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Biodiversidade e serviços ecossistêmicos de ambientes recifais brasileiros: um estudo de ecologia histórica

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O presente trabalho em nível de mestrado foi avaliado e aprovado por banca examinadora composta pelos seguintes membros:

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Certificamos que esta é a **versão original e final** do trabalho de conclusão que foi julgado adequado para obtenção do título de mestre em Ecologia.

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Nosso primeiro passeio nos arrecifes foi na chuva, chapéu de palha e espadrilhas na lancha do Instituto. Em 10 minutos estávamos encharcados e congelados. Felizmente, chegamos rapidamente ao local de trabalho. A água estava calma. Havia um canal nos corais, onde o barco ficou ancorado. O sol nos aqueceu. E aí foi a descoberta de um mundo maravilhoso, entre 1 e 3 m de profundidade: peixes azuis, achatados como um prato; negros, listrados com amarelo; prateados; alguns pequeninos totalmente azuis, outros ainda completamente pretos com grandes pontos azuis cintilantes; todos fascinantes. [...] Era muito difícil mergulhar em Recife, pois a água estava sempre turva. [...] Um dia no verão de 1962, a água estava clara e finalmente vimos um ou dois fundos de coral muito bonitos. (Laborel-Deguen em Laborel-Deguen, 2019)

RESUMO

Ambientes recifais são altamente produtivos e por isso são conhecidos como florestas tropicais dos oceanos. Assim como em outras comunidade biológicas, distúrbios, predação, competição e doenças tem se mostrado como processos importantes que afetam sua estrutura e dinâmica. Os recifes de corais brasileiros são únicos, apesar da baixa diversidade da fauna coralínea, há um alto endemismo com formações distintas chamadas "chapeirões". Os seres humanos e os recifes de corais coexistem há milhares de anos. Aproximadamente 1,2 bilhões de pessoas vivem até 100 quilômetros desses ambientes, sendo direta ou indiretamente dependentes destes ambientes. Eles desempenham funções ecossistêmicas importantes que se traduzem em inúmeros bens e serviços para toda população mundial. O termo contribuições da natureza para as pessoas foi cunhado em uma tentativa de introduzir um novo enquadramento para as relações dos seres humanos com a natureza, elas são todas as contribuições, tanto positivas quanto negativas, da natureza viva para qualidade de vida das pessoas. Muitos naturalistas visitaram o Brasil e fizeram algumas descrições do ambiente recifal, porém a maioria delas tinham um caráter geológico. Na década de 1960, Jacques Laborel foi o primeiro pesquisador a utilizar o mergulho com cilindro para estudar a biologia e funcionamento do recifes de corais brasileiros. Uma forma de resgatar informações passadas sobre um determinado ambiente é através da ecologia histórica. Ela estuda a natureza através do tempo, muitas vezes com foco nas interações entre os seres humanos e o ambiente e as causas e consequências das mudanças causadas pelos humanos no passado recente. Este trabalho aborda a composição de assembléias coralíneas e os benefícios providos pelos ambientes recifais e está dividida em dois artigos: (1) " Decades of c*hanges in Brazilian coral reef assemblages*" que compila e padroniza as informações semiquantitativas da estrutura taxonômica e funcional da comunidade coralínea e (2) "*Brazilian coral reefs by the eyes of its users"* que analisa a percepção sobre mudanças nos serviços ecossistêmicos providos pelos recifes de corais por pesquisadores, mergulhadores e usuários dos recifes de corais. Para entender como era a composição dos recifes de corais brasileiros e como ela mudou através do tempo, utilizamos dados semiquantitativos e qualitativos coletados nas décadas de 1960, 1980, 1990, 2000 e 2010. Com o intuito de trazer uma perspectiva humana atual, elaboramos um questionário on-line para entender como usuários de ambientes recifais percebem os benefícios trazidos por estes ambientes. Nossos resultados mostraram um grande declínio de diversas espécies de corais construtoras de recifes e que promovem tridimensionalidade que foi refletido na percepção dos respondentes do questionário, a grande maioria relatou uma piora na qualidade dos ambientes recifais; quanto ao cenário atual dos benefícios percebidos pelos respondentes, a maioria relacionava-se com o bem-estar que estes ambientes proporcionam. O declínio na abundância de espécies de corais pode ter implicações muito graves como a abertura de espaço para ocupação de espécies oportunistas e consequente mudança no funcionamento do recife, que irá refletir nas contribuições dos recifes para as pessoas.

Palavras-chave: Recifes de coral 1. Dados históricos 2. Brasil 3. Serviços ecossistêmicos

ABSTRACT

Reef environments are highly productive, also called tropical ocean forests. As in other biological communities, disturbances, predation, competition, and diseases have shown to be important processes that affect their structure and dynamics. Brazilian coral reefs are unique, despite the low diversity of coral fauna, there is a high endemism with distinct formations called “chapeirões”. Approximately 1.2 billion people live within 100 kilometers of these environments, being directly or indirectly dependent on these environments. They perform important ecosystem functions that translate into countless goods and services for the entire world population. The term contributions of nature to people was coined in an attempt to introduce a new framework for human beings' relationships with nature, they are all contributions, both positive and negative, of living nature to people's quality of life. Many naturalists visited Brazil and made some descriptions of the reef environment, but most of them had a more geological character. In the 1960s, Jacques Laborel was the first researcher to use diving as a tool to study the biology and functioning of Brazilian coral reefs. One way to retrieve past information about a given environment is through historical ecology. It studies nature through time, often focusing on the interactions between humans and the environment and the causes and consequences of human-caused changes in the recent past. Humans and coral reefs have coexisted for thousands of years. This work addresses the composition of coral reef assemblages and the benefits provided by reef environments and is divided into two articles: (1) “Decades of changes in Brazilian coral reef assemblages” which compiles and standardizes semi-quantitative information on the taxonomic and functional structure of the coral community and (2) “Brazilian coral reefs by the eyes of its users” which analyzes the perception of changes in ecosystem services provided by coral reefs by researchers, divers, and users of coral reefs. To understand what the composition of Brazilian coral reefs was like and how it changed over time, we used semi-quantitative and qualitative data collected in the 1960s, 1980s, 1990s ,2000s and 2010s . An online questionnaire to understand how users of reef environments perceive the benefits brought by these environments. Our results showed a great decline of several species of corals that build reefs and that promote three-dimensionality that was reflected in the perception of the respondents of the questionnaire, the vast majority reported a worsening in the quality of reef environments; as for the benefits perceived by the respondents, most were related to the well-being that these environments provide. The decline in the abundance of coral species can have very serious implications such as opening space for occupation by opportunistic species and a consequent change in the functioning of the reef, which will reflect on the contributions of reefs to people.

Keywords: Coral reefs 1. Historical data 2. Brazil 3. Ecosystem services

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IPBES Plataforma Intergovernamental sobre Biodiversidade e Serviços Ecossistêmicos

NCP Contribuições da Natureza para as Pessoas

ANMP Parque Nacional Marinho dos Abrolhos

CA Análise de Correspondência

SST Temperatura da superfície do Mar

SE Serviços Ecossistêmicos

MPAs Áreas Marinhas Protegidas

CNPQ Conselho Nacional de Desenvolvimento Científico e Tecnológico

GBE Gestão Baseada em Ecossistemas

SUMÁRIO

1 INTRODUÇÃO GERAL

Durante as minhas leituras para escrever este trabalho, mesmo sem poder mergulhar, sentada em minha cadeira, eu literalmente mergulhei nos oceanos. Callum Roberts me levou até os séculos XIII e XIX, época na qual seria normal navegar por um mar onde você se depara com um tubarão baleia entre 15 e 18 metros nadando na superfície para se alimentar, estar em um barco densamente cercado por tainhas, tão numerosas que seria fácil espetá-las sem largar a haste do arpão, mergulhar em um mar onde há grandes muralhas de corais, arbustos e dobras de cores vivas ou então se deparar com cardumes de peixes de diversas espécies, cores e tamanhos (ROBERTS, 2007).

Jacques Laborel foi um pesquisador francês que veio ao Brasil em 1961 para ocupar uma vaga no Instituto de Biologia Marítima e Oceanografia de Recife. Como já havia um pesquisador brasileiro estudando as algas marinhas, ele decidiu trabalhar com o tema "corais" já que este não havia sido tratado desde os trabalhos dos historiadores naturais e jamais através do mergulho com cilindro de oxigênio (LABOREL-DEGUEN, 2019). Laborel contou com o auxílio de sua esposa, Françoise Laborel-Deguen, e de outro pesquisador francês, Marc Kempf, para coletar dados e conduzir sua pesquisa. Kempf morou muitos anos em Arraial do Cabo e além da pesquisa, tirava fotos subaquáticas. Trabalhar com dados coletados por Jacques Laborel e escanear as fotos tiradas por Marc Kempf me proporcionaram uma outra viagem no tempo, pelos ambientes recifais brasileiros da década de 60. Laborel mencionou que os ambientes recifais no Brasil já demonstravam sinais de impactos devido a ação humana e mesmo assim não conseguiu esconder o seu encanto pela paisagem. A seguir, eu conto um pouco da história dos recifes de corais brasileiros, como eles mudaram e as implicações de tais mudanças.

1.1 RECIFES DE CORAIS

Os recifes de corais, também chamados de florestas tropicais dos oceanos, são encontrados em hábitats costeiros em áreas tropicais e subtropicais (KNOWLTON, 2001; HOEGH-GULDBERG; PENDLETON; KAUP, 2019). São formados por estruturas de carbonato produzidas e mantidas por um conjunto de organismos calcificantes, predominantemente corais escleractíneos e algas vermelhas coralinas (BARBER; HILTING; HAYES, 2001).

Brandl *et al.* (2019) citam a produção de $CaCO_3$, bioerosão, produção primária, herbívora, produção secundária, predação, liberação de nutrientes e absorção de nutrientes como os oito processos centrais no funcionamento de um recife de coral que são mediados pelos fatores ambientais e antropogênicos e pelas espécies que compõem o recife. Devido à alta diversidade nos recifes de corais torna-se difícil medir a força dos processos ecológicos que ali ocorrem (BELLWOOD *et al*., 2013). Porém, um processo extremamente importante é a remoção de algas pelos peixes, este tipo de herbivoria medeia a competição entre corais e macroalgas (NASH *et al*., 2016), facilitando a recuperação do ecossistema após perturbações como eventos de branqueamento ou grandes tempestades (RICHARDSON; GRAHAM; HOEY, 2020). As características da assembleia de peixes herbívoros afetarão a remoção de algas pois a densidade dos peixes está diretamente relacionada ao número de bocas de forrageamento, indivíduos maiores forrageiam em áreas maiores e destacam um volume maior de algas a cada mordida em comparação com indivíduos menores (BONALDO; BELLWOOD, 2008; NASH *et al*., 2016). A densidade e a composição do tamanho dos herbívoros podem ser afetadas pelo ambiente bentônico e pela composição da comunidade de peixes (NASH *et al*., 2016).

Esses ambientes vêm sendo sujeitos a um amplo espectro de distúrbios através da sua história geológica. Durante esse período os distúrbios podem variar de pulsos frequentes menores, como a predação, a eventos maiores e menos frequentes, como picos de populações predadoras de corais, furacões e mudanças no nível do mar e de temperatura (NYSTRÖM; FOLKE; MOBERG, 2000). Em recifes tropicais, a passagem recorrente de furacões pode contribuir para a manutenção da alta diversidade entre espécies competidoras evitando a monopolização do espaço (HUGHES, 1989). Os seres humanos podem alterar as escalas espacial e temporal do regime de distúrbios naturais, podendo afetar o potencial de recuperação dos recifes após um evento de perturbação (NYSTRÖM; FOLKE; MOBERG, 2000).

Estudos tem mostrado que os estressores mais significantes incluem o aparecimento de doenças, as mudanças climáticas, a sobrepesca e uma combinação de poluição e sedimentação derivada do desenvolvimento costeiro, e estão associados a perda gradual de cobertura de coral e crescimento excessivo de algas (CARILLI *et al.*, 2009; HARBORNE *et al.*, 2017). Uma das consequências do sobre crescimento de algas é o fenômeno chamado de mudança de fase, ou seja, quando um recife dominado por corais muda para um ambiente com estados persistentes de alta cobertura de macroalgas, corais moles ou outros organismos

(HUGHES, 1994; MCMANUS; POLSENBERG, 2004; NORSTRÖM *et al.*, 2009). Esse fenômeno tem sido discutido na literatura por diversos autores e já foi reportado para diferentes locais ao redor do globo, incluindo a Baía de Todos os Santos (e.g., HUGHES, 1994; MCMANUS & POLSENBERG, 2004; LEDLIE *et al*., 2007; ROFF & MUMBY, 2012; CRUZ *et al.*, 2016). Implicações de tal mudança são a perda de complexidade estrutural e capacidade de construção dos recifes, resultando em uma mudança na composição de espécies e diminuição da biodiversidade (DUDGEON et al., 2010; CRUZ; KIKUCHI; CREED, 2016).

As mudanças climáticas trazem consequências como o aumento da temperatura e a acidificação da água. Temperaturas mais altas causam o branqueamento dos corais devido a perda de pigmento e/ou células de seus dinoflagelados simbióticos essenciais (HOEGH-GULDBERG, 2011). O equilíbrio do CO_2 atmosférico com as águas superficiais dos oceanos leva à diminuição do pH, em um processo conhecido como acidificação, que diminui as taxas de calcificação dos corais e outros organismos que precipitam $CaCO_3$ nos oceanos (EREZ *et al.*, 2011). A sobrepesca desequilibra o ecossistema, resultando em mudanças no tamanho dos peixes, abundância e composição de espécies dentro das comunidades recifal e a remoção de espécies-chave de herbívoros e predadores pode causar grandes mudanças no ecossistema (BRYANT *et al.*, 2016). Na Jamaica, décadas de sobrepesca levaram a uma drástica diminuição de peixes herbívoros e os ouriços-do-mar passaram a atuar como controladores de algas. Entretanto, uma doença causou a mortalidade em massa dos ouriços permitindo que as algas dominassem os recifes (HUGHES, 1994). Já a diminuição da qualidade da água principalmente relacionada à sedimentação e turbidez tem efeitos como o sufocamento de organismos filtradores, redução da taxa de assentamento das larvas de corais e consequente redução da sobrevivência de corais devido à falta de um substrato adequado e à falha no recrutamento (SILVA *et al.*, 2013). A forma mais comum de entrada de poluentes em águas marinhas se dá através do escoamento terrestre de rios e córregos contaminados por atividades agrícolas, industriais e/ou urbanas (VAN DAM *et al.*, 2011).

1.2 RECIFES DE CORAIS NO BRASIL

No Brasil os ambientes recifais são únicos, diferindo significantemente de recifes de corais conhecidos no mundo, os principais construtores são formas arcaicas, remanescentes de uma antiga fauna de coral que remonta ao Terciário. Algas coralinas incrustantes tem um papel muito importante na sua construção e os recifes costeiros são cercados e até mesmo preenchidos com sedimentos siliclásticos lamacentos (LEÃO; KIKUCHI; OLIVEIRA, 2019).

Aqui são encontrados diferentes tipos de recifes de banco, recifes de franja, chapeirões isolados e um atol. No Brasil, podem ser encontrados em quatro grandes regiões, norte, nordeste e leste e nas ilhas oceânicas (LEÃO *et al.*, 2016).

O histórico dos estudos das comunidades coralíneas recifais brasileiras remete aos alemães von Spix e von Martius, que foram os pioneiros em 1828 ao descreverem os arrecifes na Bahia, relatando até o uso dos corais como fonte de cal (SPIX; MARTIUS, 1938). Darwin visitou os recifes que ficam ao redor das ilhas do Arquipélago de Abrolhos. Já em 1870, Hartt publicou uma revisão do estado da arte do conhecimento sobre recifes brasileiros, incluindo uma grande quantidade de informações inéditas. Branner (1904) deu continuidade a estes primeiros estudos fornecendo uma descrição minuciosa dos bancos de arenito da costa nordeste do Brasil (LEÃO, 1999; LEÃO; KIKUCHI; TESTA, 2003; FERREIRA; MAIDA, 2006). Em 1970 foi publicada a descrição mais abrangente sobre os recifes de corais brasileiros (LABOREL, 1970) e então, a partir da década de 1980 diversos estudos na área começaram a ser desenvolvidos (LEÃO; KIKUCHI; TESTA, 2003). Jacques Laborel foi um pesquisador francês que cultivou sua paixão pelo mar e descobriu o mergulho e a biologia marinha em Provença, no sudeste da França. De 1961 a 1964 ele e sua esposa vieram ao Brasil, onde ele descreveu as comunidades coralíneas da costa brasileira como parte da sua tese de doutorado, em um dos trabalhos mais abrangentes sobre o assunto (MORHANGE, 2011; LABOREL-DEGUEN et al., 2019). Ele produziu uma descrição qualitativa e semiquantitativa ao longo de quase toda a costa nordeste do país, detalhando as formações recifais e quantificando a abundância das espécies que observava (FERREIRA; MAIDA, 2006; LABOREL-DEGUEN *et al.*, 2019).

1.2.1 ESTUDO DOS RECIFES DE CORAIS

A maneira como a ciência é feita vem mudando com o passar do tempo e evolução da tecnologia, principalmente quando tratamos do recifes de corais que são ambientes mais difíceis de serem estudados por estarem submersos e geralmente ser encontrados em lugares remotos (MADIN; DARLING; HARDT, 2019). Com a evolução do conhecimento, novas tecnologias com aplicações na ciência e conservação de recifes estão surgindo em um ritmo cada vez mais rápido e tornando-se simultaneamente mais baratas e acessíveis (MADIN; DARLING; HARDT, 2019), mudando a forma como os ambientes recifais são estudados.

Em comparação com outras regiões ao redor do mundo, programas de monitoramento de ambientes recifais tardaram a começar no Brasil. Porém, mesmo em lugares em que eles começaram antes, há problemas com a consistência dos dados. No Caribe, diversos programas de monitoramento se iniciaram em 1983-1984 e dados anteriores a essa data são escassos e não muito consistentes (registros foram compilados por pessoas diferentes em momentos diferentes). Na Austrália, o Programa de Monitoramento de Longo Prazo foi estabelecido em 1983 pelo Instituto Australiano de Ciência Marinha e, no sudeste asiático, o primeiro programa de monitoramento começou nas Filipinas no final da década de 1970. Em 1986 começou o monitoramento em rede regional da Indonésia, Malásia, Filipinas, Cingapura e Tailândia, até 1994. Desde então alguns países aumentaram os esforços de monitoramento enquanto outros diminuíram (TUN et al., 2004; JACKSON et al., 2014; AIMS, 2020). Até o início dos anos 2000 o Brasil era o único país da América do Sul que ainda não havia estabelecido um programa nacional de monitoramento dos recifes de corais. Esse panorama começou a mudar em 2002 quando o projeto “Monitoramento dos Recifes de Coral do Brasil” foi aprovado (FERREIRA; MAIDA, 2006). Infelizmente, quando essa iniciativa começou, muitos dos recifes, principalmente os costeiros, já estavam impactados, prejudicando a referência inicial do estado de conservação desses ambientes. Branner (1904) relatou a prática da retirada de corais para a produção de cal já no ano 1875, descrevendo a ausência de corais vivos no norte do estado da Paraíba (BRANNER, 1904; CASTRO; PIRES, 2001).

Para proteger os recifes de corais de forma mais efetiva e adequada é necessário ter informações sobre esses ambientes em um estado mais próximo do qual eles se encontravam antes dos impactos antropogênicos. Assim, é necessário estabelecer uma linha de base, o mais antiga possível, que possibilite comparações sobre mudanças ao longo do tempo. Os dados históricos podem contribuir para preencher as falhas em conjuntos de dados temporais, ou seja, as lacunas da linha de base ou amnésia cultural, descritas como perdas sociais da memória (PAPWORTH *et al.*, 2009). Essas lacunas ocorrem, pois, cada geração de cientistas tende a tomar como linha de base a abundância de organismos observada no início de suas carreiras, para então avaliar mudanças a partir desse referencial inicial (PAULY, 1995). Sem uma perspectiva de longo prazo, corremos o risco de usar o presente, ou um passado recente, como referência da qualidade do estado ecológico de um determinado ambiente, já que o estado prístino desses ambientes muitas vezes é desconhecido e as mudanças na composição das comunidades podem ocorrer lentamente ao longo do tempo (PAULY, 1995; MACKENZIE; OJAVEER; EERO, 2011).

1.3 ECOLOGIA HISTÓRICA

A acumulação de conhecimento em escalas temporais e espaciais mais amplas se faz necessária para resgatar linhas de base em relação à estrutura das comunidades e entender melhor as mudanças que ocorreram com o passar do tempo (JACKSON *et al.*, 2001). Dessa forma, dados retrospectivos são muito valiosos na pesquisa pois eles fornecem uma linha de base situada no tempo, como uma fotografia do estado anterior de um ecossistema. Eles não apenas ajudam a esclarecer causas e taxas subjacentes de mudanças ecológicas, mas também evidenciam objetivos palpáveis para restauração e gerenciamento de ecossistemas costeiros que não poderiam ser contemplados com base apenas em observações recentes (JACKSON *et al.*, 2001). Estabelecer uma linha de base para as comunidades recifais brasileiras é extremamente importante para os cientistas, gestores e o público em geral para entendermos o quanto dos nossos recifes de corais foram impactados e auxiliar no estabelecimento de patamares para a recuperação.

O termo ecologia histórica vem sendo utilizado com diversos significados desde a primeira metade do século 20. A ecologia histórica é o estudo da natureza através do tempo, muitas vezes com foco nas interações entre os seres humanos e o ambiente e as causas e consequências das mudanças causadas pelos humanos no passado recente (SZABÓ, 2015). Através do uso de dados de diversas disciplinas (registros paleoecológicos e arqueológicos, registros históricos de jornais) Jackson e colaboradores (2001) mostram como eram diversos hábitats marinhos e o que eles se tornaram, enfatizando a importância de reconhecer essas perdas pois elas nos mostram o que esses ambientes poderiam ser. Esta área de conhecimento inclui tanto pesquisas que documentam padrões e dinâmica ecológicos no passado recente utilizando métodos históricos como também aquelas que historicizam a ecologia, ou seja, entender a relação entre a natureza e a cultura humana através do tempo (SZABÓ, 2015; BELLER et al., 2017).

