Archipelago, they form the Cagarras Islands Natural Monument, a no-take MPA created in 2010 to protect the local biodiversity, which boundaries includes the marine area 10 m from the rockyshore of each island. Further East lies Rasa Island, while Cotunduba Island is located at the entrance of Guanabara Bay. Further East, Maricás Archipelago is spread 3.5 km from the Maricá coast and is formed by Maricá and Crioula islands and two small islets.

Data source. The updated checklist of marine fishes presented herein was produced through non-destructive methods: (I) 696 Underwater Visual Censuses (UVC) were carried out using 40m^2-belt transects by two scientific divers in all of the three archipelagos and Cotunduba Island, between 2011 and 2022, at shallow waters (<10 m) and deeper waters (>11 to 25 m); (II) 468 Submersible Rotating Videos (SRV) were obtained at three different areas on shallow (<10 m) and deep (>10 m) strata (117 hours of video); Additionally, (III) fish occurrence records were compiled from previously published scientific papers and books (*e.g.*, Rangel *et al.*, 2007; Moraes *et al.*, 2013; Monteiro-Neto *et al.*, 2013; Aguiar *et al.*, 2015; Amorim, Monteiro-Neto, 2016; Garcia *et al.*, 2018; Bertoncini *et al.*, 2019; Araujo *et al.*, 2020; Hauser-Davis *et al.*, 2021); (IV) Data were also compiled from fishery landing monitoring and personal communication with Z13 and Z7 Fishermen Colonies, providing much of the species that inhabit soft bottoms, once they have fishing grounds in the surroundings of the islands. Finally, (V) Underwater Sighting Data (approx. 603 hours of scientific diving) and sightings by colleagues and volunteers *in situ* were considered in the present work.

Submersible Rotating Videos (SRV). The SRV system (Fig. 2), developed by Koenig, Stallings (2015), is an innovative rotational underwater video technique, and consists of a stainless-steel frame with an engine inside (2 rpm) and a camera of high resolution attached (*e.g.*, GoPro). This technique simulates the renowned stationary census technique, developed by Bohnsack, Bannerot (1986) and excludes the potential influence of the diver on the behavior of fishes. From each deployment, a 15-minute-video was recorded, and then after analyzed using the VLC multimedia player (http://www.videolan.org/vlc/index.html).

Data analysis. The species were identified based on Figueiredo, Menezes (2000), Humann, Deloach (2014), Hostim-Silva *et al.* (2005), Bertoncini *et al.* (2019), and consultancy to experts. The families were ordered according to Dornburg, Near (2021)

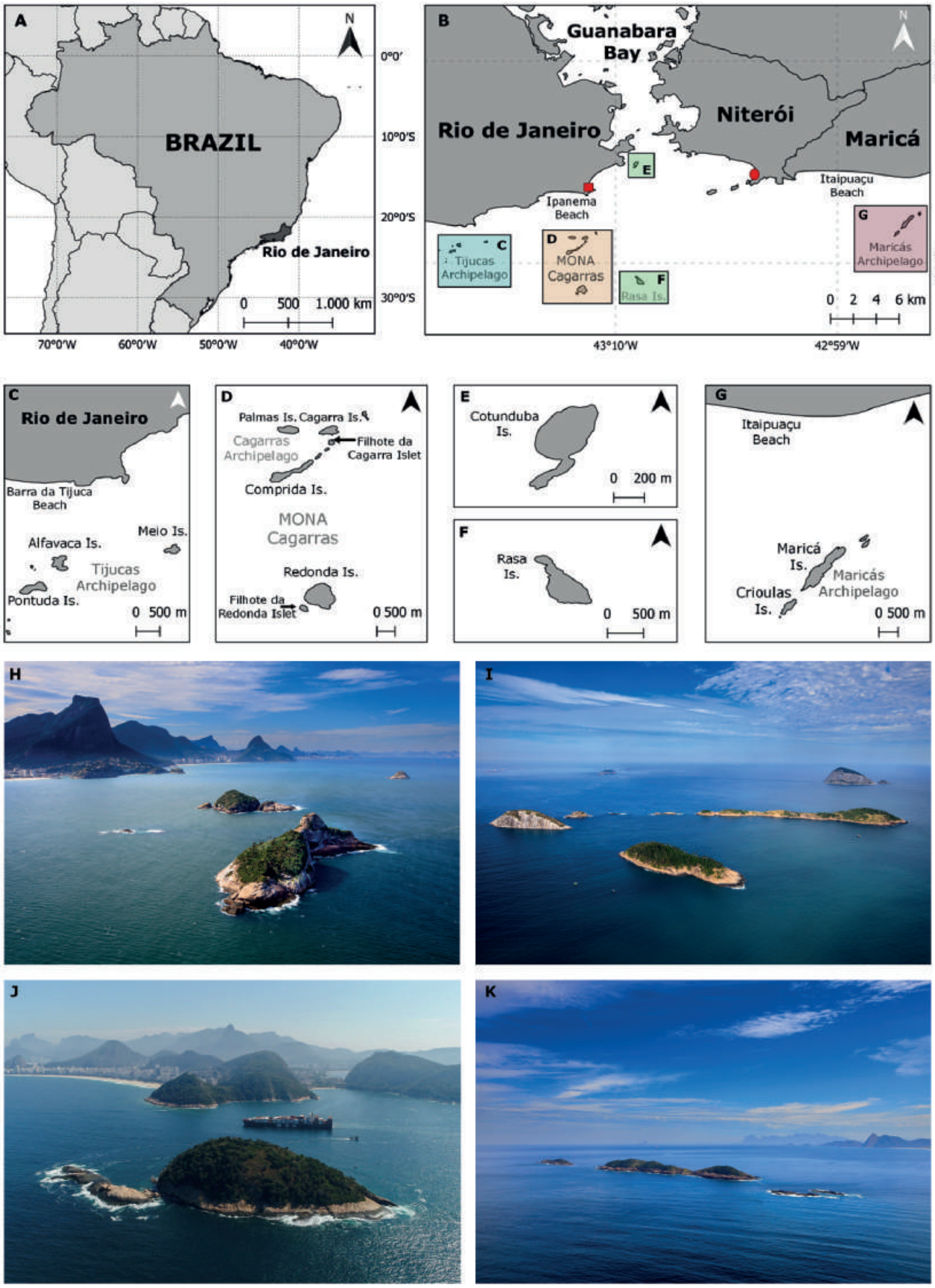

FIGURE 1 | Maps and photographs of the study area (Coastal Islands of Rio de Janeiro metropolitan region). **A.** The State of Rio de Janeiro in Southeast Brazil; **B.** The Guanabara Bay and the archipelagos/islands along the southern coast, Z13 fishermen's colony (red square) and Z7 fishermen's colony (red circle); **C.** Tijucas Archipelago; **D.** Cagarras Archipelago and Redonda Island and Filhote da Redonda Islet forming the MONA Cagarras MPA; **E.** Cotunduba Island; **F.** Rasa Island; **G.** Maricás Archipelago; **H.** Aerial view from West of the Tijucas Archipelago; **I.** Aerial view from Northwest of MONA Cagarras, depicting Rasa Island in the far background; **J.** Aerial view from Southeast of Cotunduba Island; **K.** Aerial view from East of the Maricás Archipelago. Credits: Augusto A. Machado (**A-G**); Áthila A. Bertoncini (**H, I, K**); Fred Cunha (**J**).

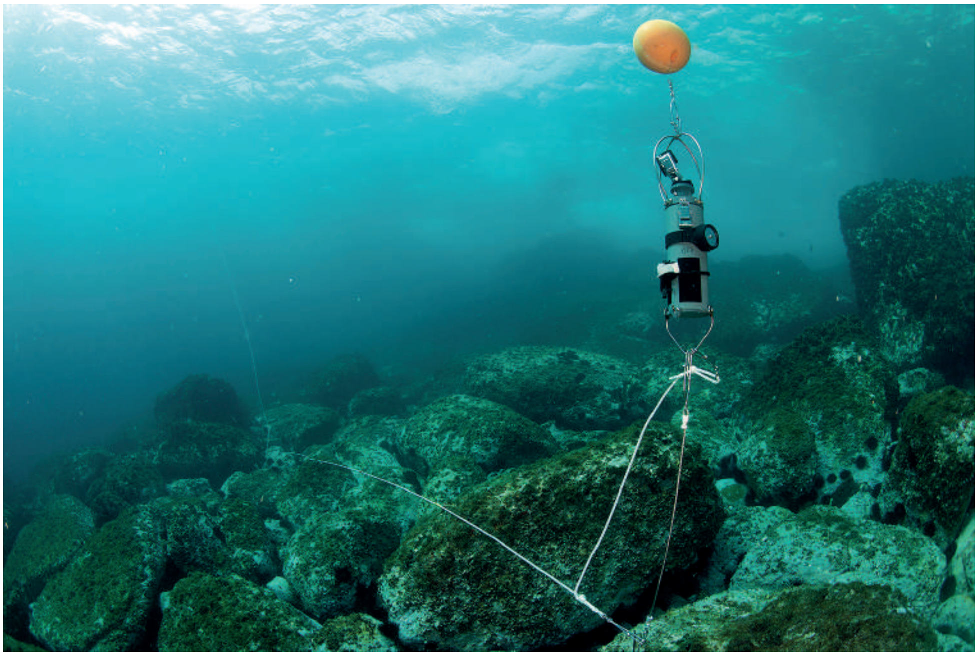

FIGURE 2 | Submersible Rotating Videos "SRV" in operation on Redonda Island. Photo: Áthila A. Bertoncini.

and species were arranged in alphabetic order inside each family. The IUCN Red List of threatened species and the Brazilian environmental agency, Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) – Red list of Brazilian Fauna Threatened of Extinction were addressed to classify the conservation status of each species (ICMBio, 2018; IUCN, 2020). The sites where the species were reported are presented here and the records of species not observed by this study are referenced. Data analyses were performed using Software R (R Development Core Team, 2020) and maps were elaborated through QGIS 3.16 (QGIS Development Team, 2022).

RESULTS

Fish database. The annotated checklist includes 282 fish species, belonging to 192 genera and 91 families cataloged at the coastal Islands of Rio de Janeiro and surrounding waters, including soft bottom habitats (Tab. 1). It is important to note in Tab. 1 that phylogenetic updates are considered for recent changes in families, *i.e.*, *Galeocerdo cuvier* (Péron & Lesueur, 1822) under Galeocerdonidae (Ebert *et al*., 2021), *Zapteryx brevirostris* (Müller & Henle, 1841) under Trygonorrhinidae (Last *et al*., 2016), *Acanthistius brasilianus* (Cuvier, 1828) under Anthiadidae (Dornburg, Near, 2021; Anderson, 2018); and genus, *i.e.*, from *Equetus* (*lanceolatus*) (Linnaeus, 1758) to *Eques Bloch*, 1793 (Parenti, 2020); and from *Chromis* (*multilineata*) (Guichenot, 1853) to *Azurina* Jordan & McGregor, 1898 (Tang *et al*., 2021).

From this total, 176 (62.4%) species were observed during Projeto Ilhas do Rio fieldwork surveys. Among the species listed herein: 102 (36.2%) were observed in SRV videos, 160 (56.7%) species were recorded by UVC, being 86 (30.5%) registered in both

TABLE 1 | Fish species observed in Coastal Islands of Rio de Janeiro arranged according to Dornburg, Near (2021). Observed sites: Tijucas Archipelago = TA; Cagarras Islands Natural Monument = MCA; Maricás Archipelago = MA; Rasa Island = RI; Cotunduba Island = CI; Conservation Status (IUCN/ICMBio): CR = Critically Endangered, EN = Endangered, VU = Vulnerable, NT = Near Threatened, LC = Least Concern, DD = Data Deficient, and NE = Not Evaluated. Record type: SIG = Sighted, LIT = Literature; FIS = Fishery (Fishermen's colony and spearfishing), MUS = Museum Voucher, SRV= Submersible Rotating Video and UVC = Underwater Visual Census. † New Records for the area. # Exotic species, Ψ Brazilian endemic species; Rangel *et al*., 2007*[1], Moraes *et al*., 2013*[2], Monteiro-Neto *et al*., 2013*[3], Amorim, Monteiro-Neto, 2016*[4], Garcia *et al*., 2018*[5], Bertoncini *et al*., 2019*[6], Araujo *et al*., 2020*[7], Hauser-Davis *et al*., 2021*[8].

Family and species	IUCN	ICMBio	Observed sites	Record type
GINGLYMOSTOMATIDAE				
Ginglymostoma cirratum (Bonnaterre, 1788)	DD	VU	MCA	SIG *[2]
RHINCODONTIDAE				
Rhincodon typus Smith, 1828 †	EN	VU	MCA	SIG
LAMNIDAE				
Isurus oxyrinchus Rafinesque, 1810	EN	NT	Z7 / Z13	FIS*[7]
CARCHARHINIDAE				
Carcharhinus brevipinna (Valenciennes, 1839)	NT	DD	Z7 / Z13	FIS*[7]
Carcharhinus falciformis (Bibron, 1839)	VU	NT	Z7	FIS*[7]
Rhizoprionodon lalandii (Valenciennes, 1839)	DD	NT	Z13	FIS*[7]
GALEOCERDONIDAE				
Galeocerdo cuvier (Péron & Lesueur, 1822)	NT	NT	Z13	FIS*[7]
SPHYRNIDAE				
Sphyrna lewini (Griffith & Smith, 1834)	CR	CR	Z7 / Z13	FIS*[7]
Sphyrna zygaena (Linnaeus, 1758)	VU	CR	Z7 / Z13	FIS*[7]
HEXANCHIDAE				
Notorynchus cepedianus (Péron, 1807) †	DD	CR	Z13	FIS
SQUATINIDAE				
Squatina guggenheim Marini, 1936	EN	CR	Z7 & Z13	FIS*[6]
NARCINIDAE				
Narcine brasiliensis (Olfers, 1831)	DD	DD	TA / Z13	SRV/ FIS*[7]
RAJIDAE				
Atlantoraja cyclophora (Regan, 1903)	VU	NT	MUS	MUS*[3]
Atlantoraja castelnaui (Miranda Ribeiro, 1907)	EN	EN	Z7 / Z13	FIS*[6]
Rioraja agassizii (Müller & Henle, 1841)	VU	EN	MUS / Z13	MUS*[3]/FIS*[7]
RHINOBATIDAE				
Pseudobatos horkelii (Müller & Henle, 1841)	CR	CR	Z7 / Z13	FIS*[6]
Pseudobatos percellens (Walbaum, 1792)	NT	DD	MCA / Z13	SRV / FIS*[7]
TRYGONORRHINIDAE				
Zapteryx brevirostris (Müller & Henle, 1841)	NT	DD	TA / MCA / MA / Z13 / MUS	UVC / MUS*[3]/FIS*[7]
DASYATIDAE				
Dasyatis hypostigma Santos & Carvalho, 2004	DD	DD	Z13	FIS*[3]
Hypanus americanus (Hildebrand & Schroeder, 1928)	DD	DD	MCA / MA / RI / Z13	UVC / SRV / FIS*[7]
Hypanus guttatus (Bloch & Schneider, 1801)	DD	LC	Z13	FIS*[7]
Hypanus say (Lesueur, 1817)	LC	DD	Z13	FIS*[4]
Pteroplatytrygon violacea (Bonaparte, 1832)	LC	DD	Z13	FIS*[7]
GYMNURIDAE				
Gymnura altavela (Linnaeus, 1758)	VU	CR	TA / MCA / MA / Z13	UVC / FIS*[3]
MYLIOBATIDAE				
Aetobatus narinari (Euphrasen, 1790)	NT	DD	TA / MCA / MA / RI	UVC/ SRV/ LIT*[1,3]
Myliobatis freminvillei Lesueur, 1824	DD	EN	MCA / RI	UVC/ SRV/ SIG*[3]
RHINOPTERIDAE				
Rhinoptera bonasus (Mitchill, 1815) †	VU	VU	MCA	UVC
MOBULIDAE				
Mobula mobular (Bonnaterre, 1788)	EN	VU	Z13	FIS*[8]
ELOPIDAE				
Elops saurus Linnaeus, 1766	LC	NE	Z13	FIS*[2]

TABLE 1 | (Continued)

ALBULIDAE				
Albula vulpes (Linnaeus, 1758)	NT	DD	Z13	FIS*[2]
MURAENIDAE				
Gymnothorax funebris Ranzani, 1839	LC	DD	MCA	SIG / LIT*[1]
Gymnothorax moringa (Cuvier, 1829)	LC	DD	TA / MCA / MA / RI	UVC / SRV / SIG*[1]
Gymnothorax ocellatus Agassiz, 1831	LC	DD	Z13	FIS*[2]
Gymnothorax vicinus (Castelnau, 1855)	LC	DD	TA / MCA / MA / RI	UVC / SIG*[3]
Muraena retifera Goode & Bean, 1882	LC	LC	TA / MCA / MA / RI / CI	UVC / SIG*[3]
OPHICHTHIDAE				
Ahlia egmontis (Jordan, 1884)	LC	LC	MCA / RI	UVC / SIG*[3]
Myrichthys breviceps (Richardson, 1848)	LC	LC	MCA	UVC / LIT*[1]
Myrichthys ocellatus (Lesueur, 1825)	LC	LC	TA / MCA / MA / RI	UVC / LIT*[3]
Ophichthus ophis (Linnaeus, 1758)	LC	LC	TA / MCA	UVC / LIT*[3]
CONGRIDAE				
Conger orbignianus Valenciennes, 1837	LC	DD	MUS	MUS*[3]
CLUPEIDAE				
Brevoortia aurea (Spix & Agassiz, 1829)	LC	LC	Z13	FIS*[2]
Harengula clupeola (Cuvier, 1829)	LC	LC	TA / MCA / MA	SRV / SIG*[3]
Opisthonema oglinum (Lesueur, 1818)	LC	LC	MCA / MA / Z13	UVC / FIS*[2] / SIG*[3]
Sardinella brasiliensis (Steindachner, 1879)	DD	DD	MCA / Z13	UVC / FIS*[2]
ARIIDAE				
Genidens barbus (Lacepède, 1803)	NE	EN	CI3 / Z13	UVC / FIS*[2]
SYNODONTIDAE				
Synodus foetens (Linnaeus, 1766)	LC	LC	MCA	LIT*[2,3]
Synodus intermedius (Spix & Agassiz, 1829)	LC	LC	TA / MCA / MA / RI	LIT*[1]/UVC
Synodus synodus (Linnaeus, 1758)	LC	LC	TA / MCA / MA / RI / CI	UVC / SRV / LIT*[1]
Trachinocephalus myops (Foster, 1801)	LC	LC	MUS	MUS*[3]
LAMPRIDAE				
Lampris guttatus (Brünnich, 1788) †	LC	LC	Z13	FIS
MERLUCCIIDAE				
Merluccius hubbsi Marini, 1933	NE	NT	Z13	FIS*[2]
GADIDAE				
Urophycis brasiliensis (Kaup, 1858)	NE	NT	Z13	FIS*[2]
HOLOCENTRIDAE				
Holocentrus adscensionis (Osbeck, 1765)	LC	LC	TA / MCA / MA / RI / CI / Z13	UVC / SRV / LIT*[1]/ FIS*[2]
Myripristis jacobus Cuvier, 1829	LC	LC	TA / MCA / MA / RI	UVC / SRV / LIT*[1]
Plectrypops retrospinis (Guichenot, 1853)	LC	LC	MCA / MA	UVC / LIT*[2]
Sargocentron bullisi (Woods, 1955)	LC	LC	MCA / MA	SIG*[3]/UVC
BATRACHOIDIDAE				
Porichthys porosissimus (Cuvier, 1829)	NE	LC	MCA / MA / Z13 / MUS	UVC / LIT*[2]/ MUS*[3] / FIS*[2]
GOBIIDAE				
Coryphopterus glaucofraenum Gill, 1863	LC	LC	TA / MCA / MA / RI / CI	UVC / LIT*[1]
Ctenogobius saepepallens (Gilbert & Randall, 1968) †	LC	LC	MA	UVC
Elacatinus figaro Sazima, Moura & Rosa, 1997 Ψ	NE	VU	TA / MCA / MA / RI / CI	UVC / SRV / LIT*[1]
Gnatholepis thompsoni Jordan, 1904	LC	LC	MCA	UVC / SIG*[6]
Gobulus myersi Ginsburg, 1939 †	LC	NE	TA	UVC
APOGONIDAE				
Apogon pseudomaculatus Longley, 1932	LC	LC	MCA / MA	UVC / LIT*[2]
Phaeoptyx pigmentaria (Poey, 1860)	LC	LC	Not Available	SIG*[3]
PTERELEOTRIDAE				
Ptereleotris randalli Gasparini, Rocha & Floeter, 2001	LC	LC	TA	UVC / SRV / SIG*[3]
GEMPYLIDAE				
Thyrsites lepidopodea (Cuvier, 1832)	NE	LC	Z13	FIS*[2]

TABLE 1 | (Continued)

POMATOMIDAE				
Pomatomus saltatrix (Linnaeus, 1766)	VU	NT	MCA / Z13	SRV / FIS*[2]
SCOMBRIDAE				
Euthynnus alletteratus (Rafinesque, 1810)	LC	LC	MCA / MA	UVC / LIT*[6]
Sarda sarda (Bloch, 1793) †	LC	LC	MCA	SIG
Scomber colias Gmelin, 1789	LC	LC	Z13	FIS*[4]
Scomberomorus brasiliensis Collette, Russo & Zavala-Camin, 1978	LC	LC	MCA / Z13	SIG / FIS*[4]
STROMATEIDAE				
Peprilus paru (Linnaeus, 1758)	LC	LC	Z13	FIS*[2]
TRICHIURIDAE				
Trichiurus lepturus Linnaeus, 1758	DD	LC	MCA / Z13	SIG*[2]/ FIS*[2]
FISTULARIIDAE				
Fistularia petimba Lacepède, 1803	LC	LC	MCA / Z13	SIG / FIS*[2]
Fistularia tabacaria Linnaeus, 1758	LC	LC	TA / MCA / MA / RI	UVC / SRV / SIG*[1]
SYNGNATHIDAE				
Halicampus crinitus (Jenyns, 1842) †	LC	LC	RI	UVC
Hippocampus erectus Perry, 1810	VU	VU	Not Available	LIT*[3]
Hippocampus patagonicus Piacentino & Luzzatto, 2004 †	VU	VU	MCA	SIG
Hippocampus reidi Ginsburg, 1933	NT	VU	TA / MCA / MA	UVC / SIG*[1]
CALLIONYMIDAE				
Callionymus bairdi Jordan, 1888	LC	LC	TA / MCA / MA	UVC / SIG*[3]
MULLIDAE				
Mullus argentinae Hubbs & Marini, 1933	LC	LC	Z13	FIS*[2]
Mulloidichthys martinicus (Cuvier, 1829) †	LC	LC	MCA / MA	UVC
Pseudupeneus maculatus (Bloch, 1793)	LC	LC	TA / MCA / MA / RI / CI / Z13	UVC/SRV/ SIG*[1] /FIS*[2]
DACTYLOPTERIDAE				
Dactylopterus volitans (Linnaeus, 1758)	LC	LC	TA / MCA / MA / CI / Z13	UVC / SRV / FIS*[2]
BLENNIIDAE				
Hypleurochilus fissicornis (Quoy & Gaimard, 1824)	LC	LC	TA / MCA / MA / RI / CI	UVC / LIT*[1]
Hypsoblennius invemar Smith-Vaniz & Acero P., 1980	LC	LC	TA / MCA / RI	UVC / LIT*[1]
Parablennius marmoreus (Poey, 1876)	LC	LC	TA / MCA / MA / RI / CI	UVC / LIT*[1]
Parablennius pilicornis (Cuvier, 1829)	LC	LC	TA / MCA / MA / RI / CI	UVC / SRV / LIT*[1]
Scartella cristata (Linnaeus, 1758)	LC	LC	TA / MCA / MA / RI / CI	UVC / SRV / LIT*[1]
CHAENOPSIDAE				
Emblemariopsis signifer (Ginsburg, 1942)	LC	LC	TA / MCA / MA / RI / CI	UVC / LIT*[1]
LABRISOMIDAE				
Gobioclinus kalisherae (Jordan, 1904)	LC	LC	TA / MCA / RI	UVC / SIG*[3]
Labrisomus cricota Sazima, Gasparini & Moura, 2002	LC	LC	Not Available	LIT*[1]
Labrisomus nuchipinnis (Quoy & Gaimard, 1824)	LC	LC	TA / MCA / MA / RI / CI	UVC / SRV / LIT*[1]
Malacoctenus triangulatus Springer, 1959	LC	LC	Not Available	LIT*[1]
Malacoctenus delalandii (Valenciennes, 1836)	LC	LC	TA / MCA / MA / RI	UVC / LIT*[1]
Paraclinus spectator Guimarães & Bacellar, 2002 Ψ	LC	LC	TA / MCA	UVC / SIG*[6]
Starksia brasiliensis (Gilbert, 1900) Ψ	LC	LC	TA	SIG / LIT*[3]
BELONIDAE				
Strongylura spp. van Hasselt, 1824	LC	LC	Not Available	LIT*[1]
Strongylura marina (Walbaum, 1792)	LC	LC	Z13	FIS*[3]
Tylosurus spp.	LC	LC	RI	UVC / SIG*[3]
Tylosurus acus (Lacepède, 1803)	LC	LC	Z13	FIS*[2]
MUGILIDAE				
Mugil curema Valenciennes, 1836	LC	DD	MCA / Z13	SIG*[2] / FIS*[2]
Mugil liza Valenciennes, 1836	DD	NT	TA / MCA / MA / CI / Z13	UVC / SRV / FIS*[2]
OPISTOGNATHIDAE				
Opistognathus vicinus Smith-Vaniz, Tornabene & Macieira, 2018 † Ψ	NE	NE	RI / MA	UVC

TABLE 1 | (Continued)

