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JOYCE DIAS GOIS RODRIGUES DE QUEIROZ

HISTÓRICO DE RECUPERAÇÃO E PADRÕES DE MOVIMENTAÇÃO DO TUBARÃO DE GALÁPAGOS *Carcharhinus galapagensis* (SNODGRASS & HELLER, 1905) NO ARQUIPÉLAGO DE SÃO PEDRO E SÃO PAULO, BRASIL

Recife
2020

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Dissertação apresentada ao Programa de Pós-Graduação em Oceanografia da Universidade Federal de Pernambuco, como um dos requisitos para a obtenção do título de Mestre em Oceanografia.

Área de concentração: Oceanografia Biológica.

Orientador: Prof. Dr. Fábio Hissa Vieira Hazin.

Coorientadora: Dra. Natalia Priscila Alves Bezerra.

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Às minhas mães Juliana, Julia e Carminha, meus irmãos Juliana e Jorge, e ao meu tio/pai Weliton Junior.

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“*Você pode nunca saber quais resultados virão de suas ações, mas se você não fizer nada, não haverá resultados”*

(Mahatma Gandhi)

RESUMO

O tubarão de Galápagos (*Carcharhinus galapagensis*) é uma espécie cosmopolita encontrada principalmente associada as ilhas oceânicas. No passado, a espécie foi considerada uma das mais abundantes do Arquipélago de São Pedro e São Paulo (ASPSP), um conjunto de ilhas brasileiras localizadas entre o Brasil e a África, no hemisfério norte próximo a região equatorial. No transcorrer dos anos, a espécie sofreu uma drástica redução após o início das atividades pesqueiras no entorno da região, chegando a ser considerada como localmente extinta. Nesse contexto, o objetivo do presente estudo foi comprovar a ocorrência e determinar os padrões de movimentação e o uso do hábitat do tubarão de Galápagos no ASPSP. Com base nas informações fornecidas pelos pescadores, em dados de captura e em registro de imagens, foi possível comprovar que a espécie não somente continua presente no ASPSP, como a sua população está em processo de recuperação, se tornando novamente bastante abundante na região. Entre 2010 e 2019, 37 tubarões de Galápagos foram capturados, para fins de marcação e mensuração, tendo sido, em seguida liberados de volta ao mar. A espécie foi a segunda mais capturada no arquipélago. Não houve diferença significativa na razão sexual e na distribuição de frequência de tamanho por sexo dos indivíduos capturados. A rápida recuperação dos tubarões carcharhinídeos foi relatada por todos os pescadores entrevistados, com a maioria deles descrevendo uma clara percepção de aumento da abundância de tubarões após a proibição da pesca de elasmobrânquios, em 2012, aspecto que enfatiza a vulnerabilidade dessas espécies à pressão pesqueira. Duas áreas foram definidas pelos pescadores como sendo de maior frequência de avistagens de tubarões. Além disso, foi observada uma clara segregação interespecífica entre o *C. galapagensis* e *C. falciformis*, com o tubarão de Galápagos sendo mais capturado do lado oeste do arquipélago e o contrário ocorrendo com o *C. falciformis*. Cinco tubarões de Galápagos capturados durante uma expedição científica em agosto de 2019 foram marcados com transmissores via satélite, no intuito de compreender os padrões de movimentação da espécie no ASPSP. Apenas duas das cinco marcas, uma Pop-up Satellite Archival Transmitting tag (PSAT) e uma Smart Position or Temperature Transmitting tag (SPOT) fixadas em um macho adulto de 223 cm e uma fêmea adulta de 220 cm de comprimento total, respectivamente, transmitiram dados para o sistema Argos de satélites. Dados dos perfis de profundidade e temperatura obtidos com a PSAT demonstram que o indivíduo realizou mergulhos abaixo da termoclina, alcançando uma profundida de 304 m. Os dois indivíduos apresentaram diferentes padrões de movimento horizontal. Enquanto o macho permaneceu próximo ao arquipélago durante o período de marcação (59 dias), a fêmea percorreu uma longa distância, sendo detectada próxima a costa da África após 168 dias de marcação. A distância percorrida por essa fêmea é a mais longa registrada para a espécie até o momento. Ambos os indivíduos marcados ultrapassaram os limites das áreas de proibição da pesca de elasmobrânquios, ressaltando a importância de se ter um amplo conhecimento sobre a ecologia espacial das espécies ameaçadas para que se possa definir medidas adequadas de manejo e conservação.

Palavras-chave: Carcharhinídeos. Recuperação populacional. Estrutura populacional. Etnobiologia. Telemetria via satélite. Conservação.

ABSTRACT

The Galapagos shark (*Carcharhinus galapagensis*) is a cosmopolitan species mostly found associated with oceanic islands. In the past, the species was considered one of the most abundant in the Saint Peter and Saint Paul Archipelago (SPSPA), a group of Brazilian islands located between Brazil and Africa, in the northern hemisphere close to the equator. Over the years, the species suffered a major decline after the beginning of fishing activity in the region, being considered locally extinct. In this context, the objective of the present study was to prove the occurrence and to determine the patterns of movement and habitat use of the Galapagos shark in the SPSPA. Based on information provided by the fishermen, catch data and video images, it was possible to confirm that the species is not only still present in the SPSPA, but that its population is recovering quickly, becoming again very abundant in the region. Between 2010 and 2019, 37 Galapagos sharks were caught and released, after being tagged and measured. The species was the second shark most caught in the archipelago. There was no significant difference in sex ratio and in the size frequency distribution of males and females caught. The rapid recovery in the abundance of carcharhinid sharks was attested by all fishermen interviewed, with most of them having reported a noticeable increase in the abundance of sharks after the complete ban on elasmobranch fishing in 2012, emphasizing the vulnerability of these species to fishing pressure. Two areas were defined by fishermen as having the greatest frequency of shark sightings. Furthermore, a clear interspecific segregation was observed between *C. galapagensis* and *C. falciformis*, with the Galapagos shark being much more abundant on the west side of the archipelago, and the contrary happening with the *C. falciformis*. Five Galapagos sharks caught during a scientific expedition in August 2019 were tagged with satellite tags to better understand their movements around the SPSPA. Only two of the five tags, a Pop-up Satellite Archival Transmitting tag (PSAT) and a Smart Position or Temperature Transmitting tag (SPOT), deployed in an adult male of 223 cm and an adult female of 220 cm total length, respectively, transmitted their data to the Argos satellite system. Profiles of depth and temperature obtained with the PSAT demonstrated that the individual made dives below the thermocline zone, reaching a depth of 304 m. The two tagged sharks displayed different patterns of horizontal movement. While the male remained close to the archipelago during the period of tag deployment (59 days), the female specimen undertook a long-distance movement, being detected close to the coast of Africa after 168 days of tag deployment. This was the longest movement recorded for the species, so far. Both individuals moved beyond the areas where elasmobranch fishing is prohibited, highlighting the importance of having a broad knowledge of the spatial ecology of threatened species to define appropriate management and conservation measures.

Keywords: Carcharhinids. Population recovery. Population structure. Ethnobiology. Satellite telemetry. Conservation.

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1 INTRODUÇÃO

Os elasmobrânquios, denominação que engloba raias e tubarões, compõem um dos grupos de vertebrados mais ameaçados do planeta, devido, principalmente, às suas características biológicas e história de vida, tais como crescimento lento, maturação sexual tardia e baixa fecundidade (CAMHI et al., 1998), as quais os tornam mais suscetíveis aos impactos humanos, em especial à sobrepesca (DULVY et al., 2014; FERRETTI et al., 2010; PIKITCH; CAMHI; BABCOCK, 2008; STEVENS et al., 2000). Em razão da sua elevada mortalidade por pesca e baixa resiliência, a maioria das populações de elasmobrânquios tende a declinar rapidamente, podendo levar várias décadas até que uma população sobrepescada se recupere (STEVENS et al., 2000), aumentando assim os riscos de extinção dessas espécies (MYERS; WORM, 2005).

Mundialmente, declínios populacionais significativos têm sido observados para espécies de elasmobrânquios que habitam tanto zonas costeiras como oceânicas (DULVY et al., 2008, 2014; FERRETTI et al., 2010; MYERS; WORM, 2005; ROFF et al., 2018), inclusive em áreas remotas, como atóis e ilhas oceânicas (EDWARDS; LUBBOCK, 1982; GRAHAM; SPALDING; SHEPPARD, 2010). Considerados como uma das maiores radiações de predadores, com boa parte dos seus representantes estando próximos ou no topo da cadeia trófica, os tubarões exercem um importante papel na dinâmica dos ecossistemas marinhos (DULVY et al., 2017; HEUPEL et al., 2014), razão pela qual a sua remoção pode resultar em diversos impactos negativos, tanto do ponto de vista ecológico como econômico (BORNATOWSKI; BRAGA; VITULE, 2014; STEVENS et al., 2000), ocasionando um efeito cascata nas interações tróficas pelo aumento de meso-predadores (FERRETTI et al., 2010; HEITHAUS et al., 2008; MYERS et al., 2007a; STEVENS et al., 2000) e reduzindo o turismo de observação de tubarões (TOPELKO; DEARDEN, 2005), por exemplo.

A família Carcharhinidae, grupo de grande importância ecológica e econômica (BARREIROS; GADIG, 2011; COMPAGNO, 1984), está entre uma das famílias mais vulneráveis à extinção, com acentuadas reduções de suas populações tendo sido registradas em várias partes dos Oceanos Atlântico, Pacífico e Índico (BARRETO et al., 2017; BAUM; MYERS, 2004; JABADO et al., 2018; ROFF et al., 2018). Este cenário é ainda mais preocupante para aquelas espécies de difícil identificação, a exemplo dos representantes do gênero *Carcharhinus* (BARREIROS; GADIG, 2011; GARRICK, 1982), grupo que é constantemente alvo da pesca (NMFS, 2010, 2011) e que possui grande importância para o equilíbrio trófico dos ecossistemas marinhos tropicais e subtropicais (GADIG, 2001).

O tubarão de Galápagos (*Carcharhinus galapagensis*) é uma espécie cosmopolita, que habita águas tropicais e temperadas de ecossistemas costeiros e insulares (COMPAGNO, 1984; GARRICK, 1982), com preferência por ambientes de fundos rochosos ou coralíneos, águas claras e fortes correntes (WASS, 1971; WETHERBEE; CROW; LOWE, 1996). Apesar da sua capacidade de percorrer longas distâncias (COMPAGNO, 1984; KOHLER; CASEY; TURNER, 1998; LARA-LIZARDI et al., 2020), o tubarão de Galápagos apresenta o habitat preferencial relativamente limitado, sendo encontrado principalmente associado a ecossistemas insulares (COMPAGNO, 1984; WETHERBEE; CROW; LOWE, 1996), com elevada abundância em algumas ilhas da América do Sul e Central (BEEBE; TEE-VAN, 1941; EDWARDS; LUBBOCK, 1982), como é o caso do Arquipélago de Galápagos, ilha que deu origem ao nome da espécie.

A preferência dessa espécie por ilhas oceânicas é uma característica comumente apresentada por grandes predadores marinhos e pode estar relacionada, principalmente, aos fenômenos associados à dinâmica oceanográfica desses ambientes, que tendem a contribuir com o aumento da biomassa de produtores primários e, consequentemente, com o fornecimento de recursos para os níveis tróficos superiores (GOVE et al., 2016), sendo normalmente considerados *hotspots* da biodiversidade pelágica (WORM; LOTZE; MYERS, 2003). No Brasil existem cinco conjuntos de ilhas oceânicas, com o tubarão de Galápagos tendo sido registrado até o momento nos arquipélagos de Fernando de Noronha (SOTO, 2001) e São Pedro e São Paulo (LUBBOCK; EDWARDS, 1981), e na cadeia de montes submarinos de Vitória-Trindade (PINHEIRO et al., 2015).

Além de apresentar caráter residente (DALE et al., 2011; MEYER; PAPASTAMATIOU; HOLLAND, 2010; WETHERBEE; CROW; LOWE, 1996) e da grande similaridade com outras espécies do gênero (COMPAGNO, 1984; DUFFY, 2016; GARRICK, 1982), o tubarão de Galápagos apresenta também comportamento de segregação por sexo e tamanho, com jovens e machos maduros preferindo águas mais profundas (em média 45,1 e 60,2 m, respectivamente), e fêmeas permanecendo em água mais rasas (em média 34,2 m) (COMPAGNO, 1984; PAPASTAMATIOU et al., 2006; WETHERBEE; CROW; LOWE, 1996). Essas características ecológicas associadas à sua fisiologia das espécies, presentes em muitos representantes do grupo dos tubarões, podem contribuir para um impacto desproporcional em suas populações (MUCIENTES et al., 2009), aumentando a sua vulnerabilidade às pressões antrópicas (BARNETT et al., 2012; KINNEY; SIMPFENDORFER, 2009; STEVENS et al., 2000).

Considerada uma espécie muito comum no arquipélago de São Pedro e São Paulo (ASPSP), uma das áreas do Oceano Atlântico com maior densidade de tubarões, o tubarão de Galápagos, assim como outros Carcharhinidae, sofreu um grande declínio populacional nos últimos anos, provavelmente associado ao aumento da pressão pesqueira no entorno da região (EDWARDS; LUBBOCK, 1982). Devido ao rápido declínio desses tubarões e à ausência de registros de *Carcharhinus* spp. durante os censos visuais subaquáticos realizados por mais de uma década (FEITOZA et al., 2003; VASKE JR et al., 2005), o tubarão de Galápagos passou a ser considerado como extinto localmente (LUIZ; EDWARDS, 2011). Porém, ao contrário do que foi reportado por outros autores, espécies de tubarão do gênero *Carcharhinus* têm sido observadas no ASPSP desde 2009 (OLIVEIRA, 2017). Em 2012, após intensos debates sobre o declínio das populações de tubarão na região, foi estabelecida a proibição da pesca de elasmobrânquios no ASPSP (SECIRM, 2012). Além disso, duas grandes áreas marinhas protegidas (AMPs) foram criadas em 2018 para garantir a conservação da biodiversidade marinha, sendo uma Área de Proteção Ambiental (APA), que abrange toda a Zona Econômica Exclusiva (ZEE, 407.052 km²) ao redor do arquipélago, e um Monumento Natural, que cobre cerca de 47.263 km² do mar territorial (BRASIL, 2018), está última considerada uma área de proteção integral.

A falta de informações essenciais para um manejo efetivo das espécies ameaçadas, como é o caso das lacunas de conhecimento sobre padrões de distribuição espacial e uso de habitat dos tubarões (HAMMERSCHLAG et al., 2012; SPEED et al., 2010), tem dificultado os esforços para a sua conservação. A compreensão dos padrões de movimento e preferências de habitat permite desvendar os fatores que favorecem a permanência desses animais em determinados locais considerados como de alta adequabilidade, cuja identificação é fundamental para balizar as medidas de manejo e ordenamento necessárias para a sua conservação (HAYS et al., 2016; HEUPEL; SIMPFENDORFER, 2005; HEUPEL; SIMPFENDORFER; HUETER, 2004; SPEED et al., 2010). No caso do tubarão de Galápagos, a compreensão desses mecanismos é ainda muito limitada em toda a sua área de ocorrência (MEYER; PAPASTAMATIOU; HOLLAND, 2010), enfatizando a necessidade da realização de pesquisas científicas que contribuam com informações sobre a biologia e ecologia da espécie, de forma a possibilitar a adoção de medidas para a recuperação dos seus estoques.

Devido à sua capacidade de monitorar remotamente os animais, os dispositivos eletrônicos (via satélite) têm contribuído substancialmente para a obtenção de dados sobre padrões de migração, habitats preferenciais e comportamento de animais aquáticos, já tendo sido utilizados com êxito no estudo de várias espécies de elasmobrânquios

(HAMMERSCHLAG; GALLAGHER; LAZARRE, 2011). Embora tenha se mostrado uma ótima ferramenta para identificar padrões de movimento e comportamento de grandes predadores marinhos, como os tubarões (AFONSO; GARLA; HAZIN, 2017; BEZERRA et al., 2019; MACENA; HAZIN, 2016; SHIPLEY et al., 2017; WENG et al., 2008), estudos com marcas via satélite ainda são escassos, especialmente nas águas tropicais e subtropicais do Oceano Atlântico (HAMMERSCHLAG; GALLAGHER; LAZARRE, 2011). Por isso, espécies que necessitam de medidas de proteção, como é o caso do tubarão de Galápagos, ainda se encontram pouco estudadas, sendo ainda limitada a compreensão sobre os padrões de movimento dessa espécie (KETCHUM et al., 2009; LOWE; WETHERBEE; MEYER, 2006; PAPASTAMATIOU et al., 2015). Nesse contexto, o presente estudo teve como objetivo comprovar a ocorrência do tubarão de Galápagos no ASPSP e identificar seus padrões de movimentação e uso do hábitat, a fim de contribuir com informações que possam subsidiar medidas eficientes para a conservação da espécie.