A ecologia histórica pode fornecer novas visões através de uma ampla escala ecológica, incluindo níveis de organização desde a população até a comunidade. No nível de população ela pode abordar questões sobre mudanças de longo prazo no tamanho da população, distribuição e estrutura. No nível de comunidade, ela pode nos ajudar a entender como mudanças na dominância de espécies no passado contribuíram com as mudanças observadas na estabilidade da comunidade (BELLER *et al.*, 2017).

Como campo de estudo, a ecologia histórica opera amplamente na interseção da ecologia, história, antropologia e geografia, usando ferramentas e técnicas de todas as quatro disciplinas para ajudar as pessoas a imaginar quais populações, comunidades, ecossistemas e paisagens existiram no passado e como eles mudaram ao longo do tempo (SZABÓ, 2015). Os tipos de dados usados na ecologia histórica são muito diversos, desde fotografias e mapas, até registros em coleções zoológicas, e dependendo da sua natureza, podem datar de milhares de anos (Figura 1).

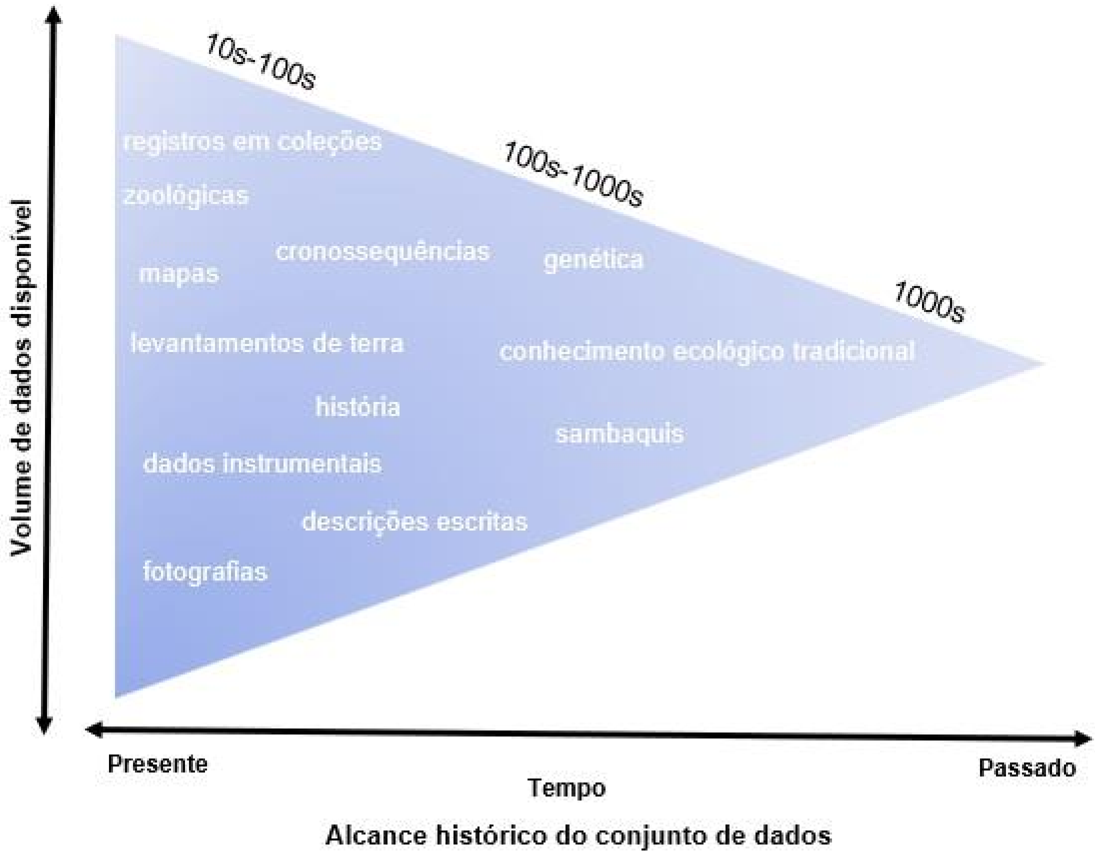

Figura 1 – Tipos de dados que podem ser utilizados na ecologia histórica e seu alcance histórico. (Adaptado de BELLER *et al.*, 2017).

Os seres humanos e os recifes de corais coexistem há milhares de anos. Aproximadamente 1,2 bilhões de pessoas vivem até 100 quilômetros desses ambientes, sendo direta ou indiretamente dependentes destes ambientes. Os recifes de corais desempenham funções ecossistêmicas importantes que se traduzem em inúmeros bens e serviços para toda população mundial (CESAR, 2000). Estima-se que aproximadamente 1 bilhão de pessoas dependam desses ambientes para obtenção de alimento, proteção da costa, práticas culturais e como forma de obtenção renda (RIVERA; CHAN; LUU, 2020).

Os ecossistemas recifais provém diversos benefícios aos seres humanos como a proteção de vilas costeiras da ação das ondas e tempestades, fornecendo benefícios de redução de risco a aproximadamente 100 a 197 milhões de pessoas (HOEGH-GULDBERG;

PENDLETON; KAUP, 2019). Sua estrutura tridimensional cria um complexo hábitat para diversos peixes, sendo fonte da pesca, uma atividade econômica e de subsistência muito importante, além de contribuir para a segurança alimentar e nutricional das pessoas; trazem benefícios biogeoquímicos como a fixação de carbono e nitrogênio; e benefícios culturais e sociais como valor estético, recreação e prática de esportes (MOBERG; FOLKE, 1999). Entretanto, esses ambientes vêm sofrendo diversas ameaças locais como a sobrepesca, despejo de esgoto não tratado, carreamento de efluentes provenientes da agricultura e ameaças globais, relacionadas as mudanças climáticas, como o aumento da temperatura da água causando o branqueamento dos corais e mudanças na composição química da águas dos oceanos, particularmente sua acidificação resultando na diminuição de eficiência de calcificação por parte dos organismos construtores de recife (RIEGL *et al.*, 2009).

Esses benefícios também são conhecidos como serviços ecossistêmicos, ou contribuições da natureza para as pessoas. No início dos anos 2000, o Millenium Ecosystem Assessment (2005) reuniu diversas organizações de mais de 70 países para discutir as consequências das mudanças no meio ambiente para o bem-estar humano. Em 2005, foi publicada a síntese que apresentava os serviços dos ecossistemas divididos em 4 categorias: serviços de aprovisionamento, de regulação, culturais e de suporte. Em uma tentativa de introduzir um novo enquadramento para as relações dos seres humanos com a natureza, objetivando superar as limitações da estrutura na abordagem de serviços ecossistêmicos (SE) e fornecer um novo discurso para os trabalhos a serem desenvolvidas pela Plataforma Intergovernamental de Políticas Científicas sobre Biodiversidade e Serviços Ecossistêmicos (IPBES) Díaz e colaboradores (2018) cunharam o conceito de contribuições da natureza para as pessoas (NCP) (DÍAZ *et al.*, 2018; MURADIAN; GÓMEZ-BAGGETHUN, 2021). As NCP são todas as contribuições, tanto positivas quanto negativas, da natureza viva (diversidade de organismos, ecossistemas e seus processos ecológicos e evolutivos associados) para qualidade de vida das pessoas (DÍAZ *et al.*, 2018). Elas estão divididas em 18 categorias: Criação de hábitat e manutenção, Polinização e dispersão de sementes e outros propágulos, Regulação da qualidade do ar, Regulação do clima, Regulação da acidificação do oceano, Regulação da quantidade, localização e tempo da água doce, Regulação da qualidade da água costeira e doce, Formação, proteção e descontaminação dos solos e sedimentos, Regulação de perigos e eventos extremos, Regulação de organismos prejudiciais e processos biológicos, Energia, Alimentos e alimentação, Materiais, companhia e mão de obra, Recursos medicinais, bioquímicos e genéticos, Aprendizado e inspiração, Experiências físicas e psicológicas, Apoio a identidades e Manutenção de opções; estas categorias estão divididas em 3 grupos abrangentes: NCP materiais, NCP não-materiais e NCP de regulação (DÍAZ *et al.*, 2018).

Em vista das ameaças enfrentadas pelos ambientes recifais tanto em escala global (aumento da temperatura e acidificação dos oceanos, sobrepesca) como em escala regional (crescimento urbano desorganizado, deficiência no tratamento de esgoto, desmatamento, mineração) (LEÃO; KIKUCHI; OLIVEIRA, 2019) é essencial conhecer não apenas o estado atual desses ecossistemas, mas também o seu passado para que objetivos palpáveis para sua restauração e gerenciamento possam ser traçados. Nesse contexto, esta dissertação está dividida em dois capítulos. No primeiro capítulo pretendemos compilar e padronizar as informações semiquantitativas da estrutura taxonômica e funcional da comunidade coralínea a partir da obra descritiva de Jacques Laborel e estabelecer a linha de base mais antiga para as comunidades recifais de Abrolhos e Porto de Galinhas. Nossas hipóteses são: a) haverá maiores mudanças em ambientes recifais mais próximos a costa e menores mudanças em ambientes recifais mais afastados mas que ainda se encontram na plataforma continental e, b) a composição da comunidade de coral será diferente ao longo dos anos, as espécies mais abundantes no passado não serão as mesmas. No segundo capítulo, nosso objetivo é analisar a percepção sobre mudanças nos serviços ecossistêmicos providos pelos recifes de corais por pesquisadores, mergulhadores e usuários dos recifes de corais. Esperamos que, devido à degradação dos ambientes recifais, usuários com mais idade, portanto, mais experiência, irão perceber mais mudanças em comparação com aqueles com menos experiência no mesmo ambiente. Por fim, nas considerações finais recomendamos algumas ações para que sua restauração e gerenciamento possam ser traçados.

REFERÊNCIAS

AIMS. Understanding how the Great Barrier Reef is changing Information about the AIMS Long-Term Monitoring Program. 2020.

BARBER, Richard T.; HILTING, Anna K.; HAYES, Marshall L. The changing health of coral reefs. **Human and Ecological Risk Assessment: An International Journal**, v. 7, n. 5, p. 1255-1270, 2001.

BELLER, Erin et al. Toward principles of historical ecology. **American Journal of Botany**, v. 104, n. 5, p. 645-648, 2017.

BELLWOOD, D. R. et al. Fifty million years of herbivory on coral reefs: fossils, fish and functional innovations. **Proceedings of the Royal Society B: Biological Sciences**, v. 281, n. 1781, p. 20133046, 2014.

BONALDO, Roberta M.; BELLWOOD, David R. Size-dependent variation in the functional role of the parrotfish Scarus rivulatus on the Great Barrier Reef, Australia. **Marine Ecology Progress Series**, v. 360, p. 237-244, 2008.

BRANDL, Simon J. et al. Coral reef ecosystem functioning: eight core processes and the role of biodiversity. **Frontiers in Ecology and the Environment**, v. 17, n. 8, p. 445-454, 2019.

BRANNER, J. C. The stone reefs of brazil: their geological and geographical relations, with a chapter on the coral reefs vol 7. Museum, 1904.

BRYANT, Dirk et al. Reefs at risk: a map-based indicator of threats to the world's coral reefs. 1998.

CARILLI, Jessica E. et al. Local stressors reduce coral resilience to bleaching. **Plos one**, v. 4, n. 7, p. e6324, 2009.

CASTRO, Clovis B.; PIRES, Débora O. Brazilian coral reefs: what we already know and what is still missing. **Bulletin of Marine Science**, v. 69, n. 2, p. 357-371, 2001.

CESAR, Herman SJ. Coral reefs: their functions, threats and economic value. 2000. In: Collected essays on the economics of coral reefs. **Coral Reef Degradation in the Indian Ocean Program**, Kalmar University, Kalmar, Sweden.

CRUZ, Igor C.; KIKUCHI, Ruy K.; CREED, Joel C. Ecological processes of phase shift to Palythoa grandiflora dominance on reefs of Todos-os-Santos Bay, Brazil. In: **Front. Mar. Sci**. Conference Abstract: XIX Iberian Symposium on Marine Biology Studies. 2016.

DÍAZ, Sandra et al. Assessing nature's contributions to people. **Science**, v. 359, n. 6373, p. 270-272, 2018.

DUDGEON, Steve R. et al. Phase shifts and stable states on coral reefs. Marine **Ecology Progress Series**, v. 413, p. 201-216, 2010.

EREZ, Jonathan et al. Coral calcification under ocean acidification and global change. In: Coral reefs: an ecosystem in transition. **Springer**, Dordrecht, 2011. p. 151-176.

FERREIRA, Beatrice Padovani; MAIDA, Mauro. **Monitoramento dos recifes de coral do Brasil**. Brasília, DF: MMA, Secretaria de Biodiversidade e Florestas, 2006.

HARBORNE, Alastair R. et al. Multiple stressors and the functioning of coral reefs. **Annual Review of Marine Science**, v. 9, p. 445-468, 2017.

HOEGH-GULDBERG, Ove. The impact of climate change on coral reef ecosystems. In: Coral reefs: an ecosystem in transition. **Springer**, Dordrecht, 2011. p. 391-403.

HOEGH-GULDBERG, Ove; PENDLETON, Linwood; KAUP, Anne. People and the changing nature of coral reefs. **Regional Studies in Marine Science**, v. 30, p. 100699, 2019.

HUGHES, Terence P. Community structure and diversity of coral reefs: the role of history. **Ecology**, v. 70, n. 1, p. 275-279, 1989.

HUGHES, Terence P. Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. **Science**, v. 265, n. 5178, p. 1547-1551, 1994.

JACKSON, Jeremy BC et al. Historical overfishing and the recent collapse of coastal ecosystems. **Science**, v. 293, n. 5530, p. 629-637, 2001.

JACKSON, J. B. C. et al. Status and trends of Caribbean coral reefs. **Global coral reef monitoring network, IUCN, Gland, Switzerland**, p. 1970-2012, 2014.

KNOWLTON, Nancy. The future of coral reefs. **Proceedings of the National Academy of Sciences**, v. 98, n. 10, p. 5419-5425, 2001.

LABOREL-DEGUEN, F. et al. Recifes do Brasil: O Legado de Laborel. Rio de Janeiro, Museu Nacional. **Série Livros**, n.64. 376p. 2019.

LABOREL, Jacques. Les peuplements de madréporaires des côtes tropicales du Brésil. Université d'Abidjan, 1970.

LEÃO, Zelinda MAN; KIKUCHI, Ruy KP; TESTA, Viviane. Corals and coral reefs of Brazil. In: **Latin American coral reefs**. Elsevier Science, 2003. p. 9-52.

LEÃO, Zelinda MAN et al. Brazilian coral reefs in a period of global change: A synthesis. **Brazilian Journal of Oceanography**, v. 64, p. 97-116, 2016.

LEÃO, Zelinda M. A. N.; KIKUCHI, Ruy K. P.; OLIVEIRA, Marília D. M. The Coral Reef Province of Brazil. In: **World Seas: An Environmental Evaluation**. Volume I: Europe, the Americas and West Africa, [S. l.], p. 813–833, 2019.

LEDLIE, M. H. et al. Phase shifts and the role of herbivory in the resilience of coral reefs. **Coral Reefs**, v. 26, n. 3, p. 641-653, 2007.

MCMANUS, John W.; POLSENBERG, Johanna F. Coral–algal phase shifts on coral reefs: ecological and environmental aspects. **Progress in Oceanography**, v. 60, n. 2-4, p. 263-279, 2004.

MAIDA, Mauro; FERREIRA, Beatrice Padovani. Coral reefs of Brazil: an overview. In: **Proceedings of the 8th international coral reef symposium**. Smithsonian Tropical Research Institute Panamá, 1997. p. 263-273.

MILLENNIUM ECOSYSTEM ASSESSMENT. Ecosystems and human well-being: synthesis. Island. **Washington, DC**, 2005.

MACKENZIE, Brian R.; OJAVEER, Henn; EERO, Margit. Historical ecology provides new insights for ecosystem management: eastern Baltic cod case study. **Marine Policy**, v. 35, n. 2, p. 266-270, 2011.

MOBERG, Fredrik; FOLKE, Carl. Ecological goods and services of coral reef ecosystems. **Ecological economics**, v. 29, n. 2, p. 215-233, 1999.

MORHANGE, Christophe. In Memoriam: Jacques Laborel (1934–2011). **Journal of Coastal Research**, v. 27, n. 6, p. 1209-1210, 2011.

MURADIAN, Roldan; GÓMEZ-BAGGETHUN, Erik. Beyond ecosystem services and nature's contributions: Is it time to leave utilitarian environmentalism behind?. **Ecological Economics**, v. 185, p. 107038, 2021.

NASH, Kirsty L. et al. Drivers of herbivory on coral reefs: species, habitat and management effects. **Marine Ecology Progress Series**, v. 554, p. 129-140, 2016.

NORSTRÖM, Albert V. et al. Alternative states on coral reefs: beyond coral–macroalgal phase shifts. **Marine ecology progress series**, v. 376, p. 295-306, 2009.

NYSTRÖM, Magnus; FOLKE, Carl; MOBERG, Fredrik. Coral reef disturbance and resilience in a human-dominated environment. **Trends in ecology & evolution**, v. 15, n. 10, p. 413-417, 2000.

O'HIGGINS, Timothy G. et al. Habitat scale mapping of fisheries ecosystem service values in estuaries. **Ecology and society**, v. 15, n. 4, 2010.

PAULY, Daniel. Anecdotes and the shifting baseline syndrome of fisheries. **Trends in ecology & evolution**, v. 10, n. 10, p. 430, 1995.

PAPWORTH, Sarah K. et al. Evidence for shifting baseline syndrome in conservation. **Conservation letters**, v. 2, n. 2, p. 93-100, 2009.

RANDAZZO-EISEMANN, Ángela; GARZA-PÉREZ, Joaquín Rodrigo; FIGUEROA-ZAVALA, Baruch. The role of coral diseases in the flattening of a Caribbean Coral Reef over 23 years. **Marine Pollution Bulletin**, v. 181, p. 113855, 2022.

RICHARDSON, Laura E.; GRAHAM, Nicholas AJ; HOEY, Andrew S. Coral species composition drives key ecosystem function on coral reefs. **Proceedings of the Royal Society B**, v. 287, n. 1921, p. 20192214, 2020.

RIVERA, Hanny; CHAN, Andrea; LUU, Victoria. Coral reefs are critical for our food supply, tourism, and ocean health. We can protect them from climate change. **MIT Sci. Policy Rev**., v. 1, p. 18-33, 2020.

ROBERTS, Callum. The unnatural history of the sea. **Island Press**, 2007.

ROFF, George; MUMBY, Peter J. Global disparity in the resilience of coral reefs. **Trends in ecology & evolution**, v. 27, n. 7, p. 404-413, 2012.

SILVA, A. S. et al. Sedimentation in the coastal reefs of Abrolhos over the last decades**. Continental Shelf Research**, v. 70, p. 159-167, 2013.

SPIX, Johan B. von; MARTIUS, Carl FP von. Viagens pelo Brasil. **Tradução de LF Lahnmeyer**. Rio de Janeiro: Imprensa Nacional, v. 4, 1938.

SZABÓ, Péter. Historical ecology: past, present and future. **Biological Reviews**, v. 90, n. 4, p. 997-1014, 2015.

TILMAN, David. Functional diversity. In: **Encyclopedia of biodiversity**, v. 3, n. 1, p. 109-120, 2001.

TUN, Karenne et al. Status of coral reefs, coral reef monitoring and management in Southeast Asia 2004. In: **Status of coral reefs of the world: 2004**. Townsville: Australian Institute of Marine Science. 235-276.

VAN DAM, Joost W. et al. Chemical pollution on coral reefs: exposure and ecological effects. In: **Ecological impacts of toxic chemicals**. Sharjah, UAE: Bentham Science Publishers Ltd., 2011. p. 187-211.

CAPÍTULO 1

[1]Decades of change in Brazilian coral reef assemblages

[1] Text formatting for the selected journal will be changed at the time of submission.

Decades of change in Brazilian coral reef assemblages

Abstract

Coral reefs are amongst the most complex, productive, and biologically diverse ecosystems on Earth. Despite their important ecological role, these ecosystems have faced many challenges over the past century. To better understand how ecosystems are being affected by human impacts it is important to examine how they have changed over time. In the absence of pristine ecosystems, one way to rescue past information about ecosystems is through historical ecology. Information on how Brazilian reefs have changed over time is scarce so reconstructing the past of Brazilian coral reefs would give a closer idea to what pristine was for these environments. We hypothesized that there will be a decline in several species abundance between 1962 and 2017 and coral community composition will be different over the years resulting in a change in species dominance and the most abundant species in the past will not be the same nowadays. We used historical data and a literature review performed on Google Scholar searching for quantitative or semi-quantitative information on coral cover for Abrolhos and Porto de Galinhas. Our analysis showed that data from 1964, 1999 and 2000 do not differ and were brought closely due to abundances of *Millepora nitida, Porites branneri*, *Montastraea cavernosa, Mussismilia hispida* and *Porites astreoides* and *Millepora braziliensis*. Species abundance declined in both locations, affecting mostly the highly branched *Millepora alcicornis* and the endemic *Mussismilia harttii*. Lowering in species abundance is very concerning given that some of them provide structural complexity and are major reef-builders; it could be an opportunity for weedy species to settle in the bottom and start colonizing. In Abrolhos, causes for decline in species abundance seems to be linked to increases in water temperature and overfishing and in Porto de Galinhas human pressures such as sedimentation and disordered tourism appear to be responsible for decrease in abundance of some species.

Keywords: historical ecology, reef environments, South Atlantic

1 INTRODUCTION

Coral reefs are amongst the most complex, productive, and biologically diverse ecosystems on Earth. While coral reefs cover only 0.1 to 0.5% of the ocean floor, they are home to approximately 25% of all marine species (MOBERG; FOLKE, 1999; SPALDING; RAVILIOUS; GREEN, 2002). Despite their important ecological role, these ecosystems have faced many challenges over the past century. Their degradation has been documented since early years of the 1900s (JOHANNES, 1975). Globally, major threats are overfishing and destructive fishing, watershed-based pollution, coastal-based pollution and damage, coastal development, thermal stress, and ocean acidification (BURKE *et al.*, 2011).

