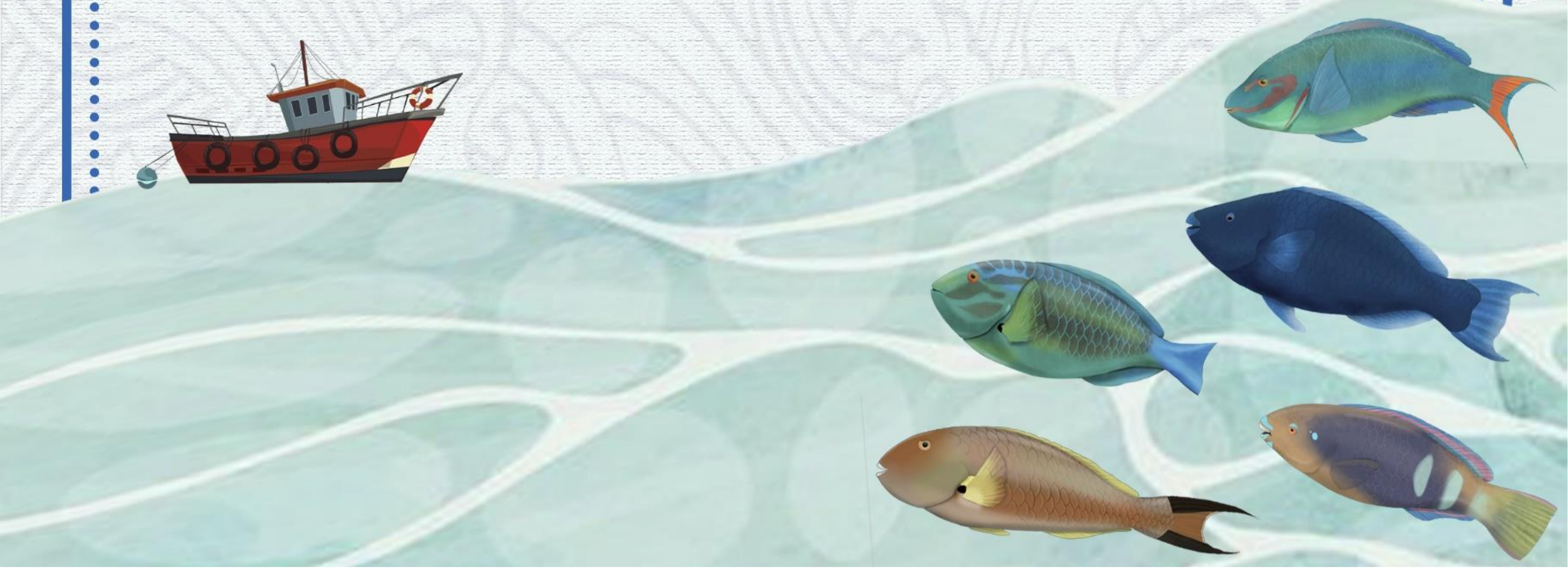
AVALIAÇÃO ESPAÇO-TEMPORAL DOS ESTOQUES DAS ESPÉCIES DE BUDIÃO AMEAÇADAS NO NORDESTE DO BRASIL

LUÍSA VALENTIM MELO DE VASCONCELOS QUEIROZ VÉRAS



UNIVERSIDADE FEDERAL DE PERNAMBUCO
CENTRO DE BIOCIÊNCIAS
PROGRAMA DE PÓS-GRADUAÇÃO EM BIOLOGIA ANIMAL

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Avaliação espaço-temporal dos estoques das espécies de budião ameaçadas no Nordeste do Brasil

Recife
2023

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Tese apresentada ao Programa de Pós-Graduação em Biologia Animal da Universidade Federal de Pernambuco, como requisito parcial para obtenção do título de doutora em Biologia Animal. Área de concentração: Biologia Animal

Orientador (a): João Lucas Leão Feitosa

Coorientador (a): Beatrice Padovani Ferreira

Recife

2023

Catalogação na Fonte:
Bibliotecária Natália Nascimento, CRB4/1743

Véras, Luísa Valentim Melo de Vasconcelos Queiroz.
Avaliação espaço-temporal dos estoques das espécies de budião ameaçadas no nordeste do Brasil. / Luísa Valentim Melo de Vasconcelos Queiroz Véras. – 2023.

128f. : il., fig.

Orientador: João Lucas Leão Feitosa.
Coorientador: Beatrice Padovani Ferreira.

Tese (Doutorado) – Universidade Federal de Pernambuco. Centro de Biociências. Programa de Pós-graduação em Biologia animal, 2023.
Inclui referências.

1. Scarini. 2. Pesca artesanal - revisão sistemática. 3. conhecimento ecológico local. 4.Reconstrução de capturas. 5. dados escassos. I. Feitosa, João Lucas Leão.(Orient.). II. Ferreira, Beatrice Padovani (coorient.). III. Título.

587 CDD (22.ed.) UFPE/CB – 2023-239

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Aprovado em: 25/08/2023.

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À Fabio Hissa Vieira Hazin, aquele que plantou em mim a sementinha do amor pela avaliação de estoques e pelas ciências pesqueiras em geral.

AGRADECIMENTOS

Uma tese é feita, na verdade, a muitas mãos. Ela é feita pelas pessoas que colocaram a mão na massa junto comigo, as que viabilizaram logística ou financeiramente a coleta dos dados e por último, mas não menos importante, as que acreditaram e foram suporte ao longo de todo esse processo. Esta tese então, contou com um time gigante, em todos os sentidos, e o mínimo que posso fazer é agradecer a cada um que contribuiu para que ela fosse publicada hoje.

Gostaria primeiramente de agradecer à minha base, meus pais, Marinês e Edilson, que desde sempre confiaram e apoiaram minhas escolhas, sendo sempre meu porto seguro. Com eles sei que tenho e terei sempre acolhimento, onde posso aportar meu barco nas tempestades mais difíceis e nas maiores calmarias também e sempre posso voltar à luta renovada, cheia de força e de grandes ensinamentos. Vocês são meus maiores exemplos de força, perseverança, luta, coragem e amor e eu agradeço a Papai do Céu todos os dias pelo presente que é ter vocês como mentores nessa vida. Agradeço também por terem me presenteado com minha irmã Tibine, ela que me acolhe e socorre sempre que preciso e sempre me ajuda com um sorriso no rosto. Muito agradecida irmã, por todo o apoio com Kauai sempre que precisei assistir aula, por todas as edições loucas de figuras em cima da hora, por me ensinar a levar a vida de forma mais leve e pela arte incrível que está estampando minha tese nesse momento, tu arrasa!

Agradecer ao meu companheiro de vida, Dráusio, que mais que ninguém segurou e dividiu comigo o trabalho árduo e prazeroso que é ser cientista, mãe/pai, acadêmic@ e don@ de casa (casa essa que está em obra ao longo de quase toda a tese!), tudo ao mesmo tempo. A gente quase pirou muitas vezes, mas deu certo! Muito agradecida por todo o apoio e por tornar esse processo muito menos difícil e muito mais divertido, tenho muito orgulho do time que a gente se tornou. Te amo.

Agradecer ao amor da minha vida, meu filho Kauai, por me ensinar sobre amor, força e propósito. Hoje eu sei que sou mais corajosa, forte e resiliente do que eu imaginava e sou uma pessoa e profissional muito melhor por isso. Agradeço por essa revolução que é ser sua mãe, te amo infinito.

Agradecer ao meu orientador, Prof. João Feitosa, que topou de cara entrar nessa comigo mesmo antes de me conhecer, sem termos experiência com avaliação de estoques e ainda por cima com uma barriga de oito meses de gestação. Não tenho nem palavras para agradecer o privilégio que foi ser orientada por você. Muito agradecida por se dedicar profundamente a este trabalho, pelo contato quase diário ao longo desses anos, por me ensinar a confiar na minha capacidade e me mostrar que eu posso ser uma profissional competente, mãe e ainda descansar nos finais de semana! Você é uma pessoa linda João, que eu tenho hoje como grande referência da profissional que quero ser. Um super pesquisador e professor, que se dedica completamente à sua profissão e ainda assim é super humilde, empático e divertido. De quebra ainda faz gráficos muito fofos e ainda ensina a gente! Você para mim hoje, além de orientador, se tornou um grande amigo. Torço para que esta parceria continue e que venham muitos outros desafios!

Agradecer à minha coorientadora, Profa. Beatrice Padovani, que mesmo com toda a carga e responsabilidade que já tem, topou participar desde trabalho comigo desde a sua concepção. Muito agradecida pelas incontáveis horas de reunião, pelas oportunidades de curso e "*networking*" que a senhora viabilizou, pela paciência com esta coorientanda que às vezes se tornava mais ausente do que deveria, pelas conversas profundas acerca da nossa profissão e nosso propósito. Você é uma referência de pesquisadora e uma grande inspiração para mim. Que honra poder escutar e aprender com você.

Gostaria de agradecer ao Prof. Jason Cope por todo o suporte nas avaliações. Que privilégio ter a oportunidade de aprender diretamente com ele que é uma das maiores referências em avaliações de estoque do mundo e para completar ainda é um professor excepcional e uma pessoa super humilde e acessível.

Gostaria de agradecer a essa equipe top da avaliação de estoques, Andrey, Matheus e Thaísa (em ordem alfabética para não dar briga), que tiveram tanta paciência comigo e me ajudaram tanto! Muito agradecida equipe, vocês são incríveis e mal posso esperar para ver a gente avaliando estoques mundo afora!

Agradecer aos professores Flávia Frédou e Thierry Frédou que abriram as portas do BIOIMPACT para mim e me receberam tão bem. Muito agradecida pelo suporte, o laboratório de vocês é incrível e espero invadir muitas outras vezes!

À Professora Camila Brasil, pelos ensinamentos no QGIS e ajuda com a produção dos Kernels. Ficaram lindooos!!

Agradecer a Jonas Vasconcelos, esse estatístico e programador top que me ajudou tanto com o R desde o início do doutorado e acabou se tornando um grande amigo.

À minha galera amada do LabPIER, Tulio, Laís, Fran, Savs, Thiago, Vini, Matheus, Clara, por todo o suporte nas coletas e na digitação dessas poucas 135.000 fichas de avaliação de desembarque. Foi um ano inteiro de trabalho mas valeu todo o esforço, resgatamos os dados oficiais de pesca de Pernambuco gente, se orgulhem muito!

A Thaís e Renata por realizarem as entrevistas dos pescadores comigo, mesmo no meio de uma pandemia mundial. Thaís, agradecida por ser essa super companhia de campo! Simbora continuar trabalhando em conjunto com esses mestres do mar e aprendendo cada vez mais com eles.

Aos pescadores das 14 comunidades de pesca entrevistadas no Rio Grande do Norte, Pernambuco e Bahia que confiaram no nosso trabalho e nos forneceram informações tão preciosas! Vocês são os verdadeiros conhecedores do mar e pra mim é uma honra trabalhar com vocês.

A Flávio Augusto Espinhara da Silva e ao Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA), por disponibilizarem o acesso às fichas de desembarque pesqueiro do estado de Pernambuco e ajudarem no suporte logístico para que essas fichas chegassem até o LabPIER.

A José Estanislau Evangelista e ao Centro Nacional de Pesquisa e Conservação da Biodiversidade Marinha do Nordeste do Instituto Chico Mendes de Conservação da Biodiversidade (CEPENE/ICMBio), por disponibilizarem acesso aos dados de comprimento de budiões provenientes do monitoramento da pesca de covo em Pernambuco e Rio Grande do Norte.

Aos pesquisadores Natália Roos, Matheus Freitas, Marília Previero e Prof. Rodrigo Moura por disponibilizarem dados de comprimento e CPUE de budiões do Rio Grande do Norte e Bahia.

Aos professores do Programa de Pós-Graduação em Biologia Animal que avaliaram e corrigiram este trabalho ao longo dos anos.

A Salomão, que foi meu psicólogo ao longo dessa jornada, me escutou tanto e salvou minha saúde mental tantas vezes nesses anos. Muito agradecida por todo o suporte Salomão! Nem imagino como teria sido fazer esse doutorado em meio a uma pandemia sem esse apoio! Só digo uma coisa, façam terapia!!

A Profa. Danielli Matias e Joedy Santa Rosa, minhas eternas e amadas vizinhas, por todo o estímulo ao longo desses anos e por acreditarem tanto no meu potencial. Tenho muito orgulho das mulheres incríveis que me cercam! Juntas vamos mais longe!

Ao Prof. José Pacheco e Ana Flávia, por cederem a casinha encantada deles no paraíso de Pontas de Pedra todas as vezes que havia coletas lá.

A todos os membros da banca de defesa, que com certeza trarão ótimas contribuições para este trabalho. Profa. Rosangela Lessa, Profa. Katia Freire, Dra. Catarina Wor, Dra. Natália Roos e Dra. Linda Eggertsen, vocês são mulheres pesquisadoras referências para mim e será uma honra tê-las avaliando meu trabalho.

Ao Projeto REPENSAPESCA pelas capacitações, workshops e *networking* em avaliações de estoque para dados escassos.

A todos do Projeto Budiões por acreditarem no meu trabalho, me fornecerem suporte logístico e financeiro para as coletas! Vamos continuar lutando pela conservação dessas criaturinhas incríveis que são os budiões! Avante!

À Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) pela bolsa de doutorado fornecida ao longo desses anos.

À Universidade Federal de Pernambuco e ao Programa de Pós-Graduação em Biologia animal, por proporcionarem educação superior pública e de qualidade!

Muito agradecida!!

“Continue a nadar
Continue a nadar
Continue a nadar, nadar, nadar
Para achar a solução
Nadar”
(Dory, 2003)

RESUMO

Os budiões do Brasil são importantes alvos da pesca artesanal, entretanto a situação de seus estoques ainda é desconhecida. Esta tese aborda diferentes aspectos da avaliação dos estoques de budião do Brasil, incluindo (1) o levantamento dos dados existentes para as espécies alvo, (2) a obtenção de novas informações do histórico da pesca por meio de Conhecimento Ecologico Local (CEL) e (3) a obtenção de novos dados de captura e a avaliação dos principais estoques. No primeiro capítulo, uma revisão de 134 documentos foi realizada abordando informações sobre avaliação de estoques. Nestes documentos, constatou-se que *Sp. axillare* e *Sc. trispinosus* são os mais estudados, assim, avaliações do tipo moderadas podem ser realizadas. As maiores lacunas foram observadas para *Sp. zelindae*, assim, apenas análises simples de risco são possíveis. Para *Sp. frondosum* e *Sp. amplum*, possivelmente seja possível executar avaliações para dados escassos. As estatísticas pesqueiras oficiais são imprecisas e foram descontinuadas desde 2010, enquanto estudos científicos são pontuais, mas representam as principais informações sobre a pesca dos budiões brasileiros. No segundo capítulo, utilizamos 200 entrevistas com pescadores para investigar o histórico da pesca dos budiões brasileiros e a percepção dos pescadores da situação dessas pescarias. Rede, arpão e covo foram identificados como as principais artes para pescar budiões no Brasil. As atividades com rede e arpão, como quantidade e duração das viagens e profundidades exploradas, são semelhantes e não mudaram com o tempo, enquanto os esforços da pescaria com covos aumentou. As áreas usadas para todas as artes de pesca e por todas as comunidades pesqueiras expandiram com o tempo, entretanto, as capturas totais e CPUEs de budião diminuíram. Seguindo as tendências de declínio relatadas pelos pescadores, a maioria considerou a situação da pesca como "pior", independentemente do tipo de arte ou da experiência dos pescadores. O terceiro capítulo traz uma reconstrução histórica das capturas das espécies de budião alvejadas pela pesca, baseada nos dados dos dois primeiros capítulos. A avaliação dos estoques das duas principais espécies capturadas é apresentada, utilizando métodos de avaliação para dados escassos. *Scarus trispinosus*, *Sparisoma axillare* e *Sparisoma frondosum* foram identificados como as espécies mais capturadas, com as duas primeiras representando aproximadamente 80% da biomassa de budiões capturados no Brasil. Estas três espécies apresentaram decréscimos nas capturas, enquanto as de *Sparisoma amplum* aumentaram de forma constante e as de *Sc. zelindae* oscilaram ao longo do tempo. O status do estoque de *Sparisoma axillare* estava acima da meta de manejo de 40%. A pesca com covos, entretanto, pode não ser sustentável da forma que vem sendo realizada, já que os pescadores estão constantemente pescando em novas áreas. O estoque de *Scarus trispinosus* foi considerado como "sobrepescado" e a pesca foi considerada como "sobrepescando" o estoque, significando que, se a pesca continuar ocorrendo no mesmo ritmo, a situação do estoque tende a piorar. As medidas de manejo implementadas não tem sido efetivas para recuperar as populações dos budiões brasileiros ameaçados. Assim, novas abordagens devem ser desenvolvidas focando nos desafios históricos, geográficos e financeiros encontrados no Brasil.

Palavras-chave: Scarini; Pesca artesanal; Revisão sistemática; Conhecimento Ecológico Local; Reconstrução de capturas; Dados-escassos

ABSTRACT

Brazilian parrotfishes are important targets from small scale fisheries; however, the status of their populations is still unknown. This thesis addresses different aspects of the evaluation of the parrotfish stocks in Brazil, including (1) a review of the available data regarding the main targeted species, (2) obtaining new data regarding the parrotfish fishing history through Local Ecological Knowledge (LEK) and (3) obtaining new catch data and assessments of the main parrotfish stocks. In the first chapter, we performed a review of 134 published documents addressing information related to stock assessments. In these documents we found that *Sp. axillare* and *Sc. trispinosus* are better studied, hence data-moderate stock assessments may be possible for both species. Information gaps are largest for *Sp. zelindae*, so only simple Risk analyses can be performed. For *Sp. frondosum* and *Sp. amplum*, the data obtained may be enough to run data-limited assessments. The official fisheries statistics available are inaccurate and have been discontinued since 2010, while scientific studies are punctual but represent the main information about the fishing of Brazilian parrotfishes. In the second chapter we used 200 fisherman interviews to investigate the fishing history of Brazilian parrotfish, and the perception of fishermen to the current situation of these fisheries. Nets, spearguns and traps were identified as the main gears used to harvest parrotfish in Brazil. Fishing activities using nets and spearguns, such as number and duration of fishing trips and the depths explored, did not change over time, while trap fishing efforts increased. Fishing grounds expanded for all fishing gears and in all communities investigated, nonetheless, total parrotfish catches and CPUEs decreased. Following the declining trends reported by fishers, most of them considered the parrotfish fishing situation as “worse” regardless of fishing gear or fishers’ experience. The third chapter presents a historical reconstruction of catches for the parrotfish species targeted by fishing, based on the data obtained in the first two chapters. Assessments of the stocks of the two main species captured are presented, performed with data-limited methods. *Scarus trispinosus, Sparisoma axillare* and *Sparisoma frondosum* were identified as the most caught parrotfishes, with the former two species representing about 80% of total Brazilian parrotfish catches. These three species presented decreases in total catches; while *Sparisoma amplum* catches increased steadily and *Sc. zelindae* catches oscillated over time. The stock status of *Sparisoma axillare* was above the management target of 40%. Trap fishing operations, however, may not be sustainable once fishers are constantly exploiting new areas. The stock of *Scarus trispinosus* was considered as “overfished” and the fishing was considered as “overfishing”, which means the fishing would aggravate the stock situation if fishing rates were maintained. The management measures adopted so far have not been effective to recover the Brazilian threatened parrotfish populations. In this way, new approaches must be developed focusing on the historical, geographic and financial challenges encountered in Brazil.

Keywords: Scarini; Artisanal fisheries; Systematic review; Local Ecological Knowledge; Catch reconstruction; Data-limited

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A CRITICAL REVIEW AND KNOWLEDGE GAPS TO ASSESS AND MANAGE THREATENED PARROTFISHES' STOCKS IN BRAZIL

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INTRODUÇÃO

Mais de 90% dos pescadores de todo o mundo dependem de atividades artesanais e a conservação e sustentabilidade destes estoques pesqueiros são objetivos essenciais para assegurar segurança alimentar e sustento para diversas comunidades, simultaneamente garantindo a manutenção dos papéis ecológicos dos recursos pescados (Jacquet & Pauly 2008, FAO 2015, Lorin et al. 2018, Pita et al. 2019). No intuito de alcançar esses objetivos, faz-se necessário entender a dinâmica de cada uma das espécies capturadas e das pescarias que as exploram, permitindo a identificação dos impactos da pesca em suas populações e no ambiente em que elas habitam (Bozec et al. 2016, Fortnam 2019, Rudd et al. 2021). Infelizmente, a maior parte dos recursos pesqueiros continua sendo explorada com pouca ou nenhuma informação sobre a história de vida das espécies ou da dinâmica de suas pescarias, o que significa que a situação de seus estoques permanece totalmente desconhecida (Pita et al. 2019, FAO 2022).

Devido às dificuldades de obtenção de dados biológicos e de pesca, gestores e a comunidade científica vêm buscando definir soluções para uma melhor avaliação dos recursos pesqueiros artesanais mesmo quando os dados existentes são poucos, através de avaliações para dados escassos (Data-limited stock assessment methods) (Babcock & Mcall 2011, Damasio et al. 2015, Winker et al. 2018). Entre elas estão a utilização de uma ou mais informações sobre séries temporais de captura, valores de biomassa relativa, utilização de dados de comprimento e idade de peixes amostrados e informações fornecidas diretamente por pescadores (Damasio et al. 2015, Sun et al. 2018 Winker et al. 2018, Rudd et al. 2021). Diversos estudos já têm demonstrado que, apesar de suas carências, tais avaliações possibilitam e embasam decisões de manejo com alto nível de competência (Costello et al. 2012, Thorson et al. 2013, Chrysafi and Kuparinen 2015, Dowling et al. 2015).

O Brasil não possui programas nacionais de monitoramento de pesca desde 2009 e não publica qualquer tipo de boletim estatístico nacional de pesca e aquicultura desde 2011, ou seja, não há dados oficiais sobre o que vem sendo pescado no país há mais de dez anos (Santos et al. 2023). Mesmo sem dados de monitoramento pesqueiro, dados científicos têm demostrado uma queda na abundância de muitas espécies-alvo no país, como é o caso dos budiões endêmicos do Brasil (Ferreira et al. 2012, Bender et al. 2014, Previero 2014, Freitas et al. 2019, Roos et al. 2020, Pereira et al. 2021). Das dez espécies de budiões brasileiros, sete são endêmicas e cinco são alvo da pesca, *Scarus trispinosus*, *Scarus zelindae*, *Sparisoma amplum*, *Sparisoma axillare* e *Sparisoma frondosum*. Os budiões (Família Labridae; Tribo Scarini) estão entre o grupo de peixes mais importantes dos ecossistemas recifais, desempenhando papéis funcionais chave para sua manutenção (Bonaldo et al. 2014, Hoey & Bonaldo 2018, Siqueira et al. 2019). Ao removerem algas e materiais associados do substrato durante sua alimentação, esses peixes auxiliam na composição e distribuição da comunidade bentônica, além de exercerem atribuições significativas em processos de bioerosão, produção e transporte de sedimentos (Graham et al. 2013, Hoey & Bonaldo 2018). Esses peixes, entretanto, também se tornaram um importante recurso pesqueiro para a pesca artesanal principalmente nos estados do Rio Grande do Norte, Pernambuco e Bahia, em especial no atual cenário em que grande parte dos peixes carnívoros estão sobreexplotados (Freire and Pauly, 2010), além do aumento no interesse de compra dessas espécies por outros países (Carvalho et al. 2013). No final dos anos 2000, o grande decréscimo de abundância observado para quatro dessas espécies de budião ao longo dos últimos

30 anos levou-as ao status de espécies ameaçadas, *Sc. zelindae, Sp. axillare* e *Sp. frondosum* estão listadas como “Vulneráveis” e *Sc. trispinosus* como “Em Perigo” de extinção (Comeros-Raynal et al. 2012, Ferreira et al. 2012, Decree No. 148, 2022). A remoção de budiões em ecossistemas recifais em outras regiões do mundo, como Caribe e Pacífico, já resultou no aumento da cobertura de algas e na diminuição de cobertura coralínea (Hughes 1994, Ferrari et al. 2012, Duran et al. 2016, Ruttenberg et al. 2019, Shantz et al. 2019). No Brasil um aumento considerável na quantidade de algas filamentosas com a remoção de herbívoros como budiões já foi demonstrada, principalmente em maiores temperaturas (Feitosa et al. 2023).

A crescente exploração dos budiões endêmicos do Brasil e sua classificação como ameaçados tornam urgente a coleta de informações biológicas e pesqueiras para avaliar a situação de seus estoques e tornar possível a tomada de ações sólidas de recuperação (Queiroz-Véras et al. 2023). Para tal, faz-se necessário o levantamento dos dados existentes para as espécies alvo, a obtenção de novos dados complementares e a realização de avaliações adequadas de seus estoques de acordo com a quantidade de dados disponíveis. Desta forma, o presente trabalho teve por finalidade avaliar espacialmente e temporalmente a situação dos estoques pesqueiros das espécies brasileiras de budião alvos da pesca, utilizando dados de captura e esforço de pesca, de abundância e de composição de tamanho dos peixes, oriundos de metodologias dependentes e independentes da pesca.

Esta tese aborda diferentes aspectos do processo de avaliação dos principais estoques de budião ameaçados do Brasil. No primeiro capítulo, intitulado “Threatened parrotfishes of Brazil: a systematic review of their life history and fisheries, with insights on knowledge gaps for stock assessment and management”, são levantados dados existentes referentes à biologia e pesca das cinco espécies de budião que são principais alvos da pesca, com o objetivo de subsidiar a avaliação de seus estoques e identificar as principais lacunas de conhecimento a serem preenchidas por estudos futuros. No segundo capítulo,“Unveiling the fishing history of threatened Brazilian parrotfishes: adaptative strategies of small-scale fisheries to maintain catches”, com o intuito de preencher lacunas de monitoramento pesqueiro identificadas no capítulo 1, o Conhecimento Ecológico Local (CEL) de pescadores foi utilizado para investigar o histórico da pesca dos budiões brasileiros e a percepção dos pescadores com relação à situação atual destas pescarias. O terceiro capítulo, “Parrotfish populations in Brazilian waters: how much is still out there?”, traz uma reconstrução histórica das capturas de cada uma das cinco espécies de budião alvos da pesca, além de apresentar a avaliação dos estoques das duas principais espécies capturadas, *Sparisoma axillare* e *Scarus trispinosus,* utilizando métodos de avaliação para dados escassos.

Além dos três capítulos que compõe a presente tese, dois outros artigos e um capítulo de livro abordando temáticas complementares foram publicados. No artigo “Effects of social organization on the feeding of the striped parrotfish, *Scarus iseri*”, publicado em 2021 no periódico Coral Reefs, observou-se que diferentes tipos de agrupamentos sociais de budiões podem exercer papéis ecossistêmicos distintos e a formação destes grupos pode ser denso-dependente. No artigo “Going further on herbivore fishing: the removal of smaller fishes from algal-dominated reefs”, publicado em 2023 no periódico Marine Ecology Progress Series, a simulação da sobrepesca sobre herbívoros de menor porte usando gaiolas de exclusão mostrou que a exploração deste grupo pode desencadear mudanças adicionais na dinâmica da comunidade bentônica que interagem com a temperatura da água. No capítulo “Herbivory and competition”, no prelo para publicação no livro “Brazilian Coral Reefs” da Marine Biodiversity Series da editora Springer, uma apresentação das interações ecológicas entre os herbívoros brasileiros e a competição da comunidade bentônica é relizada, com efoque na singularidade dos ecossistemas recifais do Brasil e suas espécies endêmicas. As informações obtidas nesses trabalhos contribuem para o conhecimento dos papéis funcionais de budiões no ambiente recifal. Estas contribuições também poderão ser usadas no futuro como base para avaliações dos estoques das espécies que considerem seu papel ecossistêmico, e por isso são vinculadas a esta tese no formato de apêndices.

CAPÍTULO I

A CRITICAL REVIEW AND KNOWLEDGE GAPS TO ASSESS AND MANAGE THREATENED PARROTFISHES' STOCKS IN BRAZIL

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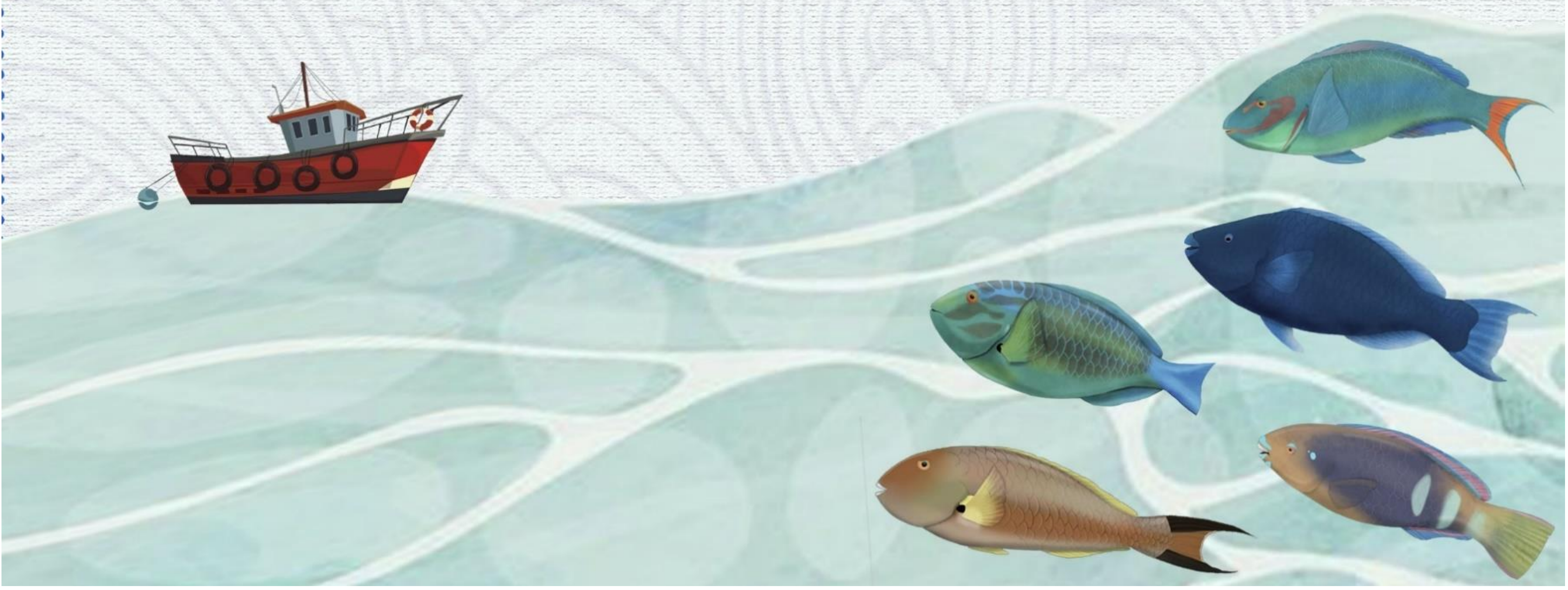

CAPÍTULO 1

A critical review and knowledge gaps to assess and manage threatened parrotfishes' stocks in Brazil

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Abstract

Given the increasing exploration of endemic Brazilian parrotfishes and their classification as threatened, there is an emergent need to gather biological and fisheries information to assess their stocks. We performed a comprehensive review of 134 studies addressing key topics of information related to stock assessments: (1) the distribution and population structure; (2) age, growth and mortality; (3) reproductive biology; (4) feeding ecology; (5) fishing data, and (6) management actions. This review focused on the most explored Brazilian parrotfish species: *Scarus trispinosus, Scarus zelindae, Sparisoma amplum, Sparisoma axillare*, and *Sparisoma frondosum*. The most abundant species, *Sp. axillare*, and the most threatened, *Sc. trispinosus*, are better studied hence data-moderate stock assessments are viable for both species. As information gaps are largest for *Sp. zelindae*, only simple Risk analyses are possible for this species. Stock productivity and status may be obtained for the remaining species, enabling data-limited assessments. The few official fisheries statistics available are inaccurate and have been discontinued since 2010; scientific studies represent the main source of information about Brazilian parrotfishes' captures but are sparse. How stocks are structured and distributed along the coast must be defined, thus genetic structuring and site fidelity studies are necessary. Life-history traits such as mortality, growth, sexual and social modes, and maturity must be a subject prioritized for all species. Brazilian fisheries statistics programs must be resumed and improved urgently. The academic community and stakeholders must focus on filling these essential knowledge gaps to promote the successful evaluation of their stocks and solid recovery actions. Otherwise, Brazilian parrotfish populations - and the fisheries and ecosystem functions dependent on them - may be at risk.

Keywords: Scarini, endemic, endangered, biology, artisanal fishing, management

1. Introduction

Assessing the status of a fishery resource represents a crucial step for conservation; establishing catch levels that allow both fishing productivity and ecosystem roles performed by organisms to be maintained is paramount (FAO 1995). More than 35% of the world's fishery stocks have been evaluated as overexploited, mainly due to exacerbated extraction and destructive fishing practices (FAO 2022). Consumption of aquatic resources has doubled since the 1970s (Maire et al. 2021; FAO 2022) and plays a key role in micronutrition, food security, livelihoods, and profits worldwide, especially in poorer countries (Béné et al. 2015; Loring et al. 2018; Maire et al. 2021; FAO 2022). To ensure the provision of these resources and maintain fisheries productivity, it is necessary to monitor the stocks' status, decrease overfishing, and achieve the sustainability of fisheries (Srinivasan et al. 2010; Béné et al. 2015).

To assess the condition of fish populations and establish total allowable catches (TAC), information about stock productivity, status, and scale are mandatory (Cope & Gertseva 2020). The stock productivity indicates the reproductive potential and growth of the population, being obtained through life history parameters, such as mortality rates, growth, and maturity, while stock status shows the relative abundance of the stock (e.g., % of unfished biomass), and can be obtained through length and age composition of catches through time (Cope & Gertseva 2020; Rudd et al. 2021). The stock scale is the absolute abundance of the fish population; total catches and/or an absolute index of abundance are needed to estimate it (Cope & Gertseva 2020).

There are several different methods to run a stock assessment, depending on the amount and type of data available, such as indices of abundances, the composition of size/age classes, and catch data (Maunder & Punt 2013; Dichmont et al. 2016). While data-rich methods, such as integrated models, are the best-case scenario, they require a large amount of data to be conducted (Rudd et al. 2021). Conversely, the developing nations that tend to be the most reliant on fish for consumption and income are generally limited in both historical data and investments in fishery science; and then, data-poor assessments have been developed to investigate stocks under these circumstances (Dowling et al. 2015; Free et al. 2017). Regardless of the method applied, a compilation of the best existing information is key to obtaining trustable assessments once the misspecification of a single important biological parameter or assumption may strongly impact the model's outcomes (Mangel et al. 2013; Carvalho et al. 2021).

Despite being a considerable economy and having left the status of a developing nation, Brazil's fishery science has received decreasingly less attention over the last decades. Official and commercial landing data are extremely poor in information, and National Fisheries Statistic Bulletins have not been published since 2010 (ICMBIO 2020). Brazil is the only country that does not report official fisheries production data to FAO (Food and Agriculture Organization of the United Nations), which has transpired since 2014 (FAO 2020, 2022). The lack of fishing data has hindered the estimation of aquatic resource stocks and left their management in the dark. This is especially worrying when considering Brazilian territorial extension and its importance to aquatic diversity; for instance, Southwestern Atlantic reef fishes present about 24% of endemism (Pinheiro et al. 2018), and about half of these endemics are limited to Brazilian coastal waters.

Ten parrotfish species are found in Brazilian waters, of which seven are endemic (Pinheiro et al. 2018). Artisanal fishers have substantially explored five of these seven species due to their larger sizes: *Scarus trispinosus, Scarus zelindae, Sparisoma amplum, Sparisoma frondosum,* and *Sparisoma axillare* (Cunha et al. 2012; Roos et al. 2016; Roos et al. 2020a). Parrotfishes (Labridae: Scarini) are functional herbivorous fish that have become important fisheries targets worldwide in recent decades due to overexploitation of top predators such as groupers and snappers (Freire and Pauly 2010). Current evidence points toward a sharp decrease in Brazilian parrotfishes' abundance and individual size in the last decades, especially for *S. trispinosus* (Ferreira et al. 2012; Bender et al. 2014; Roos et al. 2016). Consequently, *Sc. trispinosus* was categorized as Endangered by the International Union for Conservation of Nature (IUCN) (Ferreira et al. 2012), the worst threat category for any parrotfish in the world. According to the Brazilian List of Endangered Species, four other parrotfishes (*Sc. zelindae, Sp. axillare, Sp. frondosum,* and *Sp. rocha*) are considered vulnerable to extinction (Decree No. 445/2014).

Despite their threatened status, a proper evaluation of the condition of their stocks has not yet been conducted, indicating the fishing may be performed at unsustainable levels, compromising the fate of their populations and resulting in economic and environmental impacts. To make matters worse, unlike any parrotfish species in the world, the Brazilian species depends solely on the management efforts of a single country that is currently loosening environmental laws and reducing the support for research and enforcement of marine protected areas (MPA) (Abessa et al. 2019; Araújo 2020). Additionally, not until 2001, when several species of Brazilian parrotfishes were revalidated and one more described (Moura et al. 2001), they were still misidentified as morphologically-similar species from the Caribbean. Information regarding their basic life history traits, such as longevity, maturation age and size, spawning season, etc., have just started to be investigated more recently, after they were considered separate endemic species (Gaspar 2006; Véras 2008, 2009; Xavier 2015; Freitas et al. 2019).

Given the increasing exploration of Brazilian parrotfishes, there is an urgent need for reliable information to enable their stock assessment to guide and reinforce management strategies, aiming at the recovery of their populations. The goal of this work was to provide a comprehensive review of the biology, and fisheries of the endemic Brazilian parrotfish species most targeted for exploitation (*Scarus trispinosus, Scarus zelindae, Sparisoma amplum, Sparisoma axillare,* and *Sparisoma frondosum*), summarizing available data and identifying the main knowledge gaps that should be prioritized for a better assessment of their stock status.

2. Goals and literature review

It is essential to understand key aspects of the biology of parrotfishes to evaluate the status of their stocks and to investigate the impacts of their removal. Information on species distribution and population structure are addressed first, as they are the primary data used for the definition of the fishery stock. Then, the main life history parameters of mortality, age and growth, and reproductive biology were presented to characterize stock productivity. Feeding ecology information was also included in this review since it can be used in ecosystem-based assessments to investigate the environmental impacts of fish extraction. After presenting life history parameters, fishing data was summarized, including the length/age composition of catches, as they are used to obtain the status of the stock and the absolute size or scale of the population. This review concludes with a critical summary of management actions applied to the Brazilian parrotfish.

In a nutshell, six knowledge topics are presented below: (1) Distribution and population structure; (2) Age, growth, and mortality; (3) Reproductive biology; (4) Feeding ecology; (5) Fishing statistics data; and (6) Management actions; in which the available information was summarized for each of the five most fished Brazilian parrotfish species (*Scarus trispinosus, Scarus zelindae, Sparisoma amplum, Sparisoma axillare*, and *Sparisoma frondosum*). Given the paucity of literature related to Brazilian endemic parrotfishes, the review included peer-reviewed articles and unpublished literature from technical reports, theses, dissertations, statistical bulletins, official decrees, and websites.

A systematic review (SR) was done following the guidelines from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Online Resource 1). The information source was the ISI Web of Science, in which two searches were separately performed for life history data (Life history search) and fisheries data (Fisheries search). In the Life history search, the following keywords were used: Topic: (Brazil* parrotfish) OR (Brazil* roving hebivor*) OR (Scarus trispinosus) OR (Scarus zelindae) OR (Sparisoma axillare) OR (Sparisoma frondosum) OR (Brazil* Sparisoma) OR (Brazil* Scarus) OR (Brazil* Scaridae). For the Fisheries search, the keywords used were: Topic: (Artisanal fisher* Brazil* reef) OR (Compressor fishing Brazil*) OR (Brazil* parrotfish fishing) OR (Brazil* Scaridae fishing) OR (Brazil* Sparisoma fishing) OR (Brazil* recreational fisher*).