2 REVISÃO DE LITERATURA

As populações de tubarões vêm declinando significantemente nas regiões costeiras e oceânicas de todo o mundo (CAMHI et al., 2009; DULVY et al., 2008, 2014; FERRETTI et al., 2010; MYERS; WORM, 2005; ROFF et al., 2018). Apesar disto, a exata magnitude deste declínio é ainda incerta, visto que as informações disponíveis sobre quase metade das espécies de condrictes (tubarões, raias e quimeras) ainda não são suficientes para determinar seu estado de conservação, sendo considerados como “Dados Deficientes” pela União Internacional para a Conservação da Natureza (IUCN) (DULVY et al., 2017, 2014). Além disso, mais da metade das espécies de tubarões que possuem ampla distribuição geográfica (≥20 países) apresentam um elevado risco de extinção (DULVY et al., 2014; MCCLENACHAN; COOPER; DULVY, 2016). Diversos são os efeitos negativos provenientes da remoção dos tubarões dos ecossistemas marinhos, principalmente em razão desses animais desempenharem uma importante função na estruturação das comunidades, influenciando as taxas de mortalidade e o comportamento dos meso-predadores e outros organismos (FERRETTI et al., 2010; HEITHAUS et al., 2008; MYERS et al., 2007a; STEVENS et al., 2000). A diminuição das populações de tubarões também possui um efeito negativo sobre a economia de muitos países onde o valor dos tubarões vivos é muito maior do que o valor da sua carne nos mercados de peixe (CAMPANA; FERRETTI; ROSENBERG, 2016).

2.1 Ameaça aos tubarões e estratégias para sua conservação

Entre as principais ameaças enfrentadas por esse grupo, a que mais se destaca é a sobrepesca, tanto por meio da pesca direcionada, como por meio das capturas acidentais (*fauna acompanhante*) (DULVY et al., 2014; MOLINA; COOKE, 2012; OLIVER et al., 2015; STEVENS et al., 2000). O impacto da pesca se intensificou ainda mais nas última décadas devido ao aumento na demanda por nadadeiras de tubarão pelo mercado asiático (CLARKE et al., 2006a; DULVY et al., 2014), sendo a prática do “*finning*”, que consiste na remoção somente das nadadeiras e descarte do corpo ou charuto do animal, responsável pela captura de 26 a 73 milhões de tubarões por ano (CLARKE; MILNER-GULLAND; BJORNDAL, 2007).

Infelizmente, ainda existe uma grande deficiência no monitoramento da pesca e comercialização de tubarões em todo mundo, o que é extremamente preocupante, visto que muitas de suas populações quando sobreexplotadas podem levar várias décadas para se recuperarem (STEVENS et al., 2000). Essa baixa resiliência se deve principalmente às características de história de vida desses animais, tais como o crescimento lento, maturação sexual tardia, períodos longos de gestação e baixa fecundidade (CORTÉS, 2000; STEVENS et al., 2000), as quais os tornam muito mais vulneráveis à sobre-explotação e à extinção (FERRETTI et al., 2010; GALLAGHER; KYNE; HAMMERSCHLAG, 2012; REYNOLDS et al., 2005; MYERS; WORM, 2005). Estimativas apontam que mais de 90% das capturas de tubarões em todo o mundo podem ser consideradas biologicamente insustentáveis (SIMPFENDORFER; DULVY, 2017).

A sobre-explotação dos predadores de topo tem influenciado as comunidades biológicas, resultando na redução da biodiversidade e da produtividade, perda de serviços ecossistêmicos e, em alguns casos, até mesmo no colapso estrutural do ecossistema (AGARDY, 2000; FERRETTI et al., 2010; HEITHAUS et al., 2008; JACKSON et al., 2001; MYERS et al., 2007b). Com o intuito de mitigar esses impactos, uma estratégia que tem sido amplamente adotada é a criação de Áreas Marinhas Protegidas (AMPs). Essas áreas constituem uma importante ferramenta de manejo para a proteção e conservação dos ecossistemas marinhos, auxiliando na gestão pesqueira em regiões onde a pesca é permitida, contribuindo para a recuperação e proteção de populações de peixes ósseos e elasmobrânquios (BONFIL, 1999; DAVIDSON; DULVY, 2017).

A efetividade dessas AMPs é muitas vezes atrelada à relação entre o tamanho e forma dessas áreas e o deslocamento das espécies alvo, juntamente com o conhecimento sobre as pressões pesqueiras nas adjacências da região (CHIAPPONE; SULLIVAN-SEALEY, 2000; DAHLGREN; SOBEL, 2000). Nesse sentido, alguns acreditam que as AMPs não beneficiam espécies migratórias, como os grandes peixes pelágicos (ROBERTS, 2000), visto que seriam necessárias grandes AMPs para proteger essas espécies (WOOD et al., 2008). Embora os benefícios das AMPs sejam mais evidenciados para as espécies que possuem um comportamento predominantemente residente, a proteção de zonas de reprodução, berçários, e alimentação, podem beneficiar tanto as espécies residentes quanto as migratórias (HEUPEL; SIMPFENDORFER, 2005; HOOKER et al., 2011; ROBERTS, 2000). Proteger áreas como berçários, por exemplo, fornece um aumento significativo na sobrevivência dos juvenis, aumentando, consequentemente, a capacidade da espécie de suportar melhor a mortalidade por pesca (HEUPEL; SIMPFENDORFER, 2005).

Os benefícios das AMPs para espécies que realizam largos deslocamentos, como os tubarões, porém, ainda não são muito claros (CHAPMAN et al., 2013; MORA et al., 2006), principalmente porque para avaliar a efetividade das AMPs é necessário determinar a proporção de tempo que os indivíduos permanecem protegidos dentro dessas áreas, e os riscos de mortalidade aos quais esses indivíduos são expostos quando ultrapassam os limites das AMPs, tornando essencial o conhecimento sobre os seus padrões de movimentação (ESPINOZA et al., 2015; GRAHAM et al., 2016; HEUPEL; SIMPFENDORFER, 2005). Informações sobre ecologia espacial e comportamento das espécies ameaçadas devem ser obtidos preferencialmente antes da implementação das AMPs para que possam ser incorporadas nos projetos de criação dessas áreas e, desta forma, garantir que a escala e a localização dessas proteções espaciais sejam relevantes para a conservação das espécies-alvo (ESPINOZA et al., 2015; GRAHAM et al., 2016). Entretanto, as lacunas de conhecimento sobre os padrões de movimentação de muitas espécies de tubarões e raias têm dificultado a definição de AMPs adequadas para a conservação desse grupo.

Embora ainda seja um campo bastante desafiador, o número de estudos voltados à compreensão da ecologia espacial dos tubarões tem crescido bastante nas últimas décadas (e.g. BONFIL et al., 2005; DOLTON et al., 2020; HAMMERSCHLAG et al., 2017; MEYER; PAPASTAMATIOU; HOLLAND, 2010; PAPASTAMATIOU et al., 2010), principalmente devido aos avanços tecnológicos que têm permitido monitorar remotamente a movimentação das espécies em seus habitats naturais (HAMMERSCHLAG; GALLAGHER; LAZARRE, 2011; HUSSEY et al., 2015). A utilização de transmissores via satélite, como as Smart Position or Temperature Transmitting (SPOT) e Pop-up Satellite Archival Tag (PSAT), tem possibilitado compreender, por exemplo, como os tubarões utilizam seu habitat, as suas preferências de temperatura e profundidade, os padrões diários e sazonais de movimentação, o comportamento de mergulho, as áreas de residência e suas rotas migratórias (AFONSO; GARLA; HAZIN, 2017; BEZERRA et al., 2019; DOLTON et al., 2020; SHIPLEY et al., 2017), permitindo, desta forma, preencher as diversas lacunas de conhecimento ainda existentes acerca do comportamento dos tubarões e contribuindo, assim, com informações essenciais para o manejo e conservação dessas espécies.

2.2 A espécie estudada

O tubarão de Galápagos (Fig.1), *Carcharhinus galapagensis* (Snodgrass e Heller, 1905), foi catalogado em 1905 após ser encontrado nas proximidades das Ilhas Galápagos, Equador, de onde derivou seu nome. É um tubarão de grande porte, podendo atingir um comprimento máximo de 370 cm (COMPAGNO; DANDO; FOWLER, 2005; GROVE; LAVENBERG, 1997). A espécie é uma das 35 espécies do gênero *Carcharhinus*, um grupo de difícil identificação devido à grande similaridade interespecífica (BARREIROS; GADIG, 2011). Com dorso cinza ou castanho escuro, ventre claro, corpo fusiforme, focinho arredondado e nadadeira dorsal alta e quase reta (COMPAGNO; DANDO; FOWLER, 2005), o tubarão de Galápagos é geralmente confundido com outras espécies do gênero, especialmente com o tubarão fidalgo (*C. obscurus* Lesueur, 1818) (GARRICK, 1982). Essas duas espécies não apenas apresentam similaridades morfológicas, como também compartilham haplótipos do DNA mitocondrial, embora sejam geneticamente distinguíveis com base em polimorfismo de nucleotídeo único (CORRIGAN et al., 2017; PAZMIÑO et al., 2019). Diante da dificuldade em identificar esses indivíduos, muito estudos desenvolvidos com o tubarão de Galápagos foram direcionados à sistemática, genética e diferenciação da espécie (CORRIGAN et al., 2017; GARRICK, 1982; PAZMIÑO et al., 2018, 2019).

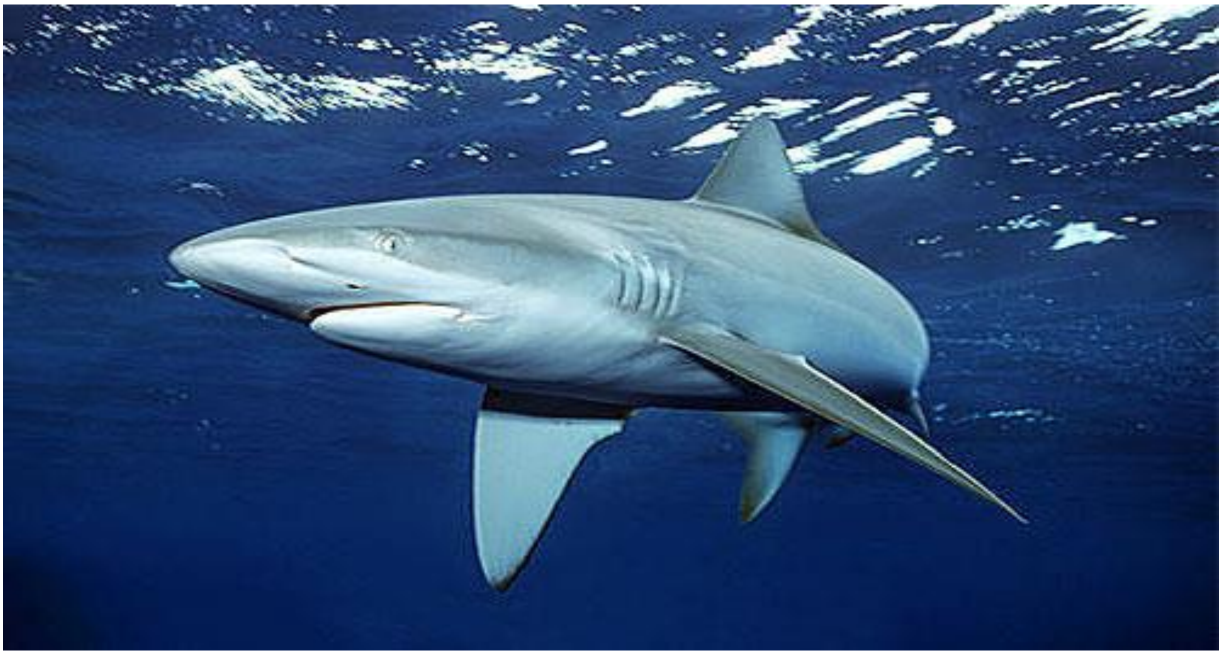

Figura 1 - Tubarão de Galápagos, *Carcharhinus galapagensis* (Snodgrass e Heller, 1905).
Fonte: www.floridamuseum.ufl.edu.

Apesar de apresentar uma distribuição circumglobal, sendo encontrado em águas tropicais e temperadas dos Oceanos Pacífico, Atlântico e Índico (Fig.2), principalmente associado a ilhas oceânicas (BEEBE; TEE-VAN, 1941; COMPAGNO; DANDO; FOWLER, 2005; COMPAGNO, 1984; EDWARDS; LUBBOCK, 1982; HOBBS et al., 2008; WETHERBEE; CROW; LOWE, 1996), pouco se conhece sobre os padrões de movimentação do tubarão de Galápagos em toda sua área de ocorrência (MEYER; PAPASTAMATIOU; HOLLAND, 2010). Estudos prévios sobre a movimentação da espécie baseados em marcação e recaptura, telemetria acústica e via satélite demonstraram que o tubarão de Galápagos tende a permanecer próximo aos locais originais de marcação (≤ 100 km), comprovando seu caráter residente associado a ecossistemas insulares (COMPAGNO, 1984; KOHLER; CASEY; TURNER, 1998; LARA-LIZARDI et al., 2020; MEYER; PAPASTAMATIOU; HOLLAND, 2010). Embora predominantemente residente, existem registros de indivíduos que percorreram longas distância em oceano aberto. Um macho marcado com marca convencional em Bermudas foi recapturado a 2.859 km de distância do local de sua marcação, na costa do Suriname (KOHLER; CASEY; TURNER, 1998). Um deslocamento ainda maior foi registrado para uma fêmea de 181 cm de comprimento total marcada na Ilha Socorro, México. Esse indivíduo se deslocou por pelo menos 3.200 km até chegar nas Ilhas Galápagos, Equador (LARA-LIZARDI et al., 2020).

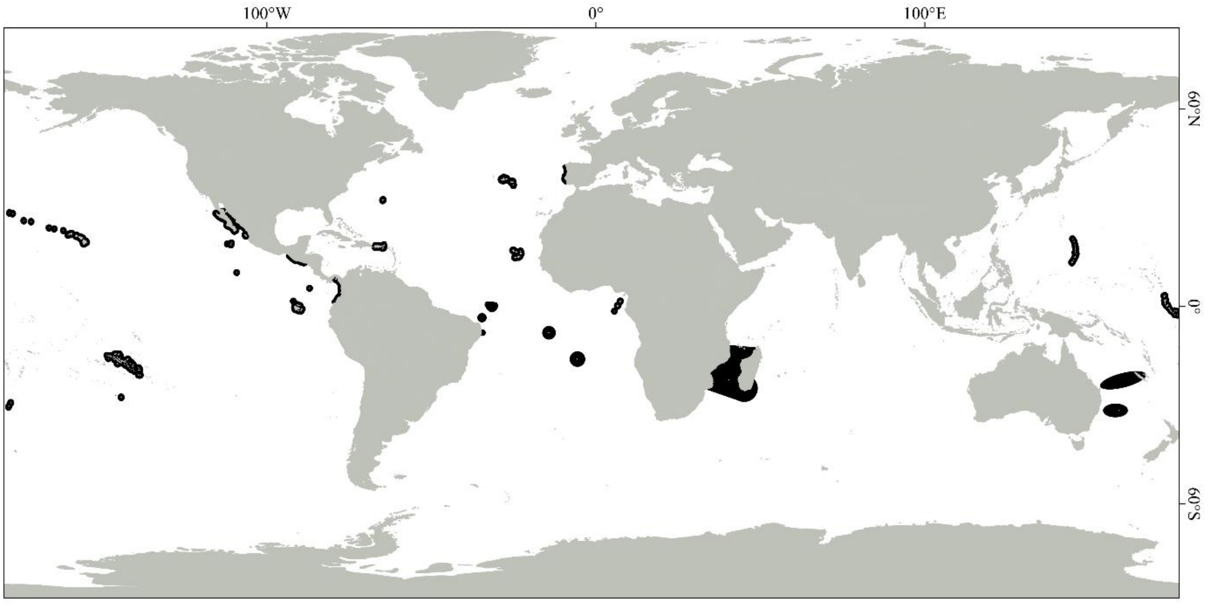

Figura 2 - Mapa da distribuição do tubarão de Galápagos (*Carcharhinus galapagensis*).
Fonte: adaptado de IUCN.