The age of Anthropocene escalated numerous pressures on natural environments challenging researchers to understand how to maintain crucial ecosystem functions to sustain coral reefs (HUGHES *et al.*, 2017). Climate change has increased the frequency of SST anomalies, responsible for bleaching events all around the globe (e.g., CASTRO; PIRES, 1999; MIRANDA; CRUZ; LEÃO, 2013; ALEMU; CLEMENT, 2014; DIAS; GONDIM, 2016; STUART-SMITH et al., 2018; TEIXEIRA et al., 2019) and has caused ocean acidification (HARBORNE *et al.*, 2017). Kroeker *et al* (2013) suggested that ocean acidification most impacted survival and calcification whereas growth and development were less affected. Overfishing destabilizes the ecosystem provoking changes in fish sizes, abundance, and composition of species within the reef community (BRYANT *et al.*, 2016). In Jamaica, decades of overfishing led to a sharp decline in herbivorous fish abundance and dominance of algae (HUGHES, 1994). Declines in water quality due to sedimentation and sewage discharge severely impact coral growth and/or reproduction (KOOP *et al.*, 2001; TARRANT; ATKINSON; ATKINSON, 2004; WEAR; THURBER, 2015). Tarrant and collaborators (2015) performed a spawning experiment in which exposure to estradiol decreased the number of bundles spawned by *Montipora capitata* colonies by 29%. Loss of dominant reef-building species resulting shifts in species dominance can have cascading and often destabilizing effects on ecological structure and function, and the capacity of these habitats to continue providing ecosystem services to society (TOTH *et al.*, 2019).

Aside these threats, in Brazil, these environments suffered countless losses due to harvesting of corals to build fortresses and to produce lime for more than 350 years and have been facing a great increase in sediment flux to the ocean as a result of deforestation, pollution from crops and lack of sanitation in coastal cities (FERREIRA; MAIDA, 2006). In Pernambuco state (8º 04' 03'', 34º 55' 00'' W), due to the incentive of the Brazilian Government in 1975 to increase ethanol production from sugarcane, there was an enormous rise in vinasse dump in rivers, polluting the sea. In 1983, a leak spreading vinasse in the metropolitan region of Recife caused the death of 50 tons of fish and an estimated reduction of 60% of invertebrates (BRAGA, 1985 apud CORREIA *et al.,* 2016).

In order to better understand how ecosystems are being affected by human impacts it is important to examine how they have changed over time, or how they differ from pristine reefs. In the case where pristine ecosystems are absent, one way to rescue past information about ecosystems is through historical ecology. This field of study encompasses many other disciplines such as geography, ecology, history, and anthropology (SZABÓ, 2015). Historical ecology concerns about the relationship between human culture and nature through time seeking to understand causes and consequences of environmental changes (BELLER *et al.*, 2017; SZABÓ, 2015). Numerous scientific papers using this approach have been published for different types of environments. Fitzpatrick & Keegan (2007) combined several data sets finding decimation of reef structures in Barbados, decline in land crabs and overharvesting of marine fish; Palomares and collaborators (2017) suggested a decrease in perceived occurrences of turtles, fish and invertebrates in Raja Ampat Archipelago; James and Lanman (2012) discovered an extended range for beavers before 1850 into California's Sierra Nevada using radiocarbon dating of wood (MCCLENACHAN *et al.*, 2015).

Brazilian reef province spreads along 3000 km (0°50′S to 18°00′S) (LEÃO; KIKUCHI; OLIVEIRA, 2019). Low diversity of species (total of 40 species) and high endemism (20 endemic species) are distinct features of Brazilian reef environments (CASTRO; ZILBERBERG, 2016). Furthermore, encrusting coralline algae plays an important role in the reef building process (LEÃO; KIKUCHI; OLIVEIRA, 2019). Information on how Brazilian reefs have changed over time is scarce. The study of reef environments in Brazil started with Spix and Martius, Darwin, Hartt, Verril, Branner and others in the 19th century and early 20th century (LEÃO; KIKUCHI; TESTA, 2003). In the late 70s scientists intensified research, providing information about flora and fauna, mapping reef areas and characterizing reef sub environments (LEÃO; KIKUCHI; TESTA, 2003). Coral reef monitoring started after 2002 (FERREIRA; MAIDA, 2006).

Reconstructing the past of Brazilian coral reefs would give a closer idea of what the pristine was for these environments, helping managers and researchers to establish tangible goals for conservation. We hypothesized there will be greater changes in inshore reef environments and smaller changes in offshore reefs; and coral community composition will be different over the years resulting in a change in species dominance, most abundant species in the past will not be the same nowadays. The choice of study areas was made based on the amount of historical data available and to include different types of reef environments.

2 MATERIALS AND METHODS

To select quantitative studies on benthic reef community for a timeline comparison we did a literature review on Google Scholar using the key words: “coral reef”, “Abrolhos”, “Porto de Galinhas” and “Brazil”. All articles or thesis containing quantitative or semi-quantitative information on coral cover for Abrolhos and Porto de Galinhas were examined. Studies were selected for comparison only if they quantified abundance of most constituent species in coral communities (as opposed to single species) and included quantification of reef top structures.

Study area

Abrolhos

The Abrolhos bank is an enlargement of the eastern Brazilian continental shelf (17º 20’-18º 10’S and 38º 35’ - 39º 20’W) up to 200 km off Caravelas municipality, located on the eastern shore of Brazil, between the southern coast of Bahia State and the northern coast of Espírito Santo State, with mean depth of 30 m (LEÃO *et al.*, 2001; LEÃO, 1999). In 1983 the Abrolhos Marine National Park was created, however only installed by the authorities in 1987. The park is divided in two areas: a smaller one, comprising the Timbebas reef, and a major one that harbors the Abrolhos Archipelago and coral reefs in the outer arc (LEAO *et al.*, 1996). A unique coral community, distinct from other parts of Brazil inhabit Abrolhos (Laborel, 1970), composed of several endemic species, including *Mussismilia braziliensis* and *Mussismilia leptophylla*. Abrolhos is of special conservation concern as an important site for fisheries, harboring large populations of species with high commercial value (DUTRA *et al.*, 2012). The Abrolhos reef ecosystem occupies around 6,000 km^2 of the northern Abrolhos Bank, it is manly constituted by bank reefs parallel to the coastline forming the inner arc, closer to the shore and affected by processes occurring in the mainland and the outer arc, about 60 km off the coast and influenced by the Brazilian Current (LEÃO et al., 2001; DUTRA; KIKUCHI; LEAO, 2006). Abrolhos is the largest and most well-studied coral reefs in the South Atlantic also including sand banks, volcanic islands, embryonic fringing reefs, and waterways (PITOMBO; RATTO; BELEM, 1988; LEÃO, 1999; KIKUCHI et al., 2003; GIGLIO; LUIZ; SCHIAVETTI, 2016).

Porto de Galinhas

Porto de Galinhas beach is located in the municipality of Ipojuca, southern coast of Pernambuco State (8º30'26"S and 34º59'52"W). Along this beach, a 1.5 km long reef is located very close to the shore with 3 major rectangular blocks in which the reef construction is guaranteed mostly by calcareous algae, milleporids (mainly *M. braziliensis*) and *Siderastrea* spp (LABOREL, 1970). Jacques Laborel (1970) illustrated a reef block (Figure 1) in the external slope with *Palythoa* on top, followed by a section of *Millepora alcicornis,* right below a section with *Mussismilia hartii* measuring almost 1m in diameter and other species such as *Millepora braziliensis*, *Siderastrea* spp and *Mussismilia hispida,* the next section was described as having columns and curtains of *Montastraea cavernosa* almost 3m high and some *Mussismilia hispida* and *Siderastrea* touching the sediment; according to Laborel, this zonation in the reef of Porto de Galinhas was the prettiest seen by him in the North East region of Brazil. In the 90s there was rapid expansion of tourism activities in Porto de Galinhas, consisting of rafting tours in natural pools, walks over the reefs and scuba diving. In 2000 Porto de Galinhas was consolidated as a national tourist destination and in 2002 as an international destination (MENDONÇA, 2004 apud

MACHADO et al., 2009). In order to preserve this environment, 85% of the reef tops were isolated in 2009 to create protected areas (SANTOS *et al.*, 2015).

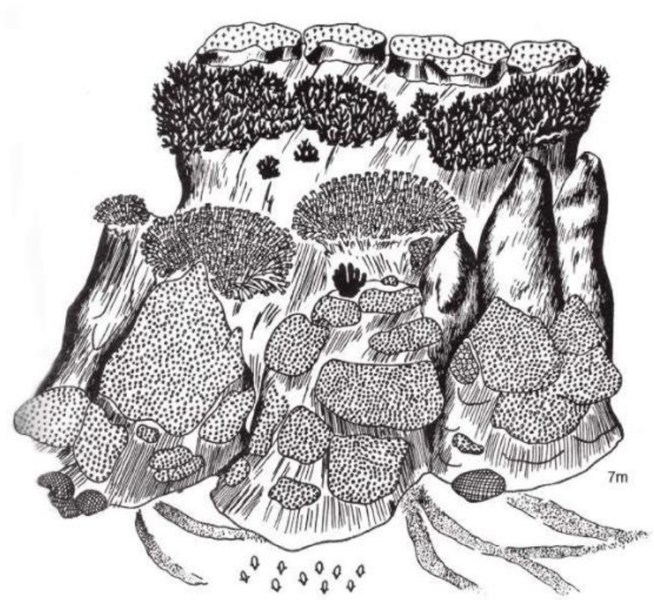

Figure 1 – Jacque´s Laborel illustration of a coral reef block in the external slope in Porto de Galinhas (LABOREL, 1970 *apud* LABOREL-DEGUEN et al, 2019).

Data collection

For the pioneering work of Jacques Laborel (1970), Lami (2017) examined his field notes to extract semi-quantitative data absent from his monograph. Species presence and abundance scores for all sites visited by Laborel were placed in a spatially referenced database by Lami (2017) and used here after a reorganization of the data and a review of species names. We compared Jacques Laborel's baseline (LABOREL, 1970) with five other studies for Abrolhos (PITOMBO; RATTO; BELEM, 1988; CASTRO *et al*., 2005; SEGAL; CASTRO, 2002, 2011; FRANCINI-FILHO *et al*., 2013). For Porto de Galinhas, three different data sets were compared with historical data (LABOREL, 1970; BARRADAS et al., 2010; DE LIMA, 2017; DA SILVA, 2018). For both locations, oftentimes different sections of the reef were sampled in each study and sometimes the same sections were sampled.

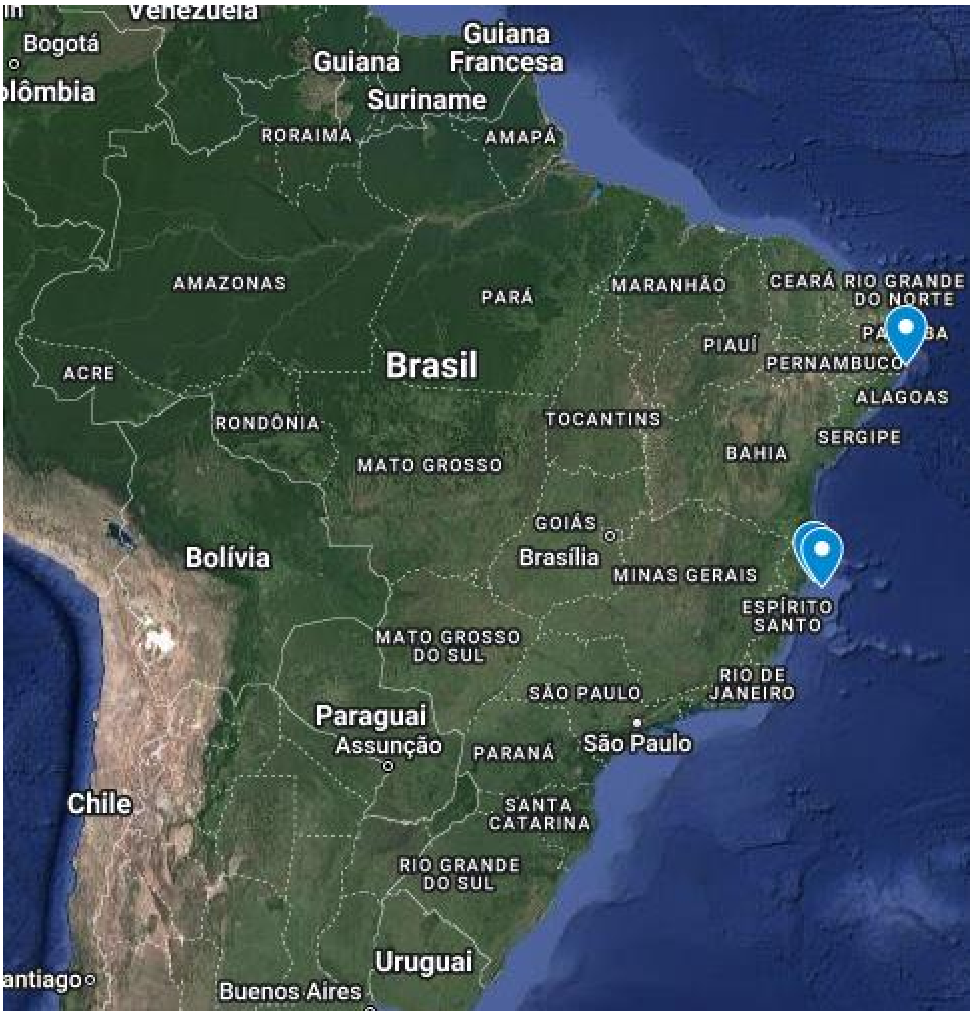

Figure 2 – Map of data collection locations in Porto de Galinhas - PE and Abrolhos - BA.

Summary of data – *Abrolhos*

Jacques Laborel (1970) conducted observations in two sites: Parcel dos Abrolhos, Parcel da Paredes and Abrolhos Archipelago. Abundance scores were provided for each species: CCC (widespread), CC (very common), C (common), AC (reasonably common), AR (reasonably rare), R (rare), RR (very rare). His data collection was carried out in 1962 and 1964, here we combined data from these two years and used as a single baseline represented by the label 1964.

Pitombo and collaborators (1988) quantified coral colony abundances and coral cover along 20 m transects within the coralline zone at different depths, according to the method proposed by Loya (1972). In Santa Barbara Island three transects were set in three depths (3.0 m, 3.2 m, and 4.0 m). In Siriba Island four transects were set in four depths (0.7 m, 1.7 m, 1.9 m, and 2.9 m). In each transect the number of colonies was counted and average size was measured. To use Pitombo *et al.* (1988) data, we calculated for all transects how many centimeters of the 20m transect each species occupied by multiplying the mean colonial length per number of colonies. After that we calculated the percentage of cover by dividing the length occupied by each species per 2000 cm (transect length) and multiplied the result by 100 to obtain the percentage.

Segal & Castro (2002) sampled three localities in depths between 1.9 and 4.0 m: northern and southern shores of Santa Bárbara Island, and the northern shore of Siriba Island. Data was collected in 1997. Five replicates of point-intercept transects were performed, using a 20 m weighted rope previously marked with 500 random points at each station. Each organism (species or functional group) positioned below the points was recorded (Segal & Castro, 2002). Coral cover estimation was computed by calculating how many points were attributed to a species in relation to the total. Here we used coral cover data directly extracted from Segal & Castro (2002).

Castro and collaborators (2005) surveyed 45 sites in the northern part of the Abrolhos Bank, including sites in the Abrolhos National Marine Park in the year 2000. In this study we only used data collected in Parcel dos Abrolhos, Parcel da Paredes and Abrolhos archipelago. The reef was divided in 3 parts: top, border and wall, and semi-quantitative estimates and presence-absence data were collected. Visual estimates and a grading system (rare-sparse, common, 1–5% bottom coverage, 5–25%, 25–50%, >50%) adapted from Braun-Blanquet system (POORE, 1955) were used to gather semi-quantitative data. In this study we only used the semi-quantitative estimates from the top position of the reef from Castro *et al.* (2005).

Figure 2 – Sites of data collection by author in the Abrolhos Marine National Park.

Segal & Castro (2011) used ten-meter-long transect lines previously tagged with 250 random points. Each organism (algae, coral or other invertebrate) positioned below each point was recorded. They sampled three sites in 1999 (Pedra de Leste and Pontas Sul, at Parcel das Paredes, and Parcel dos Abrolhos) using 5 point-intercept transects at each of the 3 stations on each site totalizing 15 transects per site (Segal & Castro, 2011). Coral cover estimation was computed by calculating how many points were attributed to a species in relation to the total. Coral cover data was extracted from the paper.

Francini-Filho *et al.* (2013) collected data between 2006 and 2008 using ten fixed photoquadrats per site in reef tops and walls. Relative cover was estimated through the identification of organism below 300 points randomly distributed. We only used data from the Abrolhos Archipelago and Parcel dos Abrolhos reef. Data from this paper was used only to visualize shift in species ranking, we chose to not include it in other analysis due to the availability of data for a few species, lacking assembly quantitative data.

Summary of data - *Porto de Galinhas*

Figure 3 – Sites of data collection by author in Porto de Galinhas – PE.

Jacques Laborel (1970) conducted observations in 1964 on the right and left edges of Porto de Galinhas reef and sampled 2 other areas in the middle of the reef (LAMI, 2017). Abundance scores were provided for each species: CCC (widespread), CC (very common), C (common), AC (reasonably common), AR (reasonably rare), R (rare), RR (very rare). For this location we use the presence/absence data available and the standardized data for coral cover.

Barradas and collaborators (2010) surveyed four stations randomly selected in 2004 along the reef with three transects per station. Two stations had easy access by tourists and two had less visiting. Observations were carried out with scuba diving using a 10 m measurement tape stretched along the reef. Benthic organisms were recorded every 5 cm and cover was calculated by a simple percentage of the transect length. In order to use this data, we estimated coral cover by summing how many times each species was accounted for in each station and calculated a percentage of total points in all transects (2400 points) - (Species total points*100/2400).

Lima (2017) adapted the Reef-check method (HODGSON, 2001) targeting only corals. Five 20 m long transects were surveyed in 2016 and the type of substratum was recorded every 0,5 m. Relative abundance of each species was estimated by the number of colonies of a species in relation to the total number of corals in the sample. In order to use this work, we used the data published by Barradas et al. (2010) in which they estimated a 7.2% cover for hydroids and scleractinian corals. The author presented the relative abundance in a bar graph (Figure 8), so we had to calculate the percentage of each species. Finally, we used the percentage of relative abundance and multiplied by 0.072, obtaining an estimated percentage of cover.

Silva (2018) collected the data in 2016 and 2017 using 20 m long transects in which relative abundance of each species was estimated by the number of species colonies in relation to the total number of colonies of all coral species accounted for in the reef. In order to use this work, we used the data published by Barradas et al. (2010) in which they estimated a 7.2% cover for hydroids and scleractinian corals and used the relative abundance values in Graph 1. We multiplied relative abundance values by 0.072 to estimate the percentage of coral cover.

Data analysis

Due to the lower resolution of the data from Porto de Galinhas we decided to look at it in a qualitative way, comparing species abundances from past with present and evaluating presence/absence data for some species. To standardize the data, observations were scored according to a semi-quantitative scale, based on abundance categories applied in Rapid Assessment (CASTRO *et al.*, 2005) (Table 1). The remaining categories employed by Laborel were attributed the same semi-quantitative scale used in Castro and collaborators (2005) was applied to the whole dataset.

Table 1 – Standardization of coral species cover data in Abrolhos. Other authors refer to the ones that we used the data and are not mentioned in the first line of the

table. These authors were not mentioned individually because their data was obtained in percentage (PITOMBO; RATTO; BELEM, 1988; SEGAL; CASTRO, 2002, 2011; FRANCINI-FILHO et al., 2013).

Abundance	Laborel 1962,1964	Castro *et al.* 2005	Other authors (% of cover)	Standardization
Superabundant (S)	CCC	>50%	>50%	6
Abundant (A)	CC	25-50%	25,01 - 50,0%	5
Common (C)	C	5-25%	5,01 - 25,0%	4
Frequent (F)	AC	1-5%	1,01 - 5,0%	3
Occasional (O)	AR	Common	0,51 – 1,0%	2
Rare (R)	R, RR	Rare-sparse	0,01 – 0,5%	1
Absent (N)	Absent	-	0%	0

To evaluate how species dominance changed over the years we ranked the species from the most abundant to the less abundant. Values from 0 to 6 were attributed to the abundance scores and the mean was calculated for each species' abundance per year. A line graph was plotted to overview changes.

Changes in abundance categories over time were calculated for *Favia gravida*, *Mussismilia braziliensis*, *Mussismilia harttii, Millepora alcicornis*, *Siderastrea stellata, Montastraea cavernosa, Porites astreoides* and *Porites branneri* in Abrolhos and for *Siderastrea* spp., *Millepora alcicornis*, *Mussismilia harttii, Montastraea cavernosa, Mussismilia hispida, Porites astreoides* and Favia gravida in Porto de Galinhas. These species were chosen due to a compatibility of available data in all studies. For each year of observation, the frequency of each abundance class was calculated per species and plotted in a bar chart to observe overall changes.

In order to compare coral community composition among the five studies (and thus over time) in Abrolhos, we performed a Correspondence Analysis (CA) with CA function from the FactoMiner package in R (R STUDIO TEAM, 2020).

3 RESULTS

Abrolhos

For this location, a total of 333 records of species abundance were obtained in this study: 39 records from the 1960s (LABOREL, 1970); 70 records from 1988 (PITOMBO; RATTO; BELEM, 1988); 40 records from 1997 (SEGAL; CASTRO, 2002); 108 observations from 1999 (SEGAL; CASTRO, 2011); and 76 records from 2000 (CASTRO *et al.*, 2005). Data collected by Francini-Filho *et al*. (2013) was used only to compare changes in species ranks and not in the CA because results presented benthic cover for five taxa while here, we use data for 12 species.

The frequency of abundance tiers observed over time in Abrolhos for *Favia gravida*, *Millepora alcicornis*, *Mussismilia braziliensis*, *Mussismilia harttii*, *Siderastrea stellata, Montastraea cavernosa, Porites astreoides* and *Porites branneri* are displayed in Figure 4. For *Favia gravida*, in 1964 most observations considered the species as frequent, while the species was scored as only being occasional or rare in 1997 and 2000. For *Mussismilia braziliensis* from 1964 to 1997 all observations accounted for scores from superabundant to frequent, for subsequent years scores occasional and rare totalized more than 50% of observations. For *Mussismilia harttii* 1964 was the only year in which this species had observation scored as common, in the subsequent years there were no observations higher than frequent. For *Millepora alcicornis,* from 1964 to 1988 all observations were scored as superabundant, abundant or frequent, from 1997 to 2000 scores as occasional and rare appeared along with others. For *Siderastrea stellata,* observations scored as occasional and rare appeared from 1997, between 1964 to 1988 species scores varied from superabundant to frequent. *Montastraea cavernosa* was the only species with 100% of observations in 1964 scored as rare, in the following years observations accounted as rare or occasional totalized less than 50%. *Porites astreoides* only had observations scored as frequent, occasional, and rare, in 1988 all observations were categorized as frequent. For *Porites branneri,* in 1964 and 1988 observations scored as frequent or higher tiers accounted 80%, in the following years scores as occasional and rare prevailed.

