UNIVERSIDADE FEDERAL DE ALAGOAS
INSTITUTO DE CIÊNCIAS BIOLÓGICAS E DA SAÚDE
Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos

CÍCERO DIOGO LINS DE OLIVEIRA

TEMAS PRIORITÁRIOS PARA CONSERVAÇÃO DE ELASMOBRÂNQUIOS MARINHOS E MÉTODOS ALTERNATIVOS PARA DETERMINAÇÃO DE RISCO DE EXTINÇÃO

MACEIÓ - ALAGOAS
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Tese de doutorado apresentada ao Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos, Instituto de Ciências Biológicas e da Saúde, Universidade Federal de Alagoas, como requisito para obtenção do título de Doutor em Ciências Biológicas, área de concentração em Conservação da Biodiversidade Tropical.

Orientador: Prof. Dr. Vandick da Silva Batista.
Coorientador: Prof. Dr. Richard James Ladle.

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Temas Prioritários para Conservação de Elasmobrânquios Marinhos e Métodos Alternativos para Identificação do Risco de Extinção

Tese apresentada ao Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos, Instituto de Ciências Biológicas e da Saúde. Universidade Federal de Alagoas, como requisito para obtenção do título de Doutor(a) em CIÊNCIAS BIOLÓGICAS na área da Biodiversidade.

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RESUMO

Os elasmobrânquios, popularmente conhecidos como arraias e tubarões, estão entre os vertebrados mais antigos ainda vivos, a aproximadamente 400 milhões de anos. Eles possuem papeis cruciais para o ecossistema marinho saudável e funcional. Porém, os elasmobrânquios são um dos principais grupos mais ameaçados de extinção, devido a sobrepesca, poluição dos oceanos e perda de habitat. Nesse contexto, a presente tese visa entender as tendencias das pesquisas científicas sobre esse grupo de animais e identificar métodos que facilitem avaliações de risco de extinção de forma rápida e segura. Para isso, no primeiro capitulo desbravamos o cenário das pesquisas cientificas sobre os elasmobrânquios marinhos, buscado entender quais fatores podem impulsionar mais pesquisas e quais temas são de maior urgência. Observamos que a produção cientifica sobre elasmobrânquios marinhos é crescente de modo exponencial, e que essa produção está mais concentrada em países mais desenvolvidos economicamente, e de alta produção pesqueira. Em relação aos temas abordados, houve uma clara mudança ao longo do tempo, sendo mais comum até os anos 2000 temas como morfologias e anatomia, e mais atualmente temas tais como história de vida, conservação, ecologia. Essa mudança foi de extrema importância, pois destaca a necessidade de entendermos melhor esses animais e buscarmos medidas mais eficaz de conservação. No segundo capítulo, testamos uma metodologia já conhecida (analise demográfica) para avaliar o status populacional local da arraia *Hypanus guttatus*, comumente capturada no Nordeste do Brasil pela pesca de arrasto. Para essa avaliação usamos apenas dados já publicados sobre história de vida e pesca na região. Detectamos que a espécie tem crescimento populacional negativo (-11,83%) na região, ocasionado principalmente pela captura de indivíduos jovens. Portanto, os principais indivíduos que precisam de atenção para continuação da espécie no Nordeste do Brasil seriam os jovens e neonatos. E no último capítulo, analisamos de forma global e a nível de comunidade os elasmobrânquios marinhos, buscado identificar quais atributos bioecologicos podem ser preditivos de risco de extinção. Observamos que as espécies que apresentam viviparidade e que estão em ambientes mais próximos a costa e habitam águas mais rasas tendem a ter maior riscos de extinção. E que áreas com maior quantidade de captura de tubarões e arrais também são aonde ocorre a maior quantidade de espécies ameaças. Logo requer maior fiscalização nessas áreas, pra evitar que espécies ameaçadas sejam capturas.

Palavras-chave: Arraias e tubarões; Produção cientifica; Conservação; Risco de extinção; Atributos bioecologicos.

ABSTRACT

Elasmobranchs, popularly known as rays and sharks, are among the oldest vertebrates still alive, at approximately 400 million years. They play crucial roles for a healthy and functioning marine ecosystem, controlling the populations of their prey. However, elasmobranchs are one of the main groups most threatened by extinction, due to overfishing, ocean pollution and habitat loss. In this context, the present thesis aims to understand the trends of scientific research on this group of animals and to identify methods to facilitate rapid and safe assessments of extinction risk. To this end, in the first chapter we explore the scenario of scientific research on marine elasmobranchs, trying to understand which factors may drive further research and which topics are of greater urgency. We have observed that the scientific production on marine elasmobranchs is growing exponentially, and that this production is more concentrated in more economically developed countries with high fishing production. Regarding the themes approached, there was a clear change over time, being more common until the 2000s themes such as morphology and anatomy, and more recently themes such as life history, conservation, and ecology. This change was extremely important, as it highlights the need to better understand these animals and to seek more effective conservation measures. In the second chapter, we applied an already known methodology (demographic analysis) to evaluate the local population status of the stingray *Hypanus guttatus*, commonly captured in the Northeast of Brazil by trawl fisheries. For this assessment, we used only previously published data on life history and fisheries in the region. We detected that the species has a negative population growth (-11.83%) in the region, caused mainly by the capture of juvenile’s individuals. Therefore, the main individuals that need attention for the continuation of the species in the Northeast of Brazil would be the juveniles and neonates. In the last chapter, we analyzed the marine elasmobranchs globally and at the community level, trying to identify which bio-ecological attributes can be predictive of extinction risk. We observed that species that present viviparity and that are in environments closer to the coast and inhabit shallower waters tend to have higher extinction risks. And that the areas with the highest amount of shark and harpoon catches are also where the highest amount of threat species occurs. Therefore, greater surveillance is needed in these areas to prevent endangered species from being caught.

Key-words: Rays and sharks; Scientific production; Conservation; Extinction risk; Bioecological attributes.

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Sumário

1. Apresentação

Os tubarões e raias formam subclasse dos elasmobrânquios (Elasmobranchii) e estão entre os vertebrados de maior sucesso evolutivo, com sua história de vida datado no período Devoniano, a aproximadamente 400 milhões de anos (Castro, 1987; Grogan & Lund, 2004). Possuem papeis cruciais para um ecossistema saudável e equilibrado, mantendo o controle das populações de suas presas (Heupel et al., 2014). Porém, os elasmobrânquios estão entre os animais mais ameaçados do mundo, algumas espécies possuem declinando populacional de até 90% em algumas regiões (Dent & Clarke, 2015). Estima-se que cerca de 25% das espécies existente estão enfrentando algum nível de ameaça (Worm et al., 2013; Dulvy et al., 2014), no entanto, é possível que essa estimativa seja ainda maior. Esses declínios acentuados estão diretamente relacionados as suas características de história de vida e às atividades antrópicas, principalmente a sobrepesca, degradação de habitats e poluição (Dulvy et al., 2008).

A alta quantidade de captura desses animais nos últimos anos elevou a preocupação internacional em relação a sustentabilidade da pesca de elasmobrânquios (Dent & Clarke, 2015). Entretanto, poucos países possuem plano de manejo para esse grupo (Clarke et al., 2006; Dent & Clarke, 2015), ocasionado principalmente pela falta de dados populacionais da espécie e dados de pesca. Sendo assim a principal ferramenta para conservação tem sido a lista vermelha global de espécies ameaças de extinção da IUNC.

Diante disso, a presente tese visa entender as tendencias das pesquisas científicas sobre esse grupo de animais e buscar métodos que facilitem possíveis avaliações de forma rápida e segura. Para isso, no primeiro capitulo desbravamos o cenário das pesquisas cientificas sobre os elasmobrânquios marinhos, buscado entender quais fatores podem impulsionar mais pesquisas e quais temas são de maior urgência. No segundo capítulo, testamos uma metodologia já conhecida (analise demográfica) para avaliar o status populacional local de uma espécie de arraia, uso como base dados já publicados. E no último capítulo, passamos a estudar de forma global e a nível de comunidade os elasmobrânquios marinhos, buscado identificar quais atributos bioecologicos podem ser preditivos de risco de extinção.

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2. Revisão da literatura

2.1. Diversidade e história de vida dos Elasmobrânquios

A teoria da história de vida tem como foco principal estudar a diversidade de estratégias do ciclo de vida, além de explicar as variações nas estratégias como resultado da seleção natural, identificando como as variações moldam a distribuição dos organismos (Roff 1993; Flatt and Heyland 2011). Os traços da história de vida representam propriedades demográficas e quantitativas que estão diretamente relacionadas aos dois principais componentes da aptidão, sobrevivência e reprodução (Braendle et al. 2011).

As análises clássicas da história de vida dos animais levam em consideração principalmente os traços como tamanho no nascimento, o padrão de crescimento, idade, tamanho de maturação, número de proles por ciclo reprodutivo, mortalidade e longevidade (Stearns and Stearns 2000; Hutchings 2008). Além disso, esses traços são decisivos para o entendimento da evolução, adaptação e seleção desses organismos (Stearns 1976; Berois et al. 2015). Portanto, o estudo dos traços da história da vida é indispensável para compreender o sucesso biológico de uma espécie ou grupo (Berois et al. 2015; Cailliet 2015).

Outra teoria que pode ajudar a explicam os traços da história de vidas dos seres vivos é a teoria da seleção r/K, formulada por MacArthur & Wilson (1967) e desenvolvido por Pianka (1970). Esta teoria propõe que as pressões seletivas naturais orientaram a evolução para duas direções estereotipadas: à seleção r ou à seleção K. E esses parâmetros r e K são determinados pelos traços da história de vida e pela composição genética da população (Pielou 1974; Oizumi et al. 2016).

Um dos grupos de animais mais antigos e bem caracterizados sobres seus traços de vidas, são os elasmobrânquios. A subclasse (Elasmobranchii) é constituída por arraias e tubarões, e são considerados componentes tróficos de alta importância (Camhi 1998; Heithaus et al. 2010). Essa subclasse apresenta uma ampla variedade em suas histórias de vida, apresentam características biológicas que impedem uma alta produtividade, essencialmente o crescimento lento, maturação tardia e baixa quantidade de filhos por ciclo reprodutivo (Musick 1999; Cortés 2008).

Os elasmobrânquios possuem alta variação em seus traços de história de vida, por exemplo, entre as arraias o comprimento máximo varia de 10 cm a 700 cm de largura de disco (média de 98 cm) e habitam ambiente marinho com profundidade média de 322 metros (FishBase, 2020). Já os tubarões variam de 5 cm a 1500 cm de comprimento total, com média de 120 cm, já a profundidade média onde esse grupo habita está em torno de 300 metros (FishBase, 2020). Outro traço muito importante para avaliação das espécies é a velocidade de crescimento (constante de crescimento dos modelos de crescimento) e idade máxima. De forma geral os elasmobrânquios tendem apresentar crescimento lento a moderado e alta longevidade (Frisk et al. 2001; Cortés 2008). As espécies que alcançam até 99 cm de comprimento total tendem a apresentar crescimento em torno de 0,25 ao ano e idade máxima 14 anos, essa velocidade de crescimento diminui para 0,17 em espécies que possuem tamanho máximo superior a 200 cm e a média da idade máxima aumenta para 27 anos (Frisk et al. 2001).

Outra característica importante da história de vida dos elasmobrânquios é a biologia reprodutiva. A diversidade de modos reprodutivos é elevada, sendo vários pesquisadores apontam que a melhor classificação desses modos é com base na contribuição materna para o desenvolvimento (Musick and Ellis 2005; Conrath and Musick 2012; Penfold and Wyffels 2019), podem assim serem classificadas em oviparidade, viviparidade - saco vitelino, viviparidade placentária, viviparidade oophagica, histotrofia mucóide e histotrofia lipídica. Além disso, os elasmobrânquios também possuem taxa de maturação tardia, variando 5 a 10 anos (Frisk et al. 2001). A atuação dessas características biológicas impede que os tubarões e as arraias tenham uma alta produtividade, e consequentemente faz com quem possuam maior vulnerabilidade a extinção. Portanto, estudos sobre os traços de história de vida dessas espécies são essenciais para determinar medidas de manejos mais adequadas.

O padrão de riqueza e a distribuições de espécies são amplamente utilizadas para caracterizar e explicar os padrões observados na biodiversidade em todo o mundo e podem ser usadas para ajudar a identificar locais de prioridade de conservação (Gaston 1996; Lucifora et al. 2012). Atualmente existem 1173 espécies de elasmobrânquios no mundo (IUCN, 2022), no ambiente marinho é onde encontra-se a maior diversidade de espécies 98% (1142 espécies), sendo 49% de habita costeiro, 3% pelágico e 48% de águas profundas (Dulvy et al. 2021). Essas espécies são classificadas em dois grandes grupos, os das arraias (Batoidea) com 636 espécies, sendo a ordem Rajiformes com a maior riqueza de espécies (46%), e o grupo dos tubarões (Selachimorpha) com 537 espécies, representado principalmente pela ordem Carcharhiniformes com 291 espécies (Figura 1).

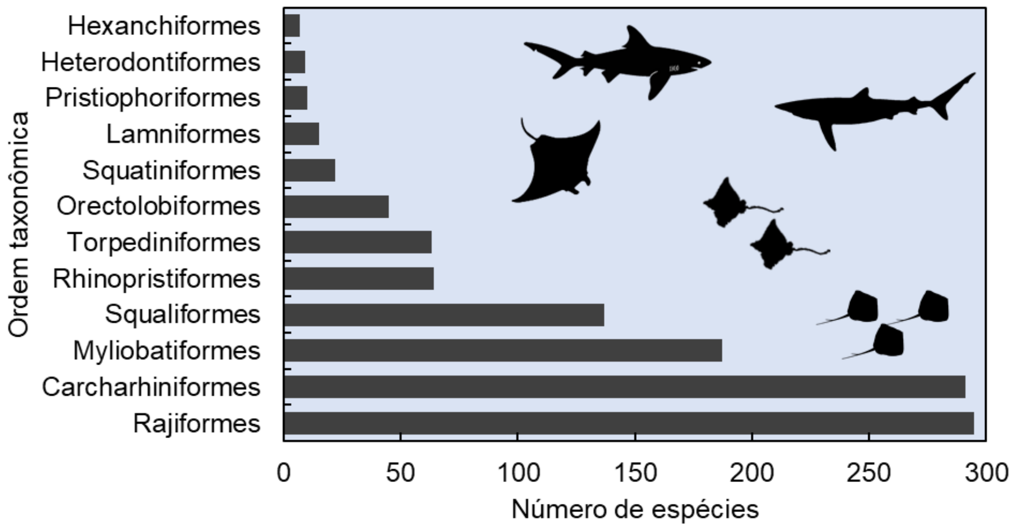

Fig. 2. 1. Distribuição das espécies de elasmobrânquios por ordem taxonômica.

Segundo Guisande et al. (2013) o padrão de riqueza dos elasmobrânquios está relacionado diretamente com fatores abióticos como temperatura e batimetria, logo ambientes com temperaturas mais alta e menores profundidades possuem maior riqueza, sendo assim as regiões costeiras possuem maior riqueza. Por outro lado, os pontos mais críticos de menor riqueza de espécies para tubarões estão em áreas offshore no sul do Japão, Taiwan e China, leste e oeste da Austrália, leste da África do Sul, Mauritânia e Ilhas Canárias. Em relação as arraias, a riqueza de espécies é maior do Marrocos ao Congo, leste da África do Sul, da Índia ao sul da China, Taiwan e sul do Japão (Guisande et al. 2013). Monitorar estas informações de riqueza e distribuição das espécies é essencial para conservação de longo prazo por permitirem entender as causas das variações biogeográficas e por subsidiarem a tomada de decisão para conservação.

Em resumo, as informações sobre os traços de história de vida dos elasmobrânquios, bem como as ocorrência e padrão de riqueza, são cruciais para a conservação desse grande grupo tão vulnerável aos efeitos antrópicos. Por outro lado, mais esforços em pesquisas são necessários para desvendar a vida desses animais vistos que aproximadamente 40% das espécies não possuem dados de história de vida documentados, dificultado assim a avaliação de risco de extinção e a definição de medidas efetivas de conservação.

2.2. Pesca de Elasmobrânquios

A pesca mundialmente tem alta relevância cultural, sendo umas das primeiras atividades desenvolvidas pela humanidade (Sainsbury 1996; Hughes 2015), tendo importância socioeconômica, contribuindo com aproximadamente 17% de toda a proteína consumida por humanos, além de gerar milhões de empregos (Gutiérrez et al. 2011; FAO 2018). Entretanto o relatório FAO da Situação Mundial da Pesca e Aquicultura - SOFIA (FAO 2018), que abrange 70% dos desembarques de todas as pescarias no mundo, estima que 34,2% dos estoques de peixes marinhos estão sobrexplotados (FAO, 2020). Nos últimos anos, menções tem sido comuns sobre o colapso de diversas espécies de peixes (Worm et al. 2009; Butchart et al. 2010; Roberson et al. 2020), incluindo espécies de tubarões e arraias (Davidson et al. 2016; Lawson et al. 2020).

A carne dos elasmobrânquios têm sido historicamente considerados de baixo valor econômico, quando comparados a outros recursos pesqueiros, sendo as barbatanas e fígados os principais produtos comercializados (Dent and Clarke 2015). No entanto, nos últimos anos, os tubarões e as arraias alcançaram altas quantidade de capturas na pesca dirigida comercial, bem como na captura incidental, principalmente nas zonas costeiras, onde são mais explotados (Oliver et al. 2015). Essa última modalidade, tem sido considerada a maior ameaça para os elasmobrânquios, principalmente para os tubarões pelágicos (Stevens et al. 2000; Dulvy et al. 2008). Aproximadamente 50% da produção global de tubarões é composta por tubarões capturados como captura incidental na pesca de espinhel pelágico (Bonfil 1994, 1997; Stevens et al. 2000). Além disso, a captura incidental de elasmobrânquios raramente é registrada em nível de espécie nas estatísticas oficiais de pesca, o que vem a gerar dados superficial sobre sua captura (Bonfil 1994; Clarke et al. 2006).

A quantidade de elasmobrânquios capturados (em toneladas) apresentou um crescimento linear até os anos 2000, quando atingiu o pico de produção (Figura 2), posterior a isso a captura de elasmobrânquios marinhos teve declínio em torno de 200.000 toneladas entre os anos 2000 a 2020 (FAO, 2022). Esse declínio pode estar relacionado com o esgotamento das populações e também com as medidas de conservação implementadas, tais como a proibição de captura, criação de áreas marinhas protegidas ou a restrição do uso de apetrechos de pesca.

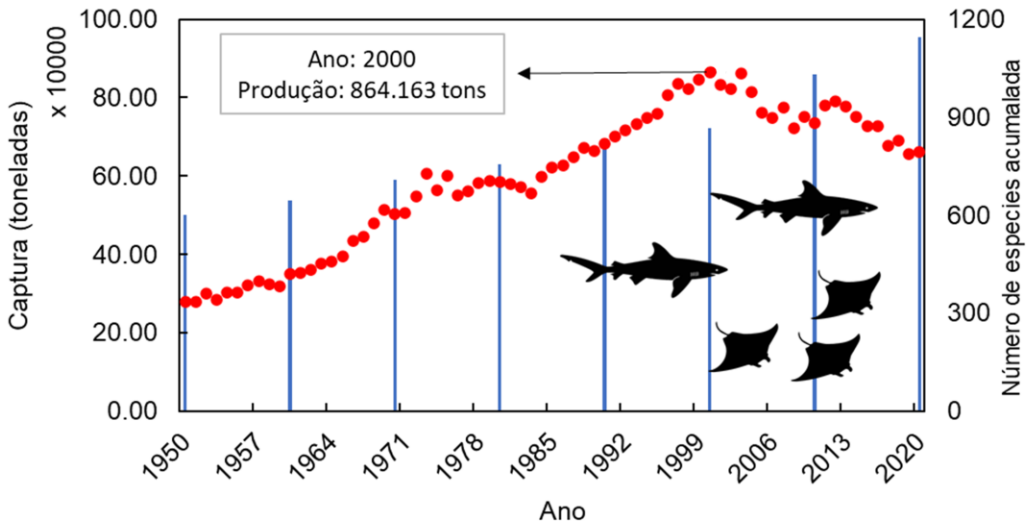

Fig. 2. 2. Histórico de captura global de elasmobrânquios marinhos e acumulo de espécies por década.