Additionally, a complementary search (CS) was performed by searching individual "curriculum lattes" (Brazilian online base of scientific researchers) of knowledgeable parrotfish specialists (Bonaldo RM, Félix-Hackradt FC, Ferreira CEL, Francini-Filho RB, Hackradt CW, Longo GO, Moura RL, and Roos NC), and directly contacting Brazilian parrotfish researchers (see Acknowledgments for the details), to compile studies unavailable online or not found by the SR, such as unpublished thesis and dissertations. The authors also included publications contained in their databases. Life history information was also searched on the websites of IUCN (https://www.iucnredlist.org/), NOAA (https://www.noaa.gov/), and FishBase (http://www.fishbase.org/search.php), looking specifically for the name of the species. Fishing data was also obtained from yearly National Fisheries Statistic Bulletins (NFSB), from 1950 to 2010, available online at https://www.icmbio.gov.br/cepsul/acervo-digital/37-download/estatistica/111-estatistica.html.

The literature search protocols were completed in January 2021 and included articles published from 1945 to 2021. A total of 230 records were obtained from the SR: Life history – 71 and Fisheries – 159. From these articles, 57 articles appeared in both searches and were excluded due to duplicity. The CS was concluded in July 2021, and 82 documents were obtained, totalizing 254 publications. Literature search results were compiled in a bibliographic database containing general descriptive fields of all obtained documents (publication type, review source, selection topic criteria found, authors, title, year, source title, volume, pages, and DOI number) (Online Resource 2). Two authors independently screened the full text of these documents and determined whether these met the inclusion criteria. To be incorporated in the survey, the study had to: (1) include at least one Brazilian parrotfish species; and (2) present information on at least one of the six knowledge topics. After the evaluation, a total of 134 references were selected, including peer-reviewed articles – 83 (62%), technical bulletins and reports – 40 (30%), thesis and dissertations – 9 (7%), and book chapters – 2 (1%).

It was possible to compile quantitative data for Brazilian parrotfishes' reproductive biology, age and growth, feeding ecology, and fisheries (Online Resource 2). They were independently extracted from the eligible documents by both reviewers to ensure uniformity. Authors of these studies were contacted if any uncertainty was found. The reproductive parameters assembled were: sex ratio, length at maturity (L50 and L100), spawning period, and fecundity. The age, growth and mortality topic gathered Von Bertalanffy parameters (Linf, k and t0), age at maturity (A50 and A100), longevity, minimum and maximum sizes, total, natural and fishing mortality rates, survival, and generation time. The parameters searched in the feeding ecology section were mean bites, foray size, and proportion of bites per substratum. Finally, national parrotfish captures per year were obtained on the fishing topic. All quantitative data obtained were tabulated and saved in xlsx format. A systematic narrative synthesis was developed as the primary outcome, containing the main conclusions of information presented, while figures and tables outline the state of knowledge for each of the six knowledge points investigated. All studies used in the review and extracted quantitative data are detailed in Online Resource 2.

3. Distribution and population structure

The starting point of a stock assessment should be the definition of the fishery stock to be evaluated, although it may be one of the most difficult steps (Sparre & Venema 1998). Information on species distribution, the genetic structure, its habitat range, and even the cooccurrence of multiple species of fishing interest may be used for stock classification (Sparre & Venema 1998; Froese & Pauly 2013). Moreover, the population of a species may present a similar genetic structure throughout its range yet have more than one fishery stock due to different exploitation histories or different site fidelities (Benger et al. 2017, 2021; Cope & Punt 2011). Understanding how exploited marine populations are distributed along the coast and within their habitats, as well as knowing their intraspecific genetic disparities, are crucial to establishing priority habitats for protection and making it possible to stipulate geographically restrictive management measures (Pinsky and Palumbi 2014).

The five targeted species (*Sc. trispinosus*, *Sc. zelindae, Sp. amplum*, *Sp. axillare*, and *Sp. frondosum*) (Table 1 and Fig. 1) are endemic to Brazil and have a similar distribution along the coast, mostly restricted to the tropical zone (Fig. 2), possibly due to higher algae biomass and productivity (Ferreira et al. 2004). All of them are found from the northern Brazilian coast in Manoel Luís Reefs to the south of São Paulo, but *Sp. axillare* and *Sp. frondosum* occurs southwards to Santa Catarina state, and the latter was recently recorded in the Amazon mesophotic reefs (Moura et al. 2001; Francini-Filho et al. 2018; IUCN 2020). *Sparisoma* species present populations in Brazilian oceanic islands, whereas *Scarus* species do not. Recently, vagrant individuals of *Sc. trispinosus* were observed in Fernando de Noronha and Rocas Atoll, and one established population of *Sc. zelindae* was registered at the Davis Seamount, in the Vitória-Trindade Island Chain (Pinheiro et al. 2015; Mazzei et al. 2017). Habitat requirements, ecological barriers, density-dependent processes, or lower availability of *Scarus* larvae at oceanic islands, may elucidate the absence of *Scarus* populations in these environments (Mazzei et al. 2017). Also, *Sparisoma* species are considered the most plastic in feeding habits, which may also explain their wider distribution range in the Brazilian Province compared to *Scarus* (Ferreira et al. 2004).

Three of the targeted endemic species studied here have expatriated populations in the southern Caribbean and offshore islands of the Eastern Atlantic coast: small groups of *Sp. frondosum* were observed in the Cape Verde Archipelago, Panama, Venezuela, and Tobago (Humann and DeLoach 2002; Freitas et al. 2014); two individuals of *Sp. axillare* were collected in Margarita Island, Venezuela (Robertson et al. 2006), and *Sp. amplum* was registered in Saint Vicent Island, Caribbean (Wilk 2003). *Sparisoma frondosum* has been recorded between 100 and 140 m deep in the Amazon mesophotic reefs (Francini-Filho et al. 2018), an indication of the permeability through the Amazon plume's barrier. Additionally, Brazilian oceanic islands are hypothesized to function as steppingstones, connecting species between Brazilian and Caribbean provinces (Pinheiro et al. 2018). These can partially explain the occasional occurrence of Brazilian *Sparisoma* species in the Caribbean and Africa, while the dispersion of coastal *Scarus* species is prevented chiefly by the Amazon River barrier on the Northern coast and cold waters southwards (Cunha et al. 2014; Pinheiro et al. 2018).

Among the five targeted species, only the genetic structure of *Sc. trispinosus* and *Sp. axillare* populations have been investigated. For *Sp. axillare*, no significant genetic substructuring was found along the Brazilian coast, which may suggest the species present only one stock along the coast, while the population from Trindade island (more than 1,000 kilometers off the nearest point on land) presented significant differences and was considered a divergent population (Verba 2019). The population of *Sc. trispinosus* presented significant substructuring along the Northeast Brazilian coast; where the samples were grouped in Northern (Rio Grande do Norte and Pernambuco states) and Southern (Bahia state) latitudinal groups, even though no genetic differences were found when sampled localities were pooled (Bezerra et al. 2018). In the absence of detailed genetic analyses for the remaining three species, the genetic richness and potential patterns in stock structuring remain unknown. Besides that, studies focusing on species site fidelity (i.e., determining species home ranges, larval dispersal capabilities), would be influential in defining stocks, but no studies related to this topic were found by the time of the SR and CR performed herein for any of the five species. Nevertheless, a recent paper, published after the review was completed, determined home ranges of adult *Sp. axillare* to be small (0.10 to 0.45 km²) (Lippi et al. 2022). Inferences on site fidelity of other species can be made based only on distribution studies.

Table 1. Overview of the five most captured Brazilian parrotfish species, including species name, the Caribbean sister-pair species common name (Portuguese/English), and maximum size registered for the species (total length in centimeters). References: (1) Moura et al. 2001; (2) Freire and Filho 2009; (3) Froese and Pauly 2020; (4) Xavier 2015; (5) Gaspar 2006; (6) Lessa et al. 2016; (7) Freitas et al. 2019.

Species	Commonly misidentified as	Common name	Max size (cm)
Sparisoma amplum	*Sparisoma viride*[1]	Budião de recife[2]/ Reef parrotfish[3]	70[4]
Sparisoma axillare	*Sparisoma rubripinne*[1]	Budião cinza[2]/ Grey parrotfish[3]	42[5]
Sparisoma frondosum	*Sparisoma chrysopterum*[1]	Budião sinaleiro[2]/ Agassiz' parrotfish[3]	37[6]
Scarus trispinosus	*Scarus coelestinus*[1]	Budião azul[2]/ Greenbeak parrotfish[3]	90[7]
Scarus zelindae	*Scarus taeniopterus*[1]	Budião banana[2]/ Zelindas' parrotfish[3]	33[1]

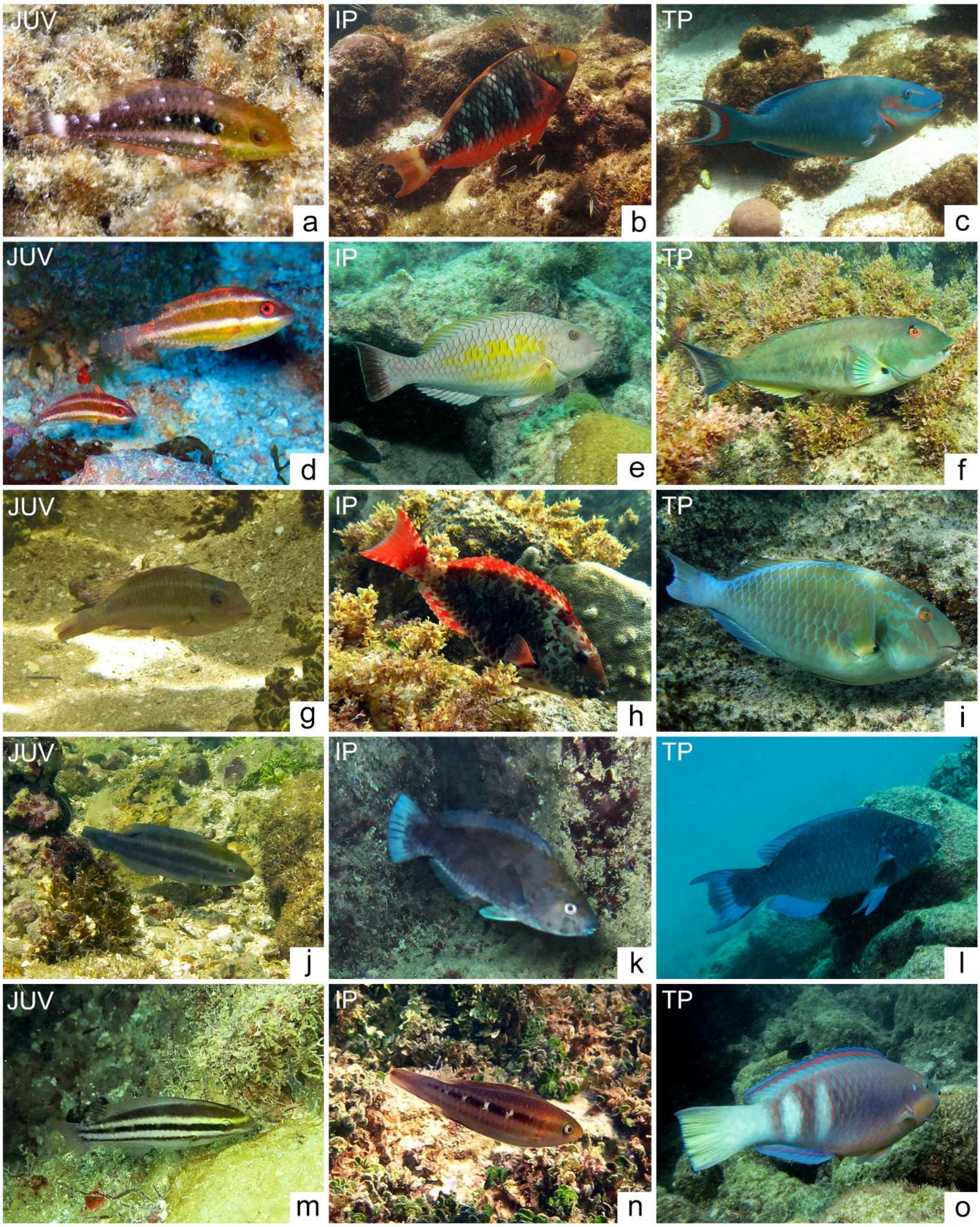

Figure 1. Photographic records of each phase (Juvenile – JUV, Initial Phase – IP, and Terminal Phase – TP) for the five most captured Brazilian parrotfish species: *Sparisoma amplum*, (a), (b), (c), *Sparisoma axillare*, (d), (e), (f), *Sparisoma frondosum*, (g), (h), (i), *Scarus trispinosus*, (j), (k), (l), *Scarus zelindae*, (m), (n), (o). Photos: Drausio Véras (a, b, c, d, f, h, i, j, m, n), João Lucas Leão Feitosa (e, g, l, o) and Luísa Véras (k).

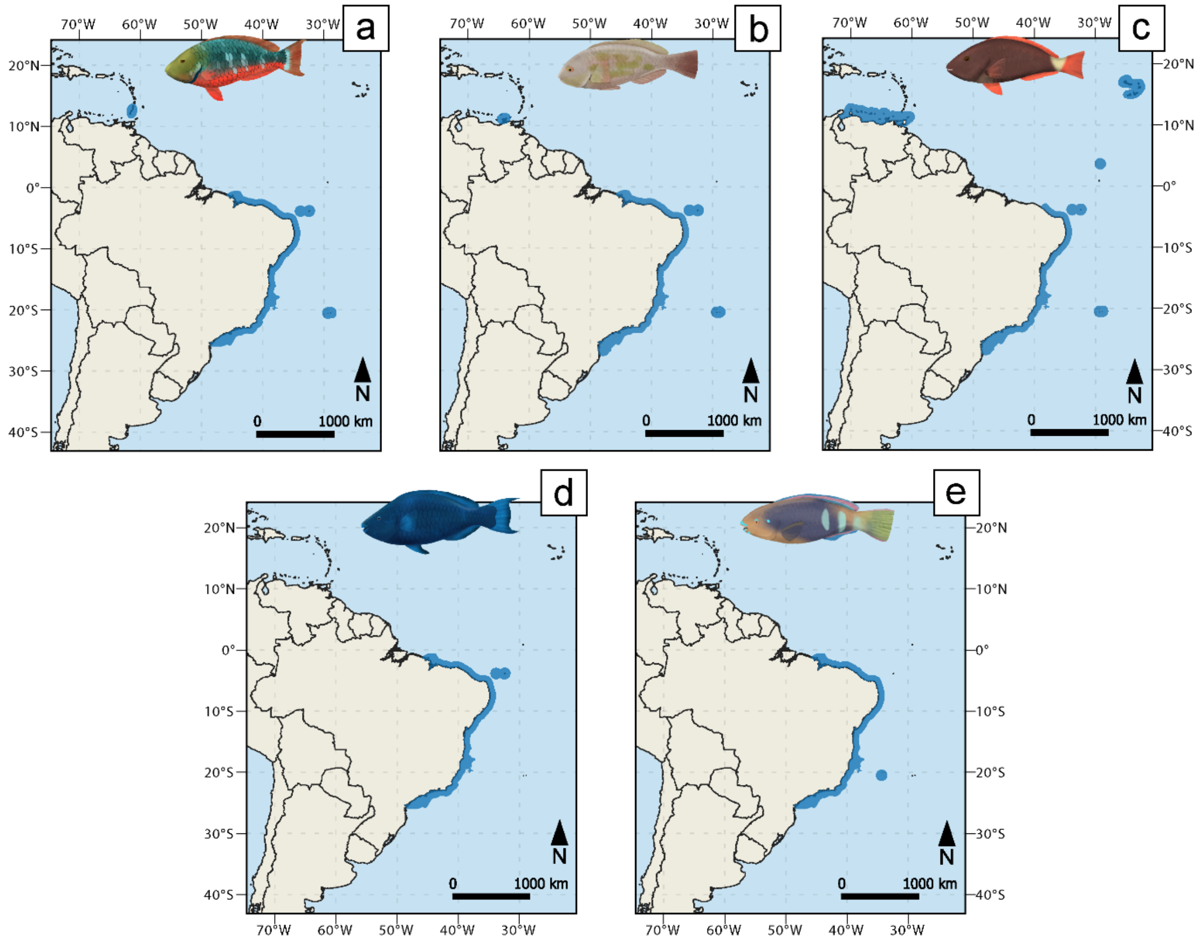

Figure 2. Distribution ranges of a) *Sparisoma amplum; b) Sparisoma axillare*; c) *Sparisoma frondosum*; d) *Scarus trispinosus*; e) *Scarus zelindae.* Maps adapted from IUCN (2020).

The biomass and abundance of the Brazilian parrotfish vary along their distribution range, according to the habitat preferences of each species, but some general abundance patterns emerge. Larger specimens and higher biomasses are generally observed in deeper reefs, while high abundances of smaller parrotfish are registered in shallower areas (Floeter et al. 2007; Feitosa and Ferreira 2014; Pereira et al. 2018; Roos et al. 2019; but see Cordeiro et al. 2016 for an exception). *Scarus trispinosus* has a preference for calcareous substrates on higher-complexity reefs (Ferreira et al. 2004; Roos et al. 2019), being more abundant in the pinnacle reefs (locally referred as "Chapeirões") of the Abrolhos region, the largest reef complex in the Southwestern Atlantic (Ferreira et al. 2004; Araújo et al. 2020). *Sparisoma amplum* and *Sc. zelindae* are the less abundant species and present increased biomasses in deeper biogenic reefs farther from the coast (Hoey et al. 2018; Roos et al. 2019). *Sparisoma axillare* is considered one of the most generalist Brazilian reef fish in terms of habitat preferences (Araújo et al. 2020), being found abundantly along all its distribution range (Francini-Filho et al. 2010; Bender et al. 2014; Feitosa and Ferreira 2014; Cordeiro et al. 2016; Hoey et al. 2018; Araújo et al. 2020). Similarly, *Sp. frondosum* is usually ubiquitous (Cunha et al. 2008; Feitosa and Ferreira 2014; Cordeiro et al. 2016; Roos et al. 2019) but presents higher biomasses at lower latitudes (Ribeiro 2004; Carvalho et al. 2013; Hoey et al. 2018) and in patch reefs (Araújo et al. 2020). Despite differences according to habitat requirements, Marine Protected Areas (MPA) have also influenced parrotfish biomass.

Increased abundances are usually registered inside fully protected areas (no-take MPAs) (Maida and

Ferreira 1997; Ferreira et al. 2004; Francini-Filho and Moura 2008a, b; Roos et al. 2020a). Also, the highest *Sc. trispinosus* abundances within Abrolhos are found in no-take areas (Francini-Filho and Moura 2008a, b; Roos et al. 2020a). *Scarus trispinosus* was also registered as the second most abundant species in Manoel Luís State Park, a no-take Marine Reserve (Rocha and Rosa 2001). *Sparisoma amplum* shows higher abundances on fully protected reserves within oceanic and coastal islands such as Fernando de Noronha, Atol das Rocas, Trindade and Abrolhos (Rosa and Moura 1997; Gasparini and Floeter 2001; Rocha and Rosa 2001; Ferreira et al. 2004; Francini-Filho and Moura 2008a, b; Hoey et al. 2018). Interestingly, *Sp. axillare* was the only species to present higher abundances outside protected areas compared to adjacent MPAs (Francini-Filho and Moura 2008a, b). Such discrepancy may be related to the habitat plasticity of the species, which may adapt to the harsh conditions of highly fished, algae-dominated areas (Ferreira et al. 2004). *Sp. frondosum* also presents increased abundances inside no-take MPAs (Rosa and Moura 1997; Rocha and Rosa 2001; Francini-Filho and Moura 2008a), and sightings of large females and terminal males outside MPAs are relatively rare (ICMBIO 2015). Unfortunately, more flexible MPA categories - those intended for multiple and extractive uses - present low abundances of *Sc. trispinosus, Sp. amplum,* and *Sp. frondosum,* similar to non-protected areas (Francini-Filho and Moura 2008a, b; Bender et al. 2014).

Fully protected marine reserves may also play essential roles in maintaining Brazilian parrotfishes' genetic diversity (Bezerra et al. 2018). Besides holding the largest population of *Sc. trispinosus*, the Abrolhos Region also exhibits higher genetic richness, probably due to the exportation of richer genetic pools from the Abrolhos Marine National Park to the surrounding areas (Bezerra et al. 2018). Besides the importance of the Abrolhos Marine National Park for conserving the *Sc. trispinosus* population, the general abundance of this species has been decreasing over time within this no-take reserve (Roos et al. 2020a). The intensive fishing of *Sc. trispinosus* adults in neighboring areas is probably directly impacting protected nursery areas (Roos et al. 2020a). The importance of nursery grounds to population maintenance and replenishment must be acknowledged. For instance, seagrass habitats and macroalgal beds are known to sustain a great abundance of juvenile parrotfish but lack appropriate protection and are currently in decline (Chaves et al. 2013; Roos et al. 2019, 2020a).

4. Age, growth and mortality

Fish age and growth determination are fundamental to fisheries management, providing critical information about stock mortality and growth rates that, if temporally evaluated, may indicate stock responses to habitat changes, recruitment success, and changes in population structuring due to fishing mortality (Morales-Nin 1992; Froese and Pauly 2013). In Brazil, growth studies were found for *Sc. trispinosus, Sp. amplum, Sp. axillare* and *Sp. frondosum,* with all studies using accurate methods of quantifying growth increments from sagittal otoliths (Gaspar 2006; Xavier 2015; Freitas et al. 2019; Roos et al. 2020b). The largest species, *Sc. trispinosus,* was the only parrotfish with studies in a wider geographic range. *Scarus zelindae* age, growth, and mortality are still to be determined (Fig. 3).

Estimating mortality parameters, especially natural mortality rates, are essential to model population dynamics and obtain stock productivity and status (Cope & Gertseva, 2020). Yet, even with most parrotfish species being studied regarding their growth, the known parameters for mortality are limited. Natural mortalities (M) were available for *Sp. amplum, Sc. trispinosus*, and *S frondosum*, with fishing mortalities

(F) around three times the natural mortality for the two first species (Xavier 2015; Freitas et al. 2019) and half the value of F for the later (Lessa et al 2016) . However, as M estimates were obtained through different empirical equations, differences should be considered with care. High fishing mortality values accelerate overfishing processes, reducing longevity and other biological parameters (Morales-Nin 1992; Simpfendorfer et al. 2005).

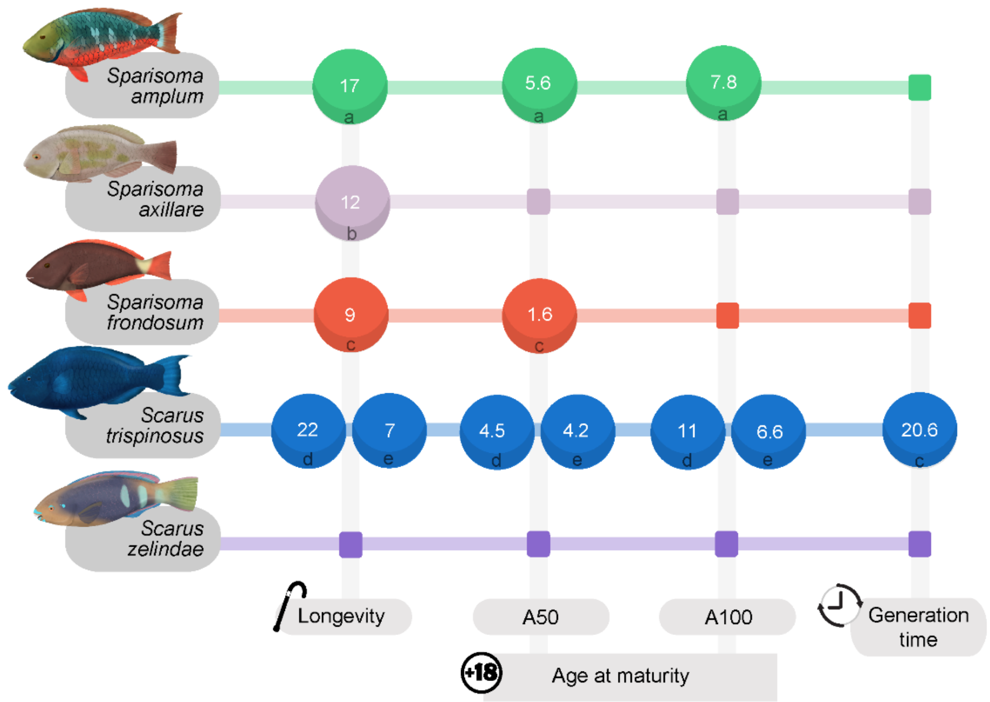

Figure 3. Growth parameters obtained for the most captured Brazilian parrotfishes, including longevity in years, age at first maturity (A50), maximum maturity age (A100), in years, and generation time, in years. References: (a) Xavier et al. 2019, (b) Gaspar 2006, (c) Lessa et al. 2016, (d) Freitas et al. 2019, (e) Roos et al. 2020b.

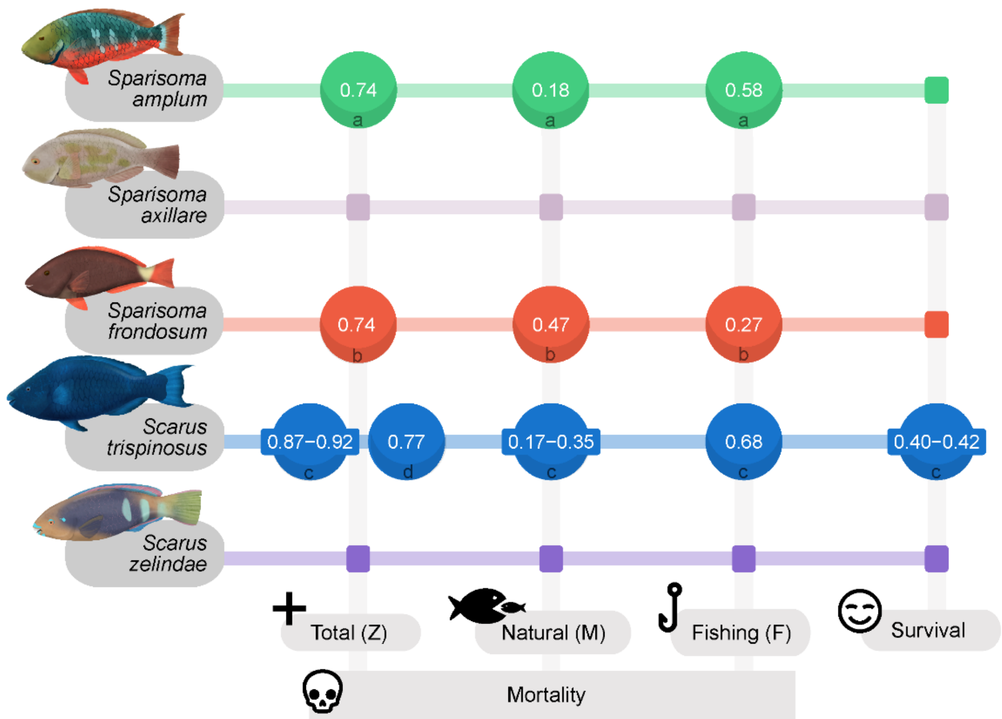

Figure 4. Estimates of Mortality (Total – Z, Natural – M and Fishing – F) and Survival per year. References: (a) Xavier 2015, (b) Lessa et al. 2016, (c) Freitas et al. 2019, (d) Roos et al. 2020b.

According to growth parameters, age at maturity (A50) diverges among species: *Sp. frondosum* reaches maturity in less than two years (Gaspar 2006), while it takes *Sc. trispinosus* and *Sp. amplum* at least twice this time to mature (Xavier 2015; Freitas et al. 2019; Roos et al. 2020b), increasing their chances of being captured before reproduction. Asymptotic lengths (Linf) estimated for *Sp. axillare* and *Sp. frondosum* were similar (< 40 cm) (Gaspar 2006; Lessa et al. 2016), while the value for *Sc. trispinosus* (Freitas et al. 2019) was more than double of almost all other species (~ 85 cm) and *Sp. amplum* had an intermediate Linf (~ 55 cm) (Xavier 2015) (Fig. 5). Consequently, lower *k* values were found for species with the higher Linf, depicting *Sc. trispinosus* as slow-growing and long-living (reaching 22 years of longevity) compared to the other Brazilian parrotfishes (Figs. 3 and 5) and many *Scarus* species (generally ranging from 5 to 15 years, Choat et al. 1996, Taylor and Choat 2014). The variability between the Linf estimated for *Sc. trispinosus* between studies reflects the differences in maximum fish size observed for each area (90 cm in Bahia, Freitas et al. 2019, and 55 cm in Rio Grande do Norte, Roos et al. 2020b), with larger and older fish found in the Abrolhos region. Roos et al. (2020b) argue that older fish may be found in deeper reefs, as younger and smaller individuals dominate the shallow area where the study was performed. Similarly, Freitas et al. (2019) registered younger individuals in shallow reefs of Abrolhos, while the largest, long-living individuals were found in deeper reefs. The curve and parameters presented in Freitas et al. (2019) may give a better picture of *Sc. trispinosus* growth due to the higher size ranges obtained and should be preferred for stock assessment models.

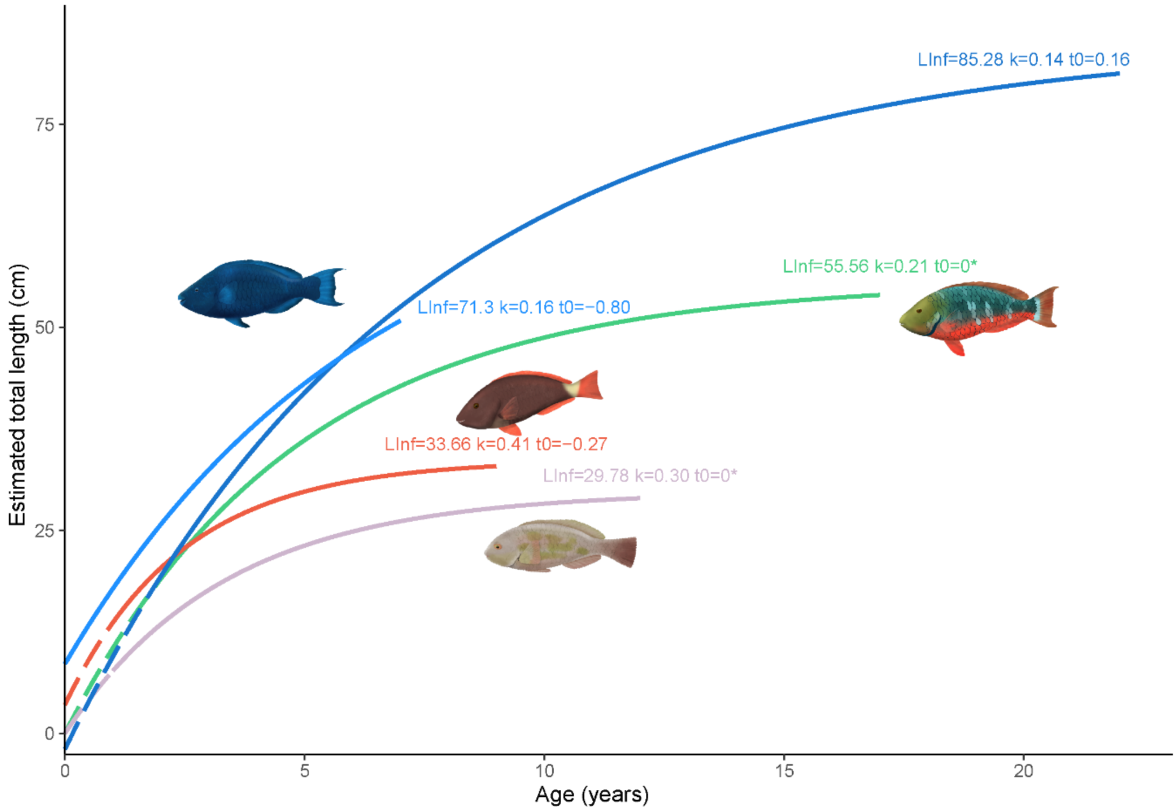

Figure 5. Von Bertalanffy curves and estimates (Linf in cm, K and t0 in year^{-1}) for the most captured Brazilian parrotfishes: *Scarus trispinosus* (blue line, Roos et al. 2020b and dark blue line, Freitas et al. 2019), *Sparisoma amplum* (green line, Xavier 2015), *Sparisoma frondosum* (red line, Lessa et al. 2016) and *Sparisoma axillare* (pink line, Gaspar 2006). Dashed lines represent the projections of the curves up to t0. * represents t0 values fixed as 0.

5. Reproductive biology

Even though reproductive parameters are needed in most stock assessment methods, information on the reproductive biology of Brazilian parrotfishes is still very scarce. Basic information - such as maturational size, fecundity, and spawning periods, important to estimate stock productivity - is still not determined for all species. Only five studies addressing Brazilian parrotfish reproduction were found, from which only three species were appraised, *Sc. trispinosus*, the most threatened, and *Sp. axillare* and *Sp. frondosum*, the most captured species (Fig. 6). More reproduction parameters were estimated for *Sp. axillare* and *Sp. frondosum*, but their populations were assessed over a decade ago and were spatially restricted (Véras 2008; Véras et al. 2009; Lessa et al. 2016), and thus need to be re-evaluated. *Scarus trispinosus* parameters are more recent, and this is the only species studied over a wider geographic area (Freitas et al. 2019; Roos et al. 2020b). Reproductive parameters for *Sc. zelindae* and *Sp. amplum* are entirely unknown.

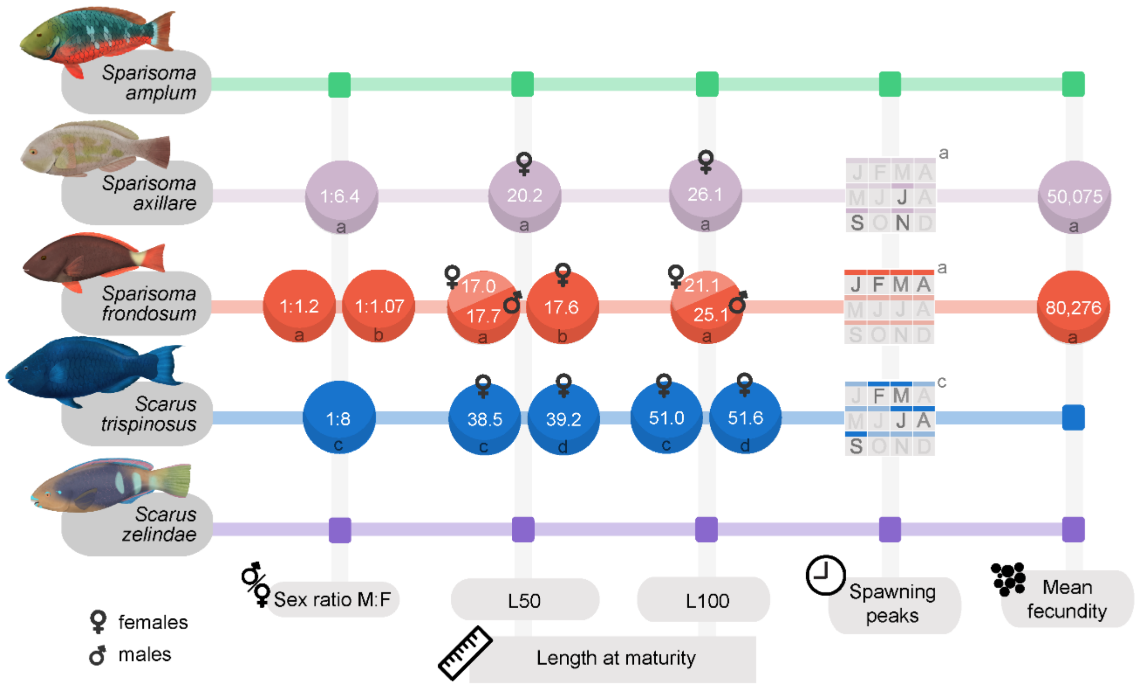

Figure 6. Reproduction parameters estimated for the most captured Brazilian parrotfishes, including sex ratio (Males: Females), length at maturity (L50 and L100 in cm), spawning peaks, and mean fecundity (based on the gravimetric method). References: (a) Véras et al. 2008, (b) Véras et al. 2009, (c) Lessa et al. 2016, (d) Freitas et al. 2019, (e) Roos et al. 2020b.

The reproduction systems of Brazilian parrotfishes are still not determined and need further investigation once reproductive modes directly impact stock assessments. Besides that, management strategies such as slot limits are sensitive to sexual and social differences, which can be present for parrotfish (Pavlowich et al. 2018). Labrids are known to present complex reproductive modes, with most taxa classified as monandric protogynous hermaphrodites (individuals mature only as females and may change sex to males after sexual maturity), but they may also be diandric protogynous hermaphrodites (primary and secondary males are present) or even gonochoric (only primary males are present) (Sadovy De Mitcheson and Liu 2008). The complex reproductive modes of labrids vary among taxa but may even differ intraspecifically, for instance, due to geographical differences (see Lowe et al. 2021 for an example). The Caribbean sister species of Brazilian *Sparisoma* are monandric protogynous hermaphrodites; however, some indications are that Brazilian parrotfishes may follow different pathways: (1) few immature males of *Sp. axillare* and *Sp. frondosum* have been registered; (2) small functional males for *Sp. frondosum* are present but are rare (Véras 2008; Véras et al. 2009; Lessa et al. 2016); both situations could indicate diandric protogyny or gonochorism. Caribbean *Scarus* species are classified as diandric protogynous hermaphrodites, and for the Brazilian *Scarus trispinosus,* some small mature males were registered, potentially primary males (Freitas et al. 2019). This pattern, nonetheless, could also be due to external factors such as overfishing, which induces early maturation in fish (Froese and Pauly 2013; Roos et al. 2016). In general, Brazilian *Scarus* and *Sparisoma* males are less abundant than females (Fig. 3), and males are restricted to larger sizes, thus being absent when sampling lacks larger fish (Véras 2008; Véras et al. 2009; Lessa et al. 2016; Freitas et al. 2019; Roos et al. 2020b); this pattern also indicates the potential that some fisheries that are highly selective to fish size, like spearfishing, have to disproportionately explore males. Research should focus on elucidating reproductive modes of Brazilian parrotfishes, which directly impact the management actions that should be applied to recover their populations (Pavlowich et al. 2018).

Despite the inconsistencies found in reproductive modes, reproductive males and females were found year-round for all species studied. They presented batch spawning along the year, peaking in some months that varied between species (Fig. 6). Overall, those peaks were consistent with the general pattern observed for parrotfishes, where breeding increases during the warmer months (Choat and Robertson 2002; Ebisawa et al. 2016). Interestingly, the increased reproductive activity periods of both *Sparisoma* species diverged, even though they were collected in the same region (*Sp. axillare,* spring-summer and *Sp. frondosum,* summer-fall). Separate timing of breeding could be related to intrinsic characteristics of each species but could also be a strategy to reduce the competition between them (as seen for cichlid fishes in Mckaye 1977). Within the reproductive periods, batch fecundity was only estimated for *Sp. axillare* and *Sp. frondosum,* with the latter presenting considerably higher fecundity (Fig. 6).

According to maturation and maximum sizes, most Brazilian endemic parrotfish species present around 30 to 40 cm maximum total length, similar to the general parrotfish mean size (Choat et al. 1996; Taylor and Choat 2014). On the other hand, the Brazilian species *Sc. trispinosus* and *Sp. amplum* are among the largest parrotfish species known (Choat et al. 1996; Taylor and Choat 2014). The length at maturity (L50) of *Sparisoma axillare* and *Sp. frondosum* was around 20 cm, while the value estimated for *Sc. trispinosus* was almost the double (38.5 cm) (Fig. 6). As a result, a great part of *Sc. trispinosus* captures consists of immature individuals (Freitas et al. 2019; Roos et al. 2020b). These larger-sized parrotfish species present increased maturity lengths and slower growth, being naturally more vulnerable to fishing impacts and demanding special attention from scientific and management organizations (Taylor and Choat 2014).

6. Feeding ecology

Trophic ecology studies allow the understanding of the ecosystem roles of parrotfish (Bonaldo et al. 2014) and enable the evaluation of how the removal of these fish may impact coral reefs through ecosystem-based assessment models (Bozec et al. 2016). Among all topics in this review, feeding ecology is the only one where all species are addressed, and each Brazilian parrotfish was studied in at least two different papers.