Dados de pesca e monitoramento acústico permitiram identificar diferenças ontogenéticas na distribuição vertical e padrões de deslocamentos diários e sazonais dos tubarões de Galápagos. No Hawaii, indivíduos adultos foram predominantemente detectados próximos às ilhas e recifes mais rasos durante a noite, com a quantidade de detecções variando de acordo com período do ano (LOWE; WETHERBEE; MEYER, 2006), enquanto que os indivíduos juvenis demostraram um padrão inverso, permanecendo em águas mais profundas durante a noite e se deslocando para áreas mais rasas durante o dia (PAPASTAMATIOU et al., 2015).

Considerado um predador de topo, a espécie exerce uma importante função no equilíbrio dos ecossistemas marinhos, se alimentando principalmente de peixe demersais, bem como de lulas e polvos. Indivíduos maiores são capazes de se alimentar também de outros elasmobrânquios, e já foram observados atacando e se alimentando de focas, leões marinhos, iguanas marinhas, e até mesmo de lixo (ANTONELIS et al., 2006; BESTER, 2020; EDWARDS; LUBBOCK, 1982; GROVE; LAVENBERG, 1997; PAPASTAMATIOU et al., 2006; SNODGRASS; HELLER, 1905; WETHERBEE; CROW; LOWE, 1996). Assim como muitos elasmobrânquios, o tubarão de Galápagos apresenta uma maturação sexual tardia, com uma idade de primeira maturação estimada entre 6 e 8 anos para os machos, e entre 6,5 e 9 anos para as fêmeas, segundo De Crosta et al (1984 *apud* WETHERBEE; CROW; LOWE, 1996). A espécie é vivípara, gerando de 4 a 16 filhotes por gestação, após um longo período gestacional, estimado em cerca de 12 meses, e um ciclo reprodutivo a cada dois ou três anos (COMPAGNO; DANDO; FOWLER, 2005; WETHERBEE; CROW; LOWE, 1996).

Existem poucas informações publicadas com relação ao uso e comercialização do tubarão de Galápagos, que é normalmente capturado acidentalmente por espinheis comerciais e de pequena escala, rede de cerco e de emalhar, tanto nas proximidades de ilhas e montes submarinos como em águas oceânicas pelágicas (PIKITCH; CAMHI; BABCOCK, 2008; TREMBLEY-BOYER; BROUWER, 2016). A espécie é geralmente retida a bordo por sua carne e nadadeiras (CLARKE et al., 2006b; FIELDS et al., 2018), com a sua abundância, consequentemente, tendo declinado em algumas regiões devido à sobrepesca (COMPAGNO; DANDO; FOWLER, 2005; KYNE et al., 2019; LUIZ; EDWARDS, 2011). Outro fator que pode contribuir para a redução das populações do tubarão de Galápagos é a captura intencional da espécie em algumas áreas com o intuito de diminuir a predação de espécies ameaçadas de extinção, como é o caso da foca-monge-do-Havaí (*Monachus schauinslandi*) (ANTONELIS et al., 2006). Apesar disto, as populações de tubarão de Galápagos se encontram aparentemente estáveis em grande parte do Oceano Pacífico, razão pela qual a espécie foi classificada como "pouco preocupante" pela IUCN (KYNE et al., 2019).

3 ARTIGOS CIENTÍFICOS

Os resultados dessa dissertação foram divididos em dois artigos que abordam a ocorrência e os padrões de movimentação do tubarão de Galápagos no Arquipélago de São Pedro e São Paulo, estruturados em formato de artigos científicos.

3.1 ARTIGO CIENTÍFICO I - BACK FROM THE DEAD? THE RESURRECTION OF THE GALAPAGOS SHARK (*CARCHARHINUS GALAPAGENSIS*) IN A REMOTE BRAZILIAN ARCHIPELAGO

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Abstract

The Galapagos shark, *Carcharhinus galapagensis* (Snodgrass & Heller, 1905) is a large circumtropical species mostly found around oceanic islands. In Brazil, commercial fishing in the Saint Peter and Saint Paul Archipelago (SPSPA), located in the equatorial Mid-Atlantic Ridge, resulted in a drastic reduction in the number of carcharhinid sharks, and the once very abundant Galapagos shark was then considered locally extinct. In opposition to this premature conclusion, this study provides records of the species in the SPSPA from the period of supposed disappearance to nowadays. Results are based on fishermen interviews, video footage and catch data obtained during the shark monitoring program conducted in the archipelago from 2010 to 2019. Galapagos shark was the second most caught shark in SPSPA, showing that this species is not only still present but is also becoming again one of the most common shark species in the archipelago. No significant difference was observed in sex ratio and in the size frequency distribution of males and females. The rapid recovery of carcharhinid sharks was attested by all fishermen interviewed. The recovery was mainly noticed after the complete ban on elasmobranch fishing, in 2012, emphasizing the vulnerability of these species to fishing pressure. Further research on the biology, ecology, behavior and distribution patterns of Galapagos sharks will greatly aid future decision-making regarding the management and conservation of the species, not only in SPSPA, but in insular ecosystems.

Keywords: experimental fishing; population recovery; population structure; ethnobiology; conservation; carcharhinids.

1. **Introduction**

The Galapagos shark (*Carcharhinus galapagensis*) is a widespread species that inhabits both coastal and insular ecosystems from tropical to temperate waters (Compagno, 1984; Garrick, 1982), with a preference for areas with rocky and coral bottoms, strong currents and clear water (Compagno, 1984; Wass, 1971; Wetherbee et al., 1996), being commonly found aggregated around oceanic islands of Atlantic and Pacific Oceans (Beebe and Tee-Van, 1941; Compagno, 1984; Edwards and Lubbock, 1982; Hobbs et al., 2008; Wetherbee et al., 1996). Despite its capacity to move great distances, Galapagos sharks exhibit limited spatial distribution (Compagno, 1984; Kohler et al., 1998; Wetherbee et al., 1996), suggesting they are mostly resident around oceanic islands (Meyer et al., 2010).

Besides their resident behavior, Galapagos sharks are also known to spatially segregate by sex and size (Compagno, 1984; Papastamatiou et al., 2006; Wetherbee et al., 1996), an ecological trait that makes sharks even more susceptible to anthropogenic impacts as a disproportionate effect may occur on different components of their populations (Mucientes et al., 2009). Moreover, the species has a limited intrinsic rebound potential (Smith et al., 1998) and is commonly misidentified due to their high similarity in external morphology with other *Carcharhinus* species (Duffy, 2016; Garrick, 1982), especially dusky sharks (*C. obscurus* Lesueur, 1818), with which Galapagos sharks have mitochondrial admixture (Corrigan et al., 2017). All these characteristics make the implementation of effective management and conservation measures for the species more difficult.

Globally classified as Least Concern by the International Union for Conservation of Nature (IUCN), Galapagos sharks may have undergone population declines at different islands (Kyne et al., 2019). In Brazil, the species is currently classified as Critically Endangered by the Brazilian official list of threatened species (decree MMA 445/2014) (Brasil, 2014) and has only been registered at the moment in the oceanic archipelagos of Saint Peter and Saint Paul (Lubbock and Edwards, 1981) and Fernando de Noronha (Soto, 2001) and in the Vitória-Trindade seamount chain (Pinheiro et al., 2015).

In the past, Galapagos shark was considered the most common species inhabiting the Saint Peter and Saint Paul Archipelago (SPSPA), an important area for the conservation of biodiversity that has long been notorious for the remarkable number of sharks present there, being considered "one of the densest shark populations in the Atlantic Ocean" (Edwards and Lubbock, 1982). The high abundance of sharks was historically reported in the 18^{th}, 19^{th} and part of the 20^{th} century by earlier visitors of SPSPA, who commonly observed these animals surrounding the boat and interacting with divers and fishing lines (Edwards and Lubbock, 1982; Fitzroy, 1839; Lubbock and Edwards, 1981; Smith et al., 1974).

Despite the high abundance of sharks around SPSPA, in the mid-20th century many visitors started to report a reduction of shark sightings, which has been attributed to the beginning of industrial fishing activity (Edwards and Lubbock, 1982). Commercial fishing begun in the vicinity of SPSPA as early as 1950's, when Japanese longliners started to operate in the Atlantic Ocean. In middle 1970's, the search for new fishing alternatives boosted the exploration of SPSPA by Brazilian fishing boats, including by longliners targeting tunas and other pelagic species (Hazin et al., 1998; Oliveira et al., 1997; Paiva and Le Gall, 1975). During this period, a lot of sharks were accidentally caught and a decline in their population started to be noticed (Edwards and Lubbock, 1982), increasing the concern and the need for better understanding and management of the region's natural resources.

In 1998, a SPSPA research program (PRO-ARQUIPÉLAGO) was implemented and a scientific station was established in the archipelago, receiving researchers all year round and contributing not only to the development of different studies but also to the monitoring of the area. In 2012, the Interministerial Commission for Marine Resources (CIRM), which is responsible for the management and surveillance of the archipelago, recommended a ban on elasmobranch fishing at SPSPA (SECIRM, 2012), an important step towards the conservation of elasmobranch diversity in the area. In addition, the International Commission for the Conservation of Atlantic Tunas (ICCAT) also prohibited, from June 2012 on, retaining on board, transshipping, or landing any part or whole carcasses of silky sharks (*C. falciformis* Muller & Henle, 1839), making their release, whether dead or alive, mandatory (ICCAT, 2011). Although targeted at a different species, due to their great similarity, the prohibition of retention of silky sharks in the Atlantic probably also had a direct positive impact on the Galapagos shark.

Since the establishment of the research station until 2009, different authors noted the scarcity of carcharhinid sharks, with a last sighting being reported in 1996 (Oliveira et al., 1997). The sharp decline of shark populations and the apparent disappearance of Galapagos sharks at SPSPA, which had not been sighted for more than one decade (Feitoza et al., 2003; Luiz and Edwards, 2011; Vaske Jr et al., 2005), led to the mistaken conclusion that it was locally extinct (Luiz and Edwards, 2011). In contrast with what has been reported by previous authors, specimens of *Carcharhinus* spp. have been observed at SPSPA since 2009 (Soto et al., 2011; BCLM, pers. obs). Using catch data from scientific small longline, video footage and fishermen interviews, we provide consistent records of Galapagos sharks in the SPSPA, contributing with information to support conservation strategies for the species.

2. Materials and methods

2.1 Study area

The SPSPA is a group of rocky islands located in the Atlantic Ocean, near the equator (Fig. 1) and just above the Mid-Atlantic Ridge (0°55’02"N; 29°20’42"W), about 1,010 km from the Brazilian coast and 1,824 km from Africa (Campos et al., 2005; Edwards and Lubbock, 1983). Considered to be the smallest and most isolated tropical island in the world (Campos et al., 2005; Feitoza et al., 2003; Vaske Jr et al., 2005), the SPSPA is influenced by the South Equatorial Current that flows westward at the surface and by the Equatorial Undercurrent that flows eastward at 40-150 m depth (Edwards and Lubbock, 1983). Due to its characteristics and strategic position, SPSPA has a great importance in the life cycle of many species, including migratory species that use this ecosystem as a feeding and reproduction ground (Hazin et al., 2008; Macena and Hazin, 2016; Vaske Jr et al., 2003).

2.2 Catch data

Sharks were caught by small pelagic longlines, from October 2010 to August 2019, during 24 scientific expeditions of the shark monitoring program (see Bezerra et al., 2019 for details on fishing methods), totalizing 146 sets (84 in the east and 62 in the west). All sharks were sexed and measured for total and fork lengths (TL and FL, respectively) immediately after gear retrieval, being then tagged and released back to the sea. All lengths reported in this study are TL. The methods applied in the research were approved by the Commission of Ethics on the Usage of Animals of Federal Rural University of Pernambuco (license number 054/2013, protocol number 23082.022567/2012).

The identification of specimens was based on external morphology using the available literature and diagnostic characteristics proposed by Snodgrass and Heller (1905), Garrick (1982) and Compagno (1984) (eg. origin, size and shape of the fins). For the Galapagos sharks, maturity stage was defined based on the size of individuals: adult males >205 cm and adult females >215 cm TL (Wetherbee et al., 1996), with all smaller individuals being considered juvenile. A chi-square goodness-of-fit test was performed to test for significant differences in sex ratio. Since Galapagos shark length data were normally distributed (Shapiro-Wilk test), a two-sample t-test assuming equal variances was used to compare the size of males and females. All statistical analyses were carried out using R software version 3.5.0 (R core team, 2019).

A general linear mixed model (GLMM) was used to analyze the effects of the presence of other *Carcharhinus* species and the distribution of catches (east vs. west) on the number of Galapagos sharks caught. The number of longline sets was included in the model as offset, while the expeditions were used as a random factor. The model analysis was performed in R with the package ‘lme4’ (Bates et al., 2014). All combinations of variables were tested using ‘dredge’ function from the package ’MuMIn’ (Barton, 2019) and the best model was selected according to the lowest AICc (corrected Akaike Information Criterion) (Burnham and Anderson, 2004).

2.3 Interviews

Interviews were conducted with the most experienced fishermen to assess the occurrence of sharks of the genus *Carcharhinus*, including *C. galapagensis*, and the fluctuation of their population at SPSPA during the period of the alleged disappearance. The interviews were conducted using semi-structured questionnaires that were applied both at SPSPA and at Natal port, the latter being the place where the boats leave for SPSPA expeditions and also where they unload their catches. A total of seven fishermen, who worked at SPSPA for at least three years prior and after the prohibition of elasmobranch fishing in 2012, were interviewed. Fishermen were mainly asked about periods of presence and absence as well as annual and interannual variability in the number of carcharhinid sharks. Images of the three most common carcharhinid species captured around SPSPA (*C. obscurus, C. galapagensis and C. falciformis*) were used to assess fishermen’s ability to discern these species.

A map of SPSPA was presented to the fishermen who were then asked to point out where carcharhinid sharks were commonly observed. This information was posteriorly used to perform a Kernel Density Estimation to create a point density raster with the Heatmap plugin in the Quantum Geographic Information System (QGIS) version 2.18.20 (QGIS Development Team, 2016). The map was used to identify the main shark sighting areas. Interview data were collected from October to November 2019 in accordance with ethical standards approved by the Ethics Committee of the Federal University of Pernambuco (process number: 3.627.356), and all fishermen gave their consent prior to their inclusion in the study.

2.4 Videos analysis

Video footages done by various researchers and fishermen were used to represent the presence of carcharhinid sharks after the ban on elasmobranch fishing, in 2012. Two videos recorded in both daylight and at night, the latter being registered during fishing activity, were reviewed in order to identify sharks to species level. Carcharhinid sharks were quantified in each video by considering the maximum number of sharks seen at any one time on screen.

3. Results

During the longline fishing surveys, 202 sharks were caught at SPSPA, including 189 carcharhinids. Of these, 142 were silky sharks, 37 were Galapagos sharks, eight were dusky sharks and two other specimens could not be identified to species level. Galapagos shark was the second most caught shark species, contributing to 18.3% of the total catch. Galapagos sharks were first captured by the monitoring program in 2012, after the ban on shark fishing, and since then they have been constantly present in catches.

Of the 37 Galapagos sharks, 15 were males (seven adults, seven juveniles and one not assessed), 21 were females (seven adults and 14 juveniles) and one was a juvenile specimen that was not sexed, resulting in a sex ratio of 1.0:1.3 (male:female). No significant difference was observed in sex ratio (Chi-square test: X^2= 0.714, *p*= 0.398). Their size ranged from 116.8 to 268.0 cm (Fig. 2), the latter being the maximum size recorded for a *Carcharhinus* species in the area. All the individuals larger than 235 cm were female, but there was no significant difference in the size frequency distribution of males and females (*p*=0.977). Average size of individuals was 189.3 cm, with most of them (60%) being juvenile. A juvenile female (138.0 cm) first caught in 2012 in the eastern side of the archipelago was recaptured after 11 months in the original tagging area, being 18.9 cm larger than its initial catch size. The growth rate of this shark was estimated to be 1.72 cm per month.

The best model to estimate the local relative abundance of Galapagos sharks, included the significant effects of two variables: the west side of the archipelago (β= 1.428, $p<0.01$) and the presence of silky sharks (β = -0.217, $p<0.01$) (Table 1), the latter having an inverse effect on the number of Galapagos sharks catches, which indicates a clear interspecific segregation.