Portanto, décadas de sobrepesca juntamente com a degradação de habitats tem resultado em populações alteradas e no declínio populacional de muitas dessas espécies de elasmobrânquios (Dulvy et al. 2014; Dent and Clarke 2015; Lawson et al. 2020). Tal é o caso dos tubarões *Isurus oxyrinchus*, *Carcharodon carcharias* e as arraias *Mobula mobula* e *Mobula birostris*, que estão em ameaça devido a sobrepesca (Cailliet et al., 2009; Fergusson et al., 2009; Sciara et al., 2016; Marshall et al., 2018). Em resposta a isto, muitos estudos passaram a ser voltados para designar ações visando a redução desses declínios populacionais. Dentre as principais ações sugeridas estão a proibição da captura das espécies em risco de extinção e o aumento e a expansão de Unidades de Conservação marinha (Allison et al. 1998; Daly et al. 2018; Gupta et al. 2020; Sabadin et al. 2020).

2.3. Status de Conservação dos elasmobrânquios marinhos

Manter a biodiversidade é crucial para os ecossistemas naturais e a sociedade, porém o número de espécies ameaçadas de extinção globalmente está em alta, 29% das espécies existentes estão algum risco de extinção, para as espécies de elasmobrânquios, esse valor sobe para 35% (IUCN 2022). A determinação dos traços de histórias de vida são crucias para compreender a vulnerabilidade, o declínio populacional e risco de extinção, bem como tornar o planejamento de proteção e conservação de espécies mais eficiente (Jennings 2000; Reynolds et al. 2001; Chichorro et al. 2019). Sendo assim, uma das principais atuações da biologia da conservação é evitar o colapso das espécies, fazendo com que elas não entre em extinção (Kareiva & Marvier, 2012). Umas das principais ferramentas usadas para determinar o status das espécies em relação ao riscos de extinção tem sido a Lista Vermelha de Espécies Ameaçadas da IUCN (Rodrigues et al. 2006; De Grammont and Cuarón 2006).

A Lista Vermelha da IUCN, é produzida pela Species Survival Commission (SSC) da World Conservation Union (IUCN; http://www.iucn.org), destaca as espécies que estão em maior risco de extinção e promove a sua conservação A lista vermelha prioriza ações de conservação ao identificar espécies de alto risco de extinção (Hoffmann et al. 2008). Os critérios de avaliação (Figura 3) foram concebidos para avaliar o risco de extinção de toda a população de uma espécie considerando a sua distribuição global (IUCN, 2022). Essas avaliações devem ser apoiadas por dados, justificativas, fontes e estimativas de incerteza (Rodrigues et al. 2006).

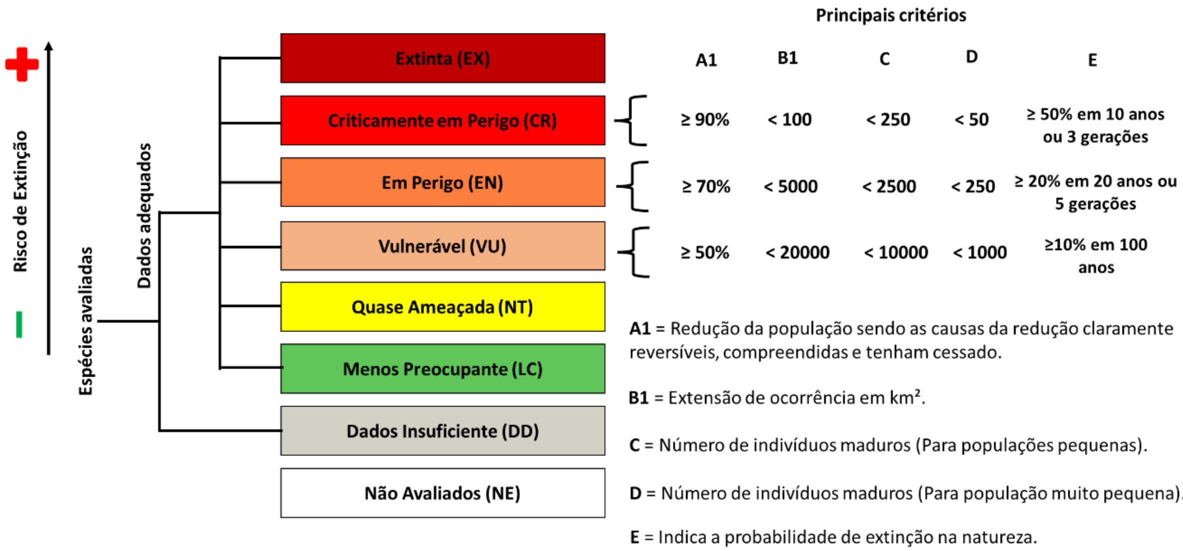

Fig. 2. 3. Classificação de risco de extinção da IUCN e seus principais critérios. Adaptado de IUCN (2022) versão 15.1.

Atualmente a IUCN já avaliou 24356 espécies de peixes, desses 46,6% são de ambiente marinhos, e 4,6% são elasmobrânquios marinhos. Entre as espécies desse último grupo 12,8% (147 espécies) são classificadas como Dados Deficiente (DD), 43,3% em Menos Preocupante (LC), 10,5% em Próximo de Ameaça (NT), 15,4% em Vulnerável (VU), 10,4% em Perigo e 7,7% em Criticamente em Perigo (IUCN, 2022).

Os principais motivos que levam a esse alto valor de espécies de elasmobrânquios marinhos ameaçadas de extinção (35,5%), são principalmente pela perda e degradação de habitat, espécies invasoras, superexploração, poluição e mudanças climáticas (Dudgeon et al. 2006; Dulvy et al. 2014). A identificação precisa das ameaças é necessária para implementar com sucesso as ações de conservação (Butchart et al. 2010; Stein et al. 2018). Visando isso Dulvy et al. (2021), analisaram se algumas espécies atuais mudaram o status de conservação, considerando as últimas avaliações. Os autores identificaram que 15 espécies mudaram de status, no qual 12 pioraram o status e apenas três melhoraram. Um exemplo desse caso foi a arraia da Nova Zelândia (*Dipturus innominatus*), que mudou da categoria NT para a LC, ocasionado pelas boas estratégias implementada na região para aumentar a população a partir do estabelecimento de cotas de captura.

Portanto, o futuro dos elasmobrânquios depende de dois pontos principais: 1) das avaliações de risco de extinção, com intuito de identificar quais espécies apresentam maior risco de extinção e são prioritárias para a conservação; e 2) aplicações das medidas de manejo adequadas para reestabelecimento das populações. Para isso faz necessário dados de boa qualidade, que possibilitem uma avaliação real dessas espécies e que os órgãos responsáveis coloquem em pratica as medidas de manejo designadas.

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3. Objetivos

3.1. Objetivo Geral

O objetivo geral desta tese foi analisar a tendência da produção científica sobre elasmobrânquios marinhos mundialmente, buscando entender os padrões e lacunas sobre essa produtividade e determinar quais atributos bioecologicos são bons preditores do risco de extinção.

3.2. Objetivos específicos

A tese foi dividida em três capítulos, cada um correspondente a um dos seguintes objetivos:

1. Identificar as tendências e lacunas da produção científica no que tange os elasmobrânquios marinhos e fatores que afetam essa produção.

2. Avaliar o status demográfico da arraia *Hypanus guttatus* a nível local (Nordeste do Brasil) a partir dos traços de história de vida, tais como biologia reprodutiva, crescimento e longevidade.

3. Determinar quais atributos bioecologicos podem estar relacionados como o risco de extinção das espécies de elasmobrânquios marinhos, e quais espécies Não Avaliadas ou classificadas como Dados Deficientes pela IUCN possuem maior perigo de extinção.

4. CAPÍTULO 1 - Patterns and trends in scientific production on marine elasmobranchs: research hotspots and emerging themes for conservation

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Abstract

Marine elasmobranchs are one of the most endangered fish taxa, with declining records worldwide, tough they remain a popular subject for scientific research and conservation. Here, we aim to quantify and understand trends in scientific production about marine elasmobranchs, with special emphasis on the theme of conservation. We performed a scientometric analysis on the Web of Science platform, collecting data on scientific production between 1950 and 2019. We identified 8,172 valid articles on elasmobranchs with production increasing exponentially during the study period. The United States and China were revealed as centers for research networks. We observed a tendency to move from descriptive biology and ecology (e.g., morphological and physiological studies) before the 1980's to themes more related to life history, conservation and fisheries during the last decades. Even so, there were few studies explicitly related to elasmobranch conservation, especially in Asian countries (only 5.5% of the articles from this region were conservation related) where threats from overexploitation are high. We observed a different pattern for rays and sharks, the latter being far more studied. We conclude that elasmobranch conservation research should be urgently prioritized, especially on species where there is limited data to support evidence-based management decisions.

Keywords: Endangered; Conservation; Sharks; Rays; Scientometric.

4.1. INTRODUCTION

The efficient management of marine resources for conservation or sustainable exploitation is feasible if science can support the development of policies and management to achieve clear objectives (Hilborn and Walters 1992; Hilborn 2007; Klein et al. 2008). In this context, evidence-based advice drawing on multiple forms of information is of preeminent value (Cooke et al. 2017), especially for managing endangered biota. The exploitation of renewable marine resources is an important social, economic and cultural activity, which frequently results in environmental degradation, population decline and even local extinction (Béné et al. 2016; Sumaila et al. 2016; Costello et al. 2016). Estimates indicate that 54 to 60% of the world's fishing stocks are extremely exploited with biomass below a sustainable level (Christensen et al. 2014; FAO 2014).

Elasmobranchs are an iconic taxon of great importance for ecosystem functioning, conservation and fisheries, whose populations have decreased by up to 90% during the last decades (Dent and Clarke 2015). They are also a very ancient and adaptable group, having survived for more than 400 million years and having faced numerous environmental challenges (Castro 1987; Grogan & Lund, 2004). Their charisma is certainly linked to the actual physical threat they pose to humans (Thompson and Mintzes 2002; Neff and Hueter 2013; O'Bryhim and Parsons 2015; Barrowclift et al. 2017), but also because of their role as a delicacy in certain regions and cultures (de Mitcheson et al. 2013). Among the known 1,051 elasmobranchs marine species, 18.9% are at risk of extinction (vulnerable, endangered, or critically endangered), and 38.2% are Data Deficient due to a lack of scientific studies with focus on these species (IUCN 2019).

Marine elasmobranch conservation is currently focused on reducing the impacts of high fishing exploitation, environmental degradation and climate change (Halpern et al. 2008; Ferretti et al. 2010). According to FAO data, there was an increase in world catches of Chondrichthyes until 2000, followed by decreased catches related to stock collapses and fisheries restrictions; these decreased catches were not enough to prompt population recovery (Dulvy et al. 2014). Furthermore, biomass reduction led to changes in the structure of marine communities (Stevens et al. 2000) due to the important ecological role of many rays and sharks in marine food-webs (Heupel et al. 2014). These trends indicate the urgent need for evidence-based approaches to elasmobranch exploitation and conservation, though to our knowledge there has not been a systematic review of the scientific literature on this iconic taxon.

Elasmobranchs are a particularly diverse taxon in terms of its bioecological features and contain many iconic species (McClenachan et al. 2012; Mazzoldi et al. 2019). The varied socio-cultural prominence of species and higher taxa has been noted, with sharks attracting more public attention than rays and skates (Shiffman et al. 2020). This, in turn, may influence researchers (through funding and other research opportunities) who are predicted to focus on sharks, especially species that are more widespread, economically important, ecologically interesting (e.g., habitat use, maximum size, trophic level) (Ducatez 2019), and whose interactions with humans (e.g., attacks, tourism) foster high levels of public interest .

Scientific knowledge is fundamental to address conservation and management challenges (Beddington et al. 2007). Scientific production about marine resource issues has grown significantly in recent years, but is very patchy and may not be meeting conservation needs (Jarić et al. 2012; Bode et al. 2019; Teixeira et al. 2020). Such production is typically linked to economic factors (Teixeira et al. 2020) and collaboration among countries (Oliveira Júnior et al. 2016). For Elasmobranchs, conservation research are frequently focused on anthropogenic impacts on fishing resources and, especially, megafauna (McClenachan et al. 2012; Dulvy et al. 2014). Consequently, there is a predominance of scientific research on bioecological factors, such as reproduction, growth, influence of abiotic factors on the population (Awruch et al. 2019; Ducatez 2019) and cultural issues (e.g., Neff and Hueter 2013; O'Bryhim and Parsons 2015). However, scientific capacity varies considerably between countries, potentially limiting the contribution of scientists from the Global South. This is critical given that effective fisheries management policies must consider effects of the economic (Sachs and Warner 1997; Doi and Takahara 2016) and human development (Gutiérrez et al. 2011), and the sustainability profile of the study system (Bundy et al. 2017).

To support conservation and fisheries policy development, adequate information must be available (or in the process of being gathered) and should be supported by appropriate levels of research funding (Mulligan and Mabe 2011; Rangeley and Davies 2012). Whatever the (diverse) motivations of scientists, understanding research trends on conservation and fisheries can provide stakeholders with useful information on trends and gaps that can, in turn, feed into evidence based policies development (Pullin and Stewart 2006). Such knowledge can also help managers to identify current and future research priorities, allowing them to close outstanding knowledge gaps for decision-making (Rizzi et al. 2014; Awruch et al. 2019).

Species-focused conservation research on elasmobranchs is commonly related to attributes such as the species' maximum size (Dulvy et al. 2014; Ducatez 2019), distribution range (Dulvy et al. 2014), shallow common depth (Dulvy et al. 2014; Ducatez 2019), trophic level (Ducatez 2019); commercial importance (Davidson et al. 2016), threat status (Dulvy et al. 2014; Ducatez 2019), charisma (McClenachan et al. 2012; Mazzoldi et al. 2019) and species incidents with humans (Neff 2012; Neff and Hueter 2013). However, if these attributes are interacting for same species or are they isolated choices is still not defined.

Here, we identify the factors associated with scientific production on marine elasmobranchs. Our goal is to test if choice of research theme is associated with socioeconomic characteristics of a researcher's country and the cultural profile of the studied species. Specifically, we hypothesize that species with more charisma and research from countries with greater economic strength, social justice, and sustainable development will shape scientific production on elasmobranchs.

4.2. MATERIAL AND METHODS

4.2.1. Bibliometrics

A search by articles in the Web of Science platform was conducted in January 2020 using the text string combination: (("elasmobranch" OR "shark" OR "batoid" OR “stingray”) NOT "freshwater"). This search was applied to the title, abstract and keywords for the publication period 1950 to 2019.

Documents returned from this search were then filtered in two ways. First, documents only the following categories of documents were retained: articles, scientific notes, and original technical contributions; excluding reviews, books, and book chapters. Second, articles out of the study scope were manually excluded. These included articles focusing on false sharks (e.g., elephant shark) or documents where the words shark/ray were not referring to the animal (e.g., shark/ray bay).

We collected information on authors and their affiliations, year of publication, article title, and keywords from the remaining articles. The species name in the title was extracted to identify the article focus. All species nomenclatures were updated following the current nomenclature (e.g., Dasyatis guttata was updated to Hypanus guttatus). In addition, the articles were classified into ten thematic groups (Table 1) based on the title and keywords, verifying on the abstract when the theme was still not clear.

Table 4. 1. Themes and their descriptions used to classify scientific articles.

Thematic	Description
Anatomy, morphology, and physiology	Analysis and descriptions of anatomy and morphology, as well as the multiple mechanical, physical, and biochemical functions.
Conservation and management	Stock assessments, demographic analysis, population decline, designation of closed areas, ecotourism, and others.
Diet and feeding	Composition and feeding habits.
Distribution, occurrence, and abundance	Description, distribution and/or abundance of species, records in new locations, with implications on the geographical distributions.
Ecology and behavior	Ethology and ecology of species interactions, effects of abiotic

Thematic	Description
	variables on populations or communities and similar, shark attack.
Fisheries and marketing	Description of catches, directed or bycatch, fishing effort, fishing gear, fish processing, marketing and consumption.
Habitat use and migration	Habitat use to breed, forage or grows, or focused on migration.
Life-history	Age and growth, reproductive biology, ontogeny.
Taxonomy, systematics, evolution, and genetics	New species, updates on systematic and taxonomy, evolutionary history.
Other	Articles that were not classified in any of the previous themes, such as description of shark parasites, stranding records etc.

4.2.2. Scientific production by country

A distribution map of scientific production was built using QGIS 2.18 version, indicating the sum of the scientific production from 1950 to 2019 for each country. VOSviewer software version 1.6.9 was used to build the network of collaboration among countries. Fishing data from 1950 to 2017 obtained from FishStatJ (FAO 2019) was considered.

4.2.3. Scientific production by research theme

Two different measures were used to evaluate research themes: 1) Percentage of themes, considering the frequency of each theme within a decade divided by the number of articles published in the same decade; 2) the absolute frequency of used keywords, without considering time period. Three keyword networks were built, considering the number of occurrences of the top 50 words linking them using VOSviewer software version 1.6.9. The first network had the term elasmobranch as requirement, the second was sharks, and the third was rays or skates. The frequency of the 15 main keywords was then calculated, considering all articles per continent. As conservation is a key topic to the current analysis, the frequency of this word was analyzed by country, grouped by continent, and compared among them.

4.2.4. Scientific production by taxa

To test preferences in the publication between Batoidea and Selachii, articles were classified into these two groups. When the article was about both groups, it was counted for both. The frequency of publication was compared between these two groups by continent to track differences using chi-squared test.

4.2.5. Statistical Analysis

The trend of annual scientific production was analyzed using three different growth models (potential, exponential, and linear), with the best fit being diagnosed by the Akaike information criterion (AICc). A Pearson correlation was then performed (Zar 2014), between the production of scientific papers and the catch of chondrichthyans (the database not provide only elasmobranchs catch). The chi-square test was applied to test for temporal differences in the proportion of countries between the periods.

A generalized linear model (GLM) was applied to identify factors associated with scientific production of the countries. Predictive attributes for the model were: (1) Human Development Index (HDI); (2) Gross Domestic Product (GDP) that were downloaded from The World Bank Data-base (**https://data.worldbank.org/**); (3) Environmental Performance Index – EPI (**https://epi.yale.edu/**) (Wendling et al. 2018), based on 2018 scores (**https://sedac.ciesin.columbia.edu/data/collection/epi/sets/browse**); (4) marine fisheries production, based on the average of the last 10 years (2008-2017) extracted from the FishStatJ (FAO, 2019); (5) coast length (km) and; (6) number of shark incidents per country, extracted from Shark Attack Data (**http://www.sharkattackdata.com/**). The last two attributes were included because both variables may bias the results.

We used the average of the models to select the models with the best explanation for the response variable. For this, we used only the models with AICc less than 4. We calculated the hierarchical partitioning of all explanatory variables (adhering to all model assumptions, as proposed by Zuur et al. (2010)). We used the lme4 package (Bates et al. 2015) to fit the models, and MuMIn for performing model selection and model averaging (Barton & Barton 2019) in the R statistical platform (R Core Team 2018).