A reduction in the abundance category of at least two levels when comparing years 1964 with 2000 was observed in four abundant species, such as *Favia gravida*, *Mussismilia harttii, Millepora alcicornis* and *Siderastrea stellata*. Mainly, species abundances evidently decreased over 40 years.

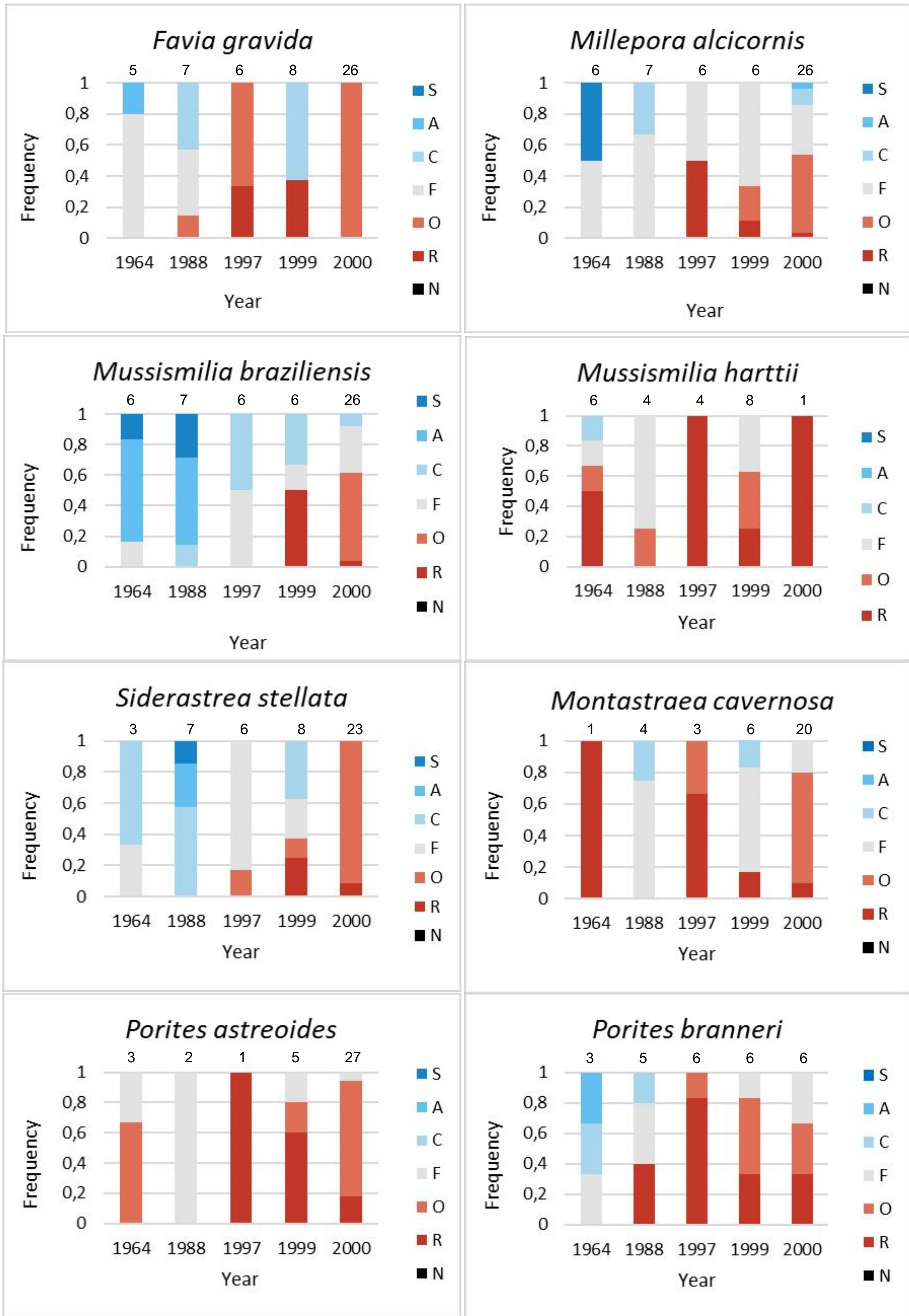

Figure 4 – Changes in abundance through time for Favia gravida, Millepora alcicornis, Mussismilia braziliensis, Mussismilia harttii, Siderastrea stellata, Montastraea cavernosa, Porites astreoides and Porites branneri in Abrolhos-BA. S (superabundant)= >50%, A (abundant)= 25,01 - 50,0%, C (common)= 5,01 - 25,0%, F (frequent)= 1,01 - 5,0%, O (occasional)= 0,51 - 1,0%, R (rare)= 0,01 - 0,5%, N (absent)= 0,0%. Numbers above bars refer to sampling (n).

Changes in species ranks for Abrolhos between 1964 and 2003 can be observed in Figure 5. In general, no great changes were observed in species rank when comparing the first and last year. At the beginning and at the end of sampling period the most abundant species was *Millepora alcicornis, Mussismilia braziliensis* occupied the third position in 1964 and in 2000 rose to second. The least abundant species in 1964 were *Favia gravida, Mussismilia harttii*, *Porites astreoides* and *Porites branneri*, in 2000 was *Mussismilia harttii*.

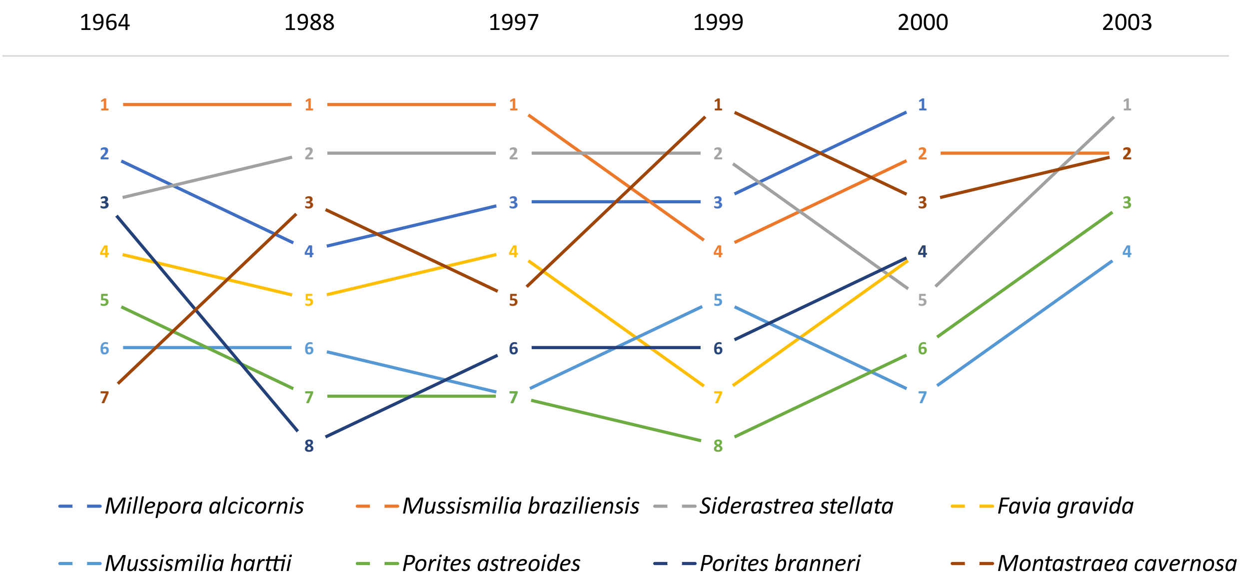

Figure 5 - Shifts in ranking through years for Favia gravida, Millepora alcicornis, Mussismilia harttii, Mussismilia hispida, Montastraea cavernosa, Porites astreoides, Porites branneri and Siderastrea stellata in Abrolhos-BA. 1964 – Laborel aboard Calypso and with Mark Kempf; 1988 – Pitombo et al. at Abrolhos Archipelago; 1997 – Segal & Castro at Abrolhos Archipelago; 1999 – Parcel das Paredes and Parcel dos Abrolhos; 2000 – Castro et al. at Abrolhos Archipelago, Parcel das Paredes, and Parcel dos Abrolhos. 2003 – Francini-Filho et al. (2013) at Abrolhos Archipelago.

The CA (Figure 6) showed 38.2% of the variation explained in the first two axes. In the right side of the graph, it is possible to find most of sites from years 1964, 1999 and 2000. Species that contribute more for this grouping in the positive portion of axis 1 is *Millepora nitida* and *Mussismilia braziliensis*. *Porites branneri*, *Montastraea cavernosa, Mussismilia hispida* and *Porites astreoides* are the species which contribute more to grouping of these years in the negative portion of axis 1. Data collected in 1988 and 1997 are grouped in the negative bottom portion of the axis 2 due to high abundances of *Mussismilia braziliensis* and *Siderastrea stellata*.

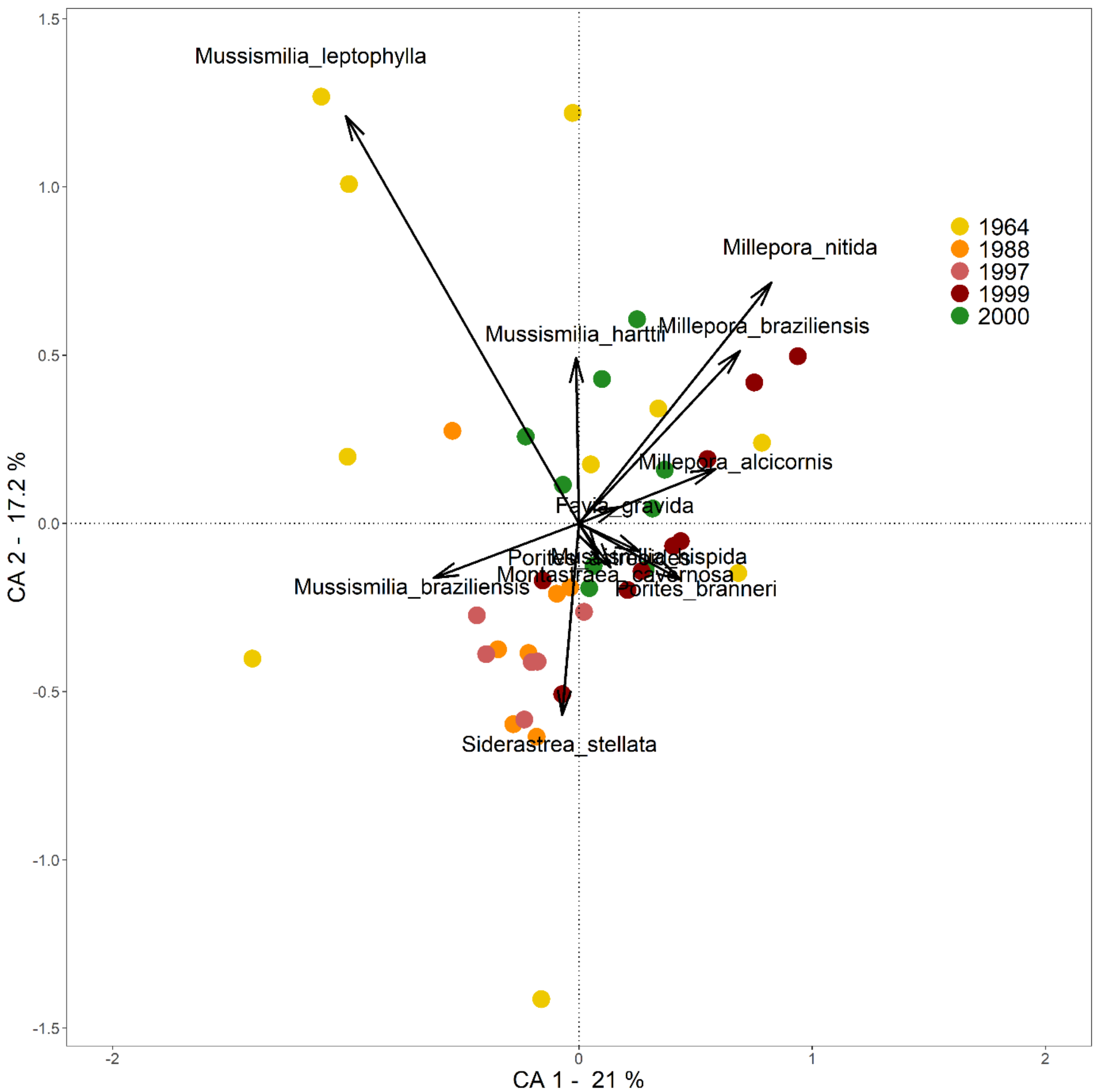

Figure 6 - Correspondence analysis (CA) for benthic organisms' abundance at Abrolhos National Marine Park.

Porto de Galinhas

For this location 32 records of species abundance were gathered, 8 from each year (BARRADAS et al. 2010; LIMA, 2017; SILVA 2018). The frequency of abundance tiers observed over time in Porto de Galinhas for *Siderastrea* spp., *Millepora alcicornis*, *Mussismilia harttii, Montastraea cavernosa, Mussismilia hispida, Porites astreoides* and *Favia gravida* are presented in Figure 7. *Siderastrea* spp was the only taxa with high scores of abundances in recent years. In 1964, this taxa scored as abundant, dropping to rare in 2004 and rising to common in the following year. *Millepora alcicornis* and *Montastraea cavernosa* in 1964 were scored as abundant, over the years the score dropped to rare. Observations for *Mussismilia hispida* in 1964 were scored as common in 1964, dropping to rare in 2017. *Mussismilia harttii* was scored as abundant in 1964, decreasing to rare in 2004. In the following years these species were accounted as absent in samples from this location. *Porites astreoides* was scored in the last two tiers of abundance in 1964, 2004 and 2017; in 2016 the species was absent from sampling. Abundance scores for *Favia gravida* ranged from rare to occasional from 1964 to 2017.

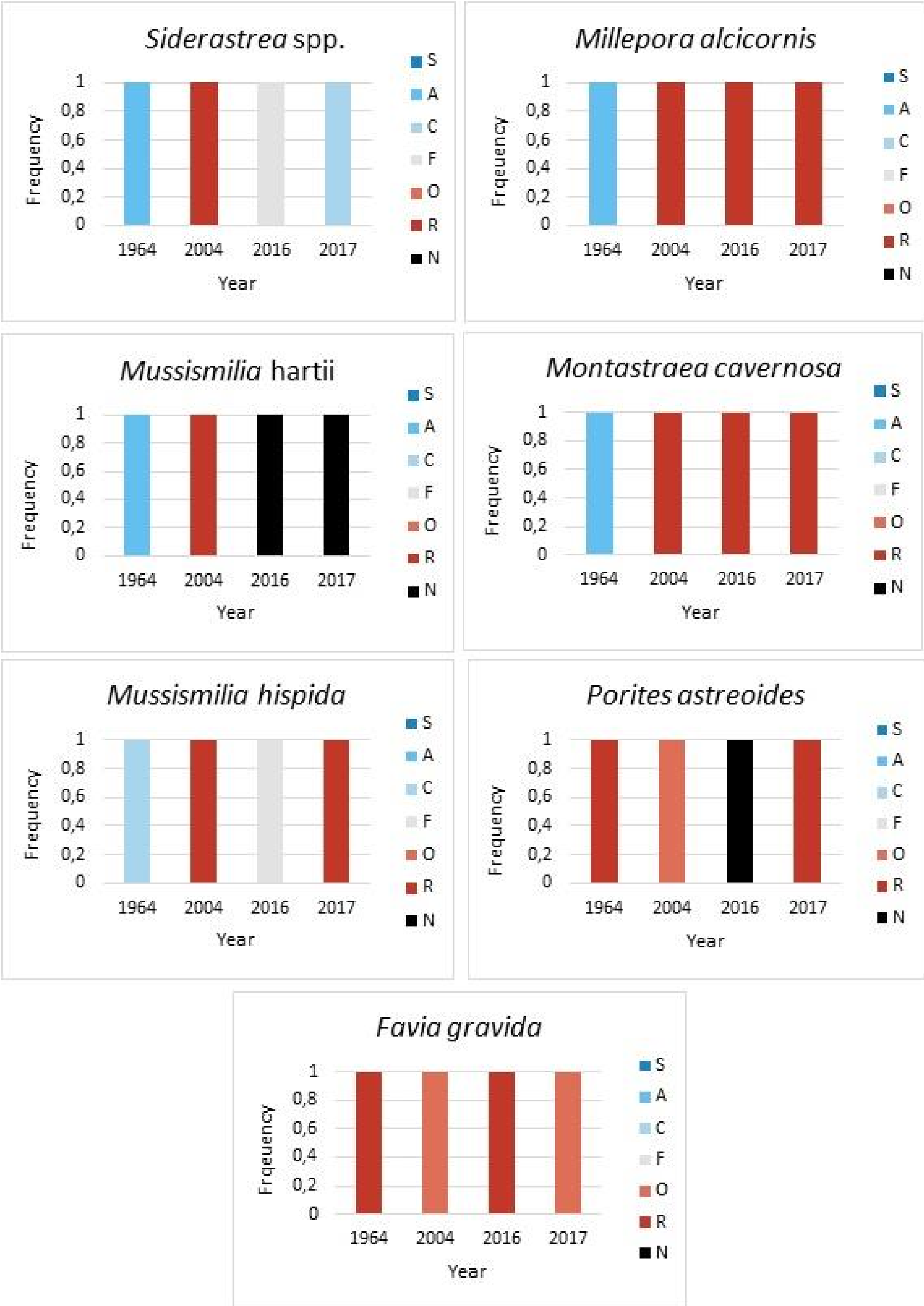

Figure 7 – Changes in abundance through time for Siderastrea spp., Millepora alcicornis, Mussismilia harttii, Montastraea cavernosa, Mussismilia hispida, Porites astreoides and Favia gravida in Porto de Galinhas-PE. S (superabundant)= >50%, A (abundant)= 25,01 - 50,0%, C (common)= 5,01 - 25,0%, F (frequent)= 1,01 - 5,0%, O (occasional)= 0,51 - 1,0%, R (rare)= 0,01 - 0,5%, N (absent)= 0,0%. Pooled data was used to plot the graph (n=1).

Shifts in species ranking for Porto de Galinhas are presented in Figure 8. However, *Mussismilia harttii* was absent for this location in 2016 and 2017 (Figure 4). In 1964, there were 3 species and 1 taxa occupying the first position (*Mussismilia* *harttii, Montastraea cavernosa, Millepora alcicornis* and *Siderastrea* spp*)*. In 2016 this scenario changed, with 2 species absent from sampling (*Porites astreoides* and *Mussismilia harttii*). In 2017 *Siderastrea* spp continued to be the most abundant as well as *Mussismilia hispida* was ranked as second. *Montastraea cavernosa, Millepora alcicornis* and *Favia gravida* occupied the 3rd position in the rank in 2016 and rose up one position in 2017.

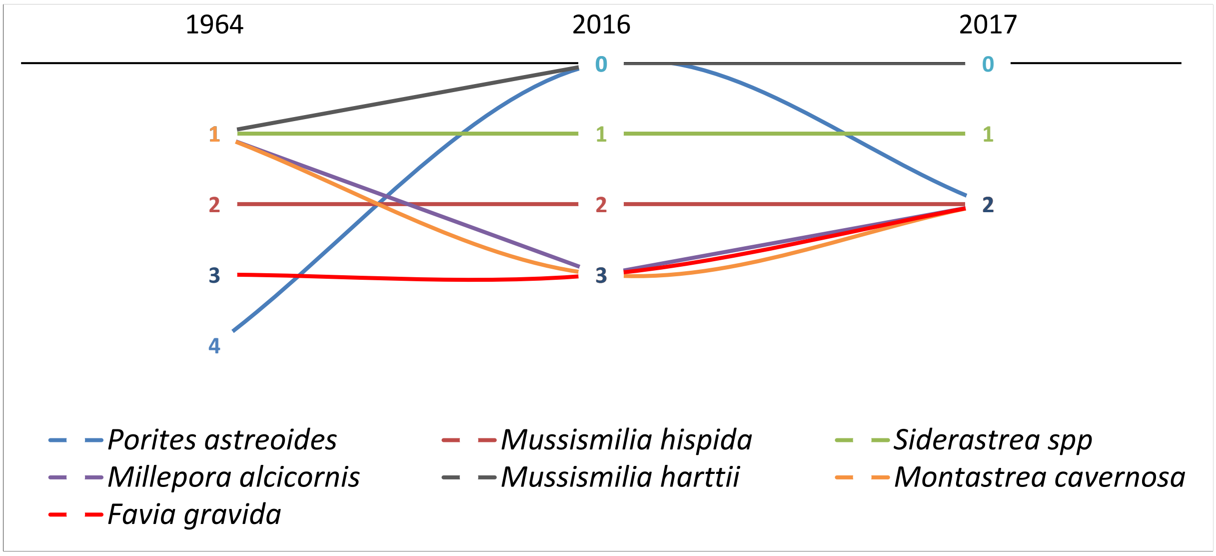

Figure 8 - Changes in ranking for Favia gravida, Millepora alcicornis, Mussismilia harttii, Mussismilia hispida, Montastraea cavernosa and Porites astreoides in Porto de Galinhas-PE.

To understand coral reef composition from the past and nowadays, we compared species and taxa listed in 1964 and in 2016. Jacques Laborel recorded many other species aside the ones shown here; however, for purposes of comparison we used only presence/absence data for species or taxa common to all studies in Porto de Galinhas. Nine species (*Favia gravida, Millepora alcicornis, Millepora braziliensis, Montastarea cavernosa, Mussismilia harttii, Mussismilia hispida, Porites astreoides, Porites branneri* and *Scolymia wellsi*) and one taxa (*Siderastrea* spp) were registered by Jacques Laborel in 1964. In 2016, Lima reported five species (*Favia gravida, Millepora alcicornis, Montastraea cavernosa, Mussismilia hispida* and *Porites branneri*) and one taxa (*Siderastrea* spp). *Millepora braziliensis, Mussismilia harttii, Scolymia wellsi* and *Porites astreoides* were not seen in Porto de Galinhas this year. Silva (2018) cataloged seven species (*Favia gravida, Millepora alcicornis, Montastraea cavernosa, Mussismilia hispida, Porites astreoides, Porites branneri* and *Scolymia wellsi*), one taxa (*Siderastrea* spp) and *Millepora braziliensis* and *Mussismilia harttii* were not seen in the areas sampled.