POMACENTRIDAE				
Abudefduf saxatilis (Linnaeus, 1758)	LC	LC	TA / MCA / MA / RI / CI / Z13	UVC / SRV /LIT*[1]/ FIS*[2]
Azurina multilineata (Guichenot, 1853)	LC	LC	TA / MCA / MA / RI / CI	UVC / SRV / LIT*[1]
Chromis flavicauda (Günther, 1880)	DD	LC	MCA	UVC / LIT*[2]
Chromis jubauna Moura, 1995 Ψ	NE	LC	MCA / RI	UVC / SRV / LIT*[1]
Chromis vanbebberae McFarland, Baldwin, Robertson, Rocha & Tornabene, 2020 †	NE	NE	MCA	UVC
Stegastes fuscus (Cuvier, 1830)	LC	LC	TA / MCA / MA / RI / CI	UVC / SRV / LIT*[1]
Stegastes pictus (Castelnau, 1855)	NE	LC	TA / MCA / MA / RI	UVC / SRV / LIT*[1]
Stegastes variabilis (Castelnau, 1855)	NE	LC	TA / MCA / MA / RI / CI	UVC / SRV / LIT*[1]
CARANGIDAE				
Caranx crysos (Mitchill, 1815)	LC	LC	TA / MCA / MA / RI / CI / Z13	UVC / SRV / FIS*[3]
Caranx hippos (Linnaeus, 1766)	LC	LC	Not Available	SIG*[3] / FIS*[3]
Caranx latus Agassiz, 1831	LC	LC	TA / MCA / MA / RI	UVC / SRV / LIT*[2]
Caranx ruber (Bloch, 1793)	LC	LC	TA / MCA / MA / RI	UVC / SRV / FIS*[3]
Chloroscombrus chrysurus (Linnaeus, 1766)	LC	LC	MCA / Z13	SIG / FIS*[2]
Decapterus macarellus (Cuvier, 1833) †	LC	LC	TA / CI	UVC
Decapterus punctatus (Cuvier, 1829) †	LC	LC	MCA	UVC
Oligoplites spp.	LC	LC	Z13	FIS*[2]
Parona signata (Jenyns, 1841)	LC	LC	Z13	FIS*[2]
Pseudocaranx dentex (Bloch & Schneider, 1801)	LC	LC	TA / MCA / MA / RI	UVC / SRV / FIS*[3]
Selar crumenophthalmus (Bloch, 1793)	LC	LC	MCA	SIG / FIS*[3]
Selene setapinnis (Mitchill, 1815)	LC	LC	MCA / Z13	SIG / FIS*[2]
Selene vomer (Linnaeus, 1758)	LC	LC	MCA / Z13	SRV / FIS*[2]
Seriola dumerili (Risso, 1810)	NT	LC	MCA / Z13	SIG*[2]/ FIS*[3]
Seriola lalandi Valenciennes, 1833	LC	LC	TA / MCA / Z13	UVC / SIG*[2] / FIS*[2]
Seriola rivoliana Valenciennes, 1833	LC	LC	TA / MCA / MA / RI	UVC / FIS*[3]
Trachinotus carolinus (Linnaeus, 1766)	LC	LC	Z13	FIS*[2]
Trachinotus falcatus (Linnaeus, 1758)	LC	LC	CI3 / Z13	SIG / FIS*[3]
Trachinotus goodei Jordan & Evermann, 1896	LC	LC	MCA / Z13	SRV / FIS*[2]
Trachinotus marginatus Cuvier, 1832	LC	LC	MCA	SIG*[2] / FIS*[3]
Trachurus lathami Nichols, 1920	LC	LC	MCA / RI / Z13	UVC / FIS*[2]
Uraspis secunda (Poey, 1860)	LC	LC	MCA / Z13	UVC / FIS*[2]
CORYPHAENIDAE				
Coryphaena hippurus Linnaeus, 1758	LC	LC	TA / MCA	UVC / FIS*[2]
ECHENEIDAE				
Echeneis naucrates Linnaeus 1758	LC	LC	TA / MCA / MA / Z13	UVC / SRV / FIS*[2]
RACHYCENTRIDAE				
Rachycentron canadum (Linnaeus, 1766) †	LC	LC	CI	SRV
XIPHIIDAE				
Xiphias gladius Linnaeus, 1758 †	LC	NT	TA	FIS
BOTHIDAE				
Bothus ocellatus (Agassiz, 1831)	LC	LC	TA / MCA / MA / RI / Z13	UVC / SRV / FIS*[2]
PARALICHTHYIDAE				
Cyclopsetta fimbriata (Goode & Bean, 1885)	LC	LC	MCA	SIG
Paralichthys orbignyanus (Valenciennes, 1839)	DD	DD	Z13	FIS*[2]
Paralichthys patagonicus Jordan, 1889	VU	NT	Z13	FIS*[2]
Syacium micrurum Ranzani, 1842	LC	LC	Z13	FIS*[4]
Syacium papillosum (Linnaeus, 1758)	LC	LC	/ Z13	SIG / FIS*[2]
CENTROPOMIDAE				
Centropomus parallelus Poey, 1860 †	LC	LC	TA	SRV
Centropomus undecimalis (Bloch, 1792)	LC	LC	TA / MCA / CI / Z13	SRV / SIG*[3] / FIS*[4]
POLYNEMIDAE				
Polydactylus virginicus (Linnaeus, 1758)	LC	LC	Z13	FIS*[2]

TABLE 1 | (Continued)

SPHYRAENIDAE				
Sphyraena guachancho Cuvier, 1829	LC	LC	Not Available	FIS*3
Sphyraena tome Fowler, 1903	NE	DD	TA / MCA / MA / CI	UVC / SRV / SIG*2
EPINEPHELIDAE				
Cephalopholis fulva (Linnaeus, 1758)	LC	LC	MCA	SIG*3
Cephalopholis taeniops (Valenciennes, 1828)	LC	NE	MCA	SIG*5/ MUS*5
Epinephelus itajara (Lichtenstein, 1822)	VU	CR	MCA	SIG*2
Epinephelus marginatus (Lowe, 1834)	VU	VU	TA / MCA / MA / RI / CI / Z13	UVC / SIG*1/ FIS*2
Epinephelus morio (Valenciennes, 1828)	VU	VU	MCA	SIG / FIS*3
Hyporthodus niveatus (Valenciennes, 1828)	VU	VU	TA / MCA / MA / RI / Z13	UVC / SIG*1 / FIS*2
Mycteroperca acutirostris (Valenciennes, 1828)	LC	DD	TA / MCA / MA / RI / CI / Z13	SRV / UVC / SIG*1 / FIS*2
Mycteroperca bonaci (Poey, 1860)	NT	VU	TA / MCA / MA / Z13	UVC / SRV / FIS*2
Mycteroperca interstitialis (Poey, 1860)	VU	VU	MCA	SRV / SIG*1/ FIS*2
Mycteroperca microlepis (Goode & Bean, 1879)	VU	DD	Z13	FIS*2
Paranthias furcifer (Valenciennes, 1828)	LC	NE	TA / RI	UVC / SIG*1
SERRANIDAE				
Diplectrum formosum (Linnaeus, 1766)	LC	LC	MCA / MA / RI / CI	UVC / SRV / SIG*2
Diplectrum radiale (Quoy & Gaimard, 1824)	LC	LC	MCA / MA / RI / CI	UVC / SRV / SIG*3
Dules auriga Cuvier, 1829	NE	LC	TA / MCA / MA / RI / CI	UVC / SRV / SIG*2
Pronotogrammus martinicensis (Guichenot, 1868)	LC	LC	MCA	SIG*3
Rypticus bistrispinus (Mitchill, 1818)	LC	LC	TA / MCA / MA / RI	UVC / SIG*1
Rypticus saponaceus (Bloch & Schneider, 1801)	LC	LC	MCA / MA / RI / MUS	UVC / SIG*1 / MUS*3
Serranus atrobranchus (Cuvier, 1829)	LC	LC	MCA / RI	UVC / SIG*2
Serranus baldwini (Evermann & Marsh, 1889)	LC	LC	TA / MCA / MA / RI	UVC / SIG*1
Serranus flaviventris (Cuvier, 1829)	LC	LC	MCA	SIG*2
ANTHIADIDAE				
Acanthistius brasilianus (Cuvier, 1828)	DD	LC	TA / MCA / MA / RI	UVC / SRV / SIG*1
PERCOPHIDAE				
Percophis brasiliensis Quoy & Gaimard, 1825	NE	LC	Z13	FIS*2
TRIGLIDAE				
Prionotus punctatus (Bloch, 1793)	LC	LC	MA / Z13	UVC / FIS*2
SCORPAENIDAE				
Pontinus corallinus Miranda Ribeiro, 1903 Ψ	NE	DD	MUS	MUS*3
Scorpaena brasiliensis Cuvier, 1829	LC	LC	MCA	UVC / SIG*1
Scorpaena isthmensis Meek & Hildebrand, 1928	LC	LC	TA / MCA / MA / RI / Z13	UVC / SIG*1 / FIS*4
Scorpaena plumieri Bloch, 1789	LC	LC	TA / MCA / MA / RI / Z13	UVC / SIG*1 / FIS*2
Scorpaenodes caribbaeus (Meek & Hildebrand, 1928)	LC	LC	MCA	SIG*2
Scorpaenodes tredecimspinosus (Metzelaar, 1919)	LC	LC	MCA	UVC / SIG*3
KYPHOSIDAE				
Kyphosus sectatrix (Linnaeus, 1758)	LC	NE	TA / MCA / MA / RI / CI / Z13	UVC/ SRV / SIG*1/FIS*2
Kyphosus vaigiensis (Quoy & Gaimard, 1825)	LC	LC	TA / MCA / MA / RI / CI	UVC / SRV / SIG*6
LABRIDAE				
Bodianus pulchellus (Poey, 1860)	LC	LC	TA / MCA / MA / RI / CI	UVC / SRV / SIG*1
Bodianus rufus (Linnaeus, 1758)	LC	LC	TA / MCA / MA / RI	UVC / SRV / SIG*1
Clepticus brasiliensis Heiser, Moura & Robertson, 2000 Ψ	LC	LC	MCA / RI	UVC / SRV / SIG*1
Cryptotomus roseus Cope, 1871	LC	LC	TA / MCA / MA / CI	UVC / SRV / SIG*2
Doratonotus megalepis Günther, 1862	LC	LC	RI	UVC / SIG*3
Halichoeres brasiliensis (Bloch, 1791) Ψ	DD	LC	TA / MCA / MA / RI / CI	UVC / SRV / SIG*1
Halichoeres dimidiatus (Agassiz, 1831)	LC	LC	TA / MCA / MA / RI	UVC / SIG*1
Halichoeres penrosei Starks, 1913 Ψ	LC	LC	MA	UVC
Halichoeres poeyi (Steindachner, 1867)	LC	LC	TA / MCA / MA / RI / CI	UVC / SRV / SIG*1
Halichoeres sazimai Luiz, Ferreira & Rocha, 2009 Ψ	NE	LC	MCA / MA / RI	UVC / SRV / SIG*1
Nicholsina usta (Valenciennes, 1840)	LC	LC	MCA / MA	UVC / SRV / SIG*3

TABLE 1 | (Continued)

Scarus trispinosus Valenciennes, 1840	EN	EN	MCA / MA	SIG*2/ FIS*3
Scarus zelindae Moura, Figueiredo & Sazima, 2001	DD	VU	MCA	SIG*2/ FIS*3
Sparisoma amplum (Ranzani, 1841)	LC	NT	TA / MCA	UVC / SIG*2
Sparisoma axillare (Steindachner, 1878)	DD	VU	TA / MCA / MA / RI	UVC / SRV / SIG*1
Sparisoma frondosum (Agassiz, 1831)	DD	VU	TA / MCA / MA / RI / Z13	UVC / SRV/ SIG*1 / FIS*2
Sparisoma radians (Valenciennes, 1840)	LC	LC	MCA / MA	SIG*2
Sparisoma tuiupiranga Gasparini, Joyeux & Floeter, 2003	LC	LC	TA / MCA / MA / RI	UVC / SRV / SIG*1
Thalassoma noronhanum (Boulenger, 1890) Ψ	LC	LC	MCA	UVC / SIG*2
Xyrichtys novacula (Linnaeus, 1758)	LC	LC	MA	UVC / SIG*6
Xyrichtys splendens Castelnau, 1855 †	LC	LC	MA	UVC
URANOSCOPIDAE				
Astroscopus ygraecum (Cuvier, 1829)	LC	LC	Z13	FIS*4
PINGUIPEDIDAE				
Pinguipes brasilianus Cuvier, 1829	NE	LC	TA / MCA / MA / RI	UVC / SRV / FIS*3
Pseudopercis numida Miranda Ribeiro, 1903	LC	NT	Not Available	FIS*3
PEMPHERIDAE				
Pempheris schomburgkii Müller & Troschel, 1848	LC	LC	TA / MCA / MA / RI / CI / MUS	UVC / SRV / SIG*1 / MUS*3
ACANTHURIDAE				
Acanthurus bahianus Castelnau, 1855	LC	LC	TA / MCA / MA / RI / CI	UVC / SRV / SIG *1
Acanthurus chirurgus (Bloch, 1787)	LC	LC	TA / MCA / MA / RI / CI	UVC / SRV / SIG *1
Acanthurus coeruleus Bloch & Schneider, 1801	LC	LC	TA / MCA / MA / RI / CI	UVC / SRV / SIG *1
GERREIDAE				
Diapterus rhombeus (Cuvier, 1829)	LC	LC	Z13	FIS*4
Eucinostomus gula (Quoy & Guaimard, 1824)	LC	LC	RI / CI	UVC / SRV / LIT*3
EPHIPPIDAE				
Chaetodipterus faber (Broussonet, 1782)	LC	LC	TA / MCA / MA / RI / CI / Z13	UVC / SRV / FIS*2
HAEMULIDAE				
Anisotremus surinamensis (Bloch, 1791)	DD	DD	TA / MCA / MA / RI / CI / Z13	UVC / SRV / FIS *2
Anisotremus virginicus (Linnaeus, 1758)	LC	LC	TA / MCA / MA / RI / CI / Z13	UVC / SRV / FIS *2
Haemulon aurolineatum Cuvier, 1830	LC	LC	TA / MCA / MA / RI / CI	UVC / SRV / FIS *3
Haemulon plumierii (Lacèpede, 1801)	LC	DD	MCA / MA / RI	SIG*1 / FIS*3
Haemulon steindachneri (Jordan & Gilbert, 1882)	LC	LC	TA / MCA / MA / RI / CI / Z13	UVC / SRV / SIG *2
Orthopristis rubra (Cuvier, 1830)	LC	LC	TA / MCA / MA / RI / CI / Z13	UVC / SRV / FIS *2
Paranisotremus moricandi (Ranzani, 1842)	LC	LC	Z13	SIG*3, FIS*3
Pomadasys ramosus (Poey, 1860) †	NE	LC	Z13	FIS
SCIAENIDAE				
Cynoscion acoupa (Lacepède, 1801)	VU	LC	Z13	FIS*2
Cynoscion guatucupa (Cuvier, 1830)	LC	LC	Z13	FIS*2
Cynoscion jamaicensis (Vaillant & Bocourt, 1883)	LC	LC	Z13	FIS*2
Cynoscion microlepidotus (Cuvier, 1830)	LC	LC	Z13	FIS*2
Cynoscion virescens (Cuvier, 1830)	LC	LC	Z13	FIS*2
Eques lanceolatus (Linnaeus, 1758)	LC	LC	MCA	SIG*2
Larimus breviceps Cuvier, 1830	LC	LC	Z13	FIS*2
Menticirrhus americanus (Linnaeus, 1758)	LC	DD	Z13	FIS*2
Micropogonias furnieri (Desmarest, 1823)	LC	LC	Z13	FIS*2
Odontoscion dentex (Cuvier, 1830)	LC	LC	MCA / RI	UVC / SRV / SIG *1
Paralonchurus brasiliensis (Steindachner, 1875)	LC	LC	Z13	FIS*2
Pareques acuminatus (Bloch & Schneider, 1801)	LC	DD	TA / MCA / MA / RI / CI	UVC / SRV / SIG *1
Pogonias cromis (Linnaeus, 1766)	LC	EN	Z13	FIS*2
Stellifer rastrifer (Jordan, 1889)	LC	LC	Z13	FIS*4

TABLE 1 | (Continued)

Umbrina canosai Berg, 1895	LC	LC	Z13	FIS*2
LUTJANIDAE				
Lutjanus analis (Cuvier, 1828)	NT	NT	MCA / Z13	SRV / FIS *2
Lutjanus cyanopterus (Cuvier, 1828)	VU	VU	Z13	FIS *2
Lutjanus jocu (Bloch & Schneider, 1801)	DD	NT	TA / MUS	UVC / MUS*3
Lutjanus synagris (Linnaeus, 1758)	NT	NT	Z13	FIS *2
Ocyurus chrysurus (Bloch, 1791)	DD	NT	MCA	SIG*1/ FIS*3
Rhomboplites aurorubens (Cuvier, 1829)	VU	NT	Z13	FIS *2
MALACANTHIDAE				
Malacanthus plumieri (Bloch, 1786)	LC	LC	TA / MA	UVC / SRV / SIG *3
POMACANTHIDAE				
Centropyge aurantonotus Burgess, 1974	LC	DD	MCA / RI	UVC / SIG *1
Holacanthus ciliaris (Linnaeus, 1758)	LC	DD	TA / MCA / MA / RI	UVC / SRV / SIG *1
Holacanthus tricolor (Bloch, 1795)	LC	DD	MCA	UVC / SIG *1
Pomacanthus arcuatus (Linnaeus, 1758)	LC	DD	MCA	UVC / SIG *1
Pomacanthus paru (Bloch, 1787)	LC	DD	TA / MCA / MA / RI / CI	UVC / SRV / SIG *1
CHAETODONTIDAE				
Chaetodon sedentarius Poey, 1860	LC	LC	TA / MCA / MA / RI	UVC / SRV / SIG *1
Chaetodon striatus Linnaeus, 1758	LC	LC	TA / MCA / MA / RI	UVC / SRV / SIG *1
Heniochus acuminatus (Linnaeus, 1758) # †	LC	NE	MCA	SRV / SIG
Prognathodes brasiliensis Burgess, 2001	LC	LC	MCA / MA	UVC / SRV / SIG *2
Prognathodes guyanensis (Durand, 1960)	LC	LC	MCA / MA / RI	UVC / SIG *1
SPARIDAE				
Archosargus probatocephalus (Walbaum, 1792)	LC	DD	Z13	FIS*2
Archosargus rhomboidalis (Linnaeus, 1758)	LC	LC	Not Available	FIS*3
Calamus penna (Valenciennes, 1830)	LC	LC	MCA / CI / Z13	UVC / FIS*2
Calamus pennatula Guichenot, 1868	LC	LC	TA / MCA / MA / RI	UVC / SRV / FIS *3
Diplodus argenteus (Valenciennes, 1830)	LC	LC	TA / MCA / MA / RI / CI / Z13	UVC / SRV / FIS *2
Pagrus pagrus (Linnaeus, 1758)	LC	LC	TA / MCA / MA / RI / Z13	UVC / SRV / FIS *2
PRIACANTHIDAE				
Heteropriacanthus cruentatus (Lacepède, 1801)	LC	LC	TA / MCA / MA / RI / CI	UVC / SRV / FIS*3
Priacanthus arenatus Cuvier, 1829	LC	LC	TA / MCA / MA / RI / CI / Z13	UVC / SRV / FIS*2
ANTENNARIIDAE				
Antennarius multiocellatus (Valenciennes, 1837)	LC	DD	MCA	SIG*2
Antennarius striatus (Shaw, 1794)	LC	DD	MUS	MUS*3
LOPHIIDAE				
Lophius gastrophysus Miranda Ribeiro, 1915	LC	NT	Z13	FIS*2
OGCOCEPHALIDAE				
Ogcocephalus vespertilio (Linnaeus, 1758)	LC	LC	TA / MCA / MA / RI	UVC / FIS *3
BALISTIDAE				
Balistes capriscus Gmelin, 1789	VU	NT	TA / MA / Z13	SRV / FIS*2
Balistes vetula Linnaeus, 1758	NT	NT	TA / MCA / Z13	UVC / SRV / FIS*2
DIODONTIDAE				
Chilomycterus reticulatus (Linnaeus, 1758)	LC	LC	TA / MCA / MA / RI	UVC / SRV / SIG*6
Chilomycterus spinosus (Linnaeus, 1758)	LC	LC	TA / MCA / MA / RI / CI	UVC / SRV / SIG*1
Diodon hystrix Linnaeus, 1758	LC	LC	MCA / MA	UVC / SIG*1
MOLIDAE				
Mola mola (Linnaeus, 1758) †	VU	LC	MCA	SIG
MONACANTHIDAE				
Aluterus monocerus (Linnaeus, 1758)	LC	NT	MCA / MA / RI / Z13	SRV / FIS*2
Aluterus scriptus (Osbeck, 1765)	LC	LC	TA	SRV / SIG*3
Cantherhines macrocerus (Hollard, 1853)	LC	LC	TA / MCA / MA / RI	UVC / SRV / SIG*1
Cantherhines pullus (Ranzani, 1842)	LC	LC	TA / MCA / MA / RI / CI	UVC / SRV / SIG*1

TABLE 1 | (Continued)

Stephanolepis hispida (Linnaeus, 1766)	LC	LC	TA / MCA / MA / RI / CI / Z13	UVC/SRV/ SIG*1 /FIS*2
OSTRACIIDAE				
Acanthostracion polygonius Poey, 1876	LC	LC	TA / MCA / MA / RI / CI	UVC / SRV / SIG *2
Acanthostracion quadricornis (Linnaeus, 1758)	LC	LC	TA / MCA	UVC / SIG *2
Lactophrys trigonus (Linnaeus, 1758)	LC	LC	MCA	SIG*1
TETRAODONTIDAE				
Canthigaster figueiredoi Moura & Castro, 2002	LC	LC	TA / MCA / MA / RI / CI	UVC / SRV / SIG*1
Lagocephalus laevigatus (Linnaeus, 1766)	LC	LC	MA / Z13	SRV / FIS*2
Sphoeroides greeleyi Gilbert, 1900	LC	LC	MCA / MA / CI	UVC / LIT*3
Sphoeroides spengleri (Bloch, 1785)	LC	LC	TA / MCA / MA / RI / CI	UVC / SRV / SIG*1
Sphoeroides testudineus (Linnaeus, 1758)	LC	DD	CI	UVC / SIG*1

sampling techniques. In addition, 16 (5.6%) species were only observed by SRV, while 73 (25.9%) species were exclusively observed through UVC. Lastly, 149 (52.8%) species were recorded in spearfishing/ artisanal fisheries', being 63 (22.3%) exclusive.

The fish inventory contains 254 (90.1%) species of Osteichthyes and 28 (9.9%) Chondrichthyes. Carangidae was the richest family with 22 species, followed by Labridae with 21 fish species, Sciaenidae (14), Epinephelidae (11), Serranidae (9), Haemulidae and Pomacentridae (8), and Labrisomidae with 7 species (Fig. 3). The most common genera were *Halichoeres* Rüppell, 1835, *Sparisoma* Swainson, 1839, and *Cynoscion* Gill, 1861 with five species each, followed by *Gymnothorax* Bloch, 1795, *Mycteroperca* Gill, 1862, *Caranx* Lacepède, 1801, *Lutjanus* Bloch, 1790, and *Trachinotus* Lacepède, 1801, with four species each. In addition, this study revealed 21 new records of fish species, as follows: *Rhincodon typus*, *Notorynchus cepedianus*, *Rhinoptera bonasus*, *Lampris guttatus*, *Ctenogobius saepepallens*, *Gobulus myersi*, *Hippocampus patagonicus*, *Halicampus crinitus*, *Mulloidichthys martinicus*, *Opistognathus vicinus*, *Chromis vanbebberae*, *Decapterus macarellus*, *Decapterus punctatus*, *Sarda sarda*, *Rachycentron canadum*, *Xiphias gladius*, *Pomadasys ramosus*, *Centropomus parallelus*, *Xyrichtys splendens*, *Mola mola*, and last but not the least, *Heniochus acuminatus*, an exotic fish species herein reported in MONA Cagarras (see † in Tab. 1).

The three most common elasmobranch species were *Gymnura altavela*, *Myliobatis freminvillei*, and *Z. brevirostris* (Figs. 4A,B,C). The Fig. 4 (D,E) brings two new records *S. sarda* and *C. vanbebberae*, and the most common species in the Archipelagos, which were *D. argenteus*, *C. pullus*, and *H. aurolineatum* (Figs. 4 F,G,H).

Yet, rare species recorded in situ are depicted in Fig. 5, *Thalassoma noronhanum*, *Paranthias furcifer*, *X. splendens.* Yet, rare species recorded in situ are depicted in Fig. 5, *T. noronhanum*, *P. furcifer*, *X. splendens*, *C. brasiliensis*, *E. lanceolatus*, *U. secunda*, *S. zelindae*, and *P. randalli*, and in Fig. 6, *Hippocampus reidi*, *Callionymus bairdi*, *Haemulon plumierii*, *Sargocentron bullisi*, *Chromis flavicauda*, *Pronotogrammus martinicensis*, *Centropyge aurantonotus*, and *Bodianus rufus*. Finally, the rare cryptic species *Gobulus myersi*, and *Paraclinus spectator* are depicted in Fig. 7.

Exotic fish record. Among the fishes listed, the SRV recorded an exotic species, originally widespread throughout the Indo-Pacific Ocean, from East Africa and Persian Gulf to the Society Islands, north to southern Japan, south to Lord Howe Island and throughout Micronesia. *Heniochus acuminatus*, commonly known as Longfin Bannerfish,

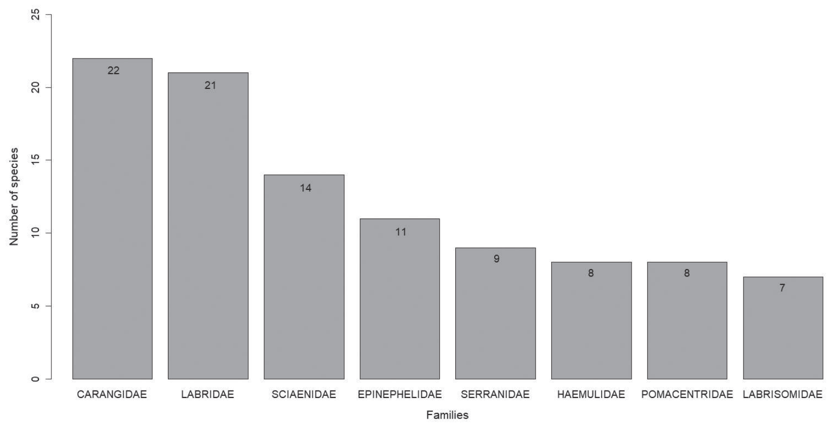

FIGURE 3 | The richest families reported along the coastal islands and surrounding waters of Rio de Janeiro metropolitan region, Brazil.

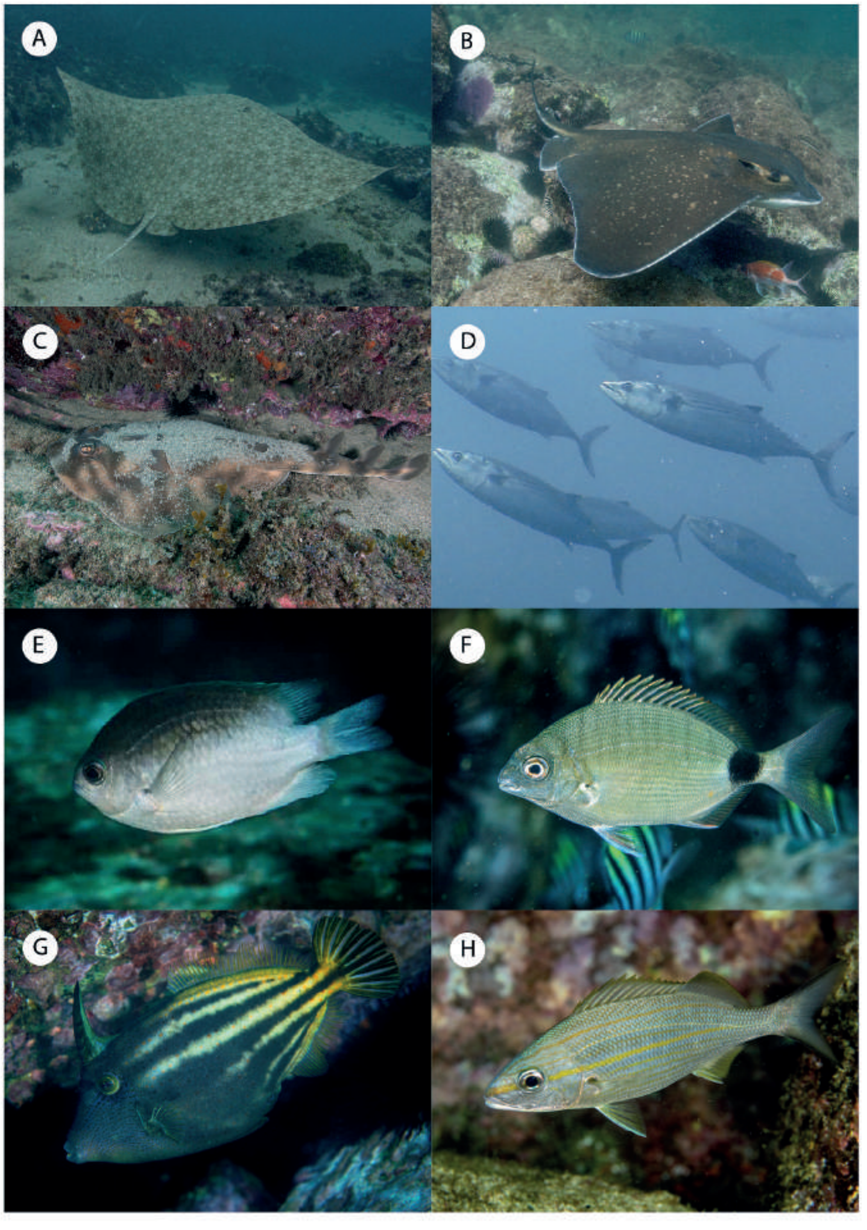

FIGURE 4 | Elasmobranchs commonly observed on Rio de Janeiro coastal islands rockyreefs: **A.** *Gymnura altavela*, **B.** *Myliobatis freminvillei*, and **C.** *Zapteryx brevirostris*; new records **D.** *Sarda sarda* and **E.** *Chromis vanbebberae*; and the most common species: **F.** *Diplodus argenteus*, **G.** *Cantherhines pullus*, and **H.** *Haemulon aurolineatum*. Photos: Augusto A. Machado (**A–B**), Suzana Guimarães (**D**), Áthila A. Bertoncini (**C, E–H**).