The proportion of themes per decade (taking each year within the decade as replicates) was assessed through permutational analysis of variance (PERMANOVA). A Kruskal-Wallis test was applied to test if there was a significant difference between continents.

To test the difference between a continents' researchers preferences for the major taxonomic groups (sharks and rays), a PERMANOVA was performed using countries as replicates. To identify factors influencing scientific production for

Superorders Selachimorpha and Batoidea (separately) a GLM model was used with the following explanatory variables: (1) maximum size (LTmax); (2) distribution; (3) minimum depth (DM); (4) average environmental temperature (Temp); (5) trophic level (TL); (6) commercial importance (CI); (7) threat status (TS); (8) public interest (INT), and; (9) number of incidents by species (INC).

The variables 1 to 6 were obtained from the platform Fishbase (**https://www.fishbase.se/search.php**), in which the data was extracted using rfishbase package (Boettiger et al. 2012, 2019). For the distribution variable, the area of occurrence (EXISTENT/RESIDENT) in square kilometers was considered (IUCN, 2019). The IUCN red list category (IUCN, 2019) based on Dulvy et al. (2014) was used for the threat status after transformed to numerical values, assigning 0 to Least Concern (LC) and 1 to in risk categories - Critically Endangered (CR), Endangered (EN), Endangered (VU) or Near Threatened (NT). The variable 8 (public interest) was measured from the average daily view per species on Wikipedia web page (**https://pageviews.toolforge.org/**), considering the count of the population's search for knowledge about the determined species count as a surrogate to the social interest on the species. This was taken by averaging daily views from 2015 to 2019, including all languages. Finally, shark incident data were obtained from the Shark Attack Database (**http://www.sharkattackdata.com/**). All statistical tests were applied at a 5% significance level.

4.3. RESULTS

4.3.1. Bibliometrics

A total of 13,772 documents were found in the WOS platform, of which 8,172 articles remained after filtering for document type and relevance (59.33% of the initial total). An exponential increase in scientific production on marine elasmobranchs was found (AICc = 629, R^2 = 0.91, p-value = 0.01) (Figure 1). This annual scientific production was significantly correlated with the annual catches of marine Elasmobranchs (r = 0.629, p-value = 0.001).

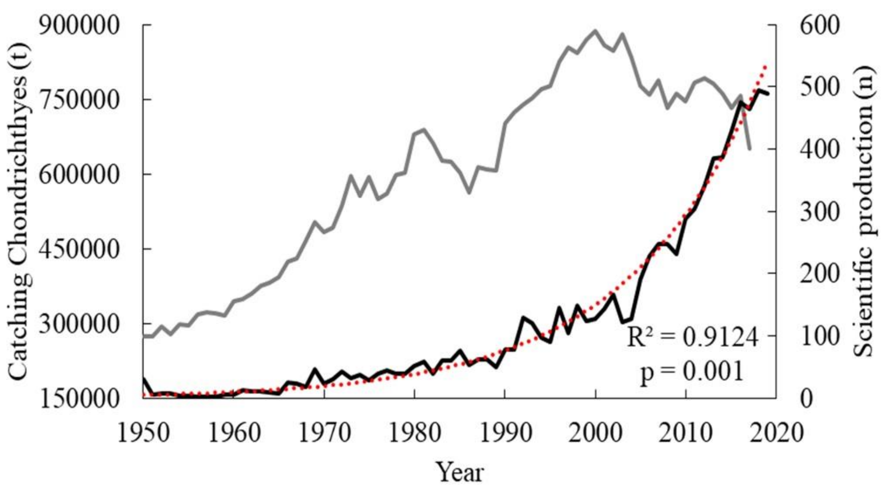

Fig. 4. 1. Scientific production on marine elasmobranchs (black line) and Chondrichthyes catch (gray line) worldwide in the period from 1950 to 2019.

4.3.2. Scientific production by country

Taking the total World scientific production per country between 2016-2019 as a reference, the USA and China accounted for 32.27% of total recorded production. European countries in the top 20th list accounted for 26.4% of production and Asian countries other than China accounted for 15.22% of production. Scientific production on elasmobranchs was (first) authored by researchers from 126 countries, mainly from America, Europe, and Oceania. Countries with the highest scientific production were the United States (2,672 articles), followed by Australia (874), Japan (374), United Kingdom (365) and Canada (341) (Figure 2).

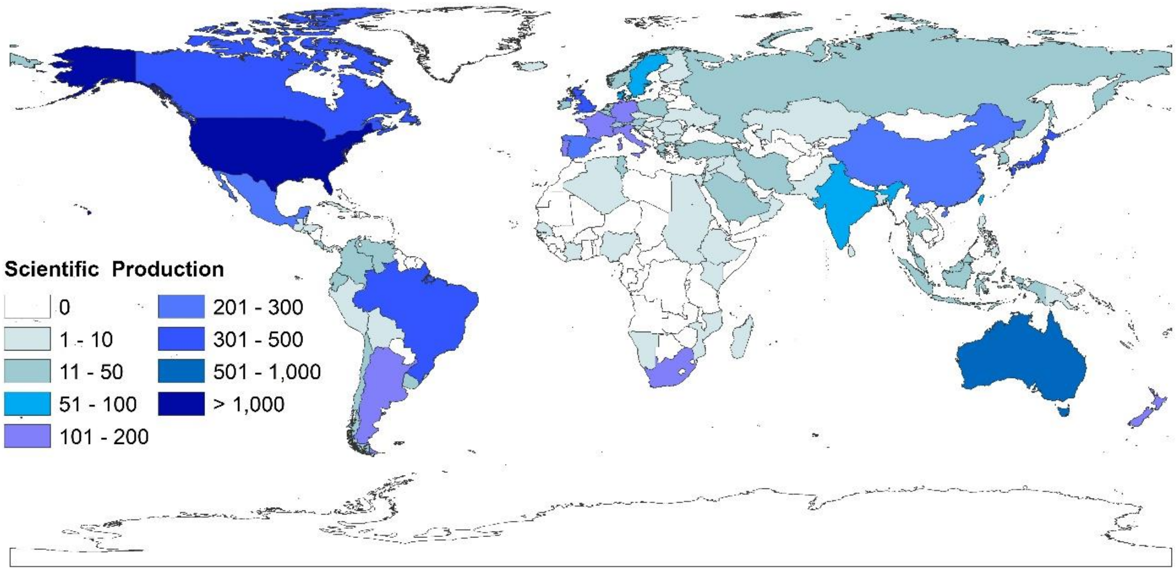

Fig. 4. 2. Scientific production of marine elasmobranchs in the world in the period 1950-2019, considering the total sum between the years.

There was also an temporal increase in research collaborations among countries. In the period from 1950 to 2003 only 336 co-authorship links among 52 countries were recorded (Figure 3.A). The United States had most collaborations (with 32 countries). Between 2004 and 2019, 4,649 links among 126 countries were recorded. In this period, the United States connections remained at the top, collaborating with 95 countries; followed by Australia (73 countries) (Figure 3.B).

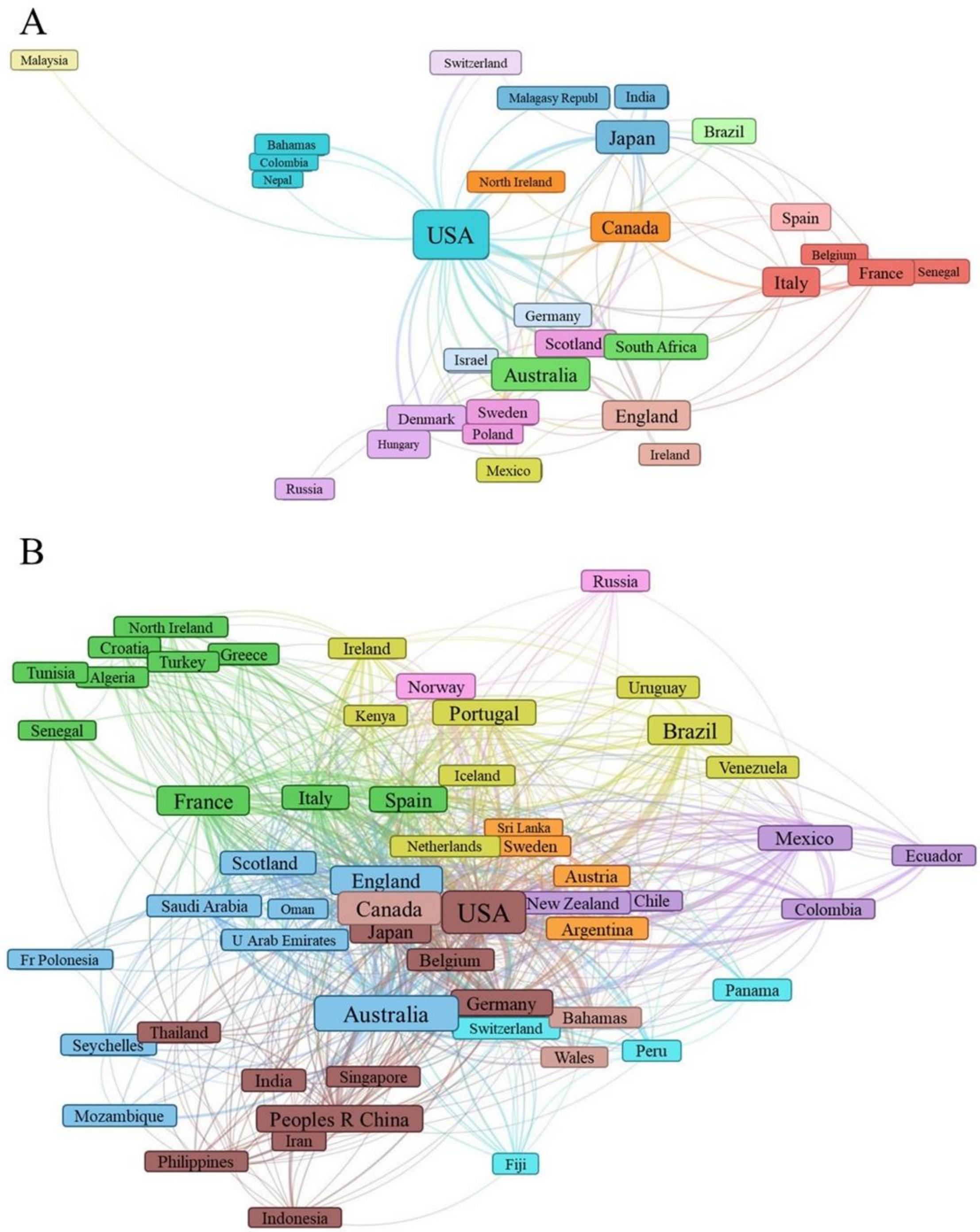

Fig. 4. 3. Network of countries with scientific publications on rays and sharks by period. A – 1950 a 2003; B – 2004 a 2019.

Country level scientific production was significantly associated with HDI, number of shark incidents, GDP and coastline length (Figure 4).

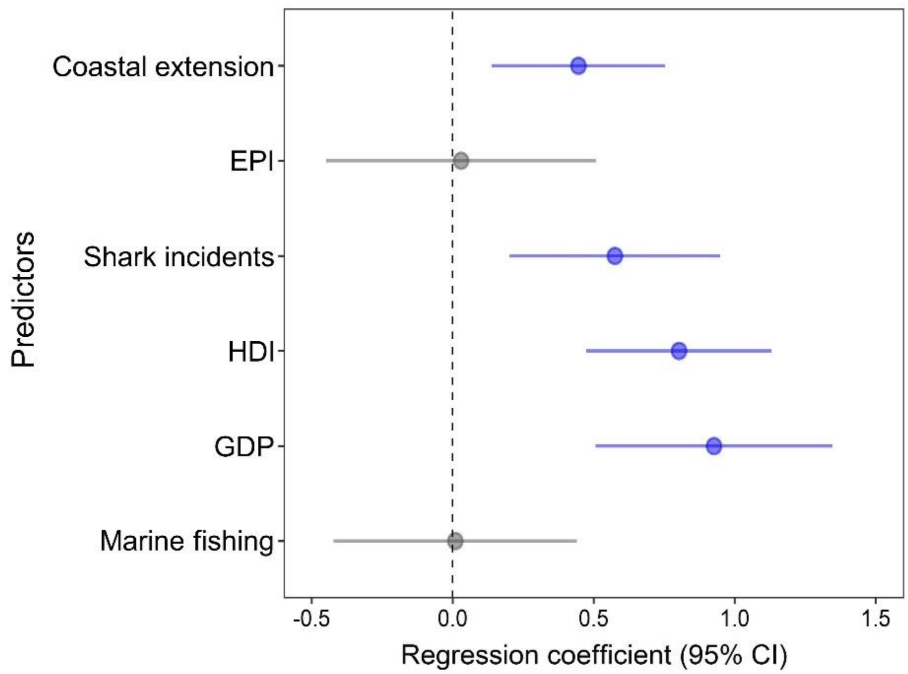

Fig. 4. 4. Effect sizes with 95% confidence intervals from Sociocultural and economic predictors related to scientific production by countries. Blue = significantly positive; Gray = not significant

4.3.3. Scientific production by theme

A total of 8,534 articles were classified for research theme. We observed significant changes in the frequency of research topics per decade (Figure 5); from the 1960's to the 1980's studies were mainly related to anatomy, morphology and physiology. After the 1980s the frequency of these themes decreased and articles related to life history, ecology, habitat use, and conservation increased in frequency. We observed a significant difference among the thematic composition per decade (p-value < 0.001), with the 2010s differing from all other decades.

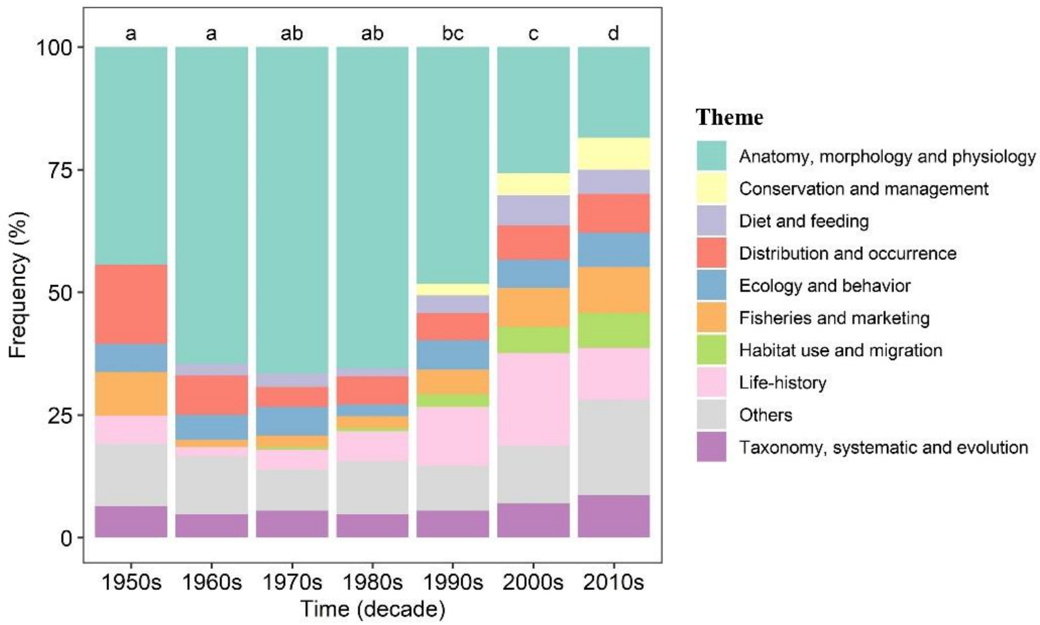

Fig. 4. 5. Thematic frequency of articles on marine elasmobranchs per decade. Different letters represent significant difference (p-value < 0.05).

The combined thematic network for Selachii and Batoidea highlighted the nodes “shark”, “ray”, “skate”, “reproduction” and “conservation” (Figure 6). Considering only shark related research, there was a strong representation of the word “bycatch” and “conservation”; the terms “rays” and “skates” were less prominent than “stingray” and “reproduction” (Supplementary Figure 1).

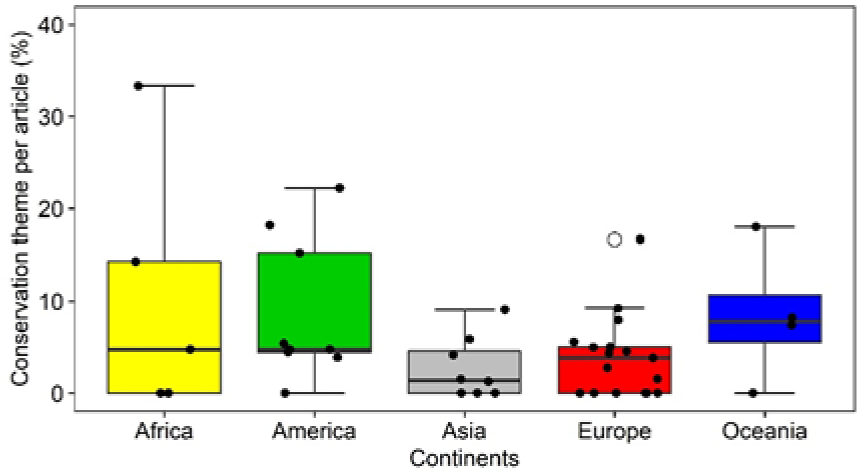

Fig. 4. 6. Frequency of term conservation in the articles published from 1990 to 2019 by continent. filled circle = countries, and circle = outliers.

At the level of continents, the most common words were “reproduction” and “growth” in Africa, “diet” in Oceania, “evolution” in Europe; Asia was the continent with the lowest occurrence of conservation and management terms (Table 2).

Table 4. 2. Relative frequency of the articles main keywords dealing with marine elasmobranchs by continent.

Area	Keywords	Africa	America	Asia	Europe	Oceania	Mean
General biology	Biology	8.23	6.21	3.14	4.45	5.43	5.49
	Evolution	1.27	6.72	4.33	8.07	3.73	4.82
	Diet	4.43	5.42	1.94	4.08	6.52	4.48
	Identification	3.8	2.64	5.08	3.45	2.64	3.52
Ecology	Growth	11.39	9.27	7.32	7.73	9.32	9.01
	Reproduction	17.72	6.3	5.53	4.2	4.35	7.62
	Behavior	8.86	8.11	2.84	8.15	8.07	7.21
	Movement	7.59	4.45	1.64	4.03	7.76	5.09
	Age	6.96	5	3.89	4.03	4.35	4.85
	Habitat use	8.23	3.15	0.45	2.65	5.9	4.08
Management	Conservation	13.92	10.84	5.53	8.91	15.84	11.01
	Management	8.23	4.54	2.39	3.24	8.39	5.36
	Coast	11.39	2.64	1.64	1.72	2.95	4.07

"Conservation" is one of the main keywords in more recent articles, with 482 occurrences since 1990. When observed by country and grouped by continent, Africa had the higher range (0 - 33.33%). However, the percentage does not differ significantly among continent (Kruskal-Wallis, p-value = 0.267).

4.3.4. Scientific production by species

Only 3,833 articles had one or more species names specified in the article title. A total of 464 species were represented: 215 Batoidea and 249 Selachii. A clear preference for sharks was observed (73-88% of the records) in all continents (t-test, p-value = 0.001). American and African research had the highest percentage of articles about rays (20-26%), while in the other continents percentage was less than 15% (Figure 7). Nevertheless, there were no significant differences between continents (p-value = 0.149).