According to the classical approach of functional groups of herbivorous reef fishes, Brazilian parrotfish are either scrapers or excavators (Longo et al. 2014; Cardozo-Ferreira et al. 2018; Lellys et al. 2019). All five parrotfish species function as scrapers at some part of their life, constantly feeding and removing benthic organisms while clearing spaces on the reef surface (Bonaldo et al. 2006; Francini-Filho et al. 2010; Longo et al. 2014). Large individuals (>30 cm) of *Sc. trispinosus* and *Sp. amplum* are morphologically adapted to function as excavators, gouging the substratum with powerful jaws to expose the reef matrix, which may be used for the settlement of reef-building organisms such as corals and encrusting calcareous algae (Francini-Filho et al. 2008; Bonaldo et al. 2014; Lellys et al. 2019).

Besides differing in feeding modes, Brazilian feeding rates are also observed to vary according to fish size, fish species, and even fish interactions with other individuals (Leitão 2020; Hoey et al. 2018; Fonseca et al. 2021). Feeding rates are generally observed to decrease with body size within the same species, and *Scarus* have higher rates than *Sparisoma* species (Bonaldo et al. 2006; Francini-Filho et al. 2010; Feitosa and Ferreira 2014; Pereira et al. 2016, Longo et al. 2018; Lellys et al. 2019; Leitão 2020). The numeric dominance of *Sparisoma* over *Scarus* in Brazil represents accountable differences in herbivore pressure compared to the Caribbean, where *Scarus* dominates over *Sparisoma* (Hoey et al. 2018). Such differences should be considered when evaluating the ecosystem roles of parrotfish in Brazilian reefs.

Foraging by all Brazilian parrotfish targets mainly the epilithic algal matrix (EAM) (Bonaldo et al. 2006; Francini-Filho et al. 2010; Pereira et al. 2016; Leitão 2020), followed by crustose coralline algae (CCA), targeted by excavator species (Francini-Filho et al. 2010). The definition of the EAM (sometimes referred to as algal turf), nonetheless, varies copiously between studies, and an extensive array of different food sources (macroalgae, propagules, filamentous algae, microalgae, detritus, small invertebrates, and sediment) organized as a conglomeration of variable length (0.5 to 10 cm) are classified as "turfs" (Connell et al. 2014). Studies also identify foraging on "macroalgae" (Bonaldo et al. 2006; Francini-Filho et al. 2010; Pereira et al. 2016), also an unsystematic term. Studies using foraging rates may not be enough to elucidate the dietary use of resources by parrotfish, as protein-rich autotrophic microorganisms have been proposed as their primary food items (Clements et al. 2016) and are found in association with both "turf" and "macroalgae".

Few recent studies have classified the algal composition of *Sp. axillare* diet in more specific, ecologically significant functional groups, some of those using stomach content analysis, nutritional composition, and stable isotopes to narrow down food items (Mendes et al. 2018; Pimentel et al. 2018; Ferreira 2019; Leitão 2020). In stomach content evaluations, detritus is also a dominant food item, while the nutritional composition and stable isotope analysis showed a much higher selectivity towards protein-rich organisms such as cyanobacteria, in addition to signatures that also indicate herbivory (Mendes et al. 2018; Ferreira 2019). Nevertheless, the contribution of macroalgae to the nutrition of parrotfishes has yet to be determined. Stomach content analysis of *Sp. axillare* juveniles (1.7 to 10 cm) also presented small crustaceans as one of the main targets, in addition to algae (Pimentel et al. 2018). The two Brazilian excavator species were registered as predating live corals (Francini-Filho et al. 2008) and were considered facultative coral predators, with a low number of bites allocated to live corals (approximately 8% of *Sp. amplum* bites and less than 1% of *Sc. trispinosus* bites) (Francini-Filho et al. 2010). A meticulous evaluation of food items' nutritional composition and absorption is needed to unveil Brazilian parrotfishes' feeding ecology and functional roles, before considering the impacts of their removal to reef systems in assessment models.

7. Fishing statistics data

Fisheries data are critical to quantify how parrotfish stocks are being exploited, including the identity, amount, and sizes of species explored by fishing (Vivekanandan 2017). Composition of catch size/age classes, as well as landing data, are mandatory for all data-rich stock assessment methods, and if properly sampled, they can be applied in catch-only, or in age/length-assessment methods, without further information. (Rudd et al. 2021; Winker et al. 2018; Carvalho et al. 2021). In the present study, information on parrotfish captures was present in almost one-third of all selected bibliographies (44 out of 134). However, hardly any of the Brazilian parrotfishes' fishery could be understood in detail; information on the amount of each species captured, the sizes explored, precise locations of capture, or the effort applied were often hard to obtain. Then, there is a significant knowledge gap on how Brazilian parrotfish species have been fished. Scientific data available is information-rich but occasional. The few existing official estimates on parrotfish landings are inconsistent. Still, these estimates have been recently reconstructed and now represent Brazil's most reliable parrotfish fisheries information that can be applied in catch-based stock assessments (Freire et al. 2021, Fig.7).

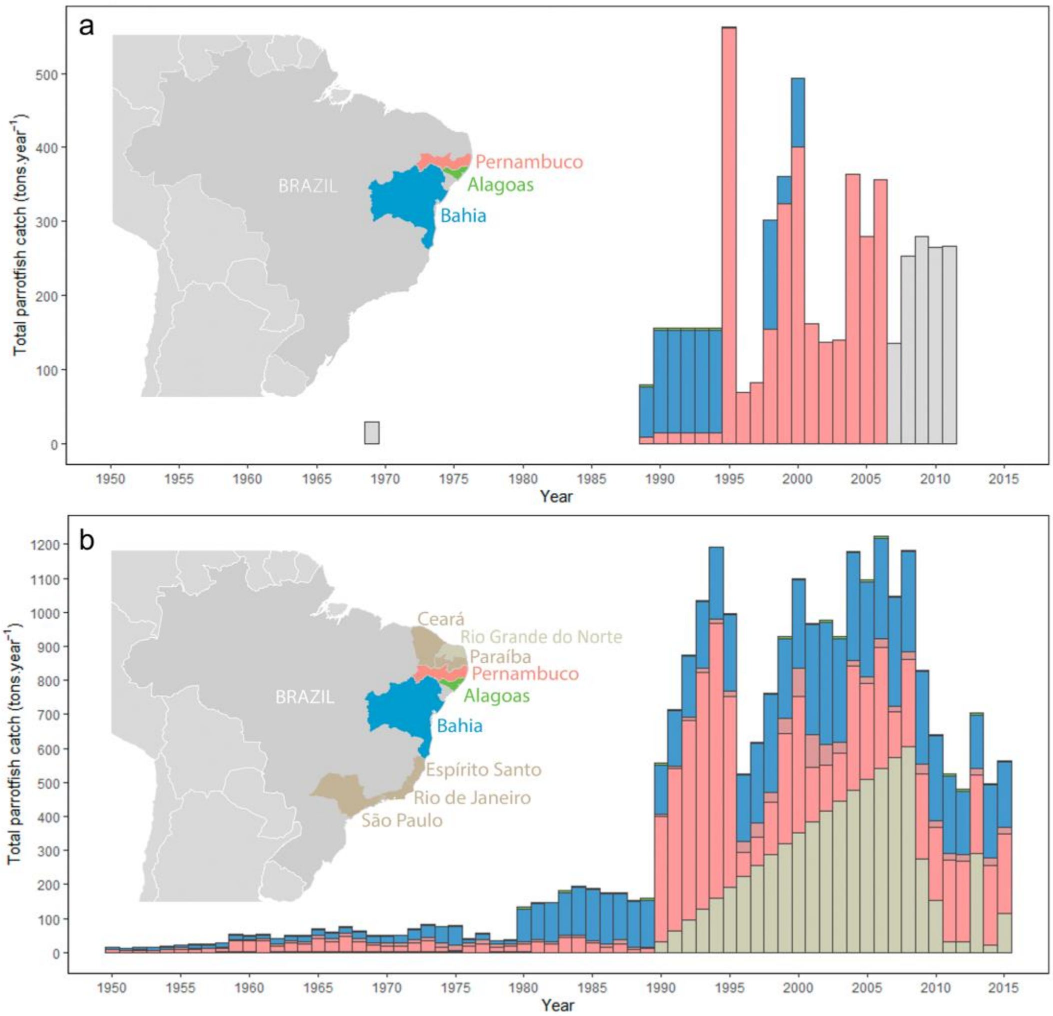

Figure 7. a) Total national parrotfish captures per year extracted from Brazilian National Statistic Bulletins, in tons. b) Reconstructed parrotfish catches, in tons, published by Freire et al. (2021). Colors indicate what states were used for total estimates. The gray bars represent non-identified locations (Just a national total catch value was reported, with no state estimates presented).

Brazilian National Statistic Bulletins began to be published in 1950 (ICMBIO 2020), with estimates of total captures based on monitored fishing sites scattered along the country produced by different government agencies over the years (MPA 2011). Since 2010, national statistics have been estimated based on previously reported catches only, and from 2014 on, no official production data have been reported to FAO, except for tuna and tuna-like species (MPA 2011; FAO 2020, 2022). Currently, the only information on fish landings comes from scattered scientific research (Cunha et al. 2012; Carvalho et al. 2013; Previero 2014; Roos et al. 2016).

Total parrotfish capture data in the National Bulletins are low in quality since landing is mostly not specified by species, pooled as "budião" (for all parrotfish species combined) or "budião batata" (for *Sparisoma* species), preventing the assessment and comparison of historical catches by species. All parrotfish catches reported in National Bulletins come from artisanal fishing, first appearing in the Bulletins in 1969, and reported again only 20 years later, then being estimated until the last published report in 2011 (Fig. 7a). Catches increased from 30 tons in 1969 to around 250 tons in 2011, with a peak of about 560 tons in 1995 (Fig. 7a). From 1989 to 2006, national captures were calculated based on local parrotfish landings from Pernambuco, Alagoas, and Bahia alone. Moreover, data for each state is inconsistent within this period, lacking parrotfish reports for many years straight and often presenting total capture for only one state (Pernambuco). Between 2007-2011 and in 1969, national total catches were reported with no separation by state, jeopardizing spatial identification of the data sources. Also, the same capture values were repeated between 1990 and 1994, probably indicating that parrotfish fishing was not monitored during this period.

According to the National Bulletins, only two states - Pernambuco and Bahia - were responsible for almost all Brazilian parrotfish catches (Fig. 7a). Pernambuco was responsible for almost 60% of national parrotfish catches. Still, these values were misjudged since reported values for the other states were missing for many years (Fig.7a). Compared to Pernambuco, Bahia presented low parrotfish captures, but these values are probably miscalculated since Bahia represented a significant part of *Sc. trispinosus* fishing in scientific studies (Previero 2014; Freitas et al. 2019; Roos et al. 2020b). A total of 25 tons were reported for Alagoas from 1989 to 1995, but it is unreliable as this data is repeated from 1990 to 1994. These catches are considered low compared to the other reported regions (around 4 tons per year), probably because parrotfishes were not reported as a target species category in the state (Rangely et al. 2010). An even worse concern is observed in the National Bulletins data: the Rio Grande do Norte state does not have parrotfish captures discriminated, but reconstructed catches, however, present it as one of the states with the highest yields in the country (Fig 7a and b). Such issues have indicated that total national estimates for parrotfishes are unrealistic and should not be used for stock assessments. Unfortunately, the National Statistics Bulletins represented the only official historical fishing data series for parrotfish. Catch-only stock assessment methods have been constantly developed and updated for data-poor fisheries and can be used for grouped species (Zhou et al. 2018). Still, they demand reliable total catch values for proper assessments. The reconstructed Brazilian catch statistics for marine waters from 1950 to 2015 (Freire et al. 2021) included parrotfish landings and found that reconstructed catches may be, in truth, at least two times higher than reported in the bulletins (Fig.7b).

The reconstructed data (Freire et al. 2021) currently represent the most reliable information on national captures for parrotfish and all commercial fish landed in Brazil. Besides presenting total values for all years, from 1950 to 2015, the reconstructed data also present separated values for *Sc. trispinosus*, *Sp. axillare* and

Sp. frondosum catches in Rio Grande do Norte and for *Sp. axillare* in Pernambuco. Additionally, total captures were estimated for five other states not included in National Statistics Bulletins, Ceará, Paraíba, Espírito Santo, Rio de Janeiro and São Paulo (Fig. 7b). Stock assessments may now use this data; however, some important sources of uncertainty are still observed. First, the reconstructed catches for RN increased at a steady state and reached really high levels in 2008 (~600 tons/year), but then drastically dropped to less than 50 tons/year by 2011. Catches from PE also presented drastic changes, increasing from 10 tons caught in 1989 to 366 tons in 1990. Also, there are cases where catches are reported by species, but a general "parrotfish" label is also presented, not making clear whether some part of the "parrotfish" catches also includes the specified species. No fishing effort is presented in reconstructed catches as well, preventing calculations of Catches Per Unit Effort (CPUEs) and the historical evaluation of how fishing gear captures evolved over the years.

The only information about parrotfish CPUEs, as some more detailed total estimates and size composition of catches, were found in scientific research articles and reports. The studies were obtained punctually for some regions in Pernambuco, Rio Grande do Norte, Bahia, Rio de Janeiro and Espírito Santo States (Previero 2014; Roos et al. 2016; Freitas et al. 2019; Barbosa-Filho et al. 2020; Guabiroba et al. 2020; Pereira et al. 2021). Unfortunately, total captures and CPUE values estimated by scientific data were not standardized among states and thus are not comparable. Nonetheless, these studies provide valuable information on parrotfish captures per species and information from the fishing gears used in each state.

Most parrotfish landings recorded through scientific research came from artisanal fishing, with a considerable portion of *Sp. axillare* and *Sp. frondosum* catches destined for international markets (Previero 2014; Roos et al. 2016; Freitas et al. 2019). In Pernambuco, the most used fishing gears were fishing traps (Cunha et al. 2012; Carvalho et al. 2013) that captured *Sp. axillare* the most (Ribeiro 2004). Parrotfish fishing in Bahia feasibly started in the 1970s using gillnets (Previero 2014) and shifted to a combined use with spearguns that targeted *Sc. trispinosus* primarily, for regional markets (Previero 2014; Roos et al. 2016; Freitas et al. 2019). Approximately 36 tons of *Sc. trispinosus* were reported to be caught in Abrolhos between 2010 and 2011 (Previero 2014). *Scarus zelindae* was also identified as a prominent species in gillnet fishing (ICMBIO 2015). In Rio Grande do Norte, a total annual catch of 9.4 tons of *Sc. trispinosus* and 15.4 tons of *Sp. axillare* and *Sp. frondosum* combined was estimated between 2013 and 2014, in only two municipalities (Roos et al. 2016). Rio Grande do Norte has also exported parrotfish the most (Cunha et al. 2012; Roos et al. 2016). One fishing company alone was responsible for sending more than 700 tons of parrotfish (*Sp. axillare* and *Sp. frondosum*) abroad from 1996 to 2008, the second most exported reef fish (Cunha et al. 2012; Carvalho et al. 2013). Regarding the gears used in this state, fishing traps were considered the most used, as in Pernambuco, but the most captured species was *Sp. frondosum* (Ribeiro 2004; Cunha et al. 2012; Carvalho et al. 2013). The size composition of catches revealed *Sp. axillare* and *Sp. frondosum* individuals are mostly caught as adults (Ribeiro 2004). Scientific information on parrotfish fishing activities and landings was also found for Rio de Janeiro (Bender et al. 2014), and Espírito Santo (Pinheiro et al. 2010). In Rio de Janeiro, historical data were obtained from questionnaires and found fishing efforts focused on *Sc. trispinosus*, starting in the 1980s and using only spearguns (Bender et al. 2014). In Espirito Santo, *Sp. axillare* was regularly caught while *Sp. frondosum* and *Sc. trispinosus* were rarely fished, even though the latter was highly targeted (Pinheiro et al. 2010).

Different from official statistics - restricted to artisanal fishing - recreational fishing also represents accountable parrotfish catches in scientific studies, occurring along the extension range of the targeted Brazilian parrotfish (From Rio Grande do Norte to Rio de Janeiro) (Roos et al. 2021), especially in Bahia (Pinheiro et al. 2010; Previero 2014; Giglio et al. 2020; Roos et al. 2021). Most *Sc. trispinosus* caught in Abrolhos in artisanal and recreational fisheries are juveniles (Freitas et al. 2019; Roos et al. 2020a; Giglio et al. 2020), but new evidence shows they are targeted at larger sizes by recreational spearfishing when compared to artisanal fisheries along the Brazilian coast (Roos & Longo 2021). Additionally, spearfishing was the only gear where *Sp. amplum* was registered in the literature (Giglio et al. 2020). Recreational captures also included illegal fishing (Barbosa-Filho et al. 2020) and have been associated with sharp decreases in local fish stocks, including parrotfish species (Barbosa-Filho et al. 2020; Guabiroba et al. 2020; Pereira et al. 2021), which are underrepresented in official national reports.

We identified that scientific efforts should focus on updating and improving reconstructed national catches, especially considering the yields of recreational fisheries. Investigating historical fishing efforts to obtain more accurate and standardized CPUEs and obtaining the size composition of catches are also very necessary. Disclosing these data may allow more robust stock assessments than when only total catches are available.

8. Management actions

The first management measure implemented for the targeted Brazilian parrotfish species was their classification as threatened. *Scarus trispinosus* was the first to be evaluated, classified as Vulnerable in the list of threatened species from Espírito Santo state, but under the name of its Caribbean sister species, *Scarus guacamaia* (Decree No. 1499-R, 2005). In 2011, the state of Santa Catarina also classified *Sc. trispinosus* as Vulnerable, along with *Sc. zelindae*, *Sp. axillare* and *Sp. frondosum* (Resolution No. 002, 2011), even though they barely have no fishing records in this state (Pinheiro et al. 2010). In 2012, *Sc. trispinosus* was listed as Endangered by the IUCN (criterion A2d) (Ferreira et al. 2012), becoming the most threatened parrotfish species worldwide. In 2014, this classification was followed by the Brazilian Red List of Endangered Species, alongside *Sc. zelindae, Sp. axillare* and *Sp. frondosum*, which were categorized as Vulnerable (Decree No. 445/2014). Even though *Sp. amplum* is also targeted by fisheries and presents lower abundances than the other four targeted parrotfishes (Hoey et al. 2018), this species is not classified as threatened on any list to the present date. The extinction risk of *Sc. trispinosus* was evaluated by NOAA in 2015, with the publication of a status review report (Salz 2015). The status found a low to moderate risk of extinction in the foreseeable future for *Sc. trispinosus*; yet, we believe the results are probably underestimated, given that all criteria used to determine the low-risk levels were based on lacking or very limited data.

The Decree 445 established the Brazilian Red List, and designated a national fishing prohibition for all Vulnerable, Endangered, and Critically Endangered aquatic species, becoming the first management action to be implemented for parrotfish in the country. Disagreements between environmental agencies and the interactions with the fishing industry led to a series of modifications in the Decree in the following years (Lees 2015; Freitas et al. 2019; Roos et al. 2020a). The fishing ban was suspended, and a Recovery Plan (Freitas 2016) was developed for the four threatened Brazilian parrotfishes targeted by fishing (*Sc.*

trispinosus, Sc. zelindae, Sp. axillare, and *Sp. frondosum*), which incorporated permissions to allow parrotfish fishing under specific circumstances (Inter-Ministerial Decrees No 59-B and 63/2018). These rules are still in effect: parrotfish fishing should occur exclusively inside multiple-use Marine Protected Areas (multiple-use MPAs) that predict the sustainable use of parrotfish through management plans, as long as it follows the Recovery Plan guidelines. This strategy of "inverted management" bans fishing outside MPAs where, theoretically, parrotfish populations would recover (Pinheiro et al. 2021). Inside multiple-use MPAs, the plan envisions only subsistence and small artisanal captures from certified fishers, excluding both sportfishing and exportation of parrotfish (Fig. 8). Diurnal free dives are the only fishing strategy permitted to capture *Sc. trispinosus, Sc. zelindae,* and *Sp. amplum*, while traps, nets, and handlines are allowed to capture *Sp. axillare* and *Sp. frondosum* above the north of Bahia. Slot-size capture limits were also implemented and captured fish should be landed in one piece for control purposes (Fig. 8).

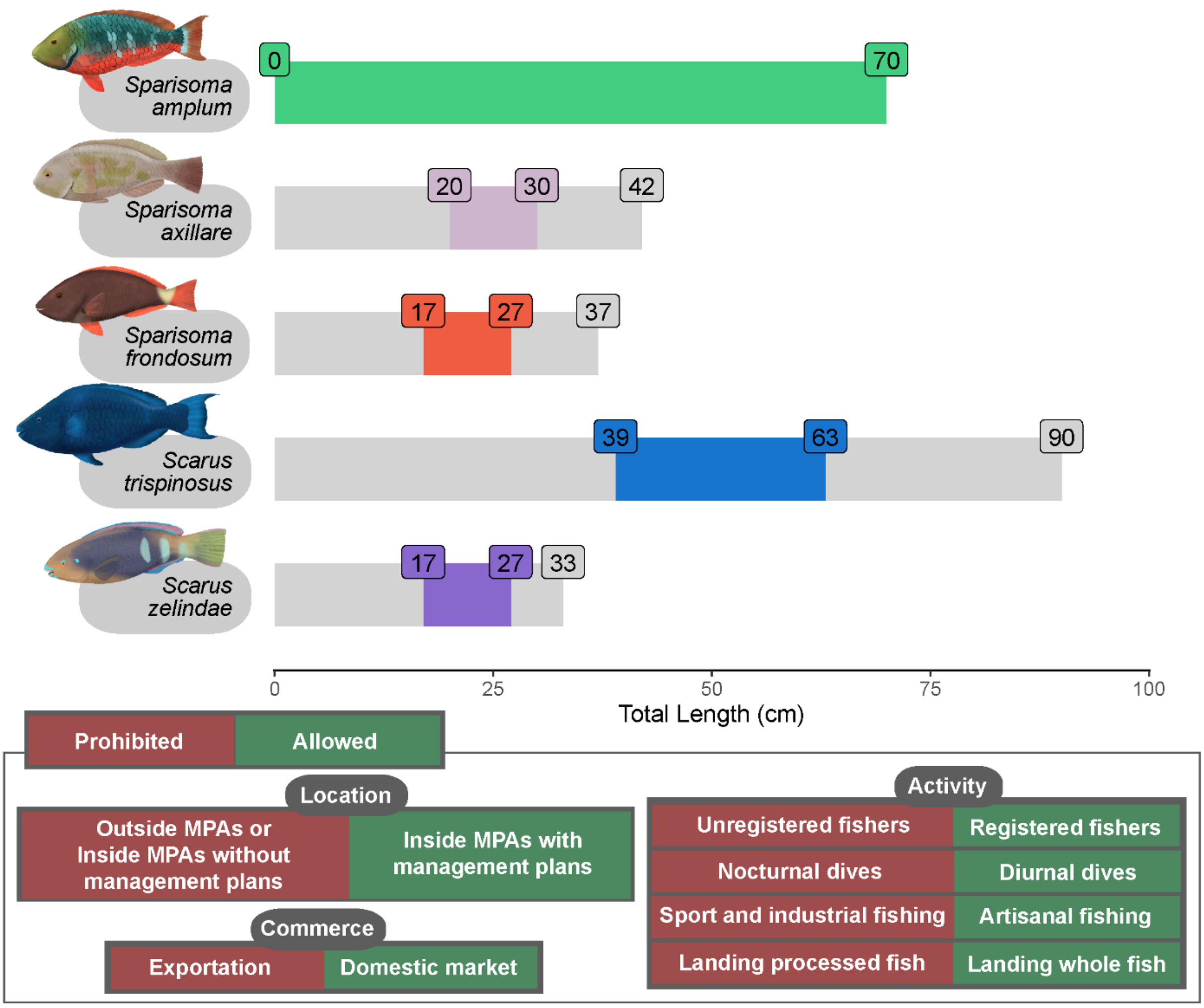

Figure 8. Management strategies established in 2018 by Inter-Ministerial Decrees No 59-B and 63 to implement the recovery plan for the threatened parrotfish populations of *Sp. axillare, Sp. frondosum, Sc. trispinosus* and *Sc. zelindae*. Colored bars represent the range of sizes allowed for capturing each species (minimum and maximum sizes are specified inside the colored squares above each of the bars). The grey bars represent sizes where capture is illegal. The highest values in each bar inside the grey squares represent the maximum length of the species. At the bottom, other rules for parrotfish capture are underlined.

As much as the legal basis has been created, the regulations on parrotfish commercial exploration are yet to be adequately implemented (Pinheiro et al. 2021; Roos & Longo, 2021). Enforcement actions, expected to be operational since June 2019, have not been consistently achieved so far. The exploitation of parrotfishes in Brazil is mostly occurring without any control: sales for international markets, which have been forbidden since 2018, continue to take place and increase yearly (Pinheiro et al. 2021, *pers. obs.*). Only two extractive reserves in the Abrolhos region have published management plans to sustainably exploit parrotfish (Decrees No 284 and 285/2021). In both, control actions defined by the Recovery Plan are considered, in addition to a catch limit of 20 individuals of *Sc. trispinosus* per fisher per day and allow the use of hand lines to catch the other three threatened species (*Sc. zelindae, Sp. axillare,* and *Sp. frondosum*). Even though *Sp. amplum* was not previously included in the Recovery Plan, a minimum capture size of 23 cm was established for the species. We find it very positive to designate quotas for the capture of parrotfish, but without a proper stock assessment, it is not known if they satisfy sustainable thresholds. Slot limits and restrictions in fishing gears are also management strategies that are challenging to implement and enforce, especially in a country with such an extensive coastline as Brazil. The artisanal fishing sector in Brazil is large, and fishing communities are sparsely distributed along the coast, making it difficult even to inform fishers of policies adopted (Ruffino 2016). Recreational and artisanal spearfishermen are even more scattered and difficult to monitor and control (Freire et al. 2020).

Implementing and enforcing such policies is jeopardized when there are not enough human and financial resources allocated to fishing management (Ruffino 2016; Abessa et al. 2019). The management strategy implemented for Brazilian parrotfishes requires an immense proportion of human resources to monitor, both in areas where fishing is banned - barely the entire coast - and to control parrotfish harvesting in permitted fishing grounds (Pinheiro et al. 2021). This strategy does not seem plausible looking at the past and present situation of fishing patrolling in Brazil. Enforcing and expanding existing no-take areas so they can be functional to conserve and export parrotfish to adjacent areas through spillover is important, but additional strategies are necessary once MPAs alone, in particular the ones where fishing is allowed, may not be enough to recover parrotfish populations (Roos et al. 2020a). New approaches must then be developed with a focus on the historical, geographical, and financial challenges found in the country. The patrol and monitoring of fishers can be effective only to some extent, and managers should also understand regional trade chains and develop strategies involving the commerce of parrotfish.

9. Conclusion, research needs, and recommendations

This review provides evidence that significant knowledge gaps persist despite recent scientific efforts in investigating the life history and fisheries of the five most captured Brazilian endemic parrotfishes (Fig. 9). Research interest in parrotfish biology and ecology highly increased two decades after the expansion of their use in fisheries in the 1990s. Still, studies on their biology are limited to particular species and study areas. Most papers present information on their distribution, but those primarily focus on community ecology and do not detail their findings for parrotfish. Population structure is the least known feature for Brazilian parrotfish, while all species have been investigated on their feeding ecology to some extent. Fisheries is a subject with a copious number of publications, but most of them lack detail. *Scarus trispinosus* is the species with more topics covered, mainly because of its endangered conservation status. More studies mention *Sparisoma axillare* than any parrotfish species (63 publications in total) due to its greater abundance and wide distribution along the Brazilian coast. Oppositely, *Sc. zelindae* has deep knowledge gaps for being rarer. *Sparisoma amplum* is also relatively rare compared to other parrotfish, and the species lacks management works the most. We attribute this fact to the lack of evaluation of its conservation status.

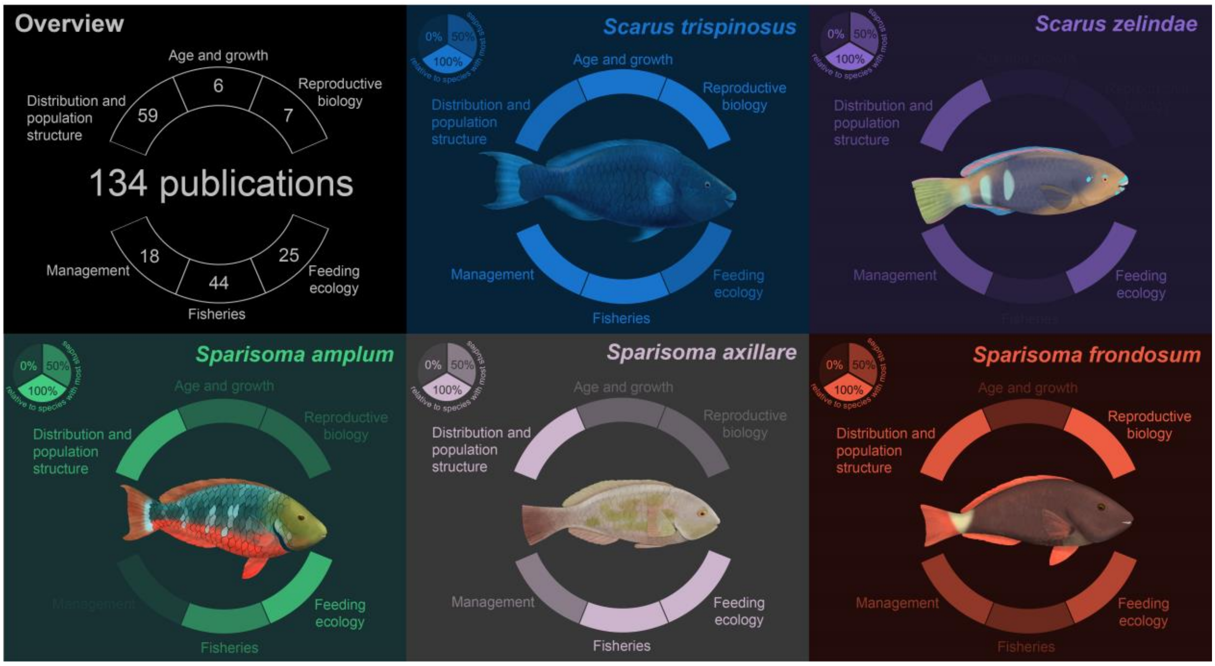

Figure 9. Overview of the review performed in the present study for the five most captured parrotfish species in Brazil, *Scarus trispinosus*, *Scarus zelindae*, *Sparisoma amplum*, *Sparisoma axillare*, and *Sparisoma frondosum*. The black block summarizes the number of studies per searched topic (distribution and population structure, reproductive biology, age and growth, feeding ecology, fisheries, and management), including all species. The summary by species per topic is demonstrated by colors, representing the percentage relative to species with most studies.

Based on the information summarized in this review, some general patterns may be taken regarding stock assessments. First, Brazilian parrotfishes' stocks are not defined; thus, to run any stock assessment, some assumptions would have to be made based on habitat characteristics and preferences to define the stocks for each species. As observed for *Sc. trispinosus*, the substructuring in northern and southern populations could be used to separate the stocks due to strong differences in habitats and in how fisheries occur between both regions. Following stock definition, some basic biology parameters, such as natural mortality, can be applied to obtain stock productivity. These parameters are completely unknown for *Sp. zelindae*, allowing only a simple risk analysis to be applied. Stock productivity and status may be obtained for the other four species, at least in the areas where biological and age/length composition data are available, enabling data-limited assessments such as indicator approaches, and length/age-based assessment models. Along with total captures, some abundance indices and life history information are available for *Sc. trispinosus* and *Sp. axillare*, thus data-moderate stock assessments are feasible, such as production models.

Genetic and site fidelity studies should be focused on identifying how parrotfish stocks are structured and distributed along the coast. Basic biological information such as the definition of mortality parameters, sexual and social modes, maturity, and growth must be prioritized for all target species, in special within the exploited populations. Appraising the populations of *Sp. amplum*, with particular attention to its threatening status, is urgently needed. Moreover, scientific efforts should consider gathering enough information to develop ecosystem-based assessments to guide fisheries management strategies, which are particularly important for parrotfish as they are the largest functional herbivorous fish in coral reefs.

Even though management strategies may be grounded on biological aspects of the species and estimates of population reduction, such as the ones currently implemented for the Brazilian parrotfish species, fisheries data and age/length composition of catches are crucial for stock assessments and, consequently, the definition of sustainable exploration levels. The low quality of historical parrotfish fishing data and the absence of monitoring in Brazil since 2010 are highly detrimental, considering that stocks may have been explored beyond sustainability; thus, ecosystem functions and the fisheries sector dependent on parrotfish are at risk. Scientific monitoring is usually punctual and should be used as complementary data, but they currently represent the only reliable information on Brazilian parrotfish captures. The resumption of Brazilian fisheries statistics programs is urgent and should be considered a top priority. Also, the monitoring data should discern parrotfish species and consider fish sizes, which were not contemplated in the past. A significant portion of recreational fisheries' captures comprises parrotfishes, mainly the endangered species *Sc. trispinosus.* Thus, monitoring efforts should also focus on recreational fishing, especially in the main localities where this activity occurs. Some of these locations were identifiedby Roos and Longo (2021) using social media posts; in-situ surveys could complement this work by mapping the activity of fishers belonging to lower income classes and not digitally included. For *Sparisoma* species, it is recognized that most of the captures are destined for exportation, and Brazilian Export Statistics are permanent, consistent, and publicly available through the Ministry of Agriculture, Livestock, and Supply (Ministério de Agricultura, Pecuária e Abastecimento - MAPA). Unfortunately, exported parrotfishes are pooled together with all other species under the "fresh whole fish" label, so specification of parrotfish exports (while currently illegal) could provide a more comprehensive view of commercial *Sparisoma* landings.

With the rising international interest in parrotfish meat and the increasing dismantling of the national environmental protection agencies, it is urgent to implement sustainable exploitation levels and new effective strategies to recover parrotfish populations in Brazil, based on reliable stock assessments. Otherwise, Brazilian parrotfishes' abundance may continue to decrease, and stocks may be in danger of collapsing.

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11. Supplemental material 1 – Prisma checklist used for the Systematic review

PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Line1 Lines 116-117
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Lines 64-99
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Lines 95-109
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Lines 139-155
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Lines 116-133
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Lines 116-123
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Lines 139-142
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Lines 145-153
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Lines 147-156
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Lines 146-147

Section and Topic	Item #	Checklist item	Location where item is reported
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Lines 146-147
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Not applicable
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Not applicable
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Not applicable
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Lines 147-153
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Lines 153-155
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	Not applicable
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	Not applicable
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Not applicable
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Not applicable
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Lines 134-144
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Not applicable
Study characteristics	17	Cite each included study and present its characteristics.	Online Resource 2
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Not applicable
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Online Resource 2, Tables and Figures
	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Begin of each topic

Section and Topic	Item #	Checklist item	Location where item is reported
Results of syntheses	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Not applicable
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	Not applicable
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Not applicable
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Not applicable
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Not applicable
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	In each topic
	23b	Discuss any limitations of the evidence included in the review.	Not applicable
	23c	Discuss any limitations of the review processes used.	Not applicable
	23d	Discuss implications of the results for practice, policy, and future research.	Lines 561 to 617
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Not applicable
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Not applicable
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	Not applicable
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Lines 30-33
Competing interests	26	Declare any competing interests of review authors.	Lines 619-620
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Lines 155-156

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

For more information, visit: http://www.prisma-statement.org/

CAPÍTULO 2

UNVEILING THE FISHING HISTORY OF THREATENED BRAZILIAN PARROTFISHES: ADAPTATIVE STRATEGIES OF SMALL-SCALE FISHERIES TO MAINTAIN CATCHES

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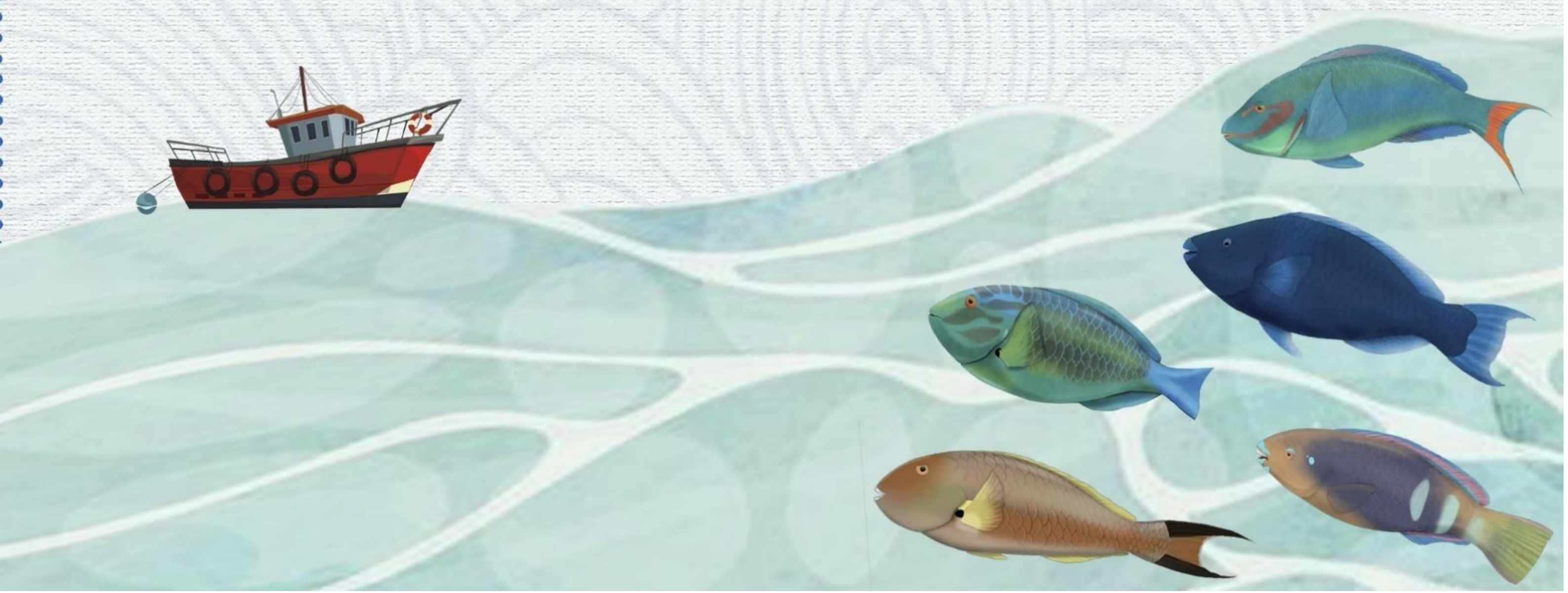
OCEAN AND COASTAL MANAGEMENT



CAPÍTULO 2

Unveiling the fishing history of threatened Brazilian parrotfishes: adaptative strategies of small-scale fisheries to maintain catches

Abstract

In Brazil, five out of seven endemic parrotfish species are classified as threatened, but little is known about how their fishing took place over time. Local Ecological Knowledge was used to investigate the historical fishing of Brazilian parrotfishes and the perception of the parrotfish fishing situation by fishers. In total, 200 interviews were performed in 14 fishing communities, in which net, speargun and trap were identified as the three main gears used to harvest parrotfish along the Brazilian coast. The number and duration of fishing trips, as well as the depths explored by fishing activities using nets and spearguns were similar and did not change over time, while trap fishing increased efforts over the years. Nevertheless, fishing grounds, as well as the number of fishers, expanded for all fishing gears and communities. With changes in fishing strategies, parrotfish catches shifted from shallow waters near the shoreline to deeper and more distant areas, yet, total parrotfish catches and CPUEs decreased with time. *Sparisoma axillare*, *Scarus trispinosus* and *Sparisoma frondosum* were the most caught species and presented similar decreasing trends in total catches. In addition, the weight of *Sc. trispinosus* individuals captured by nets and spearguns also decreased. Following the declining trends reported by fishers, most of them considered the parrotfish fishing situation as "worse" regardless of the fishing gear used or fishers' experience. Our results show indications of overharvesting of the most fished species over time, at a faster pace than that registered for any parrotfish species, within a span of 50-70 years of intensive fishing.