Regarding the identification of shark images by the interviewed fishermen, three of them grouped Galapagos shark images correctly, while four of them neither identified nor grouped this species correctly. Only one fisherman grouped Galapagos shark together with dusky shark images. Regarding the occurrence of sharks, although the majority of the interviewed fishermen (71.4%, n= 5) recognized a great reduction in the number of sharks sighted around SPSPA, no fisherman reported not having seen carcharhinid sharks for a period greater than one year. Furthermore, all fishermen interviewed perceived a recent increase in the number of sharks at SPSPA. The period in which the number of sharks began to increase varied among fishermen's answers, with most of them (85.7%, n= 6) reporting to observe this increase after 2012, when the capture of elasmobranchs was banned. They also reported that carcharhinid sharks are mainly observed around the fishing boat after dusk, especially between November and April. The high concentration of sharks during this period was attributed to the presence of flying fish (*Cheilopogon cyanopterus*), which in turn is attracted to the fishing boat due to its lights (see Video A1, Supplementary Material). Two sites were identified as high sighting areas of carcharhinid species (Fig. 3), but it is important to note that these high shark sightings may be influenced by the greater fishing activity in these specific regions, although they do allow the comparison between these two regions. Comparison of the results obtained with the interviews showed a good coherence between fishermen's answers.

The videos recorded during the day and night a maximum number of 12 and six sharks, respectively (see Video A2, Supplementary Material); however, visibility was limited, especially at night, as the video was lit up only by the lights of the boat. All the sharks identified during daylight video footage were Galapagos sharks, while at night they were all silky sharks.

4. Discussion

Galapagos shark is nowadays the second most abundant shark species in the SPSPA, thus being often caught in experimental fishing, for tag and release, since 2012, which shows that this species is still present in the area, with its local population apparently recovering over time. Additionally, the high rate of juveniles currently observed around the area resembles the pattern reported by earlier visitors of SPSPA (Edwards and Lubbock, 1982). This pattern together with the presence of females in greater number and larger than males have also been observed for Galapagos sharks in Hawaiian Islands (Wetherbee et al., 1996) with a sex ratio (1.5:1.0, female:male) close to the one observed for Galapagos sharks at SPSPA (1.3:1.0).

The juvenile female recaptured in 2013 had a relatively fast growth rate, being five times higher than the rate reported for juvenile Galapagos sharks in the eastern Pacific Ocean (Kato and Carvallo, 1967), but it was similar to the estimates made for other immature species of *Carcharhinus* (Joung et al., 2008, 2004). One of the factors that can influence the variability in growth rate is the fishing exploitation. Increase in growth rates has been observed in different shark populations that were heavily exploited, suggesting a compensatory density-dependent response (Carlson and Baremore, 2003; Cassoff et al., 2007; Sminkey and Musick, 1995).

The positive effect of the west side of SPSPA on the number of Galapagos sharks indicates a distribution preference in the archipelago. Distribution preference was also observed in Hawaii and Malpelo island, showing that Galapagos sharks are not only resident around oceanic islands but also tend to exhibit a degree of site fidelity within these islands (Meyer et al., 2010; Soler et al., 2013). In addition, Galapagos and silky sharks apparently exhibit a clear spatial segregation around SPSPA. Interspecific segregation between Galapagos sharks and other carcharhinid species such as *C. plumbeus* Nardo, 1827 and *C. albimarginatus* Rüppell, 1837 has also been observed in some islands of the Pacific Ocean (Kato and Carvallo, 1967; Wass, 1971) and can be influenced by different factors such as interspecific competition and preferences for different physical factors of the environment (Papastamatiou et al., 2006; Wass, 1971; Wetherbee et al., 1996).

Galapagos sharks were not identified or correctly grouped by the majority of fishermen; however, these experienced professionals provided relevant information about the occurrence of carcharhinids, in general, which, according to Luiz and Edwards (Luiz and Edwards, 2011), had not been sighted in SPSPA since 1993. In addition, although the majority of fishermen attested a steep decline in the number of carcharhinid sharks at SPSPA, the maximum period of absence observed by them did not exceed one year, differing markedly from the period of more than a decade of non-visualization reported by previous authors (Feitoza et al., 2003; Luiz and Edwards, 2011; Vaske Jr et al., 2005). The discrepancy in shark occurrence reports between fishermen and some researchers may be a consequence of the diving location and methodology applied by previous studies, since sharks are known to display different behavioral responses when in contact with scuba divers, including avoidance behavior, where some sharks evade the area to avoid the encounter (Baronio, 2012; Cubero-Pardo et al., 2011).

Importantly, carcharhinid sharks were not only observed but also captured at SPSPA by these fishermen (and in the present study) over the period of alleged disappearance. Furthermore, although Galapagos sharks were first registered by the shark monitoring program in 2012, Soto et al. (2011) identified three Galapagos sharks captured between 2009-2010 at SPSPA by analyzing the morphology and meristic characteristics of their jaws (deposited at the Oceanographic Museum Univali: MOVI 45243, MOVI 45244 and MOVI 45245). Both the reports of fishermen and the identification of these three specimens confirmed that carcharhinids, including Galapagos sharks, were never absent from the SPSPA. The presence of carcharhinid sharks was also attested by an assessment of catch data from commercial fishery conducted at SPSPA, between 1998 and 2004 (Vaske Jr et al., 2008).

An increase in the abundance of carcharhinid sharks over the years was noticed by all fishermen interviewed, being this change mainly observed after the ban on elasmobranch fishing at SPSPA (SECIRM, 2012). Rapid recovery of carcharhinids after exploitation has already been observed in well-managed no-take marine protected areas, demonstrating that the absence of fishing pressure even in relatively small areas can effectively contribute to the recovery of shark populations (Speed et al., 2018), including the ones that have a limited intrinsic rebound potential, such as the Galapagos sharks (Smith et al., 1998). Additionally, species that are highly resident and exhibit habitat-use limitations tend to be either more vulnerable to anthropogenic pressures or more effectively protected by well managed marine protected areas (Barnett et al., 2012). It is likely, therefore, that the pattern of spatial use exhibited by Galapagos sharks have contributed both to their rapid population decline, during the period when elasmobranch fishing was permitted, as well as to their relatively fast recovery after the ban of this activity was enacted, a measure that was also boosted by the prohibition of retention of silky sharks, in the entire Atlantic, by ICCAT, in that same year.

The prevalence of carcharhinid sharks from November onwards has been associated to the high abundance of flying fish, which is known to reproduce in the SPSPA mainly between December and March (Lessa et al., 1999). The concentration of flying fish in this spawning ground is also known to attract other large pelagic predators such as tunas and wahoo (Vaske Jr et al., 2005, 2003). Silky shark was the main shark species observed at night, usually attempting to feed on flying fish that concentrates near the fishing boat due to its lights, whilst Galapagos sharks were more sighted during daylight, a pattern that has already been observed in the SPSPA (Edwards and Lubbock, 1982; Lubbock and Edwards, 1981).

While the ban on elasmobranch fishing was undoubtedly a very important step towards the conservation of elasmobranch diversity in the SPSPA and relevant to the recovery of Galapagos shark population, it is important to highlight that premature inferences of extinction are problematic, and can not only undermine potential conservation action (Collar, 1998) but also reduce public support (Del Monte-Luna et al., 2007). Moreover, although the high number of sightings of sharks in areas close to the archipelago may be influenced by fishing activity, the lack of observations by previous studies highlights the importance of applying different methodologies to avoid misleading inferences.

An alternative to improve data collection in these cases is to include the knowledge and experience of resource users, who are constantly in contact with the natural environment (Drew, 2005) and, therefore, can contribute with relevant information, including evidence of species occurrence and distribution, even in remote areas (Poizat and Baran, 1997). In SPSPA, the inclusion of fishermen’s knowledge about the occurrence of carcharhinid sharks in previous studies would have probably prevented the erroneous conclusion of Galapagos shark local extinction.

5. Conclusion

Even though carcharhinid sharks have faced a sharp decline in the SPSPA due to fishing exploitation, the results show that Galapagos shark had not been extinct in the area. They also evidence that not only the species is still present in the SPSPA, but it is becoming again very abundant in the region. The high vulnerability of Galapagos sharks to fishing pressure as well as their rapid recovery when in favourable conditions (e.g. ban on shark fishing) are probably influenced by their patterns of spatial use. Further research on the biology, ecology, behavior and movement patterns of Galapagos sharks will allow a better definition of appropriate strategies for their management and conservation.

Appendix A. Supplementary Material

Supplementary data related to this article can be found online at

References

Barnett, A., Abrantes, G., Seymour, J., Fitzpatrick, R., 2012. Residency and spatial use by reef sharks of an isolated seamount and its implications for conservation. PLoS One 7, 1–12. https://doi.org/10.1371/journal.pone.0036574

Baronio, M., 2012. The use of a micro remotely operated vehicle as a tool for studies of shark behaviour and diver impact. PhD thesis. South. Cross Univ. Lismore.

Barton, K., 2019. Package ‘ MuMIn ,’ R package version, 1.43.15. https://doi.org/https://cran.r-project.org/package=MuMIn

Bates, D., Mächler, M., Bolker, B.M., Walker, S.C., 2014. Fitting linear mixed-effects models using lme4. J. Stat. Softw. 67, 1–51. https://doi.org/10.18637/jss.v067.i01

Beebe, W., Tee-Van, J., 1941. Eastern Pacific expeditions of the New York Zoological Society. XXV. Fishes from the tropical eastern Pacific. Part 2. Sharks. Zoologica 26, 93–112.

Bezerra, N.P.A., Macena, B.C.L., Travassos, P., Afonso, P., Hazin, F.H.V., 2019. Evidence of site fidelity and deep diving behaviour of scalloped hammerhead shark (*Sphyrna lewini*) around the Saint Peter and Saint Paul Archipelago, in the equatorial Mid-Atlantic ridge. Mar. Freshw. Res. https://doi.org/10.1071/MF19029

Brasil, 2014. Lista Nacional Oficial de Espécies da Fauna Ameaçadas de Extinção - Peixes e Invertebrados Aquáticos. Portaria MMA nº 445, de 17 de dezembro de 2014, Diário Oficial da União. Brasília, DF.

Burnham, K.P., Anderson, D.R., 2004. Multimodel inference: Understanding AIC and BIC in model selection. Sociol. Methods Res. 33, 261–304. https://doi.org/10.1177/0049124104268644

Campos, T.F. da C., Virgens Neto, J. das, Srivastava, N.K., Petta, R.A., Hartmann, L.A., de Moraes, J.F.S., Mendes, L., Silveira, S.R.M., 2005. Arquipélago de São Pedro e São

Paulo - Soerguimento tectônico de rochas infracrustais no Oceano Atlântico, Sítios Geológicos e Paleontológicos do Brasil. SIGEP 002, UNB.

Carlson, J.K., Baremore, I.E., 2003. Changes in biological parameters of Atlantic sharpnose shark *Rhizoprionodon terraenovae* in the Gulf of Mexico: Evidence for density-dependent growth and maturity? Mar. Freshw. Res. 54, 227–234. https://doi.org/10.1071/MF02153

Cassoff, R.M., Campana, S.E., Myklevoll, S., 2007. Changes in baseline growth and maturation parameters of Northwest Atlantic porbeagle, *Lamna nasus*, following heavy exploitation. Can. J. Fish. Aquat. Sci. 64, 19–29. https://doi.org/10.1139/F06-167

Collar, N.J., 1998. Extinction by assumption; or, the Romeo Error on Cebu. Oryx 32, 239–244. https://doi.org/10.1046/j.1365-3008.1998.d01-51.x

Compagno, L.J. V, 1984. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 2 - Carcharhiniformes, Food and Agriculture Organization of the United Nations. Rome.

Corrigan, S., Delser, P.M., Eddy, C., Duffy, C., Yang, L., Li, C., Bazinet, A.L., Mona, S., Naylor, G.J.P., 2017. Historical introgression drives pervasive mitochondrial admixture between two species of pelagic sharks. Mol. Phylogenet. Evol. 110, 122–126. https://doi.org/10.1016/j.ympev.2017.03.011

Cubero-Pardo, P., Herrón, P., González-Pérez, F., 2011. Shark reactions to scuba divers in two marine protected areas of the Eastern Tropical Pacific. Aquat. Conserv. Mar. Freshw. Ecosyst. 21, 239–246. https://doi.org/10.1002/aqc.1189

Del Monte-Luna, P., Lluch-Belda, D., Serviere-Zaragoza, E., Carmona, R., Reyes-Bonilla, H., Aurioles-Gamboa, D., Castro-Aguirre, J.L., Próo, S.A.G. Del, Trujillo-Millán, O., Brook, B.W., 2007. Marine extinctions revisited. Fish Fish. 8, 107–122. https://doi.org/10.1111/j.1467-2679.2007.00240.x

Drew, J.A., 2005. Use of traditional ecological knowledge in marine conservation. Conserv. Biol. 19, 1286–1293. https://doi.org/10.1111/j.1523-1739.2005.00158.x

Duffy, C.A.J., 2016. Misidentification of *Carcharhinus galapagensis* (Snodgrass & Heller, 1905) in the Southwest Pacific Ocean. Zootaxa 4132, 97–106.

Edwards, A., Lubbock, R., 1983. Marine zoogeography of St Paul’s Rocks. J. Biogeogr. 10, 65–72.

Edwards, A.J., Lubbock, H.R., 1982. The Shark population of Saint Paul’s Rocks. Copeia 223–225. https://doi.org/10.2307/1444304

Feitoza, B.M., Rocha, L.A., Luiz-júnior, O.J., Floeter, S.R., Gasparini, J.L., 2003. Reef fishes of St. Paul’s Rocks: new records and notes on biology and zoogeography. J. Ichthyol. Aquat. Biol. 7, 61–82.

Fitzroy, R.N., 1839. Narrative of the Surveying Voyages of His Majesty’s Ships Adventure and Beagle Between the Years 1826 and 1836, describing their examination of the southern shores of South America, and the Beagle’s circumnavigation of the globe, volume II. Henry Colburn, London.

Garrick, J.A.F., 1982. Sharks of the Genus *Carcharhinus*, National Marine Fisheries Service, National Oceanographic and Atmospheric Administration (NOAA) Technical Report 445, 194.

Hazin, F.H.V., Vaske Jr, T., Oliveira, P.G., Macena, B.C.L., Carvalho, F., 2008. Occurrences of whale shark (*Rhincodon typus* Smith, 1828) in the Saint Peter and Saint Paul archipelago, Brazil. Brazilian J. Biol. 68, 385–389. https://doi.org/10.1590/s1519-69842008000200021

Hazin, F.H. V, Zagaglia, J.R., Broadhurst, M.K., Travassos, P.E.P., Bezerra, T.R.Q., 1998. Review of a small-scale pelagic longline fishery off northeastern Brazil. Mar. Fish. Rev. 60, 1–8.

Hobbs, J.-P.A., Choat, J.H., Robbins, W.D., Herwerden, L.V., Feary, D.A., Ayling, A.M., 2008. Unique fish assemblages at world's southernmost oceanic coral reefs, Elizabeth and Middleton Reefs, Tasman Sea, Australia. Coral Reefs 27, 15. https://doi.org/10.1007/s00338-007-0301-3

International Commission for the Conservation of Atlantic Tuna (ICCAT), 2011. Recommendation by ICCAT on the conservation of silky sharks caught in association with ICCAT fisheries. 11-08 BYC. Disponível em: <https://www.iccat.int/Documents/Recs/compendiopdf-e/2011-08-e.pdf>. Accesso: 15 Jan. 2020.

Joung, S.J., Chen, C.T., Lee, H.H., Liu, K.M., 2008. Age, growth, and reproduction of silky sharks, *Carcharhinus falciformis*, in northeastern Taiwan waters. Fish. Res. 90, 78–85. https://doi.org/10.1016/j.fishres.2007.09.025

Joung, S.J., Liao, Y.Y., Chen, C.T., 2004. Age and growth of sandbar shark, *Carcharhinus plumbeus*, in northeastern Taiwan waters. Fish. Res. 70, 83–96. https://doi.org/10.1016/j.fishres.2004.06.018

Kato, S., Carvallo, A.H., 1967. Shark tagging in the eastern Pacific Ocean, 1962-1965, in: Gilbert, P.W., Mathewson, R.F., Rall, J.P. (Eds.), Sharks, Skates and Rays. Johns Hopkins Press., Baltimore, pp. 93–109.