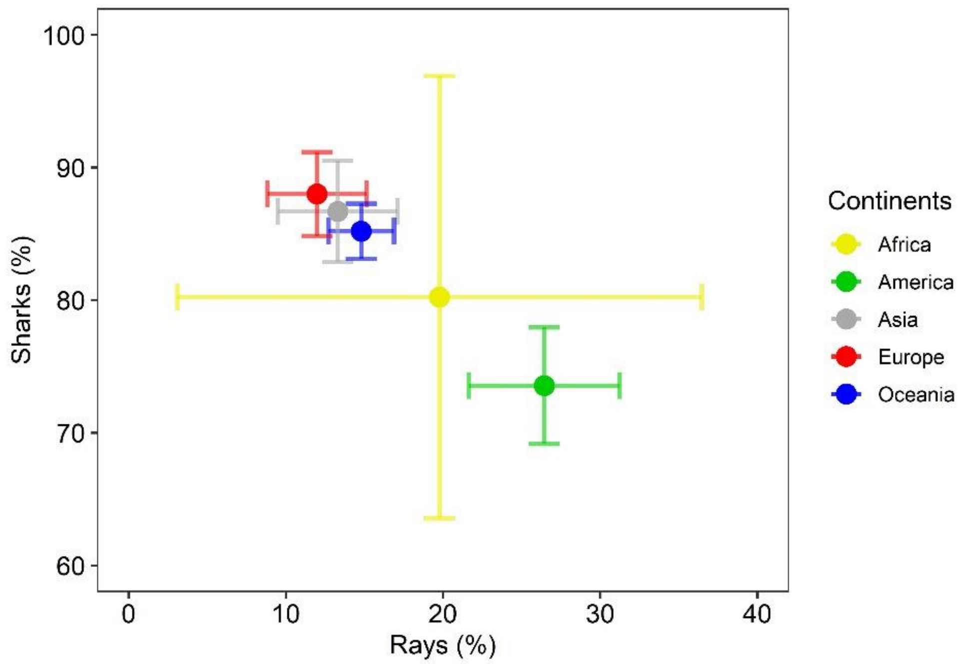

Fig. 4. 7. Frequency of publications between rays and sharks by continent. Green = America, Yellow = Africa, Blue = Oceania, Grey = Asia, and Red = Europe.

The most studied genus among sharks is *Carcharhinus* with more than 400 articles; among rays it is *Raja* with 101 articles (Figure 8.A). Among the species, the great white shark *Carcharodon carcharias* (265 articles) was eight times more studied than the most studied ray, the Atlantic stingray *Hypanus sabinus* (33 articles) (Figure 8.B).

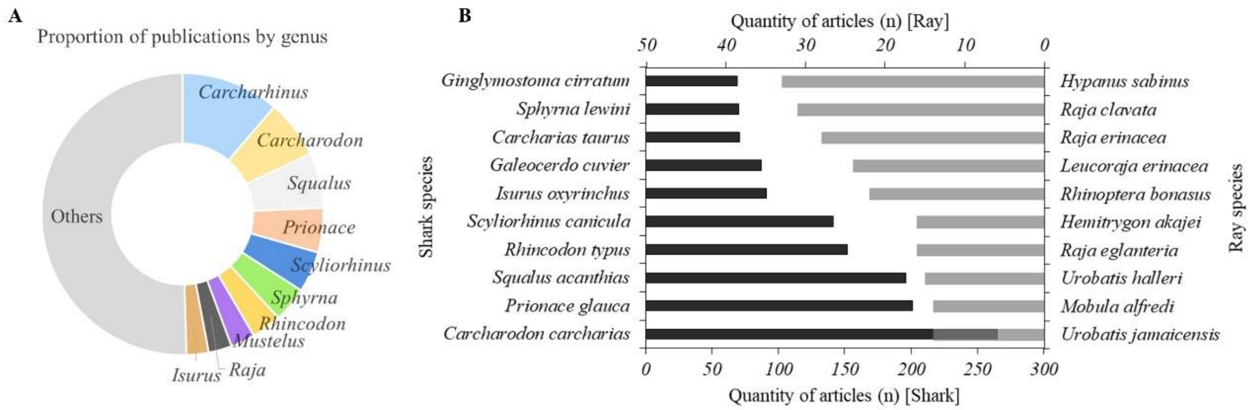

Fig. 4. 8. The ten most studied genus (A) and species (B) of elasmobranchs worldwide.

We observed a significant influence of public interest and minimum depth for scientific production about both taxa. Moreover, shark scientific production was also significantly associated with the number of incidents, commercial value, and distribution (Figure 9). In contrast, ray scientific production was also negatively associated with temperature and minimum depth (Figure 9).

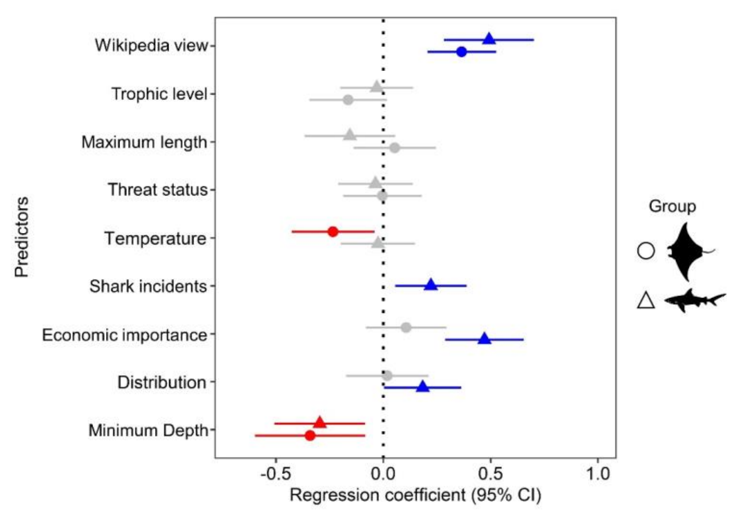

Fig. 4. 9. Effect sizes with 95% confidence intervals from sociocultural, economic, and bioecological predictors related to scientific production on sharks and rays. Blue = significantly positive; Gray = not significant; Red = significantly negative.

4.4. DISCUSSION

Our results confirmed that research on elasmobranchs is concentrated in countries with economic strength, social justice, sustainable development, and high fisheries production. There was a clear shift over time from articles on basic bioecology to more applied themes, with this shift occurring more slowly in certain countries and regions. Research effort is unevenly distributed among species and higher taxa, with greater focus on the more charismatic Selachii and less on the Batoidea. Nevertheless, scientific production of marine elasmobranchs has grown exponentially, possibly reflecting a growing understanding of the importance of this group for ecosystem functioning (Pimiento et al. 2020).

The increase in endangered elasmobranch species is mainly due to habitat destruction, directional and incidental fishing (Dulvy et al. 2008; Lucrezi et al. 2019a), and to unselective fisheries. This crisis has increased the cultural visibility of elasmobranchs and the number of research groups working on them (Neff and Hueter 2013; Neff and Yang 2013; Simpfendorfer and Dulvy 2017).

The positive association between scientific production and capture rates of marine chondrichthyans is probably indirect, since research is done on what has been landed, and richer countries tend to invest more in fishing and scientific research. Intriguingly, even with increasing numbers of scientific studies indicating that sharks and rays face high extinction risk, overfishing, and other intraspecific and ecosystem impacts (Ferretti et al. 2010; Heupel et al. 2014), elasmobranch catch rates have hardly changes, showing only small declines in recent years (FAO 2019). It is important to note that there may be a mismatch between scientific production and conservation needs, as illustrated by the large number of species still classified as Data Deficient by the IUCN (IUCN 2019). Such an absence of information makes effective resource management difficult and can lead to population collapse and local extinctions (Davidson et al. 2016).

Increasing scientific information on elasmobranchs in general and Data Deficient in particular requires greater financial investment in research (Bradshaw et al. 2010 and Ladle et al. 2012) and better prioritization. It is notable that the most productive countries also have the most collaborative profiles, e.g., United States and Australia, showing how economic and social profiles can favour scientific productivity and communication (e.g., Defazio et al. 2009; Doubleday and Connell 2017). Therefore, hot topics such as extinction risk, ecotourism, ecosystem protection, among others, can increase the number of research projects, but only if they are conditioned by funding and a favorable research environment.

We observed a clear temporal shift in research from more descriptive themes to a more applied focus, with more articles focused on growth, reproduction, habitat use, migration, and diet. This thematic shift is related to the increasing focus on attributes related to species management and conservation, including information on minimum catch size, protection of foraging areas, and reproduction (Barnett and Semmens 2012; Hammerschlag et al. 2018; Awruch et al. 2019). This more sustainability-oriented approach has grown since the 2000s, reflected in the increasing use of the terms "conservation" and "management" in the scientific literature on elasmobranchs (Kuhlman and Farrington 2010; Davidson et al. 2016; Simpfendorfer and Dulvy 2017). This shift may reflect a greater awareness of the academic community about resource decline and the increasing number of ray and shark species listed as threatened or near threatened (Davidson et al. 2016). Even so, the continued critical status of the group indicates that the increase in research is not being effectively translated into conservation policies and actions.

The ineffectiveness in protecting environments and keystone or umbrella species (sensu Mills and Doak 1993; Power et al. 1996; Roberge and Angelstam 2004) is unsurprising if we note that research focus on the "conservation" topic is still scarce for elasmobranchs, starting only in the 90's (Fowler et al. 2002; Gregr et al. 2020). Conservation research is especially low in some geographical areas, such as in Asian countries – which also have high rates of elasmobranchs capture and consumption (Clarke 2004; Clarke et al. 2006). Even knowing that the relevance of these concepts and taxa are always under scrutinization on theoretical and effectiveness forums (e.g., Paine 1995; Caro 2010; Gregr et al. 2020) is unexpected that intense direct use does not generate feedback on research efforts to the resources conservation. Competing priorities, and an incipient awareness of researchers on the subject (particularly in critical regions such as Asia) may be undermining collective research efforts.

We observed a global pattern of preference for shark research. However, this research effort is generally concentrated on only a few species group (Ducatez 2019). Research choices are affected by socio-cultural and economic issues related to direct use (Barrowclift et al. 2017), direct incidents, cultural profile (Neff 2012; Lucrezi et al. 2019b), ad to bioecological fragility (Field et al. 2009). Rays are less consumed and feared, though they are equally biologically fragile and are far less researched. As a consequence, a large proportion of marine Batoidea species are classified as data deficient - currently 239 species, corresponding to 39.25% of species (IUCN 2019). This exceeds the percentage of data deficient Selachii (179 species, 36.45%).

The higher frequency of articles related to Batoidea and Selachii from shallower waters indicates the importance of accessibility and ease of capture for many research projects (Ducatez 2019; Shiffman et al. 2020). Moreover, it is also significant for both taxa that the most viewed species on Wikipedia tend to be the most studied, such as the manta ray and the great white shark. This indicates the importance of “charisma” and visibility for attracting researchers and justifying research funding (Colléony et al. 2017; Albert et al. 2018). In addition, widely distributed sharks are more culturally visible, to the public and to researchers (Ducatez 2019). The commercial value of sharks as food is higher than that of rays, increasing their importance to fisheries and the information-based management requirement (Davidson et al. 2016). Additionally, human incidents with sharks, particularly fatal attacks, increase the reputation of these species attracting social interest and actions to minimize them (e.g., Hazin et al. 2013; Neff 2012; Neff and Hueter 2013). For Batoidea species, abundance in shallow environments and higher charisma are also important factors influencing research, mainly by researchers from temperate climate countries. Finally, Elasmobranchii with restricted distribution and that inhabit deeper areas are being neglected making threat assessment highly problematic. If accessibility is a strong determinant for research it is unlikely to have an umbrella effect on those most in need of scientific research to support management (Shiffman et al. 2020).

The scientific production on marine elasmobranchs has grown significantly in recent years, possibly in response to the depletion of these animals across the world. This is reflected in an increasing research focus on conservation and management in recent decades. Nevertheless, research is still concentrated in developed countries such as the USA and Australia which have large coastlines, strong economies, and high levels of human development. Sharks are more studied than rays, with choice of research species strongly associated with socioeconomic factors (commercial importance), public interest (incidents and Wikipedia search), and accessibility (animals found in shallower waters and widely distributed).

For effective conservation of sharks and rays, it is vitally important that there is further investment in research and that incentives are provided for new research and collaborations focused on the developing world and Asian countries. There also needs to be a greater focus on less studied species, reducing the amount of data deficient species and filling critical information shortfalls that currently compromise conservation efforts.

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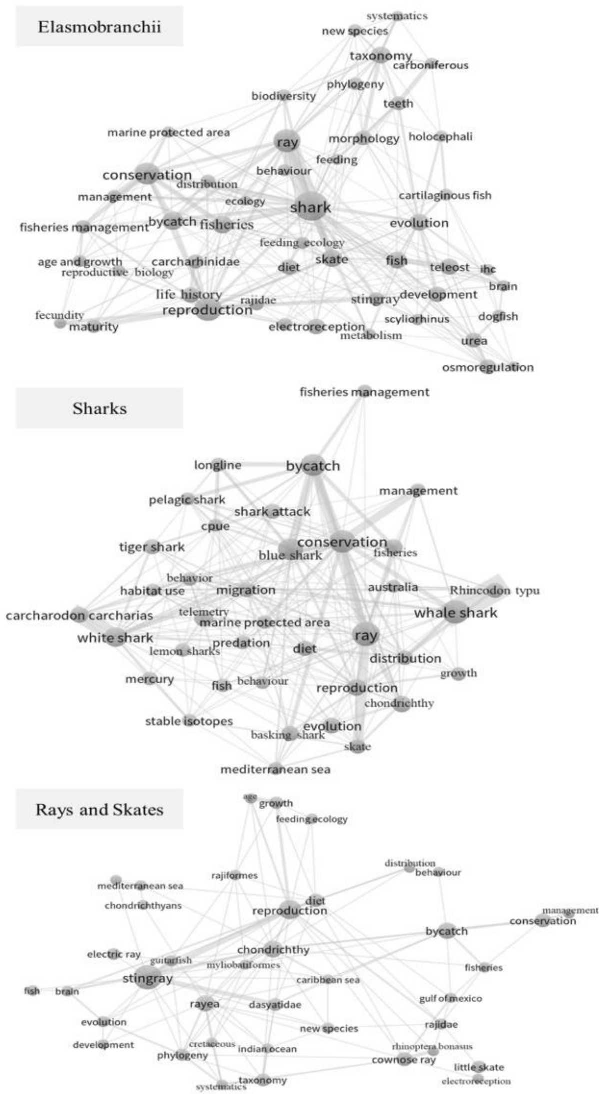
ANEXO

Supplementary figure 1. Network of keywords mentioned in the articles on marine elasmobranchs.



5. CAPÍTULO 2 - Demographic analysis reveals a population decline of the Longnose stingray *Hypanus guttatus* in Northeastern Brazil

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Abstract

High fishing pressure on elasmobranchs had caused declines in their populations worldwide, though these declines may not always be observed due to lack of monitoring. The Longnose stingray *Hypanus guttatus* is one of the most abundant and captured species in Northeast Brazil, mainly as bycatch by shrimp trawl. We aimed to estimate how the population of *H. guttatus* behaves in the face of different fishing pressures in the Northeast. For this purpose, we used a life matrix analysis from the metadata of three studies in the Northeast of Brazil (Bahia, Alagoas and Rio Grande do Norte). The average annual population growth rate estimated for the three states was strongly negative (-11.83%). However, there was considerable regional variation: data from Bahia showed in fact a low level of positive growth (3.24%) compared to the severe population decline (-29.47% per year) in Rio Grande do Norte, caused by the high mortality from shrimp trawling We conclude that the Longnose stingray has a high risk of long-term population decline in Northeastern Brazil, mainly caused by the high capture rate of juveniles.

Keywords: longnose stingray, *Hypanus guttatus*, Brazil, life table, fishing mortality, annual rate of population growth.

5.1. INTRODUCTION

The subclass Elasmobranchii includes stingrays and sharks. Members are predominantly large and predatory, playing an important role in the structure and functioning of marine communities (Camhi et al., 1998). Like most top predators, elasmobranchs are typically k-strategists, making them more susceptible to overfishing due to their low fecundity, low growth rate, and late sexual maturation (Camhi et al., 1998; Camhi et al., 2009; Stevens et al., 2000).

Elasmobranchs are often subject to high fishing pressure, especially from large scale fisheries, and to environmental degradation of coastal areas (Camhi et al., 1998; Dulvy et al., 2014). As a result, it is estimated that about 100 million sharks are killed annually, especially for the fin trade (Worm et al., 2013), and for skates and rays this figure should be close or higher, since the landings of skates and sharks are similar (Dulvy et al., 2014). According to data on shark and ray landings from the Food and Agriculture Organization of the United Nations (FAO), the capture of these animals grew until 2003, when it peaked (860,000 tons), and since then has been declining, in 2018 this value fell 21.4% (Figure 1.A). However, Worm et al. (2013) warns that this amount of capture should be much higher than informed, mainly due to lack of records and discards. Consequently, many elasmobranch populations are in decline and 20% of the species in this subclass are classified in some degree of threat to extinction (IUCN, 2020) (Fig. 1.B). The number of threatened species may be even higher, as approximately 50% of the species described do not have sufficient biological and/or fishing data to be robustly assessed, and are therefore classified as Data Deficient (DD) (Dulvy et al., 2014; IUCN, 2020). Therefore, these species classified as DD should be given no priority in population assessment studies, so that they can be classified in a more realistic status and conservation measures applied, when appropriate.

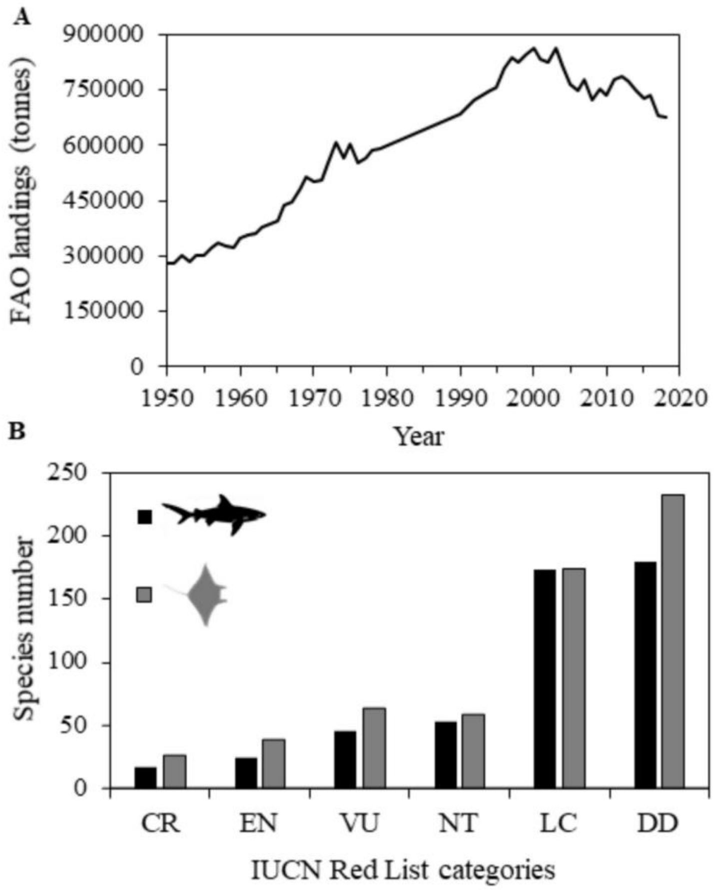

Fig. 5. 1 Capture of Elasmobranchii worldwide (A) and distribution of species by IUCN threat category (B). CR = Critically Endangered; EN = Endangered; VU = Vulnerable; NT = Near Threat; LC = Least Concern; DD = Data Deficient.