Keywords: Local Ecological Knowledge, artisanal fishing, Scarini, endemic, overfishing

1. Introduction

Small-scale fisheries (SSFs) comprise a complex and dynamic system, constantly adapting to changes in the availability of fishing resources due to fluctuations in environmental conditions and market demands (Saldana et al. 2016, Coronado et al. 2020). The demand for aquatic food has more than doubled in the last five decades, and marine catches represent the main production source, of about 44% (FAO 2022). Despite the growing demand, marine fisheries have presented stable catches since the late 1980s, while overfished fish stocks have been growing over time (FAO 2022). To maintain catches and the profitability of fishing, SSFs have been developing adaptive strategies such as expansion and shifts in fishing grounds, target species and fishing gears (Gianelli et al. 2021, Villasante et al. 2022, Wintergalen et al. 2022). Monitoring these changes is essential to understand the situation of SSFs and the target species, providing subsidies to fisheries management. Such activities, however, are challenging to be performed in countries with large coastlines and few human and financial resources destined for fisheries monitoring, such as in Brazil (Rufino 2016, Abessa et al. 2019, Freire et al. 2020, Queiroz-Véras et al. 2023).

Some of the most valued fishing resources for SSF, such as groupers and snappers, have become depleted and alternative targets have been more extensively explored (Pauly et al. 1998, Freire and Pauly 2010). Parrotfishes are one of those alternative groups and have been increasing both in capture and in market demand (Roos et al. 2016, Calwood 2021, Mansyur et al. 2021, Muraoka et al. 2022). The abundance of these fish has been decreasing worldwide, and some species are classified as threatened (Ferreira et al. 2012, Burkepile et al. 2019, Sherman et al. 2022, Taylor et al. 2022). In Brazil, five out of the seven endemic parrotfish species are classified at some threat level: four are categorized as Vulnerable (*Sparisoma axillare*, *Sparisoma zelindae*, *Sparisoma frondosum*, *Sparisoma rocha*) and one as Endangered (*Scarus trispinosus*) (Ferreira et al. 2012, Decree 148, 2022). Unlike most parrotfishes in the world, the management of these endemic species depends exclusively on a single country, rendering their recovery challenging, especially when SSF monitoring in Brazil has been discontinued since 2010 (Queiroz-Véras et al. 2023).

Although population decline is evident for Brazilian parrotfishes and ground their threated status, little is known about how their fishing has evolved. National official data on parrotfish capture are available, but the quality of this dataset is particularly poor; parrotfish capture does not discriminate species, are only present for a few states and some of the reported catches are questionable (Queiroz-Véras et al. 2023). More recent information available comes from few and sparse scientific publications that identify the importance of parrotfish catches in Northeastern Brazil (Ribeiro 2004, Marques and Ferreira 2010, Cunha et al. 2012, Roos et al. 2016, Freitas et al. 2019, Freire et al. 2021). So, there is still a lack of consistent monitoring data, such as the identification of fishing areas and changes in fish abundance and size for Brazilian parrotfishes, which would allow the assessment of their populations and their capacity to recover and maintain fisheries. The most reliable source of information may come from the fishers who carried out these activities and witnessed the development of these fisheries.

Local Ecological Knowledge (LEK) has been increasingly used to fulfill gaps or uncertainties in fishing records and represents an important source of historical fishing data, including information on fish species identification, size, catch, abundance, behavior and fishing activities (Bender et al. 2014, Barbosa-Filho et al. 2020, Giglio et al. 2020). In Brazil, integrating LEK and traditional scientific data has been an important alternative to complement the lack of data (Bender et al. 2014, Damasio et al.2015, Previero & Gasalla 2018, Zapelini et al. 2019, Fogliarini et al. 2021). Scattered LEK studies have been able to identify changes in maximum catches and sizes of the endangered Brazilian parrotfish *Sc. trispinosus* caught by spearfishing and found decreases in sizes and catches over time (Bender et al. 2014, Previero 2014, Pereira et al. 2021). However, broad-scale historical fishing information for Brazilian parrotfish species is still missing, and we lack an understanding of the development of the strategies to capture parrotfishes in Brazil.

The main goal of this paper was to use LEK to investigate the historical fishing of Brazilian parrotfishes and the perception of parrotfish stock situations by fishers. Four key questions were addressed: (1) What are the main fishing activities that capture parrotfish in Brazil and how are they performed? (2) Did these parrotfish fisheries change spatially and temporally? (3) Are the captures of individual species stable over time? (4) How do fishers evaluate the current situation of parrotfish fishing?

2. Material and Methods

2.1. Study sites

Fishing communities from four Brazilian states were selected to perform interviews: fishing communities from Rio Grande do Norte (RN), Pernambuco (PE), Bahia (BA) and Espírito Santo (ES). The communities within the first three states present the highest parrotfish landings in Brazil (Cunha et al. 2012, Previero 2014, Roos et al. 2016, Freitas et al. 2019, Queiroz-Véras et al. 2023). Fishing communities from five towns were identified as important parrotfish landing sites in Rio Grande do Norte and in Pernambuco (Queiroz-Véras et al. C*hapter 3 of this thesis*; Roos et al. 2016) and selected for the study, Goiana, Itamaracá and Itapissuma in Pernambuco and Rio do Fogo and Touros in Rio Grande do Norte. The fishing communities located at southern Bahia and northern Espírito Santo coasts explore the most extensive coral reef bank in the South Atlantic Ocean, the Abrolhos Bank, where the highest abundances of parrotfishes have been registered (Araujo et al. 2021). Within this area, we selected the largest fishing communities, located in four cities in Bahia: Caravelas, Nova Viçosa, Porto Seguro and Prado; and five cities along the coast of Espirito Santo: Conceição da Barra, São Matheus, Aracruz, Vitória and Vila Velha. In total, fishers in 14 communities were interviewed in the present study.

SSFs in these regions are performed mostly within the continental shelf, using rafts, canoes and small motorized boats up to 20 m in length (SEAP/PROZEE/IBAMA 2006, Lessa et al. 2009, Previero 2014). Rafts and canoes are restricted to shallower areas, while motorized boats can reach fishing grounds with depths of up to 1200 m, but they usually do not cross the continental shelf break when fishing for parrotfishes (SEAP/PROZEE/IBAMA 2006, Lessa et al. 2009, Previero 2014). The main gears used by these SSFs are traps, nets, lines and spearguns, and fishing trips generally do not exceed 15 days (Lessa et al. 2009, SEAP/PROZEE/IBAMA 2006, Previero 2014, Roos et al. 2016).

2.2. Fisher´s Local Ecological Knowledge (LEK)

Fisher´s knowledge regarding the past and present situation of parrotfish fishing was obtained using semi-structured questionnaires containing objective and open questions. Two hundred interviews were conducted from October 2020 to December 2021 (Fig. 1). The snowball sampling technique was used to identify the interviewees (Parker et al. 2019): the initial interaction with fishers was done by contacting the president of each fishing community. The presidents then indicated an experienced fisher, with at least 30 years of fishing (Bender et al. 2014). After interviewing those fishers, they indicated others, regardless of their fishing experience, and the selection process continued successively (Fig. 1).

The questionnaire contained three parts (Supplemental material 1). The first one included questions related to individual fishing activities performed by each fisher and should be answered according to the year when they started fishing (SF) and the last year they fished (LF). The points used to identify fishers´ strategies were: gears used, species targeted, number of fishing trips per week, duration of fishing trips, places visited, depths fished and the reasoning for temporal changes in any of the previous questions. The second part included aspects about parrotfish catches: species fished, the highest parrotfish landing (weight, year, season, place and gear used), total parrotfish catches, parrotfish catches per species and the mean and maximum weight of captured individuals per species. Finally, they were asked about the current fishing situation of each species (positive, neutral or negative), and the reason for their classification (McClean and Forrester, 2018). The third part consisted of a fishing guide containing photographs of all targeted Brazilian parrotfish species prepared for the present study, so that fishers could identify each parrotfish species.

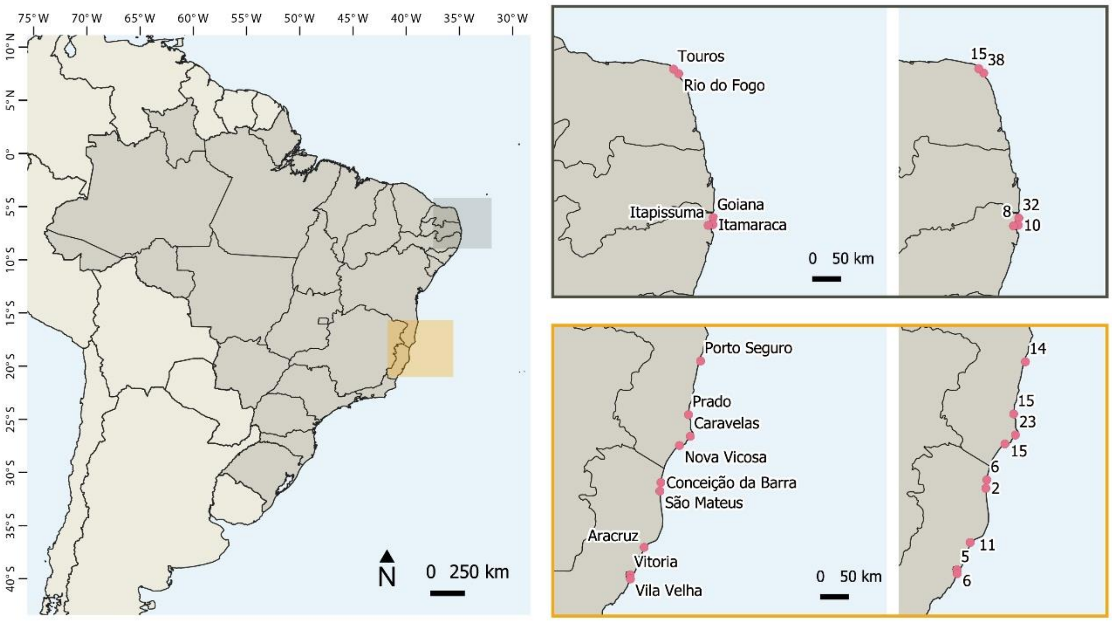


Figure 1. Map of the study area indicating the 14 investigated communities. Numbers on the panels to the right represent the total number of interviews in each locality.

2.3. Data analysis

To understand how parrotfishes are captured in Brazil, we assessed the main gears and their application, including the characteristics of fishing trips, fishing locations and species captured. To explore if fishing strategies changed temporally and spatially, we evaluated differences in fishing activities, fishing locations and captures over time. To evaluate spatial changes in fishing locations and captures, Kernel Density Estimations (KDEs) were done based on fishers' descriptions of their fishing grounds and parrotfish cacthes. The KDEs were performed using the information on mean parrotfish captures per species and the span of fished areas visited by each fisher. Of the 200 interviews, 118 presented complete information on place and depth limits explored by the individual fisher at a given time (year SF and year LF) along with data on parrotfish catches in these areas. With each of these 118 interviews, two polygons were delimited, representing the fishing areas visited by each fisher at the two time periods. The mean capture for each parrotfish species in kilograms registered for each fisher was accounted for by evenly distributing a proportional number of points inside each polygon (e.g., 100 kg of *S. axillare* captured per trip were represented by 100 points). All generated points were used to run the KDEs for four periods: before 1970, from 1971 to 1989, from 1990 to 2009 and from 2010 to 2021. We considered a minimum of four fishers for the combination of studied area and period to run a KDEs. Posteriorly, the polygons generated during the KDEs process were merged to obtain the total fishing area used by each fishing community in each time period. The KDEs and GIS workflow were performed in QGIS version 3.22.3 (QGIS 2021). Catches Per Unit Effort (CPUEs) were calculated as catch (kg).fisher^{-1}.fishing day^{-1}.gear^{-1}.size (m)$^{-1}$ for nets and as catch (kg).fisher^{-1}.fishing day^{-1}.gear^{-1}.size (m^{2})$^{-1}$ for traps. One-Way ANOVAs were used to test if total parrotfish catches within each fishing community and whether CPUEs of each fishing gear differed among time periods. To test for temporal changes in fishing activities, simple linear regressions were run for each fishing gear, with year as the independent variable and fishing depth, number of trips per week, trip duration, and gear amount and size as dependent variables. Also, linear regressions were used to investigate temporal changes in the largest parrotfish catches per gear.

To obtain historical catch trends for each targeted parrotfish species, total catches per week for each species and time period were calculated based on catches estimated by fishers for each fishing trip when started fishing (SF) and when last fished (CF). First, mean daily catches were calculated separately for fishers using traps, nets and spearguns, for each species and for each time period. Those means were then multiplicated by the total number of interviewed fishers who were active in each time period, to obtain total daily catches for each gear, species and time periods. Then the total daily catches were multiplied by the mean fishing days per week calculated for each gear and time period, to obtain total caches by week for each species and gear. Lastly, catches for similar species were summarized to obtain total catches per week, per species for each time period. Additionally, linear regressions were used to check for changes in the maximum weight of fished individuals throughout the time (year as a numeric variable) for each gear.

To evaluate how fishers perceived the situation of parrotfish fishing, we checked if fishers' experience or gears used by fishers influenced how they evaluated the parrotfish fishing situation. For this purpose, we checked for differences in the number of fishers who categorized the current fishing status as worse, neutral or better within gear categories and within fishers' experience, using Chi-squared tests. For the Chi-squared test using fishers' experience, fishers were classified as “less” or “more” experienced according to Bender et al. (2014): fishers using traps for more than 30 years and nets and spears for more than 15 years were considered as “more experienced”, and the remaining were classified as “less experienced”. Additionally, we investigated if the fisher´s assessment of the state of parrotfish fishing was related to the estimated changes in the weight of fished individuals or total captures. For that, three ratios were calculated: (1) a ratio of the mean weight at capture and the weight at maturity (CW/MW), (2) a ratio of the mean and the maximum weight at capture (CW/ MCW) and (3) a ratio of the mean parrotfish catches when last fished and when started fishing (L-LF/L-SF). Multi-species ratios were calculated for each fisher by determining separate ratios for each species and averaging them. One-Way ANOVAs were used to test if each of the three ratios differed among the situations of the fishery determined by fishers (negative, neutral or positive).

All ANOVAs, linear regressions and chi-squared tests were performed applying the “aov”, “lm” and “chisq.test” functions, respectively, from the “stats” package of R Statistical Software (v4.3.0; R Core Team 2023).

3. Results

3.1. Characterization of parrotfish gears used by Small-Scale Fisheries (SSF)

From the 200 interviews, seven types of fishing gears were reported to capture parrotfish: fish corrals, handlines, lines, longlines, nets, spearguns and traps. Among these, only four gears targeted parrotfish specifically (handlines, nets, spearguns and traps), while the remaining only captured parrotfish as bycatch. Even though handline was mentioned by most fishers, only 4 interviewees considered it their main fishing gear to capture parrotfish, and this gear was excluded from the following analyses. Also, 3 out of 30 interviewees of the southernmost fishing communities (in Espírito Santo State) identified parrotfishes as their main targets in speargun fishing, while the remaining either captured parrotfish as bycatch or never fished them. Due to the low amount of data, the interviews from Espírito Santo were excluded from further analyses. A total of 161 interviews was used to scrutinize parrotfish fishing history, which contained information from net, speargun and trap fishing. From all fishers interviewed, most are currently fishing with spearguns (75), followed by nets (49) and traps (37). Six parrotfish species were identified as targets by the fishers, *Scarus trispinosus, Scarus zelindae, Sparisoma amplum, Sparisoma axillare, Sparisoma frondosum* and *Sparisoma radians.* Fishers were not able to distinguish individual catches for *S. axillare* and *S. radians*, thus, both species were pooled as *S. axillare* as the amount of *Sp. radians* captures were considered negligible by fishers.

In net and spearfishing, *Sc. trispinosus* and *Sp. axillare* were the main targeted species (Fig. 2). In general, fishing activities by fishers using nets and spearguns were similar: fishers exploited mostly shallow waters in daily fishing trips repeated about five times a week (Fig. 2). Besides, each fisher used only a single speargun or one net during fishing trips. Nets ranged from 6 to 1500 m in length and two different ways of fishing were identified depending on net size: nets with less than 100 m were deployed on top of reefs to target fish schools previously identified by fishers and nets equal to or larger than 100 m were deployed without any previous visual assessment of fish presence.

In trap fishing, only *Sp. axillare* and *Sp. frondosum* were targeted (Fig. 2), while the other parrotfishes were eventually captured as bycatch. The number of fishing trips per week was lower than for fishers using nets and spearguns, about three times a week, but trips lasted longer (Fig. 2). Two different sizes of traps were identified and those sizes influenced their fishing depths: traps measuring 1 x 1 x 0.4 m were exclusively used in shallower waters while trap sizes of 1.2 x 1.2 x 0.4m were only deployed in deeper waters. Fishers using traps generally fished at greater depths than those using net and spearguns (Fig. 2).

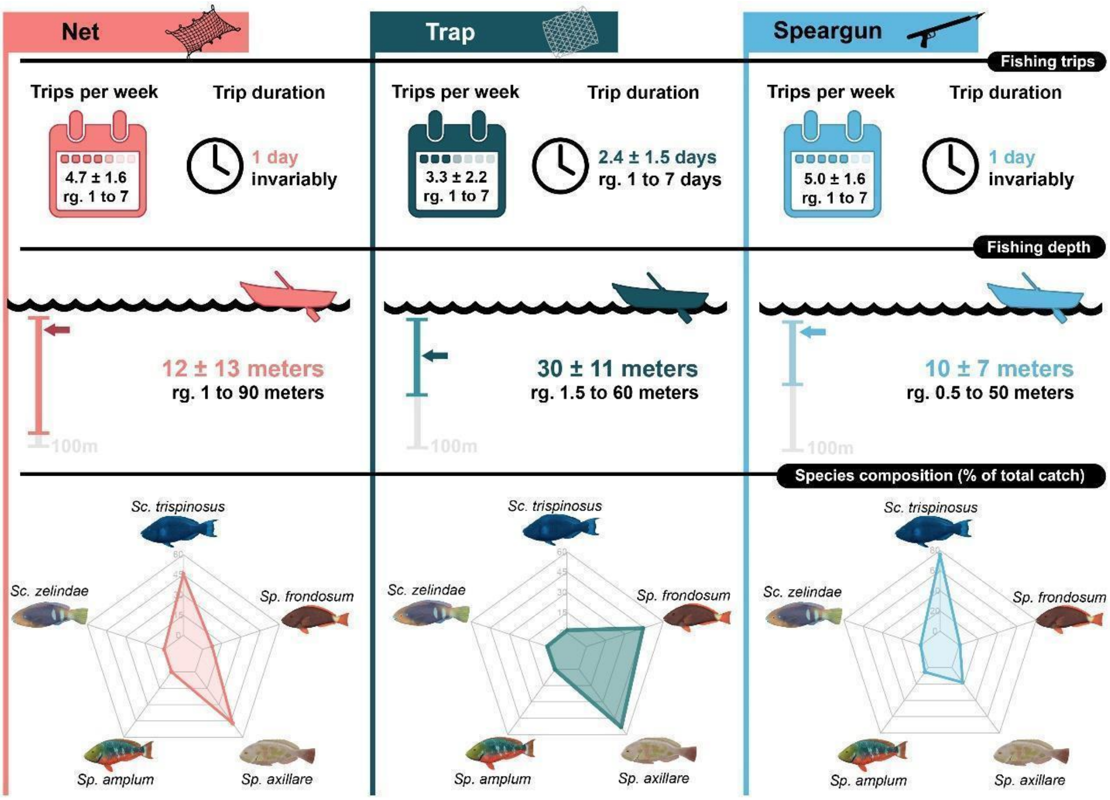


Figure 2. Description of the fishing activities using net, trap and speargun to capture parrotfishes. The descriptions include the mean number, the standard deviation and the range of fishing trips per week, trip duration and the depth fished by each gear. The percentage of catches of each species within total parrotfish catches per gear is given for *Scarus trispinosus*, *Scarus zelindae*, *Sparisoma amplum*, *Sparisoma axillare* and *Sparisoma frondosum*.

Spatial and temporal changes in parrotfish fishing strategies

Among the fishing communities investigated, interviewed fishers from Pernambuco were the ones who started fishing parrotfish first, with the first fishing record from 1946 (mean ± standard deviation of 36 ± 15 years of experience). Before the 1970s, parrotfishes were exploited by this community primarily using small nets in seagrass beds located in shallow waters close to shore (Fig. 3). Then, a shift was observed in the region in the 1970s, when traps became the prevalent gear used to capture parrotfish until the 2020s (Fig. 3). Fishers from the Rio Grande do Norte started exploring parrotfish later, with the first record in 1969 (26 ± 11) using nets, mostly around shallow reefs near the coast (Fig. 3). Spearguns were only registered in the region in the 1980s and traps only in the 1990s, but net remained as the predominant gear across all time periods. In Bahia, the parrotfish fisheries date back to the late 1960s, but most fishers targeting parrotfish were less experienced (17 ± 12 years). Speargun is historically the predominant gear used in Bahia and has been applied to capture parrotfish in shallow coral reefs (Fig. 3).

Fishers from all the fishing communities who used nets and spearguns developed fishing activities similarly over time, maintaining the same fishing depths, number of trips per week, trip duration and gear size (Table S1). Conversely, fishers using traps expanded their fishing efforts, increasing the number of traps deployed per trip, their trip durations and depths visited increased with time (Table S1). Increases in fishing efforts for traps occurred simultaneously with considerable expansions in fishing grounds (Table S2 and Figure S3). Even though fishers using net and spearguns were exploring similar depths over time, they also moved from waters near the coastline to areas further from the ports, especially in Pernambuco, where net catches nearshore almost disappeared since the 2010s (Figures S1 and S2). These expansions increased the fishing grounds for all fishing communities investigated. In about 50 years, fishers from Pernambuco increased their fishing grounds from 70 to more than 3000 km^2 and those from Rio Grande do Norte expanded three-fold (670 to 2183 km^2) (Fig. 3a and Table S2). Despite being the most recent community to target parrotfish, fishers from Bahia presented an increase in their fishing grounds of more than 40% in the last 30 years (1170 to 1661 km^2) (Fig. 3a and Table S2).

Despite the general pattern of shifting from shallow waters near the shoreline to deeper and more distant areas to capture parrotfishes, the total parrotfish catches decreased along the time in all fishing communities investigated (One-Way ANOVAs, $F=8.12$, $p<0.001$ for Rio Grande do Norte, $F=19.26$, $p<0.001$ for Pernambuco and $F=6.70$, $p<0.01$ for Bahia) (Fig. 3b). At the present, total catches in Pernambuco are just a small fraction of what they were when they peaked between 1970-1989, while fishers from the Rio Grande do Norte currently capture less than half of their catches in the same time period (Fig. 3b). Fishers from Bahia also experienced a reduction in their total catches to less than half, but this took place even faster, from 1990-2009.

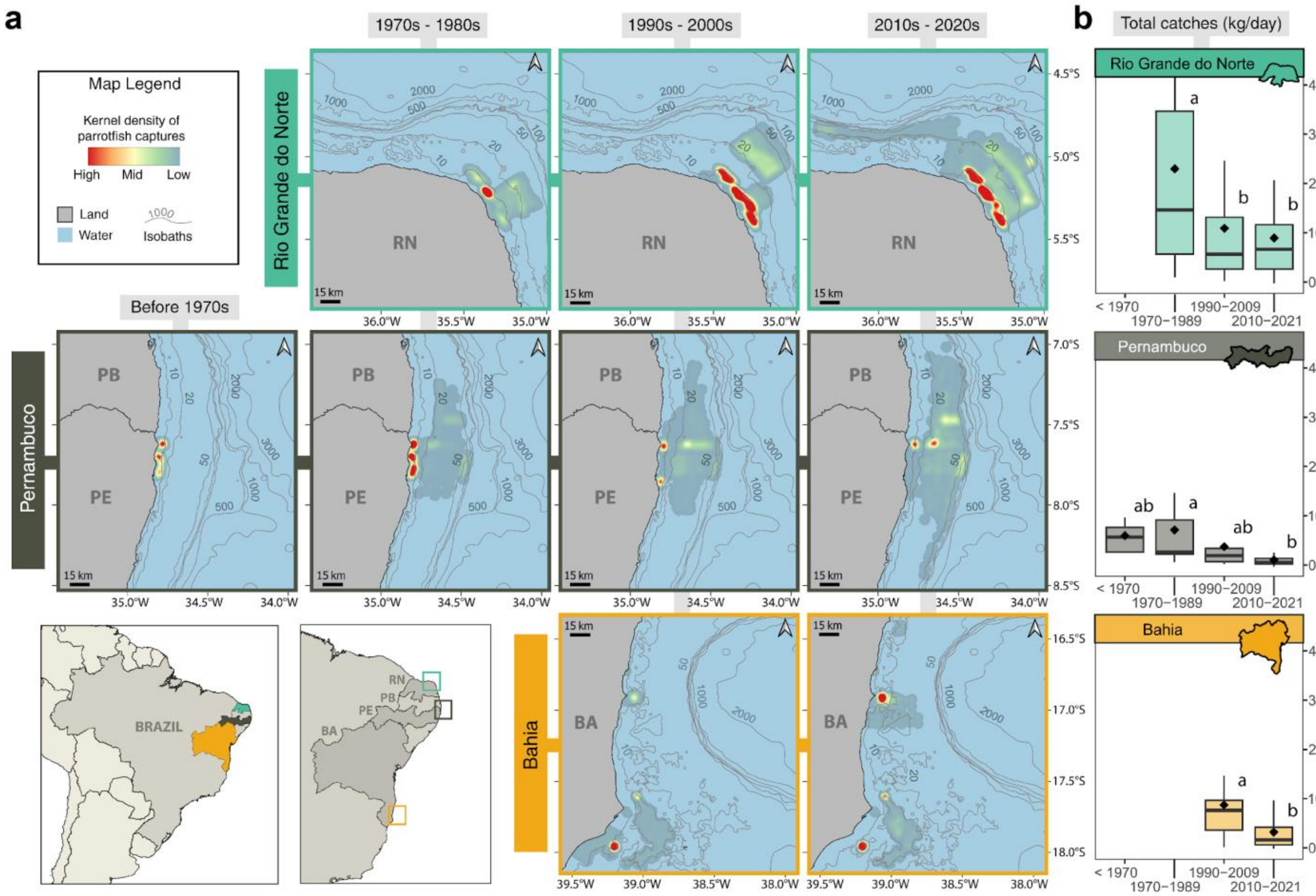


Figure 3. Spatial changes in parrotfish fisheries over time. (a) Kernel density estimates (KDE) of the percentage of parrotfish captures over the total fishing area for each fishing community and time period investigated. (b) Boxplots of total catches per fishing day in kg per fishing communities at each time period. Boxes represent quartiles, the horizontal lines represent the median and diamonds represent mean values. Periods with less than four fishers interviewed were excluded.

Catches per unit of effort (CPUEs) also decreased but revealed more drastic reductions, especially for trap and net that presented a decline of about 90% from the largest to the lowest mean CPUE values per period (One-Way ANOVA, F=7.05, p<0.01 for trap, F=4.89, p<0.01 for net and F=4.61, p=0.01 for speargun). The largest parrotfish catches reported by fishers using nets and spearguns also presented lower values over time, while values for traps remained stable (Linear Models, t=-3.52, p<0.01 for net, t=-2.26, p<0.05 for speargun and t=-1.30, p=0.20 for trap) (Figure 4).

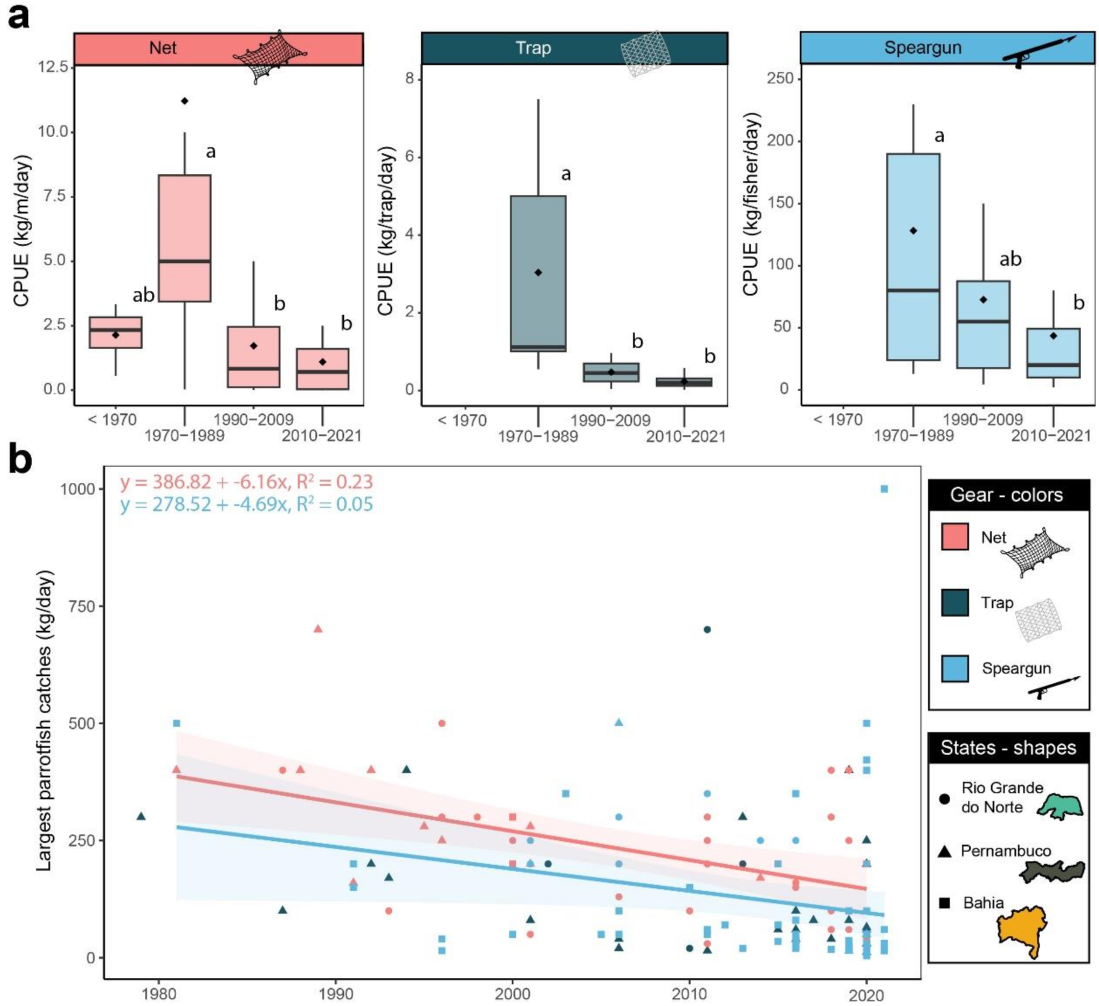


Figure 4. (a) Catches per unit of effort (CPUEs) and (b) the largest parrotfish catches reported by fishers using net, trap and speargun. Shapes represent the state where fishers were interviewed, Rio Grande do Norte (circles), Pernambuco (triangles) and Bahia (squares). The relationship between trap catches and time was not statistically significant and was omitted.

3.2. Catch trends for each parrotfish species

Before 1970, *Sparisoma axillare* and *Sparisoma frondosum* were the only parrotfish species targeted by SSF but catches both species were low in Rio Grande do Norte and Pernambuco. Since the 1970s *Sp. axillare, Scarus trispinosus* and *Sp. frondosum* started to be captured at larger scales and currently remain the most explored parrotfishes by the studied fishing communities (Fig. 5). Catches for these three species increased during time periods, reaching a peak in 1990-2009 and then decreased in the last decade. Nowadays *Sp. axillare* and *Sc. trispinosus* are caught in similar amounts, representing about 80% of total parrotfish catches while *Sp. frondosum* represents about 17% of total catches. Catches for the other two parrotfish species are still low, nonetheless, there are indications of increasing captures of *Sp. amplum* along time periods (Fig. 5). In addition to the reduction in catches, the maximum individual weight of *Sc. trispinosus* captured by nets and spearguns also decreased with time. Conversely, maximum individual weights of *Sp. frondosum* caught by nets increased, while sizes for the other species did not change with time for any fishing gear (Fig. 5 and Table S3).

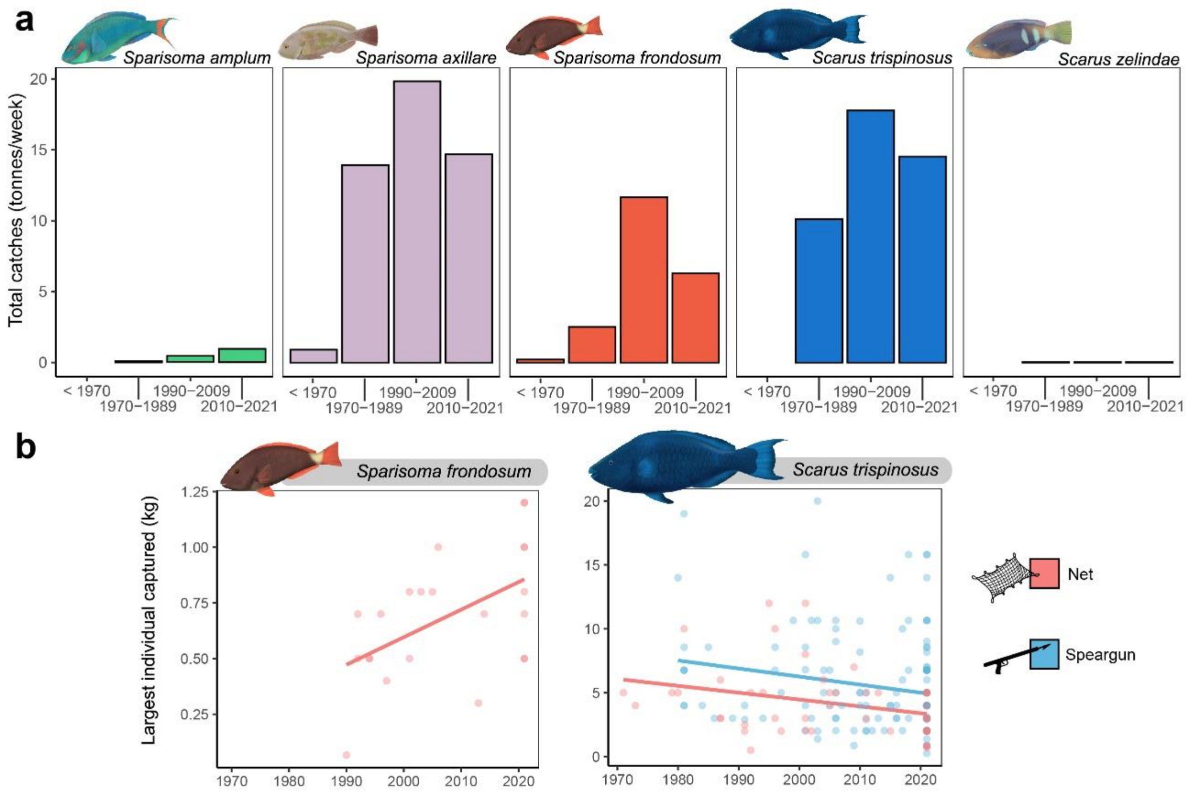


Figure 5. (a) Total catches per week, for each of the five captured parrotfish species by period and (b) Significant relationships of maximum individual weight (kg) with time, observed for *Sparisoma frondosum* and *Scarus trispinosus* caught by nets and spearguns.

3.3. Parrotfish fishing situation

In general, most fishers (~68%), considered the parrotfish fishing situation as “worse”, followed by “neutral” (~25%) and few fishers (~7%) considered the fishing “better” than when they started fishing. The worsening in parrotfish fishing was noticed by fishers regardless of the type of gears used (trap, net or speargun) or fishers´ experience (more or less experienced) (Chi-square test, x^2 =9.06, p=0.06 for gear and x-squared=5.32, p=0.07 for fishers’ experience).

Several reasons were given to explain how they evaluated the situation of parrotfish fishing: most of those who classified the situation as worse perceived reductions in abundance and size due to excessive fishing and environmental changes. Contrastingly, fishers who reported the fishing situation as neutral mostly did not perceive reductions in abundance over time, yet some of those still reported reductions related to fish moving to other areas. Finally, fishers that classified the parrotfish fishing situation as better primarily perceived increments in parrotfish abundance and also an increase in market demand and price with time.

No significant differences were found for the weight and capture estimates given by fishers who diverged in the perception of the parrotfish fishing situation. Any of the three ratios calculated with fishers estimates of parrotfish catches and weights (WC/WM, WC/MWC and L-LF/L-SF) changed among fishing situations (worse, neutral or better) (One-Way ANOVA, F=1.45, p=0.238 for WC/WM; F=1.21, p=0.301 for WC/MWC; and F=0.268 and p=0.766 for L-LF/L-SF). These similar ratios indicate that size and capture estimates were consistent among fishers, regardless of how they evaluated the situation of parrotfish fishing.

4. Discussion

Using Local Ecological Knowledge, we identified nets, traps and spearguns as the main fishing gears used to harvest parrotfishes along the Brazilian coast. Most fishers also used handline, but it was not considered by them as the principal gear to capture parrotfish. In general, fishing activities such as the number and duration of trips, depths explored and targets of nets and spearguns were similar and did not change over time, while trap fishing exploited parrotfishes differently and was the only one that increased effort. Fishing grounds were expanded for all fishing communities. The use of traps, however, made it possible for fishers to access previously unexplored places, resulting in greater fishing ground expansions at Rio Grande do Norte and Pernambuco fishing communities, which exploited parrotfishes earlier and introduced traps as gears. Regardless of changes in fishing activities and fishing grounds, there are signs of reductions in total daily catches in all fishing communities, some of them with increasing effort in an attempt to maintain catches. The large CPUE reductions are congruent with a significant reduction in parrotfish stocks, which can be seen for the most exploited species: *Sc. trispinosus* and *Sp. axillare*. Most of the fishers, regardless of fishing gear used, fishing experience and community they belong, indicated a worse situation of parrotfish fishing, which is corroborated by the catch data estimated over the years.

Nets, spearguns, traps and handlines are also the main gears used by SSF to target parrotfish in other regions of the world, such as the Caribbean and the Pacific. Within each location, gears are also variably applied, both spatially and temporally, depending on the characteristics of the fishing communities as well as the climatic, oceanographic and stock situations at the time (Gillett & Moy 2006, Gillett & Tauati 2018, Harms-Tuohy 2021). Worldwide, parrotfish fishing activities are older than the ones registered here in Brazil (Gillet 2009). Local fishing communities in Torres Strait in the tropical Pacific, for example, targeted small-sized parrotfishes in shallow water channels and tide pools near shore, four thousand years ago but only for subsistence (Weisler & McNiven 2015). Similar fishing strategies were still seen in these Pacific communities in the late 18th century (Ghaleb 1998) and even though commercial exploitation of parrotfishes started since then, and it is currently probably at the limit, catches in the region remain stable (Gillet 2009, Bedford et al. 2021). In the present study, the increase in parrotfish catches from 1970 to 2009 seem unsustainable given that the catches have already decreased in the last 20 years for all main targeted species. Before the 1970s fishers were also catching low amounts of *Sp. axillare* and *Sp. frondosum* very close to shore and were probably targeting these species for subsistence earlier than 1946, the first fishing recorded in the present study. Larger parrotfish catches, however, took place only after the 1970s. Changes from shallow to deeper catches happened only in the 1990s, which means that parrotfish fishing expansion in Brazil is recent and may continue to increase in the years to come.

The highest expansions are observed for fishers using traps, who sell part of their catches to exportation (Cunha et al. 2012, Carvalho et al. 2013, Roos et al. 2016, Queiroz-Véras et al 2023). Exportation of the Brazilian parrotfishes *Sp. axillare* and *Sp. frondosum* started in the 1990s, raising the interest in the market of these species (Cunha et al. 2012), which possibly explains the expansion in fishing grounds and efforts of trap fishing to increase catches. As observed in the present study, even with the large expansion in fishing grounds fishers were not able to increase catches. In fact, they could not maintain previous catches and decreases in fishing productivity were observed for all fishing communities. Longer fishing trips to more distant areas led to increased costs associated with fuel, the fishing crew and ice to preserve the fish (Carvalho et al. 1997, Lopes & Begossi 2011). Until now, the financial gains with exportation may still support the extra costs to maintain the viability of the fishery, even with lower catches. Parrotfish exportation, however, has been forbidden in Brazil since 2016 aiming to recover parrotfish populations (Freitas 2016), but it persists due to the lack of monitoring (Queiroz-Véras et al. 2023).