Kohler, N.E., Casey, J.G., Turner, P.A., 1998. NMFS cooperative shark tagging program, 1962-93: An atlas of shark tag and recapture data. Mar. Fish. Rev. 60, 1–87.

Kyne, P.M., Barreto, R., Carlson, J., Fernando, D., Fordham, S., Francis, M.P., Herman, K., Jabado, R.W., Liu, K.M., Pacoureau, N., Romanov, E., Sherley, R.B., 2019. *Carcharhinus galapagensis*, The IUCN Red List of Threatened Species 2019: e.T41736A2954286.

Lessa, R.P., Mafalda-Jr, P.O., Advíncula, R., Lucchesi, R.B., Bezerra-Jr, J.L., Vaske-Jr, T., Hellebrandt, D.S., 1999. Distribution and abundance of ichthyoneuston at seamounts and islands off North-Eastern Brazil. Arch. Fish. Mar. Res. 47, 239–252.

Lubbock, H.R., Edwards, A.J., 1981. The fishes of Saint Paul's Rocks. J. Fish Biol. 18, 135–157.

Luiz, O.J., Edwards, A.J., 2011. Extinction of a shark population in the Archipelago of Saint Paul's Rocks (equatorial Atlantic) inferred from the historical record. Biol. Conserv. 144, 2873–2881. https://doi.org/10.1016/j.biocon.2011.08.004

Macena, B.C.L., Hazin, F.H.V., 2016. Whale shark (*Rhincodon typus*) seasonal occurrence, abundance and demographic structure in the mid-equatorial Atlantic Ocean. PLoS One 11, 1–24. https://doi.org/10.1371/journal.pone.0164440

Meyer, C.G., Papastamatiou, Y.P., Holland, K.N., 2010. A multiple instrument approach to quantifying the movement patterns and habitat use of tiger (*Galeocerdo cuvier*) and Galapagos sharks (*Carcharhinus galapagensis*) at French Frigate Shoals, Hawaii. Mar. Biol. 157, 1857–1868. https://doi.org/10.1007/s00227-010-1457-x

Mucientes, G.R., Queiroz, N., Sousa, L.L., Tarroso, P., Sims, D.W., 2009. Sexual segregation of pelagic sharks and the potential threat from fisheries. Biol. Lett. 5, 156–159. https://doi.org/10.1098/rsbl.2008.0761

Oliveira, G.M., Evangelista, J.E. V, Ferreira, B.P., 1997. Considerações sobre a biologia e a pesca no Arquipélago de São Pedro e São Paulo, Boletin Técnico Científico do CEPENE 5, 31-52.

Paiva, M.P., Le Gall, J.-Y., 1975. Catches of tunas and tuna like fishes in the longline fishery areas off the cost of Brazil. Arq. Ciências do Mar 15, 1–18.

Papastamatiou, Y.P., Wetherbee, B.M., Lowe, C.G., Crow, G.L., 2006. Distribution and diet of four species of carcharhinid shark in the Hawaiian Islands : evidence for resource partitioning and competitive exclusion. Mar. Ecol. Prog. Ser. 320, 239–251.

Pinheiro, H.T., Mazzei, E., Moura, R.L., Amado-Filho, G.M., Carvalho-Filho, A., Braga, A.C., Costa, P.A.S., Ferreira, B.P., Ferreira, C.E.L., Floeter, S.R., Francini-Filho, R.B., Gasparini, J.L., Macieira, R.M., Martins, A.S., Olavo, G., Pimentel, C.R., Rocha, L.A., Sazima, I., Simon, T., Teixeira, J.B., Xavier, L.B., Joyeux, J.C., 2015. Fish biodiversity of the Vitória-Trindade seamount chain, southwestern Atlantic: an updated database. PLoS One 10, 1–17. https://doi.org/10.1371/journal.pone.0118180

Poizat, G., Baran, E., 1997. Fishermen's knowledge as background information in tropical fish ecology: A quantitative comparison with fish sampling results. Environ. Biol. Fishes 50, 435–449. https://doi.org/10.1023/A:1007317423165

QGIS Development Team, 2016. QGIS geographic information system, Open Source Geospatial Foundation Project.

R core team, 2019. R: A language and environment for statistical computing (Version 3.6.2), R Foundation for Statistical Computing: Vienna, Austria.

Secretaria da Comissão Interministerial para os Recursos do Mar (SECIRM), 2012. Proposta para ordenamento de atividade pesqueira. Marinha do Brasil, Brasília, DF.

Sminkey, T.R., Musick, J.A., 1995. Age and growth of the sandbar shark, *Carcharhinus plumbeus*, before and after population depletion. Copeia 1995, 871–883. https://doi.org/10.2307/1447035

Smith, H.G., Hardy, P., Leith, I.M., Spaull, V.W., Twelves, E.L., 1974. A biological survey of St. Paul's Rocks in the equatorial Atlantic Ocean. Biol. J. Linn. Soc. 6, 89–96.

Smith, S.E., Au, D.W., Show, C., 1998. Intrinsic rebound potentials of 26 species of Pacific sharks. Mar. Freshw. Res. 49, 663–678.

Snodgrass, R.E., Heller, E., 1905. Shore fishes of the Revillagigedo, Clipperton, Cocos and Galapagos Islands. Proc. Washingt. Acad. Sci. 6, 333–427.

Soler, G.A., Bessudo, S., Guzmán, A., 2013. Long term monitoring of pelagic fishes at Malpelo Island, Colombia. Lat. Am. J. Conserv. 3, 28–37.

Soto, J.M.R., 2001. Annotated systematic checklist and bibliography of the coastal and oceanic fauna of Brazil. I. Sharks. Mare Magnum 1, 51–120.

Soto, J.M.R., Macena, B., Hazin, F.H.V., 2011. Novas informações sobre a presença do tubarão-das-galápagos, *Carcharhinus galapagensis* (Snodgrass & Heller, 1905) (Carcharhiniformes, Carcharhinidae), no Arquipélago São Pedro e São Paulo, in: VII Reunião Da Sociedade Brasileira Para o Estudo Dos Elasmobrânquios - SBEEL. Anais. Rio Grande/RS, pp. 17–18.

Speed, C.W., Cappo, M., Meekan, M.G., 2018. Evidence for rapid recovery of shark populations within a coral reef marine protected area. Biol. Conserv. 220, 308–319. https://doi.org/10.1016/j.biocon.2018.01.010

Vaske Jr, T., Lessa, R.P., Nóbrega, M., Montealegre-Quijano, S., Marcante Santana, F., Bezerra Jr, J.L., 2005. A checklist of fishes from Saint Peter and Saint Paul Archipelago, Brazil. J. Appl. Ichthyol. 21, 75–79.

Vaske Jr, T., Lessa, R.P.T., Ribeiro, A.B.C., Nóbrega, M.F., Pereira, A. de A., Andrade, C.D.P., 2008. The commercial fishery of pelagic fishes off the Saint Peter and Saint Paul Archipelago, Brazil. Trop. Oceanogr. 36, 47–54.

Vaske Jr, T., Vooren, C.M., Lessa, R.P., 2003. Feeding strategy of yellowfin tuna (*Thunnus albacares*), and wahoo (*Acanthocybium solandri*) in the Saint Peter and Saint Paul Archipelago, Brazil. Bol. do Inst. Pesca 29, 173–181.

Wass, R.C., 1971. A comparative study of the life history, distribution and ecology of the sandbar shark and the gray reef shark in Hawaii. PhD dissertation, University of Hawaii, Honolulu.

Wetherbee, B.M., Crow, G.L., Lowe, C.G., 1996. Biology of the Galapagos shark, *Carcharhinus galapagensis*, in Hawai’i. Environ. Biol. Fishes 45, 299–310.

Table 1. Results of the best model for the number of Galapagos sharks captured (CCG). Treatment considered as fixed effects: Side of the archipelago (side), Presence of silky shark (FAL), Expedition (exp) and the logarithm of longline sets (loglongline). Stars indicates significance: **: $p \leq 0.01$, ***: $p \leq 0.001$.

Model	Factor	Estimate ± SE	P-value	
(CCG ~ side + FAL + (1 | exp) + offset (loglongline)	Intercept	-2.69163 ± 0.47861	1.87e-08	***
	sideWest	1.42872 ± 0.43746	0.00109	**
	FAL	-0.21756 ± 0.08146	0.00757	**

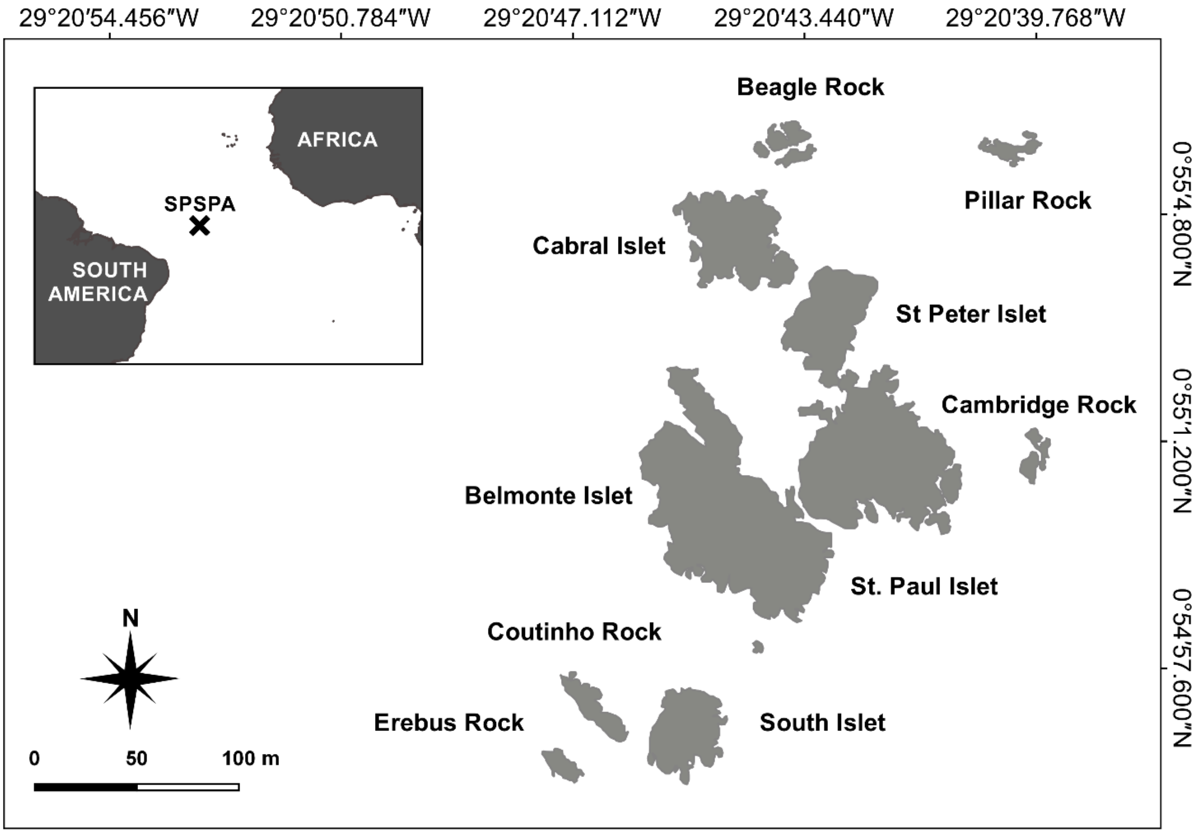


Figure 1. The Saint Peter and Saint Paul Archipelago (SPSPA) and its location in the Atlantic Ocean.

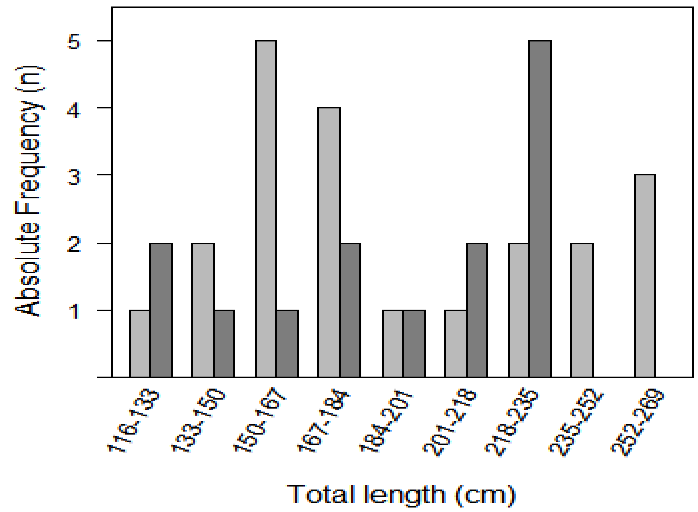


Figure 2. Absolute frequency distribution of total length of females (light gray, n= 21) and males (gray, n= 14) Galapagos sharks captured in Saint Peter and Saint Paul Archipelago between October 2010 and August 2019.

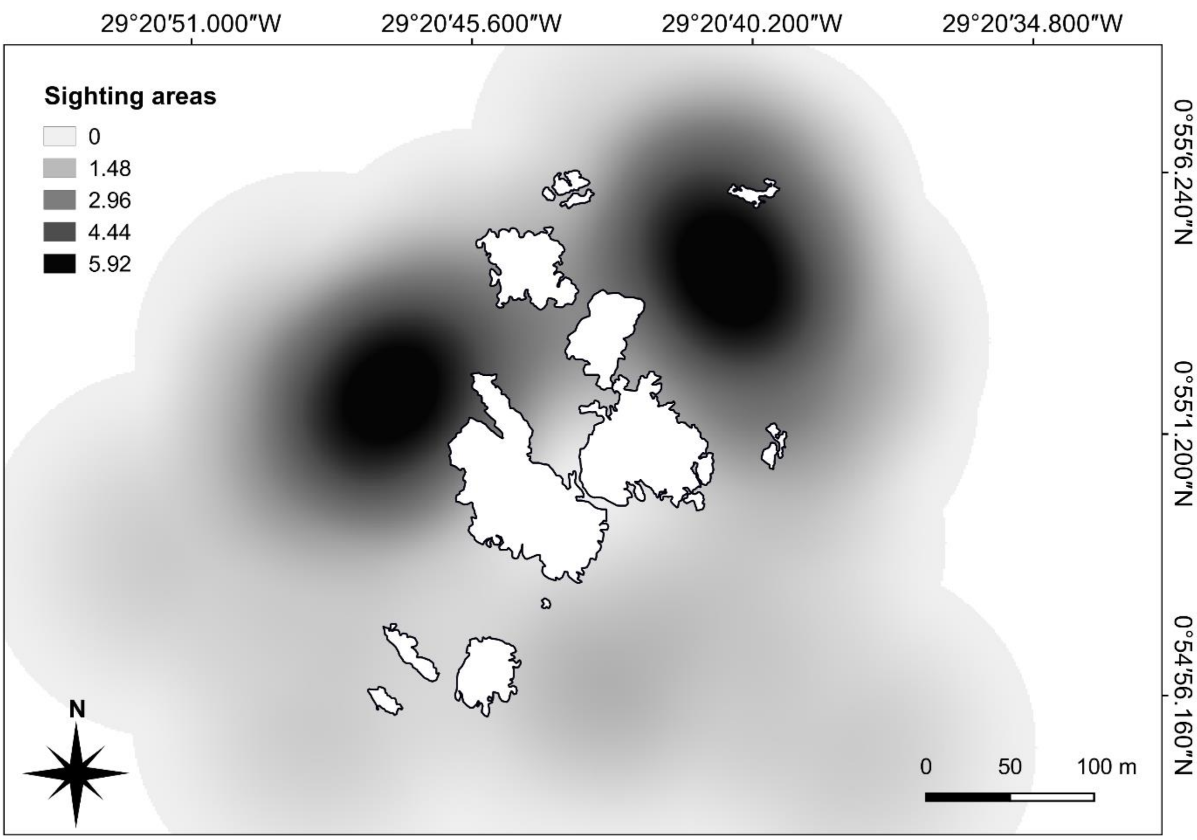


Figure 3. Shark sighting areas pointed out by fishermen of Saint Peter and Saint Paul Archipelago.