FIGURE 5 | Rare fish species recorded on Rio de Janeiro coastal islands rocky reefs: **A.** *Thalassoma noronhanum*, **B.** *Paranthias furcifer*, **C.** *Xyrichtys splendens*, **D.** *Clepticus brasiliensis*, **E.** *Eques lanceolatus*, **F.** *Uraspis secunda*, **G.** *Scarus zelindae* and **H.** *Ptereleotris randalli*. Photos: Áthila A. Bertoncini (**A–B**, **E–H**), Augusto A. Machado (**C, D**).

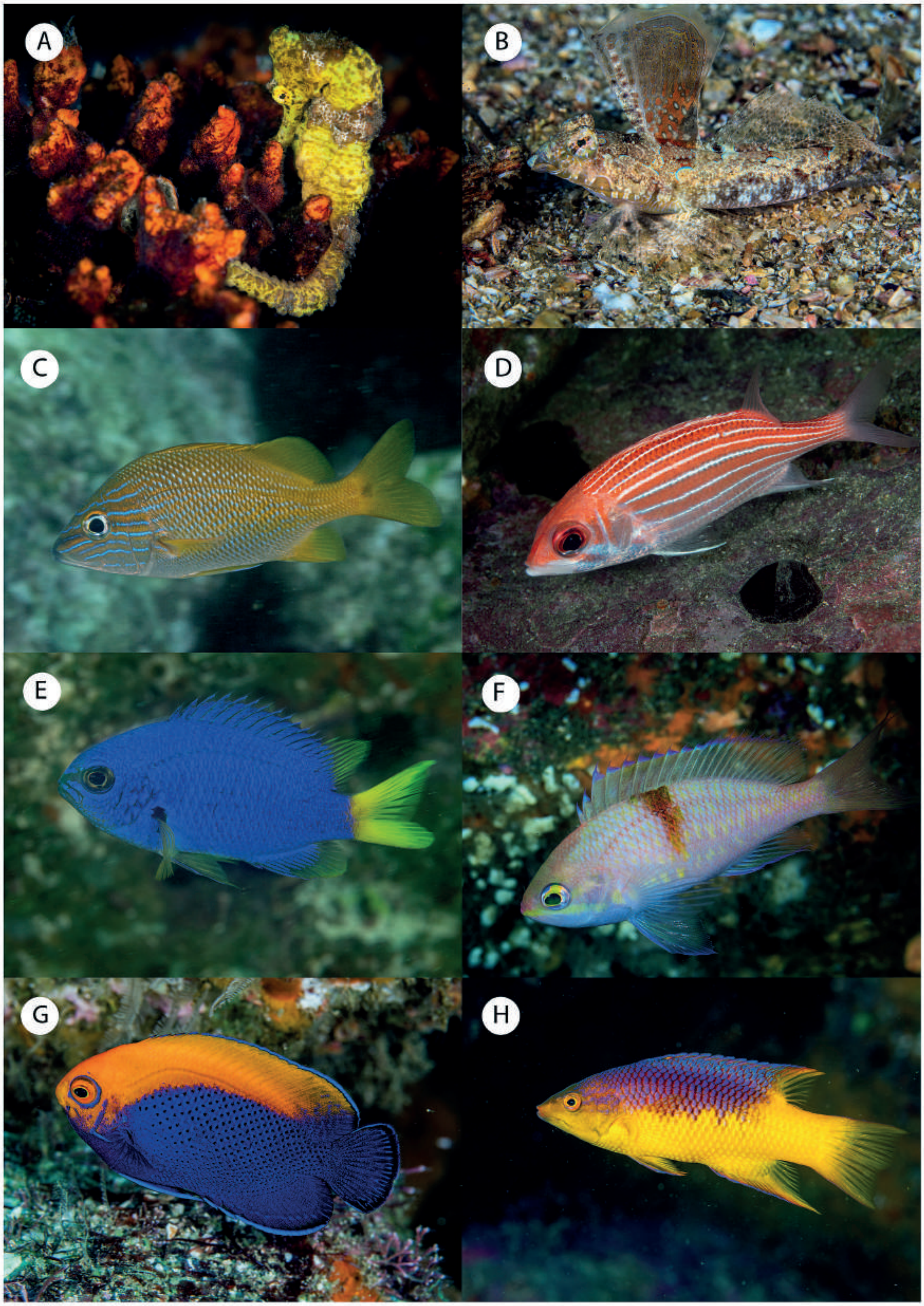

FIGURE 6 | Rare fish species recorded on Rio de Janeiro coastal islands rockyreefs: **A.** *Hippocampus reidi*, **B.** *Callionymus bairdi*, **C.** *Haemulon plumierii*, **D.** *Sargocentron bullisi*, **E.** *Chromis flavicauda*, **F.** *Pronotogrammus martinicensis*, **G.** *Centropyge aurantonotus*, and **H.** *Bodianus rufus*. Photos: Áthila A. Bertoncini.

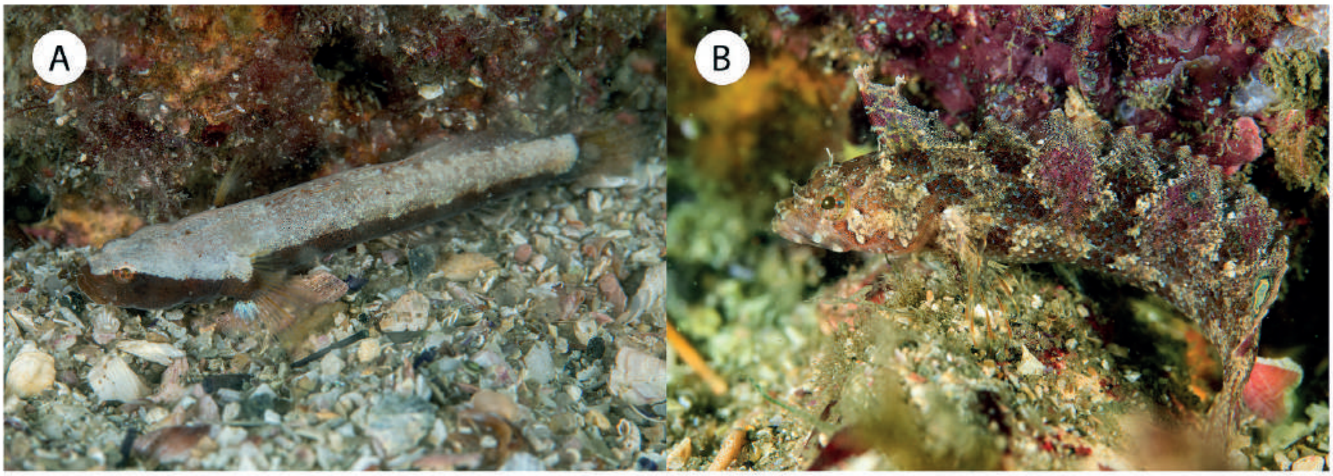

FIGURE 7 | Two cryptic species observed at a particular gravel bottom at Tijucas Archipelago. **A.** *Gobulus myersi* (new record) and *Paraclinus spectator*. Photos: Áthila A. Bertoncini.

was observed in Redonda Island at 8 meters deep. A single individual was sighted at a sampling video (Fig. 8A and in the video **S1**) in March 2019 swimming over the rocky reef covered by turf algae, among native fish species (*i.e.*, *Acanthurus bahianus*, *Acanthurus chirurgus* among others) and in February 2022, it was again observed at the same location (Suzana Guimarães, Projeto Ilhas do Rio researcher) at the same location, and on April 2022 by the authors (Fig. 8B). This species is easily identified observing its color pattern, white body with a pair of black bands, yellow truncate caudal fin, and dorsal fin spine especially long (Randall, 1995; Adelir-Alves *et al*., 2018; Froese, Pauly, 2022).

Conservation status. The fish species of coastal islands and surroundings were categorized following IUCN and ICMBio Red lists of threatened species (Fig. 9). According to IUCN, approximately 71.28% of species are assigned as Least Concern (LC), 7.45% are Data Deficient (DD), 4.26% Near Threatened (NT), and 6.74% Not Evaluated (NE). A total of 10.3% are considered threatened, being 7.45% assigned as Vulnerable (VU), 2.13% Endangered (EN) and 0.71% as Critically Endangered (CR). In parallel, the Brazilian red list (ICMBio, 2018) considers 66.31% of the species as LC, 12.41% are DD, 7.8% NT, and 2.84% are NE. Threatened species account to 10.6%, where 6.03% are VU, 2.13% EN, and 2.48% CR.

Fish richness along Rio de Janeiro and Maricás coastal islands. The richness from coastal islands of Rio de Janeiro and surroundings were widely represented through different sampling techniques (Tab. 1). We present the numbers of species recorded per archipelago, disregarding the number of islands sampled in each archipelago, where Cagarras Islands Natural Monument presented 181 fish species, with 58 exclusive species. In the Maricás Archipelago, 120 fish species, being six exclusives, whereas 115 species were recorded in Tijucas Archipelago, with 11 exclusive records (Fig. 10). In addition, samples from Rasa Island provided 108 records and in Cotunduba island, which is located within the Paisagem Carioca Municipal Natural Park – at the entrance to Guanabara Bay – 62 fish species were recorded.

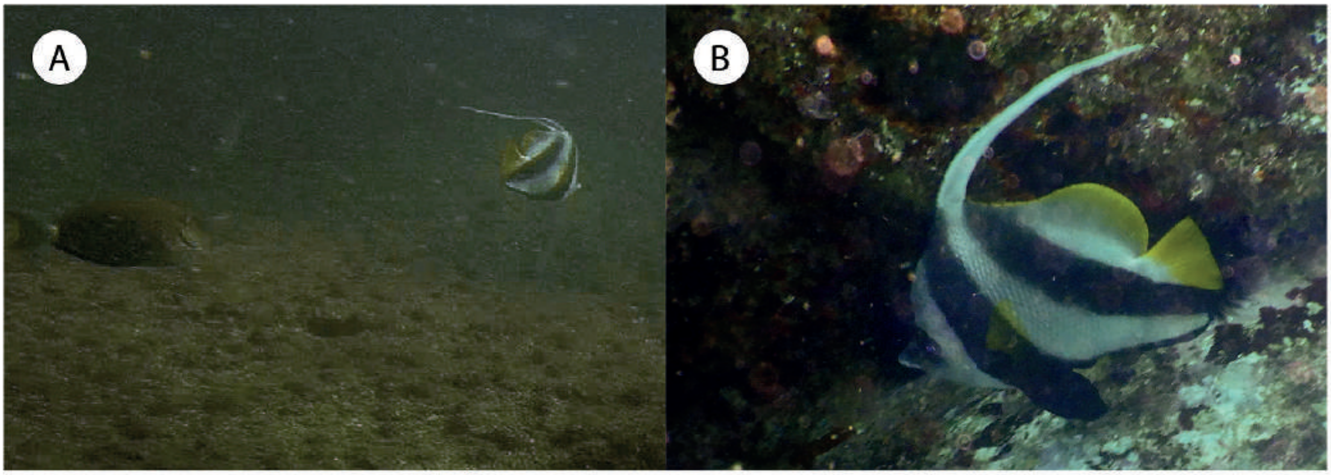

FIGURE 8 | *Heniochus acuminatus*. **A.** The SRV frame recorded on MAR 2019 at Redonda Island, inside of the MPA, close to *Acanthurus bahianus*; **B.** *H. acuminatus* photographed in April 2022 (photo by Augusto A. Machado).

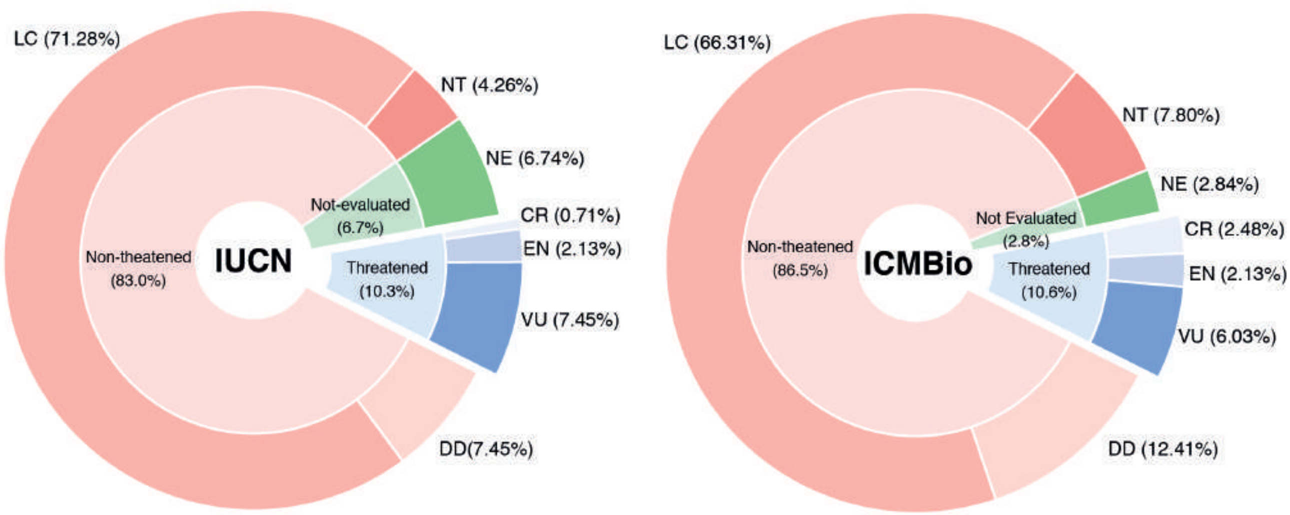

FIGURE 9 | Doughnut chart showing the assigned categories (%) of threatened fish species according to the IUCN and the Brazilian (ICMBio, 2018) red lists. CR = Critically Endangered, DD = Data Deficient, EN = Endangered, LC = Least Concern, NE = Not Evaluated, NT = Near Threatened, VU = Vulnerable.

We assessed the number of reef fish occurring simultaneously among archipelagos. The MONA Cagarras (MCA) and Maricás Archipelago presented the highest number of species in common with 112 fish species, representing 39.8% of total, that can be seen in both areas, followed by 102 species in MONA Cagarras and Tijucas Archipelago (36.3%), Maricás and Tijucas Archipelago with 93 species (approximately 33.1%) and finally only 91 or 32.4% species that can be seen in the three archipelagos (Fig. 10).

New records. This study provides 21 new records never reported for these archipelagos, occurring along the coasts of Rio de Janeiro and Maricá cities (Fig. 1). Among the sampled areas, four new occurrences were reported in the Tijucas

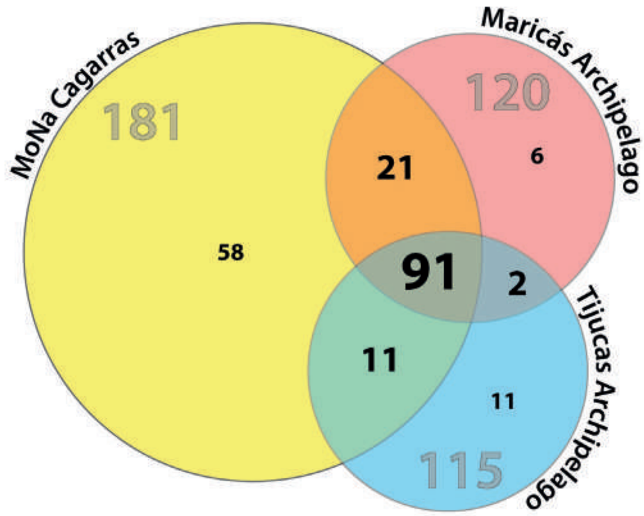

FIGURE 10 | Venn diagram representing exclusive and shared species richness recorded in the study areas: large-bold-grey numbers are the total number of species in each area; small numbers represent exclusive species in each area; medium size numbers represent the share between/among areas.

Archipelago: *Xiphias gladius* by spearfishing close to the islands, *D. macarellus* (UVC), *C. parallelus* (SRV), and *G. myersi* (UVC, Fig. 7A). The MONA Cagarras presented the greatest number of new records: *M. mola* was sighted on board close to Cagarra Island, while *D. punctatus* was observed by UVC in Comprida Island. Redonda Island provided the following new records: *Rhincodon typus* sighted on board within the MONA Cagarras Island ring, *R. bonasus*, *C. vanbebberae* (Fig. 4E), and *M. martinicus* by UVC, *S. sarda* (Fig. 4D) was sighted by Ilhas do Rio associated researchers, *H. patagonicu*s was detected through fishing activities in the surroundings of the MPA and the non-native species *H. acuminatus* registered by SRV, within of the MPA. Additionally, *O. vicinus* was observed on Rasa Island inside its sand burrow and *H. crinitus* was seen amongst the gravel bottom. The samples performed on Cotunduba Island, at the entrance of Guanabara Bay, provided records of *R. canadum* by SRV and *D. macarellus* (UVC), while Maricás Archipelago contributed with three new records from UVC: *X. splendens*, *M. martinicus* and *C. saepepallens*. Finally, at the Z13 Fishermen colony, which fishing grounds are in the vicinity of the MONA Cagarras, three records were provided: *N. cepedianus*, *P. ramosus*, and *L. guttatus*.

DISCUSSION

In order to carry out scientific research and survey of marine species biodiversity, the Ilhas do Rio Project started in 2011 to improve knowledge, developing a huge effort in the biodiversity assessment in the Coastal Islands of Rio de Janeiro, specially, the then recently created MPA, MONA Cagarras. Since then, SCUBA diving surveys, documenting the rich biodiversity have been carried out to provide basic knowledge to build up public policies, such as the MPA's Management Plan and to enhance the knowledge of the surrounding islands.

To assess fish species richness and reduce impacts, non-destructive techniques have been employed, providing relevant scientific results with minimal environmental disturbance. The use of complementary sampling techniques, especially UVC and SRV, was essential to achieve the important new records (n = 12) of species never recorded before in this study, such as the Green razorfish, *X. splendens* (Maricá Islands) (Fig. 5C); and the collaboration of Ilhas do Rio associated researchers (n = 2), that *in situ* reported the Sunfish, *M. mola*, and the Atlantic bonito, *S. sarda* (Fig. 4D).

Also, the important long-lasting relationship of researchers from Ilhas do Rio Project and the fishermen colony, provided unique records (n = 4), such as the offshore Opah, *L. guttatus*; the Broadnose sevengill shark (*N. cepedianus*), that was reported by fishing data at Z13 fishermen colony from Copacabana, Rio de Janeiro. We had 63 species (22.3%) being provided by fishermen, which is similar with the reported by Pinheiro *et al.* (2015), where out of the 221 recorded species, 26% were exclusively provided by fishermen. In addition, the spearfishing activity recorded the Broadbill swordfish (*X. gladius*) and the Patagonian seahorse (*H. patagonicus*) was caught by bottom trawling. It is paramount to develop a good relationship and share the knowledge with fishermen in order to receive new records for the studies sites.

The submersible rotating video system (SRVs) proved to be of great power in detecting species, such as the exotic Longfin Bannerfish, *H. acuminatus*, first observed by this method, in a site often visited by researchers at Redonda Island. We emphasize the importance of using multiples and complementary techniques in fish biodiversity survey studies.

The inventory herein brings a combination of different observational and fisheries records, allowing the scientific assessment of rocky reefs and the surrounding pelagic and soft-bottom environments from Coastal islands of Rio de Janeiro and Maricá, contributing thus to improve conservation and management efforts in a broader area. Our observations provided 282 fish records and 21 new species, including an exotic species, representing a significant increase (over 7.6%) in the checklist, considering previous studies in these Islands (Monteiro-Neto *et al*., 2013, Bertoncini *et al*., 2019). Marine coastal areas are known as important habitats for fish communities (Kume *et al*., 2021), thus recognizing the attributes of fish communities for future comparisons is likely to have consequences for the provision of ecosystem services such as fisheries and tourism (Chong-Seng *et al*., 2012), mainly in areas with a moderate-rate of endemic species like the Rio de Janeiro and Maricá coastal islands, circa 6%, and with circa 10.5% of the species in a threatened category according to IUCN and ICMBio.

These coastal islands are known to host a high diversity of terrestrial and marine species like seabirds, fishes, corals, and other organisms (for details, see Moraes *et al*., 2013; Bertoncini *et al*., 2019). Our study contributes to the update and improvement in the knowledge about fish biodiversity in each archipelago and surrounding areas. Data revealed the greatest fish richness within the Cagarras Islands Natural Monument, comprising about the 64.2% (181 spp.) (Fig. 10) of the total fish species encountered in Coastal islands of Rio de Janeiro and Maricá cities, showing the importance of this MPA for the conservation of fish species.

Long-term monitoring efforts are widely needed in coastal islands in order to better understand the structure of fish communities and the ecological relationships of this vertebrate group with other organisms. In addition, fish monitoring data provide important information for coastal management, to protect marine resources and efforts to assess MPA effectiveness (Jentoft *et al*., 2007; Melià *et al*., 2020). Previous studies have indicated that MPAs are appropriate places for, in addition to preserving biodiversity, recovering exploited stocks (Roberts *et al*., 2001; Halpern, 2003), especially considering that most of the studied area is subject to recreational and artisanal fisheries. It is important to highlight that the MONA Cagarras, together with its surrounding areas (including Rasa and Cotunduba islands) was, in 2021, recognized as a Hope Spot for conservation of marine biodiversity by the international nonprofit organization Mission Blue (www.mission-blue.org/hope-spots).

However, this international recognition along with the national protection such as the "Natural Monument" category, bring the spotlight to these islands, but alone they will not save nor guarantee the protection of the reef fish fauna. It is important to rethink the design and limits of the MPA, in order to provide a proper protection for deeper rocky reefs, once the MPA limits of 10m from the island's coast leave much of these areas unprotected.

The presence of exotic species such as the *H. acuminatus*, and *Cephalopholis taeniops* (Valenciennes, 1828) - previously collected in 2006 (Garcia *et al*., 2018) within MONA Cagarras, calls the attention for the management and conservation of this important area. In Brazil, there is no evidence of successful invasion of the Longfin Bannerfish. The first report occurred in 1999 from Armação dos Búzios, Rio de Janeiro State (Moura, 2000), while in 2013 it was recorded at Laje de Santos, São Paulo State (Luiz *et al*., 2014), and in 2017 it was sighted in a shipwreck in South Brazil (Paraná) (Adelir-Alves *et al*., 2018). According to Luiz *et al.* (2014) there are two possible hypotheses for the introduction in Brazil: an aquarium release or long-distance natural dispersal from the Indian-Ocean. We suspect that the former hypothesis might be the case once this species is commonly traded by aquarists in the metropolis of Rio de Janeiro. Nevertheless, *H. acuminatus* is a planktivorous species and its occurrence is unlikely to cause significant impacts in the ecosystem's health.

Additionally, the detection of alien species such as the Azores Chromis, *Chromis limbata* (Valenciennes, 183) (Leite *et al*., 2009; Anderson *et al*., 2017), and the Toadfish, *Opsanus beta* (Goode & Bean, 1880), both established in some Brazilian estuaries (Cordeiro *et al*., 2020) warns about the need to prevent the arrival and establishment of other exotic species, such as the lionfish (*Pterois* spp.) which has recently been continuously recorded in the Brazilian offshore island of Fernando de Noronha, and in coastal fisheries in North Brazil (Luiz *et al*., 2021). In the Caribbean Sea, the lionfish invasion caused several impacts due to the voracious generalist predatory behavior, while depicting exponential increases in its abundance without significant natural predatory control (Côté *et al*., 2013; Samhouri, Stier, 2021). The introduction of non-native species through human vectors is globally acknowledged to represent a major threat to biodiversity and ecosystem health (Sutherland *et al*., 2010), and, according to IOC-UNESCO (2022) it is critical to understand multiple ocean stressors and target efforts at minimizing their impacts to lessen the cumulative pressure on the resilience and health of marine life.

Besides the exotic fish species, the presence of other invasive species along Brazilian reef environments, specially composing the bottom community, such as cnidarians, *e.g.*, *Stereonephthya* sp. (Ferreira, 2003), *Sarcothelia* sp. (Xeniidae), and *Briareum* *hamrum* (Gohar, 1948) (Briareidae) (Menezes *et al*., 2022) and the Sun coral (*Tubastraea* spp.), already established in the study area (Silva *et al*., 2022), may cause negative impacts on rocky reef fish communities (Miranda *et al*., 2018), being studied (AAM, work in progress) in Rio de Janeiro's archipelagos.

Coastal islands from Rio de Janeiro and Maricá cities are close to large urban centers (7 million people live around Guanabara Bay) and suffer a great influence of marine pollution (Guanabara Bay and Ipanema Sewage Outfall), unmanaged tourism, ornamental fish trade, illegal and unregulated fishing practices, and marine exotic species (ICMBio, 2020). In order to understand how these impacts may influence the health of fish communities, this background knowledge about biodiversity and their ecological relationships is paramount. In this context, long-term monitoring programs are crucial to assist MPA managers in the development of preventive plans for biodiversity conservation of this area, that shelters one of the Brazilian hope spots.

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Rocky reef incursions: challenges faced by reef fishes in a Brazilian Hope Spot region

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ABSTRACT

Biodiversity conservation has been a critical challenge faced by environmental managers worldwide. From 2020 to 2022, a total of 576 underwater visual censuses focused on reef fishes, marine litter (ML), and non-native species were performed in the newest Brazilian Hope Spot, to understand the distribution, characteristics, and effects of ML and *Tubastraea* spp., on the reef fish community. Plastic was the main category recorded (34.54 %), followed by Metal and Line (mostly fishing gear within a Marine Protected Area). *Tubastraea* spp. was widely distributed, especially between 10-20 meters deep. The *t*-test analysis showed that fish abundance and richness were significantly higher at low *Tubastraea* cover areas. Our efforts present the baseline of ML (mean 1.92 ± 1.5 items/100 m^2) and non-native species occurrence (15) and distribution (including three new records) showing their negative impacts on rocky reef ecosystems and provide managers support in the elaboration of marine conservation strategies.