Fishing grounds for net and spearfishing are also increasing, but catches are still concentrated around shallow reefs, mostly inside Marine Protected Areas such as the Abrolhos Bank in Bahia and the Parrachos reefs in Rio Grande do Norte. The legal measures developed to recover Brazilian parrotfish populations include restrictions on parrotfish fishing, which must be exclusively performed in areas with management plans for the group (Inter-Ministerial Decrees N 59-B and 63/2018). To date, only two Extractive Reserves in the Abrolhos region comply with these rules (Decrees N 284 and 285/2021). More recently, fishing was completely banned for the most threatened species, *Sc. trispinosus* (TCU Acórdão N 3791/2022), given its status as an endangered species (Ferreira et al. 2012). Fishing for this species, as well as all others in discordance with parrotfish fisheries regulations, continues to occur illegally. Nonetheless, most fishers probably do not even know about parrotfish fishing regulations, as there is a great lack of disclosure along the Brazilian coast regarding these policies, which have been constantly modified since 2014 (TCU Acórdão N 3791/2022).

Fishing bans are commonly used in other regions of the world, such as the Caribbean, as management actions to protect parrotfishes, especially the largest species, which tend to be more attractive to fishing and more vulnerable to fishing impacts (Harms-Tuohy 2021). Illegal parrotfish fishing has also been observed in these regions, even where the policies are enforced (Pires et al. 2021), but, in general, fishing bans have been better applied than in Brazil and recoveries in local parrotfish biomasses have been reported in some places (Harms-Tuohy 2021, Taylor et al. 2022). In countries with large coastlines and few resources applied to fishing monitoring, such as Brazil, regulations in the commerce of parrotfish may provide better results (Queiroz-Véras et al. 2023). The monitoring of fishing industries and the requirement of labels on exported products, for example, demand less financial and human resources and could provoke a cascade effect reducing catches due to decreases in market demand. Similar outcomes were observed for fisheries targeting sharks in Brazil and the civil society has been demanding the establishment of labeling systems for shark products and monitoring fishing industries to reduce catches of threatened species (Rangel et al. 2021).

It is noteworthy that the number of species targeted in Brazil is lower than in other regions worldwide, while catches are higher. The Indo-Pacific holds the highest richness of parrotfishes, of about 60 species, and many are used as fishing resources (Parenti & Randall, 2000, 2011, 2017). Ten out of 13 parrotfish species in the Caribbean are targeted in fisheries (Harms-Tuohy 2021). Brazil has the lowest parrotfish diversity, harboring 10 parrotfish species of which 7 are endemic (Pinheiro et al. 2018, Queiroz-Véras et al. 2023). From those species, we registered six in captures, three as the main targets and representing most catches, *Sp. axillare, Sc. trispinosus* and *Sp. frondosum*. The number of parrotfishes caught per fishing day in Brazil also seems to be higher than in other regions, especially for spearfishing. While fishers using spearguns in Brazil currently catch about 50 kg of parrotfishes per fishing day, in the Pacific islands, a mean of about 12 kg of fish was caught in the 2000s, including all targeted species, not only parrotfishes (Gillet & Tauati 2018). Removing a few herbivore species may trigger serious outcomes in much higher diversity areas, such as the Pacific and the Caribbean, where the growth of algae has been controlled by these species (Ferrari et al. 2012, Duran et al. 2016, Ruttenberg et al. 2019, Shantz et al. 2019). The consequences of removing large amounts of large parrotfishes in ecosystems with low functional redundancy such as the Brazilian reefs may be even more severe and must be investigated.

In the present study, the decrease in total captures indicates the overexploitation of *S. axillare, Sp. frondosum* and *S. trispinosus* along the Brazilian coast, despite the increased fishing effort to maintain catches. However, stable catches for *S. amplum* and *S. zelindae* do not mean a good situation for their stocks. The steady low catches observed for these species for all fishing gears may reflect their naturally low abundances in the regions investigated (Araujo et al. 2020). Less-abundant species have an increased risk of extinction due to random fluctuations in population size (Sreekar et al. 2021) and are more vulnerable to negative fishing effects. Changes in individual fish weight over time also indicate overexploitation if the mean size does not stabilize with time (Freitas et al. 2019). Yet only the individual weights of *Sc. trispinosus* decreased over time, while the individual weights for the other species remained stable. The lack of changes in most captured species could reflect the procedures of trap fishing, which continuously explores deeper and further new fishing grounds, masking local reductions in fish weight. For *Sparisoma frondosum*, increasing individual sizes were captured with time, which could be related to the fact that this fishery previously occurred in shallower waters near the coast that harbor smaller parrotfish (Feitosa & Ferreira 2014, Pereira et al. 2018, Roos et al. 2019). Opposing patterns are observed for *S. trispinosus* fishing performed with nets and spearguns, which are restricted to shallower waters. The particularities of fisheries and species distributions must be considered when analyzing species exploitation. Due to the complexity of these activities, it is important to perform a thorough evaluation of the scenario for each species for a proper assessment of the fishing situation status instead of solely basing assessments on fish sizes or total catches.

Decreases in local abundance and size of *Sc. trispinosus* have been reported in previous studies as well (Ferreira et al. 2012, Bender et al. 2014, Freitas et al. 2019, Roos et al. 2020a, Pereira et al. 2021). LEK was also used in fishing communities from Bahia to investigate the historical fishing of this endangered species in Abrolhos and found that *Sc. trispinosus* only became a target after the 1990s but already showed signs of overexploitation (Previero 2014), corroborating with the results found in the present study. Previero (2014) also registered longer spearfishing trips in other fishing communities in Bahia, ranging from 3 to 25 days each. Those longer trips may indicate greater expansions in fishing grounds in Bahia that we could not detect. Pereira et al. (2021) have recently demonstrated drastic decreases in maximum sizes and maximum catches for *S. trispinosus* fished with spearguns along the southern Pernambuco coast. The large-scale results observed in the present study, as well as in local studies, indicate parrotfish fisheries may be at risk of overfishing the resource.

Fishers´ assessment of the parrotfish fishing situation as worse reinforces the view that parrotfish populations are overexploited. The similar ratios (WC/WM, WC/MWC and L-LF/L-SF) observed among fishers who diverged in the classification of parrotfish fishing situation provide evidence of the consistency of information presented by fishers, even for those with minority viewpoints who considered the situation of the fishing as "neutral" or "positive". The participation of local fishers in the development of stock assessments and management actions is especially relevant in the case of Brazilian threatened parrotfishes to increase awareness regarding the importance of sustainable fisheries and to increase compliance of fishers with management measures.

The use of Brazilian parrotfish species as fishing resources may be a dangerous strategy. Parrotfish populations have been decreasing worldwide, impacting reef environments and those relying on them for food and income (Hughes 1994, Shantz et al. 2019). Fishers have already perceived reductions in catches, but the current status of Brazilian parrotfish populations is unknown. Even though trap fishing has expanded more than fishing with the other two gears, the largest parrotfish removals are still done in shallower waters using nets and spears, illegally targeting the endangered *Sc. trispinosus.* Studies should focus on how these large removals from shallow environments impact parrotfish populations and the ecosystem implications. The increasing removal of parrotfish from deeper areas by trap fishing, mostly of *Sp. axillare* and *Sp. frondosum*, could be affecting important sources of recruits for these species once they are depleted in shallower waters. Parrotfish fisheries move towards a worse scenario in years to come. It is urgent that fishers, the scientific community and the government work together to evaluate the real situation of parrotfish stocks, establish objective management strategies to protect and recover parrotfish populations, and determine whether using parrotfish as a fishing resource is viable. Otherwise, the recovery actions established will fail and parrotfish populations may continue to decrease over time.

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6. Supplemental material 1 - Interview performed with fishers from Rio Grande do Norte, Pernambuco and Bahia

Roteiro de Entrevista - Conhecimento Ecológico Local (CEL)

Data: _____/______/_________

Local: ____

(   ) BA   (   )PE   (   ) RN

Supervisor(a): ____

1) Informações do entrevistado e da pesca

Nome____
Apelido____

Idade____

Possui um barco de pesca?   (   ) NÃO (   ) SIM

Mudou de arte de pesca ou espécie alvo ao longo do tempo? (   ) NÃO (   ) SIM

Quais foram essas mudanças?

Arte de pesca antes:

Arte de pesca atual:

Espécies pescadas antes:

Espécies pescadas atualmente:

Por quê?

Mudou de área de pesca? (   ) NÃO (   ) SIM

Por quê?____

Local(is) de pesca mais visitados hoje (incluindo limites mínimos e máximos de profundidade e localização)
____
____
____

Local(is) de pesca mais visitados quando começou a pescar (incluindo limites mínimos e máximos de profundidade e localização)
____
____
____

Quantas vezes na semana você costuma sair para pescar?______________________________

Quantas vezes na semana você saía para pescar quando começou? Pq mudou? Qnd mudou?

____
______ ____

Qual o alvo principal da pesca? (   )Budião (   )outro ________________________________

2) Budiões

Você tem pescado budião?   (   ) NÃO (   ) SIM   Se não, quando parou?__________________

Que tipo (espécie)? ____

Quantos budiões você pegou no melhor dia que já teve? ____________________________

Em qual mês/época isso aconteceu?____

Qual ano?____

Onde você pescou?____

Quando você começou a pescar budião? ____

Em geral, quanto da sua pescaria é budião (porcentagem/proporção)? ____________________

____

Espécie	**Tamanho ou peso do maior peixe que você já pescou?**	**Onde você pescou este peixe?**	**Qual arte de pesca você utilizou?**
Budião verde (*Sparisoma amplum*)			
Bobó (F), rabo de forquilha (M) (*Sparisoma axillare*)			
Budião, barriga mole (*Sparisoma frondosum*)			
Budião azul (*Scarus trispinosus*)			
Budião banana (*Scarus zelindae*)			

Qual o tamanho médio e máximo das espécies capturadas? (Pode ser um intervalo de tamanho) (Colocar hífen "-" nas espécies não capturadas)

Espécie	**Atualmente** (médio-máximo)		**Quando começou a pescar** (médio-máximo)	
Budião verde (*Sparisoma amplum*)				
Bobó (*Sparisoma axillare*)				
Budião, barriga mole (*Sparisoma frondosum*)				
Budião azul (*Scarus trispinosus*)				
Budião banana (*Scarus zelindae*)				

Para você como está a situação da pesca dessa(s) espécie(s)? (Colocar hífen "-" nas espécies não capturadas)

Espécie	**Negativa (piorou)**	**Neutra (não mudou)**	**Positiva (melhorou)**	**Por quê?**
Budião verde (*Sparisoma amplum*)				
Bobó (F), rabo de forquilha (M) (*Sparisoma axillare*)				
Budioa, barriga mole (*Sparisoma frondosum*)				
Budião azul (*Scarus trispinosus*)				

3) Guia de identificação das espécies de budião

Espécie	Dentro d'água	Fora d'água
Budião verde (*Sparisoma amplum*) **Fase inicial**		
Fase final		
Bobó (F), rabo de forquilha (M) (*Sparisoma axillare*) **Fase inicial**		
Fase final		

Budioa, barriga mole (*Sparisoma frondosum*) **Fase inicial**		
Fase final		
Budião azul (*Scarus trispinosus*) **Fase inicial**		
Fase final		
Budião banana (*Scarus zelindae*) **Fase inicial**		
Fase final		

Table S1. Summaries of simple linear regression results for the influence of time (year as the independent variable) in the following dependent variables: number of trips per week, duration of fishing trips, mean fishing depth, the number and the size of gears used in each trip, for each gear. SE is the standard error. Significant relationships are presented in bold. Gear amount was not tested for net and speargun once the amount was always one, and gear size was not tested for speargun and trap because the size of gears was always the same.

Gear	Dependent variable	Estimate	SE	t	r^2	p
Net	Trips per week	-0.002	22.45	-0.15	-0.01	0.877
	Fishing depth (m)	0.16	0.09	1.80	0.03	0.076
	Gear size (m)	-0.001	0.0005	1.26	0.01	0.214
Speargun	Trips per week	0.01	0.02	0.45	-0.01	0.657
	Fishing depth (m)	0.02	0.08	0.21	-0.02	0.837
Trap	Trips per week	-0.02	0.01	-1.37	0.01	0.175
	Trip duration (days)	**0.03**	**0.01**	**2.92**	**0.10**	**0.005**
	Fishing depth (m)	**0.24**	**0.07**	**3.29**	**0.13**	**0.002**
	Gear amount	**2.95**	**1.28**	**2.30**	**0.16**	**0.032**

Table S2. Size of parrotfish fishing grounds (in km^2) explored by fishers interviewed in fishing communities of Rio Grande do Norte (RN), Pernambuco (PE) and Bahia (BA) for the four periods registered.

	< 1970s	1970s-1980s	1990s-2000s	2010s-2020s
RN	-	670	1129	2183
PE	70	1828	2079	3287
BA	-	-	1170	1661

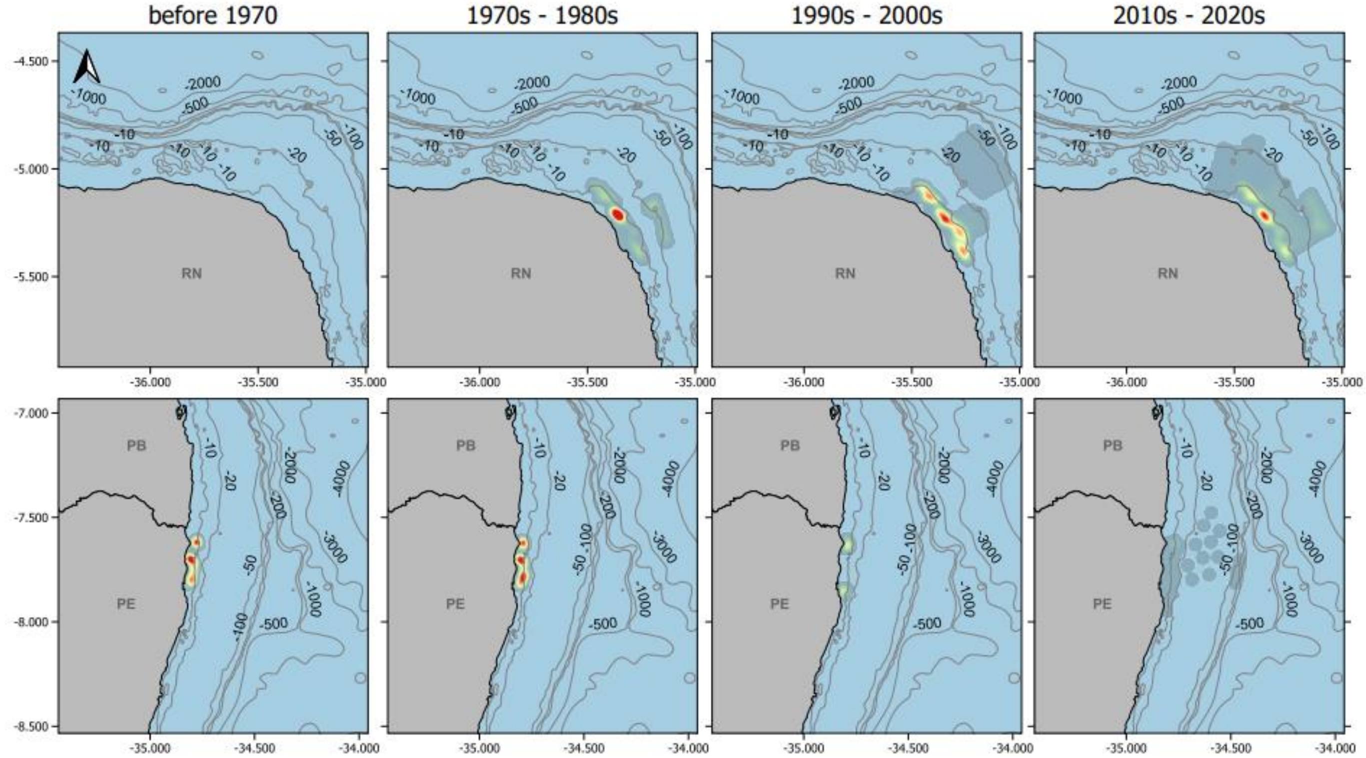


Figure S1. Kernel density estimate (KDE) heatmaps visualized as a percentage of parrotfish captures by net fishers over the total fishing area, separated by state and periods investigated.

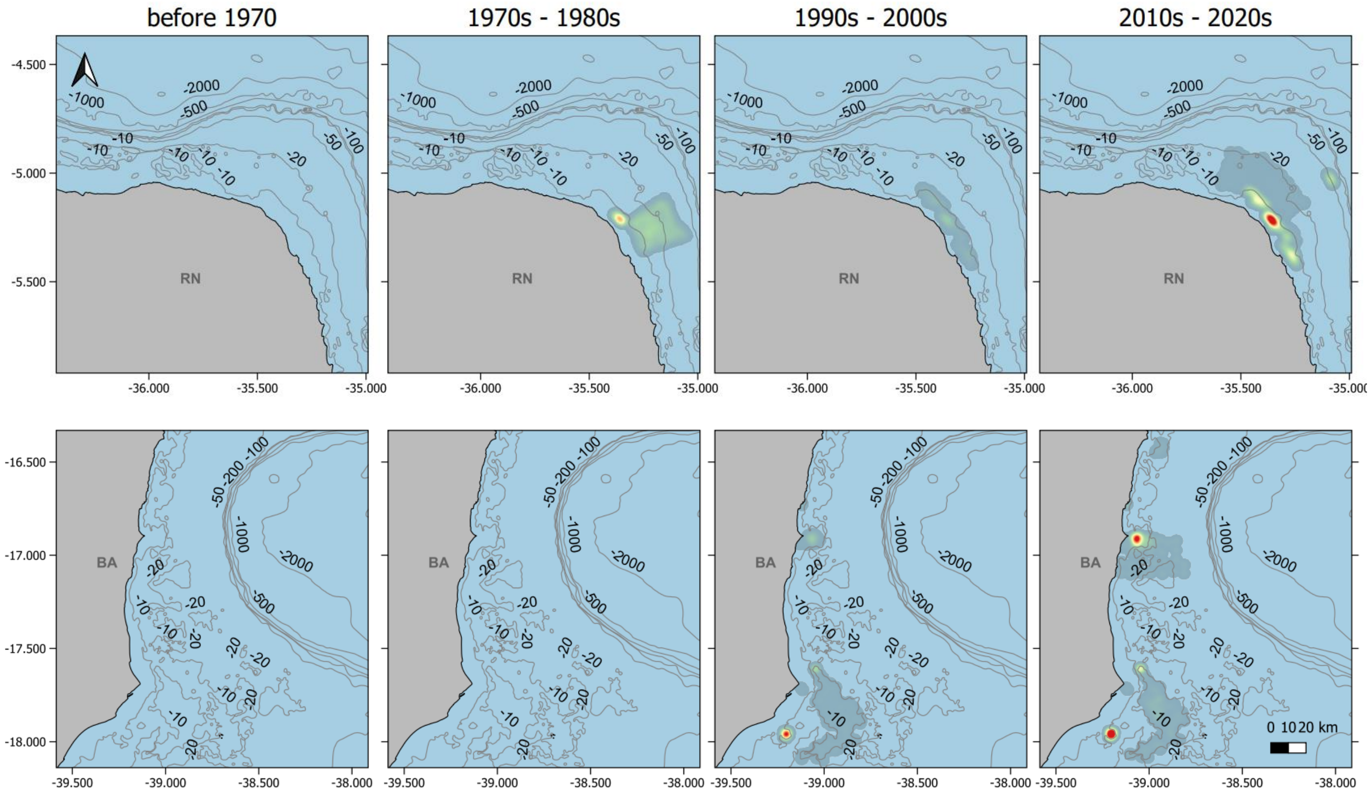


Figure S2. Kernel density estimate (KDE) heatmaps visualized as a percentage of parrotfish captures by speargun fishers over the total fishing area, separated by state and periods investigated.

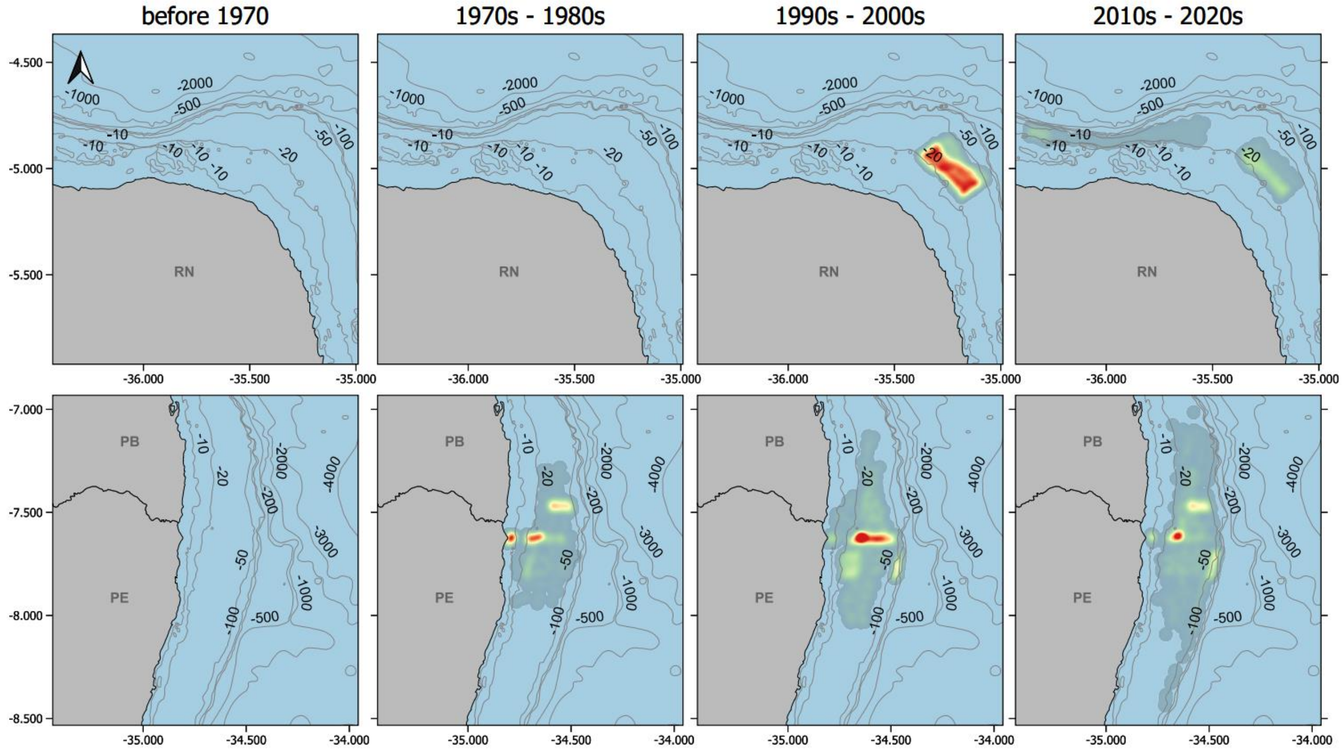


Figure S3. Kernel density estimate (KDE) heatmaps visualized as a percentage of parrotfish captures by trap fishers over the total fishing area, separated by state and periods investigated.

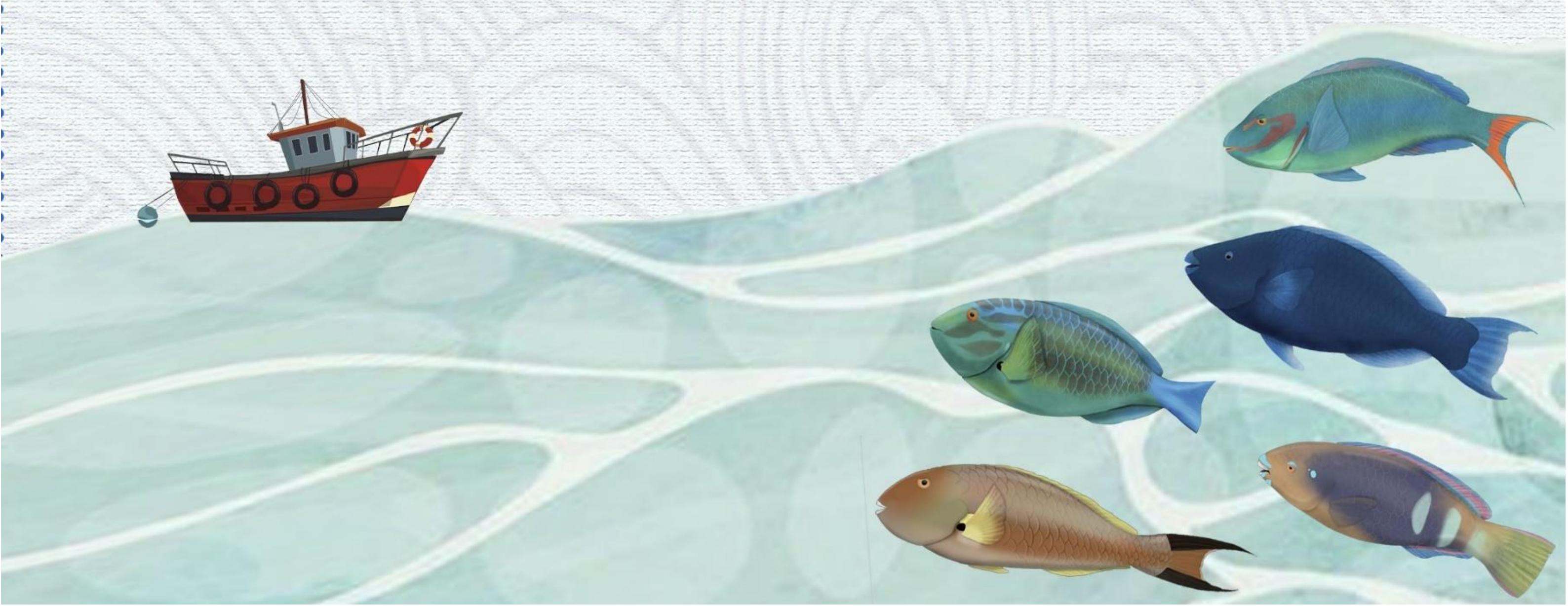
Table S3. Summaries of simple linear regression results for the influence of time (year as numeric) in the maximum individual weight by each fishing gear. Significant relationships are presented in bold. SE is the standard error.

Gear	Species	Estimate	SE	t	r^2	p
Net	***Scarus trispinosus***	**-0.050**	**0.030**	**-2.080**	**0.070**	**0.044**
	Sparisoma axillare	0.002	0.003	0.580	0.010	0.565
	Sparisoma frondosum	**0.010**	**0.003**	**2.970**	**0.230**	**0.006**
Speargun	***Scarus trispinosus***	**-0.06**	**0.030**	**-2.330**	**0.030**	**0.021**
	Scarus zelindae	0.01	0.020	0.600	-0.270	0.612
	Sparisoma amplum	-0.03	0.030	1.080	0.000	0.311
	Sparisoma axillare	0.01	0.010	0.680	-0.040	0.512
	Sparisoma frondosum	0.01	0.010	0.370	-0.140	0.721
Trap	*Scarus trispinosus*	-0.010	0.030	-0.240	-0.020	0.808
	Scarus zelindae	-0.001	0.003	-0.380	-0.030	0.706
	Sparisoma amplum	0.010	0.010	0.410	-0.050	0.688
	Sparisoma axillare	0.003	0.003	0.990	-0.000	0.328
	Sparisoma frondosum	0.001	0.003	0.460	-0.010	0.646

CAPÍTULO 3

PARROTFISH POPULATIONS IN BRAZILIAN WATERS: HOW MUCH IS STILL OUT THERE?

ARTIGO A SER SUBMETIDO PARA A REVISTA ANIMAL CONSERVATION



CAPÍTULO 3

Parrotfish populations in Brazilian waters: how much is still out there?

Abstract

Brazilian parrotfishes have been increasingly targeted by small scale fisheries and decreases in abundance have led to the classification of some species as threatened. The current status of their populations, nonetheless, is still unknown. In this study we reconstructed the historical fishing catches of each of the five targeted Brazilian parrotfishes and evaluated the use of the most captured species as fishing resources. *Scarus trispinosus, Sparisoma axillare* and *Sparisoma frondosum* were identified as the most caught species, with the first two species representing about 80% of the total Brazilian parrotfish catches. These three species presented decreases in total catches, while *Sparisoma amplum* catches increased steadily and *Sc. zelindae* catches oscillated over time. The stock evaluation of the two most captured species indicated the stock status of *Sparisoma axillare* is in a good condition, above the management target of 40%, but the trap fishing activities mostly used to capture them may not be sustainable and could be masking changes in the stock status. The stock of *Scarus trispinosus* was considered as "overfished", which means if fishing continues to occur at the same rate, the situation of the stock tends to become even worse. Brazilian parrotfishes present important roles for reef ecosystems and for the artisanal fishing communities relying on them. The management measures adopted so far have not been effective in improving stock status or maintaining social and economic benefits of the fishing activity. In this way, new approaches for the management of these species must be developed focusing on the historical, geographic and financial challenges encountered in Brazil.

Keywords: Data-poor methods, artisanal fisheries, catch reconstruction, Scarini, overfished

1. Introduction

Stock assessments are required to evaluate fisheries sustainability and prevent overfishing (FAO 2022). These modeling approaches commonly rely on biological information of the stock and fisheries statistics to estimate population size, optimal harvest rates and population status (Booth & Quinn 2006, Bozec et al. 2016, Cope 2020.Nonetheless, most fishing resources are still being exploited with little or no biological or catch information, which means their stock status remains unknown (Costello et al. 2012, FAO 2022). The last report on the State of the World Fisheries and Aquaculture (FAO 2022) estimated that about 60% of the world's fishery stocks have not been assessed, mainly due to difficulties in obtaining information from small-scale fisheries (SSFs) (Pita et al. 2019, FAO 2022). Therefore, most of the catches in the world are not monitored and when they are, only about 65% of the catches are reported at the species level. The other 35% of the monitored catches in the world are only reported for groups of species, such as "sardine", "hammerhead shark", etc, or even more broadly such as "shark" or "other fish", preventing the identification of the captured species and the use of this data in stock assessments.

Due to the difficulty in obtaining catch and biological data, researchers have made increasing efforts to evaluate fish populations even when little data is available, using Data-limited Stock Assessment Methods (Babcock & Mcall 2011, Damasio et al. 2015, Winker et al. 2018). In this type of assessment, the status of a fish stock can be evaluated using few or incomplete data series of landings, biological parameters, length and age compositions of captured fish and information from fishers and experts (Booth & Queen 2006, Rudd et al. 2021). Large groups of specialists have been working on reconstructing fishing captures around the world to be used in stock assessments or by stakeholders and recently published a reconstruction of world marine captures, including reconstructed data for all countries in the world (Pauly & Zeller 2016).

In Brazil, no official fishing monitoring program has been conducted since 2008, no national fisheries statistic reports have been published after 2010 and Brazil is the only country in the world that has not been reporting data to FAO since 2014 (FAO 2020). Even with no fishing monitoring data, decreases in the abundance of many target species have been observed, as is the case of the Brazilian endemic parrotfishes. Seven out of the ten parrotfish species in Brazil are endemic and five of those are targeted by fisheries, *Scarus trispinosus, Scarus zelindae, Sparisoma amplum, Sparisoma axillare* and *Sparisoma frondosum.* In the early 2010s, the large decrease in abundance observed over the last 30 years for four of these species led to their categorization as threatened: *Sc. zelindae, Sp. axillare* and *Sp. frondosum* as vulnerable and *Sc. trispinosus* as endangered (Ferreira et al. 2012).

A fishing ban on all threatened parrotfish species was determined in 2014 after the publication of the Brazilian Red List of Threatened Species but the list and the fishing bans ended up being suspended (Lees 2015, Freitas et al. 2019, Roos et al. 2020b). A series of management actions were published since then, but recently, a complete fishing ban has been established on *Sc. trispinosus* due to its Endangered status (TCU Acórdão No 3791/2022), while sizes, gear and spatial restrictions were maintained for the other three threatened species (See Queiroz-Véras et al. 2023 for the details in parrotfish management actions).

Despite their classification as threatened, little information on parrotfish landings was available: national official data were published from 1989 to 2010 in addition to 1969 but the quality of this dataset was particularly poor. Parrotfish catches in official bulletins were not separated by species, were only reported for a few states and had an increasing trend over time, but reported numbers were questionable (Queiroz-Véras et al. 2023). For instance, national parrotfish catches were calculated by the sum of the captures reported for each state, but just four states reported catches and none of them presented reported values for all years (Queiroz-Véras et al. 2023). Some additional information was available from scientific publications and included punctual landing estimates for some states (Ribeiro 2004, Cunha 2012, Roos 2016).

With the publication of the Reconstructed Catch Statistics for Brazilian marine waters, total catches per state were then estimated for the Brazilian parrotfishes, from 1950 to 2015 (see Freire et al. 2021 for the detailed methodology). With this new historical parrotfish catch series, it was possible to observe that landings were decreasing since the 2000s, and values were at least five times higher than what was published in the National Bulletins (Freire et al. 2021). Rio Grande do Norte, Pernambuco and Bahia were also identified as the main states exploiting parrotfish, accounting for ~95% of total parrotfish catches in the country (Freire et al. 2021). This reconstructed database represents the most consistent information on national captures of commercial fishing in Brazil, but due to their broad scope of species to address, information on catches for parrotfish at species level is not detailed and no information on fishing fleets or fishing effort is published.

Information on the main fishing strategies used to harvest parrotfish in Brazil, as well as the species composition of catches was recently investigated using Local Ecological Knowledge (LEK) of fishers along the Brazilian coast and found that net, speargun and trap were the main gears used in parrotfish fishing, and *Sparisoma axillare* and *Scarus trispinosus* are the two parrotfish species composing most catches in Brazil (Queiroz-Véras, Chapter 2 of this Thesis). These data, along with those from reports and articles regarding fishing effort can be used to separate total parrotfish catches present in Freire et al. (2021) into species catches by fishing type, and these discriminated catches may be used to evaluate the status of the Brazilian parrotfish stocks.

The main goal of this paper was to investigate the historical fishing catches of each of the five targeted Brazilian parrotfishes and evaluate the viability of the use of the most captured species as fishing resources. For that, three main questions were outlined: (1) How much of each of the five targeted parrotfish species biomass has been exploited from Brazilian waters? (2) What has been the trend of their catches over time? (3) Based on their use for fisheries and life history traits, what is the stock status of the most captured species?

2. Material and Methods

To estimate quantities and trends in the exploitation of Brazilian parrotfish, related to the first two questions, we reconstructed total parrotfish catches by species and gear, using information from landing data, published documents and fisher's LEK to discriminate catches from Freire et al. (2021). To define the stock status of the most captured parrotfish species, related to the third question, we ran data-limited stock assessments for *Sparisoma axillare* and *Scarus trispinosus.*

2.1. Reconstruction of parrotfish catches by fishing activity and species

Total parrotfish catches per year for each of the five target species and for each fishing activity were estimated from 1950 to 2015 for the states of Rio Grande do Norte, Pernambuco and Bahia, which represented most parrotfish catches in the country. To reconstruct parrotfish catches by each targeted parrotfish species and the gears used to capture them, we used published information on total parrotfish catches, parrotfish fishing activities and the composition of species in each type of fishing activity. The main database of total parrotfish landings used to calculate species catches came from the Reconstructed Catch Statistics for Brazilian Marine Waters from 1950 to 2015 (Freire et al. 2021). Even though this database provided some information on captures by species, most catches were discriminated as "Sparisoma", "Scaridae" or "Budião" (common name of parrotfish in Portuguese), so we complemented this series by reconstructing the sum of all parrotfish catches discriminating each of the five targeted species.

To obtain information on the composition of species in each fishing activity, we used percentages of total species catches by fishing gear estimated by 161 fishers from Rio Grande do Norte, Pernambuco and Bahia, for four periods, before the 1970s, 1970s-1980s, 1990s-2000s and 2010s-2020s (Queiroz-Véras, Chapter 2 of this thesis) (Table S1). Information from Ribeiro (2004), Previero (2014) and Roos et al. (2016) were also used to confirm the trends found in Queiroz-Véras (Chapter 2 of this Thesis).

To find information about parrotfish fishing activities in each of the investigated states, we used three types of data: fishing logbooks, information from published documents and fishers' LEK information. Fishing logbooks were obtained by request from the ESTATPESCA Program, for the period of 1997 to 2010 and from local fishing monitoring programs of Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA), for the period of 1986 to 1996 and 2011, both databases for the state of Pernambuco. The published documents systematically reviewed in Queiroz-Véras et al. (2023) were searched for information on parrotfish fishing activities that could complement the landing data and additionally, a Fishing Statistical report from the ESTATPESCA Program (MMA 2004) was found for PE and RN. Fishers' LEK on fishing activities was comprised of percentages of catches for each fishing gear within total parrotfish catches from Rio Grande do Norte, Pernambuco and Bahia for four periods, before the 1970s, 1970s-1980s, 1990s-2000s and 2010s-2020s (Table S2) (Queiroz-Véras, Chapter 2 of this Thesis). The detailed database for each State is listed in Table 1. Since each State presented different availability of data, the reconstruction of catches per fishing gear was done separately for each state.

Table 1. Description of each database or document used to obtain information about the fishing activities used to capture parrotfish in Rio Grande do Norte, Pernambuco and Bahia states.

	Period	Source	Information type	File Type
Pernambuco	1946-2021	Queiroz-Véras et al. *in prep*	LEK catches per species and gear/year	Excel
	1950-2015	Freire et al. 2021	Reconstructed total catches/year	Excel
	1986-2011	IBAMA	Daily fishing landing control forms	Physical forms
	1997-2010	ESTATPESCA	Daily fishing landing control forms	Excel
	2004	ESTATPESCA	Total catches per gear/year	PDF
	2004	Ribeiro 2004	Species composition of trap fishing	PDF
Rio Grande	1950-2015	Freire et al. 2021	Reconstructed total catches/year	Excel
do Norte	1969-2021	Queiroz-Véras et al. *in prep.*	LEK catches per species and gear/year	Excel
	2004	ESTATPESCA	Total catches per gear/year	PDF
	2004	Ribeiro 2004	Species composition of trap fishing	PDF

	2014	Roos et al. 2016	Estimated total catches per species	PDF
Bahia	1950-2015	Freire et al. 2021	Reconstructed total catches/year	Excel
	1969-2021	Queiroz-Véras et al. *in prep.*	LEK catches per species and gear/year	Excel
	1980-2014	Previero 2014	Description of historical fishing fleets	PDF

2.1.1. Rio Grande do Norte

Even though this state was included in the final ESTATPESCA report (MMA 2004), no information about parrotfish catches is included, so information about fishing gears for this state was based on Queiroz-Véras (Chapter 2 of this thesis) and complemented by Ribeiro (2004) and Roos et al. (2016) (Table S2). The percentages of trap fishing catches estimated using Queiroz-Véras (Chapter 2 of this thesis) (always below 20% of total parrotfish catches) diverged from values estimated using Ribeiro (2004) (about 480 tonnes in 2004 or 60% of total parrotfish catches), so values from Ribeiro were applied (Table S2).

The total parrotfish catches from Freire et al. (2021) for the years 2011, 2012 and 2014 were much lower than the previous and following years of the time series and were also lower than the catches estimated by Roos et al. (2016) for 2013/2014, for only two municipalities in this state. These values were then excluded from the time series and total catches for the excluded years were estimated using the "smooth.spline" function from the "stats" package of R Statistical Software (v4.3.0; R Core Team 2023). The smoothing parameter was estimated in the model.

2.1.2. Pernambuco

For the state of Pernambuco, fishing landing control forms from the ESTATPESCA program were obtained for the period of 1997 to 2010. These data were previously used to calculate total catches published in National Statistic Bulletins, which were posteriorly used by Freire et al. (2021). Additionally, fishing landing control forms from Small-Scale Fisheries (SSFs) collected by IBAMA were obtained for the period of 1986 to 1996 and 2011, totalizing 26 years of detailed landing data. Approximately 135,000 individual control forms from IBAMA, for the period of 1986 to 2011. were collected physically and then scanned and tabulated prior to data analysis. We used the landing and effort data, to estimate yearly percentages referring to the catches of each fishing gear within total catches to split total parrotfish catches from Freire et al. (2021) into catches by fishing gear.