3.2. ARTIGO CIENTÍFICO II- SHORT AND LARGE-SCALE MOVEMENTS OF GALAPAGOS SHARKS (*CARCHARHINUS GALAPAGENSIS*) IN THE EQUATORIAL ATLANTIC OCEAN

Abstract

Despite the ecological importance of the Galapagos shark (*Carcharhinus galapagensis*), little is known about its spatial ecology across its range. In the Saint Peter and Saint Paul Archipelago (SPSPA), Galapagos sharks suffered a major decline after the beginning of fishing activity in the area, raising concern about the health of their local population and highlighting the need to assess their movement patterns and habitat use, in order to develop appropriate conservation measures. Here the results obtained from a pop-up satellite archival transmitting tag (PSAT) and a smart position or temperature transmitting tag (SPOT) deployed in two Galapagos sharks (one male and one female) are briefly reported. The two tagged sharks displayed different patterns of movement. While the male, tagged with a PSAT, showed a short displacement from the original tagging site during all period of tag deployment, the female specimen, tagged with a SPOT, undertook a long-distance movement towards the coast of Africa, the longest movement recorded for this species, so far. Despite the short displacement of one of the sharks, both individuals moved beyond the marine protected area, demonstrating the importance of having a broad knowledge of the spatial ecology of threatened species, to improve management and conservation measures.

Introduction

The Galapagos shark, *Carcharhinus galapagensis* (Snodgrass & Heller, 1905), is a large-bodied carcharhinid (up to 3-4 m, Compagno, 1984) with a circum-global distribution in both tropical and temperate waters, demonstrating a preference for oceanic islands of Pacific and Atlantic oceans (Beebe and Tee-Van, 1941; Compagno, 1984; Edwards and Lubbock, 1982; Hobbs et al., 2008; Wetherbee et al., 1996). Despite its wide distribution, Galapagos sharks are known for exhibiting limited horizontal displacement (Compagno, 1984; Wetherbee et al., 1996) and site fidelity, which suggest they are predominantly resident around oceanic islands (Meyer et al., 2010; Soler et al., 2013).

Galapagos sharks were once considered the most abundant shark species inhabiting the Saint Peter and Saint Paul archipelago (SPSPA), an isolated oceanic island known for the remarkable number of carcharhinid sharks (Edwards and Lubbock, 1982; Lubbock and Edwards, 1981). However, this scenario began to change when commercial tuna fishing started in the Atlantic (Hazin et al., 1998; Oliveira et al., 1997; Paiva and Le Gall, 1975), resulting in an important population decline for some pelagic sharks, particularly after the eighties. The observed declines were particularly severe for a few species, such as the Galapagos sharks, due to their habitat-use limitations and intrinsic biological characteristics (Compagno, 1984; Kohler et al., 1998; Wetherbee et al., 1996). Such a reduction led to the inclusion of Galapagos shark in the Brazilian official list of threatened species, being currently classified as Critically Endangered (decree MMA 445/2014) (Brasil, 2014). On the other hand, the population of Galapagos shark in the Pacific Ocean is apparently stable over its geographic range, being classified as Least Concern by the IUCN (International Union for Conservation of Nature) Red List of Threatened Species (Kyne et al., 2019).

The increasing concerns over the health of shark populations led to the ban on elasmobranch fishing at SPSPA, in 2012 (SECIRM, 2012). Furthermore, given the importance of SPSPA in the life cycle of different species, including species of high ecological and economic importance (Albuquerque et al., 2019; Macena and Hazin, 2016; Vaske Jr et al., 2003), two large marine protected areas (MPAs) were created in 2018 by decrees of the Brazilian Government to ensure the conservation of marine biodiversity in that remote area. The recently created Environmental Protected Area encompasses all the 200-miles Exclusive Economic Zone (EEZ) around SPSPA (407,052 km²) and the Marine Natural Monument covers about 47,263 km² of the territorial sea (Brasil, 2018), the latter being a strictly protected area.

Large MPAs, when properly enforced and managed, have the potential to maintain, protect and regenerate the health and diversity of marine ecosystems, benefiting even the highly mobile species, such as sharks, by reducing their interaction with fisheries (Koldewey et al., 2010; White et al., 2017). In SPSPA, although Galapagos sharks have demonstrated a rapid recovery after the ban on elasmobranch fishing (Queiroz, unpublished data), the lack of information on their spatial ecology makes it difficult to assess the degree to which this species is protected by these MPAs, highlighting the importance of understanding their movement patterns and environmental preferences. The knowledge of spatial ecology is essential to improve management and conservation initiatives (Heupel et al., 2004; Heupel and Simpfendorfer, 2005; Speed et al., 2010), and have been investigated by different techniques, including satellite-based telemetry, which has proven to be highly valuable in assessing the movement patterns and habitat use of sharks (Bezerra et al., 2019; Dolton et al., 2020; Meyer et al., 2010; Shipley et al., 2017; Simpfendorfer et al., 2011; Speed et al., 2010). In this work, two types of satellite transmitters were used to examine the spatial dynamics of Galapagos sharks caught and tagged in the proximity of SPSPA, providing the first data on large-scale movements of this species in the equatorial Atlantic Ocean.

Material and methods

Study area

SPSPA is a small and rocky archipelago located in the middle of the Atlantic Ocean (0°55’02"N; 29°20’42"W). It is under the influence of both the surface-flowing, westward, South Equatorial Current, and the eastward Equatorial Undercurrent, which provide biotic inputs from eastern and western Atlantic regions, respectively (Edwards and Lubbock 1983). Due to its strategic position, the SPSPA is known for playing an important role in the conservation of biodiversity, serving as reproduction and feeding grounds for several species, many of which are highly migratory (Albuquerque et al., 2019; Hazin et al., 2008; Macena and Hazin, 2016; Mendonça et al., 2018).

Shark catches and transmitter deployments

Sharks were caught using a small longline baited with fish and soaked for 2 hours. Once caught, sharks were brought on board the fishing boat, where all measuring and tagging procedures were conducted. All sharks were measured for total length (TL), were sexed and had a small piece of tissue collected and preserved in ethanol 96% for posterior genetic analysis as part of a parallel project. All the sharks tagged in the present study were analyzed using nuclear single nucleotide polymorphisms (SNPs) to confirm their species. The size of individuals was used to define maturity stage, with males and females being considered to be adult when they were greater than 205 and 215 cm TL, respectively (Wetherbee et al., 1996).

Two types of satellite transmitters manufactured by Wildlife Computers were used to understand the spatial dynamics of Galapagos sharks: Pop-up Satellite Archival Transmitting (PSAT) tags (n= 3, Model Mk10-PAT); and Smart Position or Temperature Transmitting (SPOT) tags (n= 2, Model SPOT5). Prior to PSAT attachment to the shark, a small hole (~3 mm diameter) was made on the anterior edge of its first dorsal fin, using an aluminum pole. PSAT tags were attached with a monofilament leader wrapped in heat-shrink tubing, which passed through the dorsal fin and was then closed using silver-metal crimps. SPOT tags were attached near the tip of the first dorsal fin by using a template to make three small holes (~3 mm diameter) through which threaded nylon rods passed, being secured on the opposite side of the fin with washers and lock nuts. After the transmitters were attached, the hook was removed, and the sharks were released. The entire handling process took less than seven minutes, in all cases. All the procedures were approved by the Animal Ethics Committee of the Federal Rural University of Pernambuco (license number 054/2013, protocol number 23082.022567/2012).

Satellite transmitters

All PSAT tags were programmed to collect and store temperature (0.05°C resolution), depth (0.5 m resolution) and light level every second for 90 days. PSATs were also programmed to generate and transmit profiles of depth and temperature (PDT). After the deployment period, the tags detached from the sharks and floated to the surface, starting the transmission of archived data to the Argos satellite system. SPOT tags provide geographic positions whenever the dry/wet sensor breaks the water surface and the tags successfully uplink to the Argos satellite array. Argos positions are classified, according to their associated error, in seven location classes (LC): LC3, <250 m; LC2, 250-500 m; LC1, 500-1.500 m; LC0, >1.500 m and Classes A, B and Z, with no estimates provided.

Data treatment and statistical analysis

Estimates of the tracks performed by the Galapagos sharks tagged with PSATs were based on the light level using a Hidden Markov Model (HMM) built by the manufacturer's proprietary software (WC-GPE3, Wildlife Computers). The HMM incorporates bathymetry, swimming speed of the animal and environmental variables to estimate the most likely tracks. The swimming speed used in the model was 1.0 m s^{-1}, close to the speed used in a previous satellite telemetry study on Galapagos sharks (Meyer et al., 2010). Daily positions with estimates of the most likely tracking were then refined with the Kalman filter state-space model (Nielsen and Sibert, 2007), using the 'kftrack' package in R (R core team, 2019). PDTs were plotted using the package 'ggplot2' (Wickham, 2009) to allow the visualization of depth and temperature preferences. For the Galapagos sharks tagged with SPOT tags, when multiple low-quality positions (LC worse than "1") were received within a 12 h period, an average position was calculated to minimize possible location errors, following Heithaus et al. (2007). The average positions were calculated based on the centroid of the minimum convex polygon and plotted using QGIS version 2.18.20 (QGIS Development Team, 2016). The most likely track was then mapped, to characterize individual movement patterns.

Results and discussion

Three male and two female Galapagos sharks were tagged in August 2019 (Tab 1). All the five individuals had their species confirmed by genetic analysis. Two PSATs and one SPOT failed to transmit to the Argos system. The remaining tags, one PSAT (GAL1) and one SPOT (GAL5), provided few location estimates. GAL1 released prematurely after 59 days and provided only incomplete data from the last eight days of deployment. GAL5 transmitted 13 positional fixes, 12 of them detected between the first nine days of tag deployment and one detected after 168 days. The detections were infrequent and of low-quality, and no reliable positions were obtained; therefore, only four average positions were selected. The sparsity and low-quality of SPOT tag detections are probably related to the preference of Galapagos sharks for non-surface waters, as reported for this species in Hawaii (Meyer et al., 2010).

The PDT data showed that GAL1 swimming depth and water temperature ranged from 0 to 304 m and from 29.2°C to 11.0°C, respectively, with the shark performing dives below the thermocline zone (>150 m) during all the period of PDT data acquisition (Fig. 1).

Table 1. Summary information for Galapagos sharks tagged with PSAT and SPOT tags in the Saint Peter and Saint Paul Archipelago.

ID	PTT number	Deployment date	Tag type	Sex/ maturity stage	Total length (cm)	Deployment duration (days)	Max. displacement (km)
GAL1	62893	07Aug2019	PSAT	Male, mature	223	59	74.9
GAL2	62892	07Aug2019	PSAT	Male, juvenile	195	Failed	Failed
GAL3	129564	08Aug2019	PSAT	Male, mature	235	Failed	Failed
GAL4	60860	08Aug2019	SPOT	Female, mature	256	Failed	Failed
GAL5	60859	10Aug2019	SPOT	Female, mature	220	240	4.354

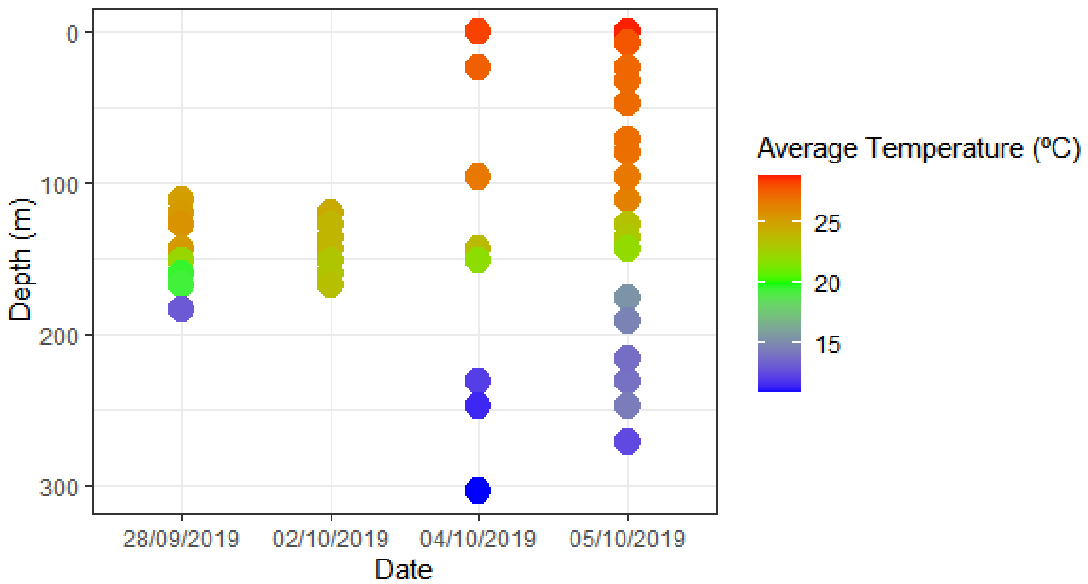


Figure 1. Profile of depth and temperature (PDT) recorded for Galapagos shark around the Saint Peter and Saint Paul Archipelago.

A similar study in Hawaii demonstrated that Galapagos sharks occasionally dive to depths below the thermocline, to a maximum of 680 m and water temperature of 7°C (Meyer et al., 2010). Even though the analysis of dive profiles may provide relevant information on vertical movements (Queiroz et al., 2017), problems with the transmission of data by this PSAT tag made it difficult to clearly evaluate diving behavior, as well as depth and temperature preferences of Galapagos sharks around the SPSPA.

The Kalman-filtered track of GAL1 indicated that the individual moved up to 74.9 km northward from the SPSPA, remaining within the Environmental Protected Area throughout the period of tag deployment (59 days) (Fig. 2). Galapagos sharks are known for their limited spatial distribution, which has been observed in other regions of the Atlantic and Pacific Oceans (Kohler et al., 1998; Lowe et al., 2006; Meyer et al., 2010; Papastamatiou et al., 2015). For example, Galapagos sharks tagged off Bermuda were mostly recaptured within 100 km of their tagging sites (Kohler et al., 1998); whereas in Hawaii, multi-tagged Galapagos sharks demonstrated a smaller displacement, with sharks moving less than 30 km away from their original tagging localities, suggesting this species is mostly resident around oceanic islands (Meyer et al., 2010).

GAL5, on the other hand, showed a remarkably different pattern of displacement than commonly observed for this species. The female of 220 cm total length moved 219.6 km westward from its original tagging location during the first eight days of tag deployment and then returned towards the archipelago. After 168 days, however, GAL5 was detected once more, but this time in the coast of Africa, 4.354 km from the SPSPA (Fig. 2). Although this is the longest movement recorded for this species, there have been reports of Galapagos sharks moving for long distances in open ocean, as well. A female Galapagos shark (181 cm) tagged in Socorro Island, Mexico, for instance, was detected by the acoustic receivers of Galapagos Archipelago, Ecuador, having moved at least 3.200 km through the Pacific Ocean (Lara-lizardi et al., 2020). A long displacement was also observed in the Atlantic Ocean, with a male Galapagos shark tagged off Bermuda being recaptured near the coast of Suriname, 2,859 km from its tagging site (Kohler et al., 1998). Furthermore, genetic assessment of Galapagos shark populations identified a connectivity between the eastern and western Pacific stocks, suggesting that some individuals may migrate long distances across that Ocean (Pazmiño et al., 2018). In addition, long-distance movements in the open ocean towards the coast of Africa have already been recorded for other shark species, such as the tiger and the white shark; and although these long movements seem to be associated with reproduction and feeding-related events, the reasons for these migrations are still unclear (Afonso et al., 2017; Bonfil et al., 2005; Heithaus et al., 2007).

Even though GAL5 have undergone long-distance movements, previous studies using conventional and acoustic tags have suggested that Galapagos sharks remain for long periods around SPSPA (Hazin et al., 2018). This limited distribution is probably the reason for the rapid recovery of their population in the archipelago that has been observed since the ban on elasmobranch fishing, in 2012 (Queiroz, unpublished data). Since highly resident sharks tend to be more successfully protected by marine protected areas (Barnett et al., 2012), the MPA around SPSPA, if well-managed, may contribute significantly for the protection of the local population of Galapagos sharks.

Long-distance movements, however, may expose Galapagos sharks to fishing pressure as they leave the protected waters of SPSPA. Furthermore, despite the short displacement of GAL1, this individual also exceeded the area where elasmobranchs are protected, highlighting the importance of having a broad knowledge of the spatial ecology of threatened species in developing conservation and management measures (Heupel et al., 2004; Heupel and Simpfendorfer, 2005; Speed et al., 2010). It also highlights the necessity of an efficient monitoring of large marine protected areas, especially remote ones (Jones and De Santo, 2016; Soares and Lucas, 2018), such as SPSPA, otherwise the conservation objectives may be seriously compromised.