1. Introduction

Biodiversity conservation has been an urgent challenge due to increasing environmental disturbances. Biological diversity changes can cause negative effects on ecological systems altering ecosystems productivity, species trophic web complexity, and environmental resilience capacity (Tilman et al., 1996; Donohue et al., 2016). Over the years, the anthropogenic impacts are becoming more evident worldwide, mainly in inhabited coastal areas due to the intensification of human activities capable of causing environmental degradation on coastlines (Halpern et al., 2008; Henriques et al., 2013; Carneiro et al., 2021). In order to mitigate marine environmental impacts (e.g. overfishing, unsustainable tourism), the implementation of Marine Protected Areas (MPAs) emerges as an important and strategic tool for the protection of biodiversity and ecosystem services (Borja and Elliott, 2013; Blowes et al., 2020).

MPA are delimited spaces through laws to protect the ecosystem's biodiversity and its natural resources. Among the benefits, MPAs play an essential role in protecting biodiversity and reducing anthropogenic disturbances that directly affect native species (Babcock et al., 2010; Edgar et al., 2014). In the case of no-take MPA, which are zones that do not allow any extractive activities (i.e. fishing, mining, and drilling), enhancements in fish biomass (i.e. size classes) and abundance are expected to be higher inside such areas than outside them (Lester et al., 2009; Rolim et al., 2019), where fishing is permitted. Assessing the MPAs' effectiveness represents a primary challenge to understanding the potential for biodiversity protection reached by these areas (Bates et al., 2019). In Brazil, MPAs represent a small part, circa 26.4 %, of the Brazilian Exclusive Economic Zone (CNUC-MMA, 2019). Unfortunately, MPAs usually lack long-term monitoring programs and have low enforcement levels (Oliveira-Júnior et al., 2016; Bertoncini, 2009).

The Cagarras Islands Natural Monument (MONA Cagarras) is a no-

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take MPA located in southeastern Brazil. MONA Cagarras comprises four islands (Palmas, Comprida, Cagarra, and Redonda), two islets (Cagarra and Redonda islets), and protection extends 10 m off the islands. These islands have high marine biodiversity, including hundreds of macroalgae, invertebrates, and reef fish species (Bertoncini et al., 2019). Due to its proximity to the coast and astonishing scenic beauty, this area is used for recreation (Stand Up Paddle, Hawaiian Outrigger Canoeing, Recreational Scuba Diving) enhancing local tourism and fishing activities income (ICMBio, 2021a). Moreover, MONA Cagarras and the surrounding area were recognized as a Hope Spot for the conservation of marine biodiversity by the international nonprofit organization Mission Blue (https://missionblue.org/hope-spots/). Despite its relevance, this area has suffered from several environmental impacts (e.g. non-native and invasive alien species, marine litter, sewage discharge, and unsustainable fisheries) (ICMBio, 2020). Additionally, the region is under the influence of heavy maritime traffic from port and marina facilities in Guanabara Bay (Messano et al., 2019; ICMBio, 2020).

Among the major impacts that affect MONA Cagarras, marine litter (ML) represents a special threat to the local marine environment and has two primary sources: Nautical activities (e.g., Tourism and fishing) and land-based litter originating from coastline, rivers, the Guanabara Bay, and beach waste (UNEP, 2009; Cardozo et al., 2018). The marine degradation by anthropogenic debris may cause negative effects on economic activities, such as tourism (Lo et al., 2020), and may cause deleterious effects on the composition of natural communities (Tutman et al., 2017; Henderson and Green, 2020), once sessile non-native species may take advantage of the artificial substrate (Mantelatto et al., 2020), contributing to the spread of opportunistic non-native species (NNS) and invasive alien species (IAS).

Invasive alien species and marine litter pose a major threat to coastal and marine ecosystems (Bax et al., 2003; Ryan, 2015). According to Ferreira et al. (2009) due to the extensive Brazilian coastline (~8000 km) distributed between tropical and subtropical ecosystems, Brazil is one of the countries with the greatest introduction of NNS in the world. Among the species, the Sun coral (*Tubastraea* spp.) is recognized as an IAS and widely spread along Southeastern Brazilian (Silva et al., 2014; Creed et al., 2017; Machado et al., 2021), including the MONA Cagarras (Batista et al., 2013; Silva et al., 2022). Previous studies in Brazil have shown that *Tubastraea* spp. is able to cause necrosis in native coral species and, with increasing bottom cover, leading the loss of native community's structure and function (Creed, 2006; Lages et al., 2011; Miranda et al., 2016), such as in the reef fish community (Miranda et al., 2018).

Reef fish are valuable marine resources capable of providing food and a source of income for thousands of people worldwide (Sadovy, 2005). They are widely spread in tropical coastal marine communities and may vary according to environmental factors, such as depth and temperature (Pauly et al., 2002; Nelson et al., 2016). The reef fish biodiversity at MONA Cagarras has been extensively studied (e.g., Monteiro-Neto et al., 2013; Bertoncini et al., 2019; Machado et al., 2022). However, there are few studies related to the effects caused by stressors, such as ML and IAS (e.g. Sun coral) on the fish community.

In this context, the hypothesis proposed is that the Sun Coral and marine litter represent challenges to the reef fish community negatively impacting reef fish richness and abundance. This study aimed to assess the presence of marine litter and non-native species distribution and investigate their effects on reef fish communities along the coastal islands of Rio de Janeiro. These two threats were already pointed out as priority study according to the Research Plan of MONA Cagarras (ICMBio, 2021b). Thus, the present study also intends to assist decision-makers in elaborating marine conservation strategies and propose short, medium, and long-term management and conservation measures/actions for the MONA Cagarras and surrounding areas.

2. Materials and methods

2.1. Study area and fieldwork

The study was developed seasonally between September 2020 and June 2022 along the coastal islands of the state of Rio de Janeiro, located between south Rio de Janeiro and Maricá cities (Fig. 1), through the Underwater Visual Census (UVC) in each site. From West to East, Pontuda Island is part of the Tijucas Archipelago and is positioned at approximately 1.7 km off Barra da Tijuca beach. The Cagarras Islands Natural Monument (referred here as MONA Cagarras) is located approximately 5 to 8 km off Ipanema Beach, Rio de Janeiro. In this area, samplings were performed at Comprida and Redonda Islands (both inside of the MPA). In addition, samples were taken in two sites of Rasa Island (southwest side, known as "Portinho" and northeast side, known as "Guincho"), which are close (~ 4.5 km) to the MONA Cagarra. The sampling was also carried out at Marica Island, which is 3.5 km off Itaipuaçu Beach, in Marica City. Due to the proximity to the mainland, these marine areas are commonly sought by boat trips, recreational SCUBA divers, stand-up paddle practitioners, and recreational/commercial fishers. Furthermore, the Tijucas Archipelagos, MONA Cagarras, and Rasa Island are under the influence of polluted waters, such as Joatinga Channel (Barra da Tijuca) and the Ipanema submarine sewage outfall, and the Guanabara Bay.

2.2. Marine litter and Sun coral (Tubastraea spp.) surveys

Due to the proximity of the coast, the origin of marine debris was assigned to coastal activities, such as sanitary and sewage release through the Guanabara Bay, Ipanema Submarine sewage outfall, Joatinga Channel, and litter disposed on beaches by users. In addition, in the coastal islands of Rio de Janeiro and its surroundings, the sea-based litter, i.e. released in situ, is frequently released by vessels of uncontrolled tourism and recreational fisheries activities in the surrounding area. Marine litter on the sea floor and *Tubastraea* spp. were accessed by two scuba divers and evaluated through 40 m^2-belt transects (20 m × 2 m). A total of 12 transects were performed on each site quarterly (6 in shallow waters [up to 10 m] and 6 in deep waters [11 to 20 m]). Benthic ML was identified, counted, and classified into five categories: Plastic; Fishing Line; Glass; Metal, and Others (e.g., wood, tire, cloth).

The Sun Coral (*Tubastraea* spp.) coverage degree was accessed for each 40m^2-transect following the DAFOR scale (Sutherland, 2006). The Sun Coral was classified as Dominant when coverage areas were equal or larger than 1 m^2; Abundant when *Tubastraea* spp. occurred commonly forming patches between 50 up to 100 cm in diameter; Frequent when isolated colonies or in small groups were between 10 and 50 cm in diameter; Occasional when five to ten colonies were counted per transect; Rare when it was observed one to five colonies per transect and Absent when no colonies were observed in the at all (Silva et al., 2014).

2.3. Reef fish sampling

Fish communities were assessed by Underwater Visual Census (UVC) through 40 m^2-belt transects (20 m × 2 m). In this method, divers swam for 5 minutes along 20 m strip transects, observing 1 meter on each side, parallel to the rocky reef shore on each sampling site. The surveys were carried out at a minimum visibility of 3 m, identifying, and counting the fish to obtain abundance and richness data. To reduce potential diver error, the same divers performed all samplings. In summary, during transect release, the richness and abundance of fish were obtained. While recovering the transect, we quantified and classified litter and *Tubastraea* spp. in the transect area.

2.4. Non-native species monitoring

The inventory of NNS was compiled from previously published

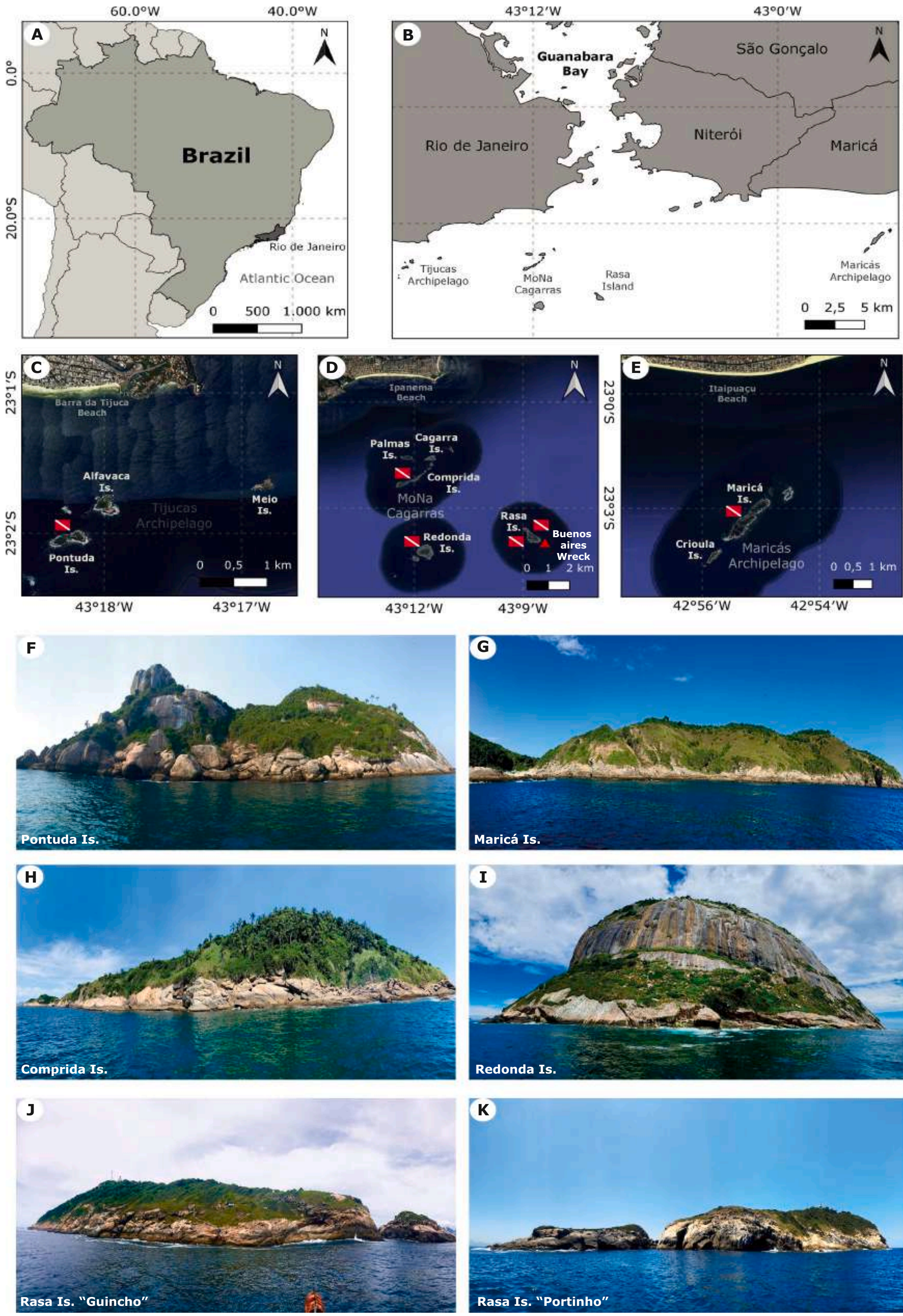

Fig. 1. Study area of coastal islands of Rio de Janeiro. A: Brazil map; B: Coastal islands of Rio de Janeiro State between Rio de Janeiro and Maricá cities; C: Tijucas Archipelago; D: MONA Cagarras and the Rasa Island located outside the MPA with two sampling areas: Northeast side (known as "Guincho") and southwest side ("Portinho"); E: Maricás Archipelago; Dive flags represent sampling points. The sampling areas panoramic photos (F-K) were taken by Augusto A. Machado.

scientific papers and books. In addition, intensive underwater surveys were carried out to verify the distribution of previously reported NNS and to detect possible new records. In this method, a pair of divers swam randomly for 60 min along the rocky shores, looking for NNS and recording in underwater wet note.

2.5. Data analyses

A descriptive analysis of the benthic ML and its categories are presented through a stacked bar chart along the sampling areas, using a color-blind friendly pallet from Adobe's color-accessibility tool (see https://color.adobe.com/pt/create/color-accessibility). Grouped bar charts are used to represent seasonal mean litter density. Seasonal analyses considered Summer (January to March), Fall (April to June), Winter (July to September), and Spring (October to December). The *Tubastraea* genus distribution is represented through the DAFOR scale using a scatter chart between shallow and deep waters during sampling years.

To assess the effects of the marine litter and *Tubastraea* genus on reef fish abundance and richness, the ML data were grouped in categories according to the number of items recorded in each transect, Low (0 to 3 items of ML) and High (4 to 7). The DAFOR data were also grouped into two major groups of highest coverage categories, composed of Dominant, Abundant, and Frequent (DAF), and lowest coverage categories, composed of Occasional, Rare, and Absent (ORA).

All fish species were recorded per transect. However, for the data analysis, were considered species that interact with rocky reefs (e.g., Roving Herbivores, Territorial Herbivores, Mobile Invertivores, Sessile Invertivores, and Omnivores). The richness and abundance normality were tested through the Shapiro-Wilk test and then Standardized by logarithmic transformation. The Two Sample *t*-test was used to verify if there were significant differences in the abundance and richness of reef fish between areas with high and low abundance of marine litter and *Tubastraea* genus, using a significance level of 0.05. Data analyses were performed using software R (R Core Team, 2021) and maps were elaborated using QGIS 3.16 (QGIS Development Team, 2022).

3. Results

3.1. Marine litter items amount

A total of 576 transects (96 in each of the six sampling sites) of marine litter and *Tubastraea* genus were performed. Marine litter observations through Underwater Visual Census provided the detection of 443 litter items, with a mean value of 1.92 ± 1.5 items / 100 m^2. In Maricá Island a total of 129 litter items were recorded, followed by Pontuda Is. (Tijucas archipelago) with 122 records, Redonda Is. (79 items), Guincho at Rasa Is. with 50 counted items, Comprida Is. (44) and finally Portinho at Rasa Is. with 19 items (see Fig. 2).

The main category of ML observed was plastic which represented approximately 34.54 % of the total, followed by lines and metal with 27.09 % and 23.25 % respectively (mainly fishing gear), then Others category (10.61 %) such as wood, clothes, others, and the least abundant the glass category represented with only 4.51 % of the total ML (Fig. 2). The plastic category represented the major number of records on Maricá, Pontuda, and Comprida Islands, followed by lines and metals. At Redonda Island, lines, and metals, mostly fishing gear, dominated the records. At the Guincho sampling site (Rasa Is.), the others, plastic and line categories showed approximately similar values (14, 13, and 13 items respectively). On the benthic habitat of the Portinho site (Rasa Is.), the main categories recorded were line and metal with 8 and 6 items observed. See Fig. 3 for examples.

3.2. Seasonal distribution of marine litter

Among the sampled seasons, Fall represented the highest number in the total of ML records compared to the other seasons (approximately 34.76 % of the total). Summer, represented 24.15 % (107 items) of items recorded, followed by Spring (20.99 %) and Winter (20.19 %). In addition, Fall represented the highest mean density of litter recorded between seasons in Maricá, Pontuda, and Redonda Islands and in the Northeast and Southwest sides on Rasa Island with 4.79 (± 3.53 items/ 100 m^2), 3.75 (± 3.39), 2.60 (± 2.93), 2.92 (± 4.49), and 0.73 (± 1.35) pieces of ML per 100m^2 (Fig. 4). However, at Comprida Island, Summer presented the highest mean density of ML compared to the other seasons (17 items).

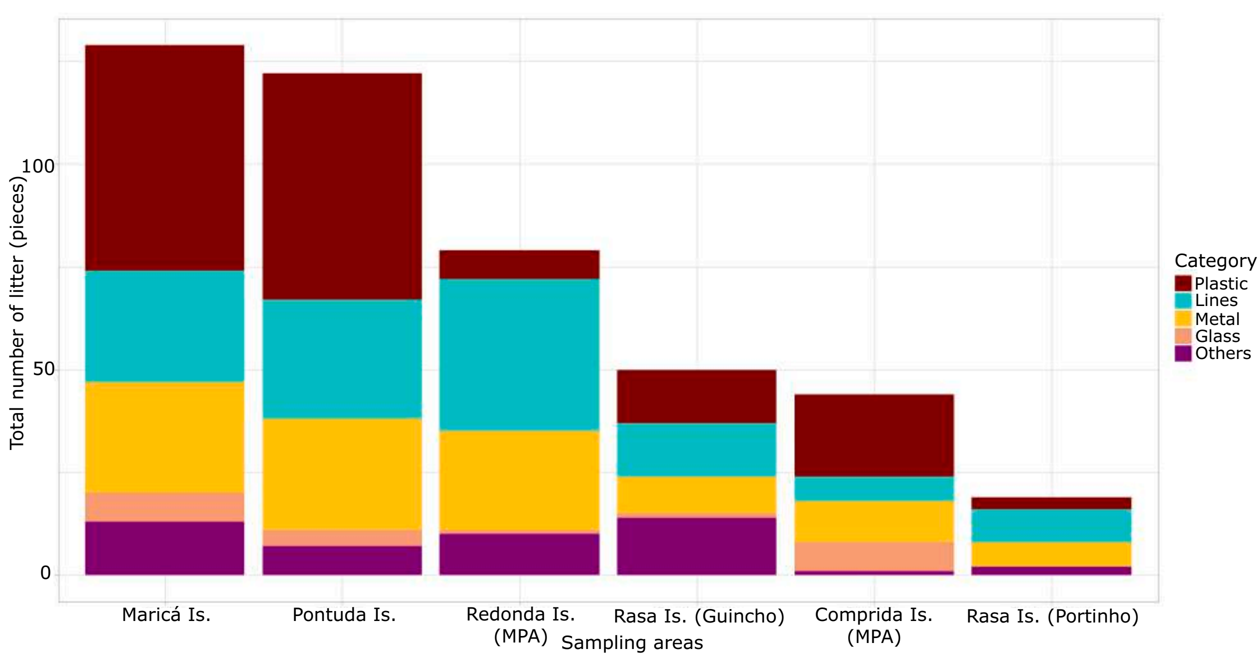

Fig. 2. Stacked Bar Chart showing the total occurrence of different benthic marine litter categories along the Coastal Islands of Rio de Janeiro.

Fig. 3. Marine litter recorded along of coastal islands of Rio de Janeiro. A. Plastic bag on top of the sea urchin (*Lytechinus variegatus*); B. Fishing line and hook-on top of the sea urchin (*L. variegatus*); C. Fish (*Balistes vetula*) caught on hook (ghost fishing); D. The sun coral (*Tubastraea tagusensis*) settled on a lost anchor; E. a glass bottleneck covered by Crustose Coralline Algae and F. Blue flip flop between rocks. Photos: Augusto A. Machado (A, D—F), Áthila A. Bertoncini (C), and Fernando C. de Moraes (B).

3.3. *Tubastraea spp. distribution*

According to the distribution of the genus *Tubastraea* along coastal islands (Fig. 5), Redonda Island (within the MPA) presented the most critical situation compared to the other islands with the highest frequency of transects classified as "Dominant", especially in deep waters (10-20 m). In the first year (Y1) 10 records and in the second year (Y2) 23, or 96 % of the deep transects were categorized as "Dominant". Portinho on Rasa Is. also presented a significant number of areas dominated by *Tubastraea* spp. (Y1–2 records, Y2–10 records), followed by Pontuda Island (Y1–2, Y2–6) and Guincho (Rasa Is.) with two records (Y1), while in the second year, five deep transects were classified as "Dominant".

Comprida Island presented a low coverage degree of *Tubastraea* spp. with two dominant transects in each year and most of the total amount of transects were classified as "Absent" (Y1–16 [67 %], Y2–10 [42 %]) in deep waters, "Rare" (Y1–6, Y2–10) and "Occasional" (Y1–2, Y1–1). Finally, in Maricá Island no colonies were detected between 10 and 20 m

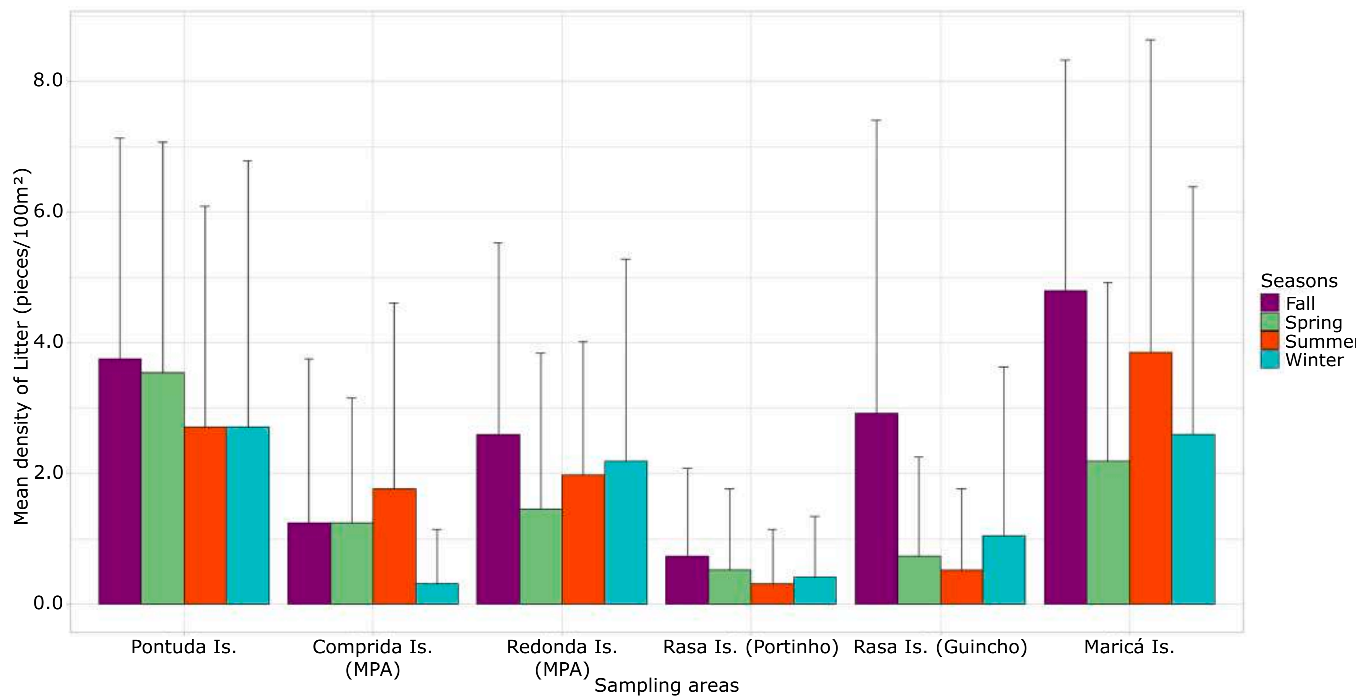

Fig. 4. Bar chart of marine litter grouped by islands representing the seasonally mean density (± SD) of litter recorded along the Coastal Islands of Rio de Janeiro.

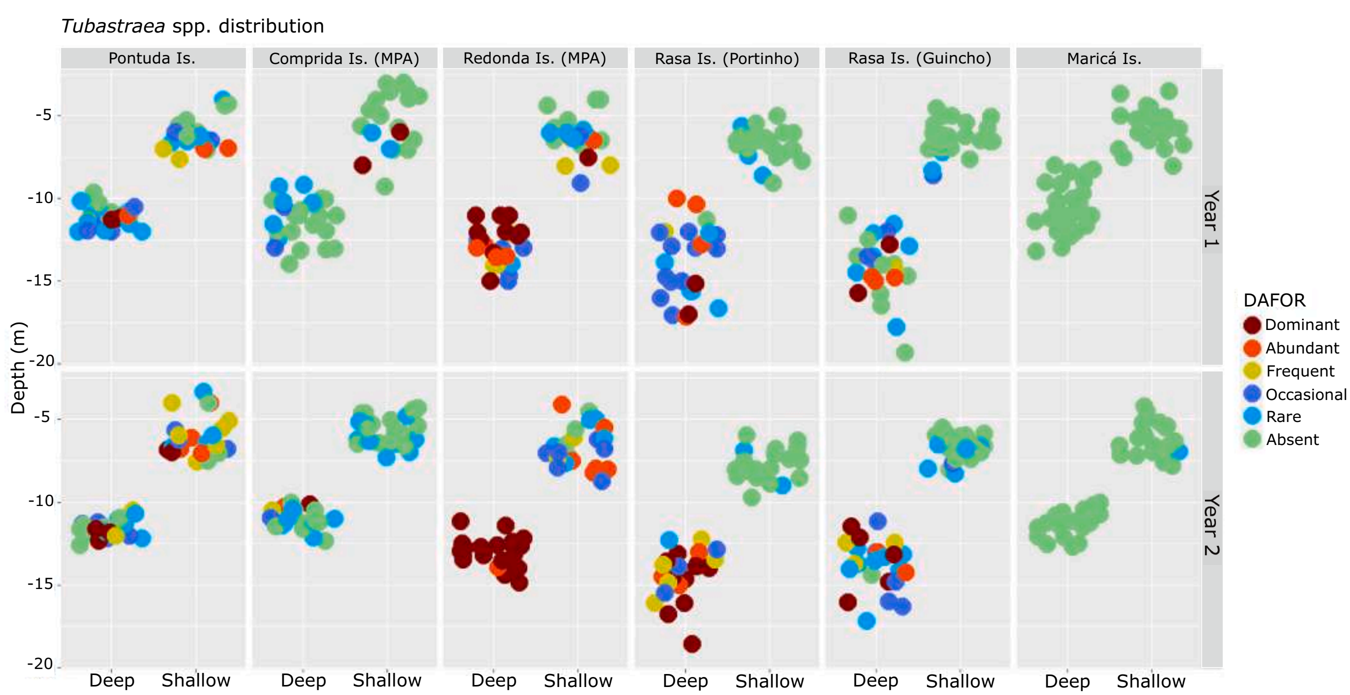

Fig. 5. Scatter chart with circles representing each transect sampled recording Sun Coral (*Tubastraea* spp.) occurrence and its semi-quantitative abundance progress along two sampling years using the DAFOR scale in the coastal islands of the Rio de Janeiro and Maricá cities. Year-1 (September-2020 to June-2021) and Year-2 (July-2021 to June-2022).

deep, i.e. 100 % of the transects performed in deep waters were classified as "Absent" during the two years of data collection.