The lack of population data has driven a growing interest in elasmobranch life-histories (Bonfil, 1994; Walker and Hislop, 1998; FAO, 2000; Stevens et al., 2000). The risk of stingrays and sharks becoming endangered directly depends on a population's life-history characteristics, which can vary in terms of reproduction, growth and mortality (Dulvy and Forrest, 2009). Demographic analysis incorporates life-history information plus fishing mortality information, thus producing more realistic estimates of intrinsic rates of population growth (Cortés, 1998).

The Longnose stingray *Hypanus guttatus* (Bloch & Schneider, 1801) is a good candidate for demographic analysis. It is among the most caught stingrays in Brazil, and is especially common in the catches of artisanal fishing in the Northeastern region (Rosa and Furtado, 2016). It is a demersal coastal marine species that also inhabits brackish water, found at 35 m average depth, and occurs from the Central Atlantic in the Mexico (Gulf of Mexico) to Southern Brazil (Last et al., 2016). The species can reach up to 180 cm disc width (DW), however it has slow growth and low fecundity (Yokota and Lessa, 2007; Last et al., 2016; Gianeti et al., 2019).

According to Brazil's federal environment agency (ICMBio), *H. guttatus* is classified in Brazil as Least Concern (LC), despite being the target of sport fishing in the state of Paraíba, and by bycatch in Maranhão (northern coast) and Rio Grande do Norte (northeastern) and increasing fishing pressure on the species in others northern and northeastern states (Frédou and Asano-Filho, 2006; Lessa et al., 2015; ICMBio, 2016). To our knowledge, there have been no population assessments based on fisheries data and the International Union for Conservation of Nature (IUCN, 2020) considers the species to be Data Deficient (DD) due to the general lack of population and biological information (Rosa and Furtado, 2016).

In this context, the present study tests the hypothesis that the longnose stingray *Hypanus guttatus* has a high risk of population decline in Northeastern Brazil, due to its reproductive biology, growth, longevity and the high catches by fishing on the region. The hypothesis will be tested based on a metadata analysis using demographic technic to estimate trends on the species population abundance. In summary, our objective was to determine the rate of population decline of *H. guttatus* in Northeastern Brazil.

5.2. MATERIAL AND METHODS

5.2.1. Search and adjustment data

To carry out the study, we take metadata from papers carried out in the Northeastern coast, available on the Google Scholar® platform. From these studies, the frequency distribution of the length of the females were analyzed, using the Image J 2.0 software, to accurately determine the number of individuals per length class. Size classes were essential in determining total mortality, but which the different classes were allocated among studies, this could interfere in the results. Therefore, the size classes were changed to make them as close as possible in order to minimize errors (Suppl. material 1).

The size-frequency data were obtained from three studies: Gianeti et al. (2019), which addresses the capture of 339 females in the state of Rio Grande do Norte, during August 2007 to July 2008 and fishing recruitment size (FR) of 17.5 cm; Silva et al. (2018), with a sample number of 366 females in the state of Alagoas, during April 2009 to February 2011 and FR of 22 cm; and Marion (2015), which addresses the capture of 636 females in the state of Bahia during January 2012 to January 2013 and FR of 48 cm (Fig. 2).

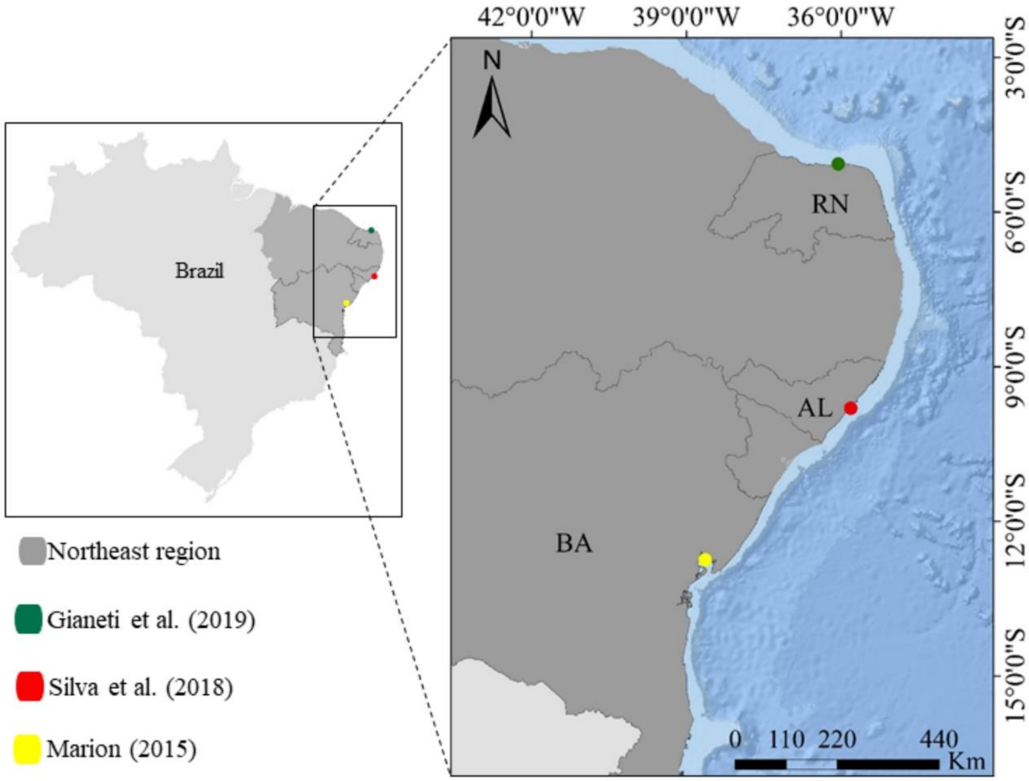

Fig. 5. 2. Schematic map of sampling locations of Hypanus guttatus individuals in Northeast Brazil. RN = Rio Grande do Norte; AL = Alagoas; BA = Bahia.

5.2.2. Life-history parameters

Mean values of reproductive characteristics were derived from Yokota and Lessa (2007) and Silva et al. (2018). The maturation size (TL_{50}) of 59.8 cm (SD 7.3), average fecundity (*fec*) of 3 (SD 2), with the sex ratio of puppies per brood was 1:1, and two reproductive cycle per year were used (Suppl. material 2).

Growth parameters were derived from Gianeti et al. (2019) who obtained the parameters for northeast Brazil through readings of annual vertebrae rings. The obtained parameters were: asymptotic disc width (DW_∞) = 102.56 cm; growth constant (k) = 0.103; and theoretical age at zero length ($t0$) = −1.384 years. These data correspond to the estimated growth parameters for females with von Bertalanffy growth model (Suppl. material 2).

5.2.3. Mortality and survival

The accuracy of natural mortality is essential parameter for demographic studies (Smith et al., 2008), as there is no model that integrates several parameters of life history that can influence mortality, we have opted for the use of seven models, enabled for *H. guttatus*. The probability and interaction of these models were used to determine the following demographic parameters:

Pauly(1983):

$$\ln(M) = -0.0066 - (0.279 \times \ln(DW\infty)) + (0.654 \times \ln(k)) + (0.463 \times \ln(Temp))$$

Rikhter and Efanov (1976): $M = \frac{1.521}{TL_{50}^{0.72}} - 0.155$

Hewitt and Hoenig (2005): $M = \frac{4.22}{T_{max}}$

Hoenig (1) (2005): $\ln(M) = 1.46 - 1.01 \times \ln(T_{max})$

Hoenig (2) (2005): $\ln(M) = 0.941 - 0.873 \times \ln(T_{max})$

Jensen (1) (1996): $M = 1.6 \times k$

Jensen (2) (1996): $M = 1.5 \times k$

at which *Temp* is the temperature (27 ºC according to Yokota and Lessa, 2007), TL_{50} is age of maturation, and T_{max} is maximum age.

The Holden (1974) model was used to estimate the equilibrium mortality rate (*Z'*) which was interpreted as natural mortality in the untapped population using the equation:

$$Z' = mx \times (e^{(-Z \times TL_{50})})$$

at which the number of female embryos per adult female per year (*mx*) = average fecundity × number of reproductive cycles per year × 0.5 × female embryos proportion.

The survival (*S*), for each mortality rate, were estimated by the formula proposed by Ricker (1975):

$$S = e^{-Z}.$$

The total mortality (*Z*) was estimated by the average of two models. The first model was the capture curve by length class (Ricker, 1975); this model adopts the slope of the linear regression line between the two variables, indicative of this rate (*Z* = -*b*). The second model was that of Beverton and Holt (1956), which is based on the equation:

$$Z = k \times \frac{L\infty - \overline{TL}}{TL - \mathrm{FR}}$$

at which, $\boldsymbol{k}$ = growth constant; $\boldsymbol{DW\infty}$ = asymptotic disc width; $\overline{\boldsymbol{DW}}$ = average disc width of the sample.; $\mathbf{FR} =$ Fishing recruitment size.

The fishing mortality (*F*) was calculated according to Pauly (1983), who defined *F* as the difference between total mortality (*Z*) and natural mortality (*M*).

5.2.4. Demographic analysis (age-structure model)

A life table (following Caswell (2001)) was built. This table that combines mortality and reproduction data to generate the following parameters:

$$R0 = \sum lxmx;\ G = \sum lxmxX / R0;\ r = \ln R0 / G;\ \lambda = \exp(r)$$

where: *X* = age in years; *n0* = initial number of individuals; *R0* = multiplication rate per generation; *G* = generation time; *r* = intrinsic rate of population growth; *λ* = annual rate of population growth; *lx* = proportion of surviving females; and *mx* = female embryos by adult female.

In order to simulate the theoretical demographic conditions that would characterize the population if there were no fishing, a life table was constructed in which the *M* average worked in all age groups (Scenario M). In the second hypothetical scenario, *Z'* in all age groups was used (Scenario Z'). Finally, *Z* and size of fishing recruitment (*FR*) for each location were used to estimate the real scenarios: RN, AL and BA, for Rio Grande do Norte, Alagoas and Bahia, respectively. Thus, five scenarios were carried out: two hypotheticals (M and Z') and three reals (RN, AL and BA).

For better reliability of demographic results, Monte Carlo simulations (Hood, 2006) were performed with 1000 repetitions and 95% confidence interval for each scenario as proposed by Sminkey and Musick (1996) and Beerkircher et al. (2003), varying the input parameters: *mx* (mean and SD), maturity age (mean and SD), maximum age (with one year deviation for more and less), and natural mortality (equal probability among the seven models) (Fig. 3).

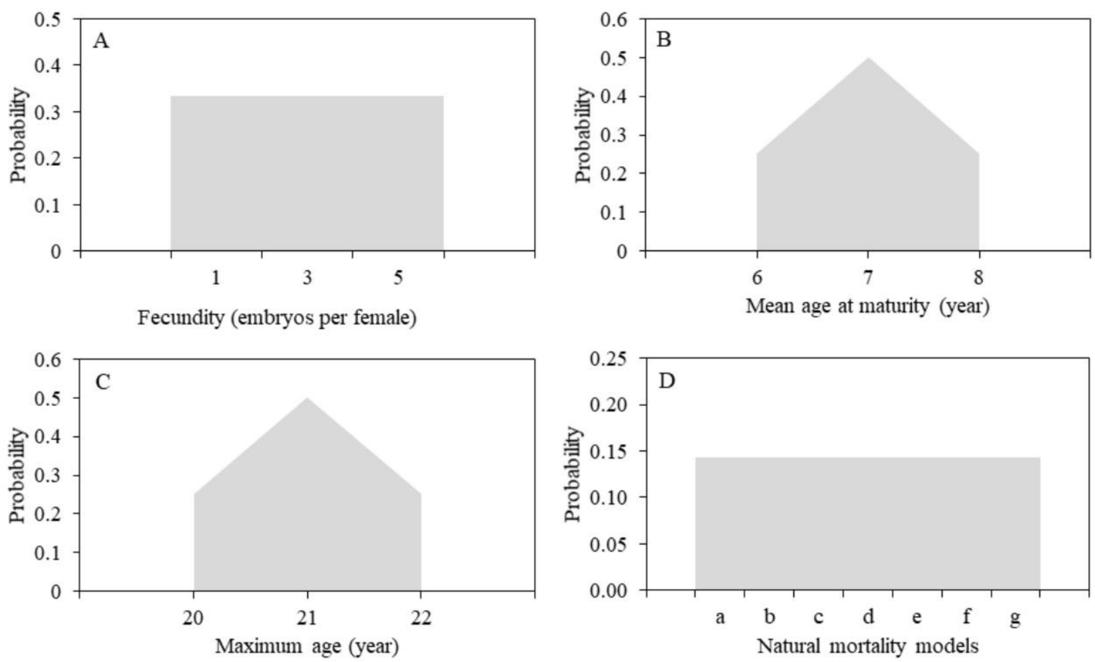

Fig. 5. 3. Probability distributions for (A) fecundity, (B) mean age at maturity, (C) longevity, and (D) natural mortality (a = Pauly; b = Rikhter and Efanov; c = Hewitt and Hoenig; d = Hoenig 1; e = Hoenig 2; f = Jensen 1; g = Jensen 2) for use in Monte Carlo.

5.2.5. Other analyses

Elasticity analysis was conducted to assess the proportional contribution of changes in survival and reproduction to population growth rate (Caswell, 2001). Each population's (by state) life table was expanded to incorporate the elements necessary to obtain individual elasticities following Kroon et al. (1986). Elasticities were calculated by age groups (neonate < 1 year; young = 1 to 7 years; sub-adult = 8 to 9 years and; adult > 10 years) for each state. The elasticity values for each age and fertility are additive and since elasticity is proportional, their sum is equal to one. The elasticity was calculated by the following equation (Kroon et al., 1986):

$$e_{ij} = \frac{a_{ij} \times v_i \times w_i}{\Lambda \times (w, v)}$$

being, e_{ij} = elasticity; a_{ij} = transition matrix elements; Λ = annual rate of population growth; v = reproductive value by specific age; w = eigenvector age structure.

Finally, a stepwise regression test was performed between the independent variables [recruitment size (*FR*) and; fishing mortality (*F*)] and the dependent variable [annual rate of population growth (*Λ%*)] of five scenarios. The stepAIC function of the MASS package in the R software (Venables and Ripley, 2002) was used to calculate the value of the Akaike Information Criterion for small samples (*AICc*) for each model, then performed the *ΔAICc*, which is based on the subtraction of the *AICc* from the model and the value of the smaller *AICc*. The calculated *AICc* weight (*AICc-Wt*), which takes *ΔAICc* into account, was also done to choose the best model (Akaike, 1973).

5.3. RESULTS

The metadata of the three different sources presented different characteristics in the length classes of *Hypanus guttatus* (no surprises). By standardizing to the maximum, so that there was no interference in mortality calculations, it resulted in identical classes between AL and RN, and similar with BA (Fig. 4).

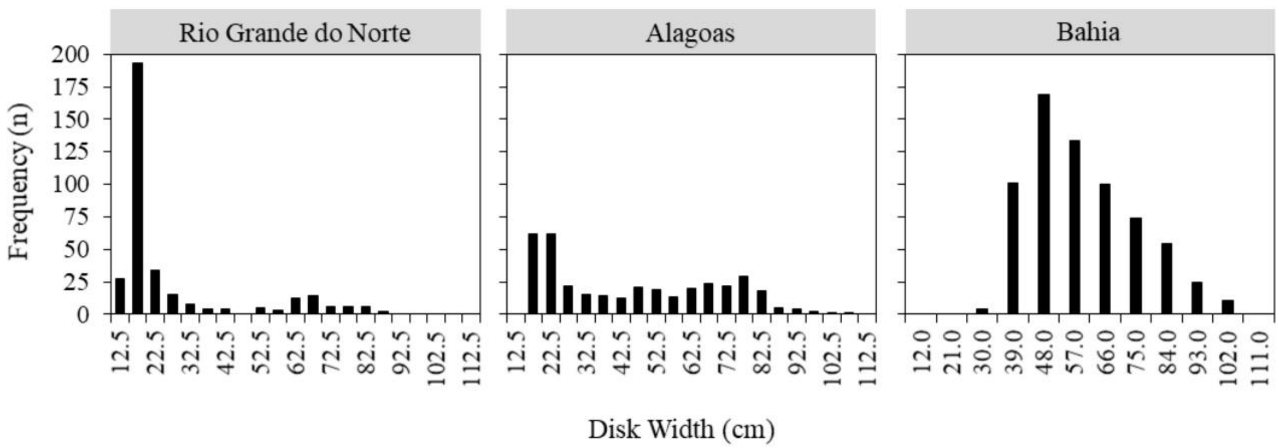

Fig. 5. 4. Length classes of Hypanus guttatus by state (Rio Grande do Norte, Alagoas, Bahia) in Northeastern Brazil.

The natural mortality for *H. guttatus* was estimated at 0.197 year^{-1} (SD 0.044), resulting in low natural mortality and high survival (Table 1), and equilibrium mortality (*Z'*) was estimated at 0.317 year^{-1}. The total mortality ranged from 0.232 to 0.725 year^{-1} (Fig. supplementary 1), resulting in fishing mortality of 0.53, 0.17 and 0.03 year^{-1} for RN, AL and BA, respectively.

Table 5. 1. Natural and total mortality, and survival rate (S) for Hypanus guttatus in Northeast Brazil.

Natural Mortality (*M*)		
Model	***M* (year^{-1})**	***S* (year^{-1})**
Pauly (1980)	0.284	0.753
Rikhter and Efanov (1976)	0.216	0.806
Hewitt and Hoenig (2005)	0.195	0.823
Hoenig (1) (1983)	0.193	0.824

Natural Mortality (*M*)			
Model	***M* (year $^{-1}$)**	***S* (year $^{-1}$)**	
Hoenig (2) (1983)	0.171	0.843	
Jensen (1) (1996)	0.165	0.848	
Jensen (2) (1996)	0.155	0.857	
Mean	0.197	0.821	
Total Mortality (*Z*)			
Model	RN	AL	BA
Ricker (1975)	0.877	0.530	0.199
Beverton and Holt (1956)	0.574	0.193	0.264
Mean *Z* (year $^{-1}$)	0.725	0.362	0.231
S (year $^{-1}$)	0.484	0.697	0.793

RN = total mortality in Rio Grande do Norte; AL = total mortality in Alagoas; BA = total mortality in Bahia.

The demographic analysis indicated a high divergence of demographic parameters between the localities, except in the generation time (*G*) which had an average of 9.84 years. The BA locality scenario was the only one with increasing values in the intrinsic rate of population growth (*r*) of the annual rate of population growth (*ʎ*) (Table 2).

Table 5. 2. Demographic parameters for Hypanus guttatus in Northeast Brazil.

Scenario	*ʎ*	95% CI	*r*	95% CI	*R0*	95% CI	*G*	95% CI
M	1.07	±0.05	0.07	±0.04	2.02	±1.38	10.07	±0.70
Z'	1.01	±0.08	0.00	±0.09	1.25	±0.81	9.89	±1.56
RN	0.71	±0.06	-0.35	±0.09	0.06	±0.05	9.63	±1.28
AL	0.91	±0.08	-0.03	±0.08	0.89	±0.54	9.58	±1.22
BA	1.03	±0.05	0.03	±0.05	1.38	±1.00	10.02	±0.77

λ = annual rate of population growth; *r* = instant rate of population growth; *R0* = multiplication rate per generation; *G* = generation time; 95% CI = 95% confidence interval. Scenario M = Scenario using natural mortality; Z' = Scenario using equilibrium mortality; RN = Scenario using total mortality of Rio Grande do Norte, considering the size of fishing recruitment; AL = Scenario using total mortality of Alagoas, considering the size of fishing recruitment; BA = Scenario using total mortality of Bahia, considering the size of fishing recruitment.