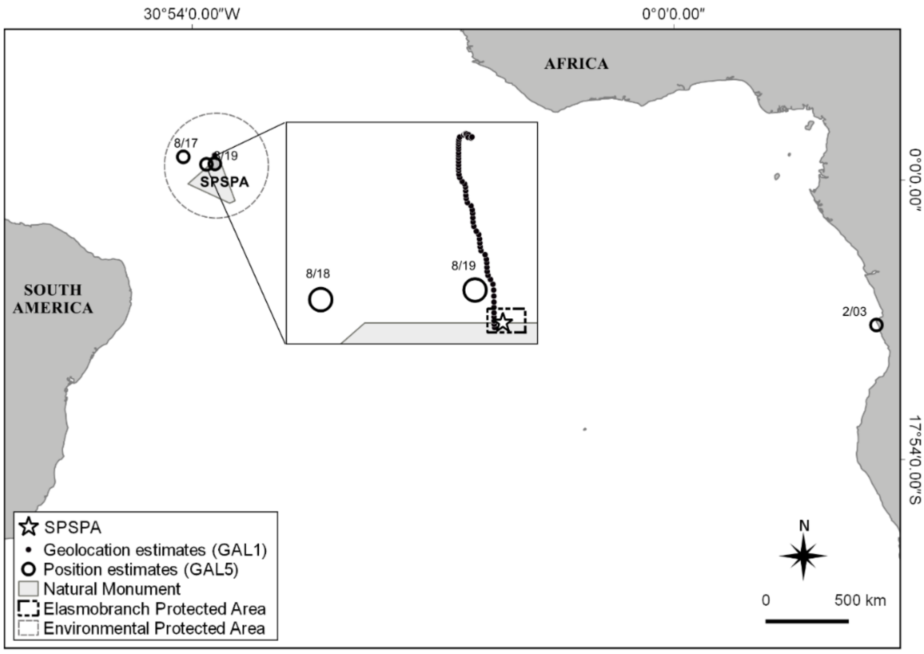


Figure 2. Position estimates of Galapagos sharks equipped with dorsal fin mounted SPOT (GAL5) and PSAT (GAL1) tags at Saint Peter and Saint Paul Archipelago, and the boundaries of marine protected areas.

Although the sample size was low (n= 2), these preliminary results provide the first insights into long-distance movements of Galapagos sharks monitored by satellite tags in the equatorial Atlantic Ocean. However, the degree to which this species can travel outside the protected area, becoming, thus, vulnerable to fishing, remains unclear. Therefore, a more comprehensive knowledge of the movements and habitat use of the Galapagos sharks in the SPSPA is essential to ensure the survival of the species. Despite the limitations of satellite tags, such as the need to break the water surface long enough to establish communication with satellites (e.g. SPOT tags) and the significant errors associated with light-based geolocation estimates (e.g. PSAT tags) (Braun et al., 2018, 2015), these electronic tags do have the potential to reveal details of site fidelity, diving behaviors, depth and temperature preference of shark species (Bezerra et al., 2019; Dolton et al., 2020; Shipley et al., 2017). Thus, further studies on spatial ecology of Galapagos sharks should be developed, ideally coupling information from satellite tags with passive telemetry to improve knowledge of fine-scale spatiotemporal distribution of this important apex predator (Hussey et al., 2015).

References

Afonso, A.S., Garla, R., Hazin, F.H.V., 2017. Tiger sharks can connect equatorial habitats and fisheries across the Atlantic Ocean basin. PLoS One 12, 1–15. https://doi.org/10.1371/journal.pone.0184763

Albuquerque, F. V., Navia, A.F., Vaske Jr, T., Crespo, O., Hazin, F.H.V., 2019. Trophic ecology of large pelagic fish in the Saint Peter and Saint Paul Archipelago, Brazil. Mar. Freshw. Res. 70, 1402–1418. https://doi.org/10.1071/MF18352

Barnett, A., Abrantes, G., Seymour, J., Fitzpatrick, R., 2012. Residency and spatial use by reef sharks of an isolated seamount and its implications for conservation. PLoS One 7, 1–12. https://doi.org/10.1371/journal.pone.0036574

Beebe, W., Tee-Van, J., 1941. Eastern Pacific expeditions of the New York Zoological Society. XXV. Fishes from the tropical eastern Pacific. Part 2. Sharks. Zoologica 26, 93–112.

Bezerra, N.P.A., Macena, B.C.L., Travassos, P., Afonso, P., Hazin, F.H.V., 2019. Evidence of site fidelity and deep diving behaviour of scalloped hammerhead shark (*Sphyrna lewini*) around the Saint Peter and Saint Paul Archipelago, in the equatorial Mid-Atlantic ridge. Mar. Freshw. Res. https://doi.org/10.1071/MF19029

Bonfil, R., Meÿer, M., Scholl, M.C., Johnson, R., O'Brien, S., Oosthuizen, H., Swanson, S., Kotze, D., Paterson, M., 2005. Transoceanic migration, spatial dynamics, and population linkages of white sharks. Science. 310, 100–103. https://doi.org/10.1126/science.1114898

Brasil, 2018. Decreto n. 9.313, de 19 de março de 2018. Cria a Área de Proteção Ambiental do Arquipélago de São Pedro e São Paulo e o Monumento Natural do Arquipélago de São Pedro e São Paulo., Diário Oficial da União.

Brasil, 2014. Lista Nacional Oficial de Espécies da Fauna Ameaçadas de Extinção - Peixes e Invertebrados Aquáticos. Portaria MMA nº 445, de 17 de dezembro de 2014, Diário Oficial da União. Brasília, DF.

Braun, C.D., Skomal, G.B., Thorrold, S.R., 2018. Integrating Archival Tag Data and a High-Resolution Oceanographic Model to Estimate Basking Shark (*Cetorhinus maximus*) Movements in the Western Atlantic. Front. Mar. Sci. 5, 1–14. https://doi.org/10.3389/fmars.2018.00025

Braun, C.D., Skomal, G.B., Thorrold, S.R., Berumen, M.L., 2015. Movements of the reef manta ray (*Manta alfredi*) in the Red Sea using satellite and acoustic telemetry. Mar. Biol. 162, 2351–2362. https://doi.org/10.1007/s00227-015-2760-3

Compagno, L.J. V, 1984. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 2 - Carcharhiniformes, Food and Agriculture Organization of the United Nations. Rome.

Dolton, H., Gell, F., Hall, J., Hall, G., Hawkes, L., Witt, M., 2020. Assessing the importance of Isle of Man waters for the basking shark *Cetorhinus maximus*. Endanger. Species Res. 41, 209–223. https://doi.org/10.3354/esr01018

Edwards, A.J., Lubbock, H.R., 1982. The Shark population of Saint Paul's Rocks. Copeia 223–225. https://doi.org/10.2307/1444304

Hays, G.C., Broderick, A.C., Glen, F., Godley, B.J., Nichols, W.J., 2001. The movements and submergence behaviour of male green turtles at Ascension Island. Mar. Biol. 139, 395–399. https://doi.org/10.1007/s002270100580

Hazin, F.H.V., Rocha, B.C.L.M., Viana, D., Lana, F., Oliveira, L., Bezerra, N.P.A., Mendonça, S.A., 2018. Elasmosbrânquios do Arquipélago de São Pedro e São Paulo, in: Oliveira, J., Viana, D., Souza, M. (Eds.), Arquipélago de São Pedro e São Paulo: 20 Anos de Pesquisa. Recife, pp. 143–159.

Hazin, F.H.V., Vaske Jr, T., Oliveira, P.G., Macena, B.C.L., Carvalho, F., 2008. Occurrences of whale shark (*Rhincodon typus* Smith, 1828) in the Saint Peter and Saint Paul archipelago, Brazil. Brazilian J. Biol. 68, 385–389. https://doi.org/10.1590/s1519-69842008000200021

Hazin, F.H. V, Zagaglia, J.R., Broadhurst, M.K., Travassos, P.E.P., Bezerra, T.R.Q., 1998. Review of a small-scale pelagic longline fishery off northeastern Brazil. Mar. Fish. Rev. 60, 1–8.

Heithaus, M.R., Wirsing, A.J., Dill, L.M., Heithaus, L.I., 2007. Long-term movements of tiger sharks satellite-tagged in Shark Bay, Western Australia. Mar. Biol. 151, 1455–1461. https://doi.org/10.1007/s00227-006-0583-y

Heupel, M.R., Simpfendorfer, C.A., 2005. Using acoustic monitoring to evaluate MPAs for shark nursery areas: The importance of long-term data. Mar. Technol. Soc. J. 39, 10–18. https://doi.org/10.4031/002533205787521749

Heupel, M.R., Simpfendorfer, C.A., Hueter, R.E., 2004. Estimation of shark home ranges using passive monitoring techniques. Environ. Biol. Fishes 71, 135–142. https://doi.org/10.1023/B

Hobbs, J.-P.A., Choat, J.H., Robbins, W.D., Herwerden, L.V., Feary, D.A., Ayling, A.M., 2008. Unique fish assemblages at world's southernmost oceanic coral reefs, Elizabeth and Middleton Reefs, Tasman Sea, Australia. Coral Reefs 27, 15. https://doi.org/10.1007/s00338-007-0301-3

Hussey, N.E., Kessel, S.T., Aarestrup, K., Cooke, S.J., Cowley, P.D., Fisk, A.T., Harcourt, R.G., Holland, K.N., Iverson, S.J., Kocik, J.F., Flemming, J.E.M., Whoriskey, F.G., 2015. Aquatic animal telemetry: A panoramic window into the underwater world. Science. 348, 1255642. https://doi.org/10.1126/science.1255642

Jones, P.J.S., De Santo, E.M., 2016. Viewpoint – Is the race for remote, very large marine protected areas (VLMPAs) taking us down the wrong track? Mar. Policy 73, 231–234. https://doi.org/10.1016/j.marpol.2016.08.015

Kohler, N.E., Casey, J.G., Turner, P.A., 1998. NMFS cooperative shark tagging program, 1962-93: An atlas of shark tag and recapture data. Mar. Fish. Rev. 60, 1–87.

Koldewey, H.J., Curnick, D., Harding, S., Harrison, L.R., Gollock, M., 2010. Potential benefits to fisheries and biodiversity of the Chagos Archipelago/British Indian Ocean Territory as a no-take marine reserve. Mar. Pollut. Bull. 60, 1906–1915. https://doi.org/10.1016/j.marpolbul.2010.10.002

Kyne, P.M., Barreto, R., Carlson, J., Fernando, D., Fordham, S., Francis, M.P., Herman, K., Jabado, R.W., Liu, K.M., Pacoureau, N., Romanov, E., Sherley, R.B., 2019. *Carcharhinus galapagensis*, The IUCN Red List of Threatened Species 2019: e.T41736A2954286.

Lara-lizardi, F., Hoyos-padilla, M., Hearn, A., Klimley, A.P., Galván-Magaña, F., Arauz, R., Bessudo, S., Castro, E., Clua, E., Espinoza, E., Fischer, C., Peñaherrera-Palma, C., Steiner, T., Ketchum, J.T., 2020. Shark movements in the Revillagigedo Archipelago and connectivity with the Eastern Tropical Pacific. bioRxiv. https://doi.org/doi: https://doi.org/10.1101/2020.03.02.972844

Lowe, C.G., Wetherbee, B.M., Meyer, C.G., 2006. Using acoustic telemetry monitoring techniques to quantify movement patterns and site fidelity of sharks and giant trevally around French Frigate Shoals and Midway Atoll. Atoll Res Bull 543, 281–303.

Lubbock, H.R., Edwards, A.J., 1981. The fishes of Saint Paul's Rocks. J. Fish Biol. 18, 135–157.

Macena, B.C.L., Hazin, F.H.V., 2016. Whale shark (*Rhincodon typus*) seasonal occurrence, abundance and demographic structure in the mid-equatorial Atlantic Ocean. PLoS One 11, 1–24. https://doi.org/10.1371/journal.pone.0164440

Mendonça, S.A., Macena, B.C.L., Afonso, A.S., Hazin, F.H.V., 2018. Seasonal aggregation and diel activity by the sicklefin devil ray Mobula tarapacana off a small, equatorial outcrop of the Mid-Atlantic Ridge. J. Fish Biol. 93, 1121–1129. https://doi.org/10.1111/jfb.13829

Meyer, C.G., Papastamatiou, Y.P., Holland, K.N., 2010. A multiple instrument approach to quantifying the movement patterns and habitat use of tiger (*Galeocerdo cuvier*) and Galapagos sharks (*Carcharhinus galapagensis*) at French Frigate Shoals, Hawaii. Mar. Biol. 157, 1857–1868. https://doi.org/10.1007/s00227-010-1457-x

Nielsen, A., Sibert, J.R., 2007. State-space model for light-based tracking of marine animals. Can. J. Fish. Aquat. Sci. 64, 1055–1068. https://doi.org/10.1139/F07-064

Oliveira, G.M., Evangelista, J.E. V, Ferreira, B.P., 1997. Considerações sobre a biologia e a pesca no Arquipélago de São Pedro e São Paulo, Boletin Técnico Científico do CEPENE 5, 31-52.

Paiva, M.P., Le Gall, J.-Y., 1975. Catches of tunas and tuna like fishes in the longline fishery areas off the cost of Brazil. Arq. Ciências do Mar 15, 1–18.

Papastamatiou, Y.P., Meyer, C.G., Kosaki, R.K., Wallsgrove, N.J., Popp, B.N., 2015. Movements and foraging of predators associated with mesophotic coral reefs and their potential for linking ecological habitats. Mar. Ecol. Prog. Ser. 521, 155–170. https://doi.org/10.3354/meps11110

Pazmiño, D.A., Maes, G.E., Green, M.E., Simpfendorfer, C.A., Hoyos-Padilla, E.M., Duffy, C.J.A., Meyer, C.G., Kerwath, S.E., Salinas-De-León, P., Van Herwerden, L., 2018. Strong trans-Pacific break and local conservation units in the Galapagos shark (*Carcharhinus galapagensis*) revealed by genome-wide cytonuclear markers. Heredity (Edinb). 120, 407–421. https://doi.org/10.1038/s41437-017-0025-2

QGIS Development Team, 2016. QGIS geographic information system, Open Source Geospatial Foundation Project.

Queiroz, N., Vila-Pouca, C., Couto, A., Southall, E.J., Mucientes, G., Humphries, N.E., Sims, D.W., 2017. Convergent foraging tactics of marine predators with different feeding strategies across heterogeneous ocean environments. Front. Mar. Sci. 4, 1–15. https://doi.org/10.3389/fmars.2017.00239

R core team, 2019. R: A language and environment for statistical computing (Version 3.6.2), R Foundation for Statistical Computing: Vienna, Austria.

Shipley, O.N., Howey, L.A., Tolentino, E.R., Jordan, L.K.B., Ruppert, J.L.W., Brooks, E.J., 2017. Horizontal and vertical movements of Caribbean reef sharks (*Carcharhinus perezi*): conservation implications of limited migration in a marine sanctuary. R. Soc. Open Sci. 4. https://doi.org/10.1098/rsos.160611

Simpfendorfer, C.A., Heupel, M.R., White, W.T., Dulvy, N.K., 2011. The importance of research and public opinion to conservation management of sharks and rays: a synthesis. Mar. Freshw. Res. 62, 518–527. https://doi.org/10.1071/MF11086

Soares, M. de O., Lucas, C.C., 2018. Towards large and remote protected areas in the South Atlantic Ocean: St. Peter and St. Paul´s Archipelago and the Vitória-Trindade Seamount Chain. Mar. Policy 93, 101–103. https://doi.org/10.1016/j.marpol.2018.04.004

Soler, G.A., Bessudo, S., Guzmán, A., 2013. Long term monitoring of pelagic fishes at Malpelo Island, Colombia. Lat. Am. J. Conserv. 3, 28–37.

Speed, C.W., Field, I.C., Meekan, M.G., Bradshaw, C.J.A., 2010. Complexities of coastal shark movements and their implications for management. Mar. Ecol. Prog. Ser. 408, 275–293. https://doi.org/10.3354/meps08581

Vaske Jr, T., Vooren, C.M., Lessa, R.P., 2003. Feeding strategy of yellowfin tuna (*Thunnus albacares*), and wahoo (*Acanthocybium solandri*) in the Saint Peter and Saint Paul Archipelago, Brazil. Bol. do Inst. Pesca 29, 173–181.

Wetherbee, B.M., Crow, G.L., Lowe, C.G., 1996. Biology of the Galapagos shark, *Carcharhinus galapagensis*, in Hawai'i. Environ. Biol. Fishes 45, 299–310.