In addition, in the shallow waters (up to 10 m) the distribution of the *Tubastraea* spp. presented low benthic coverage when compared to deep waters. In four sampled areas (Maricá Is., Portinho and Guincho at Rasa Is., and Comprida Is.), the "Absent" category was the main classification recorded in transects. However, on Pontuda Island the *Tubastraea* spp. showed no preference between shallow and deep waters with Dominant (2), Abundant (5), and Frequent (6) categories representing about 54 % of the shallow samplings for the second year there.

At Redonda Island, the genus *Tubastraea* presented a significant increment in shallow benthic coverage when comparing the samplings years. In the first year, only two transects were classified as “Abundant”, while in the second year, this number increased to five. The same happened in the “Occasional” (Y1–3, Y2–6), and “Rare” (Y1–4, Y2–5) categories. The “Absent” category was recorded in 12 transects during the first year, while the second year presented only five records.

3.4. Marine litter and Sun coral effects on rocky reef fish community

The comparison of mean fish abundances (log-transformed) between high ML areas 1.37 (± 0.26) and low marine litter areas 1.29 (± 0.33) along the deep-water stratum showed no significant differences (p = 0.2146). Similarly, on the shallow stratum the mean abundances between high marine litter areas 1.50 (± 0.32), and low ML areas 1.60 (± 0.28), presented no significant differences ($p = 0.0969$) (Table 1).

Additionally, t-test results showed that reef fish richness values in the high presence of ML was 0.13 (± 0.09), while in the low presence was 0.09 (± 0.13) for the deep stratum presented p-value = 0.1639. In the shallow stratum, the mean values of species richness were 0.16 (± 0.12) in high amounts areas of ML, while in low amounts of ML were 0.20 (± 0.08) and presented p-value = 0.0691 (see Table 1). Therefore, it was not possible to detect any significant difference in the studied ecological descriptors (i.e., abundance and richness) on the rocky shore fish community regarding ML presence.

Results regarding Sun coral coverage revealed a significant difference in mean fish abundance between high-abundance areas (DAF) and low-abundance areas (ORA) of Sun coral (See Table 1), in both the deep (p-value = 0.0194) and shallow level (p-value = 0.0086). The mean species richness data varied significantly in the deep water stratum (p = 0.0215). Nonetheless, the observed difference in mean fish abundance in shallow water was not significant ($p = 0.2792$).

The mean value of reef fish abundance recorded in the Deep level was 1.24 (± 0.04) for DAF areas (high Sun coral coverage), and in areas with low coverage (ORA) was 1.34 (± 0.02). In the Shallow stratum, the mean abundance was 1.47 (± 0.05) in DAF areas, while in low coverage (ORA) it was 1.62 (± 0.02). The results showed the highest mean values of fish abundance at low *Tubastraea* coverage areas when compared to areas with high *Tubastraea* coverage at both depth levels (Fig. 6).

The mean fish richness on High coverage *Tubastraea* areas (DAF) in the Deep stratum was 0.87 ± 0.02 log richness (Fig. 7). In contrast, in Low coverage areas (ORA) of *Tubastraea*, the fish species richness mean was 0.93 (± 0.01). In the Shallow stratum, the fish richness mean was 0.98 (± 0.05) in High coverage areas of Sun coral, while in Low coverage areas, it was 1.03 (± 0.03). The fish richness data revealed a significant difference in the Deep stratum between High and Low Sun coral coverage treatments, where more fish species were observed at Low coverage areas of the *Tubastraea*. At the Shallow stratum, there is a difference in mean richness between treatments (ORA > DAF) but not significant (see Table 1).

3.5. Non-native species distribution and new records

A total of 15 NNS were recorded along the sampled coastal islands (Table 2). *Tubastraea tagusensis* (Wells, 1982), *Perna perna* (Linnaeus, 1758), *Branchiomma luctuosum* (Grube, 1870) and *Ophiothela mirabilis* Verrill, 1867 were observed in all-sampling areas. Redonda and Comprida islands (Within the MPA) showed the highest number of non-native species (13 and 11 respectively), and both islands together are home to 93.3 % (14) of the total NNS recorded in the study area. They are followed by Maricá Island with six records, Guincho (Rasa Island) and Pontuda Islands (5), and Portinho at Rasa Island with four records.

Our efforts revealed occurrence of three new records of NNS to the region (Fig. 8). The Azores chromis (*Chromis limbata*) native to the Macaronesian islands, was recorded for the first time in July 2022 for the state of Rio de Janeiro swimming over the Buenos Aires shipwreck (Guincho’s side), among native fish species (i.e., *Epinephelus adscensionis* and *Haemulon aurolineatum*). Later in September 2022 a single specimen was sighted at Maricá Island (23°0.689′S, 42°55.140′W) representing the northernmost distribution limit on the Brazilian coast (See Fig. 8A).

The sea urchin (*Pseudoboletia* cf. *maculata*), native to the Pacific Ocean, was recorded for the first time at Redonda Island in December 2020 and was later observed spawning at Maricá Island in June 2021. In February 2022 one specimen was observed at Comprida Island (See Fig. 8B), and later five specimens were observed at Redonda, at 13 m depth.

The Green mussel (*Perna viridis*) native to the Indo-Pacific Ocean, was recorded fixed on a drifting styrofoam next to Guincho in September 2020 (See Fig. 8C). Thereafter, in June 2023 it was observed on Comprida and Redonda Islands at 5 m depth, among a *P. perna* bank, representing the first record of the Green mussel settled on a rocky reef in the Coastal Islands of Rio de Janeiro (within MONA Cagarras). This species has been previously recorded inside Guabanara Bay (Messano et al., 2019).

4. Discussion

4.1. Marine litter amount and its characteristics

Marine litter of anthropogenic origin represents a great danger to marine biodiversity, and it can be considered a threat due to the different negative impacts on native species, such as suffocation, entanglement, and effects on human health (Kühn et al., 2015; Barboza et al., 2018), as well as aesthetic impacts that can cause detrimental effects on tourism. The marine debris origin may be reported by multiple anthropogenic activities depending on the oceanographic process and distance from the coastline (Galgani et al., 2000; Ramirez-Llodra et al., 2013; Lebreton et al., 2017), but when it reaches the sea bottom it may cause negative interactions involving a vast number of animals/groups, for instance, invertebrates, fishes, and sea turtles, among others (Laist, 1997; Havens et al., 2011; Gall and Thompson, 2015).

The study shows that Maricá Island was the most affected area, with 129 items recorded, with densities as high as 4.79 items/100m^2. The Plastic, Lines, and Metals categories represented approximately 89 % of the observed items. This region is frequently used by fishers that spend many days camping and catching fish around the island (AAM pers. observ.). Not rarely, the area is surrounded by nets along the rocky reef. In addition, Guanabara Bay and the coastal islands of the Rio de Janeiro region, including Maricá Island are influenced by the South Atlantic Central Water (Melo, 2004). This oceanographic current may be carrying anthropogenic debris released on Guanabara Bay and beaches along the coast.

Table 1
Results of the Two Sample t-test comparing means of ecological descriptors (abundance and richness) in deep and shallow levels on different marine litter densities and *Tubastraea* spp. abundance classes. *p-value <0.05 and ** p-value <0.01.

Ecological descriptors	Depth	Marine litter			Sun coral (*Tubastraea* spp.)		
		t	df	p-value	t	df	p-value
Abundance	Deep	1.2439	286	0.2146	−2.3518	286	0.0194*
	Shallow	1.6658	286	0.0969	−2.6458	286	0.0086**
Richness	Deep	1.3958	286	0.1639	−2.3112	286	0.0215*
	Shallow	1.8244	286	0.0691	−1.0842	286	0.2792

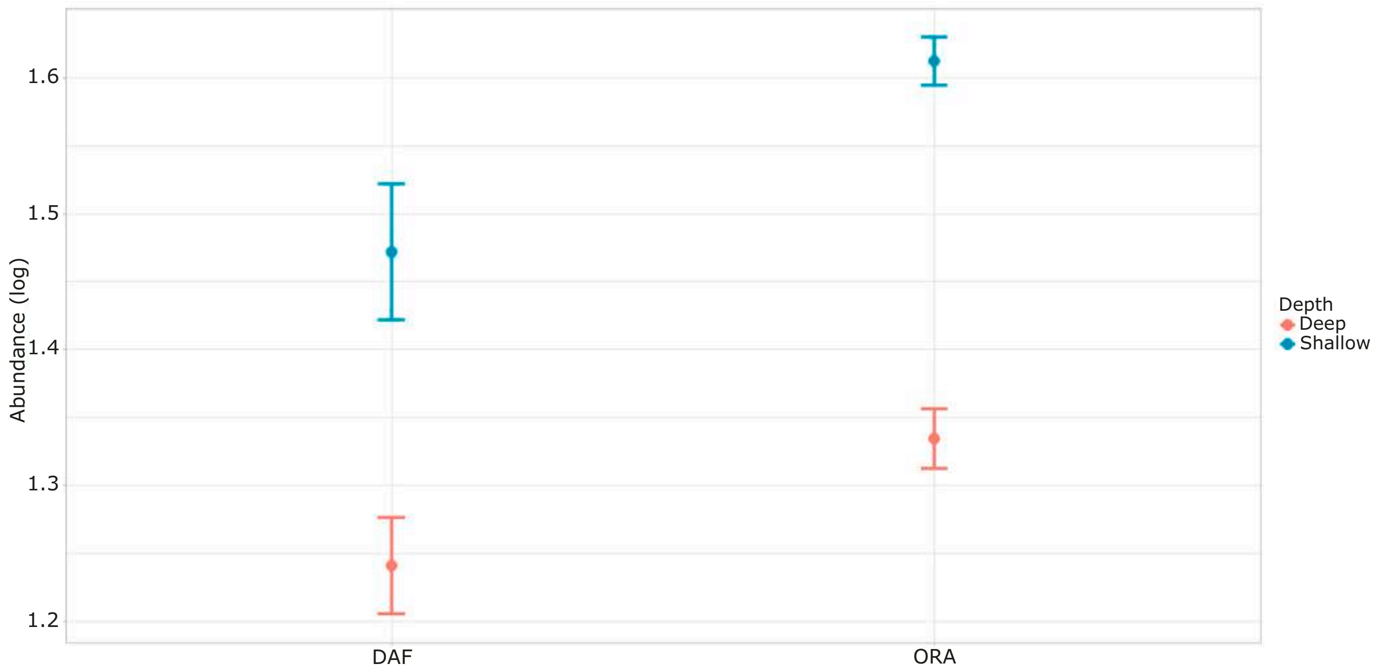

Fig. 6. Plot with standard deviations and the circle representing mean fish abundance (log fish/m^2) recorded in High *Tubastraea* coverage (DAF) and Low *Tubastraea* coverage (ORA) between shallow level (light blue) and deep level (red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

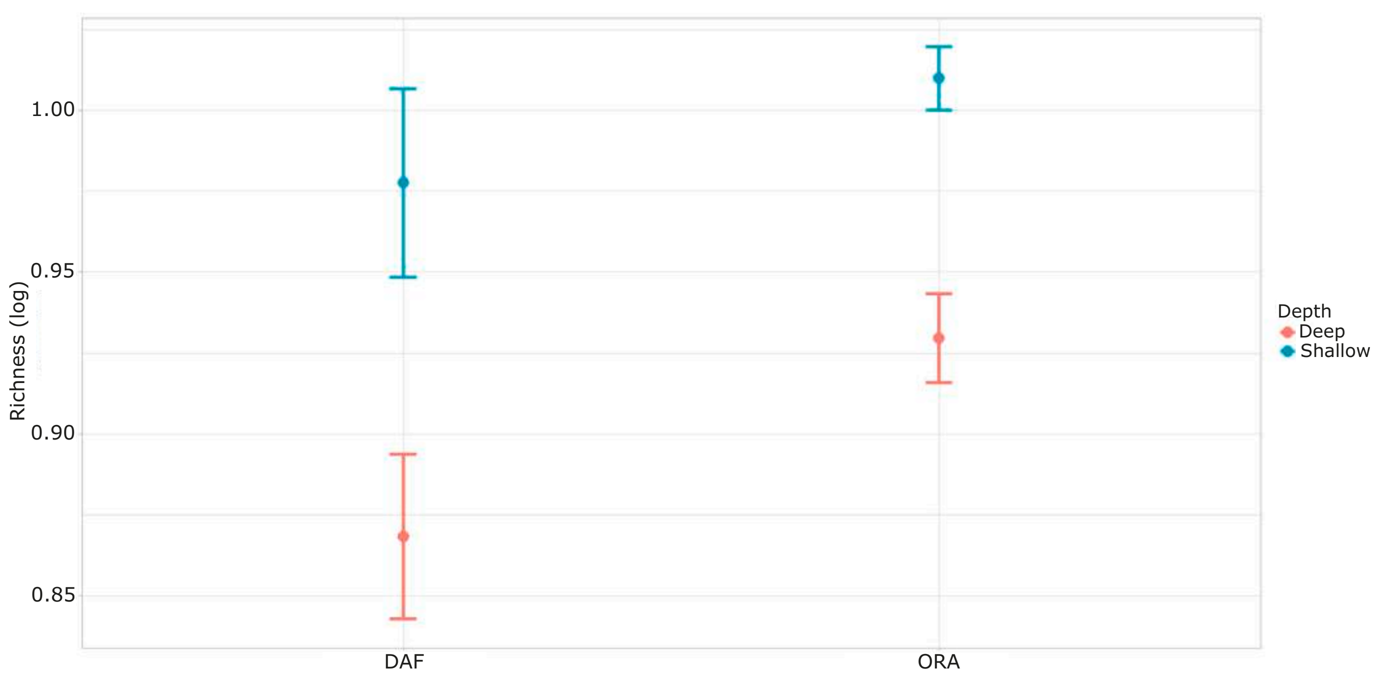

Fig. 7. Plot of mean log of fish richness (log fish/m^2) in depth strata and *Tubastraea* coverage with standard deviations. DAF = High *Tubastraea* coverage; ORA = Low *Tubastraea* coverage (ORA). Shallow strata (light blue) and deep level (red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Pontuda Island (122 items recorded), on the extreme West of our study area, was the second most affected area. Due to its proximity to the coast, it is frequently used by fishers, tourists, and sport practitioners, and it is affected by anthropogenic debris released by users of the Barra da Tijuca beach, with the Plastic, Lines, and Metals categories representing about the 90 % of the total ML for this area. Redonda Island, within the MPA, was the third area with more records of ML, besides being the most offshore island. It was found 77 % (61 items) of its records are associated with fishing gears, including ghost fishing gears. Despite its protection status, it is evident that the MPA efficiency is not effective to avoid the effects caused by anthropogenic debris (Soto-Navarro et al., 2021), especially illegal fishing activity. This is apparently the case for MONA Cagarras, due to its location close to one of the major coastal metropolitan areas of the world. The other sampling areas

Table 2
Non-native species distribution recorded along the coastal islands of Rio de Janeiro and Marica. Data sources: *1 – Batista et al., 2013; *2 - Garcia et al., 2018; *3 - Bertoncini et al., 2019; *4 – Silva et al., 2022; *5 – Machado et al., 2022; # - New records and #1 – New record recorded fixed in a drifting styrofoam (marine litter) located near to the Guincho at Rasa Island (See Fig. 8).

Non-native species/sites	Pontuda Is.	Comprida Is. (MPA)	Redonda Is. (MPA)	Portinho Rasa Is.	Guincho Rasa Is.	Maricá Is.
Paraleucilla magna Klautau et al., 2004*[1]		X	X			
Tubastraea tagusensis Wells, 1982*[1,4]	X	X	X	X	X	X
Tubastraea coccinea Lesson, 1829*[1,4]	X	X	X	X	X	
Megabalanus coccopoma (Darwin, 1854)*[1]		X				
Leiosolenus aristatus (Dillwyn, 1817)*[1]		X	X			
Isognomon bicolor (Adams, 1845)*[1]			X			
Perna perna (Linnaeus, 1758)*[1]	X	X	X	X	X	X
Perna viridis (Linnaeus, 1758) #		X	X		X[#1]	
Branchiomma luctuosum (Grube, 1870)*[3]	X	X	X	X	X	X
Ophiothela mirabilis Verrill, 1867*[3]	X	X	X	X	X	X
Pseudoboletia cf. *maculata* Troschel, 1869 #		X	X			X
Styela plicata (Lesueur, 1823)*[1]		X	X			
Cephalopholis taeniops (Valenciennes, 1828)*			X			
Chromis limbata (Valenciennes, 1833) #					X	X
Heniochus acuminatus (Linnaeus, 1758)*[5]			X			

had lower values of ML, where Guincho (Rasa Is.) had 50 records, Comprida Island with 44 items, and Portinho (Rasa Is.) had 19 items of anthropogenic origin (Fig. 2), mainly containing Plastic, Lines, and Metals as the main categories.

4.2. Seasonal distribution and composition of Marine litter

Fall season had the highest ML amount detected (34.8 % records). In Rio de Janeiro, the end of summer is characterized by an intensive rainy period. This rainy period and runoff from the mainland can be responsible for carrying debris of anthropogenic origin released on beaches, urban rivers, Guanabara Bay (through outflow marine current), and other marine and terrestrial sources. These results reflect the same pattern when analyzing data on each island separately. The fall had the highest mean values of ML density in five of the six sampling areas. The exception was Comprida Island, which had its greatest records in summer. Comprida Island is an important area for tourist activities throughout the year, especially in summer, because it is a protected zone of strong marine currents (ICMBio, 2021a). Therefore, the total abundance of ML items in Comprida Island during Summer period, the second season with higher records among others (24.2 % of the total), might be possibly associated with intensive recreational activities (Simeonova et al., 2017). Previous studies showed that tourist activities are recognized as the greatest contributor to ML on beaches (Grelaud and Ziveri, 2020), which may cause a reduction in the quality of ecosystems and their services, resulting in economic losses, and affecting tourism income and fisheries stocks (McIlgorm et al., 2022).

Plastic was the highest ML category recorded on islands, with 153 items (34.54 %) represented by cups, bags, and food packs which were the main items observed. According to Lamb et al. (2018) plastic debris can cause stress on corals, depriving them of light and oxygen, and in the case of tissue absorption, it increases the chance of the development of diseases. In addition, the plastic presence may reduce fish feeding on the benthos (Menezes et al., 2022), including abandoned nets that may result in ghost fishing events (Masompour et al., 2018; Beneli et al., 2020). In previous studies, Plastic was recorded as accidentally ingested by sea turtles, seabirds, and marine mammals getting stored in their stomach content (Clukey et al., 2017; Chua et al., 2019; Costa et al., 2020).

The second and third greatest ML categories recorded were Lines and Metal (27.09 % and 23.25 %, respectively). The Line category composition was basically fishing lines, while in the Metal category mainly hooks were detected, fishing lead, anchors, and rarely beer/soda cans. Therefore, approximately 50 % of all records were associated with fishing gear. In Brazil, due to the extensive coastline and strong tradition in fisheries, the marine biodiversity has been affected by abandoned, lost, or otherwise discarded fishing gear (Link et al., 2019; Beneli et al., 2020), thus disrupting ecological processes (De Carvalho-Souza et al., 2018). Furthermore, the Metal (e.g., anchor) and Other category (e.g. wood, tire) may act as artificial substrates for IAS dispersion, such as the Sun Coral (Mantelatto et al., 2020; Renchen et al., 2021).

4.3. Sun coral distribution and its progress

Invasive alien species are recognized as a threat to global biodiversity due to their capacity to change the structure and function of communities, by excluding native species (Ruiz et al., 1997; Bax et al., 2003). In Brazil, *Tubastraea* spp. is widely distributed along the coast, from the state of Ceará (Northeast) to the coastal islands of Santa Catarina in Southern Brazil (Creed et al., 2017; Crivellaro et a., 2022). Its presence has caused economic and environmental impacts (Creed, 2006; Miranda et al., 2016), such as the negative impacts on reef fish communities reported by Miranda et al. (2018). In MONA Cagarras and surrounding areas, the *Tubastraea* genus is widely distributed (Batista et al., 2013; Silva et al., 2022). Our results revealed the main impacted islands and *Tubastraea* genus distribution along different depth levels through the DAFOR scale.

The present work shows that Sun coral colonization, which is an

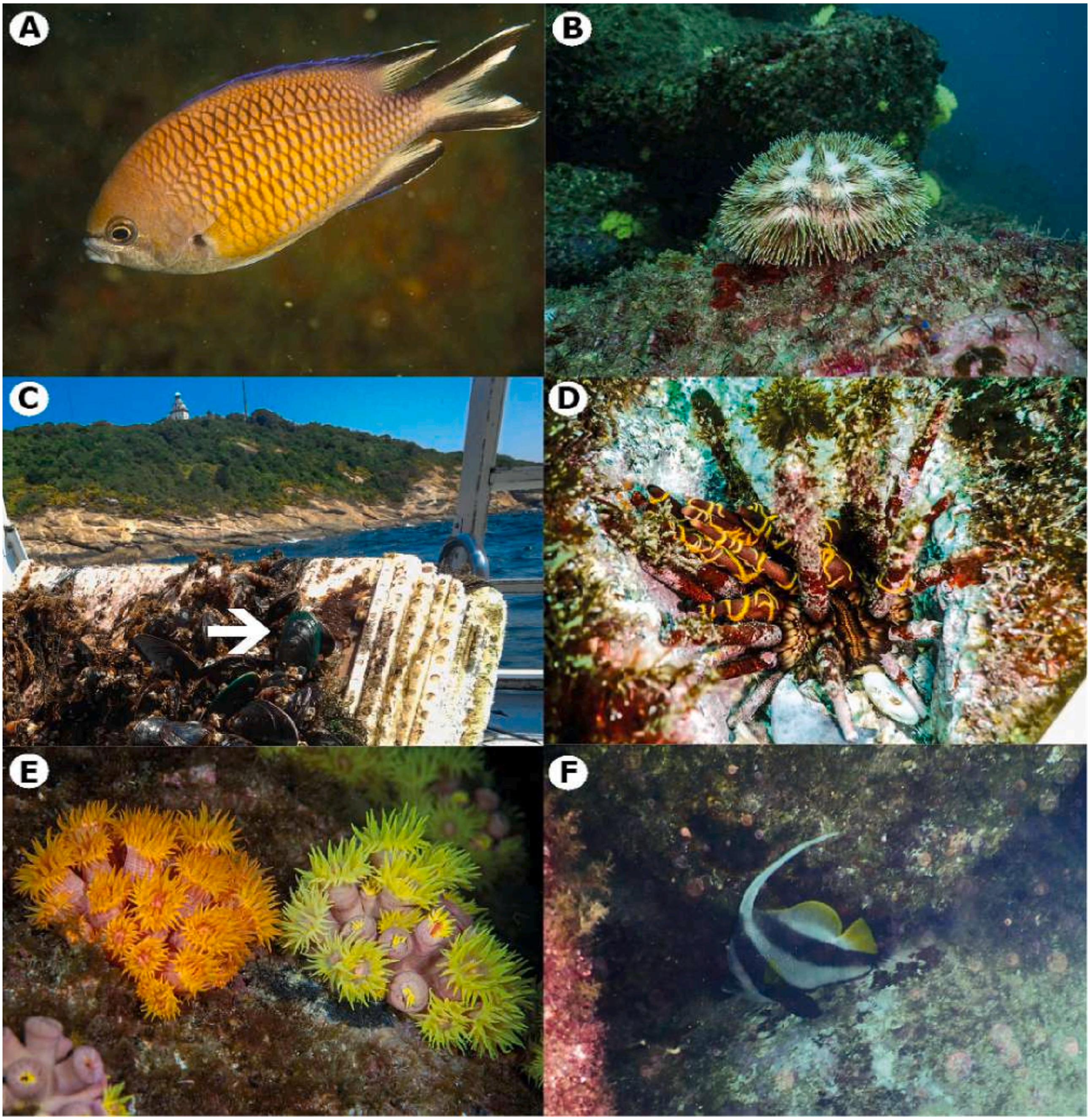

Fig. 8. Non-native marine species recorded on or nearby the coastal islands of Rio de Janeiro. New records: A. *Chromis limbata* (Valenciennes, 1833), B. *Pseudoboletia* cf. *maculata* Troschel, 1869 and C. *Perna viridis* (Linnaeus, 1758) on Styrofoam float near Rasa Island. Previous records: D. *Ophiothela mirabilis* Verrill, 1867 on *Eucidaris tribuloides* (Lamarck, 1816). E. *Tubastraea* spp. Lesson, 1829. F. *Heniochus acuminatus* (Linnaeus, 1758). Photos: A and E (AAB); B, C, D, and F (AAM).

azooxanthellate species, is recorded mainly at a deep level (between 10 and 20 m deep). This preference was common in all sampling areas except Maricá Island where it was recorded as a single colony. Nonetheless, the data recorded in shallow waters has shown an increase in the coral coverage degree during samplings years, including many transects with high coverage, especially in Redonda and Pontuda Island. The Redonda Island (within MPA) presented the highest number of Sun coral-dominated areas compared to the other sampled islands, with a significant increase between the first and second sampling years. These data call attention to the need for managers to draw up strategies to control the establishment and dissemination of sun coral along the coast, mainly within protected areas.

4.4. Marine litter and Sun coral effects on rocky fish community

In the coastal islands of Rio de Janeiro, the analysis performed did not detect a relationship between the reef fish and marine litter (see Table 1). Our findings agree with the results obtained in studies conducted by Rizzo et al. (2021) and partially reject the hypothesis of this work, suggesting to data, that marine litter apparently does not directly influence reef fish communities. Although ML does not present direct effects on the ecological descriptors of the fish community, ML is related to several events, such as wildlife entanglement, suffocation and ingestion, ghost fishing, and serving as substrate for the dispersion of invasive alien species (Beneli et al., 2020; Mantelatto et al., 2020).

Regarding the *Tubastraea* presence, there is a clear influence of the coverage (which is expanding) on rocky reef fish ecological descriptors on the coastal islands from Rio de Janeiro. Fish richness and abundance are lower when the IAS coverage is high. Additionally, there are no records of predation by fish at the study site. Our findings agree with the results found by Miranda et al. (2018) and reinforce the Enemy Release Hypothesis where native species are not capable to regulate of non-native coral invasions (Keane and Crawley, 2002). Previous studies that evidenced a low interest of generalist fish predators in Sun coral colonies tissue due to allelochemicals may explain our findings (Lages et al., 2010; Moreira and Creed, 2012). In addition, these results can be supported by several studies, where the use of chemical substances by benthic organisms may influence feeding activities, foraging strategies, and habitat use by fishes (Choat and Climents, 1998; Hay, 2009).