The mean for annual rate of population growth in percentage (*λ%*), considering the three localities, indicates a decline of 11.83% per year. This rate of *λ%* ranged from 3.24% (BA) to -29.47% (RN) (Fig. 5).

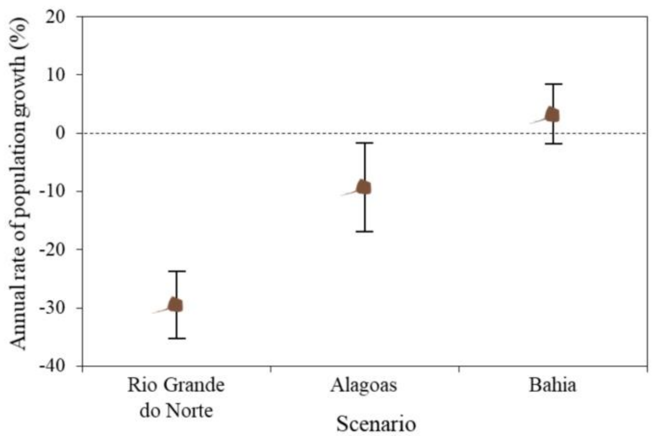

Fig. 5. 5. Annual rate of population growth in percentage (mean ± standard deviation) for Hypanus guttatus in the sceneries of Rio Grande do Norte, Alagoas and Bahia, with 95% confidence interval (whisker).

The elasticity analysis indicated that the protection of juvenile individuals (1 to 7 years) would be the most effective conservation measure, since this class was the most sensitive to fishing disturbances (Fig. 6).

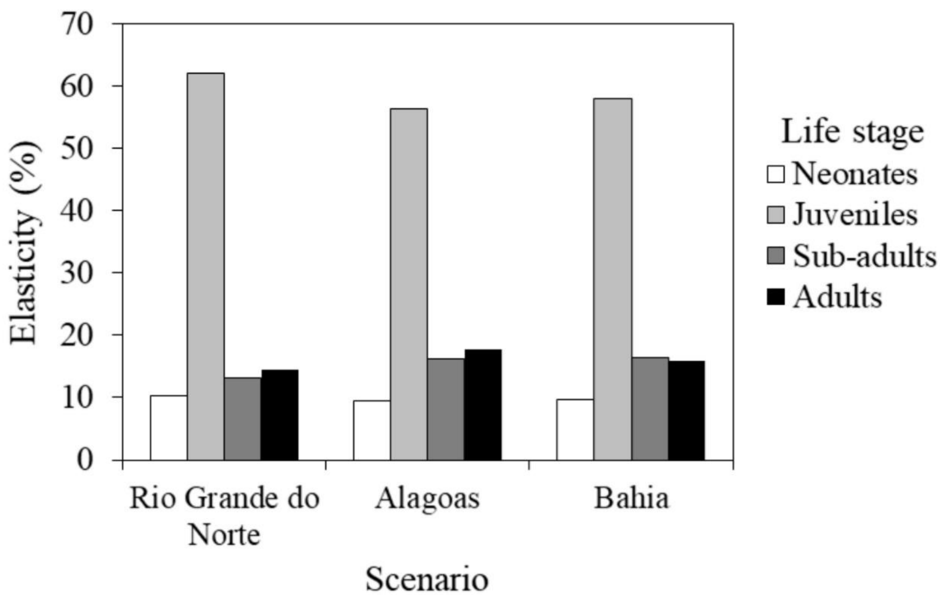

Fig. 5. 6. Elasticity analysis for Hypanus guttatus by life stage and location, in Northeast Brazil. Neonates: 0 to 1 year; juveniles: 1.1 to 7 years; adults: 7.1 to 9 years, and adults: > 9 years).

The linear regressions indicate that both variables are highly related to the annual rate population growth, however, the size of fishing recruitment was not significant. The best model that represents the growth rate was the model that unites both variables, has an effect of 98% (Table 3).

Table 5. 3. Linear models between annual rate of population growth in percentage (ʎ%) and fishing mortality and recruitment size variables.

Intercept	*FR*	*F*	*df*	*R*	*F*	*p-value*	*AICc*	*ΔAICc*	*AICc-Wt*

-32.238	0.746		1;3	0.6659	8.971	0.058	38.99	11.239	0.20
5.998		-68.335	1;3	0.961	99.66	0.002	28.246	0.495	43.75
-1.479	0.159	-57.857	2;2	0.9823	55.35	0.01774	27.751	0	56.04

Intercept = Intercept value estimated for linear models; *FR* = fishing recruitment size; *F* = fishing mortality; *df* = degrees of freedom; *R* = correlation coefficient; *f* = test F value; *p-value* = significance probability; *AICc* = Akaike Information Criterion for small samples; *ΔAICc* = difference between the *AICc* of a given model and that of the best model; *AICc-Wt* = Akaike weights.

5.4. DISCUSSION

Accurate measurements of natural mortality are essential for demographic studies, but they are difficult to obtain for many marine populations (Vetter, 1988; Smith et al., 2008). In the absence of direct data on natural mortality, we used several models to simulate the effect of different mortality values of *H. guttatus*, thereby reducing the errors generated by choosing a single model. Mortality values varied considerably, indicating a low natural mortality – recorded for several elasmobranchs (Cortés, 2002; Mollet and Cailliet, 2002; Smith et al., 2008; Pierce and Bennett, 2010). In contrast, the estimated total mortality varied widely, and was close to natural mortality in BA. This low value may be related to the low number of juvenile individuals in the study (Marion, 2015).

The difference in the presence of young individuals between the study sites is related to habitats use, in which young and neonate individuals are commonly found in shallow coastal areas, while adults are found in deeper areas (Silva et al., 2001; Lessa et al., 2008; Grijalba-Bendeck et al., 2012). This fact corroborates the rare capture of young individuals reported by Marion (2015) in state of Bahia, since the author reports the main catch method was the longline, but this does not mean that young and neonate individuals are not caught in Bahia. The study performed in state of Alagoas, was carried out using several catch methods and a depth varying between 2 to 60 m, and there was a higher equilibrium between young and adult individuals when compared to other study sites. In the state of Rio Grande do Norte, neonatal and young individuals were predominant, due to shrimp trawling, an active activity in Northeast Brazil, especially at this state for being a nursery region. (IBAMA, 2002, Lessa et al., 2015). Shrimp trawls can affect the populations of elasmobranchs in Northeast Brazil, and it is common to catch young rays (Yokota and Lessa, 2006; Lessa et al., 2008). The high capture of immature individuals can directly imply population growth rates. Thus, these individuals will not contribute to the population's biomass and consequently decrease the reproductive potential of the populational stock (Longhurst and Pauly, 1987; Sparre and Venema, 1997), thus justifying the high rates of mortality and decline for the state of Rio Grande do Norte, and the low rates for state of Bahia. Therefore, the survival of individuals in the youth phase is crucial for successful population growth. (Frisk et al., 2001).

In general, demographic projection for *H. guttatus*, reveals sharp population declines for Northeast Brazil, except in state of Bahia, which shows a small growth. In a review on characteristics of the life history of long-lived marine species, Musick (1999) reported populations with intrinsic annual rates below 10% were particularly vulnerable to increased mortality. This matches our analysis of the population decline in *H. guttatus*, because in all the calculated scenarios, the growth rate did not exceed 10%, even in the absence of fishing mortality. In other studies on stingrays, low population growth was also observed (without the presence of fishing pressure), as for *Bathyraja maculata, B. minispinosa* and *B. trachura*, which also showed growth of less than 10% (Barnett et al., 2013), *Dipturus laevis*, categorized as EN by IUCN, showed a growth of 4.5% (Frisk et al., 2004). We can also mention the famous and threatened manta rays (*Mobula birostris*, *M. mobular* and *M. thurstoni*) presented population growth close to 2% (Rambahiniarison et al., 2018) (Table 4).

Table 5. 4. Annual rate and instant rate of population growth estimated for ray and some sharks in Brazil.

Specie	**Status of IUCN**	**Place**	**λ**	***r***	**Mortality used**	**Ref.**
Hypanus guttatus	DD	Northeast Brazil	1.070	0.067	*M*	Present study
Hypanus guttatus (RN)	DD	Northeast Brazil	0.705	-0.353	*Z*	Present study
Hypanus guttatus (AL)	DD	Northeast Brazil	0.907	-0.034	*Z*	Present study
Hypanus guttatus (BA)	DD	Northeast Brazil	1.032	0.032	*Z*	Present study
Hypanus dipterurus	DD	Magdalena Bay in Mexico	1.010	0.010	*Z*	Smith et al., 2008
Bathyraja lindbergi	LC	Bering Sea	1.110	0.104	*M*	Barnett et al., 2013
Bathyraja maculata	LC	Bering Sea	1.079	0.076	*M*	Barnett et al., 2013
Bathyraja minispinosa	LC	Bering Sea	1.096	0.092	*M*	Barnett et al., 2013
Bathyraja taranetzi	LC	Bering Sea	1.116	0.110	*M*	Barnett et al., 2013
Bathyraja	LC	Bering Sea	1.046	0.045	*M*	Barnett et al.,

Specie	Status of IUCN	Place	*λ*	*r*	Mortality used	Ref.
trachura						2013
Dipturus laevis	EN	Western Atlantic	1.221	0.200	*M*	Frisk et al., 2002
Leucoraja erinacea	NT	Western Atlantic	1.234	0.210	*M*	Frisk et al., 2002
Leucoraja ocellata	EN	Western Atlantic	1.139	0.130	*M*	Frisk et al., 2002
Mobula birostris	VU	Bohol Sea	1.019	0.019	*M*	Rambahiniarison et al., 2018
Mobula mobular	EN	Bohol Sea	1.016	0.016	*M*	Rambahiniarison et al., 2018
Mobula thurstoni	EN	Bohol Sea	1.038	0.037	*M*	Rambahiniarison et al., 2018
Pristis pectinata	CR	United States	1.150	0.140	*M*	Carlson and Simpfendorfer, 2015
Pteroplatytrygon violacea	LC	Atlantic ocean	1.165	0.153	*M*	Cortés et al., 2010
Pteroplatytrygon violacea	LC	-	1.174	0.160	*M*	Mollet and Cailliet, 2002
Rhinoptera steindachneri	NT	Gulf of California	0.978	-0.023	*Z*	Colin, 2019
Carcharhinus porosus	DD	Northern Brazil	0.756	-0.285	*Z*	Santana et al., 2020
Carcharhinus signatus	VU	Northeast Brazil	0.922	-0.081	*Z*	Santana et al., 2009
Isogomphodon oxyrhynchus	CR	Northern Brazil	0.909	-0.095	*Z*	Lessa et al., 2016

ʎ = annual rate of population growth; *r* = instant rate of population growth; DD = Data Deficient; LC = Least Concern, NT = Near Threat; VU = Vulnerable; EN = Endangered; CR = Critically Endangered; M = natural mortality; Z = total mortality;

The demographic projection inserting fishing pressure is even more worrying. A similar study carried out in the Magdalena Bay Lagoon complex in Mexico with *Hypanus dipterurus*, showed this ray was also quite vulnerable to fishing pressure; without fishing presence, the population tended to grow 14%, but with fishing mortality (0.05 $year^{-1}$) the population grew only 1%. (Smith et al., 2008). Fishing mortality has also negatively affected shark populations in Brazil, with emphasis in *Carcharhinus porosus* (Santana et al., 2009), *Carcharhinus signatus* (Santana et al., 2020) and *Isogomphodon oxyrhynchus* (Lessa et al., 2016). The low population growth rates in elasmobranchs (Table 4) are reflections of their life histories, characterized by low fertility, long gestation periods, and slow growth. This result in slow recovery from fishing-induced mortality and greater risk of extinction (Stevens et al., 2000; Smith et al., 2008).

The demographic parameters per scenario discussed above predicts the impact of fishing on population growth; moreover, the elasticity analysis maked possible to assess potential responses of the populations to fishing, indicating which life stage is most important for population growth (Ehrleń et al., 2001). The elasticity results indicated that the population growth of *H. guttatus* was more strongly influenced by juvenile survival, followed by adults. This is in line with the general trend observed for other stingrays, such as *H. dipterurus* (Smith et al., 2008), *Dipturus batis*, *R. clavata* (Walker and Hislop, 1998) and *P. violacea* (Mollet and Cailliet, 2002). Juveniles are clearly a key stage for conserving *H. guttatus* populations, being putatively more sensitive to anthropogenic disturbances.

These data corroborate the linear regression analysis, which indicated a high cause-and-effect relationship between population growth rate, fishing mortality and fishing recruitment size. The positive population growth in BA is reflected in the proportion of young and adult capture close to one, and this is directly related to fishing recruitment size, which was close to the maturation size; while in RN the capture is more biased towards neonates and juveniles. Our findings are potentially valuable to support conservation and management strategies for this species. Specifically, the elasticity analysis clearly indicates that management measures aimed at protecting juvenile individuals will be more effective for species conservation.

Hypanus guttatus is categorized as DD by the IUCN, mainly due to the lack of fishing data, population dynamics and ecology throughout its area of occurrence (Rosa, and Furtado, 2016). In fact, there is no report of catch data of this species on the FAO FishStat platform, which I gathered data from 1950 to 2018 (FAO-FishStat, 2018). In Brazil, lack of data on *H. guttatus* is no different, there are major flaws in the official fishing data (only general data on the total of rays caught) that were only reported until 2011 (Barreto et al., 2017). Even with the absence of a capture records of *H. guttatus*, it is classified as LC in Brazil (ICMBio, 2018). Our work is the only one to assess the population status of this species, and revels an indication of population decline, caused mainly by fishing. However, even though we have used demographic models based on the best available data, we emphasize that more robust data are needed to increase the reliability of our results. In light of this, we suggest new studies assessing the population status of *H. guttatus* be carried out not only in Brazil but also in other countries. Finally, fisheries monitoring, especially shrimp trawling, in breeding and nursery areas can improve fisheries management.

5.5. CONCLUSION

This research reveals the impact of fishing on population growth potential, showing that fishing mortality and recruitment size are the main factors that will alter population growth. When these values are high, as was the case in the study analyzed in RN, which had high fishing mortality and low recruitment size, it generated a worse scenario for the species, reaching a decline of 29%, already when there is low fishing mortality and recruitment size similar to maturation (study in BA), the demographic parameters show population growth. This is corroborated in the elasticity analysis, which indicates the protection of juvenile specimens as the most promising conservation strategy for the population. However, further studies are still needed to empirically confirm this predicted population decline.

Conflict of Interest Statement

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

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Anexo

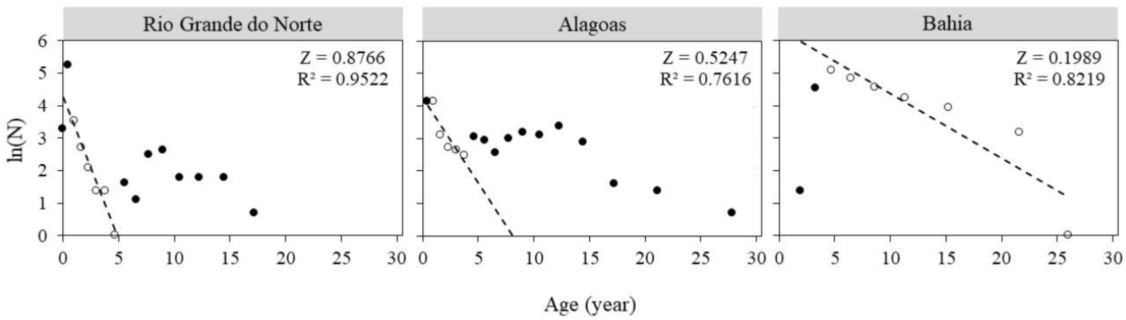

Fig. Suppl. 1. Total mortality capture curve (*Z*) for *Hypanus guttatus* by state (Rio Grande do Norte, Alagoas, Bahia) in Northeastern Brazil. White circles were used for the regression to estimate the total mortality.

6. CAPÍTULO 3 - Bioecological attributes as global extinction risk predictors for marine elasmobranchs

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Artigo em revisão no periódico ICES Journal of Marine Science.

Abstract

ABSTRACT

Marine elasmobranchs are in global decline, but identifying appropriate conservation actions is problematic due to a lack of basic biological and ecological information on, for example, growth parameters, reproduction and fishing data. Here, we identify biological and ecological attributes that can be both easily obtained and are effective predictors of extinction threat. To do this, we constructed a database of bioecological attributes of recognized elasmobranch species that included information on maximum length, habitat, reproductive mode, trophic level, and conservation status, among others. Data sources included Shark-References, IUCN, and FishBase databases. In total, data were compiled for 1,173 species of marine elasmobranchs (537 sharks and 636 rays). A correlation matrix was performed to identify highly correlated attributes and generalized linear models (GLMs) were used to model IUCN threat status as a function of attributes. We then applied the model to as yet unclassified species (DD or N.E.) to determine their extinction risk probability. Overall, our analysis indicates that 58.6% of the ray species and 44.3% of sharks may be at risk of extinction. These results clearly demonstrate how bio-ecological attributes can be used as proxies of extinction risk in elasmobranchs and provide a clear basis for conservation planning and prioritization for this ecologically important but data poor taxon.

Keywords: Bioecological traits; Chondrichthyes; Conservation status; IUCN Red List; Threat status.

6.1. INTRODUCTION

Extinction is a natural process (Purvis et al. 2000) that shows pulses during extreme periods or events (Arens and West 2008); it is estimated that 99.9% of the species that once existed are now extinct (Toukhsati 2018). During extinction pulses, when extinction rates are exceptionally high, ecosystem functioning can be affected through the loss of ecologically important species (Toukhsati 2018) with the accompanying loss of the diverse goods and services that nature contributes to human societies (Dirzo et al. 2014; Forest et al. 2015). It is estimated that there have been five mass extinction events (pulses) during the Earth’s history and that a sixth event is currently occurring due to human impacts on the environment (Braje and Erlandson 2013; Young et al. 2016; Toukhsati 2018), Extinctions have many causes (Ladle & Jepson 2008), including climate change (Blois et al. 2013; Bestion et al. 2015), habitat destruction (Olivier et al. 2013), overexploitation (Sissenwine et al. 2014; Toukhsati 2018), and the introduction of exotic species (Woinarski et al. 2015; Doherty et al. 2015).

The International Union for Conservation of Nature’s (IUCN) Red List of Threatened Species is the most comprehensive inventory of the conservation status of biological species worldwide (IUCN 2021). It uses several criteria (e.g. population trends, range size) to assess extinction risk, classifying species into different threat categories (Least Concern, Near Threatened, Vulnerable, Endangered, Critically Endangered, Extinct in the Wild and Extinct) (Rodrigues et al. 2006). Nevertheless, identifying extinction is a highly complex process with numerous uncertainties (Forest et al. 2015), mainly due to the lack of accurate population data for many species and especially those from remote or inaccessible areas. Consequently, it is difficult to assess actual extinction risk status of many organisms according to IUCN criteria (Rodrigues et al. 2006) and many species are consequently classified as data deficient (DD) or Not Evaluated (NE). For such species, extinction risk needs to be evaluated through other methods that extrapolate from other bioecological characteristics (Bender et al. 2013)(Chichorro et al. 2019).