Table 2 - Comparison of species and taxa listed between Laborel (1970), Lima (2017) and Silva (2018). Years in the table refer to the year in which the data was collected, black dots indicate presence, and the letter “X” indicates absence of species.

Species/Taxa	Laborel (1964)	Lima (2016)	Silva (2016, 2017)
Favia gravida	●	●	●
Millepora alcicornis	●	●	●
Millepora braziliensis	●	X	X
Montastraea cavernosa	●	●	●
Mussismilia harttii	●	X	X
Mussismilia hispida	●	●	●
Porites astreoides	●	X	●
Porites branneri	●	●	●
Scolymia wellsi	●	X	●
Siderastrea spp	●	●	●

4 DISCUSSION

The historical ecology approach used here through the retrieval of information from different sources and data standardization revealed that there were no major changes in the coral reef assemblage over time however, we observed significant changes in species abundance, despite limitations on quantitative data regarding structure of coral reef benthic communities. Overall, there was a decline in coral abundance over the years for both locations, and some species, such as *Mussismilia harttii* and *Millepora braziliensis,* could not be found in Porto de Galinhas in the last surveys. We understand that species abundance varies naturally over time and that different survey methodologies can favor or disfavor the estimation of coral cover (JOKIEL et al., 2015).

Changes in coral reef assemblage over time

Comparison between communities over years did not allow to differentiate them based on the period data was collected. This result can indicate that the coral reef assemblage in Abrolhos had undergone through a change prior 1960 or that there was no or little change due to the resilience of the system in this time frame. It has been suggested that reef corals in the South Atlantic exhibit features that confers resilience to them. Longo and collaborators (2020) reported a remarkable capacity of a colony of *Siderastrea stellata*, one of the main reef builders encountered in Brazil, to recover from a burial showing a healthy-like state after 1 month of reattachment. Other authors point to their great ability to recover from events of bleaching. In 2019, the Abrolhos Reef Bank was affected by the strongest heat wave since 1985, in a monitored area 80% of *Mussismilia braziliensis* colonies bleached (FERREIRA et al., 2021). Six months after the event, all colonies of this species were healthy (FERREIRA et al., 2021). Findings of Mies *et al*. (2020) suggest that characteristics of Brazilian coral reefs that make them less vulnerable to mas coral bleaching are deeper bathymetric distribution, higher tolerance to turbidity, higher tolerance to nutrient enrichment, higher morphological resistance, and more flexible symbiotic associations.

Although results do not show significant changes in the structure of coral reef assemblages in Abrolhos, ecosystem services such as provision by fisheries has been showing changes. Pressure from fishing activities comes from bycatch, aquarium trade, bottom trawling, and overfishing, resulting in several reef-fish species classified as threatened with extinction (GASPARINI et al., 2005; FRANCINI-FILHO; DE MOURA, 2008; BENDER et al., 2013; ROOS et al., 2020).

A few studies describe coral reef loss through time in Brazil. Leão *et al.* (1997) reported a devastating decline in coral cover over the last 3,000 years in north Bahia. They estimated a loss of 19% when comparing old tops with living walls. *Mussismilia braziliensis,* a species considered as the most abundant in the upper level of reef formations in southern Bahia, was absent from the walls of nearshore reefs as well as on the surface of nearshore reef banks at depths of 12-16 m. Fogliarini and collaborators (2022) discovered a loss of 28% in the overall spatial extent of inshore reefs in the Abrolhos region over the past 160 years. The most affected reefs are those close to the shore, which suffered with extraction of corals to be used as lime since the 19th century.

In the 1960s Porto de Galinhas was a small fishing village. The oil crisis in 1973 forced the government to encourage sugarcane culture in the Northeast. One of the residues from ethanol production is vinasse, characterized by its high nutrient content, low pH and high oxygen consumption in aquatic environments, whose effect negative in larvae, recruits and adults of builder corals was found by Correia et al. (2016) (Pérez, 2019). Deforestation in the coast of the municipality of Ipojuca, for urban, industrial and agricultural development, caused great pressures on the coastal ecosystem, increasing erosion from the coast and, therefore, the runoff of water carrying sediments and organic matter to the reef environment (Pérez, 2019).

These findings highlight our results that reef environments found next to the shore have suffered much more impacts due to human activities compared to the reef community in Abrolhos showing the importance of taking action to mitigate impacts.

Changes in species abundances

Declines in species abundances give the opportunity for other ones, with different life strategies to conquer the bottom. Studies based on species traits indicate that 'weedy' species (smaller corals, with brooding reproduction and fast growth) are likely to be more resistant to consequences of reef degradation (KNOWLTON, 2001). Darling *et al.* (2012) used a trait-based approach and identified four life strategies of scleractinian coral: competitive, weedy, stress-tolerant and generalist taxa. Weedy species can thrive in disturbed environments due to their faster reproduction being able to opportunistically settle in freshly perturbed environments and they are poor competitors with algae (DARLING *et al.*, 2012; RANDAZZO-EISEMANN; GARZA-PÉREZ; FIGUEROA-ZAVALA, 2022). Furthermore, this group may be better survivors because of a greater variation in their species traits in comparison to others (DARLING *et al.*, 2012). Species classified as weedy by Darling *et al.* (2012) present in the Brazilian reef fauna are: *Agaricia humilis*, *Madracis decactis*, Porites astreoides, *Agaricia fragilis* and *Agaricia humilis.*

Our results showed that *Porites astreoides* gained ranking positions from 1962 to 2016 in both locations, this ascension indicates a greater contribution of *Porites astreoides* to Brazilian coral reef fauna. In the Caribbean some studies (GREEN; EDMUNDS; CARPENTER, 2008; EAGLESON et al., 2021) have shown an increase in the relative abundance of this species probably due to its weedy life-history strategy. In the Florida Keys Reef Tract, a comparison between Holocene and contemporary assemblages revealed that relative species composition from the Lower, Middle and Uppers Keys is significantly different from the one in the middle Holocene in the same regions, mostly due to relative decreases in *A. palmata*, and *Orbicella* spp (massive coral reef builders) and relative rises in *P. astreoides* and *S. siderea* (weedy species) (TOTH *et al.*, 2019). However, further studies are necessary to understand if this specific group is gaining bottom coverage in Brazil.

In the 1960s, *Mussismilia harttii* was one of the most abundant species in northeast Brazil. Lima (2017) evaluated the state of conservation of the endemic coral *Mussismilia harttii* and registered its local extinction of Porto de Galinhas; only cemeteries of this species could be found. Silva (2018) sampled different sites compared to Lima (2017) and no live colonies of *Mussismilia harttii* were found. A sharp decline was detected in the species abundance for northeast Brazil, from Areia Vermelha reef in the state of Paraíba to Recife de Fora reef in the state of Bahia (LIMA, 2017). The pattern of decreasing abundance of *Mussismilia harttii* could have been widespread in the Brazilian coast, including Abrolhos based on the declines reported by Lima (2017) in nearby areas. Furthermore, the genus *Mussismilia* plays an important role in harboring a great diversity of invertebrate species with higher densities associated to *Mussismilia harttii*, showing its importance on maintaining biodiversity (NOGUEIRA; NEVES; JOHNSSON, 2015). Recently, the Brazilian Ministry of Environment updated the status of *Mussismilia harttii* to an endangered species (MMA, 2022).

The taxa *Siderastrea* spp was the only one which presented high abundance in recent years in Porto de Galinhas. The most common species of this taxa in Brazil is *Siderastrea stellata,* a species resilient due to its brooding reproduction mode in which larvae is released in an advanced stage of development, for having an early onset of reproduction, for its massive skeletons, and medium size colonies (DE

BARROS; PIRES; CASTRO, 2003; DE BARROS; PIRES, 2006). In the Caribbean, a congeneric, very similar species, *Siderastrea radians* is one of the most stress-tolerant species. Its resilience is attributed to the capability of recovering after losing a great percentage of their tissue (LIRMAN; MANZELLO; MACIÁ, 2002).

Decreases in the abundance of *Millepora alcicornis* are very concerning. This species, alongside *Millepora braziliensis,* are the only branching species in the Brazilian coral fauna and play a critical functional role: they harbor several fish species, mainly small-bodied fishes and juveniles of larger species (CONI *et al.*, 2012). Fire-corals have poisonous nematocysts offering protection to those who associate with it (LEWIS, 2006; HOLBROOK, SCHIMITT, 2002). Coni and collaborators (2012) found that juveniles of three species of surgeonfish and three parrotfishes inhabit fire-coral colonies in Abrolhos, showing their importance to the conservation of these species. A recent study reports a greater sensibility of *Millepora alcicornis* to thermal stress, registering a very high mortality rate (~86% in Itacolomis Reef Complex and ~43% in Coroa Vermellha reef) after the 2019 thermal stress (DUARTE *et al.*, 2020).

Furthermore, touristic development is accompanied by urbanization which has much more impacts. In such places infrastructure comes in form of resorts, marinas, harbor, and housing. This urbanization process causes devastation of green areas increasing erosion and pollution due to lack of sanitation and incorrect disposal of garbage (GALVÃO *et al.* 2021). Other possible aggravating factor is the sedimentation. Costa (2012) calculated a sedimentation rate of 229,94 $mg.cm^{-2}.day^{-1}$ for Porto de Galinhas. Burke *et al.* (2001) estimated levels of threat for coral reefs all over the world. In the northeastern region of Brazil, the great majority of reefs are considered as high or very high threatened by overfishing and destructive fishing, coastal development, watershed-based pollution, and marine-based pollution and damage.

Coping with changes

Marine Protected Areas (MPAs) are delimited areas in the marine environment, created to preserve biodiversity (EDGAR; RUSS; BABCOCK, 2007) playing an important role in sheltering biodiversity in coral reef ecosystems from climate-related impacts and in the recovery of corals from massive bleaching events (SALM; SMITH; LLEWELLYN, 2001). In Brazil, MPAs increased the abundance of species, length of individuals, and community diversity in 17%, when related to open-access areas, fully protected MPAs increased biodiversity by 45% (FERREIRA et al., 2021). Our results emphasize the importance of legally protecting reef environments. When comparing changes in species abundance from both locations, decreases in Porto de Galinhas are far worse than in Abrolhos likely due to the existence of protected areas and distance from the shoreline. In the areas surveyed in this study, in the Abrolhos Bank reef there are two protected areas with different degrees of protection and distinct distances from shoreline: the APA Ponta da Baleia/Abrolhos is a Multiple use area which comprises the coastal arc about 10 to 20km off-shore and the Abrolhos Marine National Park is a No-take zone about 70 km off-shore (LEÃO, 1999; UNIDADES DE CONSERVAÇÃO NO BRASIL, 2022). Porto de Galinhas is an open-access area next to the shore with partially protected areas (approximately 85% of the total reef area) (SANTOS et al., 2015), much more susceptible to direct and indirect effects of human impacts.

One way to improve the effectiveness of MPAs is by planning, designing, and implementing it using participatory and broad thinking approaches which consider trophic interactions, connectivity, ecosystem functioning factors and how human activities interact with species and ecosystem services (RUCKELSHAUS et al., 2008). In the Great Barrier Reef, a large-scale study over 20 years provided robust evidence that decreasing anthropogenic impacts could make coral reefs more resilient to a range of stressors, including coral bleaching (MELLIN et al., 2016). Furthermore, diminishing sedimentation and nutrient enrichment possibly will improve ecosystem health for next decades and consequently, improve coral reef resilience to face global threats (HARVEY et al, 2018).

Historical data sets have a considerable potential to shed light on species distribution and abundance gaps, although these data do not come without their challenges. For those researching historical ecology it is common to come across non standardized and incomplete data. In addition, new methodologies were developed through the years becoming a challenge to compare information collected with different protocols. In this study we bumped into the same challenges cited above. The data gathered for his work came from different sources, with different sampling methods becoming necessary to find a way to standardize the data. Furthermore, in order to use the data from Lima (2017) and Silva (2018) regarding Porto de Galinhas we had to estimate coral cover based on the literature available given that these authors made available the relative abundance. However, making the right choices to explore the data are crucial to extract correct and useful information.

Since 2000, coral reef research in Brazil has improved, however we have much more to discover and understand about our reefs. Threats to this environment only worsened with the arising of diseases (FRANCINI-FILHO *et al.*, 2008), growth of tourism industry and escalation of the effects of climate change (LEÃO; KIKUCHI; OLIVEIRA, 2019). In the Caribbean, long thermal and anthropogenic stress are considered as one of the causes for higher level of diseases (BARTON; CASEY, 2005). We strongly recommend and support continued efforts of coral reef monitoring in the areas studied here and others. Furthermore, we suggest that design of marine protected areas is combined with projects of costal urban development and includes coastal reefs with remaining populations of threatened species. Standardized sampling is crucial to make further comparisons without losing resolution.

5 CONCLUSION

In the last 60 years there was a decline in relative abundance of some important species to coral reef maintenance, such as reef builders and providers of structural complexity, in both locations. The most affected species were the highly branched *Millepora alcicornis* and the endemic *Mussismilia harttii*. In addition to the decrease in abundance, in Porto de Galinhas, two species could not be found, rising concerns about the health of the reef environment in this location. This reduction could mean an opportunity for species with faster reproduction and growth, being able to opportunistically settle in perturbed environments, changing the functioning of the reef system. These results reinforce the need to continuously monitor our coral reefs to deepen the knowledge about it and to identify species that demand specific actions to ensure their preservation. This study can be considered as a first attempt in comparing different data sets to contribute to continuous data analysis on two representatives of important systems in the South Atlantic.

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7 REFERENCES

ALEMU I, Jahson Berhane; CLEMENT, Ysharda. Mass coral bleaching in 2010 in the southern Caribbean. **PLoS one**, v. 9, n. 1, p. e83829, 2014.

BARRADAS, Juliana Imenis et al. Spatial distribution of benthic macroorganisms on reef flats at Porto de Galinhas Beach (northeastern Brazil), with special focus on corals and calcified hydroids. **Biotemas**, v. 23, n. 2, p. 61-67, 2010.

BARTON, A. D.; CASEY, K. S. Climatological context for large-scale coral bleaching. Coral Reefs, v. 24, n. 4, p. 536-554, 2005.

BELLER, Erin et al. Toward principles of historical ecology. **American Journal of Botany**, v. 104, n. 5, p. 645-648, 2017.

BENDER, M. G. et al. Biological attributes and major threats as predictors of the vulnerability of species: a case study with Brazilian reef fishes. **Oryx**, v. 47, n. 2, p. 259-265, 2013.

BONGIORNI, Lucia et al. First step in the restoration of a highly degraded coral reef (Singapore) by in situ coral intensive farming. **Aquaculture**, v. 322, p. 191-200, 2011.

BURKE, Lauretta et al. **Reefs at risk revisited**. World resources institute, 2011.

CASTRO, Clovis B.; PIRES, Débora O. A bleaching event on a Brazilian coral reef. **Revista brasileira de Oceanografia**, v. 47, p. 87-90, 1999.

CASTRO, Clovis B.; PIRES, Débora O. Brazilian coral reefs: what we already know and what is still missing. **Bulletin of Marine Science**, v. 69, n. 2, p. 357-371, 2001.

CASTRO, C. B. et al. Distribution and diversity of coral communities in the Abrolhos Reef Complex, Brazil. **A rapid marine biodiversity assessment of the Abrolhos Reef Complex, Brazil. Washington: Conservation International**, p. 19-39, 2006.

CASTRO, Clovis; Zilberberg, Carla. Recifes brasileiros, sua importância e conservação. *In:* Zilberberg, Carla. Conhecendo os Recifes Brasileiros. Rede de Pesquisa Coral Vivo. – Rio de Janeiro: Museu Nacional, UFRJ, p. 17-26, 2016.

CONI, Ericka Oliveira Cavalcanti et al. An evaluation of the use of branching fire-corals (Millepora spp.) as refuge by reef fish in the Abrolhos Bank, eastern Brazil. **Environmental Biology of Fishes**, v. 96, n. 1, p. 45-55, 2012.

CORREIA, J.r.M.b. Ecotoxicologia do vinhoto das plantações de cana-de-açúcar nas fases de vida iniciais e adulta de corais do gênero Mussismilia (Cnidaria, Scleractinia). Dissertação (Mestrado em Ciências Biológicas - Zoologia) - Programa de Pós- graduação em Ciências Biológicas (Zoologia), Museu Nacional, Universidade Federal do Rio de Janeiro. Rio de Janeiro, RJ, Brasil. 124p, 2012

CRUZ, Igor CS et al. Evidence of a phase shift to Epizoanthus gabrieli Carlgreen, 1951 (Order Zoanthidea) and loss of coral cover on reefs in the Southwest Atlantic. **Marine Ecology**, v. 36, n. 3, p. 318-325, 2015.

DARLING, Emily S. et al. Evaluating life‐history strategies of reef corals from species traits. **Ecology Letters**, v. 15, n. 12, p. 1378-1386, 2012.

DE BARROS, Monica Moraes Lins et al. Sexual reproduction of the Brazilian reef coral Siderastrea stellata Verrill 1868 (Anthozoa, Scleractinia). **Bulletin of marine science**, v. 73, n. 3, p. 713-724, 2003.

DE BARROS, Monica Moraes Lins; PIRES, Debora Oliveira. Aspects of the life history of Siderastrea stellata in the tropical Western Atlantic, Brazil. **Invertebrate Reproduction & Development**, v. 49, n. 4, p. 237-244, 2006.

DIAS, Thelma Lúcia Pereira; GONDIM, Anne Isabelley. Bleaching in scleractinians, hydrocorals, and octocorals during thermal stress in a northeastern Brazilian reef. **Marine Biodiversity**, v. 46, n. 1, p. 303-307, 2016.

DUARTE, Gustavo AS et al. Heat waves are a major threat to turbid coral reefs in Brazil. **Frontiers in Marine Science**, p. 179, 2020.

DUTRA, Guilherme F. et al. **A rapid marine biodiversity assessment of the Albrolhos Bank, Bahia, Brazil**. Center for Applied Biodiversity Science (CABS), 2005.

DUTRA, L. X. C.; KIKUCHI, R. K. P.; LEÃO, Z. M. A. N. Effects of sediment accumulation on reef corals from Abrolhos, Bahia, Brazil. **Journal of Coastal Research**, p. 633-638, 2006.

DUTRA, Guilherme Fraga et al. Abrolhos: desafios para a conservação e o desenvolvimento sustentável na área com a maior biodiversidade marinha do Atlântico Sul. **Field Actions Science Reports. The journal of field actions**, n. Special Issue 3, 2011.

EAGLESON, Ryan G. et al. Coverage Increases of Porites astreoides in Grenada Determined by Shifts in Size-Frequency Distribution. **Diversity**, v. 13, n. 7, p. 288, 2021.

EDGAR, Graham J.; RUSS, Garry R.; BABCOCK, Russ C. Marine protected areas. **Marine ecology**, v. 27, p. 533-555, 2007.

FITZPATRICK, Scott M.; KEEGAN, William F. Human impacts and adaptations in the Caribbean Islands: an historical ecology approach. **Earth and Environmental Science Transactions of the Royal Society of Edinburgh**, v. 98, n. 1, p. 29-45, 2007.

FERREIRA, Beatrice Padovani; MAIDA, Mauro. **Monitoramento dos recifes de coral do Brasil**. Brasília, DF: MMA, Secretaria de Biodiversidade e Florestas, 2006.

FERREIRA, Beatrice Padovani et al. The status of coral reefs in Brazil. In: **Proc. 10th Intern. Coral Reef. Symp**. 2006. p. 1011-1015.

FERREIRA, Lucas Cabral Lage et al. Different responses of massive and branching corals to a major heatwave at the largest and richest reef complex in South Atlantic. **Marine Biology**, v. 168, n. 5, p. 1-8, 2021.

FRANCINI-FILHO, Ronaldo B. et al. Diseases leading to accelerated decline of reef corals in the largest South Atlantic reef complex (Abrolhos Bank, eastern Brazil). **Marine Pollution Bulletin**, v. 56, n. 5, p. 1008-1014, 2008.

FRANCINI-FILHO, Ronaldo Bastos; DE MOURA, Rodrigo Leão. Dynamics of fish assemblages on coral reefs subjected to different management regimes in the

Abrolhos Bank, eastern Brazil. **Aquatic Conservation: Marine and Freshwater Ecosystems**, v. 18, n. 7, p. 1166-1179, 2008.

FRANCINI-FILHO, Ronaldo B. et al. Dynamics of coral reef benthic assemblages of the Abrolhos Bank, eastern Brazil: inferences on natural and anthropogenic drivers. **PloS one**, v. 8, n. 1, p. e54260, 2013.

GALVÃO, Daniel Brandt et al. Ambientes recifais da região nordeste: um olhar para a influência da atividade humana do mar. In: Ciências do Mar: dos oceanos do mundo ao Nordeste do Brasil. **Design Publicações**, vol 1, p 240-267, 2021.

GASPARINI, J. L. et al. Marine ornamental trade in Brazil. **Biodiversity & Conservation**, v. 14, n. 12, p. 2883-2899, 2005.

GIGLIO, Vinicius J.; LUIZ, Osmar J.; SCHIAVETTI, Alexandre. Recreational diver behavior and contacts with benthic organisms in the Abrolhos National Marine Park, Brazil. **Environmental management**, v. 57, n. 3, p. 637-648, 2016.

GREEN, Daniel H.; EDMUNDS, Peter J.; CARPENTER, Robert C. Increasing relative abundance of Porites astreoides on Caribbean reefs mediated by an overall decline in coral cover. **Marine Ecology Progress Series**, v. 359, p. 1-10, 2008.

HARBORNE, Alastair R. et al. Multiple stressors and the functioning of coral reefs. **Annual Review of Marine Science**, v. 9, p. 445-468, 2017.

HARVEY, Bethany J. et al. Ecosystem‐based management of coral reefs under climate change. **Ecology and evolution**, v. 8, n. 12, p. 6354-6368, 2018.

HAY, Mark E. Fish-seaweed interactions on coral reefs: effects of herbivorous fishes and adaptations of their prey. **The ecology of fishes on coral reefs**, p. 96-119, 1991.