4.5. Non-native species incursions

In the coastal islands of Rio de Janeiro, the occurrence of NNS are known, for instance: *Paraleucilla magna* Klautau et al., 2004, *Tubastraea coccinea* Lesson, 1829, *Tubastraea tagusensis* Wells, 1882, *Megabalanus coccopoma* (Darwin, 1854), *Leiosolenus aristatus* (Dillwyn, 1817), *Isognomon bicolor* (Adams, 1845), *Perna perna* (Linnaeus, 1758), *Branchiomma luctuosum* (Grube, 1870), *Ophiothela mirabilis* Verrill, 1867, *Styela plicata* (Lesueur, 1823), *Cephalopholis taeniops* (Valenciennes, 1828), *Heniochus acuminatus* (Linnaeus, 1758), however, little is known about their distribution in this region (See Moraes et al., 2013; Bertoncini et al., 2019; Machado et al., 2022).

Our study provides an inventory of 15 NNS and their distribution in the MONA Cagarras and surrounding areas, including three new records (see Table 2). The NNS occurrence outside their local of origin may represent a threat due to the capacity to cause local extinction of native species (Doherty et al., 2016; Anton et al., 2019), while some others can provide benefits to the native communities (Ramus et al., 2017). In light of this, long-term monitoring programs, especially to detect non-native species, are essential to support MPA managers in awareness activities and especially in preventive strategies for biodiversity conservation of the MPA, including management actions beyond their boundaries in surrounding areas (Holenstein et al., 2021).

The presence of NNS, such as *Pseudoboletia* cf. *maculata* and *Perna viridis* within MONA Cagarras and *Chromis limbata* on islands surrounding the MPA, calls attention to the development of monitoring and management actions in this relevant area. The occurrence of the *Pseudoboletia* genus was first reported in Trindade island (Martins et al., 2016), and later in Arraial do Cabo (RJ) and Santa Catarina in southern Brazil (Lopes et al., 2017). Our findings reveal a new record of this sea urchin in the study area, but its presence is, so far, unlikely to cause significant negative impacts on the marine ecosystem's health. *Chromis limbata,* on the other hand, has been reported since 2009 in Santa Catarina (Leite et al., 2009), and has spread northward, reaching now the coast of Rio de Janeiro. Since then, the species' establishment has become more evident in southern and southeast Brazil (Adelir-Alves et al., 2018; Anderson et al., 2020). The efforts performed by this study allowed the detection of the northernmost occurrence record on the Brazilian coastline at Maricá Island. These records warn about the need to develop preventive actions against the arrival and establishment of other alien species, such as the lionfish (*Pterois* spp.) that has been continuously recorded in the Brazilian northeast (Luiz et al., 2021) and is spreading southward the Brazilian coast, being detected in North Pernambuco to date (AAB pers. comm.). Its presence is responsible for causing several impacts on the Caribbean sea (Samhouri and Stier, 2021).

4.6. Challenges faced in a Hope Spot region

Hope Spot regions are places scientifically considered critical to ocean health. This recognition is given by the international nonprofit organization Mission Blue to areas that show high species richness and the potential to reverse injury from negative anthropogenic impacts (https://missionblue.org/hope-spots/). The MONA Cagarras and surrounding areas were recognized in 2021, as the newest Brazilian Hope Spot region (Machado et al., 2022). Due to its proximity to a large urban center, this important area is easily accessed and faces significant threats, such as the increase in the number of records of NNS and their distribution, as well as ML impacts on marine species reported in this study. Among the main challenges, managers face are avoiding fishing activities within the limits of the MPA, controlling the dispersion of NNS, and the arrival of ML, which are nowadays the most crucial threats within the MPA.

Developing strategies for marine conservation is not an easy task in multiple-use protected areas. Long-term ecological monitoring is essential to assist MPAs managers in developing conservation actions for local biodiversity. Our findings on marine litter provide a baseline to support mitigating actions by public authorities, as well as in the elaborating awareness campaigns targeting users, involving tourism operators in the region. In addition, social involvement has been a valuable tool for detecting, monitoring the distribution, and mitigating the arrival of IAS and ML worldwide (Machado et al., 2021; Kawabe et al., 2022). Social awareness activities play a key role in society's engagement, especially considering citizen science to obtain data continuously. The blossoming of initiatives that allow the detection of problems in the ocean, should be encouraged by the academic community, society, environmental managers, and tourism companies.

Initiatives such as the Brazilian bioinvasion platform (https://bioinvasaobrasil.org.br/) and Dive Against Debris (https://www.diveagainstdebris.org/) are important examples that collect information on invasive alien species and marine debris of anthropogenic origin throughout digital platforms. In this context, community encouragement to contribute to environmental monitoring actions and access to knowledge is crucial to archive a high level of involvement of citizens, providing better practices on marine biodiversity conservation in this area, which shelters the newest Brazilian Hope Spot.

5. Conclusion

This study presents a scenario poorly known by managers and Brazilian society. The presence of marine litter on rocky reefs may represent a great threat to the local marine biodiversity and can even facilitate the dispersal of IAS. The results herein presented evidence of a large amount of ML present and its effects along the coastal islands of Rio de Janeiro. Despite our results do not show a direct effect of ML on the richness and abundance of reef fish, they do affect through ghost fishing events, and suffocation, besides serving as an artificial substrate to IAS, such as Sun Coral (see Fig. 3D), negatively impacting the marine biodiversity as a whole. In addition, our findings reveal that *Tubastraea* genus abundance increased during our effort (two years) and its presence on the rocky shores of Rio de Janeiro has been causing negative effects on fish communities, especially on richness and abundance. Finally, our efforts allowed us to detect three new records of NNS, evidencing the importance of long-term monitoring programs to detect and prevent the arrival of NNS that could seriously impact local biodiversity.

Marine Protected Areas have been considered a major tool for stock recovery and marine conservation (Fenberg et al., 2012). Although the MONA Cagarras is classified as a "Natural Monument" (a no-take MPA, according to the Brazilian law n° 9.985, July 18th in 2000) and has received together with the surrounding, areas, the recognition of a Hope Spot, the islands alone will not safeguard or guarantee the health of the reef fish communities and rocky reef ecosystem. It is important to improve oversight strategies, avoid fishing activities within the boundaries of MPA, as well as rethink the limits of the protected area providing safeguarding protection to deeper rocky reefs. In addition, seeking the engagement of local actors and visitors that use the area is crucial for developing more sustainable practices, so urgent for marine conservation in the Ocean Decade.

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CRediT authorship contribution statement

Augusto A. Machado: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Bruno P. Masi:** Formal analysis, Writing – review & editing. **Aline A. Aguiar:** Writing – review & editing, Formal analysis, Project administration. **Maria E.C. Ozorio:** Writing – review & editing. **Caio N. Salles:** Writing – review & editing. **Maurício Hostim-Silva:** Writing – review & editing, Supervision. **Áthila A. Bertoncini:** Conceptualization, Methodology, Investigation, Writing – review & editing, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Capitulo 3: No-take zone in check: An ecological assessment of the management role in reef fish conservation in a Brazilian Hope Spot region

No-take zone in check: An ecological assessment of the management role in reef fish conservation in a Brazilian Hope Spot region

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Abstract

Marine Protected Areas (MPAs) have been considered one of the most effective conservation management strategies worldwide. Despite its relevance, anthropogenic disturbances continue to cast doubt on its importance. Here we explored the effects of protection of No-Take Zones (NTZs) on fish community in the second Brazilian Hope Spot. For two years (2020-2022), underwater visual censuses (UVC) and submersible rotating videos (SRV) were performed to assess the ecological descriptors, as well as threatened and fishery-target species distribution. A significant difference between study areas (Protected, Rasa is., and Far) was detected ($p<0.05$), showing higher values of fish median richness in both sampling techniques and higher median density through SRV within MPA limits. Besides that, Cagarras Islands Natural Monument sheltered about 84.7% (n=17) of the total threatened species recorded in the study area, according to the International Union for Conservation of Nature (IUCN). Our integrated study with other stakeholders' knowledge may provide a powerful tool to decision-makers elaborate management measures to improve marine conservation. In light of this, thinking of Hope Spots as an opportunity to realize the need to change unsustainable human practices, protecting mainly on Ocean Decade the life below the water.

Keywords: No-take zone; Hope spot; Reef fish; Ocean management; Marine conservation; South Atlantic

1. INTRODUCTION

During the last four decades, fisheries activities were responsible for removing more than 100 million tons of marine species biomass each year (Pauly et al., 2020). Disturbances caused by unsustainable fishing can lead to loss of habitats and changes in fish community structure (Mumby et al., 2006; Lundquist et al., 2018). In addition, the fishing gear development with the increasing demand for marine-based food has intensified the overfishing in targeted fisheries, leading to decline of several fish species worldwide (White et al., 2017; Sala et al., 2018). These negative impacts added to by-catch fisheries and marine pollution represent a risk to residents and transient megafauna, including sharks, and marine mammals (Dulvy et al., 2014; Meyer et al., 2017).

Fish species may represent important mobile links between marine ecosystems, allowing the transfer of nutrients and trophic subsidies along habitats (Berkström et al., 2012; Shantz et al., 2015). In addition, reef fish and fishery products are socially and economically valuable to humans (Sandovy, 2005), providing food and income for millions of people worldwide (Nelson, 2016; Tacon and Metian, 2018). Although the fish community represents valuable ecological, socioeconomic, and cultural resources, it has suffered a decline worldwide caused by local and global threats, such as unsustainable fisheries (Bellwood et al., 2019). Overfishing is responsible for causing a decrease in the abundance of reef fish and can lead to changes in the trophic web and also a reduction of fish biomass, causing an availability decrease in ecosystem services (Rocha et al., 2015; Trindade-Santos et al., 2020). Understanding the magnitude of these impacts can help elaborate management measures to mitigate fishing impacts on marine biodiversity, especially on threatened species.

No-take marine zones have been widely used to protect marine biodiversity within their limits (Agardy et al., 1994; Halpern and Warner, 2002; Claudet et al., 2011). Among the benefits of the implementation of Marine Protected Areas, is the increase in abundance, richness, fish biomass, and fisheries stock recovery (Rolim et al., 2022), which may allow spillover to adjacent areas (Di Lorenzo et al., 2016). Moreover, MPAs are strategic areas for developing scientific research, environmental education actions, and sustainable tourism activities (Abbad et al., 2022). In Brazil, the National System of Conservation Units (National Law Nº. 9.985, 2000) aims that protected areas should be managed and planned to stimulate integration among citizens, government, and the environment.

The Cagarras Islands Natural Monument (MONA Cagarras) is a no-take marine reserve in Rio de Janeiro state (Brazilian southeast). The MONA Cagarras comprises four islands: Comprida, Redonda, Palmas, and Cagarra Islands and two islets: Filhote da Cagarra and Filhote da Redonda, and 10 meters of the marine surrounding area. These coastal islands present high marine biodiversity, such as algae, invertebrates, and reef fish species (Bertoncini et al., 2019; Machado et al., 2022). With its proximity to the Rio de Janeiro coast, this region is commonly used for recreational activities (e.g., Scuba Diving and free diving), and fishers use surrounding areas to obtain food and income (ICMBio, 2021a). Due to high species richness and closeness to the coast, MONA Cagarras and surrounding areas were recognized, in 2021, as Hope Spot (HS) by the international nonprofit organization Mission Blue (https://missionblue.org/hope-spots/). Despite its recognized importance for marine conservation, these coastal islands and surrounding areas have been constantly impacted by marine litter (including fishing gear), invasive species, sewage discharge, and unsustainable fisheries (ICMBio, 2020; Machado et al., 2023).

Non-destructive techniques have been extensively used in ecological studies, mainly in MPAs (Bayley et al., 2019; Schmid et al., 2020; Rolim et al., 2022). The Underwater Visual Census is commonly employed to assess and monitor reef fish communities' parameters (e.g., diversity, and density), as well as negative impacts on fishes in the reef ecosystems (Daros et al., 2018; Motta et al., 2021; Machado et al., 2023). In addition, underwater remote videos have been widely used as a complementary technique to obtain fish ecological data, allowing to detection of species that are affected by diver presence (Dickens et al., 2011; Mallet and Pelletier, 2014; Pinheiro et al., 2020). Among the techniques, the Submersible Rotational Video developed by Koenig and Stallings (2015), emerges as a valuable and non-destructive technique for a marine fish survey, especially within MPA, and can simulate the known stationary census technique (Bohnsack and Bannerot, 1986). These complementary powerful techniques provide relevant ecological descriptors data, allowing to understand the health of insular marine communities.

On the Brazilian coast, reef fish communities are distributed from off the mouth of the Amazon River to the coast of Santa Catarina state in southern Brazil, including oceanic islands (Hostim-silva et al., 2005; Moura et al., 2016; Pinheiro et al., 2020). The MONA Cagarras reef fish communities have been widely studied (e.g., Bertoncini et al., 2019; Machado et al., 2022). However, there are few studies related to the MPA's role in the conservation of the reef fish communities. In this study, we tested the hypothesis that the MPA (MONA Cagarras) harbors the highest density and richness of fish species within its limits. This work aimed to compare these ecological descriptors inside and outside MPA areas. Furthermore, we assessed the distribution of the threatened and fishery-targeted species Rio de Janeiro's coastal islands. The present study is listed as one of the priorities in the Research Plan of MONA Cagarras (ICMBio, 2021b), and intends to help decision-makers strengthening marine conservation measures for the second Brazilian Hope Spot and surrounding areas.

2. MATERIALS AND METHODS

2.1. Study area

The study was conducted seasonally between September 2020 and June 2022 at the coastal islands of Rio de Janeiro and Maricá cities (Fig.1). The data collection was performed on Pontuda Island (within the Tijucas Archipelago), which is located about 1.7 km off Barra da Tijuca beach. Samples were also taken at the Comprida and Redonda islands, inside the limits of the MONA Cagarras, located approximately 5 km off Ipanema Beach. Samplings were also carried out on southwest (Portinho) and northeast (Guincho) sides of Rasa Island, located on the surroundings of MONA Cagarras, but outside the MPA boundaries. Finally, the data collection was also performed on Maricá Island, which is located 3.5 km from Itaipuaçu beach (Maricá municipality).

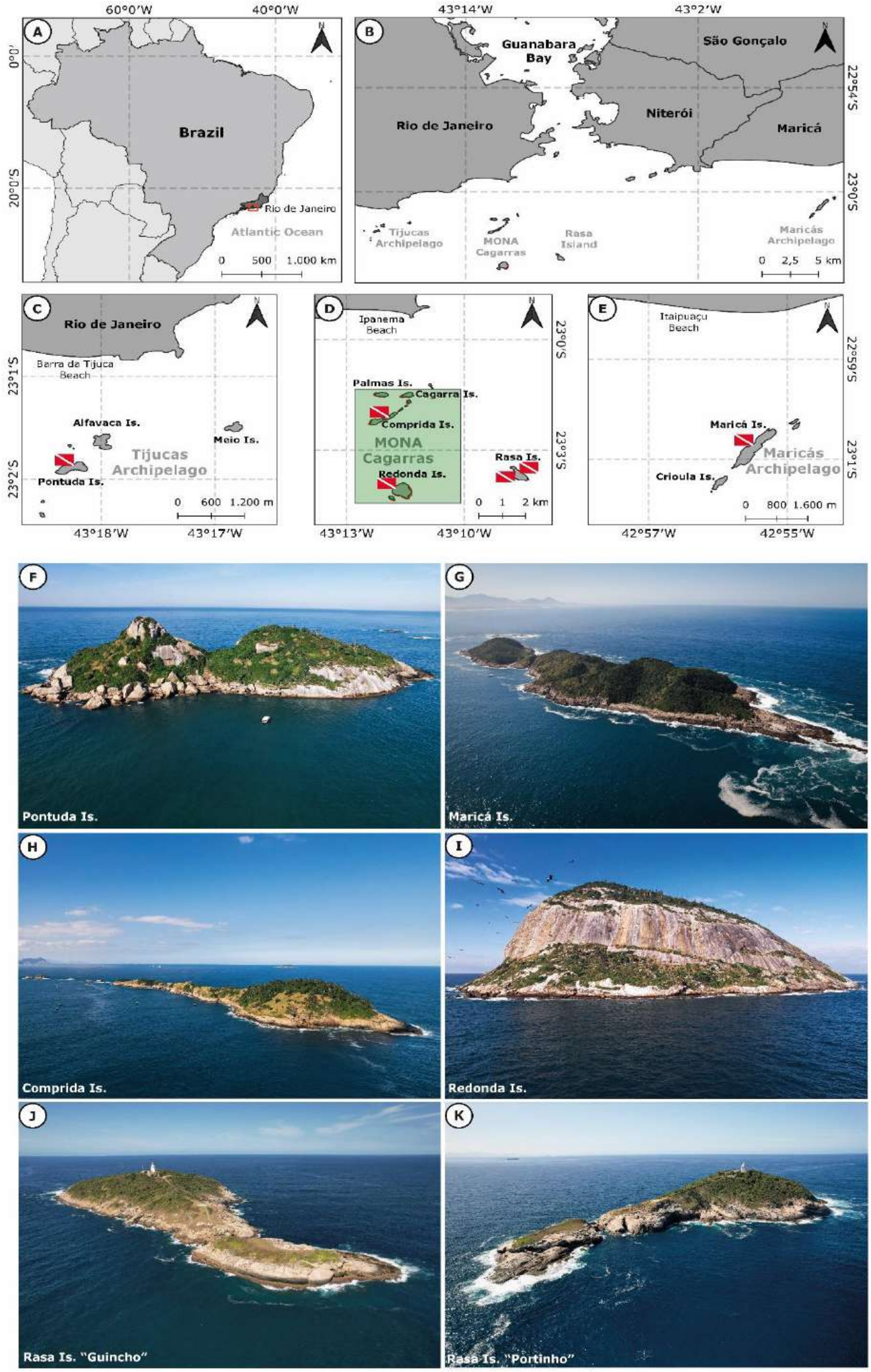

Fig. 1. The coastal islands of Rio de Janeiro Map. **A**. Brazil map; **B**. Coastal Islands of the Rio de Janeiro and Maricá cities; **C**. Tijucas Archipelago; **D**. MONA Cagarras and Rasa Island; **E**. Maricás Archipelago. Dive flag representing the sampling areas. Green square showing the MONA Cagarras location. Aerial photos (F – K) were taken using an aerial drone by Áthila A. Bertoncini.

2.2. *Underwater Visual Census surveys*

Reef fish community was recorded through line transects performed seasonally, between 8 a.m. to 04:00 p.m., on rocky reefs up to 20 m deep (inside and outside the MPA). Fish data were assessed through 20 m long strip transects positioned parallel to the line rocky shore on each island, where two scientific divers recorded the fish species within 1 meter from the line (Brock, 1954; Kimmel, 1985). The reef fish species were identified and counted to obtain density and richness data.

2.3. *Submersible Rotational Video samples*

The SRV technique consists of a waterproof stainless-steel frame with a sealed rechargeable battery, a gear motor inside (2 rpm), and a single GoPro HD camera attached (See Fig. 2). The underwater remote video techniques have been commonly used to avoid the potential diver influence on the fishes' behavior (Andradi-Brown et al., 2016; Bayley et al., 2019; Machado et al., 2022). The SRV samplings were performed seasonally along the rocky shores up to 20 m deep. From each launch of the SRV, a 15-minute per video was recorded. Finally, it was analyzed using the VLC multimedia player software (http://www.videolan.org/vlc/index.html), obtaining fish richness and relative density data, considering the greatest number of individuals seen in the continuous view per frame (NMax) up to 3 meters away marked on SRV cable.

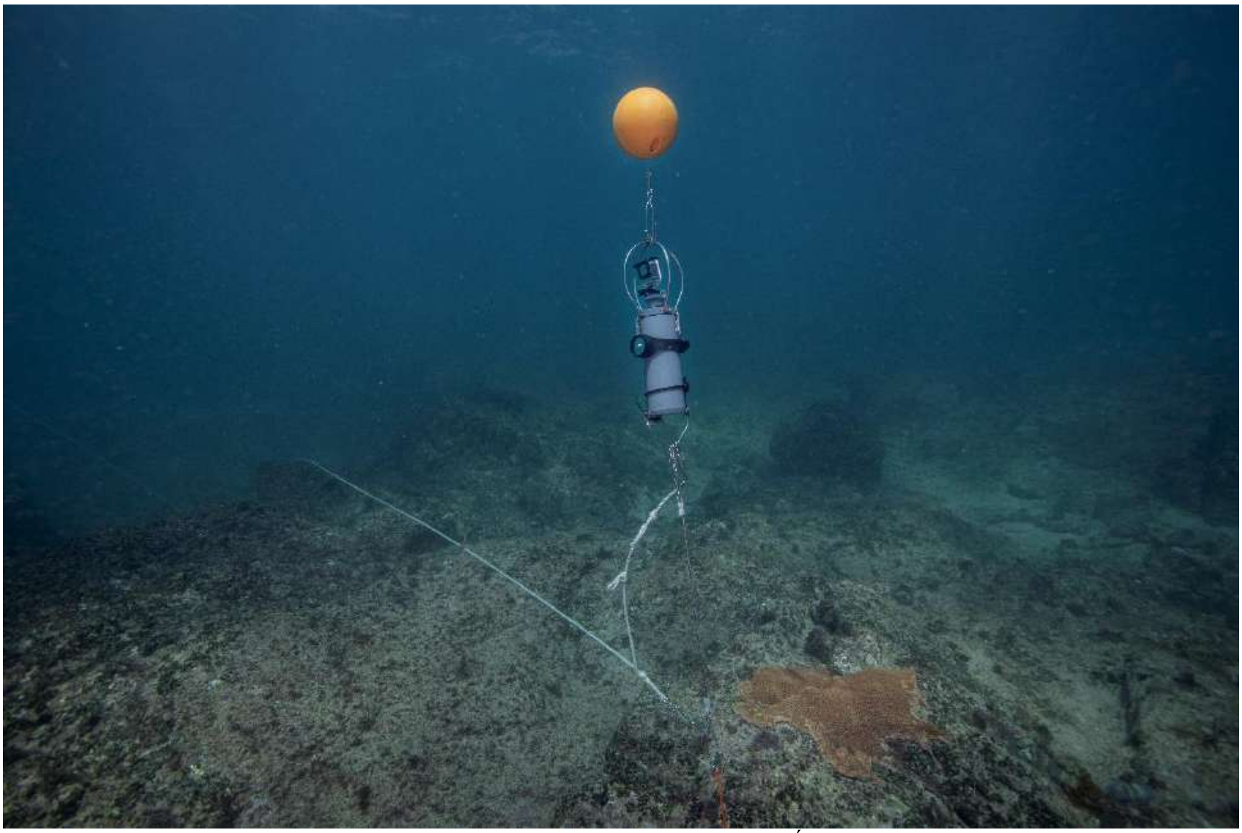

Fig. 2. Submersible Rotating Videos "SRV" in progress on Marica Island. Photo: Áthila A. Bertoncini.

2.4. *Landed and threatened fish species data*

The survey of the landed fish species data along the Rio de Janeiro and Maricá cities' coastline was compiled by assessing the Rio de Janeiro State Fisheries Institute Foundation (FIPERJ) technical reports (between 2020-2023) on fishing landings that occurred in the Z8 and Z13 fishermen colonies (available on: http://www.fiperj.rj.gov.br/index.php/publicacao). From that, the main target species were recorded considering the values of the fish biomass species caught by artisanal fisheries according to FIPERJ. In addition, the recreational fishing data (ex: anglers with rod and line) were obtained through personal communication and observation during the fieldwork. After that, these fisheries data were associated with UVC data allowing us to detect the target-fisheries species range. In addition, the fish species recorded through UVC technique were identified and classified according to IUCN Red List Categories and the Brazilian environmental agency, Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio) - Red List of Brazilian Fauna (ICMBio, 2018).

2.5. *Data analysis*

The fish data collected were grouped into three categories of sampling areas according to their location. The Comprida and Redonda Islands represent the "MONA" category. The Rasa island category includes the southwest side (Portinho) and the northeast side (Guincho) located less than 10 km from MONA Cagarras. Finally, the Maricás and Pontuda Islands, which are located more than 10 km away from MONA Cagarras were categorized as “Far”. Density and Richness data were assessed using the Shapiro-Wilk normality test and indicated that the data distributions were not normal ($P < 0.05$). Thus, the non-parametric Kruskal-Wallis test was applied to assess the differences in the fish richness and density data among sampling areas considering a significance level of 0.05. After that, to understand the pairwise differences, the Dunn post-hoc test of multiple comparisons was performed using corrected values by the Holm method (Dunn, 1964; Holm, 1979). The boxplot and violin charts combined were performed to represent the density and richness values of fish using the ‘ggplot2’, and the ‘ggbetweenstats’ function available in the 'ggstatsplot' library (Wickham, 2016; Patil, 2021).

The fish species classified in the threatened species categories according to IUCN and ICMBio (CR = Critically Endangered, EN = Endangered, and VU = Vulnerable) and the landed species were obtained by literature and data collected on fieldwork. These results were represented through the Venn diagram, which shows its range along the studied Rio de Janeiro coastal islands. The mean density of fishery-targeted species (individuals per $100m^2$), including recreational and artisanal fisheries data, was obtained through UVC's data and represented using a bar chart. All statistical analyses and graphics were performed through the R language (R Core Team, 2021), and the maps were elaborated through QGIS 3.16 (QGIS Development Team, 2022).

3. Results

3.1. Density of reef fish species

A total of 288 submersible rotation videos were taken with 96 videos per site obtaining fish density and richness data. The highest value of median fish density, obtained using the SRV technique, was represented in the 'MONA' category with 70.74 individuals per $100m^2$, followed by 'Rasa Is.' presenting 60.13 ind./$100m^2$ and finally, the 'Far' category with 37.14 ind./$100m^2$ (Fig. 3). The comparison of median fish density between sampling areas through the Kruskal-Wallis test showed a significant difference (p = 0.000105). The Dunn's multiple comparison post-hoc test revealed mainly a significant difference among the 'MONA' and 'Far' categories with p-value = 0.0000105, and 'Rasa Is.' and 'Far' with p-value = 0.01. In contrast, the ‘MONA’ and ‘Rasa Is.’ did not differ significantly (see Table 1).

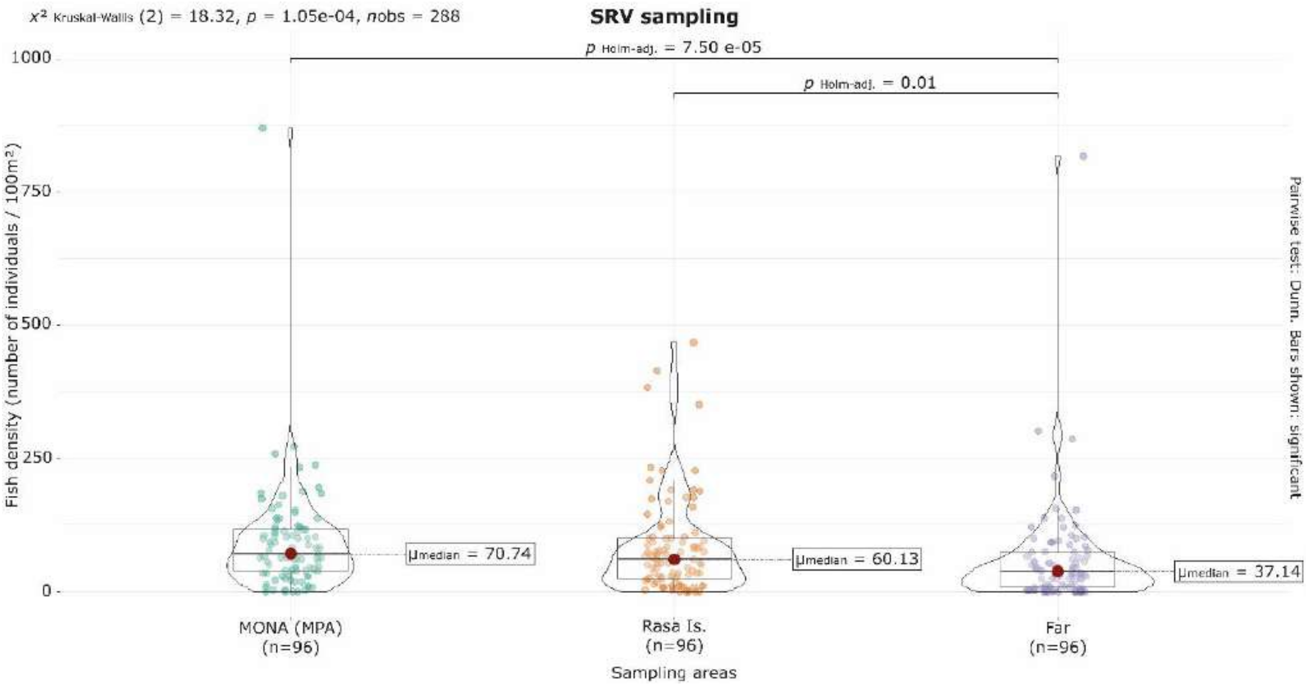

Fig. 3. The density of fish through the Submersible Rotating Videos technique along sampling areas with the results of the Kruskal-Wallis non-parametric analysis and Dunn's post hoc test.