Studies that extrapolate extinction risk from bioecological characteristics have typically focused on attributes such as body size (Verde Arregoitia 2016) (Graham et al. 2011), species distribution patterns (Hawkins et al. 2000), life history attributes (Cheung et al. 2005; Oliveira et al. 2021; de Barros et al. 2022) and other bioecological information such as habitat use, diet or migration (Chichorro et al. 2019). These attributes can have direct and indirect influences on extinction risk, and can act synergistically (e.g., Bender et al., 2013; Ceretta et al., 2020). Seeking alternative forms of extinction risk evaluation may be particularly useful for poorly evaluated groups such as fish - only 61% of fish species are currently evaluated by the IUCN, compared to 91% of mammals, 100% of birds, 87% of amphibians, and 87% of reptiles (Miranda et al. 2022). This lack of evaluation is mainly attributable to a lack of appropriate data for many fish species (IUCN 2021). In this contex fish are strong candidates for alternative methods of extinction risk evaluation based on analysis of key bioecological attributes.

Within the fish, one of the Elasmobranchii subclass is one of the most threatened and least known. Comprising sharks and rays (approximately 1200 described species), elasmobranchs are among the most evolutionary successful vertebrate groups over approximately 400 million years (Janvier et al. 2004; Stein et al. 2018). It is estimated that 32.6% of existing marine elasmobranch species face some threat (Dulvy et al. 2021), though this is probably an underestimate given that many species lack fundamental data on life history, biology, abundance and population dynamics (Jorgensen et al. 2022). Marine elasmobranchs are therefore a priority group for conservation action and there is an urgent need to develop alternative methods to evaluate extinction risk. Therefore, the objectives of the present study are: 1) to investigate whether simple bioecological attributes can be used to broadly evaluate extinction risk of marine elasmobranchs, and; 2) to use these attributes to identify which geographic areas contain species with the highest risk of extinction.

6.2. MATERIAL AND METHODS

6.2.1. Database

A survey of valid ray and shark species was conducted using the Shark-References (https://shark-references.com/), IUCN (https://www.iucnredlist.org/), FishBase (https://www.fishbase.se/), and World Register of Marine Species (https://www.marinespecies.org/) databases. In addition, supplementary searches were conducted on the Scopus, Web of Science, and Google scholar platforms using the keywords “new* species” and (chondrichthyes* OR elasmobranchii* OR sharks OR rays) to complement the species database.

Subsequently, the rfishbase package (Boettiger et al., 2019) was used to extract the bioecological attributes from the FishBase database and data from the IUCN platform were also extracted. A total of 20 attributes were used (Supplementary Material S1), they were classified as numerical and nominal (Table 1).

Table 1. Bioecological attributes of marine elasmobranchs, their description and source.

Variable type	Attribute	Attribute description	Source
Nominal	Environmental climate (Env)	Type of environment the species can be found in: boreal, deep water, polar, subtropical, temperate, and tropical.	Fishbase
	FAO Major Fishing Areas (AreaFAO)	presence of the species in large FAO subdivided fishing areas.	Fishbase
	Feeding habits (Feed)	Species feeding habitat type: detritivore, herbivore, omnivore, carnivore	Fishbase
	Habitat type (Hab)	Preferred habitat: deep benthic, intertidal, neritic, coastal,and oceanic.	Fishbase
	Migration (Mig)	Type of migration performed by the species can be: amphidromous, oceanodromous, or non-migrant.	Fishbase
	Nocturnal habits (Noct)	If the species has a Nocturnal habit	Fishbase
	Reproductive mode (Reprod)	Type of reproduction performed by the species based on Musick and Ellis (2005): oviparous, viviparous histotrophic, viviparous lecithotrophy or viviparous placentotrophy.	Musick and Ellis (2005)

	Resilience (Res)	Related to the minimum doubling time of the population, which can be: very low, low, medium and high.	Fishbase
	Schooling (Schoo)	Forms or not shoals.	Fishbase
	Threat status IUCN (StatusIUCN)	IUCN classified threat status: Critically Endangered - CR, Endangered - EN, Vulnerable - VU, Near Threatened - NT, Least Concern - LC, Data Deficient - DD, and Not Evaluated - NE.	IUCN
	Type of marine ecosystems (Ecos)	Ecosystem preference for species: bathydemersal, bathypelagic, benthopelagic, demersal, pelagic, pelagic-neritic, pelagic-oceanic, and reef-associated	IUCN
Numerical	Average Temperature (Temp)	Preferred average temperature (in ºC);	Fishbase
	depth (dep)	Maximum and minimum depth (in meters).	Fishbase
	Distribution range (Range)	Information on the distribution range of the species was extracted from the IUCN database, considering the occurrence type (existing and resident) in square kilometers	IUCN
	Fecundity (Fec)	Number of offspring per reproductive cycle.	Fishbase

Growth constant (Growth)	Value of the growth velocity determined by the k (growth constant) of the von Bertalanffy model.	Fishbase
Maturation size (L50)	Size at which the species reaches sexual maturity (in cm).	Fishbase
maximum length (LT)	Maximum size of the largest individual ever recorded (in cm).	Fishbase
Trophic level (Troph)	Index numeric based on food items.	Fishbase
Vulnerability to fishing (Vuln)	Value between 0 and 100.	Fishbase

6.2.2. Data Analysis and Modeling

The resilience attribute was converted to numerical values, in which the “very low” category was equivalent to a value of 0, “low” to 1, “medium” to 2, and the “high” category to a value of 3. The IUCN threat status categories were also converted to numerical values, following Weeks et al. (2022), with the range being from “of least concern” = 1 to “critically endangered” = 5. Species classified as DD or NE were not assigned numerical values. Minimum and maximum depth were used to estimate the mean depth of occurrence of the species (Dulvy et al. 2021). Subsequently, all attributes were separated into two groups (nominal and continuous).

A Pearson correlation matrix (Zar 2014) was calculated, with the use of R statistical software (R Core Team 2018) and the Vegan package (Dixon 2003), for the numerical attributes. Highly correlated variables ($r > 0.4$ or < -0.4 and $p<0.05$) were excluded. Other attributes were also excluded due to deficiency of information, such as maturity size and fecundity (less than 50% of the species had this information), growth constancy (less than 40%), schooling (less than 48%), and nocturnal habit (less than 35%). Feeding habit was initially assessed but was excluded because of the low variability (44% Carnivore and 56% Omnivore) and our preference for using the trophic level.

Generalized linear models (GLMs) were used to determine which Bioecological attributes could be used with insights to predict the threat status of marine elasmobranch species. IUCN threat status was used as the response variable, and all independent attributes as explanatory variables (StatusIUCN = LT+Dep+Troph+ Vuln+Hab+Ecos+Env+Mig+Reprod). Before proceeding with the modeling, we checked the normal distribution of the explanatory variables and performed standardization of these variables. The model average was used to select the model with the highest explanatory value. To reduce model selection bias, we averaged all models that had AICc<2 (Burnham and Anderson 2002). We calculated the hierarchical split of all explanatory variables (adhering to all model assumptions, as proposed by Zuur et al. (2010). We used the lme4 package (Bates et al. 2015) to fit the models and MuMIn to perform model selection and model averaging (Barton, K., & Barton 2019) in the R statistical software (R Core Team 2018).

The modeling procedure was applied three times: 1) to all species (sharks and rays) were considered in an ensemble; 2) to only ray species, and; 3) to only sharks. The response variable was back-calculated based on the values of the model's explanatory attributes to validate the model and determine its power to predict species at higher risk of being threatened.

The back-calculated attribute was converted into the status categories (LC, NT, VU, EN and CR), then the proportion of identical results (between back-calculated and IUCN status) was checked, evaluating the difference with the chi-squared test at the 5% significance level (Zar, 2014). The back-calculated attribute was also converted to a more generalist scale, being classified into a lower risk of extinction – L.R. (values less than 2, corresponding to LC category) and higher risk of extinction - H.R. (values equal to or greater than 2, corresponding to NT, V.U., EN, and CR category). A chi-square test was used to compare the proportion of convergent and divergent results. Finally, once validated, the model was used to back-calculate the threat status of species classified as DD or NE. by the IUCN.

Finally, the proportion of H.R. species per FAO fishing area was estimated. Then, the Pearson correlation analysis was performed between the proportion of H.R. and the average elasmobranch catch (considering the catch from 2010 to 2019) by FAO area. Catch data (in tons) of elasmobranchs were extracted from FishStatJ (FAO 2020).

6.3. RESULTS

6.3.1. Descriptive results

Data were compiled for 1,173 species of marine elasmobranchs (537 sharks and 636 rays) (Table 1). The rays have the highest proportion of species at risk of extinction and a high percentage of non-evaluated species (12%), compared to 3.9% for sharks (Table 1).

Table 6. 1. Species composition of marine sharks and rays by Red List threat status.

	Total	CR	EN	VU	NT	LC	DD	NE
Ray	636	51 (8.01%)	54 (8.49%)	89 (13.99%)	67 (10.53%)	230 (36.16%)	69 (10.85%)	76 (11.95%)
Shark	537	34 (6.33%)	53 (9.87%)	74 (13.78%)	47 (8.75%)	241 (44.88%)	67 (12.48%)	21 (3.91%)
Total	1173	85 (7.25)	107 (9.12%)	163 (13.90%)	114 (9.72%)	471 (40.15%)	136 (11.59%)	97 (8.27%)

The area with the highest species richness of marine elasmobranchs and exclusive species is the Pacific – Western Central. However, the Eastern Indian Ocean has the highest number of species classified by the IUCN as critically endangered and those classified as DD and NE (Table 2).

Table 6. 2. Distribution of marine elasmobranch species by FAO area and Red List threat status.

Area FAO	**N**	**Exclusive species**	**NE**	**DD**	**LC**	**NT**	**VU**	**EN**	**CR**
Arctic Ocean	12	0	0	0	6	3	3	0	0
Atlantic - Antarctic	7	0	0	1	4	0	1	1	0
Atlantic - Eastern Central	168	11	7	6	40	25	39	30	21
Atlantic - Northeast	110	8	0	3	39	16	22	15	15
Atlantic - Northwest	94	3	4	1	35	12	20	17	5
Atlantic - Southeast	160	11	2	9	59	17	34	27	12
Atlantic - Southwest	194	46	5	15	63	19	38	29	25
Atlantic - Western Central	185	56	5	8	87	18	28	26	13
Indian Ocean - Antarctic	12	3	0	1	7	1	3	0	0
Indian Ocean - Eastern	348	80	15	31	125	37	62	44	34
Indian Ocean - Western	300	75	10	45	70	37	62	46	30
Mediterranean and Black Sea	93	5	3	4	11	15	24	17	19
Pacific - Antarctic	2	0	0	1	1	0	0	0	0
Pacific - Eastern Central	169	14	5	13	55	18	38	25	15

Area FAO	N	Exclusive species	NE	DD	LC	NT	VU	EN	CR
Pacific - Northeast	41	2	0	3	24	5	6	2	1
Pacific - Northwest	303	72	17	19	91	32	70	50	24
Pacific - Southeast	180	27	12	16	57	21	39	20	15
Pacific - Southwest	182	32	3	27	76	19	31	17	9
Pacific - Western Central	400	98	16	44	132	46	74	57	31

6.3.2. Modeling and Predicting Extinction Risk

There was a significant relationship between Red List threat status and two variables, maximum length (LTmax) ($r = 0.30$ and $p<0.05$) and mean depth ($r = -0.39$ and $p<0.05$) (Figure 1). Additionally, there was a strong relationship between LTmax and distribution range ($r=0.54$ and $p<0.05$) and between LTmax and vulnerability to fishing ($r=0.44$ and $p<0.05$) (Figure 1). These strong correlations were also present when sharks and rays were analyzed individually (Supplementary Material S2). Consequently, these two (distribution range and vulnerability to fishing) attributes were not entered into the GLM model.

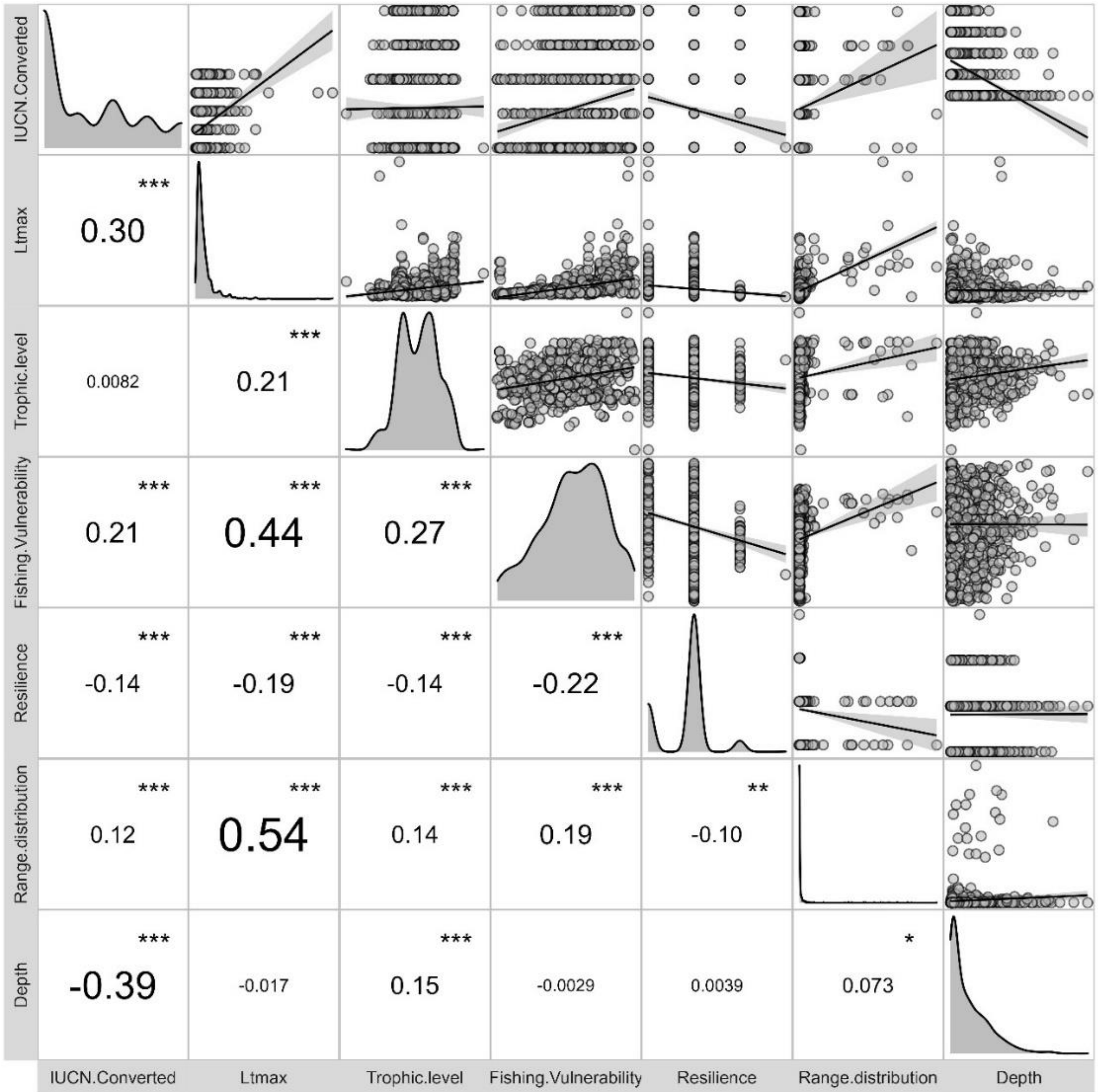

Fig. 6. 1. Correlation matrix between bioecological attributes of marine elasmobranchs.

The general GLM (rays and sharks together) showed five significant bioecological attributes were associated with Red List threat status (Figure 2). Species that exhibit histotrophic and lecithotrophic viviparity and have longer body lengths are the most threatened. Pelagic-oceanic species and species that occur at high depths were estimated to be less threatened.

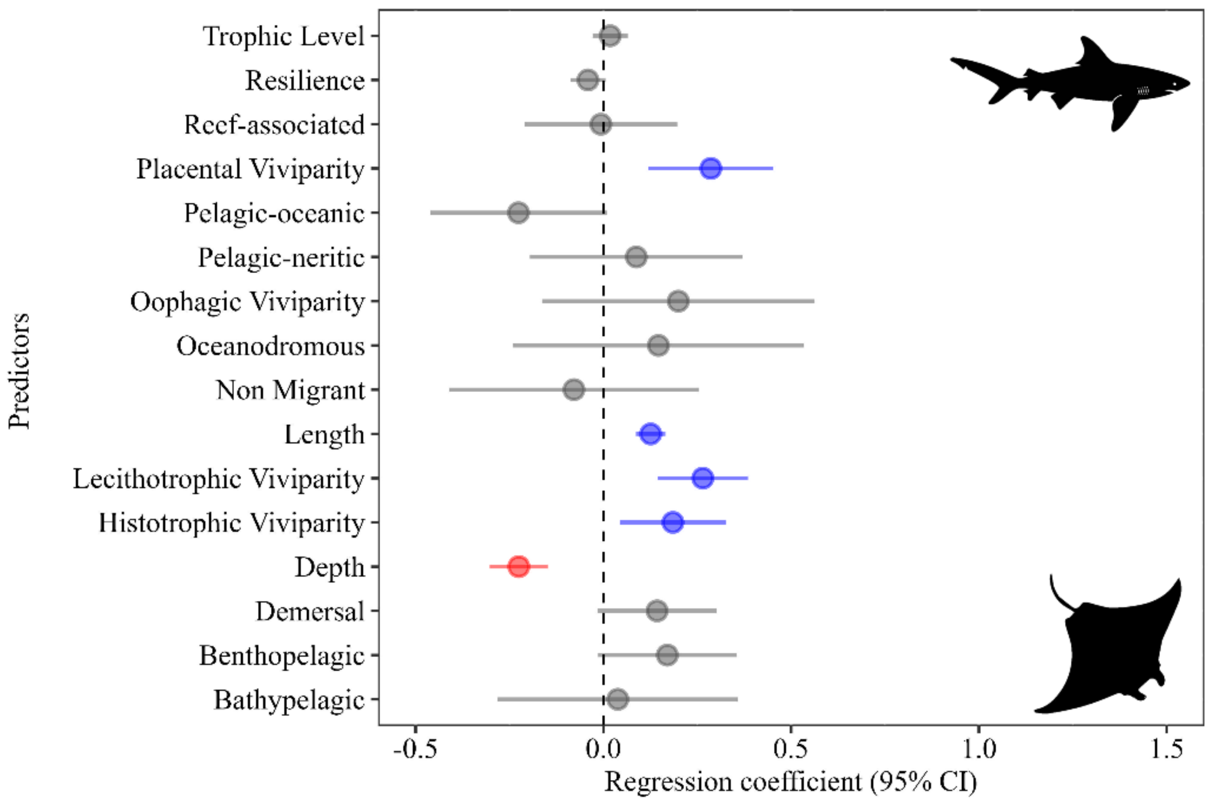

Fig. 6. 2. Effect sizes with 95% confidence intervals of marine elasmobranch bioecological predictors related to extinction threat category. Blue = significantly positive; Gray = not significant; Red = significantly negative.

The ray-exclusive model (Supplementary Material S3) generated more significant associations, with positive correlations for maximum length, lecithotrophic viviparity and neritic habitat types, and a negative correlation for mean depth (Figure 3).