The monitoring effort done by IBAMA to obtain the landing data mentioned above was not evenly distributed over the years, so we performed simple standardizations in the data to obtain more consistent percentages, less influenced by the monitoring effort. First, for each gear, we summed all parrotfish landing data registered for the year and divided by the number of times the fishing was monitored at that specific year, obtaining a mean parrotfish landed weight registered per monitoring day. We then calculated the mean number of fishing trips per month, in a specific year, done by a boat in each type of fishing and multiplied by the mean catches obtained previously, to estimate how much parrotfish each boat captured per month and the estimates of all months from the same year were summed to obtain total catches per year per boat. Finally, the total number of boats per year for each fishing activity was estimated using a smooth of the total number of boats registered per year in the IBAMA control forms from 1986 to 2011, using the "smooth.spline" function with the smoothing parameter estimated in the model. The calculated number of boats for each fishing activity was multiplied by the parrotfish catches estimated above, to obtain the total parrotfish captured per year by each fishing gear.

To obtain total catches per gear for the years 1950 to 1985, which were not included in the landing data mentioned above, we first ran a smooth for the estimated yearly catches for each fishing activity from 1986 to 2011, using the smooth.spline function with a high smoothing parameter specified as 0.75 out of 1 to maintain the general tendency of the data. Negative catch values were replaced by zeros. From the smoothed curves, we calculated the percentage of the catches for each gear within the sum of those catches for the year. For the last four years of the series, 2012 to 2015, once these values were only represented by estimates, we decided to estimate total catches per fishing gear, assuming these catches were correlated with the general tendency of the corrected series. For the imputation, we used an uncertainty grid to forecast catch time series which uses four different methods of data imputation (Sant'Ana & Mourato 2022) and calculated a mean of the catches estimated.

When the sum of the estimated catches per fishing gear for each state was higher than the yearly total parrotfish catches presented in Freire et al. (2021), values from Freire et al. (2021) were substituted by the total catches estimated in the present study.

2.1.3. Bahia

For the state of Bahia, no additional detailed landing data was available and the state was not included in the ESTATPESCA report (MMA 2004). Historical information about parrotfish fishing gears was then based on the descriptions available in Previero (2014) and in Queiroz-Véras (Chapter 2 of this thesis*)*. Using fishers LEK information from Queiroz-Véras (Chapter 2 of this thesis), the percentage of each fishing gear within total parrotfish catches was calculated for each time period (Table S2). Only one parrotfish catch estimate was given before the 1970s by fishers, so for these years we followed Previero (2014) who identified net fishing as the only fishing type capturing parrotfish. The percentages were used to discriminate total catches from Freire et al. (2021) in catches per fishing gear.

The total catches from Freire et al. (2021) from 1976 to 1979 presented drops to near zero catches, so for these years, total catches were estimated using the "smooth.spline" function with the smoothing parameter estimated in the model.

2.2. Stock Assessments of *Scarus trispinosus* and *Sparisoma axillare*

Despite being the most extensive and detailed dataset compiled for parrotfish in Brazil to date, the resulting dataset still included limitations in terms of time-series coverage, and limited sample sizes., Data-Limited Stock-Synthesis were performed using the Stock-Synthesis Data Limited Tool (SS-DL tool) (Cope 2020). The SS-DL tool uses a unified modeling framework to run the Stock Synthesis (Methot and Wetzel 2013) and other data-limited methods, depending on the data availability (Cope 2020).

To run the analyses, we used the biological parameters for each species to define stock productivity (Tables S3 and S4). For the main gears used to capture these species, we assumed selectivity parameters to identify which part of the stock was being targeted, total parrotfish catches to estimate stock scale, catches per unit effort (CPUEs) as indexes of relative stock abundance and length data to estimate stock status (Supplemental Material 2).

After running the base models, likelihood profiles were performed for natural mortality (NatM), initial stock recruitment (SR_LN(R0)) and asymptotic length (L at Amax), to generate confidence intervals for these parameters and we also ran sensitivity analysis within models (Tables S6).

2.2.1. Stock definition, selection and scale

We assumed that only one stock is present along the Brazilian coast for *Sc. trispinosus* for two main reasons. First, because no significant genetic substructuring of individuals from Rio Grande do Norte, Pernambuco and Bahia was found (Bezerra et al. 2018). The second reason was that reproductive parameters (L50 and L100) estimated in Rio Grande do Norte (39.2 and 51.6 cm, respectively) (Roos et al. 2020a) were similar to the ones estimated in Bahia (ed in Bahia (38.5 and 51 cm, respectively) (Freitas et al. 2019), even with the large geographic distance between regions and the differences in lengths of sampled individuals (8 to 56 cm in RN and 13.5 to 86 cm in BA). More than 95% of total catches for this species came from gillnet and speargun fishing from Rio Grande do Norte and Bahia, so total catches for each state and fishing activity were included in the model as four different fleets: from 1950 to 2015 for the gillnet fleets from Rio Grande do Norte and Bahia and from 1970 to 2015 for the speargun fleets from Rio Grande do Norte and Bahia (Fig.1).

The population of *Sp. axillare* was also modeled as single stock based on lack of genetic differences found along the Brazilian coast in previous studies (Verba et al. 2022). The majority of the catches for these species were from the states of Rio Grande do Norte and Pernambuco. The catches were split into five fleets: from 1950 to 2015 for the gillnet fleet from Rio Grande do Norte, trap fleets from Rio Grande do Norte and Pernambuco and seine net fleet from Pernambuco, and from 1970 to 2015 for the speargun fleet from Rio Grande do Norte (Fig.1).Smoothed catches from Rio Grande do Norte were used as inputs in the models, running the smooths with a high smoothing parameter of 0.8 out of 1 to visually maintain the general tendency of the series. Priors for selectivity parameters and shapes were estimated from length data (Tables S3 and S4) or from the authors' expertise but were posteriorly estimated by some of the models (Figs S6 and S13). The selectivity shape from seine net in Pernambuco and gillnet and speargun in Rio Grande do Norte was defined as "dome-shaped" as large individuals are not found in the shallow waters where this gears are used.

2.2.2. Stock productivity

In the models, we assumed the biological parameters were known and based on values reported on Tables S3 and S4. Biological and natural mortality parameters were obtained from Gaspar (2004) and Véras (2008) for *Sp. axillare* and from Freitas et al. (2019) for *Sc. trispinosus.* Roos et al. (2020a) also estimated reproductive and growth parameters for *Sc. trispinosus*, but values from Freitas et al. (2019) were used due to the larger number and size range of sampled individuals. Natural mortality parameters were estimated from the package FishLife (Thorson et al. 2023) or from the Natural-mortality tool (Cope & Hamel 2022) (Tables S3 and S4).

2.2.3. Relative stock abundance

Catches per unit of effort (CPUEs) were searched for from different sources of data for each state, for the main fishing gears identified previously. No CPUE data was obtained for Rio Grande do Norte. For the state of Pernambuco, we calculated trap and seine net CPUEs based on the detailed landing database we had from ESTATPESCA and IBAMA from 1986 to 2011. This database included the date (date), the season (season), which was defined as dry (from September to February) and wet (from March to August) (APAC, 2023), the locality of the landing port (local), number of fishers in each the fishing trip (fisher), duration of the fishing trip (fishing day), the number of gears used by each fishing activity, i.e. 100 traps or 2 gillnets (gear), the size of the gears (size) and the weight of parrotfishes landed per fishing trip (catch). For trap fishing, fishing days were calculated differently, corresponding to the number of days the gears were submersed in the intervals between trips. Intervals higher than 7 days were excluded, as fishers do not leave traps underwater longer than a week (Queiroz-Véras, Chapter 2 of this thesis) and values possibly occurred because other trips within this period were not registered. For the landing data from IBAMA, from 1986 to 1996 and 2011, only positive values were present in the database, so we removed the zeroes from the remaining years and used only the positive catches (Barreto et al. 2015, Martin et al. 2005). CPUEs were calculated as catch (kg).fisher^{-1}.fishing day^{-1}.gear^{-1}.size (m)$^{-1}$ for seine nets and as catch (kg).fisher^{-1}.fishing day^{-1}.gear^{-1} for traps.

Nominal CPUE values from trap and seine net fishing in Pernambuco were standardized using year, season and location as explanatory variables. Various distributions and link functions were tested for the CPUE standardization and the Gamma distribution with identity link was chosen, based on low AIC values and better model fit. All covariates were used to run an initial model and a forward stepwise process was applied to select the most appropriate combination of the explanatory variables. Due to the high variation in CPUE values, we modeled the log (CPUE+1). The GLMs and stepwise processes were performed using the "glm" and "step" functions, respectively, from the "stats" package of R Statistical Software (v4.3.0; R Core Team 2023). The model chosen for trap was (log $CPUE_{trap}$ + 1) ~ year (factor) + season (factor).

For *Sp. axillare,* after CPUE values were standardized for each fishing fleet, we estimated gillnet and trap CPUEs for this species also using the species' percentages from total parrotfish catches obtained from fishers' LEK (Figs 1, S2 and S3 and Table S3). For *Sc. trispinosus* mean spearfishing CPUEs per year for the state of Bahia were obtained from previous local monitoring projects carried out in 2010 and 2011 (Freitas et al. 2019) (Figs.1 and S9). As mean yearly values were already provided, the standardization of these CPUES was not possible.

Length time-series data for both species was obtained from published documents compiled in Queiroz-Véras et al. (2023), from previous data collected by the authors, or from directly requesting data from researchers (Fig 1 and z, Table S5). The distribution of the data used to run each of the stock assessments is detailed in Figure 1.

2.1.1. *Stock evaluation*

For the stock assessment for each species, we obtained predicted yearly values of relative spawning biomass (B_{year} or B/B0) and fishing mortality (F), as well as the spawning biomass at the Maximum Sustainable Yield (B_{MSY}). We determined the minimum stock size threshold as the percentage of the spawning biomass of the stock at B_{MSY}. The yield curve was produced by the model including the Maximum Sustainable Yield

(Y_{MSY}), yield values at the "current" exploitation levels (last year of the series) (Y_{year}) and at the Biomass ($Y_{40\%}$) and Spawning Potential Ratio (Y_{SPR}) thresholds. Fishing mortality values were estimated for the last year of the series (F_{year}), at MSY (F_{MSY}), Biomass ($F_{40\%}$) and SPR (F_{SPR}). Differences in relative spawning biomass for the same species were also obtained from the likelihood profiles and sensitivity analyses.

We defined the management target of the relative spawning biomass at 0.4 (the spawning should be maintained above 40% of the initial unfished spawning biomass of the stock) which is a target commonly used for species from low to moderate resilience (Gabriel & Mace 1999). If B_{2015}/B_{MSY} was below 1, the stock was considered "overfished" or, if over 1, it was considered as "not overfished" (Costello et al. 2016), thus the minimum stock size threshold was defined as the B_{MSY} (the relative spawning biomass should be above the spawning biomass at MSY). Additionally, if F/F_{MSY} was over 1, the fisheries were considered to br "overfishing" the stock or, if below 1, the fisheries were classified as "not overfishing" (Costello et al. 2016).

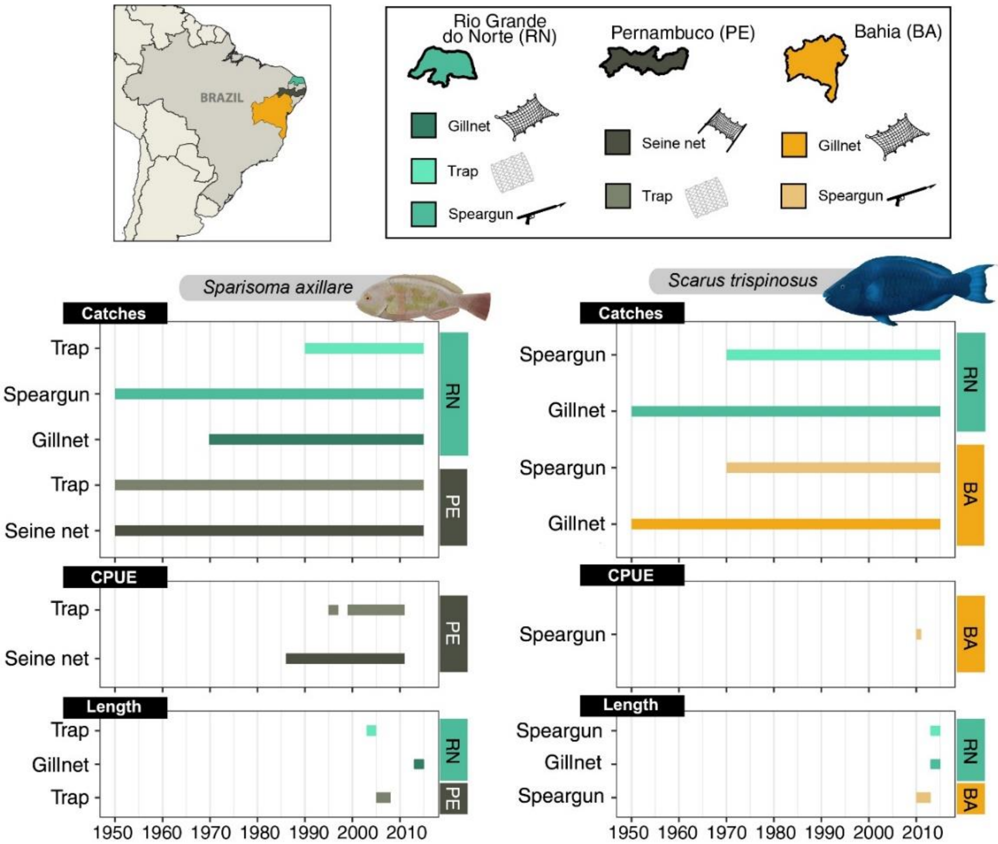


Figure 1. Distribution of the data used to run the Data-limited Stock Synthesis: catches, abundance indices and length compositions data of *Sparisoma axillare* and *Scarus trispinosus*.

3. Results

3.1. Reconstructed parrotfish catches

Parrotfishes were resources little exploited in Brazil until 1985, with less than 200 tons of all parrotfish species combined captured per year for the whole country (Fig. 2a). Total parrotfish catches slowly increased until 1985 but then drastically amplified in the following years, reaching almost 1300 tonnes of landed parrotfish in 1994 (Fig. 2a). Similar peaks were observed until 2008, when catches decreased. By 2015, catches reached half of the total captures of 2008 (Fig.2a). Similar patterns of increased parrotfish catches in the 1990s and decreases in the following decade was observed for all three states (Supplemental

Material 1). Seine net alone represented most parrotfish catches in the country until the 1990s, when gillnet, trap and speargun fishing expanded and became the prevalent gears. Speargun captured the highest amount in the last year of the series (Fig. 2b). Except for trap fishing in Pernambuco, catches decreased for the main fisheries in all three states, but seine net fishing decreased the fastest (in less than 10 years after this fishery expanded) (Fig. S1 b, e and h).

From 1950 until 2015, *Sc. trispinosus* and *Sp. axillare* were the most targeted parrotfish species in Brazilian waters, together representing about 80% of all parrotfish landed since the beginning of the series. *Sparisoma axillare* showed an exponential expansion in catches in the middle of the 1980s (from about 25 tonnes in 1985 to 775 tonnes in 1991), being the main species caught from 1988 until 1995 along the Brazilian coast. Catches of *Sc. trispinosus* increased gradually over time and the species has generally presented the highest catches per year, except for the period when *Sp. axillare* catches were higher. In the beginning of the 1990s *Sp. frondosum* landings increased and since 2000 the species has been caught in similar amounts as *Sp. axillare.* As observed for total parrotfish catches, the landings for these three species also showed decreases. The largest decreases were observed for *Sp. axillare* landings which dropped from about 800 tons in 1991 to 145 tons in 2015. Landings for the other two species in 2015 were about half what they were only five years earlier (Fig. 2c). Contrastingly, catches for *Sp. amplum*, continually increased over the years but total captures remained low, reaching about 30 tons of landed fish in 2015 (Fig. 2c). *Sc. zelindae* was the least captured species and catch oscillated over the years but were always below one ton of landed fish.

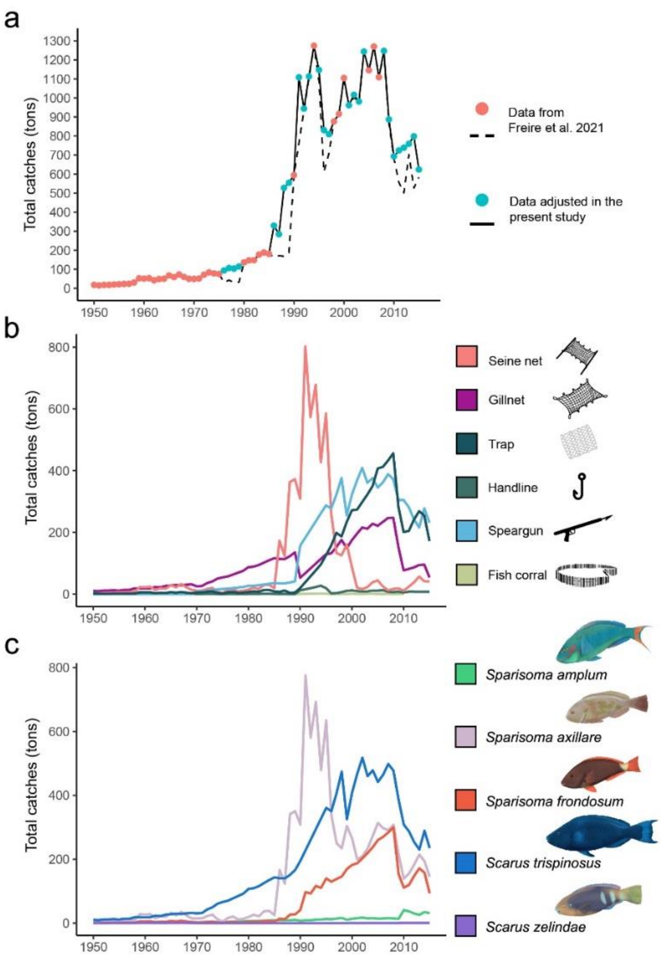


Figure 2. Reconstructed parrotfish catch from Brazil (from 1950 to 2015): (a) Total parrotfish catch, discriminating between data used from Freire et al. 2021 and the present study; (b) Parrotfish catch by fishing gear; (c) Parrotfish catch by species.

3.2. Data-limited Stock-Synthesis

3.2.1. *Sparisoma axillare*

Catches of *Sp. axillare* were below 50 tonnes until the late 1990s, when they rapidly increased to almost 800 tonnes in 1991 and then decreased until 2000, stabilizing until the end of the series with about 200 tonnes of landed parrotfishes per year (Fig. 3). Catches of *Sp. axillare* were mostly obtained by seine nets until 1996, then traps started to be the main fishing gear used along the Brazilian coast (Fig. 3).

The standardized abundance indices of seine net fishing from Pernambuco oscillated over time, but showed an increasing trend from 2000 to 2010, the last year in the time-series, similar to the patterns observed in the non-standardized CPUEs (Fig S2a). Standardized mean CPUEs from trap fishing presented a decreasing trend until 2004 and increased in the following three years, and then stabilized in the last years of the series (Fig. S3a). Trends in standardized abundance indices from trap fishing diverged from nominal indexes, which showed an increasing trend over time (Fig. S3a). In general, the length of sampled individuals did not change between the different fishing gears and *Sp. axillare* catches were mostly comprised of adults (larger than 20 cm) (Fig S4). An exception was observed in fishes caught by seine nets, which were primarily sexually immature individuals (smaller than 20 cm) (Fig. S6).

The predicted biomass of *Sp. axillare* declined slowly until 1987, when stocks remained above 80% of the unfished biomass. Then, the predicted biomass showed a sharp decrease that persisted until 2001, and the *S. axillare* population in this period was below the management target of 40% and the minimum stock size MSY threshold of 30% (Fig. 4a). The biomass then started to recover, reaching the 40% relative biomass of the stock in 2008 and continued increasing through 2013. In the most recent years of the series, the spawning biomass decreased slightly (Fig. 4a). The relative biomass of *Sp. axillare* in 2015 (B_{2015}) was estimated to about 55% of the initial unfished biomass, above the management target of 40% (Fig. 4a). Yields for fishing *Sp. axillare* in 2015 (Y_{2015}) were estimated in about 280 tonnes, while Y_{MSY} was estimated in about 365 tonnes (Fig 4b). Y_B and Y_{SPR} values were between Y_{2015} and Y_{MSY}, estimated in about 350 and 340 tons, respectively (Fig. 4b). B_{2015}/B_{MSY} was estimated at 1.83, so the stock was considered as “Not overfished” and F_{2015}/F_{MSY} was estimated at 0.4, indicating the fishery is “not overfishing” the stock (Table 2).

Likelihood profiles were conducted for initial recruitment (R0), natural mortality (NatM) and Asymptotic size (*L*inf) values. In general, changes in these parameters did not affect the situation of the stock, which were always above target thresholds, except for the lowest values of R0 (Fig. S7). The sensitivity analyses also did not show differences in the stock status with predicted spawning biomass always above the 40% management target in the last year of the series (Fig. S8)

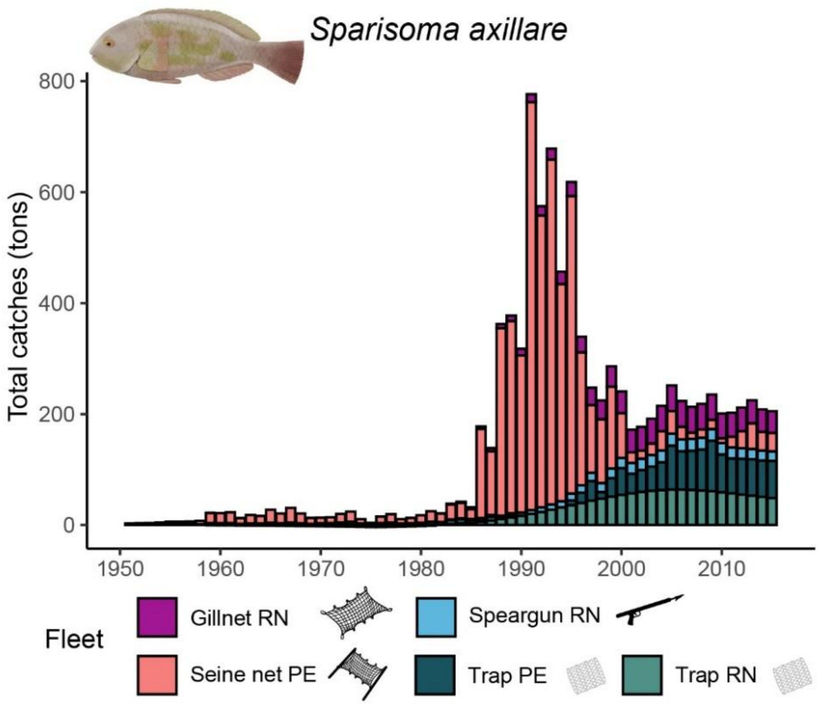


Figure 3. Total catches for *Sparisoma axillare* for each of the main five fishing fleets from Rio Grande do Norte (RN) and Pernambuco (PE) used in the Data-Limited Stock Synthesis.

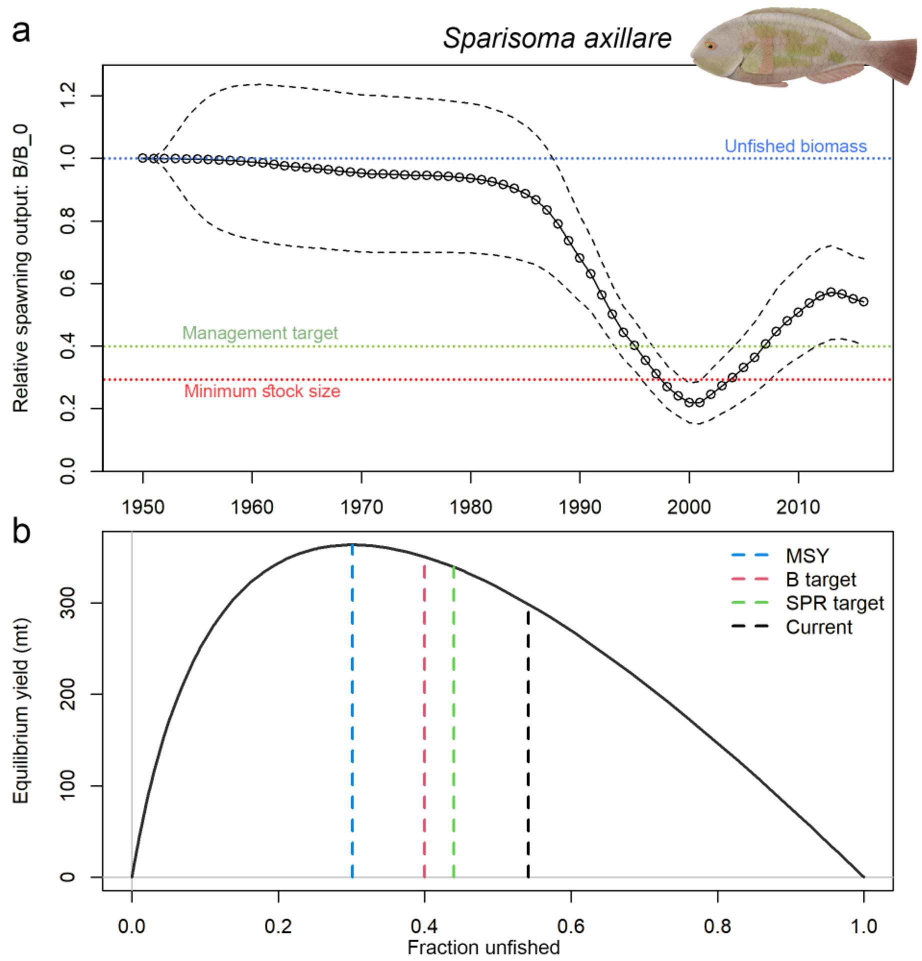


Figure 4. SSDL-tool plots of *Sparisoma axillare*: (a) Relative spawning biomass: B/B0 with ~95% asymptotic intervals; (b) Yield curve with reference points: Maximum Sustainable Yield (MSY), Biomass target yield (B target) and current fraction of unfished biomass yield (Current).

Table 2. Fishing mortality values of *Sp. axillare* obtained at the management target of 40% ($F_{40\%}$), at the Maximum Sustainable Yield (F_{MSY}) and in the last year of the series (F_{2015}); Relative biomass values obtained for the Maximum Sustainable Yield (F_{MSY}) and in the last year of the series (F_{2015}) and the ratios of the relative spawning biomass and fishing mortality in the last year of the series and in the Maximum Sustainable Yield, B_{2015}/B_{MSY} and F_{2015}/F_{MSY}, respectively.

		Value
Sp. axillare	$F_{40\%}$	0.12
	F_{MSY}	0.15
	F_{2015}	0.06
	B_{MSY}	0.30
	B_{2015}	0.55
	Ratios	Status
B_{2015}/B_{MSY}	1.83	Not overfished
F_{2015}/F_{MSY}	0.4	Not overfishing

3.2.2. *Scarus trispinosus*

Scarus trispinosus was initially mainly caught by gillnets, from the beginning of the series until 1990, followed by spearguns, which expanded after the 1990s and became the main fishing gear (Fig. 5). In general, catches gradually increased over the years, reaching higher landing volumes in the 1990s. A peak of more than 500 tonnes of *Sc. trispinosus* was observed in the early 2000s, when catches started to decrease, and were reduced to about 300 tonnes in the last year of the series (Fig. 5). In general, the mean length of sampled individuals were higher for speargun fishing in Bahia (~55 cm) followed by speargun fishing in Rio Grande do Norte (45 cm). The smallest mean length of *Sc. trispinosus* was registered for those caught by gillnets in Rio Grande do Norte (~25 cm) (Fig. S10a).

The predicted biomass of *Sc. trispinosus* declined steadily from the beginning of the series until 2008, and then showing a steep decline in the 1990s (Fig. 6a). Relative spawning stock biomass was at 18% of unfished levels, even below the minimum stock size threshold and then presented a small recovery in the following years of the series (Fig. 6a). The predicted relative spawning stock biomass of *Sc. trispinosus* in 2015 was 26%, much lower than the management target of 40% and below the minimum stock size threshold of 32% (Fig. 6a). Values presented increased uncertainties in the last years of the series, with the 95 percent asymptotic confidence interval ranging from almost 60 to 0 % (Figs 6a). Yields for *Sc. trispinosus* in the last year of the series were estimated at about 320 tonnes, similar to the yield obtained if the stock would be exploited at the MSY level, at 32% (Fig 6b). Yield values obtained from management and SPR targets were slightly lower than the current yield, with 312 and 304 tonnes, respectively (Fig. 6b). B_{2015}/B_{MSY} was calculated for 0.81, so the stock was considered overfished and F_{2015}/F_{MSY} was calculated at 1.36, indicating that the fisheries are also overfishing the stock.

The likelihood profiles were conducted for initial recruitment (R0), natural mortality (NatM) and Asymptotic size (*L*inf) and changes in these parameters did not considerably affect the final status of the stock, which was generally maintained below the management target and the minimum stock size threshold (Fig. S13). The sensitivity analysis with the base model and two additional models, the first with biased recruitment corrected by the model and the second with selectivity shapes estimated by the model, showed worse situations of the stock in the alternative models, which presented relative spawning biomass values lower than 0.21 (Fig. S14).

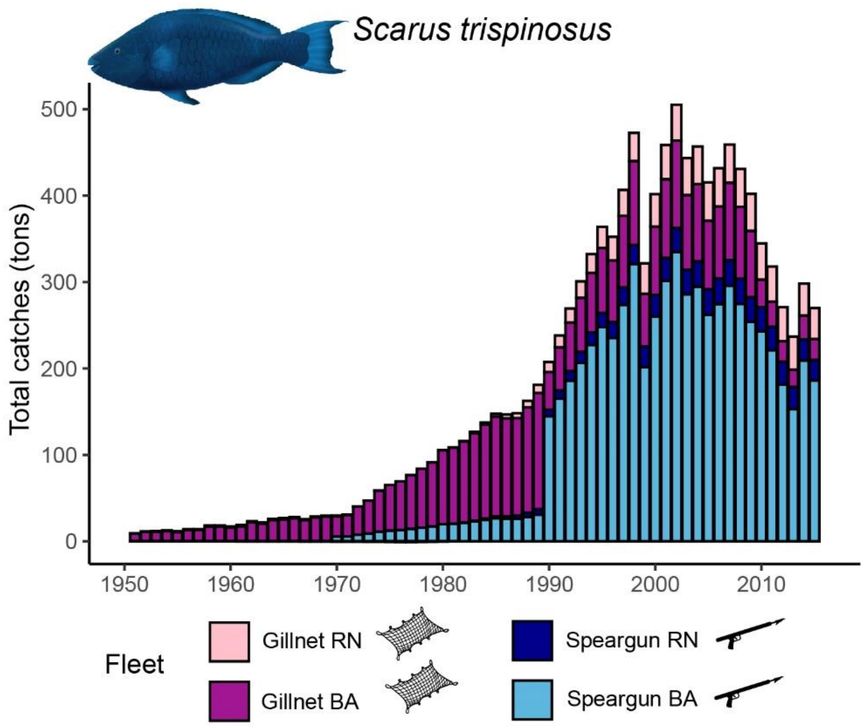


Figure 5. Total *Scarus trispinosus* catches for each of the four fleets in Rio Grande do Norte (RN) and Bahia (BA), used in the Data-limited Stock Synthesis.

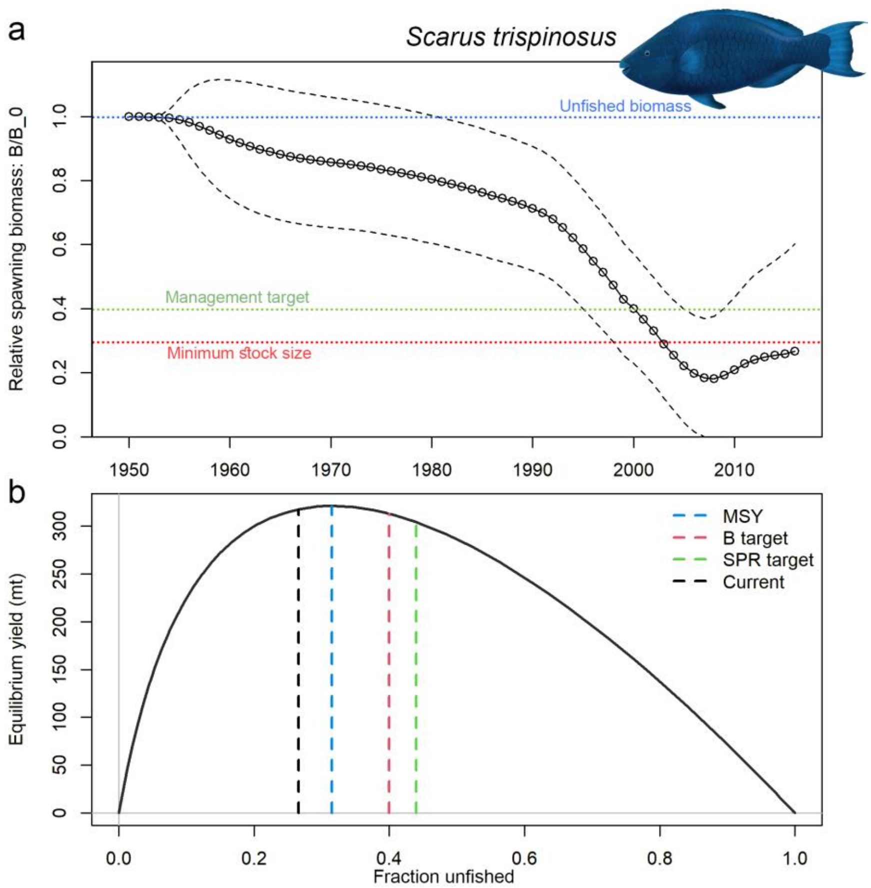


Figure 6. SSDL-tool plots of *Scarus trispinosus*: (a) Relative spawning biomass: B/B0 with ~95% asymptotic intervals; (b) Yield curves with reference points: Maximum Sustainable Yield (MSY), Biomass target yield (B target), Spawning potential ratio target yield (SPR target) and current fraction of unfished biomass yield (Current).

Table 3. Fishing mortality values of *Scarus trispinosus* obtained at the management target of 40% ($F_{40\%}$), at the Maximum Sustainable Yield (F_{MSY}) and in the last year of the series (F_{2015}); Relative biomass values obtained for the Maximum Sustainable Yield (B_{MSY}) and in the last year of the series (B_{2015}) and the ratios of the relative spawning biomass and fishing mortality in the last year of the series and in the Maximum Sustainable Yield, B_{2015}/B_{MSY} and F_{2015}/F_{MSY}, respectively.

		Value
Sc. trispinosus	$F_{40\%}$	0.08
	F_{MSY}	0.11
	F_{2015}	0.15
	B_{MSY}	0.32
	B_{2015}	0.26
	Ratios	Status
B_{2015}/B_{MSY}	**0.81**	**Overfished**
F_{2015}/F_{MSY}	**1.36**	**Overfishing**

4. Discussion

The reconstructed catches obtained in the present study represent the first historical catch series that discriminates between the five targeted parrotfish species and by the main fleets that use them as resources in Brazil. These series are complementary to the data previously published by Freire et al. (2021), ranging from 1950 to 2015. *Scarus trispinosus, Sparisoma axillare* and *Sparisoma frondosum* were identified as the most caught species since the 1990s, and the first two species represent about 80% of total Brazilian parrotfish catches. These three species presented showed decreases in total catches: *Sparisoma axillare* captures decreased earlier in time, at the beginning of the 1990s, and the catches of the other two species diminished at the end of the 2000s. Contrastingly, the catches for the other two target species remained low during the timeframe analyzed; *Sparisoma amplum* catches slightly and constantly increased, while landings of *Sc. zelindae* oscillated over time. The stock evaluation of the two most captured species indicated the stock status of *Sparisoma axillare* as “not overfished” and above the management target of 40%. The fisheries were deemed to be “not overfishing” the stock, which means if fishing continued at this rate, the stock would not become overfished in the long term. For *Scarus trispinosus* the stock was considered “overfished” with the relative spawning biomass predicted at only 26% of the initial unfished biomass, much below the management target of 40% and below the minimum stock size of 32%. Additionally, the fishing was considered as “overfishing” the stock, i.e., fishing would aggravate the stock situation if current fishing rates are maintained.

The drops in the relative spawning biomass of *Sc. trispinosus* after 1987 possibly occurred due to the large catches registered for the seine net fishing in Pernambuco. This fishing activity presented drastic changes in catches in a short time span of 15 years, with the highest catches for all fishing gears (>700 tonnes) and then dropping to less than 50 tonnes, suggesting there was a local biomass depletion that persisted until the end of the series. Seine net fishing in Pernambuco occurred in very shallow waters near the coast, focusing almost exclusively on juveniles of *Sp. axillare:* fishers indicated a sharp abundance drop in the 2000s, which forced them to change fishing efforts to other areas (Chapter 2 of this thesis). When the data used as model inputs were limited to specific sites where *Sp. axillare* catches were higher, these catches possibly lowered the stock biomass estimated by the model, even though they were not representative of the whole stock. The main chances are that the drop below minimum limit reference point between 1998 snd 2003 did not in fact occur, and the relative spawning biomass has been decreasing gradually until reaching 55% in 2015.

The relative spawning biomass of *Sp. axillare* in the last year of the series was above the management thresholds and the fishing activities were "not overfishing" the stock, which means the fishing activities targeting this species could possibly still be expanded, especially in Rio Grande do Norte and Pernambuco where this species is mostly targeted and reach larger yields at the MSY levels without compromising the self-renewable capacity of the stock. These values, however, should be taken with caution for two main reasons: (1) once parrotfishes are protogynous hermaphrodites, these species are more susceptible to negative fishing-effects and quotas alone may not be enough to maintain the population in sustainable levels (Hawkings & Roberts 2003); (2) because trap fishing activities, which was the main fishing activity catching *Sp. axillare* in 2015, may not be sustainable as they are being currently performed. Trap fishing in Pernambuco and in Rio Grande do Norte was identified to be intensely exploiting shallower fishing areas closer to the ports (mean depth of about 20 m in the 1970s) and, as they become depleted, are moving to further deeper grounds (mean depth of about 35 m in the 2020s) (Chapter 2 of this thesis). Fishers constantly expanded their fishing grounds following the increase in the interest of this species for exportats, and areas have increased from 70 to more than 3000 km^2 in Pernambuco and more than three-fold in Rio Grande do Norte, from 670 to 2183 km^2 (Chapter 2 of this thesis). The continuous exploitation of new unfished areas until their depletion may mask the actual situation of the fishing stock of *Sp. axillare.* These changes could also explain the increases in the relative abundance indexes obtained for trap fishing in Pernambuco from 2002 to 2009 observed in the present study. Even though this species is considered one of the most habitat generalist reef fishes in Brazil and is usually abundant along the tropical Brazilian coast (Hoey et al. 2018, Araújo et al. 2020, Feitosa et al. *in press*), its deepest record is only 55 m (Feitoza et al. 2005). If fishing activities gradually deplete fishing grounds as new ones are exploited, the biomass of the stock may drop sharply or even collapse following the exhaustion of new areas to exploit.

The stock of *Sc. trispinosus* was considered overfished in 2015 according to our data-limited assessment, with relative spawning biomasses of 26%, which is below the minimum stock size threshold of 32%. Previous studies have been calling attention to the possible overfished situation of the stock of this species, due to observations of decreasing sizes and abundances in many parts of Brazil (Ferreira et al. 2012, Bender et al. 2014, Previero 2014, Freitas et al. 2019, Roos et al. 2020a, Pereira et al. 2021). The classification of this species as "Endangered" was based on visual censuses that recorded a reduction of more than 50% abundance in the last 30 years (Ferreira et al. 2012). The results presented here corroborates with these studies and indicate the fishing activities focused on this species are not sustainable as they are currently performed. The slight increase in the relative biomass of *Sc. trispinosus* in the last years of the series may be an indicative of an initial recovery of the stock, but more recent data are necessary to evaluate if the increasing trend continued or not.