The present study encompasses a total of 576 line transects by scientific divers with 96 performed in each sampling area providing data on fish density and richness. The highest median density of fish recorded through the UVC technique was at 'Rasa Is.' category with 92.50 individuals per $100m^2$, followed by 'MONA' with 80.00 ind./$100m^2$, and finally 'Far' category which presented the median value of 70.00 ind./$100m^2$ (Fig. 4). The Kruskal-Wallis test using fish density through UVC technique revealed a significant difference (p=0.00129). In addition, the post-hoc test of Dunn using pairwise multiple comparisons showed a significant difference mainly among 'MONA' and 'Far' (p=0.01) and the 'Rasa Is.' and 'Far' categories (p=0.00153). The 'MONA' and 'Rasa Is.' categories did not show a significant difference (see Table 1).

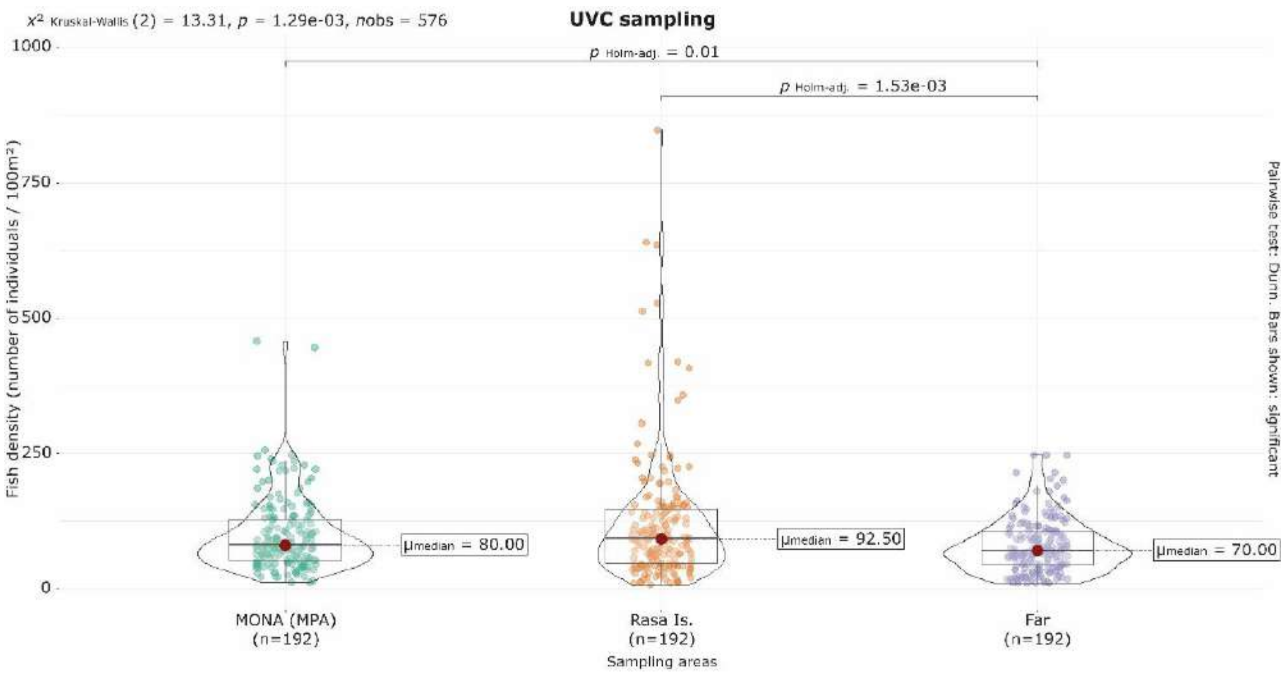

Fig. 4. The density of fish through the Underwater Visual Census technique along sampling areas with the results of the Kruskal-Wallis non-parametric analysis and Dunn's post hoc test.

Table 1. Results of the Kruskall-Wallis test and Dunn's Multiple Comparison post-hoc test comparing medians of density between sampling areas. **p-value* < 0.05, ** *p-value* < 0.01, and *** *p-value* < 0.001.

	SRV (Nobs = 288)		**UVC** (Nobs = 576)	
Kruskal-Wallis test	**Ɛ²=0.16**	***p* = 0.000105*****	**Ɛ²=0.12**	***p* = 0.00129****
Pairwise multiple comparisons	**df**	***p*-value**	**df**	***p*-value**
MONA x Rasa Is.	18.32	0.14	13.31	0.44
MONA x Far	18.32	0.0000075***	13.31	0.01*
Rasa Is. x Far	18.32	0.01*	13.31	0.00153**

3.2. Reef fish species richness

The fish species richness, obtained through the SRV, were compared between the coastal islands of Rio de Janeiro and Maricá cities. The ‘MONA’ represented the highest richness median value with 8.00 species, followed by the 'Rasa is.' category comprising 7.00, and finally 'Far' sites with 5.00 species (Fig. 5). The Kruskal-Wallis test revealed significant differences among sampling areas with *p-value*= 0.01. Furthermore, the Dunn's post-hoc test showed a significant difference only between 'MONA' and 'Far' (*p*=0.00742), the other pairwise comparisons did not differ significantly (Table 2).

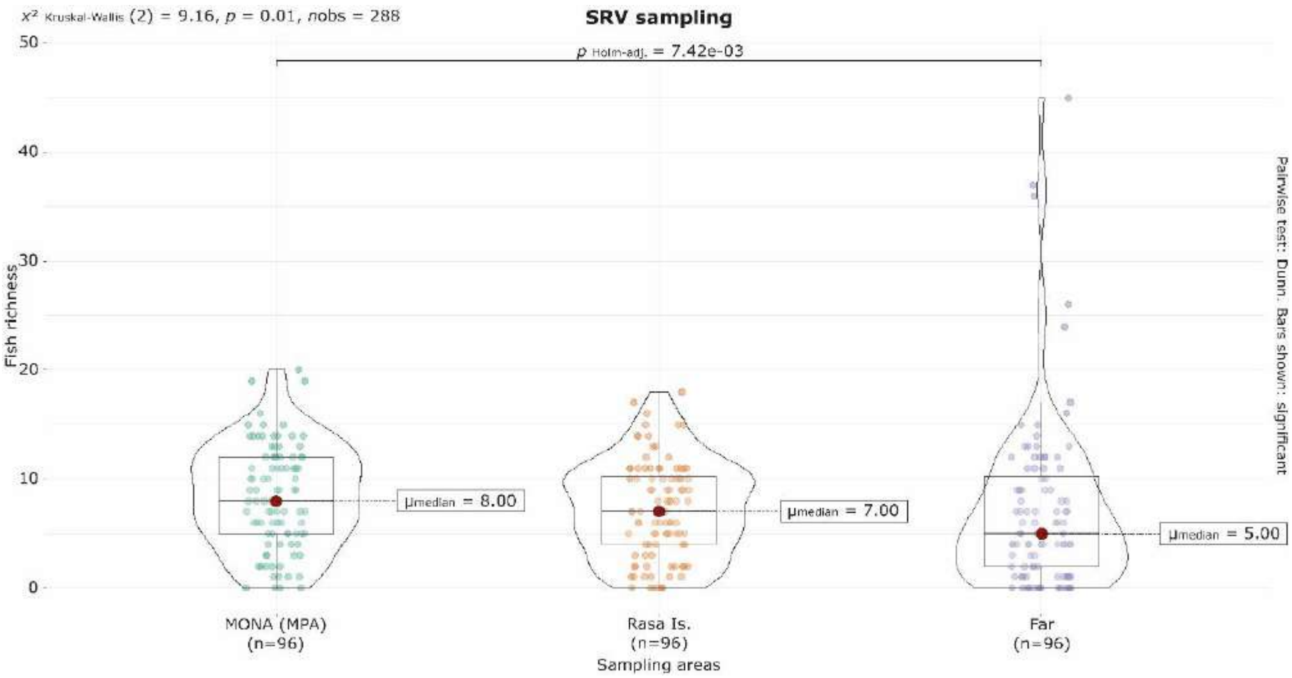

Fig. 5. The richness of fish through the Submersible Rotating Videos technique along sampling areas with the results of the Kruskal-Wallis non-parametric analysis and Dunn's post hoc test.

The UVC technique was also used to obtain the richness of species and their median values were compared among the sites. The 'MONA' samples represented the highest richness median value with 12.00 species, followed by the 'Far' category with 11.00, and 'Rasa Is.' represented with 10.00 species (Fig. 6). The non-parametric Kruskal-Wallis test showed a significant difference with *p*-value = 0.00000674. Dunn's post-hoc test revealed a significant difference mainly between 'MONA' and 'Rasa Is.' (*p*=0.00000540), and 'MONA' and 'Far' with *p-value* = 0.00223. The 'Rasa Is.' and 'Far' categories comparison did not evidence a significant difference (see Table 2).

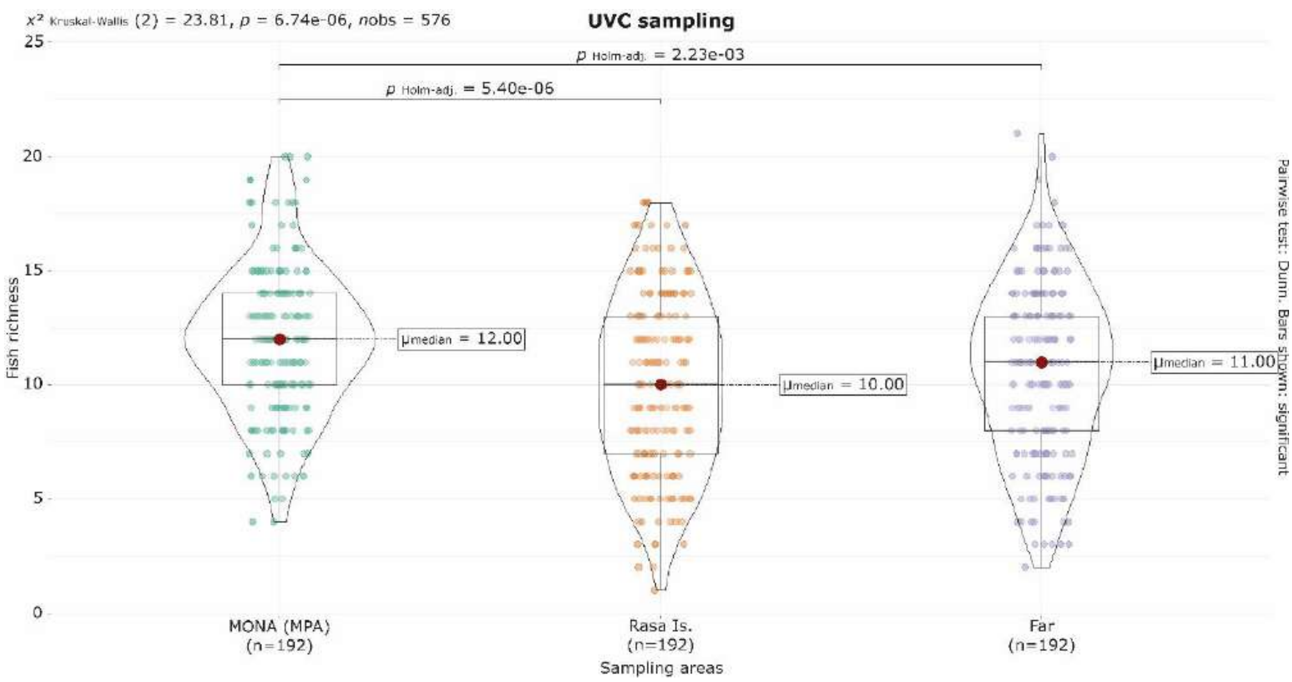

Fig. 6. The richness of fish through the Underwater Visual Census technique along sampling areas with the results of the Kruskal-Wallis non-parametric analysis and Dunn's post hoc test.

Table 2. Results of the Kruskall-Wallis test and Dunn's Multiple Comparison post-hoc test comparing medians of richness between sample areas. **p-value* < 0.05, ** *p-value* < 0.01, and *** *p-value* < 0.001.

	SRV (N_{obs} = 288)		**UVC** (N_{obs} = 576)	
Kruskal-Wallis test	**$\mathcal{E}^2$=0.03**	***p* = 0.01***	**$\mathcal{E}^2$=0.04**	***p* = 0.00000674*****
Pairwise multiple comparisons	**df**	***p*-value**	**df**	***p*-value**
MONA x Rasa Is.	9.16	0.24	23.81	0.00000540***
MONA x Far	9.16	0.00742**	23.81	0.00223**
Rasa Is. x Far	9.16	0.24	23.81	0.13

3.3. Distribution of landed and target species

The survey of fish species captured by fisheries activities during the last decade through literature and FIPERJ technical reports revealed 261 landed fish species. From this total, about 159 species (61.02%) were recorded during fieldwork on sampling areas (see Fig. 7A). The MONA Cagarras shelters the greatest percentage of landed fish species (95.6% or 152 species) with 17.6% (28) exclusively recorded at MONA, followed by 'Far' areas with 79.2% (126 spp.) with 4.4% (7) exclusive species, and in the 'Rasa Is.' areas with 60.4% (96 spp.) with no exclusive species recorded. Finally, about 57.2% or 91 species were recorded in the three areas.

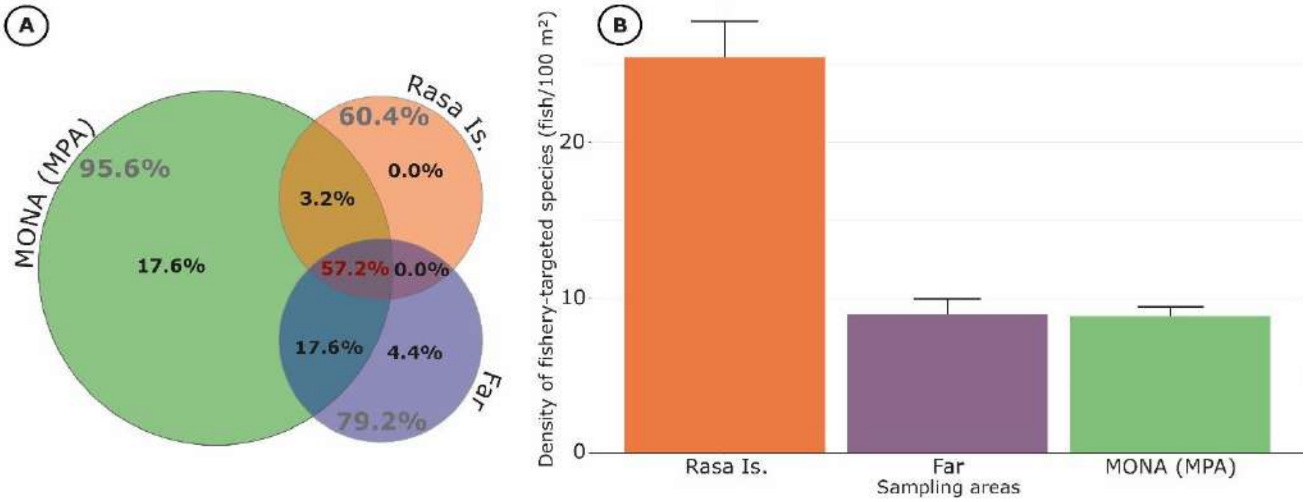

Fig. 7. A. Venn diagram showing the fish species landed distribution along the Rio de Janeiro Coastal Islands; **B.** the mean density (± SE) of the main fishery-targeted species.

According to previous FIPERJ technical reports, the main fish biomass caught by artisanal fisheries in the study area was represented mainly by 'Liza' *Mugil* spp., 'Whitemouth croaker' *Micropogonias furnieri*, 'Little tuna' *Euthynnus alleteratus*, 'Acoupa weakfish *Cynoscion* spp., 'Common snook' *Centropomus undecimalis*, and 'Atlantic spadefish' *Chaetodipterus faber* which were caught principally through gillnet fisheries. In addition, recreational fish landing is poorly documented in MONA's surrounding areas by literature. However, throughout personal observation during the fieldwork (AAM), the main fish species caught were the ‘Glasseye’ *Heteropriacanthus cruentatus*, ‘Grunt’ *Haemulon atlanticus*, 'Grey triggerfish' *Balistes capriscus*, 'Black margate' *Anisotremus surinamensis*, and ‘Silver porgy’ *Diplodus argenteus* (see Fig. 8).

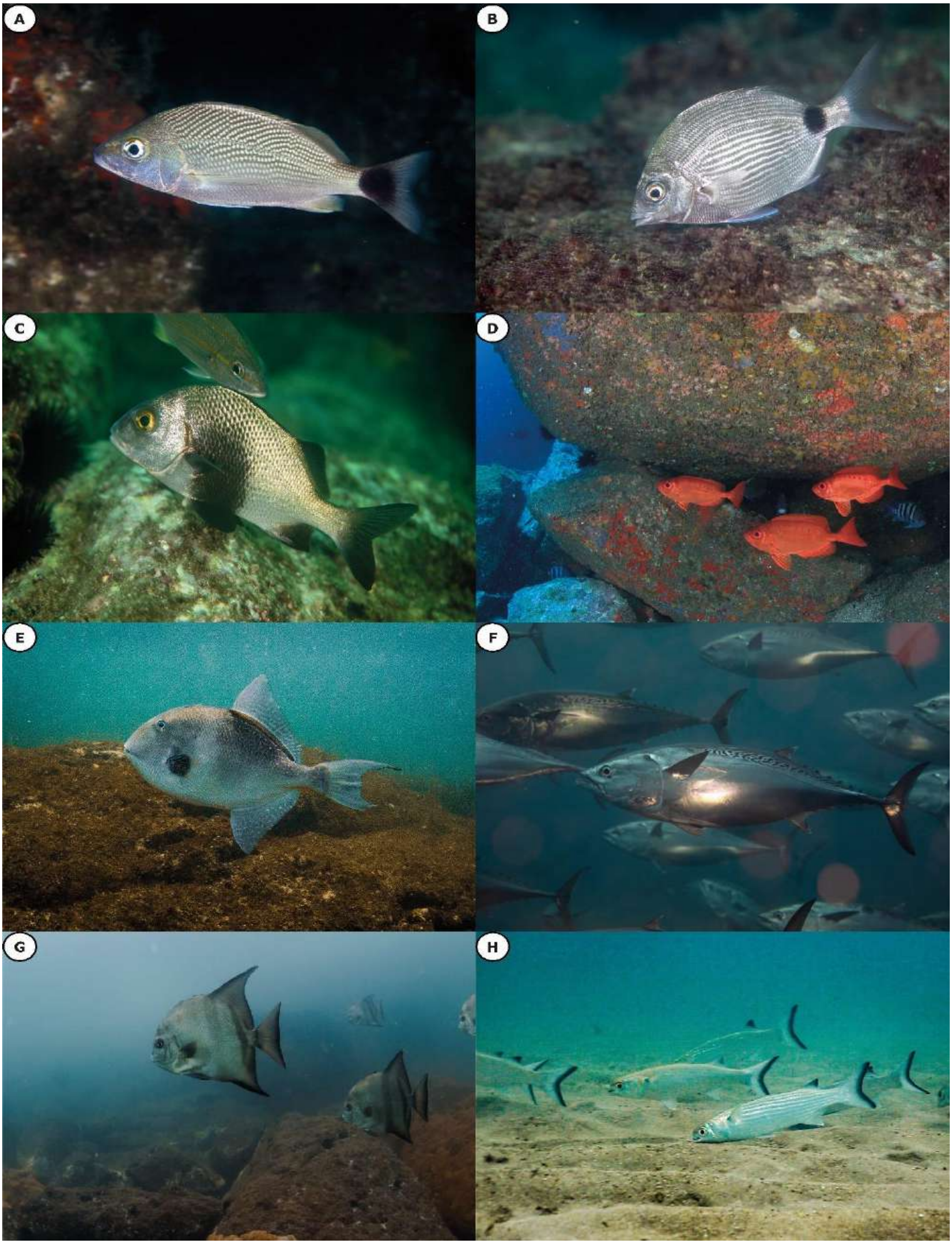

Fig. 8. The main target species for fishing with lines and hooks in recreational fishing (A-E) and through gillnets in artisanal fishing (F-H). A. *Haemulon atlanticus*; B. *Diplodus argenteus*; C. *Anisotremus surinamensis*; D. *Heteropriacanthus cruentatus*; E. *Balistes capriscus*; F. *Euthynnus alleteratus*; G. *Chaetodipterus faber*; H. *Mugil* spp. Photos: Áthila A. Bertoncini (A-D;F), Augusto A. Machado (E and G), and Edson Farias Jr. (H).

The mentioned species above, which are commonly caught by gillnet, were rarely recorded on rocky reefs. Despite that, the target fish species caught by recreational fishing were widely observed on rocky reefs (Fig. 7B), especially on Rasa Is. which represented the greatest mean density of fisheries-target with 25.5 individuals per 100m², followed by Far category (8.9 ind./100m²). Finally, the MONA category presented about 8.8 individuals per 100m². Among these target fish species, the Silver porgy represented 87.4% of the mean density of target species (by recreational fishing) found on rocky shores, and the Atlantic spadefish (gillnet) was recorded, representing 4.0% of the total mean density.

3.4. Distribution of threatened species

A total of 20 threatened species were recorded during the sampling effort, with 13 fish species classified by the IUCN red list, 16 according to the ICMBio, and 9 species occurring in both red lists. According to the IUCN red list, approximately 84.7% of the threatened species were observed within "MONA" Cagarras (Fig. 9A) with 46.1% reported exclusively in the MPA. Followed by 'Far' areas with 46.2% (exclusively 7.7%), and in the "Rasa Is." category with 30.8% of threatened species reported there (7.7%).

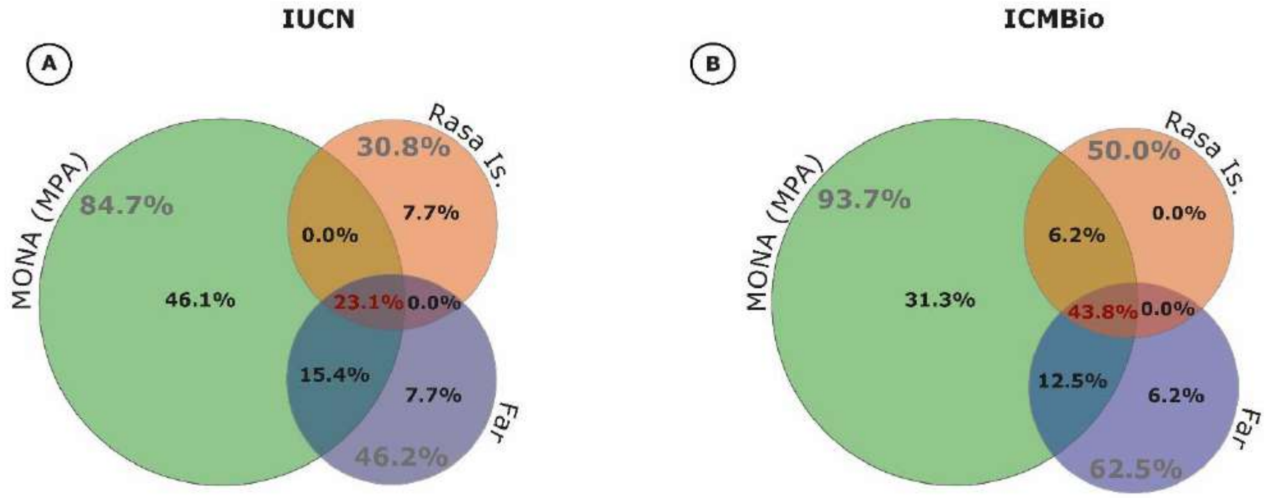

Fig. 9. The distribution of threatened species along the sampling areas according to IUCN and ICMBio red lists of threatened species. The inventory of threatened fish species may be encountered in the Supplemental Material.

In addition, about 23.1% of threatened species were recorded simultaneously in all sampling areas. Additionally, according to the ICMBio red list, about 93.7% of the total threatened fish species inside of MONA Cagarras limits were recorded (Fig. 9B), with 31.3% exclusively observed at MONA. Approximately 62.5% of the total threatened species were reported in the sampling sites classified as 'Far' (6.2% exclusive). In the Rasa Is., about 50% of the total threatened species were observed, with no single species reported exclusively for this area. Finally, 43.8% of threatened species were reported simultaneously along the three sampling sites.

4. Discussion

4.1. No-take zone role in reef fish conservation

In a general way, no-take MPAs provide a high level of protection to the native biodiversity, reducing anthropogenic disturbances and allowing an increase in fisheries resources biomass (Edgar et al., 2014; Di Lorenzo et al., 2016). Our results showed the greatest fish density median values within MPA through the SRV system. However, the fish density data obtained using the UVC technique presented a higher median value when for 'Rasa Is.' among sampling areas, although it didn't differentiated significantly from the MONA. In this context, there is strong evidence that the MPA is fulfilling its role in harboring a significant higher density of fish within its limits, which is one of the main purposes of creating marine reserves (Halpern and Warner, 2002; Batista et al., 2015).

The outcomes expected from protected areas may vary according to different factors, such as location, size, or marine reserve age (Edgar et al., 2014). Therefore, the MPA implementation aims to protect biodiversity, favoring the increase of fish diversity (Garcia-Charton et al., 2008; Cooke et al., 2023). Our findings evidenced the highest fish richness values within the MONA Cagarras boundaries, presenting significant differences between the areas through sampling techniques. In addition, considering the fish density and richness, our results reinforce the study hypothesis that the MPA is home to significant fish communities. Finally, this study provides empirical evidence of the no-take zone's importance to fish conservation, avoiding changes in the ecosystem caused by unsustainable fisheries (Rolim et al., 2022).