HOLBROOK, Sally J.; SCHMITT, Russell J. Competition for shelter space causes density‐dependent predation mortality in damselfishes. **Ecology**, v. 83, n. 10, p. 2855-2868, 2002.

HORN, Michael H. Biology of marine herbivorous fishes. **Oceanogr Mar Biol**, v. 27, p. 167-272, 1989.

HUGHES, Terence P. Community structure and diversity of coral reefs: the role of history. **Ecology**, v. 70, n. 1, p. 275-279, 1989.

HUGHES, Terry P. et al. Coral reefs in the Anthropocene. **Nature**, v. 546, n. 7656, p. 82-90, 2017.

JAMES, Charles D.; LANMAN, RICHARD B. Novel physical evidence that beaver historically were native to the Sierra Nevada. **California Fish and Game**, v. 98, n. 2, p. 129-132, 2012.

JOHANNES, R. E. Pollution and degradation of coral reef communities. In: **Elsevier Oceanography Series**. Elsevier, 1975. p. 13-51.

JOKIEL, Paul L. et al. Comparison of methods used to estimate coral cover in the Hawaiian Islands. **PeerJ**, v. 3, p. e954, 2015.

KIKUCHI, R. K. P. et al. Rapid assessment of the Abrolhos reefs, eastern Brazil (Part 1: Stony corals and algae). **Atoll Research Bulletin**, v. 496, p. 172-187, 2003.

KNOWLTON, Nancy. The future of coral reefs. **Proceedings of the National Academy of Sciences**, v. 98, n. 10, p. 5419-5425, 2001.

KROEKER, Kristy J. et al. Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. **Global change biology**, v. 19, n. 6, p. 1884-1896, 2013.

LABOREL, Jacques. **Les peuplements de madréporaires des côtes tropicales du Brésil**. Université d'Abidjan, 1970.

LABOREL-DEGUEN, F. et al. Recifes do Brasil: O Legado de Laborel. Rio de Janeiro, Museu Nacional. Série Livros, n.64. 376p. 2019.

LAMI, T. Écologie historique des changements spatio-temporels des communautés récifales du Brésil. Dissertação de Mestrado. Expertise et Gestion de L´environnement Littoral – Université de Bretagne Occedentale, Brest. 2017.

LANMAN, Richard B. et al. The historical range of beaver in the Sierra Nevada: a review of the evidence. **California Fish and Game**, v. 98, n. 2, p. 65-80, 2012.

LEÃO, Z. M. A. N. et al. Impact of tourism development on the coral reefs of the Abrolhos area, Brazil. **Biological Conservation**, v. 2, n. 76, p. 215-216, 1996.

LEÃO, Z. M. A. N. et al. A catastrophic coral cover decline since 3000 years BP, Northern Bahia, Brazil. In: **Proceedings of the 8th International Coral Reef Symposium. Panama**. 1997. p. 583-588.

LEÃO, Z. M. A. N. Abrolhos-O complexo recifal mais extenso do Oceano Atlântico Sul. **Schobbenhaus, C.; Campos, DA; Queiroz, ET; Winge, M**, p. 345-359, 1999.

LEÃO, Z. M. A. N.; KIKUCHI, R. K. P. The Abrolhos reefs of brazil. In: **Coastal marine ecosystems of Latin America**. Springer, Berlin, Heidelberg, p. 83-96, 2001.

LIRMAN, Diego; MANZELLO, Derek; MACIÁ, Silvia. Back from the dead: the resilience of Siderastrea radians to severe stress. **Coral Reefs**, v. 21, n. 3, p. 291-292, 2002.

LEÃO, Zelinda MAN; KIKUCHI, Ruy KP; TESTA, Viviane. Corals and coral reefs of Brazil. In: **Latin American coral reefs**. Elsevier Science, p. 9-52, 2003.

LEÃO, Zelinda Margarida Andrade Nery; KIKUCHI, Ruy Kenji Papa de; OLIVEIRA, Marília de Dirceu Machado de. Branqueamento de corais nos recifes da Bahia e sua relação com eventos de anomalias térmicas nas águas superficiais do oceano. **Biota Neotropica**, v. 8, p. 69-82, 2008.

LEÃO, Zelinda MAN et al. Brazilian coral reefs in a period of global change: A synthesis. **Brazilian Journal of Oceanography**, v. 64, p. 97-116, 2016.

LEÃO, Z. M. A. N.; KIKUCHI, R. K. P.; OLIVEIRA, M. D. M. The Coral Reef Province of Brazil. World Seas: an Environmental Evaluation (Second Edi., Vol. 1, pp. 813–833). 2019.

LEWIS, J. B. Biology and Ecology of the Hydrocoral Millepora on Coral Reefs. **Advances in Marine Biology**, v. 50, p.1–55, 2006.

LIMA, Gislaine Vanessa de. Avaliação do estado de conservação do coral endêmico Mussismilia harttii (Verrill, 1868)(Cnidaria: Anthozoa) no Brasil. Dissertação de Mestrado. Universidade Federal de Pernambuco. 2017

LOIOLA, Miguel; OLIVEIRA, Marília DM; KIKUCHI, Ruy KP. Tolerance of Brazilian brain coral Mussismilia braziliensis to sediment and organic matter inputs. **Marine pollution bulletin**, v. 77, n. 1-2, p. 55-62, 2013.

LOIOLA, Miguel et al. Structure of marginal coral reef assemblages under different turbidity regime. **Marine environmental research**, v. 147, p. 138-148, 2019.

LONGO, Guilherme O.; CORREIA, Louize FC; MELLO, Thayná J. Coral recovery after a burial event: insights on coral resilience in a marginal reef. **Marine Biodiversity**, v. 50, n. 6, p. 1-6, 2020.

LOYA, Yossef. Community structure and species diversity of hermatypic corals at Eilat, Red Sea. **Marine Biology**, v. 13, n. 2, p. 100-123, 1972.

MACHADO, Raquel C. Assis et al. Percepção sócio-ambiental dos turistas e trabalhadores da praia de Porto de Galinhas (Pernambuco-Brasil) acerca do ecossitema recifal. **Revista de Gestão Costeira Integrada-Journal of Integrated Coastal Zone Management**, v. 9, n. 3, p. 71-78, 2009.

MCCLENACHAN, Loren et al. Ghost reefs: Nautical charts document large spatial scale of coral reef loss over 240 years. **Science advances**, v. 3, n. 9, p. e1603155, 2017.

MAGRIS, Rafael A. et al. A blueprint for securing Brazil's marine biodiversity and supporting the achievement of global conservation goals. **Diversity and Distributions**, v. 27, n. 2, p. 198-215, 2021.

MAIDA, Mauro; FERREIRA, Beatrice Padovani. Coral reefs of Brazil: an overview. In: Proceedings of the 8th international coral reef symposium. Smithsonian Tropical Research Institute Panamá, 1997. p. 74.

MELLIN, Camille et al. Marine protected areas increase resilience among coral reef communities. **Ecology letters**, v. 19, n. 6, p. 629-637, 2016.

MENDONÇA, L. C. A invenção de Porto de Galinhas: História, empreendedorismo e turismo. 248p. **Persona, Recife, PE, Brasil. (ISBN-85981790)**, 2004.

MIES, Miguel et al. South Atlantic coral reefs are major global warming refugia and less susceptible to bleaching. **Frontiers in Marine Science**, v. 7, p. 514, 2020.

MIRANDA, Ricardo J.; CRUZ, Igor CS; LEÃO, Zelinda MAN. Coral bleaching in the Caramuanas reef (Todos os Santos Bay, Brazil) during the 2010 El Niño event. **Latin American Journal of aquatic research**, v. 41, n. 2, p. 351-360, 2013.

MMA. PORTARIA MMA Nº 148, DE 7 DE JUNHO DE 2022. Altera os Anexos da Portaria nº 443, de 17 de dezembro de 2014, da Portaria nº 444, de 17 de dezembro de 2014, e da Portaria nº 445, de 17 de dezembro de 2014, referentes à atualização da Lista Nacional de Espécies Ameaçadas de Extinção. Disopnível em: https://www.icmbio.gov.br/cepsul/images/stories/legislacao/Portaria/2020/P_mma_148_2022_altera_anexos_P_mma_443_444_445_2014_atualiza_especies_ameacadas_extincao.pdf. 2022

MOBERG, Fredrik; FOLKE, Carl. Ecological goods and services of coral reef ecosystems. **Ecological economics**, v. 29, n. 2, p. 215-233, 1999.

NEWMAN, Steven P. et al. Reef flattening effects on total richness and species responses in the C aribbean. **Journal of Animal Ecology**, v. 84, n. 6, p. 1678-1689, 2015.

NOCK, Charles A.; VOGT, Richard J.; BEISNER, Beatrix E. Functional traits. **eLS**, p. 1-8, 2016.

NOGUEIRA, Marcos M.; NEVES, Elizabeth; JOHNSSON, Rodrigo. Effects of habitat structure on the epifaunal community in Mussismilia corals: does coral morphology influence the richness and abundance of associated crustacean fauna?. **Helgoland Marine Research**, v. 69, n. 2, p. 221-229, 2015.

OLIVEIRA, Marília DM; LEÃO, Zelinda MAN; KIKUCHI, Ruy KP. Cultivo de Millepora alcicornis como uma ferramenta para Restauração e Manejo dos Ecossistemas Recifais do Nordeste do Brasil. **Revista de Gestão Costeira Integrada-Journal of Integrated Coastal Zone Management**, v. 8, n. 2, p. 183-201, 2008.

PALOMARES, Maria Lourdes D.; HEYMANS, Johanna J.; PAULY, Daniel. Historical ecology of the Raja Ampat Archipelago, Papua Province, Indonesia. **History and philosophy of the life sciences**, p. 33-56, 2007.

PITOMBO, F. B.; RATTO, C. C.; BELÉM, M. J. C. Species diversity and zonation pattern of hermatypic corals at two fringing reefs of Abrolhos Archipelago, Brazil. In: **Proceedings of the 6th International Coral Reef Symposium**. 1988. p. 817-820.

PÉREZ, Carlos Daniel. Recifes e/ou ambientes coralíneos de Suape a Porto de Galinhas (PE). In: LABOREL-DEGUEN, F.; CASTRO, C. B.; NUNES, F. L.D.; PIRES, D. O. (Org.). Recifes brasileiros: o legado de Laborel. Rio de Janeiro: Stampa, p. 156-159, 2019.

RANDAZZO-EISEMANN, Ángela; GARZA-PÉREZ, Joaquín Rodrigo; FIGUEROA-ZAVALA, Baruch. The role of coral diseases in the flattening of a Caribbean Coral Reef over 23 years. **Marine Pollution Bulletin**, v. 181, p. 113855, 2022.

ROOS, Natalia C. et al. Demography of the largest and most endangered Brazilian parrotfish, Scarus trispinosus, reveals overfishing. **Endangered Species Research**, v. 41, p. 319-327, 2020.

RStudio Team. RStudio: Integrated Development for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/. 2020

SALM, Rodney V.; SMITH, Scott E.; LLEWELLYN, Ghislaine. Mitigating the impact of coral bleaching through marine protected area design. In: **Coral Bleaching: Causes, Consequences and Response. Selected papers presented at the 9th International Coral Reef Symposium on “Coral Bleaching: Assessing and Linking Ecological and Socioeconomic Impacts, Future Trends and Mitigation Planning.” Coastal Management Report**. 2001. p. 81-88.

SANTANA, Erika FC et al. Turbidity shapes shallow Southwestern Atlantic benthic reef communities. **Marine Environmental Research**, v. 183, p. 105807, 2023.

SANTOS, Gleice S. et al. The impact of trampling on reef Macrobenthos in Northeastern Brazil: how effective are current conservation strategies?. **Environmental management**, v. 56, n. 4, p. 847-858, 2015.

SARMENTO, Visnu C.; BARRETO, Aliny FS; SANTOS, Paulo JP. The response of meiofauna to human trampling on coral reefs. **Scientia Marina**, v. 75, n. 3, p. 559-570, 2011.

SEGAL, B.; CASTRO, C. B. Community structure at the Abrolhos Archipelago, Brazil. In: **Proceedings of 9th International Coral Reef Symposium, Bali, Indonesia**. 2000. p. 23-27.

SEGAL, Bárbara; CASTRO, Clovis B. Coral community structure and sedimentation at different distances from the coast of the Abrolhos Bank, Brazil. **Brazilian Journal of Oceanography**, v. 59, p. 119-129, 2011.

SILVA, Leandro Luiz da. Avaliação do estado de conservação dos corais do recife de Porto de Galinhas baseada na descrição de Laborel (1969). Dissertação de Mestrado. Universidade Federal de Pernambuco. 2018

SPALDING, Mark et al. **World atlas of coral reefs**. Univ of California Press, 2001.

STUART-SMITH, Rick D. et al. Ecosystem restructuring along the Great Barrier Reef following mass coral bleaching. **Nature**, v. 560, n. 7716, p. 92-96, 2018.

SZABÓ, Péter. Historical ecology: past, present and future. **Biological Reviews**, v. 90, n. 4, p. 997-1014, 2015.

TEBBETT, Sterling B.; STREIT, Robert P.; BELLWOOD, David R. A 3D perspective on sediment accumulation in algal turfs: Implications of coral reef flattening. **Journal of Ecology**, v. 108, n. 1, p. 70-80, 2020.

TEDESCO, Erik C. et al. Conservation of Brazilian coral reefs in the Southwest Atlantic Ocean: a change of approach. **Latin american journal of aquatic research**, v. 45, n. 2, p. 228-245, 2017.

TEIXEIRA, Carolina D. et al. Sustained mass coral bleaching (2016–2017) in Brazilian turbid-zone reefs: taxonomic, cross-shelf and habitat-related trends. **Coral Reefs**, v. 38, n. 4, p. 801-813, 2019.

THURSTAN, R. H. et al. Filling historical data gaps to foster solutions in marine conservation. **Ocean & Coastal Management**, v. 115, p. 31-40, 2015.

TILMAN, David. Functional diversity. Encyclopedia of biodiversity, v. 3, n. 1, p. 109-120, 2001.

TOTH, Lauren T. et al. The unprecedented loss of Florida's reef-building corals and the emergence of a novel coral-reef assemblage. **Ecology**, v. 100, n. 9, p. e02781, 2019.

UNIDADES DE CONSERVAÇÃO NO BRASIL. Disponível em: https://uc.socioambiental.org/arp/1208.

WOODLAND, D. J.; HOOPER, J. N. A. The effect of human trampling on coral reefs. **Biological Conservation**, v. 11, n. 1, p. 1-4, 1977.

ZAWADA, Kyle JA; DORNELAS, Maria; MADIN, Joshua S. Quantifying coral morphology. **Coral Reefs**, v. 38, n. 6, p. 1281-1292, 2019.

ZILBERBERG, Carla; ABRANTES, Douglas Pinto; MARQUES, Joseane Aparecida (Ed.). Conhecendo os recifes brasileiros: rede de pesquisas Coral Vivo. Museu Nacional, Universidade Federal do Rio de Janeiro, 2016.

ZWEIFLER, Adi et al. Turbid coral reefs: past, present and future—A review. **Diversity**, v. 13, n. 6, p. 251, 2021.

CAPÍTULO 2

[2]Brazilian coral reefs' contributions by the eyes of its users

[2] Text formatting for the selected journal will be changed at the time of submission.

Brazilian coral reefs' contributions by the eyes of its users

Abstract

Healthy coral reef environments provide many benefits to people. At least 500 million people living in coastal communities around the world are highly dependent on benefits provided by coral reefs. Nature´s contributions to people is a concept recently proposed to introduce a new framework for human beings' relationships with nature, they are all contributions, both positive and negative, of living nature to people's quality of life. This study analyzes the perception of researchers, divers, and users of coral reefs about the provision of ecosystem services by these environments, that is, the contributions of these environments to people. We collected data through an online questionnaire investigating respondent's socioeconomic profile and people's perception of the contributions of reef environments in Brazil, focusing on different types of reefs (biogenic and rocky reefs). We classified the NCPs cited by the participants into 18 categories according to the conceptual framework of the Intergovernmental Platform on Biodiversity and Ecosystem Services. A total of 71 people answered our questionnaire. The main benefits of coral reefs perceived by respondents were classified as "Physical and Psychological experiences" (35.5% of 269 total statements), followed by "Habitat creation and maintenance" (20%) and "Learning and inspiration" (17.7%). The perception of changes was not related to the respondent's experience (Fisher's exact test, $p=0.11$) or main activity (research, tourism, and others; Fisher's exact test $p=0.12$). Most statements of changes were negative, highlighting the decrease in biodiversity, increase in solid waste, disorganized growth in tourism and reduced water quality. Improvement statements were related to biodiversity, use, environmental quality, governance/management, and learning. Shifting baseline syndrome was not observed in this study probably due to the great number of scientists that answered the questionnaire, and the low participation of elderly people probably due to the online method chosen. Published literature supports the changes perceived by reef users and the few positive perceptions can be influenced by social initiatives towards biodiversity conservation that contributed to raise awareness about the sea environment.

Keywords: environmental changes, perceptions, coral reefs

1 INTRODUCTION

At least 500 million people living in coastal communities around the world are highly dependent on benefits provided by coral reefs (HOEGH-GULDBERG; PENDLETON; KAUP, 2019). Healthy coral reef environments provide many benefits to people, attracting tourists, moving the local economy, acting as a nursery for many species and inspiring people and their cultures all around the world (MOBERG; FOLKE, 1999; WOODHEAD *et al.*, 2019).

The concept of nature´s contributions to people (NCP) was recently proposed by Diaz and collaborators (2018) in an attempt to introduce a new framework for human beings' relationships with nature, aiming to overcome the limitations of structure in the approach to ecosystem services (ES) and provide a new discourse for the work developed by the Intergovernmental Platform for Science Policies on Biodiversity and Ecosystem Services (IPBES) (DÍAZ *et al.*, 2018; MURADIAN; GÓMEZ-BAGGETHUN, 2021). NCPs are all contributions, both positive and negative, of living nature (diversity of organisms, ecosystems, and their associated ecological and evolutionary processes) to people's quality of life (DÍAZ *et al.*, 2018) This approach recognizes the central and overarching role that culture plays in defining all the links between people and nature (DÍAZ *et al.*, 2018)

In Brazil, compared to other regions of the world, studies on coral reefs took a long time to start (LEÃO; KIKUCHI; TESTA, 2003). Perhaps, this is one of the reasons that reef science in Brazil is not recognized worldwide, being left out of several global studies (e.g., see HUGHES et al., 2018; ANDRELLO et al., 2022), although the country has the only coral reefs in the south Atlantic. One of the modern pioneering research efforts began in the summer of 1961 with the arrival of Jacques Laborel arrived at the Institute of Maritime Biology and Oceanography in Recife (LEÃO; KIKUCHI; TESTA, 2003; LABOREL-DEGUEN et al., 2019). He was the first researcher to use compressed air cylinders and take underwater photos of Brazilian reef environments (LABOREL-DEGUEN *et al.*, 2019). Recent research indicates threats to these environments, such as coastal runoff and urban development, tourism, predatory fishing, invasive species, exploitation of fossil fuels and the consequences of global warming (LEÃO *et al.*, 2016). In addition, in 2019 a large oil spill on the northeast coast impacted not only the ecosystem, but also the local populations that depend on the sale of fish and tourist activities to survive (SILVA *et al.*, 2022).

Different perceptions of the environment influence on how coral reef's users perceive contributions of these environments to people. Perception happens when the activity of sensory organs is associated with brain activities (DE OLIVEIRA; CORONA, 2008; MELAZO, 2009). This stimulation is translated into values that are attributed according to culture, history, age, sex, education, social class, politics, religion, individuality (DE OLIVEIRA; CORONA, 2008; MELAZO, 2009). Intra and intercultural differences in perception, influenced by age, individual social role, time of residence and time of experience with certain environments, can also influence the perception of nature (SILVA *et al*., 2016).

In this context, our objectives are to analyze the perception of researchers, divers and users of coral reefs (any person who uses the reef for personal or professional purposes) about contributions of these environments to people. We expect that, due to the greater degradation of reef environments in recent decades, users with more experience with these coral reefs will perceive more changes, compared to those with less time of experience in these same environments, and we expect that people with different occupations in the reef perceive changes in different ways.

2 MATERIALS AND METHODS

Study area

For this study, three sites were chosen: Porto de Galinhas (08°30' S), Abrolhos (18°00' S), and Arraial do Cabo (23°00' S). They are scattered along the Brazilian coast, with Porto de Galinhas and Abrolhos in the Northeast region and Arraial do Cabo in the Southeast region. In addition to geographic representation, they also harbor a diversity of reef formations. The Cabo Frio area (where Arraial do Cabo is located) is well known for its rocky shores rich in biodiversity, already called "coral oasis" by Jacques Laborel (1970) due to very dense coral populations, especially in Arraial do Cabo Bay. The Abrolhos reef complex there are unique shapes, known as "chapeirões", which can form 20-meter-high pinnacles (LABOREL, 1970); and Porto de Galinhas is known for its coastal reef forming natural pools (Mendonça, 2004 *apud* Machado et al, 2009).

Arraial do Cabo

This municipality is located in the State of Rio de Janeiro (22° 58'' S, 42° 02' W), and is known for the occurrence of coastal upwelling, a phenomenon in which deep waters emerge on the sea surface near the coast, enriching the water column with nutrients and causing high productivity. Its coastal region consists of rocky shores, important marine ecosystems that contain very rich and extremely complex benthic communities (BATISTA; GRANTHOM-COSTA; COUTINHO, 2020).

From the 1970s, travel to the region was facilitated due to the construction of the Rio-Niterói bridge, encouraging summer and weekend tourism and, from the 1990s onwards, the region was consolidated as a tourist destination (DE MIRANDA MENDONÇA; DE MORAES; MACIEL, 2013). Currently, the resident population is approximately 29,000 people, which may triple during the high season (BATISTA; GRANTHOM-COSTA; COUTINHO, 2020).

Porto de Galinhas

Located in the municipality of Ipojuca in the State of Pernambuco (08º30' S, 35º00' W) these reef formations are found along 900 meters divided into three main blocks, separated by two channels (LABOREL, 1970; BARRADAS et al., 2012). These formations are very close to the coast. It is possible to reach the reefs by swimming or walking at low tide, allowing tourists to walk freely, and resulting in trampling (RANIERO *et al.*, 2007). Tourism is the main economic activity in this area. In a year, Porto de Galinhas receives over 750 thousand visitors (ZAMBONI; PÉREZ, 2013).