Scarus trispinosus fishing is focused on coral reefs such as the Parrachos reefs in Rio Grande do Norte and the Abrolhos reefs in Bahia, which are located, at least partially, inside Marine Protected Areas (Freitas et al. 2019, Roos et al. 2020b, Chapter 2 of this thesis). Despite the management control rules inherent to MPAs, only the no-take reserves, where fishing is prohibited, show increased abundances of *Sc. trispinosus* (Rocha and Rosa 2001, Francini-Filho and Moura 2008a, b; Roos et al. 2020b), while those intended for sustainable use, where fishing was allowed, have low abundances, similar to those of non-protected areas (Francini-Filho and Moura 2008a, b; Bender et al. 2014). Recent work indicated that the biomasses of *Sc. trispinosus* are decreasing with time within no-take reserves, which could be because the fishing in neighboring areas is impacting their nursery grounds (Roos et al. 2020b) but could also be related to inefficient enforcement inside the no-take areas. Management actions taken so far seem to be ineffective to guarantee the recovery of *Sc. trispinosus* populations, even inside fully protected areas.

Concerning parrotfish importance to reef ecosystems, using them as fishing targets is worrisome. Parrotfishes are some of the few roving herbivore species in Brazilian reefs (Hoey et al. 2018, Araújo et al. 2020), being responsible for unique roles in reef functioning. *Scarus trispinosus* is the largest functional herbivore in Brazilian waters and in conjunction with larger individuals of *Sp. amplum*, are the only two species in Brazil to act as excavators (Pinheiro et al. 2018, Lellys et al. 2019). Bioeroding the substrate, they participate in sediment creation and transport and expose the reef matrix to the colonization of new reef-building organisms (Bonaldo et al. 2014, Lellys et al. 2019, Siqueira et al. 2019, Feitosa et al. *in press*). The smaller individuals of all targeted parrotfish species are functionally classified as scrapers, constantly clearing spaces on the reef surface due to their habits of continuously feeding on benthic organisms (Francini-Filho et al. 2010, Longo et al. 2014), as well as controlling the growth of filamentous algae (Feitosa et al. 2023). This functional role influences the composition, distribution and succession of the benthic community, as well as the production and transport of sediments (Francini-Filho et al. 2010; Graham et al., 2013, Longo et al. 2014, Feitosa et al. 2023). Even small parrotfishes have been identified as contributors in diminishing the impacts of increasing temperatures on the algal cover, once in their absence filamentous algae increased at higher temperatures but was controlled in their presence (Feitosa et al. 2023).

The ecosystem impacts of reducing the populations of these species were not evaluated in our assessment. However, ecosystem-based approaches evaluated the impacts of harvesting parrotfish in Caribbean reefs and found that initial coral covers would just be maintained if only a maximum of 10% of the initial parrotfish stocks' biomass was harvested annually (Bozec et al. 2016). Brazilian reefs are possibly more impacted than Caribbean reefs when considering coral cover, being mostly dominated by algae (Aued et al. 2018). Additionally, the abundance of parrotfishes in Caribbean reefs is higher than in Brazilian waters (Bozec et al. 2016, Hoey et al. 2018), so it is possible that if similar ecosystem-based assessments were developed for Brazilian parrotfishes chances are that current exploration rates would indicate ecosystem overfishing.

According to the threatened status of both species, especially for *Sc. trispisosus* that is currently classified as endangered, in addition to the management actions published for these threatened species and the stock status of at least one of them classified as overfished in the present study, it is urgent to direct efforts to monitor and recover Brazilian parrotfish populations. In other regions of the world, fishing bans have been able to recover populations of parrotfishes (Harms-Tuohy 2021, Taylor et al. 2022), but regulatory actions were generally better enforced than they are in Brazil. With such large coast and few human and financial resources available, trying to control artisanal fishing activities in Brazil is an extremely difficult task. Controlling the commerce of parrotfish demands fewer human and financial resources, so this could be a more effective alternative to control fishing activities. The prohibition of *Sc. trispinosus* sales and the correct size ranges for sale of the other species could be monitored directly in fishing companies and fish markets and the cascade effect could be responsible for controlling the catch without controlling the fisheries per se.

For future stock assessments, we recommend obtaining additional and more recent catch, CPUEs and length data for all five targeted species, but especially for *Sc. zelindae*, *Sp. amplum* and *Sp. frondosum*, whose assessments were not presented here. The reconstructed catches for these species were generally very low and population trends were hard to evaluate. Additional data would probably enable a proper assessment of these species and a more recent evaluation of *Sc. trispinosus* and *Sp. axillare*. In the data-limited fitted models used in the present study, the highest uncertainties were associated with parrotfish catches performed by the fleets from Rio Grande do Norte, which increased linearly in reconstructed catches and showed some arbitrary changes in patterns. We included conservative catch values for this state in the assessment models for both species, using the smooth of the catches, but these catches may be higher than what was used in the models. It is very important to further investigate parrotfish landings and CPUEs along the coast, especially in the three states where they are mostly captured (Rio Grande do Norte, Pernambuco and Bahia), to better understand past and future catch values and stock trajectories to improve the models. Furthermore, this work focused on investigating parrotfish fishing by the artisanal fishing fleet, but a considerable amount of parrotfish is also caught by sport fishing. Future work focusing on these fisheries is needed to understand the additional impact of this exploitation on stocks.

The return of the Brazilian Fishing Statistics Program is urgent (Santos et al. 2023). No information on catches is available after 2015 in Brazil, but since 2008 they are represented by estimates, which means we do not have fisheries monitoring data for almost 15 years and the stock status obtained in the present study are almost 10 years old already. After several years of dismantling the Brazilian environmental protection agencies and science denialism (Abessa et al. 2019, Araújo 2020), a new environment and science-supportive government head has taken place at the beginning of 2023 (Tollefson 2022, Bustamante et al. 2023). Expectations are that scientifically-based fishing monitoring programs will be resumed. Meanwhile, recent initiatives have been taken by the scientific community: the ‘Projeto Budiões’, an initiative for parrotfish conservation, started a fishing monitoring Program in 2020 in Bahia and is now expanding to Rio Grande do Norte and Pernambuco. This monitoring program represent the only recent data collection directed to parrotfish fishing in Brazil, and may be applied in the future to update the stock assessments performed here. Closed-loop simulation models may also be generated using the present stock assessment models done here to evaluate the management strategies (MSE) currently implemented for the Brazilian parrotfish (Huynh et al. 2022).

The endemic Brazilian parrotfishes are important for reef ecosystems, as well as for artisanal fishing communities along the coast (Queiroz-Veras et al. 2023, Feitosa et al 2023). The management measures published so far have not been effective in maintaining their environmental, social and financial functions. New approaches for the management of these species must be developed focusing on the historical, geographic, political and financial challenges encountered in Brazil.

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6. Supplemental Material 1 – Reconstructed catches by state

Table S1. Percentage of catches per fishing gear within total parrotfish catches for four different time periods (<1970, 1970s-1980s, 1990s-2000s and 2010s-2020s), obtained through fishers´ LEK for the state of Bahia.

State	time period	gear	sp	% of total catches
RN	< 1970	net	tri	100.0
RN	1970s-1980s	net	axi	36.6
RN	1970s-1980s	net	fro	2.2
RN	1970s-1980s	net	tri	61.1
RN	1970s-1980s	speargun	axi	36.3
RN	1970s-1980s	speargun	fro	0.7
RN	1970s-1980s	speargun	tri	63.0
RN	1990s-2000s	net	axi	44.7
RN	1990s-2000s	net	fro	12.1
RN	1990s-2000s	net	tri	43.2
RN	1990s-2000s	speargun	axi	42.1
RN	1990s-2000s	speargun	tri	57.9
RN	1990s-2000s	trap	axi	28.4
RN	1990s-2000s	trap	fro	71.6
RN	2010s-2020s	net	axi	49.0
RN	2010s-2020s	net	fro	7.2
RN	2010s-2020s	net	tri	43.8
RN	2010s-2020s	speargun	axi	41.8
RN	2010s-2020s	speargun	fro	0.2
RN	2010s-2020s	speargun	tri	58.0
RN	2010s-2020s	trap	axi	26.6
RN	2010s-2020s	trap	fro	73.4
PE	< 1970	net	axi	80.8
PE	< 1970	net	fro	19.2
PE	< 1970	trap	axi	66.7
PE	< 1970	trap	fro	16.7
PE	< 1970	trap	zel	16.7
PE	1970s-1980s	net	axi	93.1
PE	1970s-1980s	net	fro	6.9
PE	1970s-1980s	speargun	amp	1.3
PE	1970s-1980s	speargun	axi	43.5
PE	1970s-1980s	speargun	fro	2.2
PE	1970s-1980s	speargun	tri	52.2
PE	1970s-1980s	speargun	zel	0.9
PE	1970s-1980s	trap	amp	0.3
PE	1970s-1980s	trap	axi	61.9
PE	1970s-1980s	trap	fro	33.2
PE	1970s-1980s	trap	tri	3.9
PE	1990s-2000s	net	axi	91.7
PE	1990s-2000s	net	fro	8.3
PE	1990s-2000s	speargun	axi	80.0
PE	1990s-2000s	speargun	fro	10.0
PE	1990s-2000s	speargun	tri	10.0
PE	1990s-2000s	trap	amp	0.7
PE	1990s-2000s	trap	axi	76.9
PE	1990s-2000s	trap	fro	21.0
PE	1990s-2000s	trap	tri	1.0
PE	1990s-2000s	trap	zel	0.3
PE	2010s-2020s	net	axi	81.7
PE	2010s-2020s	net	fro	18.3
PE	2010s-2020s	speargun	amp	1.7
PE	2010s-2020s	speargun	axi	55.9
PE	2010s-2020s	speargun	fro	35.6
PE	2010s-2020s	speargun	tri	5.1
PE	2010s-2020s	speargun	zel	1.7
PE	2010s-2020s	trap	amp	0.3
PE	2010s-2020s	trap	axi	62.2
PE	2010s-2020s	trap	fro	34.1
PE	2010s-2020s	trap	tri	2.9
PE	2010s-2020s	trap	zel	0.5
BA	1970s-1980s	net	tri	100.0
BA	1970s-1980s	speargun	amp	24.6
BA	1970s-1980s	speargun	tri	75.4
BA	1990s-2000s	net	tri	100.0
BA	1990s-2000s	speargun	amp	4.8
BA	1990s-2000s	speargun	tri	95.2
BA	2010s-2020s	net	tri	100.0
BA	2010s-2020s	speargun	amp	14.2
BA	2010s-2020s	speargun	tri	85.8

Table S2. Percentage of catches per fishing gear within total parrotfish catches for four different time periods (<1970, 1970s-1980s, 1990s-2000s and 2010s-2020s), obtained through fishers´ LEK for the state of Rio Grande do Norte and Bahia.

state	time period	gear	% of total parrotfish catches	Source
RN	< 1970	net	100.0	Queiroz-Véras et al. *in prep.*
RN	1970s-1980s	net	73.6	Queiroz-Véras et al. *in prep.*
RN	1970s-1980s	speargun	26.4	Queiroz-Véras et al. *in prep.*
RN	1990s-2000s	net	75.3	Queiroz-Véras et al. *in prep.*
RN	1990s-2000s	speargun	4.8	Queiroz-Véras et al. *in prep.*
RN	1990s-2000s	trap	20.0	Queiroz-Véras et al. *in prep.*
RN	2010s-2020s	net	67.4	Queiroz-Véras et al. *in prep.*
RN	2010s-2020s	speargun	23.0	Queiroz-Véras et al. *in prep.*
RN	2010s-2020s	trap	9.6	Queiroz-Véras et al. *in prep*
RN	2004	trap	59.9	Estimated from Ribeiro (2004) and MMA (2004)
BA	1970s-1980s	net	76.6	Queiroz-Véras et al. *in prep*
BA	1970s-1980s	speargun	23.4	Queiroz-Véras et al. *in prep.*
BA	1990s-2000s	net	22.4	Queiroz-Véras et al. *in prep.*
BA	1990s-2000s	speargun	77.6	Queiroz-Véras et al. *in prep.*
BA	2010s-2020s	net	10.2	Queiroz-Véras et al. *in prep.*
BA	2010s-2020s	speargun	89.8	Queiroz-Véras et al. *in prep*

- **Results of reconstructed catches for each state**

For Rio Grande do Norte state, parrotfish catches were at or near zero until 1989 and then exponentially and sharply increased until they reached 605 tons of landed parrotfish in 2008, when catches drastically dropped. Values oscillated in the following years and reached about 100 tons of parrotfish caught in 2015 (Fig. S3a). Even though general catch trends could be observed for this state, most values from this series follow a perfect linear trend and changes in catches are drastic in some occasions, which are indicatives the series may not be accurate. Most parrotfish catches in Rio Grande do Norte came from trap fishing, followed by gillnet and speargun fishing (Fig. S3b). The decreases in total catches observed after 2008 for trap fishing were in accordance with information provided by fisherman in Queiroz-Véras et al. (*n prep*), however, decreases were much more drastic than what was reported by fishers. The severe decreases in trap fishing after 2008 also diverged from information provided in Roos et al. (2016), who suggested an increase in the exportation of parrotfish captured by trap fishing, indicating that catches after 2008 are possibly underestimated. Rio Grande do Norte was the only state to capture *Sparisoma frondosum* the most, followed by *Sp. axillare* and *Sc. trispinosus,* with all three species presenting large decreases in catches after 2008 as well (Fig. S1c).

In Pernambuco, parrotfish catches were below 50 tons until 1987, when they sharply increased to more than 800 tons in 1991 and then decreased after 1993 (Fig. S3d). Total catches varied between 150 to 400 tons in the next 10 years and seemed to stabilize around 250 tons since 2008 (Fig. 2d). Six fishing gears were identified to capture parrotfish, but trap and seine net fishing were responsible for most parrotfish catches in the state (Fig. 2d). Parrotfish catches were done predominantly by seine nets since 1950, but sharply decreased in the 2000s, when trap fishing started to expand. Since 2004 trap fishing was responsible for most parrotfish catches in the state of Pernambuco (Fig. 2e). *Sparisoma axillare* and *Sparisoma frondosum* comprise almost the totality of parrotfish catches in PE, with *Sp. axillare* as the most caught species (Fig. 2f).

In Bahia, catches gradually increased along the time, reaching its peak in 2002, with about 450 tons of parrotfish captured and then decreased until the last year of the series, with 240 tons of landed parrotfish (Fig. 2g). Net and spearfishing were used to capture parrotfish in Bahia, the first predominating until the end of the 1980s, when spearfishing became the gear with most catches (Fig. 2h). *Scarus trispinosus* and *Sparisoma amplum* are targeted in the region, but the first species composes about 97% of total catches (Fig. 2i). Following the trend in total parrotfish catches, *Sc. trispinosus* landings decreased since the early 2000s, while a steady increase in *Sp. amplum* catches along the time has been observed (Fig. 2).

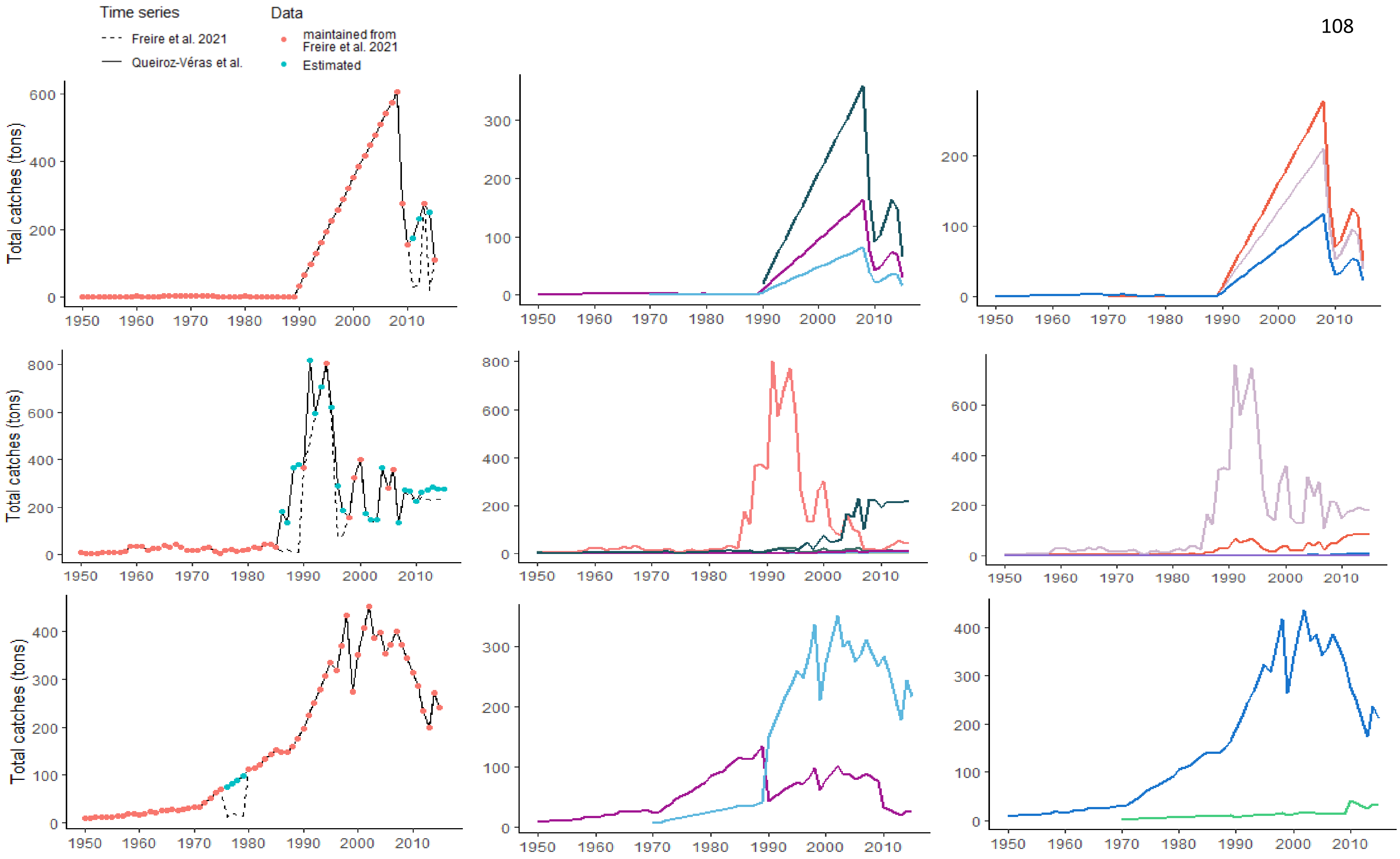


Figure S1. (a) Published and estimated total parrotfish catches for the state of Rio Grande do Norte; (b) Reconstructed parrotfish catches by fishing gear for the state of Rio Grande do Norte; (c) Reconstructed catches by each parrotfish species for the state of Pernambuco; (d) Published and estimated total parrotfish catches for the state of Pernambuco; (e) Reconstructed parrotfish catches by fishing gear for the state of Pernambuco; (f) Total catches for each parrotfish species for the state of Pernambuco; (g) Published and estimated total parrotfish catches for the state of Bahia; (h) Reconstructed parrotfish catches by fishing gear for the state of Bahia; (i) Reconstructed catches by each parrotfish species for the state of Bahia.

7. Supplemental Material 2. Databases used to run the Data-limited Stock Synthesis models

7.1. Life history inputs

Table S3. Priors of biological and assumed selectivity parameters for *Sparisoma axillare* used in the Data-limited Stock Synthesis (SSDL-tool): initial recruitment (R0), natural mortality (NatM), Asymptotic length (Linf), growth constant (k), time of length zero (t0), size at first maturity for 50% of the population (L50%), size at first maturity for 95% of the population (L95%), Length-weight relationship a constant (W-L a), Length-weight relationship b constant (W-L b); and sources of the data.

Parameter	Value	Source/reasoning
Log(R0)	10	Chosen due to better model convergence in SSDL-tool
NatM	0.45	Natural Mortality Tool (Cope & Hemel 2022)
Linf	32.3	Gaspar 2006
k	0.222	Gaspar 2006
t0	-0.477	Gaspar 2006
L50%	20.2	Véras 2008
L95%	26.1	Véras 2008
W-L a	0.0000649	estimated based on lenghts from Véras 2008
W-L b	2.5676	estimated based on lenghts from Véras 2008
Fec a	0.0000573	estimated based on lenghts from Véras 2008
Feb b	2.60772	estimated based on lenghts from Véras 2008

Fleets	Type	Sel50%	Sel95%	Decline length	Decline width	Max size sel.
Gillnet RN	Logistic	23	28	-	-	-
Seine net PE	Dome-shaped	4	8	10	12	0.01
Speargun RN	Logistic	23	28	-	-	-
Trap PE	Logistic	18	24	-	-	-
Trap RN	Logistic	18	24	-	-	-

Table S4. Inputs of biological and assumed selectivity parameters for *Scarus trispinosus* used in the Data-limited Stock Synthesis (SSDL-tool): initial recruitment (R0), natural mortality (NatM), Asymptotic length (Linf), growth constant (k), time of length zero (t0), size at first maturity for 50% of the population (L50%), size at first maturity for 95% of the population (L95%), Length-weight relationship a constant (W-L a), Length-weight relationship b constant (W-L b); and sources of the data.

Parameter	Value	Source/reasoning
Log(R0)	9	SSDL-tool standard value
NatM	0.26	Freitas et al. 2019
Linf	85.28	Freitas et al. 2019
k	0.14	Freitas et al. 2019
t0	0.16	Freitas et al. 2019
L50%	38.85	Freitas et al. 2019
L95%	51.3	Freitas et al. 2019
W-L a	0.00001	SSDL-tool standard value
W-L b	3	SSDL-tool standard value
Fec a	0.00001	SSDL-tool standard value
Feb b	3	SSDL-tool standard value

Fleets	Type	Sel50%	Sel95%	Decline length	Decline width	Max size sel.
Gillnet RN	Dome-shaped	20	25	30	40	0.01
Speargun RN	Dome-shaped	20	35	40	40	0.01
Gillnet BA	Logistic	30	40	-	-	-
Speargun BA	Logistic	40	50	-	-	-

7.2. CPUE standardization

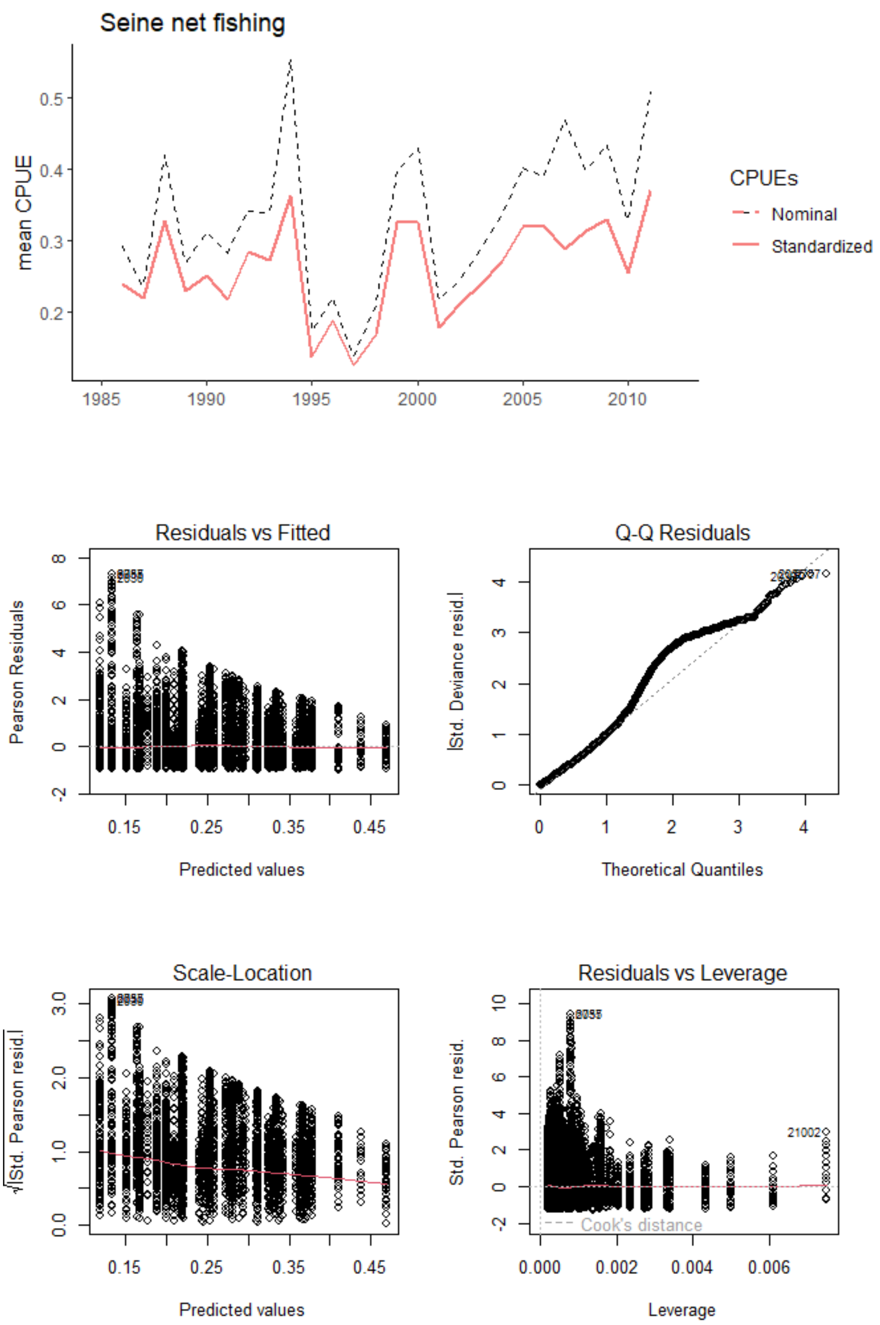


Figure S2. (a) Nominal and stardardized mean CPUEs per year for seine net fishing, calculated as catch (kg) x fisher x fishing day^{-1} x gear^{-1} x size^{-1}; (b) Residual plots from CPUE standardization.

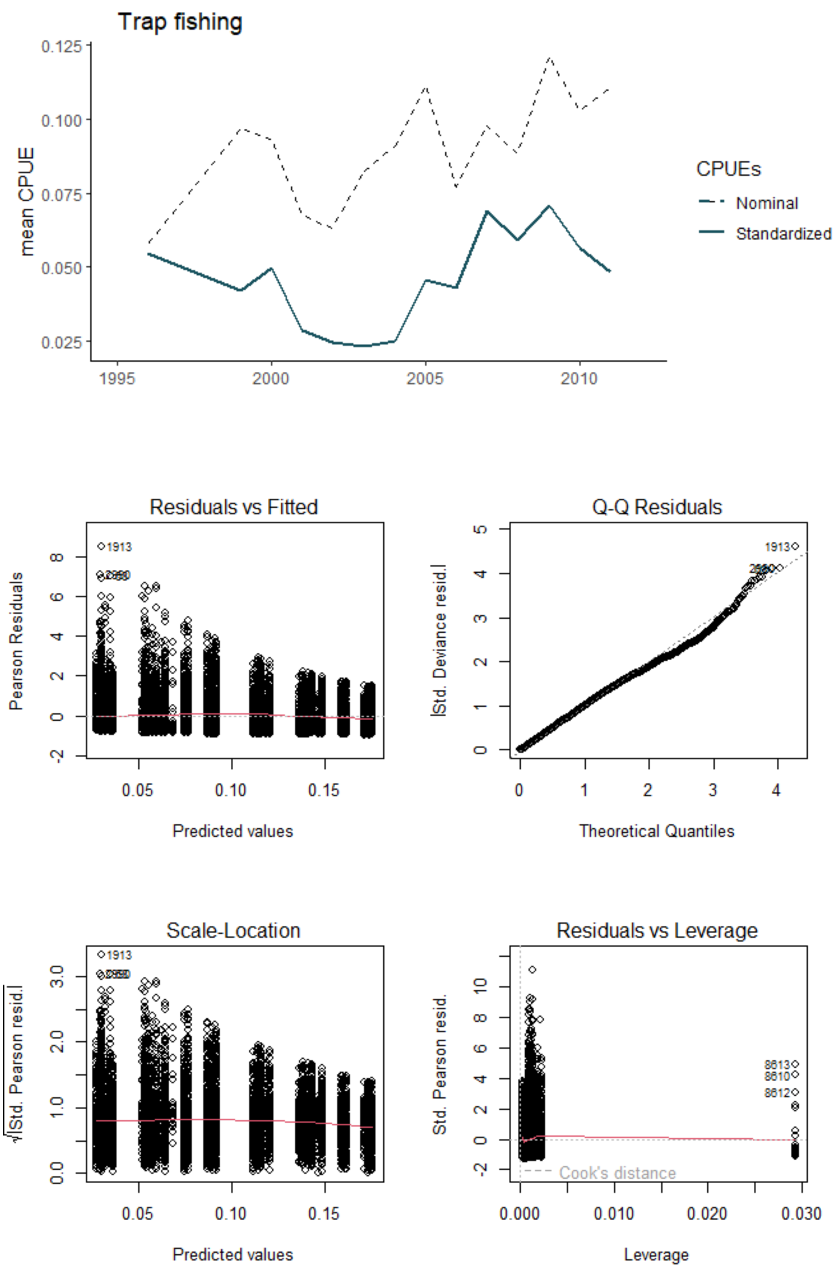


Figure S3. (a) Nominal and stardardized mean CPUEs per year for trap fishing, calculated as catch (kg) x fisher x fishing day^{-1} x gear^{-1}. (b) Residual plots from CPUE standardization.

7.3. Length data

Table S5. Description of the length data obtained for *Sparisoma axillare* and *Scarus trispinosus.*

	Fleet	Period	N	Source
Sparisoma axillare	Seine net PE	2001	33	Estimated from Schwamborn 2004
	Trap PE	2005-2008	299	Véras 2008
	Trap PE	2021	50	Provided by Projeto Budiões
	Trap RN	2003-2005	221	Provided by IBAMA
	Gillnet RN	2013-2014	85	Roos et al. 2016
Scarus trispinosus	Gillnet RN	2014 and 2017	109	Provided by Roos N
	Speargun RN	2014 and 2017	76	Provided by Roos N
	Speargun BA	2010-2013	2647	Freitas et al. 2020
	Speargun BA	2020-2021	225	Provided by Projeto Budiões
	Gillnet BA	1999	9	Provided by Frédou T
	Gillnet BA	2021	22	Provided by Projeto Budiões

7.4. Additional models

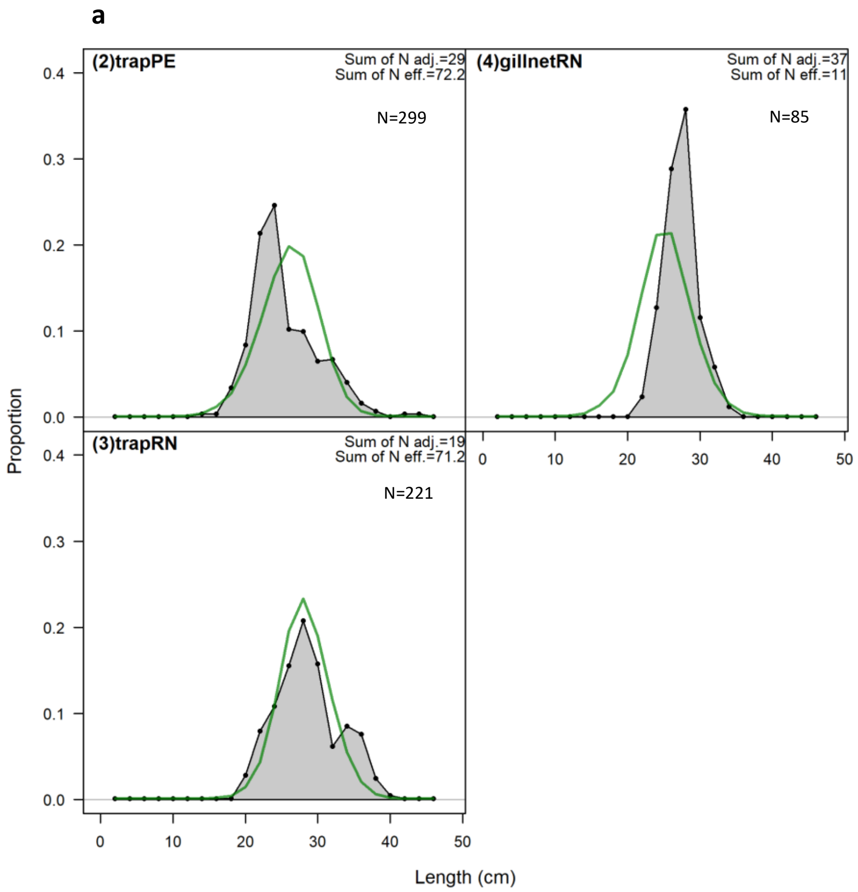
Table S6. Base and alternative models ran for each species, posteriorly compared through model sensitivity analyses.

	Model	Description
Sp. axillare	axi_smooth_recdev (*base model*)	Model with smoothed catches for RN, fixed selectivity shapes for all fleets, fixed selectivity values for the fleets gillnet RN and speargun RN, estimated selectivity values for the other 3 fleets and biased recruitment corrected by the model.
	axi_Freire_sel	Model with predicted catches for RN (not smoothed), fixed selectivity shapes for all fleets, and estimated selectivity for all 5 fishing fleets.
	axi_smooth_sel	Model with smoothed catches for RN, fixed selectivity shapes for all fleets, and estimated selectivity values for all 5 fishing fleets.
	axi_smooth_sel_recdev	Model with smoothed catches for RN, fixed selectivity shapes for all fleets, estimated selectivity values for all 5 fishing fleets and biased recruitment corrected by the model.
Sc. trispinosus	tri_tot_smooth2 (*base model)*	Model with smoothed catches for RN, fixed selectivity shapes for all fleets and estimated selectivity values for all 4 fishing fleets.
	tri_tot_smooth2_recdev	Model with smoothed catches for RN, fixed selectivity shapes for all fleets, estimated selectivity values for all 4 fishing fleets and biased recruitment corrected by the model.
	tri_tot_smooth	Model with smoothed catches for RN, estimated selectivity shapes for all fleets and estimated selectivity values for all 4 fishing fleets.

8. Supplemental Material 3 – Data limited Stock Synthesis for Sparisoma axillare

8.1. Data Fits

Length data fits were evaluated based on Pearson residuals-at-length (Fig S12), and aggregated length composition data for each of the three fleets whose data was present (Fig S11). Length data with lowest Pearson residuals came from the trap RN fleet, possibly due to the higher amount of sampled fish, while the highest residuals was observed in gillnet RN fleet (Fig S11a). Most residuals were observed in length compositions peaks (Fig. S11 and S12), especially when samples sizes are small and the peaks were more pronounced (Fig. S11a,b). Besides the residuals, the models represented the general tendency of the fleet length distributions (Fig S11a).



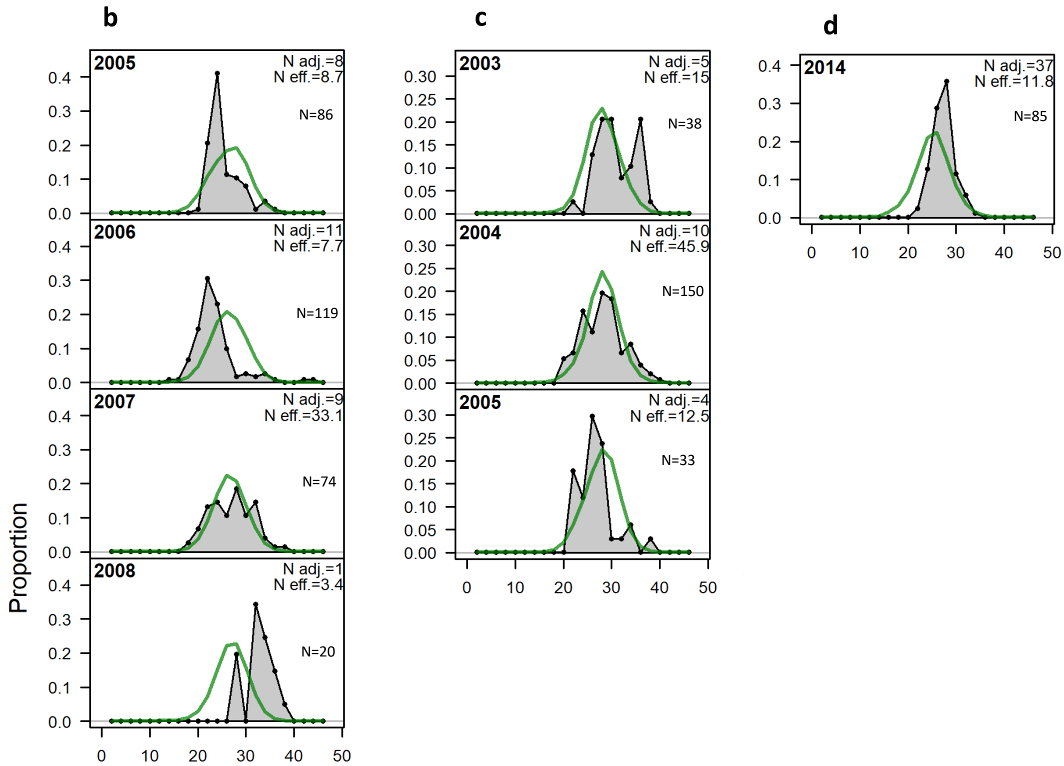


Figure S4. SSDL-tool plots of length compositions of *Sparisoma axillare*, the green lines represent the values estimated by the model and the gray areas represent the data inserted in the model (a) aggregated across time by: (2) trap PE fleet, (3) trap RN fleet and (4) gillnet RN fleet; and separated length composition by year for (b) trap PE, (c) trap RN and (d) gillnet RN.

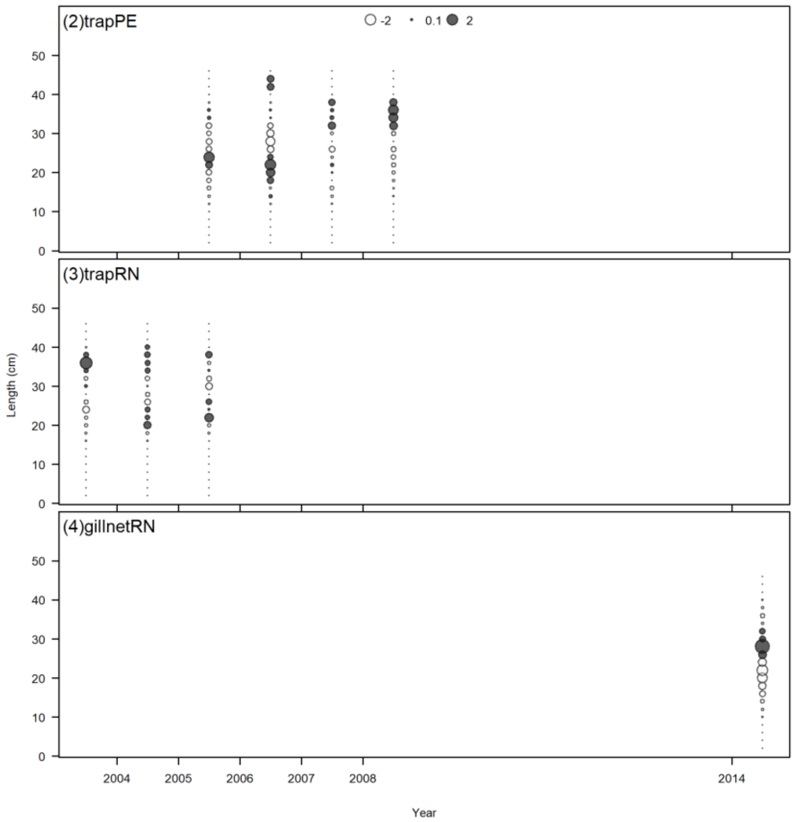


Figure S5. SSDL-tool plots of Pearson residual, comparing across fleets for *Sparisoma axillare*. Closed bubbles are positive residuals (observed > expected) and open bobbles are negative residuals (observed < expected).