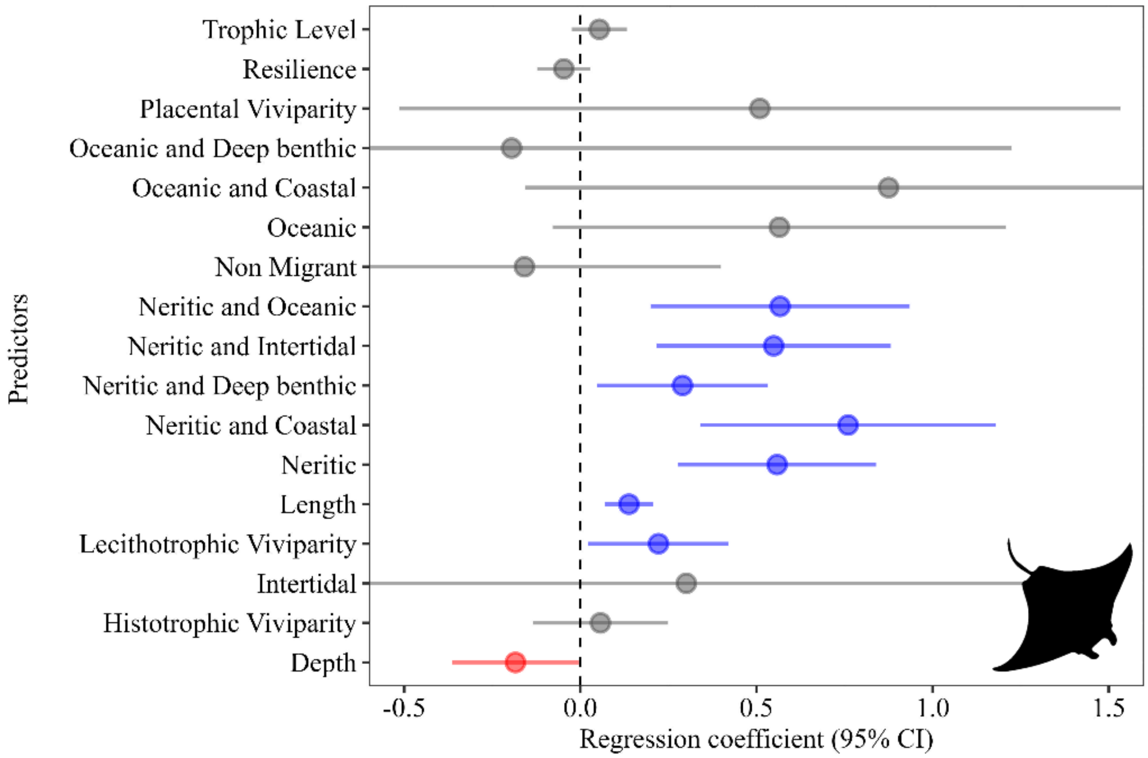

Fig. 6. 3. Effect sizes with 95% confidence intervals of marine stingray bioecological predictors related to extinction threat category. Blue = significantly positive; Gray = not significant; Red = significantly negative.

The shark-specific model (Supplementary Material S3) generated similar results to the general model, with significant associations for maximum length, average depth, and lecithotrophic viviparity. In addition, placental viviparity and pelagic-oceanic ecosystem were significantly associated with threat status (Figure 4).

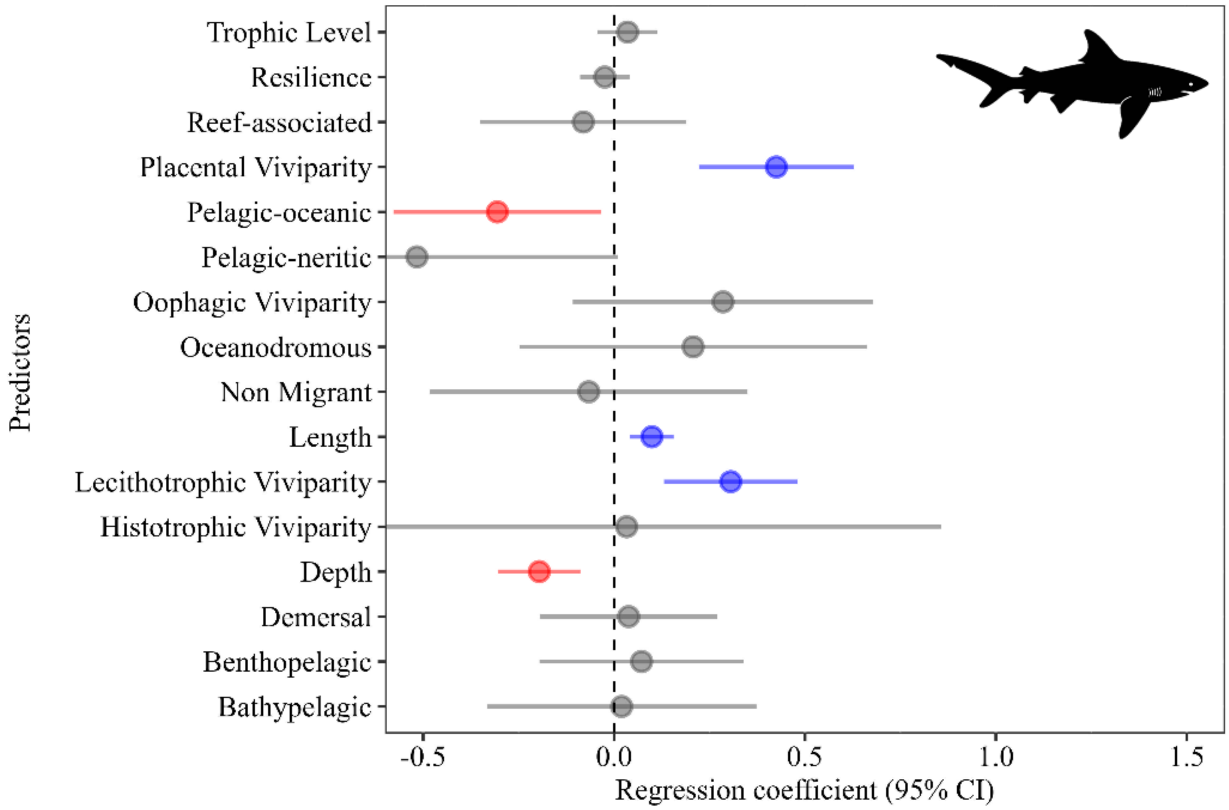

Fig. 6. 4. Effect sizes with 95% confidence intervals of shark bioecological predictors related to extinction threat category. Blue = significantly positive; Gray = not significant; Red = significantly negative.

Due to the differences in the significant variables between rays and sharks, we back-calculate the response variable (IUCN threat status converted to a numeric value) using separate models. For rays, the model was effective in detecting the threat status of 46% of the species at the fine scale (considers the IUCN Red List categories) but at the more general scale - lower risk of extinction (LR) and higher risk of extinction (HR) the model achieves 77% accuracy. For sharks, the percentage was 49% for the fine-scale and 74% for the more generalist scale (Table 3).

Table 6. 3. Composition of marine elasmobranch species by categories from the Red List of Threatened Species and the generalized linear model. LR - lower risk of extinction; HR - higher risk of extinction.

Category		Fine-scale						Generalist scale		
		CR	EN	VU	NT	LC	Total	LR	HR	Total
Ray	IUCN Status	51	54	89	67	230	491	230	261	491
	Back-calculated status	5	10	77	194	205	491	205	286	491
	Matching rate (%)	5.9	9.3	24.7	53.7	70.0	46.2	70.0	83.1	77.0
Shark	IUCN Status	34	53	74	47	241	449	241	208	449
	Back-calculated status	3	4	65	172	293	449	244	205	449
	Matching rate (%)	1	2.0	23.0	36.2	75.9	48.6	75.9	70.7	73.5

Back-calculation for DD and NE ray species indicates that 59% are estimated to be HR, considering the generalist scale (Table 4), *with Pristis perotteti* (Müller & Henle, 1841) and *Leucoraja compagnoi* (Stehmann, 1995) having higher scores (Supplementary material S4). For sharks, 44% are estimated as HR (Table 4), especially *Proscyllium venustum* (Tanaka, 1912) and *Heterodontus ramalheira* (Smith, 1949) (Supplementary material S4).

Table 6. 4. Classification of marine elasmobranch species considered as DD and NE after applying the generalized linear model. LR - lower risk of extinction; HR - higher risk of extinction.

		Fine-scale					Generalist scale	
Group	DD and NE	CR	EN	VU	NT	LC	LR	HR
Ray	145	2	2	22	59	60	60 (41.4%)	85 (58.6%)
Shark	88	1	1	11	26	49	49 (55.7%)	39 (44.3%)

Our geographical analysis indicates that 14 FAO areas have more than 50% of the elasmobranch species classified as HR (Figure 5). Among these areas, the Mediterranean and the Black Sea stand out, with 72.8% of species classified as having a higher risk of extinction. Furthermore, these percentages of HR species per FAO area were significantly correlated with the average elasmobranch catch per FAO area (r= 0.547; p-value= 0.018).

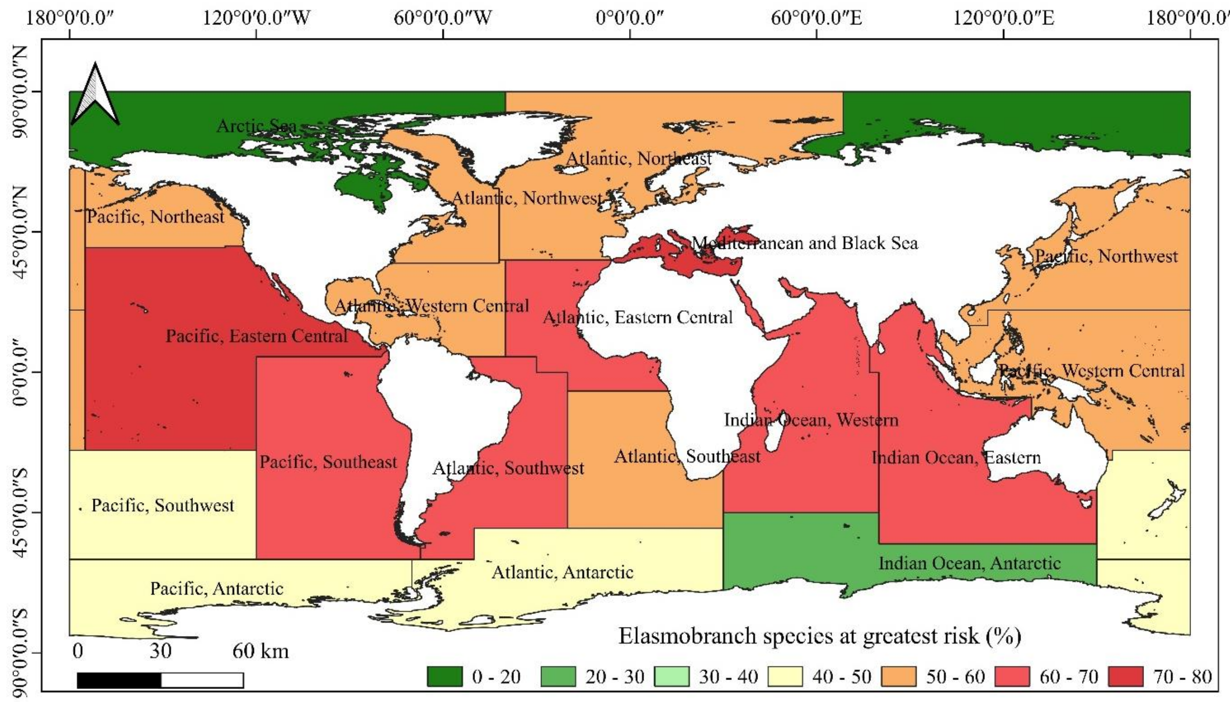

Fig. 6. 5. Map classifying FAO fishing area using the percentages with higher extinction risk species based on 1173 species.

6.4. DISCUSSION

The first global assessment of the IUCN Red List of Threatened Species in 2014 indicated that only 17.4% of 1,041 elasmobranchs were threatened, although just over 45% were classified as DD (Dulvy et al. 2014). Currently, the percentage of threatened or near-threatened species is 39%, while DD species have dropped to 11% due to strong incentives to increase the amount of primary and fundamental research on the bioecology of elasmobranch species. Nevertheless, 11% is still a very high proportion for such an ecologically important taxon and decreasing the number of species classified as DD should be apriority for the global research community.

Although research on sharks and rays is increasing, conservation measures do not seem to be effectively mitigating threats and very few species have seen improvements in their threat status classification. Specifically, adopted management measures are typically insufficient or not correctly implemented (Dulvy et al., 2021), making it difficult to reverse population decline and range collapse. The lack of data further compromises evaluation and is a barrier to determining risk levels. Some of the least known species are also the most threatened. When data was forthcoming for *Carcharhinus porosus* (Ranzani, 1839) and *Gymnura tentaculate* (Müller & Henle, 1841), they were reclassified from DD (in 2019) to CR in the last IUCN assessment (2021). This highlights the importance of rapid risk assessment of data deficient or non-evaluated species, since it opens the door for emergency protection measures that might be critical in avoiding extinction.

In the present study, we observed that a few simple bioecological attributes may be sufficient, in the absence of high-quality demographic data, to identify species with an elevated risk of extinction. Such assessments could be used support conservation prioritization and management interventions in the absence of population assessments. However, it should be noted that the bioecological attributes used to predict the risk of extinction at a finer scale (categories LC to CR) was not very accurate (only 47% assertive rate). This low assertive rate may be related to the detail of the data since the categories are defined based on refined population parameters, such as population size, the occupational area size of the population, growth, fecundity and others (IUCN 2021). However, these parameters were not included in the present study due to the unavailability of data for many species. An example is the growth constant which is estimated for only 50% of the species documented. As for the generalist scale, the assertive rate was 74 and 77% for sharks and rays, respectively, above the acceptable predictive accuracy of 70% (Walls and Dulvy 2020). Thus, such predictions of extinction risk can effectively and economically contribute to the protection of species with limited data (Bland et al. 2015).

Among the attributes used in the models of the present study, maximum size of the species and average depth for the two groups (stingrays and sharks) were key variables, as already reported in other studies (Dulvy et al. 2014, 2021; Walls and Dulvy 2020). Body size is thought to be related to extinction risk because large rays and sharks tend to have slower growth rates and take longer to reach maturity (Sun et al. (2013); Dulvy et al. 2021). Depth may be important in determining levels of exploitation due to the depth limits of fisheries; deeper species are caught less frequently than shallow ones (Walls and Dulvy 2020).

Ray habitat use may also be a useful predictor of the threat status, as in the case of neritic stingrays which had higher extinction risk values. Neritic rays, especially epipelagic ones, have a higher proportion of threatened species than those typical of other habitats, again due to elevated fishing pressure in these habitats (Dulvy et al. 2017). In the case of sharks, oceanic pelagic species had lower risk due to the high productivity and lower fishing activity in these regions (Sibert et al. 2006). Another significant attribute for both groups was the reproductive mode. Viviparous species had a higher estimated risk of extinction, probably because they generally have lower fecundity than oviparous species and are therefore less able to compensate for fishing mortality (Forrest et al. 2008; Dulvy and Forrest 2010).

Our study predicts that among the species not yet evaluated (97) and those classified as DD (136), approximately 53% have a presumptively higher risk of extinction are candidates to be classified as NT by the IUCN. Furthermore, the rays *Pristis perotteti* (Müller & Henle, 1841) and *Leucoraja compagnoi* (Stehmann, 1995) are identified as priorities for extinction risk assessment having attribute similar to CR species. The sharks *Proscyllium venustum* (Tanaka, 1912) and *Heterodontus ramalheira* (Smith, 1949) are also identified as having a high probability of being at risk of extinction. This is supported by analysis that suggests that the elasmobranch genera *Pristis, Leucoraja, Proscyllium and Heterodontus* are amongst the most vulnerable to extinction (Dulvy et al. 2014; Fernandez-Carvalho et al. 2014).

Including data deficient species in our analysis, we were able to identify that the areas with the highest percentage of elasmobranch species classified as at higher risk of extinction are also those where they are more captured. Specifically, regions with high proportions of endangered species include the Mediterranean and Black Seas and the Pacific-Eastern Central waters. This is supported by studies that indicate that taxon sensivity to continuously high levels of fisheries mortality (accidental or directional) is the major cause of depletion of elasmobranch populations worldwide (Ferretti et al. 2010).

Although measures to mitigate the population decline of elasmobranchs, such as fishing limits and trade restrictions, have been implemented (Oliver et al. 2015; Friedman et al. 2018), these actions cover a few species, are applied unevenly, and often do not fully comply with scientific advice (Davidson et al. 2016; Lawson and Fordham 2018). Reducing the impact of direct or incidental elasmobranch fisheries is not just a bioeconomic matter but also an ethical one. Societies must be made aware of the critical status of elasmobranch fish stocks using the best available information, and must understand that doing nothing is not a viable option if these ecologically, culturally and economically important species are to survive in the medium and long-term. The major threat to elasmobranchs is fisheries, and these should be more efficiently monitored and managed, especially in areas with high rates of capture of threatened species.

6.5. REFERENCES

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7. Conclusão Geral

A partir dos nossos resultados podemos concluir que a produção cientifica sobre elasmobrânquios marinhos é crescente de modo exponencial. Entretanto, é importante destacar que a produção analisada não leva em consideração a produção cinza, exemplo: teses, dissertações, e relatórios técnicos. Além disso, artigos científicos publicados em periódicos não indexados na Web of Science também não foram considerados. Portanto, a produção científica sobre esses animais vai além do que foi analisado.

Considerado ainda produção cientifica, observamos que ela está concentrada em países que apresentam índices econômicos (Indice de Desenvolvimento Humano e Produto Interno Bruto) mais alto. Em relação aos temas abordados, houve uma clara mudança ao longo do tempo, sendo mais comum até os anos 2000 temas como morfologia e anatomia, e mais atualmente temas tais como história de vida, conservação, ecologia. Essa transição temática que vem ocorrendo é importante pois aponta que temas mais voltados para conservação (diretamente ou indiretamente) estão ganhando destaque, e consequentemente estão subsidiando avalições de risco de extinção, criação de planos de manejos e leis que visam a proteção desses animais.

O levantamento realizado também apontou que para algumas espécies consideradas como Dados Insuficientes (DD), já existiam dados apropriados para uma avaliação previa. Este foi o caso da arraia *Hypanus guttatus* avaliada no 2º capitulo da tese. A partir dos dados disponíveis na literatura e internet, observamos que a espécie considerada DD apresenta alto risco de extinção no Nordeste, ocasionado principalmente pela alta mortalidade de indivíduos jovens e neonatos na região. Portanto, algumas espécies mesmo classificadas como DD pela IUCN possuem dados que permitem que sejam avaliadas.

Em contrapartida, há espécies que não possuem dados adequados em termos qualitativos e quantitativos para que seja avaliado o seu risco de extinção. Nesses casos o uso dos atributos bioecologicos pode ser uma ferramenta auxiliar para diagnosticar o risco de extinção. No terceiro artigo da tese, concluímos que espécies que apresentam viviparidade, que estão em ambientes mais próximos a costa e habitam águas mais rasas tendem a ter maior riscos de extinção. Esses atributos, juntamente com os outros analisados na tese (ex. nível trófico, tamanho máximo), podem ser preditores para identificar quais espécies tendem a ter maior riscos de extinção. Assim, sugerimos destinar maior esforço para pesquisas de história de vida, uso de habitat e conservação dessas espécies.

Portanto, de forma geral, mesmo havendo uma crescente na quantidade de artigos publicados sobre elasmobrânquios marinhos, observamos que ainda existem muitas lacunas no conhecimento, principalmente sobre as espécies pouco estudadas e em temas como história de vida, uso de habitat, conservação, pesca e consumo. Esses temas são urgentes e essenciais para as avaliações de risco de extinção e tomadas de decisões que visem a conservação.