Abrolhos

The Abrolhos National Marine Park (ANMP) (17º 20' - 18º10'S and 038º35' - 39º20'W) was created in 1983 with the aim of conserving biodiversity and promoting sustainable tourism (GIGLIO; LUIZ; SCHIAVETTI, 2016). It is located in the south of State of Bahia, and concentrates the most extensive and richest area of corals in Brazil and the Southwest Atlantic. It occupies approximately 6,000 km^2 of the northern bank of Abrolhos, comprising two reef arcs, volcanic islands, sandbanks, and channels (LEÃO *et al.*, 2001). Fishing is one of the most important economic activities in the region: estimates suggest that around 20.000 fishers, mostly artisanal, use natural resources from the region as their main source of livelihood (DUTRA et al., 2011). However, in recent years, an increasing number of industrial fishing vessels have moved to the region, escalating the pressure on fish stocks and competing with artisanal fisheries (DUTRA et al., 2011). Tourism is another important economic activity. The ANMP receives approximately 1300 scuba divers per year totaling 9100 dives in 15 sites annually (GIGLIO; LUIZ; SCHIAVETTI, 2016). In 2018, 6403 vessels visited the ANMP and 8063 visits were registered in the visitor center, an increase of 67.7% since 2010 (ICMBIO, 2019).

Data collection

We collected data through an online questionnaire containing questions about the respondent's socioeconomic profile and questions aimed at people's perception of the contributions of reef environments, focusing on Porto de Galinhas, Abrolhos and Arraial do Cabo. Sampling was intentional, through the authors' contacts with potential respondents who had diving experience or living in proximity to reef environments in at least one of the three focus areas. The invitation to participate in the survey and the online form were sent on May 19, 2021, initially to 45 people via email and through social media network, being available for 3 months. The voluntary participation of each respondent was conditioned to a prior informed consent. We also used an adaptation of snowball sampling (GOODMAN, 1961), requesting indications of other potential respondents at the end of each questionnaire. This study was authorized by the Ethics Committee of the Federal University of Santa Catarina (CEPSH-UFSC, 37193120.0.0000.0121).

To understand the perception of NCPs from coral reefs, we asked about the benefits and harms of reef environments for the personal and professional life of the respondent, which aspects have changed in the reef landscape comparing the first and last visit to the site, what was the degree of change in environment, and year of first and last site visit (the full questionnaire is available in Supplementary Material 1). Subsequently, we classified the mentioned changes by themes: solid waste, tourism, tourism/fisheries, biodiversity, water quality, use, abiotic environment, sediments, pollution, environmental quality (general), coral bleaching, climatic changes (general changes in climate), climate changes (changes associates with climate change), associated environments, invasive species, governance/management, learning, and fisheries.

We classified the NCPs cited by the participants into 18 categories according to the conceptual framework of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) (DÍAZ *et al.*, 2018) following the description of each category present in table S1. The difference between the dates of the first and last visit to the site is what we call experience, reflecting how many years a participant has known that reef environment (Porto de Galinhas, Abrolhos, or Arraial do Cabo). The answers were also grouped by types of activity carried out in the reef environment: research, tourism, and others and we also indicated to which broad group the NCP category belongs. Diaz *et al.* (2018) distinguished the 18 NCP categories in 3 broad groups: Material NCP, Non-material NCP and Regulating NCP. A single category can belong to one or more broad group (e.g., “Maintenance of options” is a category that comprises the many dimensions of potential opportunities offered by nature and for this reason occupies all three NCP groups).

To verify if the perception of change in the reef environment varied according to the activity performed on the reef and the experience of the respondent, we applied a Fisher's exact test. A Sankey diagram was produced to visualize the most cited categories for personal and professional life. The main changes perceived comparing the first and last visit were classified into themes and made available in a bar graph. The small number of respondents, especially for Porto de Galinhas, did not allow for a comparison between sites.

3 RESULTS

A total of 71 people responded our questionnaire, with a higher proportion of women, of people with ages between 31 and 40 years old (29.5%), and researchers (55%). As for the locals of interest, 36,5% of respondents refer to Arraial do Cabo, 43,5% to Abrolhos and 20% to Porto de Galinhas. Comparing the first and the last visit to the same coral reef environment, the average years of experience of the respondents was approximately 14 years (minimum 1 year and maximum 53 years).

Age of respondents with more than 30 years of experience in the same reef varied 41 to 70 years old, respondents between 1 to 5 years of experience were aged from 18 to 60 years old.

Table 1. Socioeconomic characteristics of respondents (n=71).

Variable	***Category***	***Total***
Sex	Men	31
	Women	40
Age group	Between 18 and 30 years	16
	Between 31 and 40 years	21
	Between 41 and 50 years	15
	Between 51 and 60 years	15
	Between 61 and 70 years	4
Activity practiced at reef environment	Research	39
	Tourism	22
	Other	9
Sites	Arraial do Cabo	26
	Abrolhos	31
	Porto de Galinhas	14

*Socioeconomic questions were not mandatory, and some participants did not answer all questions.

The main benefits of coral reefs perceived by respondents belonged to the categories "Physical and Psychological experiences" (35.5% of 269 statements), followed by "Habitat creation and maintenance" (20%) and "Learning and inspiration" (17.7%). Other benefits were mentioned with frequencies lower than 8%.

The NCPs mentioned by respondents were split in those reflecting benefits for personal life, and for professional life (Figure 1). The majority of contributions mentioned were non-material NCP, followed by regulating NCP. When asked about the benefits of coral reefs in relation to personal life, 40% of responses were classified as “Physical and Psychological experiences", followed by “Habitat creation and maintenance” with 17% and “Learning and inspiration” with 12.6%. When asked about the benefits of coral reefs in relation to professional life, 31.5% of the responses fall into the category “Learning and inspiration", followed by “Habitat creation and maintenance” with 27.2% and “Physical and Psychological experiences” with 24.6%. Other categories of NCPs for personal life with proportions higher than 4% were: “Formation, protection, and decontamination of soils and sediments”, “Supporting identities”, “Food and feed” and “Materials, companionship, and labor”. For activities carried out in the reef environment the remaining categories mentioned in proportions lower than 5.2% were: “Materials, companionship, and labor”, “Food and feed”, “Supporting identities”, “Maintenance of options” and “Formation, protection, and decontamination of soils and sediments”.

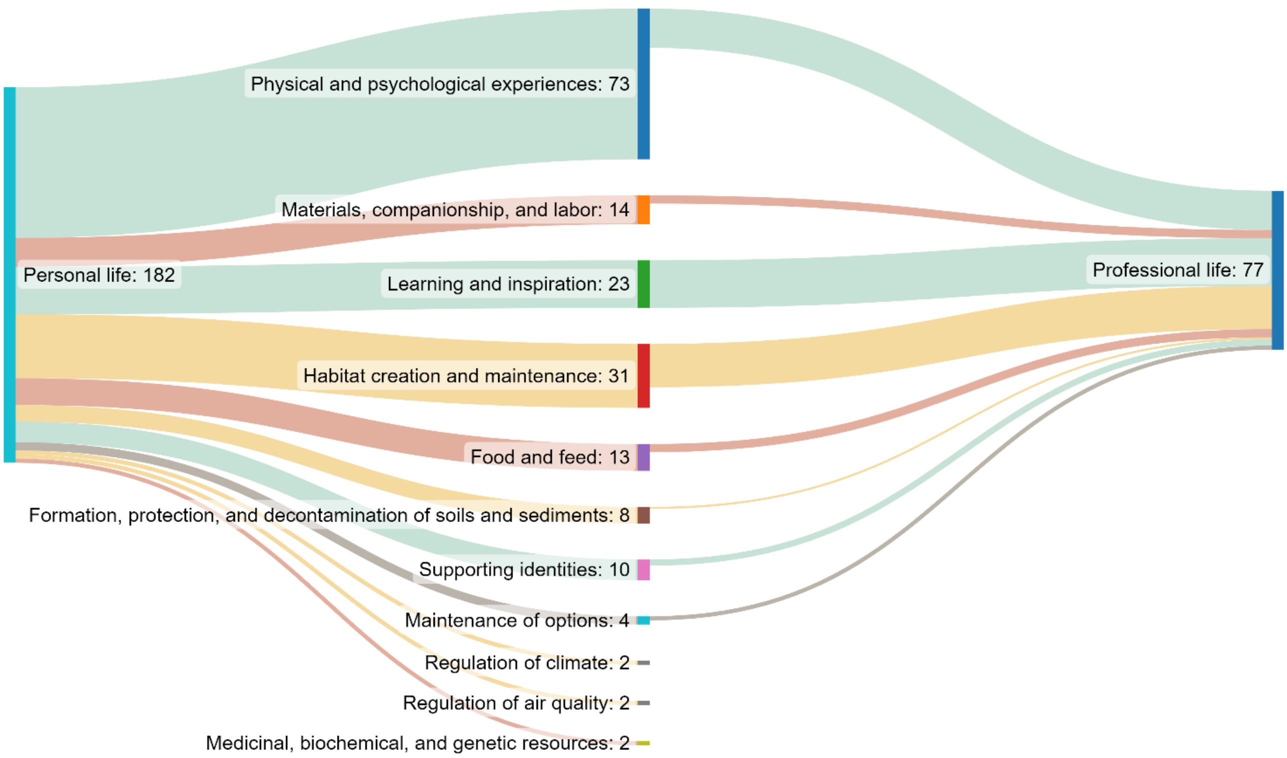

Figure 1- Comparison of the perception of NCP for personal life and for professional life by the interviewees. The thickness of the lines shows how much the category is cited, the thicker, the more mentions of benefits that fit that category. The lines are colored according to the type of NCP: material NCP are presented in rose, non-material NCP are presented in blue, and regulating NCP are presented in orange; maintenance of options is a category which contains benefits of all three types (material, non-material and regulating), and it is colored in gray.

Changes noticed between the first and last visit to the reef environment were mentioned by 86% of respondents. The perception of changes was neither related to the respondent's experience (Fisher's exact test, $p=0.11$) nor to main activity (research, tourism, and others; Fisher's exact test $p=0.12$).

Figure 2 summarizes the changes noticed between the first and last visit to the reef environment. On the left, they are separated by themes and on the right, by the NCP category affected. For example, one change cited was the increase in the number of vessels – this increase could have occurred because of fishing or tourism, or both – impacting both the material and non-material category. Most of the statements regarding changes were negative, highlighting the decrease in biodiversity, increase in solid waste, disorganized growth in tourism, and worsening of water quality. Statements of improvement mentions related to biodiversity, use, environmental quality, governance/management, and learning. Changes reflecting improvements in Arraial do Cabo were related to creation of no-fishing zones with more surveillance and sighting of more sea turtles in coastal reefs compared with previous years. In Abrolhos, there was a statement for recover of the recovery of some species from a bleaching event and perception of improvement in awareness towards the marine environment.

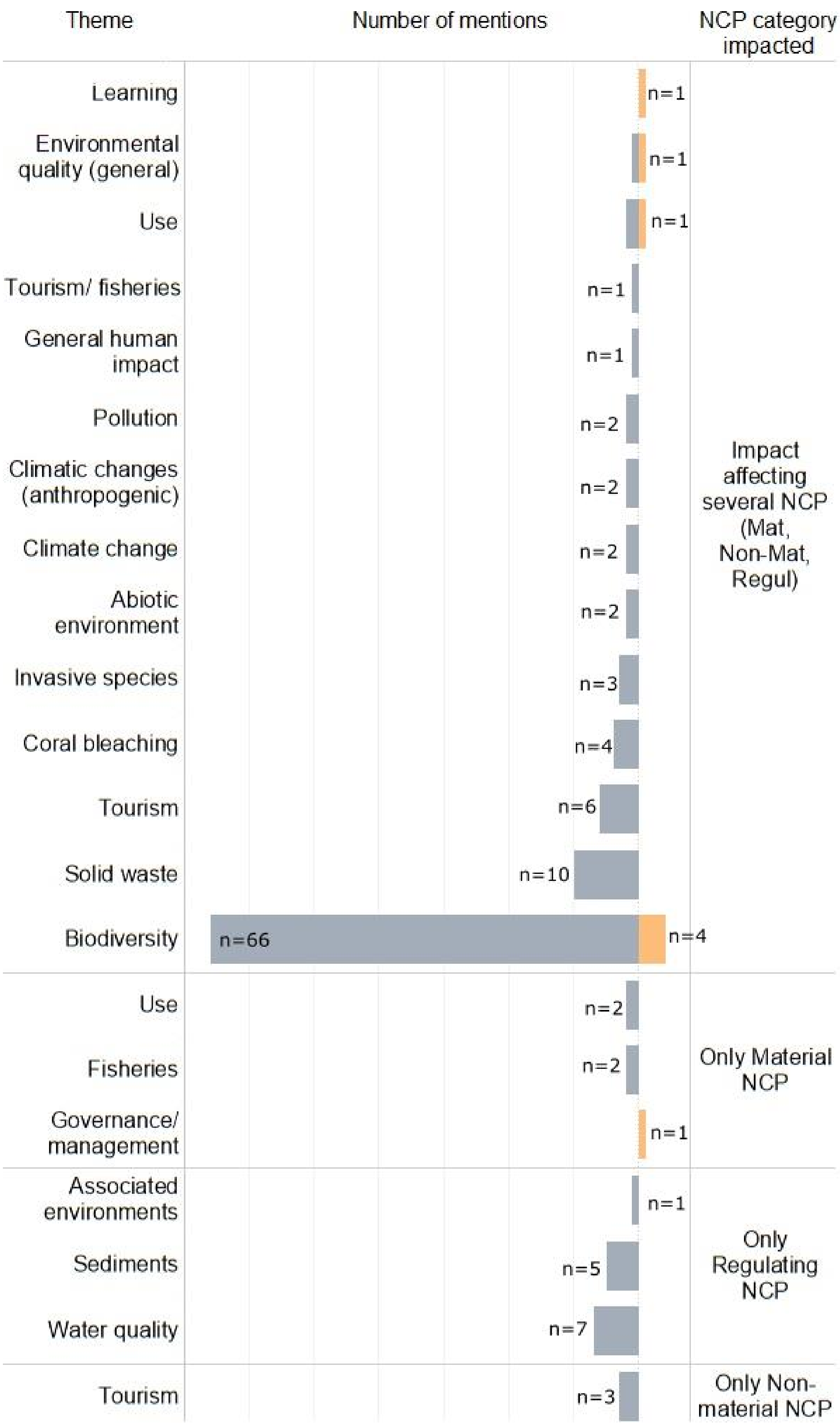

Figure 2- Main changes perceived comparing the first and last visit to the coral reef. Gray bars indicate a worsening in quality and orange bars show an improvement.

4 DISCUSSION

Perceived benefits from coral reef environments are mostly related to "Physical and Psychological experiences", "Habitat creation and maintenance" and "Learning and inspiration" categories. These results are similar to other coral reefs' users studied in other locations. Results from Santavy and collaborators (2021) show that beneficiaries who use coral reefs in the U.S. perceived similar benefits, such as diving, snorkeling, contemplation (classified here as “Physical and Psychological experiences”), abundance of species classified here as "Habitat creation and maintenance") and pharmacological species; and showed the same concerns with water quality. Fisher´s perceptions of most important benefits from coral reefs in Seychelles were habitat services related to coral reefs and recreation services (WOODHEAD *et al.*, 2021), which are in consonance with our results. Non-material NCP were more than 50%, altogether with regulating NCP represented 78% of all NCP mentioned for respondents of all locations studied here.

We investigated if a person's experience influences their perception of the environment. Our results indicate that the perception of changes in coral reefs did not differ between experienced users and those with less experience, contradicting our hypothesis. We understand that frequency of visitation is an important component of experience, however we did not collect this information. Experience here is scored by how many years the respondent knows the reef. Perceptions of change also did not differ between the main groups of activities of the interviewees (researchers, tourism related jobs, and other). However, some interesting results were obtained when comparing NCP for personal lives and professional activities of the participants, who reported a deterioration of reef environments investigated here.

The shifting baseline syndrome (SBS) refers to the change in human perceptions about biological systems due to the lack of experience over previous conditions (PAULY, 1995). In his study, Pauly (1995) noted that each generation of scientists considers the abundance and composition of species observed at the beginning of their careers as a baseline and uses this baseline to assess over time. Despite some authors reporting SBS (SÁENZ-ARROYO et al., 2005; BUNCE et al., 2008; FOGLIARINI et al., 2021), this phenomenon was not observed in this study. The non-observation of SBS may be attributed to some factors. Firstly, in order to evaluate the perception of change through time a larger sample of people with more experience was needed. Additionally, the online form was spread through a research network and most of our respondents were researchers, who tend to have knowledge based not only on their own observations, but also based on the worldwide literature. Even so, the number of scientists who participated in the research represents a small fraction of marine scientists in Brazil (on CNPq Lattes platform, we found 2678 curriculum vitae of doctors researching marine biology, marine ecology, and oceanography in Brazil) (PLATAFORMA LATTES, 2022).

The use of online forms, disseminated electronically, confers several advantages, such as cost reduction and the possibility of carrying out a larger sample. However, they also bring disadvantages that can bias the sample, such as a less chance to include people with a limited computer knowledge, lack of internet access and a low participant motivation (LATKOVIKJ; POPOVSKA, 2019). The use of an online form was probably one of the factors that hampered the reach of elderly people due to lack of familiarity with the internet and electronic equipments. According to Freitas & De Carvalho (2012), in 2011 internet users in Brazil were younger than the world´s average, 60% of them were less than 34 years old. Furthermore, this methodology may have excluded people with little or no internet access; it is also worth mentioning that during the COVID-19 pandemic, many people got exhausted from social media, becoming unmotivated to answer the questionnaire.

When comparing the benefits mentioned for personal life and activity performed in the reef, the category “Learning and inspiration” was the most cited, most likely due to more than 50% of participants having lines of research associated with reef environments. Regarding the benefits for personal life, many cited well-being and contemplation, making “Physical and psychological experiences” the category with the highest number of statements. According to Bratman and collaborators (2019), different types of experiences with nature are associated with benefits for mental health. Furthermore, Robinson *et al*. (2021) reported that during the pandemic, people generally visited nature for health and well-being benefits and the majority felt that going out helped them manage through the pandemic.

The decrease in the quality of the NCPs noticed by the respondents, mainly in terms of biodiversity and water, is also noticed by the scientists who study these environments. Sedimentation and pollution are considered chronic threats to these environments and have been the main cause of coral loss in Brazilian coastal reefs (FERREIRA et al., 2020). Other authors report damage caused by disordered urban development (LEÃO *et al.*, 2016) and tourism and overexploitation of reef organisms due to the proximity of the coast facilitating access (LEÃO et al., 2001; FRANCINI-FILHO et al., 2013). In Seychelles, fishers also perceived a decrease in coral reef ecosystem services such as less fish, loss of habitat services and coral bleaching (WOODHEAD *et al.*, 2021). The degradation of natural landscapes is perceived in other biomes in Brazil, reflecting a widespread change. In the Amazon Forest, Brito *et al*. (2020) found out that the great majority of problems mentioned by respondents was environmental degradation. This decline is not something particular to Brazil, but it is perceived around the globe. Díaz *et al*. (2019) estimate a decline in nature's capacity to support quality of life in the majority of categories considered by the IPBES. Although the main changes perceived were negative, there were a few statements of positive differences. For example, a statement of improvement in awareness towards the marine environment can be a result of social initiatives towards biodiversity conservation such as Coral Vivo Project and Tamar Project. Since 2003, the Coral Vivo Project works on the conservation of marine environments, using environmental education as a tool to sensitize different social groups (GOUVEIA; CASTRO, 2015). Tamar Project was first created because of international pressure to preserve sea turtles and in 1982, two experimental bases were created (BAPTISTOTTE, 1994). After 13 years, more than one million young turtles were released in the sea, this positive outcome is a result of environmental education and engagement with local communities (BAPTISTOTTE, 1994).

Findings of this research gave us an idea of how some of the different groups that use coral reefs perceive the benefits provided by them. Despite the general perception of environmental decline, statements of positive changes help us to think about alternative approaches to ensure the future of coral reefs. In 2017, the United Nations proclaimed that an Ocean Decade (2021-2031) would be held as an initiative to support efforts to reverse the decline in ocean (TURRA, 2021). Perhaps it is time to enroll in the movement and raise engagement of world's citizens to increase awareness about human impacts in the ocean.

5 CONCLUSION

The perception of changes in coral reefs in Porto de Galinhas, Abrolhos and Arraial do Cabo was not influenced either by age or by the type of activity practiced. Overall, the main benefits most noticed by participants fall into the categories "Physical and psychological experiences", "Habitat creation and maintenance" and "Learning and inspiration". In this study, most respondents belonged to the research or tourism area, resulting in a possible bias. Future studies with face-to-face and more wide sampling are needed for a better investigation. Finally, most of changes observed were negative, showing a worsening in the quality of the reef environments investigated by this research.

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7 REFERENCES

ANDRELLO, Marco et al. A global map of human pressures on tropical coral reefs. **Conservation Letters**, v. 15, n. 1, p. e12858, 2022.

BAPTISTOTTE, Cecíclia. Tartarugas marinhas: Projeto TAMAR. In: **Congresso de Herpetologia no Brasil**. 1994. p. 33-37.

BARRADAS, Juliana Imenis et al. Tourism impact on reef flats in Porto de Galinhas beach, Pernambuco, Brazil. 2012.

BATISTA, Daniela et al. Biodiversidade Marinha dos Costões Rochosos de Arraial do Cabo: histórico, ecologia e conservação. **Arraial do Cabo: Instituto de Estudos do Mar Almirante Paulo Moreira**, 2020.

BRATMAN, Gregory N. et al. Nature and mental health: An ecosystem service perspective. **Science advances**, v. 5, n. 7, p. eaax0903, 2019.

BRITO, Rafael Melo de et al. Perception of Nature’s Contributions to People in Rural Communities in the Eastern Amazon. **Sustainability**, v. 12, n. 18, p. 7665, 2020.

BUNCE, Matthew et al. Shifting baselines in fishers' perceptions of island reef fishery degradation. **Ocean & Coastal Management**, v. 51, n. 4, p. 285-302, 2008.