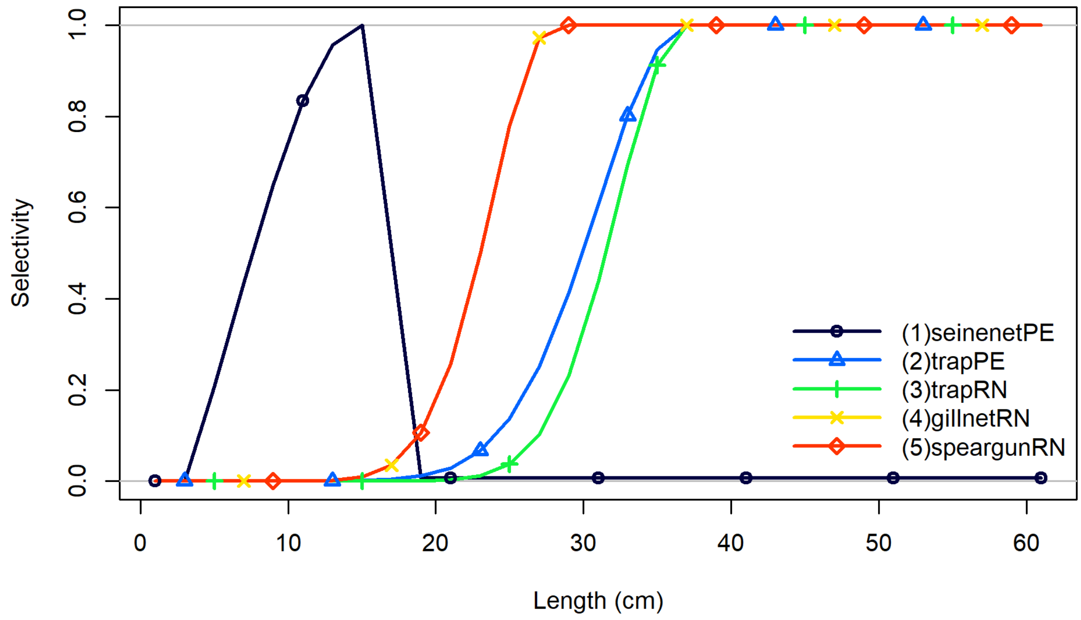


Figure S6. SSDL-tool plot of selectivities at length estimated by the model of *Sparisoma axillare* for seine net PE fleet (1), trap PE fleet (2), trap RN fleet (3), gillnet RN fleet (4) and speargun RN fleet (5).

8.2. Model diagnostics

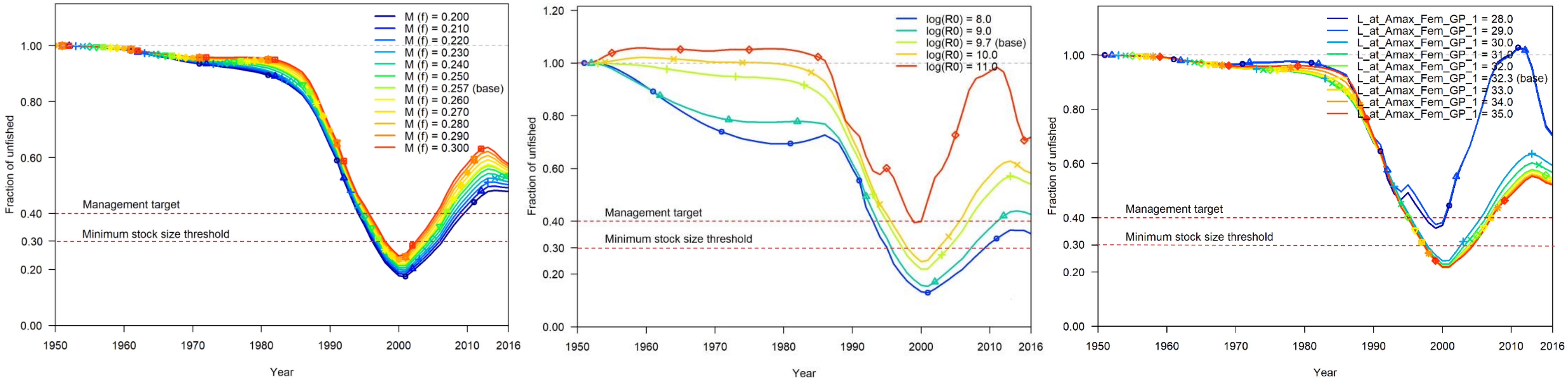


Figure S7. Log likelihood profiles of (a) initial recruitment (log(R0)), (b) natural mortality (M (f)) and (c) Asymptotic length (L_at_Amax) of *Sparisoma axillare*'s fraction of unfished stocks.

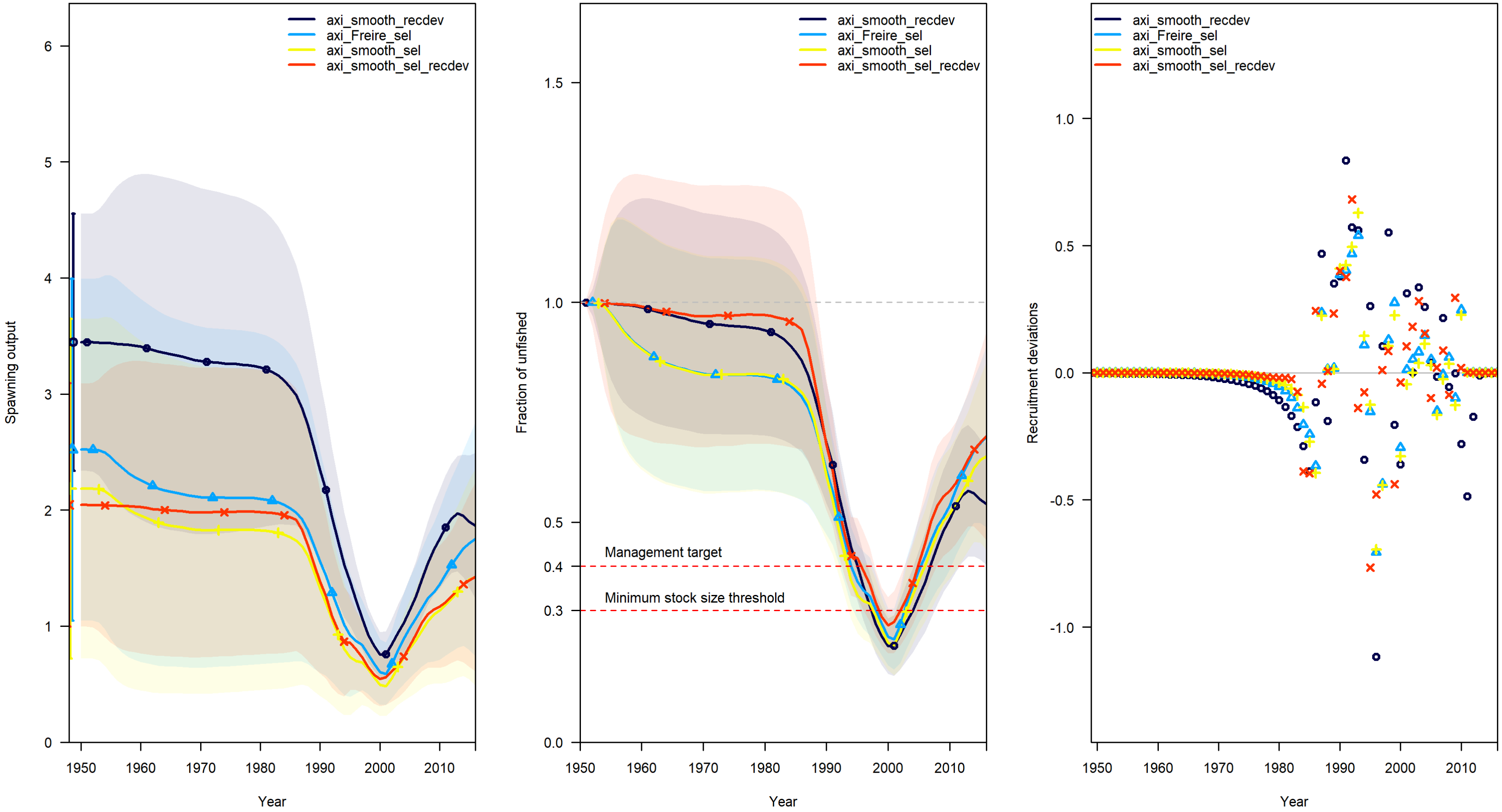


Figure S8. Sensitivity analysis plots for four different predicted models of *Sparisoma axillare* spawning biomass, used to investigate models uncertainties: *axi_smooth_recdev* is the base model with smoothed catches for RN, fixed selectivity shapes for all fleets, fixed selectivity values for the fleets gillnet RN and speargun RN, estimated selectivity values for the other 3 fleets and biased recruitment corrected by the model; *axi_Freire_sel* with predicted catches for RN (not smoothed), fixed selectivity shapes for all fleets, and estimated selectivity for all 5 fishing fleets; *axi_smooth*_sel with smoothed catches for RN, fixed selectivity shapes for all fleets, and estimated selectivity values for all 5 fishing fleets; and *axi_smooth_sel_recdev* with smoothed catches for RN, fixed selectivity shapes for all fleets, estimated selectivity values for all 5 fishing fleets and biased recruitment corrected by the model.

9. Supplemental Material 4 – Data limited Stock Synthesis for Scarus trispinosus

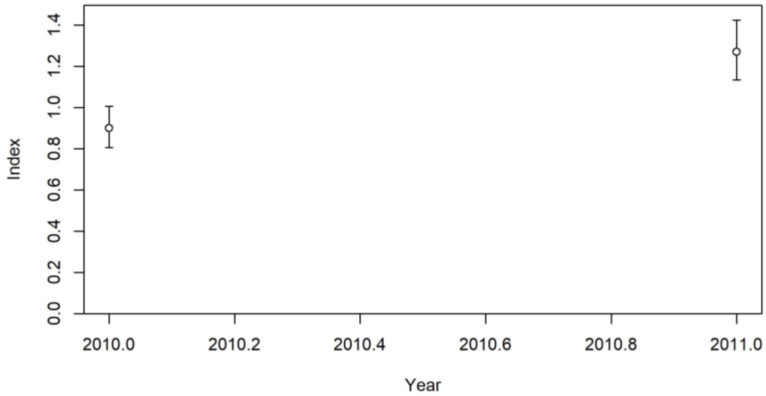


Figure S9. SSDL-tool plot of Index data for the fleet of Speargun BA for *Scarus trispinosus*. Lines indicate 95% uncertainty interval around index values based on the model assumption of lognormal error.

9.1. Data Fits

Length data fits were evaluated based on Pearson residuals-at-length (Fig S5), and aggregated length composition data for the fleets whose data was present (Fig S4). In general, residuals were small and the model represented well the composition of lengths (Fig S4a). No pattern of residual distribution was observed, with residuals spread along the entire length composition of the fleets (Fig. S11 and S12), especially when samples sizes are small and the peaks were more pronounced (Fig. S11a,b). Length data with lowest Pearson residuals came from the year of 2012, possibly due to the higher number of sampled fish, while the highest residuals was observed in 2010 possibly due to the opposite reason (Fig S4b) Models estimated similar mean sizes of capture of about 55 cm for all years (Fig S4b).

a

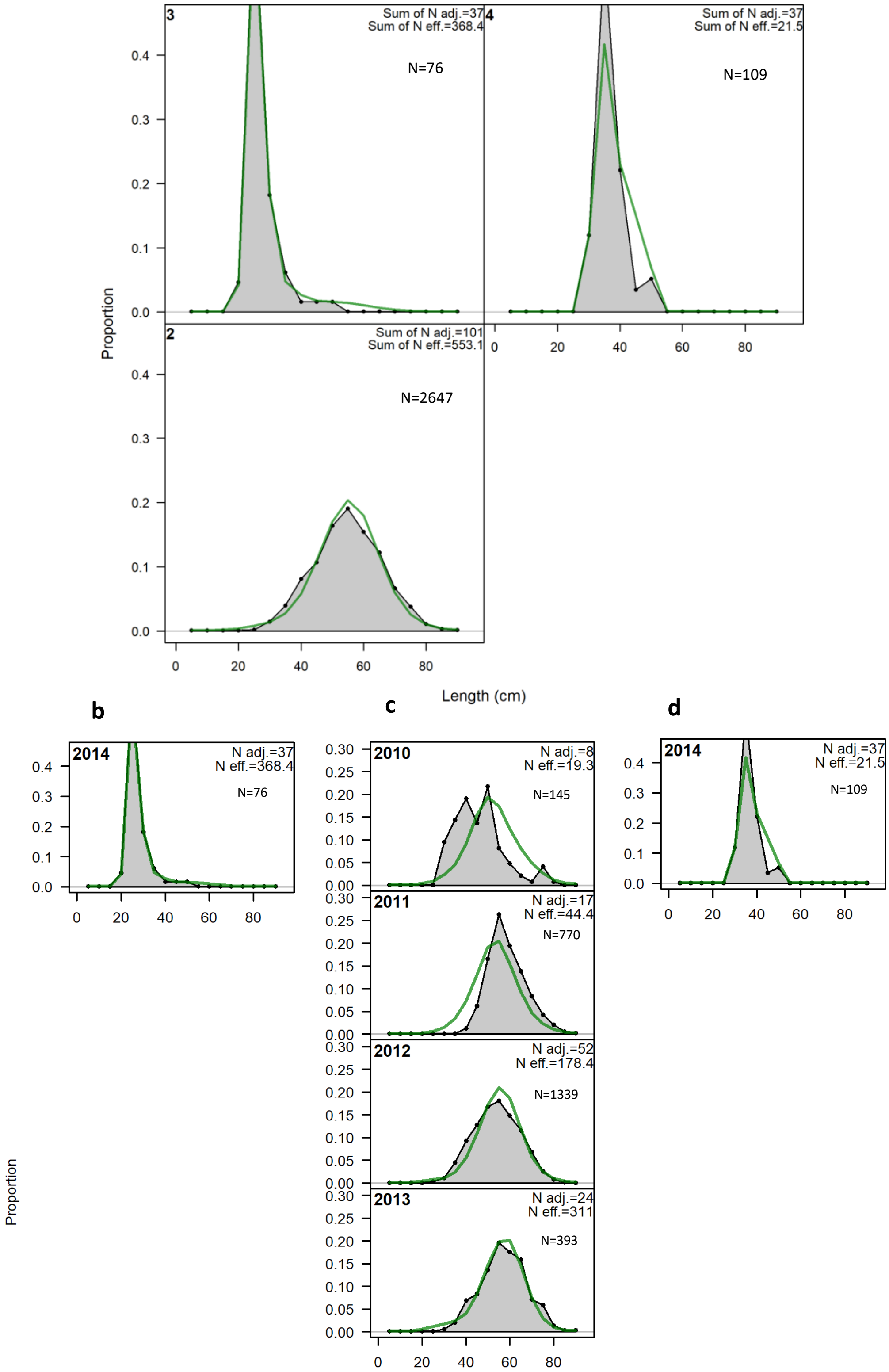


Figure S10. SSDL-tool plots of length compositions of *Scarus trispinosus*, the green lines represent the values estimated by the model and the gray areas represent the data inserted in the model (a) aggregated across time for the fleets (2) speargun BA, (3) gillnet RN and (4) speargun RN, and separated by year for (b) gillnet RN, (c) speargun BA and (d) speargun RN.

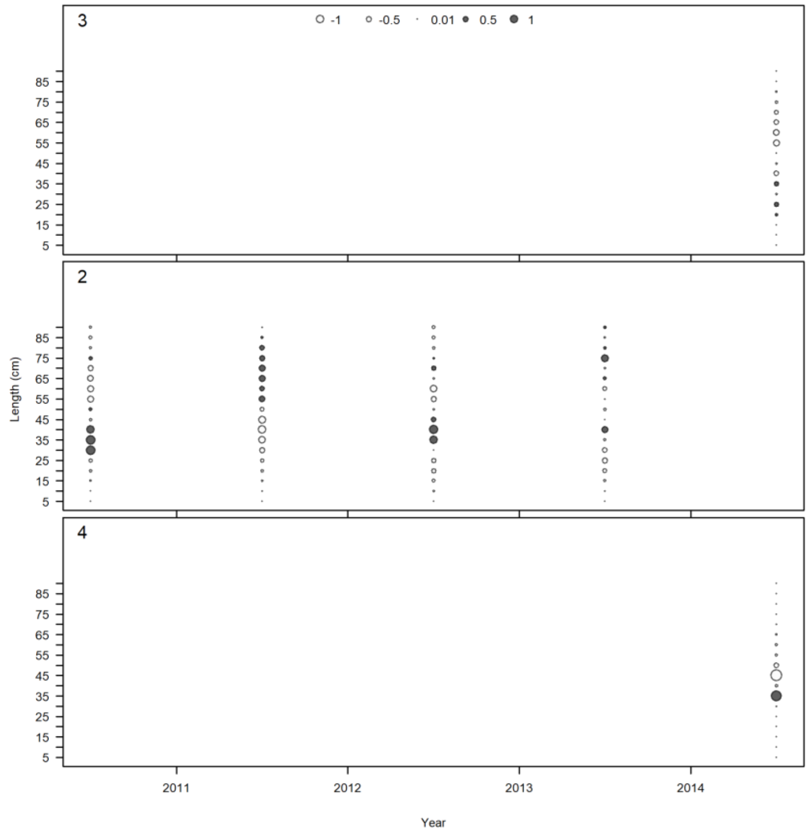


Figure S11. SSDL-tool plot of Pearson residuals, comparing across fleets for *Sc. trispinosus*: for (2) speargun BA, (3) gillnet RN, and (4) speargun RN. Closed bubbles are positive residuals (observed > expected) and open bubbles are negative residuals (observed < expected).

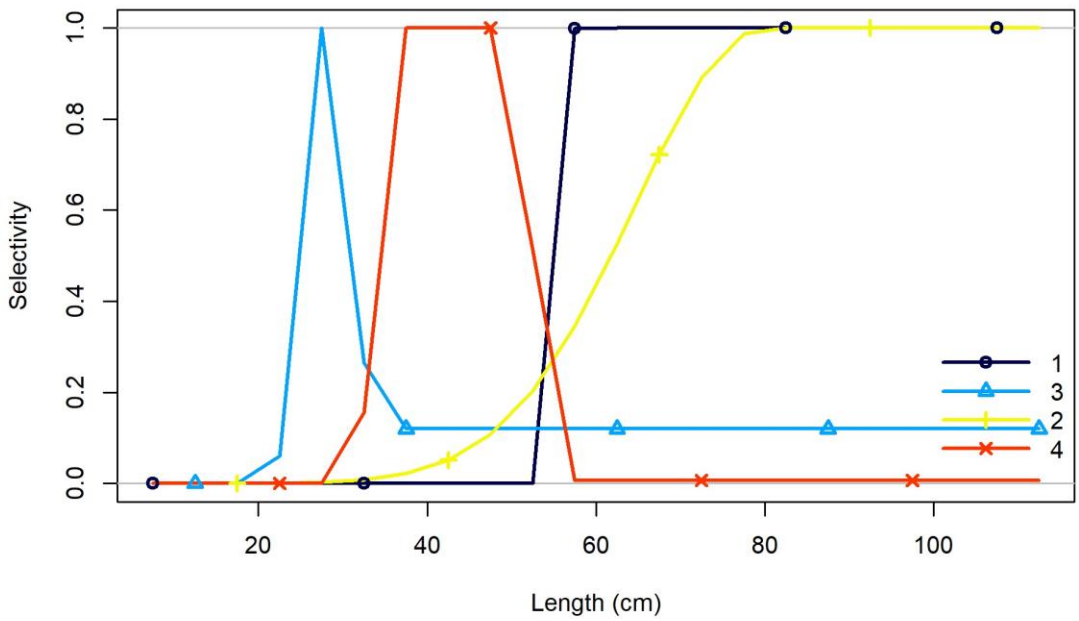


Figure S12. SSDL-tool plot of selectivities at length estimated by the model of *Sc. trispinosus* for the fleets (1) gillnet BA, (2) speargun BA, (3) gillnet RN, and (4) speargun RN.

9.2. Model diagnostics

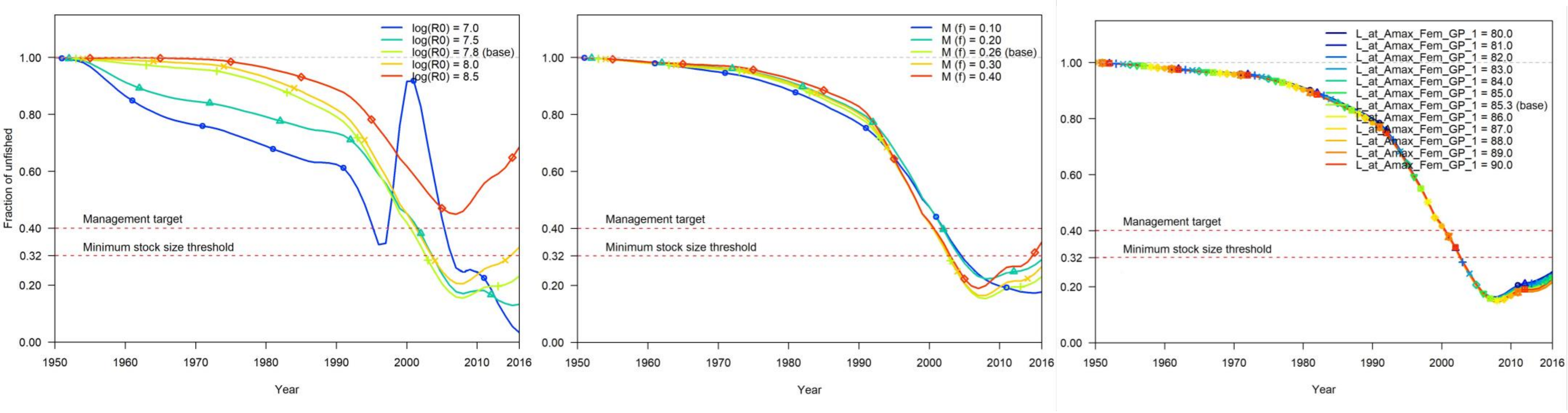


Figure S13. SSDL-tool Log likelihood profiles of *Scarus trispinosus* (a) initial recruitment (log(R0)), (b) natural mortality (M (f)) and (c) Asymptotic length (L_at_Amax) parameters used to predict fractions of Southern unfished stocks.

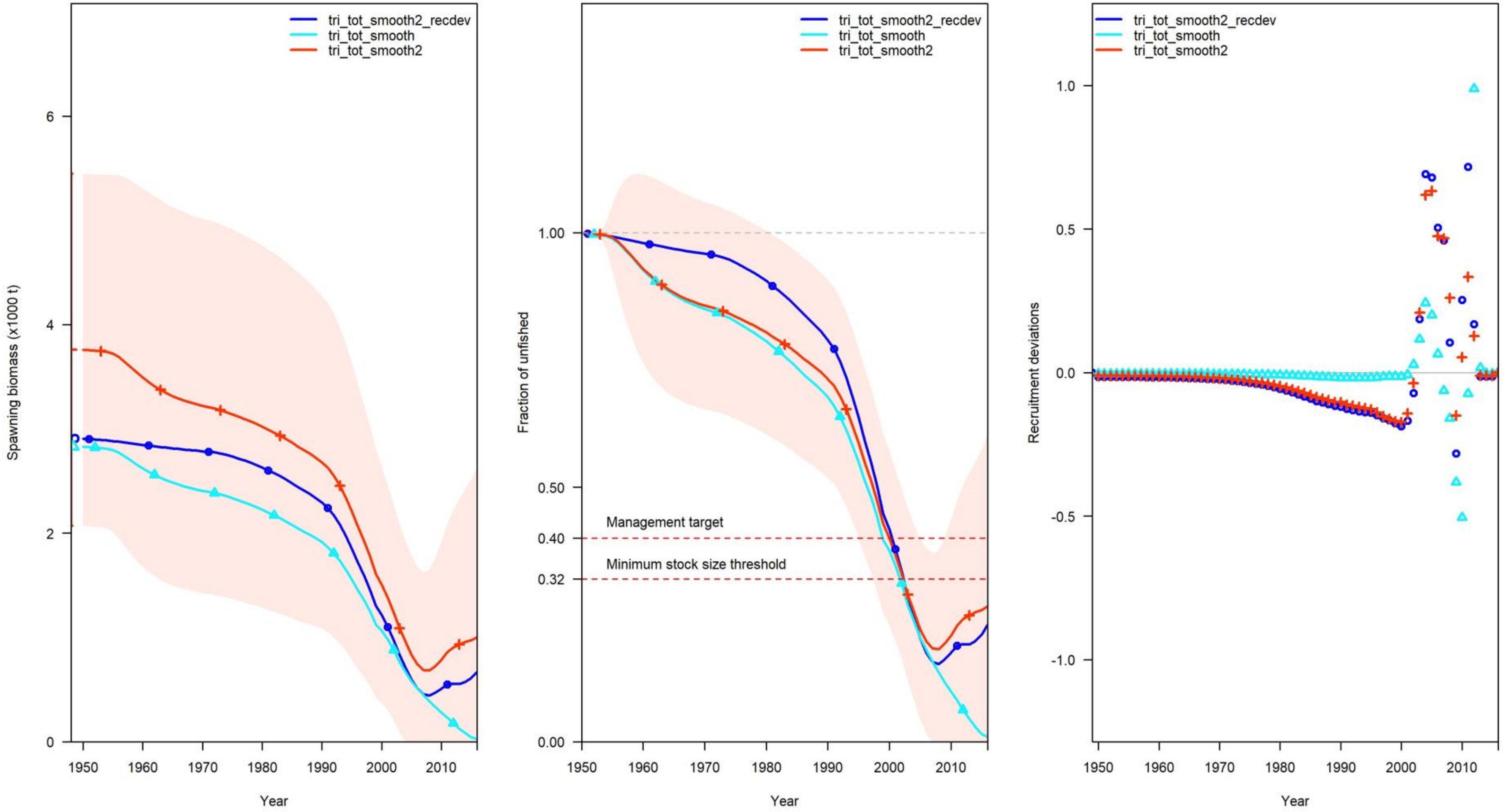


Figure S14. Sensitivity analysis plots for four different predicted models of *Scarus trispinosus* spawning biomass, used to investigate models' uncertainties: *tri_tot_smooth2_recdev* is the base model with smoothed catches for RN, fixed selectivity shapes for all fleets, estimated selectivity values for all 4 fishing fleets and biased recruitment corrected by the model; *tri_tot_smooth2* with smoothed catches for RN, fixed selectivity shapes for all fleets and estimated selectivity values for all 4 fishing fleets and; *tri_tot_smooth* with smoothed catches for RN, estimated selectivity shapes for all fleets and estimated selectivity values for all 4 fishing fleets.

CONSIDERAÇÕES FINAIS

O interesse na pesca dos budiões endêmicos do Brasil cresceu nas últimas décadas e uma redução considerável na abundância de quatro das cinco espécies alvo levou estas espécies a serem categorizadas como ameaçadas. Apesar de sua importância ambiental e social, o desenvolvimento desta pesca ao longo do tempo e a situação das pescarias e dos estoques de budião era pouco conhecido. O presente trabalho fez um levantamento abrangente de dados publicados e inéditos que permitiram a descrição histórica do desenvolvimento da pesca de budiões no Brasil, incluindo a reconstrução das capturas para cada uma das cinco espécies alvo e a avaliação da situação atual destas pescarias e dos estoques das duas espécies mais capturadas. Parte dessas informações já vem sendo apresentada em reuniões governamentais e serão de grande importância para embasar tomadas de decisões sólidas para a recuperação e conservação das espécies endêmicas de budião alvos da pesca no Brasil.

Apesar das lacunas de informação ainda existentes, foi possível perceber o risco de se ter espécies de budião como alvos da pesca. Das três espécies mais abundantes, *Scarus trispinosus* é a mais vulnerável aos efeitos da pesca e seu estoque já foi considerado como sobreexplotado. *Sparisoma axillare* e *Sparisoma frondosum* são populações mais resilientes e a avaliação de estoque da primeira demonstrou que ela ainda está acima dos limites clássicos da gestão pesqueira. Entretanto, a pesca dessa espécie pode estar ocorrendo de forma insustentável, mascarando potenciais reduções nos estoques. *Sparisoma amplum* e *Scarus zelindae* possuem abundâncias geralmente baixas, o que as torna vulneráveis até a pequenas pressões pesqueiras e suas capturas têm mostrado crescimento ao longo do tempo. A obtenção de dados históricos adicionais e atualizados é essencial para permitir avaliações apropriadas para as espécies que não foram avaliadas no presente trabalho e a continuidade das avaliações de *Scarus trispinosus* e *Sparisoma axillare.* Além disso, o presente trabalho focou na investigação da pesca de budiões pela frota pesqueira artesanal, mas uma quantidade considerável de budiões também é capturada pela pesca esportiva. Futuros trabalhos com enfoque nestas pescarias são necessários para entender o impacto adicional desta explotação nos estoques.

Tendo em vista o impacto da retirada dos budiões do ecossistema recifal, a preocupação se torna ainda maior. Devido à grande importância dessas espécies tanto para a pesca de diversas comunidades pesqueiras quanto para o meio ambiente, é essencial que a comunidade científica, pesqueira e de gestão se unam em prol da conservação destas espécies em níveis de uso plausíveis também para a manutenção do seu papel ecossistêmico. As medidas de manejo publicadas até o momento não têm sido efetivamente aplicadas e novas abordagens devem ser desenvolvidas focando nos desafios históricos, geográficos e financeiros encontrados no Brasil. Com base nas informações sumarizadas no presente trabalho, é possível que o monitoramento da cadeia comercial dessas espécies seja uma estratégia mais efetiva, demandando menos recursos humanos e financeiros, sendo responsável pelo controle indireto das atividades de pesca.

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APÊNDICE 1 – Artigo publicado na revista Aquatic Sciences

Aquatic Sciences (2023) 85:44
https://doi.org/10.1007/s00027-023-00939-x

Aquatic Sciences

OVERVIEW

A critical review and knowledge gaps to assess and manage threatened parrotfishes' stocks in Brazil

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Received: 21 February 2022 / Accepted: 17 January 2023

Abstract

Given the increasing exploration of endemic Brazilian parrotfishes and their classification as threatened, there is an emergent need to gather biological and fisheries information to assess their stocks. We performed a comprehensive review of 134 studies addressing key topics of information related to stock assessments: (1) the distribution and population structure; (2) age, growth and mortality; (3) reproductive biology; (4) feeding ecology; (5) fishing data, and (6) management actions. This review focused on the most explored Brazilian parrotfish species: *Scarus trispinosus*, *Scarus zelindae*, *Sparisoma amplum*, *Sparisoma axillare*, and *Sparisoma frondosum*. The most abundant species, *Sp. axillare*, and the most threatened, *Sc. trispinosus*, are better studied; hence data-moderate stock assessments are viable for both species. As information gaps are largest for *Sp. zelindae*, only simple Risk analyses are possible for this species. Stock productivity and status may be obtained for the remaining species, enabling data-limited assessments. The few official fisheries statistics available are inaccurate and have been discontinued since 2010; scientific studies represent the main source of information about Brazilian parrotfishes' captures but are sparse. How stocks are structured and distributed along the coast must be defined, thus genetic structuring and site fidelity studies are necessary. Life-history traits such as mortality, growth, sexual modes, social organization, and maturity must be a subject prioritized for all species. Brazilian fisheries statistics programs must be resumed and improved urgently. The academic community and stakeholders must focus on filling these essential knowledge gaps to promote the successful evaluation of their stocks and solid recovery actions. Otherwise, Brazilian parrotfish populations—and the fisheries and ecosystem functions dependent on them—may be at risk.

Keywords Scarini · Endemic · Endangered · Biology · Artisanal fishing · Management

Introduction

Assessing the status of a fishery resource represents a crucial step for conservation; establishing catch levels that allow both fishing productivity and ecosystem roles performed by organisms to be maintained is paramount (FAO 1995). More than 35% of the world's fishery stocks have been evaluated as overexploited, mainly due to exacerbated extraction and destructive fishing practices (FAO 2022). Consumption of aquatic resources has doubled since the 1970s (Maire et al. 2021; FAO 2022) and plays a key role in micronutrition, food security, livelihoods, and profits worldwide, especially in poorer countries (Béné et al. 2015; Loring et al. 2018; Maire et al. 2021; FAO 2022). To ensure the provision of these resources and upkeep fisheries productivity, it is necessary to monitor the stocks' status, decrease overfishing, and achieve the sustainability of fisheries (Srinivasan et al. 2010; Béné et al. 2015).

To assess the condition of fish populations and establish total allowable catches (TAC), information about stock productivity, status, and scale are mandatory (Cope and Gertseva 2020). The stock productivity indicates the reproductive potential and growth of the population, being obtained through life history parameters, such as mortality rates, growth, and maturity, while stock status shows the relative

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Published online: 06 February 2023

APÊNDICE 2 – Artigo publicado na revista Coral Reefs

Coral Reefs
https://doi.org/10.1007/s00338-021-02080-3

NOTE

Effects of social organization on the feeding of the striped parrotfish, *Scarus iseri*

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Received: 24 September 2020 / Accepted: 11 March 2021

Abstract Parrotfishes contribute to important reef processes through their feeding. Individuals may join groups with distinctive social behavior, with unknown implications for their feeding ecology and, ultimately, their functional roles in reef systems. Using *Scarus iseri* populations in Isla Colón, Panama, we investigated whether individuals belonging to the two main social groups formed by this species ('Territorial' and 'Stationary' groups) differed in their feeding preferences. Territorial groups had access to a diversity of potential food sources, yet showed selectivity for feeding on sandy substrate. Stationary groups showed high selectivity for filamentous algae, despite this resource being less available for this group than for territorial individuals. Initial phase fish had higher bite rates on plants than terminal phase individuals, while the latter had higher bite rates on soft substrata and sponges, both indicating detritus consumption. Parrotfish sociobiology may therefore influence their relative ecosystem impact, with territorial and terminal individuals in both social groups more involved in the detrital food web and stationary groups contributing to a greater extent on algal removal.

Keywords Sociobiology · Fish feeding behavior · Territoriality · Herbivory · Functional ecology · Coral reefs

Introduction

Much effort has been dedicated to define the ecological key processes for coral reef ecosystem functioning, especially the role of the associated biota to maintain these mechanisms (Brandl et al. 2019). Grazer and excavator species, such as parrotfishes, contribute to core processes in the reef system, such as herbivory, bioerosion and nutrient cycling, and therefore are critical components for sustaining functional reefs (Crossman et al. 2001; Bonaldo et al. 2014). Nevertheless, parrotfish contribution to these processes changes between and within species, depending on dietary preferences, food availability and individual choice (Hoey and Belwood 2008; Feitosa and Ferreira 2014; Robinson et al. 2019).

Despite the recent evidence depicting the importance of species' social interactions for ecosystem functioning (Gil and Hein 2017), the effects of social organization on parrotfish functional roles need further study (Bonaldo et al. 2014). Parrotfish social habits are particularly complex, due to the diverse array of reproductive modes and feeding-oriented behaviors exhibited, which vary intraspecifically more often than not (van Rooij et al. 1996a; Girolamo et al. 1999). Parrotfishes can present up to three distinct social categories within a single species, which is generally unusual in reef fishes (but see Warner 1991 and Petersen and Warner 2002 for more instances of complex social organizations in reef fish). Social groups seem to serve a dual function for feeding and spawning, quantitatively differing in regards to habitat use, sex ratio, sexual activity and energetic demand (van Rooij et al. 1996a; Girolamo et al. 1999).

Topic Editor Andrew Hoey

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00338-021-02080-3.

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Published online: 02 April 2021

APÊNDICE 3 - Artigo publicado na revista Marine Ecology Progress Series

Vol. 713: 117–132, 2023
https://doi.org/10.3354/meps14335

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

Published June 29

Going further on herbivore fishing: the removal of smaller fishes from algal-dominated reefs

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ABSTRACT: Overfishing of large herbivorous fishes is connected to the rise of algal-dominated states on coral reefs. The recovery of their populations is challenging, and future herbivore assemblages may be composed of smaller fish. With fisheries now targeting these smaller-sized herbivore populations, coral reef benthic communities may face unknown outcomes. We performed caging experiments in algal-dominated reefs of Northeastern Brazil, that have been depleted of large herbivorous fishes, to appraise the effects of removing small herbivores on benthic community composition and succession. Full cages simulated herbivore removal, and partial cages and open plots functioned as controls. In total, 36 experimental plots were monitored for 1 yr, accounting for the influence of seasonal changes in local conditions of temperature and turbidity. Overall macroalgal cover did not change between experimental treatments, but filamentous algae increased 5-fold inside full cages by the end of the experiment, surpassing articulated coralline forms as the dominant group. Higher temperatures during the dry season promoted filamentous algae when the top-down control of the herbivores was removed, while a reverse pattern was observed when fishes were allowed to feed inside plots. Small herbivores accelerated benthic succession, facilitating the dominance of articulated coralline algae as the climax community. Our findings oppose previous studies performed at sites with high abundances of large-bodied fishes, where herbivory decreased overall macroalgal cover, promoted filamentous and crustose coralline algae and delayed community succession. The further depletion of smaller-bodied herbivores can trigger shifts in benthic community dynamics that interact with water temperature, which may have implications for reef resilience in an ocean-warming scenario.

KEY WORDS: Herbivory · Fishing effects · Phase shift · Coral reefs · Parrotfish · Surgeonfish · Damselfish · Functional ecology · Brazilian reefs · Community ecology

1. INTRODUCTION

The role of herbivorous fish has been a recurring subject in coral reef studies for the past 2 decades (Bonaldo et al. 2014, Hoey & Bonaldo 2018, Lange et al. 2020). They have been regarded as one of the essential components for reef functioning, and their feeding activities are thought to regulate core ecological processes (Adam et al. 2015a, Harborne & Mumby 2018, Topor et al. 2019). Attributable to these fishes are the mediation of benthic competition by macroalgae removal, promoting reef builders such as coral and crustose coralline algae (CCA), production and transport of reef sediments and predation on coral and sponges (Mumby & Steneck 2008, Graham et al. 2013, Cordeiro et al. 2020). However, variable degrees in the delivery of these functions have been increasingly identified, and both experimental and observational works point toward the functional complementarity of piscine herbivores (Burkepile & Hay 2008, 2010, 2011, Adam et al. 2015b, 2018, Capitani et al. 2021). Many factors are linked to the

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APÊNDICE 4 – Capítulo no prelo para publicação no o livro "Brazilian Coral Reefs" da Editora Springer

Chapter 5

Herbivory and competition for space

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Abstract Brazilian coral reefs are quite singular, presenting a particular set of endemic coral species supporting the construction of reefs that diverge in form and structure from any other coralline systems. These distinctive reef formations shelter a herbivore functional group that is low in diversity but is composed barely of endemic species. Algal assemblages in Brazil are akin to reefs worldwide, but the coexistence with such a unique assortment of endemic species provides an interesting scenario for interactions to be studied. Conversely, we are nowhere near understanding ecological relationships in Brazilian reefs compared to the Indo-Pacific and the Caribbean. Even before reaching this objective, Brazilian coral reefs have been burdened by anthropogenic impacts common to other reefs worldwide, and these species interactions are being increasingly disrupted. The coral fauna is challenged by nutrification, increased temperature, sedimentation and turbidity, herbivore overfishing and, more recently, the invasion of exotic species. Brazilian researchers have developed copious literature, most of it undertaken in the light of these impacts. This chapter compiles the results of coral reef studies on herbivory and competition for space, primarily performed in the past two decades. We present these findings and briefly discuss their implications to this singular reef system.

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Keywords Herbivores, Endemic species, Functional ecology, Allelopathy, Competitive strategies, Invasive species, Overfishing, Phase-shifts

5.1. Introduction

While most work on competition and herbivory was developed in Indo-Pacific and Caribbean reefs, Brazilian systems present a distinct scenario. Compared to other reef systems, Brazilian reefs retain low-diversity communities, impoverished in corals and fish species. Hermatypic corals are mostly endemic, some of those derived from a Tertiary fauna that remained part of the dominant taxa (Leão et al. 2003). These species have found a refuge of appropriate conditions to thrive in Brazil; here, the profuse turbidity and high sedimentation rates favor massive coral forms with large