4.2. Fisheries management at MPA surrounding

Nowadays, the fishing activities regulation of the MONA Cagarras's surroundings prohibit the use of the purse seines or gill nets within up to a 200 m radius and all extractive actions up to the 10 m limit of each island (ICMBio, 2020). Although there are restrictive measures for fisheries inside this MPA, a recent study by Machado et al., (2023) showed that fishing gears (e.g. fishing nets, lines, and hooks) were recorded within MONA Cagarras' boundaries. Despite these unsustainable actions, the fisheries are performed mainly on MPA's surroundings and have been reported through fish landing (data available from FIPERJ technical reports). Among the fish species landed, about 95.6% of the total may be found on rocky reefs within the MPA, including a small part of the target species (circa 10%).

MPAs are known to harbor more species when compared to non-protected areas (Cooke et al., 2023), and their fisheries stocks have been assessed through estimates of unfished biomass (Hanns et al., 2022). In MONA Cagarras surroundings, the fishing catch and gear have been previously studied (Amorim and Monteiro-Neto, 2016; Loto et al., 2018), however, there is little information about the marine reserve role in target species conservation. Our results showed the highest mean density of target fish species (25.5 individuals/100m²) on Rasa Island and the lowest value on MONA Cagarras (8.8 ind./100m²). However, it's important to highlight that although Rasa island is not within the MPA, it's daily monitored by the Brazilian Navy which inhibits these activities in its surroundings, while the MONA is susceptible of occasional inspections. Our findings represented a first step to understanding the target species' data and evidenced a lower target fish density within the MPA limits.

4.3. *A Hope Spot to Threatened biodiversity*

Hope spot regions are singular places recognized scientifically by the Mission Blue Organization as crucial to Ocean health, aiming mainly to safeguard marine biodiversity (https://missionblue.org/). In this context, this initiative emerges as a valuable tool, since only 8.16% of the ocean worldwide is covered by MPA according to the World Database on Protected Areas (https://protectedplanet.net/), and only 2.9% is highly or fully protected from fisheries damage. Furthermore, the period between 2021 to 2030 has been recognized as the United Nations Decade of Ocean Science for Sustainable Development. In this sense, Brazil has demonstrated management actions that help face the Ocean Decade Challenges (Diederichsen et al., 2024), including the protection of life below water.

Although the Brazilian scenario shows an increase in the total extent of MPAs in recent decades, the MPA's capacity to preserve threatened species is poorly known (Vilar and Joyeux, 2021). In addition, according to the Convention on Biological Diversity (CBD) protecting threatened species is an essential tenet, and included in the 4th target of the CDB-2030 Goals (https://www.cbd.int/gbf/targets/4/). Our findings revealed the importance of the MONA Cagarras on fish conservation, harboring more than 80% in both red list (IUCN and ICMBio) of the threatened fish species total within its boundaries. These results warrant decision-makers' attention to the need to develop conservation measures for threatened species management in the MPA and its surroundings.

4.4. *Conservation strategies: Scientific research, Social engagement, and Co-management*

No-take MPAs have been considered worldwide as the greatest biodiversity conservation tool which can increase fish density, size, and biomass recovery (Pinheiro et al., 2018; Sala and Giakoumi, 2018). Furthermore, the MPA implementation with active management, scientific research, as well as social engagement may represent a valuable strategy to improve its effectiveness level, avoiding the risk of becoming mere "Paper parks" (Halpern, 2014; Relano and Pauly, 2023). In this context, a long-term monitoring program is crucial for detecting and informing decision-makers about the actual scenario of protected ecosystem health, allowing the elaboration of conservation measures.

Non-destructive techniques to assess marine ecosystem health have been widely deployed, especially within no-take zone limits (Andradi-Brown et al., 2016; Rolim et al., 2022). The SRV has been used complementary to UVC in our study area and represents a powerful sampling technique that provides ecological data (e.g. fish richness and density), including non-native species detection (Machado et al., 2022). These scientific data associated with social engagement may represent a helpful strategy to protect MONA Cagarras' biodiversity. Previous studies revealed the success of citizen participation in assisting in invasive alien species detection (Machado et al., 2021), and monitoring threatened fish species (Edgar et al., 2017), as well as reef fish biomass recovery through community-managed no-take zones (Gilchrist et al., 2020).

The stakeholders' participation could act as an advisory council, which is a key instrument for biodiversity conservation in MPA allowing a co-management strategy. In Brazil, no-take MPA consultative council are composed mainly of scientists, local government agents, members of local associations, and employees of non-governmental organizations (Laurino et al., 2024). The advisor council of MONA Cagarras, composed of different stakeholders, has acted since 2010 aiming to conserve local biodiversity, and elaborate legal instruments for planning public use and fishing activities in its surroundings (ICMBio, 2020). The consultative council model used at MONA Cagarras has been positive and can be evidenced by our findings, although Machado et al. (2023) have recorded environmental threats (e.g. Fishing gear, invasive alien species) within its limits. Despite some positive results of the present study, it is important the MPA enforcement and review the no-take zone boundaries, including the entire reef ecosystem in the fully protected area, fostering and ensuring an even better protection.

4.5. The future perspectives of a Hope Spot region

The HS regions may be represented by already protected areas, while others still require awareness of the need to implement protection. In the Brazilian domain, the Hope Spot recognition was first established in 2017 at Abrolhos Bank, and 4 years later on Cagarras Islands and surrounding waters. Finally, in August 2024, the Alcatrazes Archipelago located near off the coast of São Paulo was recognized as the newest Brazilian Hope Spot. The second Brazilian HS includes a small part with a MPA, and its surrounding waters yet to be protected, where anthropic activities occur freely, for instance, vessel traffic, sewage discharge, fisheries, and others (ICMBio, 2020). To start thinking about a better future, it is necessary to consider that these areas are under strong anthropic pressure (i.e. Rio de Janeiro Harbor), especially in areas where a high number of threatened species may be found, such as MONA Cagarras. In this context, regulating human activities (e.g. unsustainable fisheries, invasive alien species dispersion by vessels, marine litter releasing), even outside the MPA, is an important measure to avoid potential damage to marine life.

The Mission Blue Organization has spread Hope Spots worldwide, aiming to inspire a conservation movement to reinforce the ocean's importance. The future perspective expected is an increase in the public and managers' attention to the environmental and economic relevance of these areas. In this way, starting an upwelling of protection measures that increase the MPA extent worldwide, especially the fully protected areas. Furthermore, an increase in public awareness of the valuable resources available, providing greater social engagement and sustainable practices for protecting marine ecosystems, principally during the current Ocean Decade.

5. Conclusions

Rio de Janeiro city presents only two no-take zones, one around Cotunduba Island (At the entrance of Guanabara Bay) including a 50 m radius and the other on the MONA Cagarras which comprises 10 meters of MPA around each island. Therefore, a broader view of island protection is important to protect biodiversity and safeguard the connectivity of the Rio de Janeiro coastal islands. In this context, no-take marine reserves represent a promising area for marine conservation worldwide, especially, when addressed beyond its limits. The herein study evidenced the role of the MONA Cagarras harboring high reef fish richness and density compared to surrounding areas, despite its discreet protected area. The HS recognition reinforces the importance of rethinking the no-take marine reserve boundaries to include entire reef areas and surrounding rocky slabs and outcrops, considering the survival needs of fishermen. In addition, it is essential to consider a buffer zone covering on the surrounding area of the islands, including the Rasa island, and in this context avoiding the loss of target species richness and density found there.

The Hope Spot recognition itself will not guarantee the protection of marine communities but can foster greater awareness about the valuable living resources available there, mainly threatened species. In this context, our study highlighted the importance of protected areas and encourages that the integration between scientific data and other local stakeholders' knowledge (e.g. MPA managers, fishermen, and tourism operators...) could be a starting point for implementing conservation measures in biodiverse regions located nearby to large urban centers. The public participation and transparency in the decision-making process were already appointed previously as a constraint for Ocean Decade challenges (Diederichsen et al., 2024). Making the ocean better known and valued requires improvement in management practices with stakeholders' involvement and general public awareness, allowing long-lasting results worldwide, including in the newest Brazilian Hope Spot.

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Credit authorship contribution statement

Augusto A. Machado: Conceptualization, Methodology, Formal analysis, Investigation, Writing - Original Draft, Writing - Review & Editing. **Aline A. Aguiar:** Writing - Review & Editing, Project administration. **Maria L. Abieri:** Writing - Review & Editing. **Bruno P. Masi:** Writing - Review & Editing. **Mauricio Hostim-Silva:** Writing - Review & Editing, Supervision. **Áthila A. Bertoncini:** Conceptualization, Methodology, Investigation, Writing - Review & Editing, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplemental Material. The inventory of threatened fish species recorded. 0. Absent.- 1. Present

Species	MONA Cagarras' Category	Rasa Is. Category	Far category	Status IUCN	Status ICM-Bio
Ginglymostoma cirratum (Bonnaterre, 1788)	1	0	0	DD	VU
Rhincodon typus Smith, 1828	1	0	0	EN	VU
Zapteryx brevirostris (Müller & Henle, 1841)	1	0	1	VU	VU
Tetronarce puelcha (Lahille, 1926)	0	0	1	CR	VU
Gymnura altavela (Linnaeus, 1758)	1	1	1	VU	CR
Myliobatis freminvillei Lesueur, 1824	1	1	0	DD	EN
Elacatinus figaro Sazima, Moura & Rosa, 1997	1	1	1	NE	VU
Hippocampus patagonicus Piacentino & Luzzatto, 2004	1	0	0	VU	VU
Hippocampus reidi Ginsburg, 1933	1	0	1	NT	VU
Scarus trispinosus Valenciennes, 1840	1	0	0	EN	EN
Sparisoma axillare (Steindachner, 1878)	1	1	1	DD	VU
Sparisoma frondosum (Agassiz, 1831)	1	1	1	DD	VU
Epinephelus marginatus (Lowe, 1834)	1	1	1	VU	VU
Hyporthodus niveatus (Valenciennes, 1828)	1	1	1	VU	VU
Mycteroperca bonaci (Poey, 1860)	1	0	1	NT	VU
Mycteroperca interstitialis (Poey, 1860)	1	0	0	VU	VU
Pomatomus saltatrix (Linnaeus, 1766)	1	0	0	VU	NT
Rhomboplites aurorubens (Cuvier, 1829)	0	1	0	VU	NT
Balistes capriscus Gmelin, 1789	1	0	1	VU	NT
Mola mola (Linnaeus, 1758)	1	0	0	VU	LC

6. Considerações gerais:

6.1. Monitoramento ecológico de longa duração

Programas de Pesquisas Ecológicas de Longa Duração, conhecidos como PELD, são fundamentais na avaliação da biodiversidade e compreensão das possíveis mudanças sofridas nos ecossistemas (Lindenmayer e Likens, 2009; Capitani et al., 2022). Esse instrumento de monitoramento é capaz de alertar sobre as alterações nas cadeias tróficas, o declínio das populações, a presença de potenciais ameaças que levem à vulnerabilidade funcional, incluindo o risco de extinção das espécies (Gaiser et al., 2020; Cordeiro et al., 2022). Além disso, os PELDs permitem avaliar a efetividade das AMPs (Roos et al., 2020), o que é crucial para a gestão das UCs na formulação de ações que reduzam as perturbações sobre os ecossistemas.

Nesse contexto, o Projeto Ilhas do Rio (PIR), conduzido pelo Instituto Mar Adentro, realiza suas ações de conservação desde 2011, as quais incluem o levantamento da biodiversidade de peixes no MONA Cagarras e áreas do entorno (Moraes et al., 2013). O esforço realizado pelo primeiro capítulo desta tese reuniu os dados da literatura (e.g. Rangel et al., 2007; Monteiro-neto et al., 2013; Bertoncini et al., 2019), da parceria com a colônia de pesca de Copacabana (Z13), do monitoramento realizado pelos pesquisadores do PIR por meio do censo visual e das câmeras remotas subaquáticas, para fornecer um inventário com mais de 280 espécies de peixes detectadas para a região (Machado et al., 2022). Esse estudo ainda revelou que o MONA Cagarras e as águas do entorno servem de lar para um nível moderado de espécies endêmicas (~6,0%), ou seja, espécies cuja distribuição é restrita à província brasileira. Ademais, cerca de 10,5% do total de espécies de peixes está sob algum grau de ameaça de acordo com a lista vermelha da IUCN.

Os estudos realizados nesta tese, por meio de técnicas complementares de amostragem, permitiram acessar o ambiente e detectar mais de 21 novos registros da ictiofauna que nunca haviam sido reportados para a região. Esse levantamento incluiu espécies não-nativas, como o peixe Borboleta-de-Penacho, *Heniochus acuminatus* (Linnaeus, 1758) e a Donzela-dos-Açores, *Chromis limbata* (Valenciennes, 1833) que foram registrados pela primeira vez na área amostrada, respectivamente, pelo SRV e pelo UVC (Machado et al., 2023). Por fim, os resultados apresentados pelo primeiro capítulo dessa tese realçaram a importância do MONA Cagarras na conservação dos peixes, abrigando cerca de 64% do total das espécies dentro dos seus limites e contribuindo para a candidatura da região como um Hope spot, junto a Mission Blue.

6.2. Obstáculos antrópicos à saúde da comunidade de peixes recifais

O desenvolvimento desordenado das cidades litorâneas, causando a intensificação das atividades humanas, acarreta o aumento da pressão antrópica sobre as comunidades marinhas costeiras (Lamb et al., 2018; Santander-Monsalvo et al., 2018). A degradação de áreas marinhas próximas à costa, especialmente em ambientes recifais, ocasiona prejuízos imensuráveis para a qualidade de vida e bem-estar social das pessoas que dependem diretamente delas (Pandolfi, 2003; Carneiro et al., 2021). Nessa perspectiva, diversos desafios são enfrentados pelas comunidades recifais devido ao desenvolvimento humano insustentável, que muitas vezes resulta no descarte inadequado de produtos, permitindo que alcancem os ecossistemas marinhos.

O lixo marinho representa uma grande ameaça aos ecossistemas marinhos, devido ao seu potencial de gerar a morte da fauna marinha por sufocamento, emaranhamento e pela inanição causada pelo sua ingestão irregular (Kühn et al., 2015; Rangel-Buitrago et al., 2022). Dessa forma, o capítulo dois dessa tese contribuiu com o primeiro diagnóstico sobre o lixo marinho detectado dentro do MONA Cagarras e nas Ilhas do entorno. O estudo identificou o plástico como o principal componente, representando cerca de 34,54% do total de itens encontrados. Apesar de as ilhas protegidas legalmente (Comprida e Redonda) não terem apresentado os resultados mais severos, a pesquisa revelou uma grande quantidade de petrechos de pesca dentro dos limites da UC de proteção integral, onde as atividades extrativistas são proibidas. Além disso, ao longo do estudo, foram detectados itens de lixo servindo de substrato artificial para a biodiversidade marinha local, inclusive contribuindo na dispersão de espécies invasoras (Machado et al., 2023).

Ao longo das últimas duas décadas, as espécies não-nativas têm se dispersado e ampliado a sua distribuição ao redor do mundo como consequência do aumento da mobilidade humana e da globalização do comércio entre as nações (Seebens et al., 2017; Ward et al., 2020). Diante disso, os esforços aqui realizados forneceram uma lista de verificação atualizada contendo 15 espécies alóctones vivendo dentro e fora do MONA Cagarras, incluindo quatro novos registros nunca reportados para área. Dentre as espécies não-nativas, o Coral-Sol (*Tubastraea* spp.), reconhecido como uma espécie invasora devido aos efeitos negativos previamente reportados sobre os ecossistemas (Creed et al., 2006; Lages et al., 2011), mostrou-se amplamente distribuído ao longo das ilhas costeiras, especialmente entre 10-20 m. Por fim, o segundo capítulo desta tese revelou que, nas áreas com maior abundância relativa do coral invasor, foram detectados menores valores médios para a riqueza e abundância de peixes. Contudo, em locais com menor cobertura de *Tubastraea* spp. foram obtidas maior riqueza e abundância de peixes.

Seguindo nessa direção, os resultados aqui apresentados preenchem lacunas importantes assinaladas no Plano de Pesquisa pela gestão do MONA Cagarras (ICMBio, 2021a). Esses achados reforçam a necessidade da elaboração de medidas que atenuem os impactos dentro dos limites protegidos, eliminando toda e qualquer atividade extrativista não permitida. Além disso, os esforços aqui efetuados evidenciaram um aumento na cobertura do coral invasor, comprovando que, a realização de ações de manejo do Coral-sol, aliadas ao monitoramento contínuo, são medidas cruciais, não apenas dentro da área marinha protegida, mas também no entorno, visando o controle e a redução dos seus efeitos nas comunidades marinhas recifais.

6.3. O papel das reservas marinhas na conservação da ictiofauna

Reservas marinhas, também reconhecidas como AMPs, têm sido estabelecidas ao redor do mundo como uma estratégia de conservação que visa proteger a biodiversidade regulando as atividades dentro dos seus limites (Halpern et al., 2003; Cheng et al., 2019). Os benefícios dessas áreas, quando planejadas adequadamente, são frequentemente observados com a recuperação de estoques pesqueiros anteriormente sobre-explorados, de cadeias tróficas e do habitat (Claudet et al., 2011; Laffoley et al., 2019). Diante disso, as reservas marinhas são áreas com capacidade de prover serviços ecossistêmicos, resultando em vantagens econômicas para a população local por meio de atividades recreativas, do turismo e do aumento do faturamento das atividades pesqueiras no entorno da proteção (Leenhardt et al., 2015; Costello, 2024).

De acordo com o Plano de Manejo do MONA Cagarras (ICMBio, 2020), a biodiversidade marinha está sob uma condição preocupante em razão dos impactos antrópicos realizados nessa região, em especial a pesca ilegal e a sobrepesca. Outros fatores colaboram para esta situação, como as invasões biológicas, a visitação desordenada, o lixo marinho, a poluição marinha oriunda da Baía de Guanabara e do Emissário Submarino de Ipanema (ICMBio, 2020; ICMBio, 2021b). Apesar desse cenário alarmante, o terceiro capítulo desta tese expõe um panorama positivo sobre a riqueza de peixes do MONA Cagarras. Os recifes rochosos amostrados dentro da reserva marinha apresentaram diferenças significativas para os maiores valores medianos de riqueza de espécies quando comparados aos localizados próximo (<10km) e distante (>10km) por meio de ambas as técnicas de amostragem (e.g. SRV e UVC). Ademais, a densidade mediana obtida com o vídeo rotacional também foi maior dentro da AMP em relação às ilhas do entorno.

As atividades pesqueiras na região das Ilhas Cagarras e do seu entorno são realizadas há décadas (Gerhardinger et al., 2009), e, desde então, o declínio dos estoques pesqueiros vem sendo reportados (Moraes et al., 2013b). Os resultados incipientes sobre as espécies alvo das pescarias no entorno do MONA, conferem à ilha Rasa o maior valor médio de densidade (25,5 ind./100m²), por meio dos dados do UVC, ao ser comparada com as demais áreas. Apesar de esse local não estar dentro dos limites da AMP, essa ilha é habitada pela Marinha do Brasil, a quem é atribuída a responsabilidade de controlar as atividades do entorno (Gerhardinger et al., 2009). Por fim, a presente tese chama a atenção dos tomadores de decisão sobre o papel do MONA Cagarras na conservação das espécies ameaçadas, tendo em vista que cerca 84.7% (IUCN) ou 93,7% (ICMBio) das espécies que estão ameaçadas podem ser encontradas dentro da reserva marinha e 46,1% (IUCN) ou 31,1% (ICMBio) foram exclusivamente reportadas dentro do seus limites.

6.4. Um ponto de esperança na conservação marinha no Rio de Janeiro

Os Pontos de Esperança são áreas especiais que abrigam uma alta diversidade e abundância de seres vivos, incluindo espécies endêmicas e com algum risco de extinção (https://missionblue.org/hope-spots/). Nesse contexto, o reconhecimento das Ilhas Cagarras e das águas do entorno como um "Hope Spot" surge como uma estratégia fundamental para realçar a importância dessa área na conservação da biota marinha. Apesar dos desafios reportados neste estudo (e.g. lixo marinho e espécies invasoras) e mais os apontados pelo Plano de Manejo (ICMBio, 2020), o MONA Cagarras ainda resiste como UC de proteção integral abrigando mediana de maiores valores de riqueza e densidade de peixes quando comparado às áreas adjacentes. Além disso, os estudos abordados por esse documento ressaltam a importância da AMP na conservação das espécies endêmicas (i.e. província brasileira) e a presença valiosa de espécies ameaçadas na região (Machado et al., 2022; Machado et al., a ser submetido).

Em vista desse cenário, torna-se imprescindível considerar os crescentes impactos que foram registrados durante esses anos de estudo, uma vez que o segundo capítulo desta tese traz evidências dos efeitos do coral invasor sobre os descritores ecológicos da ictiofauna, além de reportar diferentes registros da presença de âncoras, cordas, pneus abandonados, entre outros que servem como substrato artificial, contribuindo para a dispersão do Coral-Sol. Seguindo nessa direção, o presente trabalho também destaca a ação do lixo marinho sobre a fauna da região, em especial petrechos de pesca encontrados com grande frequência dentro dos limites da AMP, ou seja, em áreas onde a atividade extrativista é proibida. Diante disso, a presente tese fornece para a gestão do MONA Cagarras o primeiro estudo contribuindo com um diagnóstico primário do lixo marinho e reporta uma lista de espécies não nativas e a sua distribuição ao longo das ilhas costeiras, incluindo quatro novos registros para a região dentro da AMP.

Os resultados aqui apresentados reforçam que a hipótese, onde o MONA Cagarras vem cumprindo seu papel como UC de Proteção Integral, porém necessita de uma maior atenção. Tendo em vista que, embora a AMP abrigue maiores valores de riqueza e densidade de espécies de peixes quando comparadas as áreas adjacentes, a presença de petrechos de pesca, a dispersão de espécies não nativas e a baixa densidade de espécies de peixe alvo das pescarias encontrada dentro do MONA evidenciam as suas fragilidades. Dessa forma, o presente estudo revela que o MONA Cagarras tem cumprido parcialmente o seu papel previsto no SNUC para uma UC de proteção integral, que é de "Art.7-§1º- Preservar a natureza, sendo admitido apenas o uso indireto dos seus recursos naturais". Diante disso, é esperado que essa tese realce a importância do MONA Cagarras, os seus desafios dentro e no entorno da AMP e que sejam implementadas medidas de manejo capazes de trazer mais esperança para a conservação marinha.

6.5. Percepções do autor

O substantivo feminino Esperança, de acordo com o dicionário Michaelis (2024), tem relação com o "[1]Ato de esperar aquilo que se desejar obter". No entanto, quando se trata da conservação marinha, faz-se necessário, decerto, que se tenha aquela esperança do verbo "esperançar", ensinada por Paulo Freire, que traz consigo a necessidade de ir atrás, construir e principalmente não desistir (Freire, 1992). A esperança, por si só, é apenas um substantivo abstrato, ou seja, ela precisa de alguém para existir e se esse não tiver voz, ela então contará com vozes que falem por ela sobre as suas necessidades. A iniciativa da organização Mission Blue surge com o objetivo de dar voz às formas de vida abaixo da água, esperando inspirar milhares de pessoas ao redor do mundo a falarem em nome da conservação marinha. Nesse sentido, ter "Esperança" é acreditar ser possível, diante dos desafios gerados pelas atividades humanas, unirmos as nossas mãos e vozes em prol de um mundo mais sustentável.

"You may say I'm a dreamer
But I'm not the only one
I hope someday you'll join us
And the world will be as one…"
Imagine – John Lennon

O Monumento Natural das Ilhas Cagarras está localizado próximo a três dos principais pontos turísticos do Rio de Janeiro: as praias de Copacabana e Ipanema e as formações rochosas do Arpoador. Apesar disso, milhares de pessoas que frequentam essa região e observam de longe a beleza cênica formada pelas ilhas, ainda desconhecem o potencial e o tanto de vidas marinhas que essa região guarda. O MONA Cagarras e o seu entorno auxiliam no sustento de centenas de famílias que obtêm a sua subsistência por meio da pesca e/ou do turismo (ICMBio, 2020). Nesse sentido, a proteção dessa área marinha é crucial na manutenção do seu encanto, bem como da conservação da biodiversidade marinha de um ambiente tão biodiverso como esse. Portanto, uma maneira de melhorar a conservação marinha, além do reforço na fiscalização, decorre da necessidade da ampliação da reserva marinha, que atualmente protege 10 m para pelo menos 1 milha no entorno de cada ilha protegida, tornando-a capaz de abrigar todo o recife rochoso, incluindo lajes próximas e uma porção arenosa circundante aos costões. Além disso, estimular atividades que visem sensibilizar a população fluminense e turistas, criando um sentimento de pertencimento, capaz de tornar essa pequena porção do oceano mais saudável e resiliente.

O papel da gestão do MONA Cagarras é crucial na mitigação dos impactos gerados sobre esta área, sendo capaz de reunir os atores sociais diretamente envolvidos na realização de atividades dentro e no entorno da UC (e.g. comunidade acadêmica, agentes do governo, representantes de associações locais, entre outros) e dessa forma elaborar estratégias em parceria com o conselho consultivo que minimizem impactos. Entre as estratégias, atividades que busquem a sensibilização dos operadores de turismo, pescadores e usuários da região sobre a importância do papel exercício pelo MONA Cagarras na conservação marinha e sustentabilidade dos seus recursos naturais.

7. Conclusão

O Monumento Natural das Ilhas Cagarras e as suas águas do entorno servem de lar para mais de 280 espécies de peixes, incluindo um nível moderado de espécies com distribuição restrita à província brasileira (~6%) e classificadas em alguma das categorias de ameaça de acordo com a lista vermelha do ICMBio e da IUCN (~10,5%). O presente estudo, além de contribuir com mais de 21 novos registros de espécies nunca reportadas, ainda fornece dados importantes sobre os desafios enfrentados pela fauna marinha na região (e.g. lixo marinho e espécies não nativas). A detecção do lixo marinho participando de eventos de sufocamento, emaranhamento, pesca fantasma e na dispersão do Coral-Sol, aliada à lista atualizada de espécies não nativas na área de estudo (incluindo 4 novas observações), reforçam a necessidade de um plano de ação que mitigue os seus impactos sobre a fauna marinha da região. Apesar desses estressores ecológicos, O MONA Cagarras ainda resiste como uma UC, abrigando uma maior riqueza e densidade de espécies de peixes dentro dos seus limites.

A implementação do Monumento Natural e o reconhecimento como um Ponto de Esperança na região, por si só, não serão o suficiente para garantir a proteção da biodiversidade marinha e dos seus serviços ecossistêmicos. É fundamental que a gestão do MONA Cagarras, em parceria do seu conselho consultivo, estabeleça planos e metas que visem a redução dos impactos sobre essa área. A união entre os tomadores de decisão, comunidade acadêmica, membros das associações, representantes do governo e da sociedade civil é uma ferramenta poderosa capaz de mudar hábitos, ampliar a fiscalização e pensar em ações que permitam proteger a vida abaixo da água. A Esperança, para alguns, é última que morre e fazer desse local um Ponto de Esperança é acreditar ser possível reduzir a pressão humana, de uma das maiores metrópoles brasileiras, sobre a vida marinha. Sem dúvidas, até 2030, muitos desafios ainda precisarão ser enfrentados no litoral brasileiro. Mas saber que há muitas pessoas empenhadas e motivadas na busca por melhorias, traz uma esperança do verbo 'esperançar' de que a década da ciência oceânica não terá passado em vão e que mais pessoas estarão reunidas nessa luta. Por fim, é esperado que os resultados dessa tese unidos aos gestores governamentais, a população do Rio de Janeiro e outros (as) interessados (as) possam andar lado a lado na busca por um MONA Cagarras mais conhecido e valorizado por todos e todas.

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