DE MIRANDA MENDONÇA, Teresa Cristina; DE MORAES, Edilaine Albertino; MACIEL, Maria Angélica. Turismo e pesca nas Reservas Extrativistas Marinhas de Arraial do Cabo (RJ) e da Prainha do Canto Verde (CE): possibilidades e limites de complementaridade. **Caderno Virtual de Turismo**, v. 13, n. 3, p. 372-390, 2013.

DE OLIVEIRA, Kleber Andolfato; CORONA, Hieda Maria Pagliosa. A percepção ambiental como ferramenta de propostas educativas e de políticas ambientais. **Revista Científica ANAP Brasil**, v. 1, n. 1, 2008.

DÍAZ, Sandra et al. Assessing nature's contributions to people. **Science**, v. 359, n. 6373, p. 270-272, 2018.

DÍAZ, Sandra et al. Pervasive human-driven decline of life on Earth points to the need for transformative change. **Science**, v. 366, n. 6471, p. eaax3100, 2019.

DUTRA, Guilherme Fraga et al. Abrolhos: desafios para a conservação e o desenvolvimento sustentável na área com a maior biodiversidade marinha do Atlântico Sul. **Field Actions Science Reports. The journal of field actions**, n. Special Issue 3, 2011.

FERREIRA, Beatrice P. et al. Status and trends of coral reefs of the Brazil region. In Status of coral reefs of the world: 2020. **Global Coral Reef Monitoring Network; International Coral Reef Initiative, Australian Institute of Marine Science: Townsville, Australia**, 2020.

FOGLIARINI, Carine O. et al. Telling the same story: Fishers and landing data reveal changes in fisheries on the Southeastern Brazilian Coast. **PloS one**, v. 16, n. 6, p. e0252391, 2021.

FRANCINI-FILHO, Ronaldo B. et al. Dynamics of coral reef benthic assemblages of the Abrolhos Bank, eastern Brazil: inferences on natural and anthropogenic drivers. **PloS one**, v. 8, n. 1, p. e54260, 2013.

FREITAS, Ian; DE CARVALHO, Daniel Estima. O aumento no acesso à internet por jovens da base da pirâmide no Brasil e suas particularidades. **Future Studies Research Journal: Trends and Strategies**, v. 4, n. 2, p. 132-163, 2012.

GIGLIO, Vinicius J.; LUIZ, Osmar J.; SCHIAVETTI, Alexandre. Recreational diver behavior and contacts with benthic organisms in the Abrolhos National Marine Park, Brazil. **Environmental management**, v. 57, n. 3, p. 637-648, 2016.

GOODMAN, Leo A. Snowball sampling. **The annals of mathematical statistics**, p. 148-170, 1961.

GONDIM, Anne Isabelley; BENDAYAN DE MOURA, Rafael; CHRISTOFFERSEN, Martin Lindsey. Catalogue of living crinoids (Echinodermata: Crinoidea) from Brazil. **Zootaxa**, v. 4995, n. 1, p. 27-55, 2021.

GOUVEIA, Maria Teresa de Jesús; BARREIRA E CASTRO, Clovis. Educação ambiental e a conservação de ambientes marinhos: o caso do Projeto Coral Vivo, Brasil. **AmbientalMente Sustentable: Revista científica galego-lusófona de educación ambiental**, v. 20, p. 487-498, 2015.

HOEGH-GULDBERG, Ove; PENDLETON, Linwood; KAUP, Anne. People and the changing nature of coral reefs. **Regional Studies in Marine Science**, v. 30, p. 100699, 2019.

HUGHES, Terry P. et al. Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. **Science**, v. 359, n. 6371, p. 80-83, 2018.

Instituto Chico Mendes de Conservação da Biodiversidade (ICMBIO). Relatório anual do Programa de Monitoramento da Visitação do Parque Nacional Marinho dos Abrolhos (Ano:2018). Caravelas, 2019.

ICMBIO. Relatório anual do Programa de Monitoramento da Visitação do Parque Nacional Marinho dos Abrolhos (Ano:2018). Caravelas, 2019. 19 p.

LABOREL, Jacques. **Les peuplements de madréporaires des côtes tropicales du Brésil**. Université d'Abidjan, 1970.

LABOREL-DEGUEN, F. et al. Recifes do Brasil: O Legado de Laborel. Rio de Janeiro, Museu Nacional. Série Livros, n.64. 376p. 2019.

LATKOVIKJ, Marija; POPOVSKA, Mirjana. Online research about online research: advantages and disadvantages. **E-methodology**, v. 6, n. 6, p. 44-56, 2019.

LEÃO, Z. M. A. N.; KIKUCHI, R. K. P. The Abrolhos reefs of brazil. In: **Coastal marine ecosystems of Latin America**. Springer, Berlin, Heidelberg, 2001. p. 83-96.

LEÃO, Zelinda MAN; KIKUCHI, Ruy KP; TESTA, Viviane. Corals and coral reefs of Brazil. In: **Latin American coral reefs**. Elsevier Science, 2003. p. 9-52.

LEÃO, Zelinda MAN et al. Brazilian coral reefs in a period of global change: A synthesis. **Brazilian Journal of Oceanography**, v. 64, p. 97-116, 2016.

MACHADO, Raquel C. Assis et al. Percepção sócio-ambiental dos turistas e trabalhadores da praia de Porto de Galinhas (Pernambuco-Brasil) acerca do ecossitema recifal. **Revista de Gestão Costeira Integrada-Journal of Integrated Coastal Zone Management**, v. 9, n. 3, p. 71-78, 2009.

MELAZO, Guilherme Coelho. Percepção ambiental e educação ambiental: uma reflexão sobre as relações interpessoais e ambientais no espaço urbano. **Olhares & Trilhas**, v. 6, n. 1, 2005.

MOBERG, F. Moberg and Folke 1999. **Ecological Economics**, v. 29, p. 215-233.

MURADIAN, Roldan; GÓMEZ-BAGGETHUN, Erik. Beyond ecosystem services and nature's contributions: Is it time to leave utilitarian environmentalism behind?. **Ecological Economics**, v. 185, p. 107038, 2021.

PAULY, Daniel. Anecdotes and the shifting baseline syndrome of fisheries. **Trends in ecology & evolution**, v. 10, n. 10, p. 430, 1995.

Plataforma Lattes. CNPQ. Disponível em: <https://lattes.cnpq.br/>. Acesso em: 8 de agosto de 2022.

RANIERO, Luiza Montoya et al. Exploração de recurso ambiental: viabilidade do turismo sustentável no recife de corais de Porto de Galinhas/PE. **Anais**, 2007.

ROBINSON, Jake M. et al. Nature’s role in supporting health during the COVID-19 pandemic: A geospatial and socioecological study. **International journal of environmental research and public health**, v. 18, n. 5, p. 2227, 2021.

SÁENZ-ARROYO, Andrea et al. Rapidly shifting environmental baselines among fishers of the Gulf of California. **Proceedings of the Royal Society B: Biological Sciences**, v. 272, n. 1575, p. 1957-1962, 2005.

SANTAVY, Deborah L. et al. What is it about coral reefs? Translation of ecosystem goods and services relevant to people and their well-being. **Ecosphere**, v. 12, n. 8, p. e03639, 2021.

SILVA, Taline Cristina da et al. Biota perception and use. In: **Introduction to ethnobiology**. Springer, Cham, 2016. p. 99-104.

SILVA, Felipe Roberto da et al. Oil Spill and Socioeconomic Vulnerability in Marine Protected Areas. **Frontiers in Marine Science**, p. 718, 2022.

TURRA, Alexander. The Ocean Decade in the perspective of the Global South. **Ocean and Coastal Research**, v. 69, 2022.

WOODHEAD, Anna J. et al. Coral reef ecosystem services in the Anthropocene. **Functional Ecology**, v. 33, n. 6, p. 1023-1034, 2019.

WOODHEAD, Anna J. et al. Fishers perceptions of ecosystem service change associated with climate-disturbed coral reefs. **People and Nature**, v. 3, n. 3, p. 639-657, 2021.

ZAMBONI, Nadia Selene; PÉREZ, Carlos Daniel. Análise da capacidade de carga turística como ferramenta para a gestão sustentável do turismo nos ambientes recifais da praia de Porto de Galinhas, Ipojuca/PE. In: **CONGRESSO BRASILEIRO DE GESTÃO AMBIENTAL**. 2013. p. 1-8.

ZILBERBERG, Carla; ABRANTES, Douglas Pinto; MARQUES, Joseane Aparecida (Ed.). **Conhecendo os recifes brasileiros: rede de pesquisas Coral Vivo**. Museu Nacional, Universidade Federal do Rio de Janeiro, 2016.

Supplementary Material 1

Percepção de serviços ecossistêmicos associados aos ambientes recifais

Quem pode participar dessa pesquisa? Qualquer pessoa (pescadores, mergulhadores, pesquisadores, turistas, moradores locais e outros) que visitou ou mora em Porto de Galinhas-PE, Abrolhos-BA e Arraial do Cabo-RJ. Caso você tenha vivência em mais de um lugar, se puder, responda o questionário duas vezes; se não, escolha aquele que você julga ter mais memórias...
Este questionário é curto, em geral, as pessoas levam em média 10 minutos para respondê-lo. Mas, esse tempo pode variar dependendo da experiência do participante.
Se precisar tirar qualquer dúvida sobre a pesquisa ou tiver comentários, fique à vontade para entrar em contato comigo pelo e-mail: marianasumi@hotmail.com

Caso você tenha intresse em receber os resultados desta pesquisa, deixe seu endereço de e-mail abaixo:

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Termo de Consentimento Livre e Esclarecido Simplificado

Durante a pesquisa você responderá a um questionário a respeito da sua interação com os ambientes recifais. O objetivo é avaliar as mudanças no provimento de serviços ecossistêmicos associados a esses ambientes ao longo dos últimos 60 anos. Não existe nenhum objetivo financeiro com esta pesquisa e para participar deste projeto, você não terá nenhum custo, nem receberá qualquer vantagem financeira. Essa pesquisa não traz nenhum benefício imediato. Caso sinta-se desconfortável em participar da pesquisa, ou por qualquer outro motivo, a qualquer hora o (a) senhor(a) pode fechar a guia, sem nenhum prejuízo pessoal ou financeiro. Os aspectos éticos desta pesquisa são regulamentados pela resolução 466/12 do Conselho Nacional de Saúde e leis complementares, das quais a professora/pesquisadora e seu orientador estão cientes e comprometem-se a seguir rigorosamente. O projeto de pesquisa, seus objetivos e metodologia, bem como este termo de consentimento livre e esclarecido, foram avaliados e aprovados pelo Comitê de Ética em Pesquisa com Seres Humanos da Universidade Federal de Santa Catarina (CEPSH-UFSC), que pode ser contatado pessoalmente na rua Desembargador Vitor Lima 222, Prédio Reitoria II, 4o. andar, sala 401, Florianópolis, SC, pelo telefone (48) 3721-6094 e pelo e-mail cep.propesq@contato.ufsc.br. O CEPSH é um órgão colegiado interdisciplinar, deliberativo, consultivo e educativo, vinculado à Universidade Federal de Santa Catarina, mas independente na tomada de decisões, criado para defender os interesses dos participantes da pesquisa em sua integridade e dignidade e para contribuir no desenvolvimento da pesquisa dentro de padrões éticos.

O Termo de Consentimento Livre e Esclarecido na íntegra pode ser acessado neste link:
https://drive.google.com/file/d/197bfLXTEzBZSSk1FxD-M7EpT71WCSN9D/view?usp=sharing

Concordo em participar voluntariamente do projeto “Recifes Brasileiros no Antropoceno: estimando os impactos da perda da biodiversidade no funcionamento e provisão de serviços ecossistêmicos". Responderei a um questionário sobre a minha percepção sobre os ambientes recifais. Estou ciente de que minha identificação será mantida em sigilo e que as informações por mim fornecidas serão usadas exclusivamente para fins deste projeto de pesquisa.
( ) Sim
( ) Não

Questionário sócio-econômico

1- Local de vivência (ambiente recifal que tem experiência)?
( ) Arraial do Cabo - RJ
( ) Porto de Galinhas - PE
( ) Caravelas/Abrolhos - BA

2-Qual a sua faixa etária?

( ) Até 18 anos
( ) Entre 18 e 30 anos
( ) Entre 31 e 40 anos
( ) Entre 41 e 50 anos
( ) Entre 51 e 60 anos
( ) Entre 61 e 70 anos
( ) Entre 71 e 80 anos
( ) Mais de 81 anos

3- Qual o seu gênero?
( ) Feminino
( ) Masculino
( ) Outro
( ) Prefiro não informar

4- Qual sua profissão?
____

5- Qual a sua escolaridade?
( ) Ensino fundamental incompleto
( ) Ensino fundamental completo
( ) Ensino médio incompleto
( ) Ensino médio completo
( ) Ensino superior incompleto
( ) Ensino superior completo
( ) Pós graduação nível mestrado
( ) Pós graduação nível doutorado (até 15 anos de formação)
( ) Pós graduação nível doutorado (mais de 15 anos de formação)

6- Dentre as opções abaixo, qual é a principal atividade associada ao ambiente recifal que você realiza?
( ) Pesca
( ) Mergulho

( ) Artesanato

( ) Turismo

( ) Mineração

( ) Pesquisa

( ) Outro

7- Caso você tenha respondido outro na questão anterior, qual a atividade associada ao ambiente recifal que você realiza?

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8- Há quanto tempo você atua nesta atividade?

( ) 0 a 6 meses

( ) 7 meses a 1 ano

( )1 a 5 anos

( ) 6 a 10 anos

( ) 11 a 20 anos

( ) 21 a 30 anos

( ) 31 a 40 anos

( ) 41 a 50 anos

( ) 51 a 60 anos

( ) Mais de 60 anos

Percepção sobre serviços ecossistêmicos

9- Sobre a sua vivência em Arraial do Cabo, Porto de Galinhas ou Caravelas/Abrolhos: você se lembra quando foram suas primeiras visitas a este lugar? Tente colocar a data mais aproximada possível (exemplo: mês/ano).

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10- Quando foi a sua última visita a este lugar (ou seja, a mais recente)? Tente colocar a data mais aproximada possível (exemplo: mês/ano).

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11- Os recifes de corais proporcionam algum benefício e/ou prejuízo para sua vida pessoal?

( ) Sim

( ) Não

( ) Talvez

12- Se você respondeu sim ou talvez na questão anterior, quais são eles? Detalhe todos os benefícios e/ou prejuízos que forem possíveis.

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13- Com relação aos BENEFÍCIOS citados na questão 12, você consegue dizer se eles aumentaram ou diminuíram desde as suas primeiras visitas ao local? Considere que 1 não aumentaram e 5 aumentaram muito.

( ) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5

14- Com relação aos PREJUÍZOS citados na questão 12, você consegue dizer se eles aumentaram ou diminuíram desde as suas primeiras visitas ao local? Considere que 1 não aumentaram e 5 aumentaram muito.

( ) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5

15- Os recifes de corais proporcionam algum benefício e/ou prejuízo para a atividade associada ao ambiente recifal que você realiza?

( ) Sim

( ) Não

( ) Talvez

17- Com relação aos BENEFÍCIOS citados na questão 16, você consegue dizer se eles aumentaram ou diminuíram desde as suas primeiras visitas ao local? Considere que 1 não aumentaram e 5 aumentaram muito.

( ) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5

18- Com relação aos PREJUÍZOS citados na questão 16, você consegue dizer se eles aumentaram ou diminuíram desde as suas primeiras visitas ao local? Considere que 1 não aumentaram e 5 aumentaram muito.

( ) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5

19- Pensando nas suas últimas visitas a este local: se compararmos o ambiente recifal de hoje com aquele de suas primeiras visitas, você nota mudanças (ex: na qualidade da água, qualidade e quantidade de vida marinha, paisagem marinha)? Considere que 1 não mudou e 5 mudou muito.

( ) 1 ( ) 2 ( ) 3 ( ) 4 ( ) 5

20- Se você respondeu 2, 3, 4 ou 5 na questão anterior detalhe todas as mudanças que você notou e se para você elas são positivas (para melhor) ou negativas (para pior).

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21- Com relação às mudanças percebidas, você consegue dizer quando o ambiente começou a mudar? Tente colocar a data mais aproximada possível. Exemplo: mês/ano.

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22- Na sua opinião, quais seriam as principais causas dessas mudanças?

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23- Você poderia nos indicar outras pessoas (pesquisadores, mergulhadores, moradores locais, etc.) que tenham familiaridade com os ambientes recifais de Arraial do Cabo, Porto de Galinhas ou Caravelas/Abrolhos, e que poderiam participar desta pesquisa? (nome e e-mail se possível)

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CONCLUSÃO GERAL

Neste trabalho nós investigamos o passado recente das comunidades recifais brasileiras através de duas abordagens distintas. Para entender como era a composição dos recifes de corais brasileiros e como ela mudou através do tempo, utilizamos dados semiquantitativos e qualitativos coletados nas décadas de 1960, 1980, 1990, 2000 e 2010, incluindo dados obtidos pelo primeiro pesquisador a estudar esses ambientes mais a fundo, o francês Jacques Laborel. Com o intuito de trazer uma perspectiva humana atual para o trabalho, elaboramos um questionário on-line para entender como usuários de ambientes recifais percebem os benefícios trazidos por estes ambientes e para averiguar se pessoas com mais anos de experiência teriam a percepção de um ambiente mais preservado no passado.

Em Abrolhos, quando comparamos a assembleia recifal através do tempo não foram notadas mudanças significativas. Porém, ao comparar a abundância de cada espécie, grandes declínios foram percebidos desde a década de 1960. No geral, a abundância das espécies abordadas neste estudo diminuiu. Espécies construtoras de recifes como *Millepora alcicornis*, *Mussismilia braziliensis*, *Mussismilia harttii* e *Siderastrea stellata* (FERREIRA & MAIDA, 2006) podiam ser encontradas em classes de abundância entre superabundante e comum, diminuindo principalmente para as classes ocasional e raro com o passar dos anos. Em Porto de Galinhas, algo semelhante aconteceu, com uma grande diminuição da abundância de espécies como *Montastraea cavernosa*, *Mussismilia hispida* e *Millepora alcicornis*; entretanto, ainda mais grave foi a ausência das espécies *Millepora braziliensis* e *Mussismilia harttii* das amostragens mais recentes, indicando uma possível extinção local em breve caso nenhuma medida seja tomada.

Os participantes do questionário online perceberam benefícios diferentes para sua vida pessoal e para atividade exercida no ambiente recifal. Os benefícios mais citados estavam relacionados com o bem-estar pessoal, mostrando a grande importância destes ambientes para a vida das pessoas, e com a capacidade dos recifes de corais de manutenção e criação de hábitat para outros organismos. Não pudemos identificar a percepção de um ambiente mais preservado pelas pessoas com mais experiência comparado com as menos experientes. Além disso, a maior mudança notada pelos respondentes foi uma diminuição da biodiversidade provavelmente devido ao declínio geral na abundância de espécies, tornando o recife menos atrativo.

É importante ressaltar algumas limitações metodológicas deste estudo: os dados de abundância das espécies foram coletados com métodos e esforços amostrais diferentes e, para que pudessem ser comparados, foi necessário transformá-los e algumas suposições tiveram que ser feitas. Por exemplo, a diferença nas metodologias utilizadas pelos autores que coletaram dados em Porto de Galinhas nos forçou a pensar em uma maneira de transformar a abundância relativa em porcentagem de cobertura para que pudéssemos comparar com os dados de Laborel. Então, assumimos que a porcentagem de cobertura de corais nesta localidade era 10% e a partir dessa suposição pudemos calcular a porcentagem de cobertura dos organismos. No capítulo 2, nós optamos pelo uso do formulário on-line devido à pandemia de COVID-19. O uso dessa metodologia permitiu a coleta dos dados, porém, muito provavelmente, foi um dos fatores que nos impediu de alcançar um público mais variado e, especialmente, pessoas com mais idade.

Diante das informações apresentadas nesse trabalho, frente às ameaças locais e globais enfrentadas pelos ambientes recifais, recomendamos:

- o monitoramento de espécies oportunistas para entender melhor se elas estão realmente se tornando mais abundantes e ganhando cobertura frente à perda de espécies construtoras e de espécies que proporcionam estrutura tridimensional;

- que os desenhos de áreas marinhas protegidas sejam pensados de forma a incluir áreas que abrangem populações saudáveis de espécies em declínio (como *Mussismilia harttii*) e locais favoráveis para o assentamento de larvas com nível de proteção integral. Dessa forma, nestas áreas se manterão indivíduos saudáveis e, portanto, mais aptos para enfrentar eventos de ondas de calor e outros impactos relacionados ao aquecimento global.

- uso de instrumentos como a Gestão Baseada em Ecossistemas (GBE) com o intuito de integrar as ações voltadas aos recifes de corais e áreas adjacentes. O princípio básico é baseado em uma abordagem integrada e interdisciplinar que considera todos os setores e aspectos envolvidos em um ecossistema, inclusive os seres humanos (TEDESCO *et al*., 2017). A implementação da abordagem (GBE) demanda um pensamento amplo que considere interações da cadeia trófica, conectividade, fatores de funcionamento do ecossistema e como as atividades humanas interagem com as espécies e serviços do ecossistema (RUCKELSHAUS *et al*., 2008). Este tipo de abordagem pode ser muito benéfica, principalmente para os ambientes recifais que se encontram muito próximos à costa pois ela levará em conta as ações antropogênicas que causam danos aos recifes.

- outras práticas como o cultivo de espécies de corais podem ser utilizadas para restaurar os recifes. Já foi testado o cultivo de fragmentos da espécies *Millepora alcicornis*, que se mostrou promissor se levadas em consideração as condições bióticas e abióticas da área a ser restaurada (OLIVEIRA; LEÃO, KIKUCHI, 2008).

- maior fiscalização de atividades turísticas, principalmente na região nordeste que possui recifes costeiros, já que esta atividade se mostra como predatória e tem consequências devastadoras para a biodiversidade desse ecossistema;

- ações direcionadas a espécies com declínios muito acentuados na abundância, como por exemplo a *Mussismilia harttii*, a fim de evitar a extinção local de tais espécies e as consequências que tal extinção acarretam (abertura de espaço para colonização de espécies "weedy" e, consequentemente, mudanças no funcionamento do recife de coral);

- o monitoramento contínuo dos nossos ambientes recifais, que é essencial para o entender o funcionamento do sistema, seu estado de saúde, detectar doenças e branqueamentos, sendo fundamental para o seu gerenciamento e para propor ações de restauração;

- e por fim, intensificar ações de conscientização e engajamento da população em relação aos ambientes marinhos.