White, T.D., Carlisle, A.B., Kroodsma, D.A., Block, B.A., Casagrandi, R., De Leo, G.A., Gatto, M., Micheli, F., McCauley, D.J., 2017. Assessing the effectiveness of a large marine protected area for reef shark conservation. Biol. Conserv. 207, 64–71. https://doi.org/10.1016/j.biocon.2017.01.009

Wickham, H., 2009. ggplot2: elegant graphics for data analysis. 1st ed. New York Springer. URL https://cran.r-project.org/package=ggplot2

4 CONSIDERAÇÕES FINAIS

No Brasil, a proporção de elasmobrânquios ameaçados tem superado a taxa global, com a família Carcharhinidae sendo considerada uma das mais ameaçadas no país. Entre os membros dessa família se encontra o tubarão de Galápagos, atualmente listado como criticamente ameaçado de extinção, segundo a Portaria do Ministério do Meio Ambiente n° 445. Apesar dessa condição, pouco são os estudos realizados com relação aos seus padrões de movimentação e uso de habitat em áreas de ocorrência da espécie, especialmente no Oceano Atlântico, como é o caso do ASPSP, onde a espécie chegou a ser considerada como localmente extinta. Diante disso, o estudo focou em comprovar a ocorrência do tubarão de Galápagos no ASPSP e compreender os seus padrões de movimentação a partir de monitoramento via satélite.

A utilização do conhecimento ecológico dos pescadores, dados de capturas e vídeos feitos durante as expedições ao arquipélago permitiram comprovar que o tubarão de Galápagos não apenas continua presente no ASPSP, como está se recuperando rapidamente após a proibição da pesca de elasmobrânquios, em 2012. Apesar dos benefícios associados à proibição da pesca, o monitoramento eletrônico via satélite demonstrou que os indivíduos marcados no ASPSP se afastaram dessas áreas de proteção, ficando vulneráveis à pressão pesqueira em outras regiões oceânicas. Essa foi a primeira inciativa para compreende a ecologia espacial do tubarão de Galápagos no Atlântico Equatorial por meio de telemetria via satélite e ressalta a importância do conhecimento sobre a ecologia espacial das espécies para a definição de estratégias adequadas de manejo e conservação.

Apesar do grande potencial dos transmissores via satélite no desenvolvimento de pesquisas sobe uso de habitat e padrões de movimentação dos elasmobrânquios, essas tecnologias apresentam algumas limitações. No caso do tubarão de Galápagos, que não se orienta muito pela superfície, como observado por outros estudos, a eficiência das marcas SPOT fica comprometida, visto que esses transmissores precisam permanecer com a antena fora da água por tempo suficiente para estabelecer comunicação com os satélites. Futuros estudos que visem ampliar o conhecimento sobre a ecologia espacial da espécie podem potencializar o monitoramento da movimentação desses animais, associando os transmissores via satélite com os transmissores acústicos, contribuindo assim com uma maior compreensão sobre a distribuição espaço-temporal dos tubarões de Galápagos.

REFERÊNCIAS

AFONSO, A. S.; GARLA, R.; HAZIN, F. H. V. Tiger sharks can connect equatorial habitats and fisheries across the Atlantic Ocean basin. **PLoS ONE**, v. 12, n. 9, p. 1–15, 2017.

AGARDY, T. Effects of fisheries on marine ecosystems: A conservationist's perspective. **ICES Journal of Marine Science**, v. 57, n. 3, p. 761–765, 2000.

ALBUQUERQUE, F. V. et al. Trophic ecology of large pelagic fish in the Saint Peter and Saint Paul Archipelago, Brazil. **Marine and Freshwater Research**, v. 70, n. 10, p. 1402–1418, 2019.

ANTONELIS, G. A. et al. Hawaiian monk seal (*Monachus schauinslandi*): status and conservation issues. **Atoll Research Bulletin**, v. 543, p. 75–101, 2006.

BARNETT, A. et al. Residency and spatial use by reef sharks of an isolated seamount and its implications for conservation. **PLoS ONE**, v. 7, n. 5, p. 1–12, 2012.

BARONIO, M. **The use of a micro remotely operated vehicle as a tool for studies of shark behaviour and diver impact.** 2012.

BARREIROS, J. P.; GADIG, O. B. **Catálago ilustrado dos tubarões e raias dos açores**, 2011.

BARRETO, R. R. et al. Rethinking use and trade of pelagic sharks from Brazil. **Marine Policy**, v. 85, p. 114–122, 2017.

BARTON, K. **Package ' MuMIn 'R package version, 1.43.15**. Disponível em: <https://cran.r-project.org/package=MuMIn>.

BATES, D. et al. Fitting linear mixed-effects models using lme4. **Journal of Statistical Software**, v. 67, n. 1, p. 1–51, 2014.
BAUM, J. K.; MYERS, R. A. Shifting baselines and the decline of pelagic sharks in the Gulf of Mexico. **Ecology Letters**, v. 7, p. 135–145, 2004.

BEEBE, W.; TEE-VAN, J. Eastern Pacific expeditions of the New York Zoological Society. XXV. Fishes from the tropical eastern Pacific. Part 2. Sharks. **Zoologica**, v. 26, p. 93–112, 1941.

BESTER, C. **Biological Profiles: Galapagos Shark.** Disponível em: <https://www.floridamuseum.ufl.edu/discover-fish/species-profiles/carcharhinus-galapagensis/>. Acesso em: 14 maio. 2020.

BEZERRA, N. P. A. et al. Evidence of site fidelity and deep diving behaviour of scalloped hammerhead shark (*Sphyrna lewini*) around the Saint Peter and Saint Paul Archipelago, in the equatorial Mid-Atlantic ridge. **Marine and Freshwater Research**, n. October, 2019.

BONFIL, R. **Marine protected areas as a shark fisheries management tool**. (B. Seret, J. Y. Sire, Eds.). Proceedings of the 5th Indo-Pacific Fish Conference Noumea, 1997. Societe

Francaise d'Ichtyologie (pp. 217–230). **Anais**...Paris: Paris and Institut de Recherche pour le Development, 1999.

BONFIL, R. et al. Transoceanic migration, spatial dynamics, and population linkages of white sharks. **Science**, v. 310, n. 5745, p. 100–103, 2005.

BORNATOWSKI, H.; BRAGA, R. R.; VITULE, J. R. S. Threats to sharks in a developing country: The need for effective and simple conservation measures. **Natureza & Conservação**, v. 12, n. 1, p. 11–18, 2014.

BRASIL. **Lista Nacional Oficial de Espécies da Fauna Ameaçadas de Extinção - Peixes e Invertebrados Aquáticos. Portaria MMA nº 445, de 17 de dezembro de 2014Diário Oficial da União**. Brasília, DF. Disponível em: <http://www.icmbio.gov.br/cepsul/images/stories/legislacao/Portaria/2014/p_mma_445_2014_lista_peixes_ameaçados_extinção.pdf>. Acesso em: 31 jan. 2019.

BRASIL. **Decreto n. 9.313, de 19 de março de 2018. Cria a Área de Proteção Ambiental do Arquipélago de São Pedro e São Paulo e o Monumento Natural do Arquipélago de São Pedro e São Paulo.Diário Oficial da União**, 2018.

BRAUN, C. D. et al. Movements of the reef manta ray (*Manta alfredi*) in the Red Sea using satellite and acoustic telemetry. **Marine Biology**, v. 162, n. 12, p. 2351–2362, 2015.

BRAUN, C. D.; SKOMAL, G. B.; THORROLD, S. R. Integrating Archival Tag Data and a High-Resolution Oceanographic Model to Estimate Basking Shark (*Cetorhinus maximus*) Movements in the Western Atlantic. **Frontiers in Marine Science**, v. 5, n. 25, p. 1–14, 2018.

BURNHAM, K. P.; ANDERSON, D. R. Multimodel inference: Understanding AIC and BIC in model selection. **Sociological Methods and Research**, v. 33, n. 2, p. 261–304, 2004.

CAMHI, M. et al. Sharks and their Relatives: Ecology and Conservation. **Occasional Paper**, n. 20, p. 39, 1998.

CAMHI, M. D. et al. The conservation status of pelagic sharks and rays. In: **Report of the IUCN shark specialist group pelagic shark red list workshop.** Newbury, UK: IUCN. p. 19–23.

CAMPANA, S. E.; FERRETTI, F.; ROSENBERG, A. Sharks and other elasmobranchs. In: **The First Global Integrated Marine Assessment, World Ocean Assessment I**. United Nations. p. 1437–1451.

CAMPOS, T. F. DA C. et al. **Arquipélago de São Pedro e São Paulo - Soerguimento tectônico de rochas infracrustais no Oceano AtlânticoSítios Geológicos e Paleontológicos do Brasil**. SIGEP 002, UNB, 2005.

CARLSON, J. K.; BAREMORE, I. E. Changes in biological parameters of Atlantic sharpnose shark *Rhizoprionodon terraenovae* in the Gulf of Mexico: Evidence for density-dependent growth and maturity? **Marine and Freshwater Research**, v. 54, n. 3, p. 227–234, 2003.

CASSOFF, R. M.; CAMPANA, S. E.; MYKLEVOLL, S. Changes in baseline growth and maturation parameters of Northwest Atlantic porbeagle, Lamna nasus, following heavy exploitation. **Canadian Journal of Fisheries and Aquatic Sciences**, v. 64, n. 1, p. 19–29, 2007.

CHAPMAN, D. D. et al. Give shark sanctuaries a chance. **Science**, v. 339, p. 757, 2013.

CHIAPPONE, M.; SULLIVAN-SEALEY, K. Marine reserve design criteria and measures of success: Lessons learned from the Exuma Cays Land and Sea Park, Bahamas. **Bulletin of Marine Science**, v. 66, n. 3, p. 691–705, 2000.

CLARKE, S. C. et al. Global estimates of shark catches using trade records from commercial markets. **Ecology Letters**, v. 9, n. 10, p. 1115–1126, 2006a.

CLARKE, S. C. et al. Identification of shark species composition and proportion in the Hong Kong shark fin market using molecular genetics and trade records. **Conservation Biology**, v. 20, n. 1, p. 201–211, 2006b.

CLARKE, S.; MILNER-GULLAND, E. J.; BJORNDAL, T. Social, Economic, and Regulatory Drivers of the Shark Fin Trade. **Marine Resource Economics**, v. 22, n. 1, p. 305–327, 2007.

COLLAR, N. J. Extinction by assumption; or, the Romeo Error on Cebu. **Oryx**, v. 32, n. 4, p. 239–244, 1998.

COMPAGNO, L.; DANDO, M.; FOWLER, S. **Sharks of the World**. Princeton University Press, Princeton, 2005.

COMPAGNO, L. J. V. **Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 2 - Carcharhiniformes. Food and Agriculture Organization of the United Nations**. Rome, 1984.

CORRIGAN, S. et al. Historical introgression drives pervasive mitochondrial admixture between two species of pelagic sharks. **Molecular Phylogenetics and Evolution**, v. 110, n. March, p. 122–126, 2017.

CORTÉS, E. Life History Patterns and Correlations in Sharks. **Reviews in Fisheries Science**, v. 8, n. 4, p. 299–344, 2000.

CUBERO-PARDO, P.; HERRÓN, P.; GONZÁLEZ-PÉREZ, F. Shark reactions to scuba divers in two marine protected areas of the Eastern Tropical Pacific. **Aquatic Conservation: Marine and Freshwater Ecosystems**, v. 21, n. 3, p. 239–246, 2011.

DAHLGREN, C. P.; SOBEL, J. Designing a Dry Tortugas ecological reserve: How big is big enough? ...To do what? **Bulletin of Marine Science**, v. 66, n. 3, p. 707–719, 2000.

DALE, J. J. et al. The Shark Assemblage at French Frigate Shoals Atoll, Hawai‘i : Species Composition , Abundance and Habitat Use. **PLoS ONE**, v. 6, n. 2, 2011.

DAVIDSON, L. N. K.; DULVY, N. K. Global marine protected areas to prevent extinctions. **Nature Ecology and Evolution**, v. 1, n. 2, p. 1–6, 2017.

DEL MONTE-LUNA, P. et al. Marine extinctions revisited. **Fish and Fisheries**, v. 8, n. 2, p. 107–122, 2007.

DOLTON, H. et al. Assessing the importance of Isle of Man waters for the basking shark Cetorhinus maximus. **Endangered Species Research**, v. 41, p. 209–223, 2020.

DREW, J. A. Use of traditional ecological knowledge in marine conservation. **Conservation Biology**, v. 19, n. 4, p. 1286–1293, 2005.

DUFFY, C. A. J. Misidentification of *Carcharhinus galapagensis* (Snodgrass & Heller, 1905) in the Southwest Pacific Ocean. **Zootaxa**, v. 4132, n. 1, p. 97–106, 2016.

DULVY, N. et al. Minireview Challenges and Priorities in Shark and Ray Conservation Minireview. **Current Biology**, v. 27, n. 11, p. 565–572, 2017.

DULVY, N. K. et al. You can swim but you can't hide: the global status and conservation of oceanic pelagic sharks and rays. **Aquatic Conservation: Marine and Freshwater Ecosystems**, v. 18, n. 5, 2008.

DULVY, N. K. et al. Extinction risk and conservation of the world's sharks and rays. **eLife**, p. 1–34, 2014.

EDWARDS, A. J.; LUBBOCK, H. R. The Shark population of Saint Paul's Rocks. **Copeia**, n. 1, p. 223–225, 1982.

EDWARDS, A.; LUBBOCK, R. Marine zoogeography of St Paul's Rocks. **Journal of Biogeography**, v. 10, n. 1, p. 65–72, 1983.

ESPINOZA, M. et al. Contrasting movements and connectivity of reef-associated sharks using acoustic telemetry: Implications for management. **Ecological Applications**, v. 25, n. 8, p. 2101–2118, 2015.

FEITOZA, B. M. et al. Reef fishes of St. Paul's Rocks: new records and notes on biology and zoogeography. **Jornal of ichthyology and Aquatic Biology**, v. 7, n. 2, p. 61–82, 2003.

FERRETTI, F. et al. Patterns and ecosystem consequences of shark declines in the ocean. **Ecology Letters**, v. 13, n. 8, p. 1055–1071, 2010.

FIELDS, A. T. et al. Species composition of the international shark fin trade assessed through a retail-market survey in Hong Kong. **Conservation Biology**, v. 32, n. 2, p. 376–389, 2018.

FITZROY, R. N. **Narrative of the Surveying Voyages of His Majesty's Ships Adventure and Beagle Between the Years 1826 and 1836, describing their examination of the southern shores of South America, and the Beagle's circumnavigation of the globe, volume II.** London: Henry Colburn, 1839.

GADIG, O. B. F. **Tubarões da costa brasileira**. 2001.

GALLAGHER, A. J.; KYNE, P. M.; HAMMERSCHLAG, N. Ecological risk assessment and its application to elasmobranch conservation and management. **Journal of Fish Biology**, v. 80, n. 5, p. 1727–1748, 2012.

GARRICK, J. A. F. **Sharks of the Genus *Carcharhinus*. National Marine Fisheries Service, National Oceanographic and Atmospheric Administration (NOAA) Technical Report 445, 194**, 1982.

GOVE, J. M. et al. Near-island biological hotspots in barren ocean basins. **Nature Communications**, v. 7, p. 1–8, 2016.

GRAHAM, F. et al. Use of marine protected areas and exclusive economic zones in the subtropical western North Atlantic Ocean by large highly mobile sharks. **Diversity and Distributions**, v. 22, p. 534–546, 2016.

GRAHAM, N. A. J.; SPALDING, M. D.; SHEPPARD, C. R. C. Reef shark declines in remote atolls highlight the need for multi-faceted conservation action. **Aquatic Conservation: Marine and Freshwater Ecosystems**, v. 20, n. 5, p. 543–548, 2010.

GROVE, J. .; LAVENBERG, R. J. **The fishes of the Galápagos Islands**. Stanford University Press, Stanford, 1997.

HAMMERSCHLAG, N. et al. A Comparison of Spatial and Movement Patterns between Sympatric Predators: Bull Sharks (*Carcharhinus leucas*) and Atlantic Tarpon (*Megalops atlanticus*). **PLoS ONE**, v. 7, n. 9, p. 1–14, 2012.

HAMMERSCHLAG, N. et al. Diel habitat use patterns of a marine apex predator (tiger shark, *Galeocerdo cuvier*) at a high use area exposed to dive tourism. **Journal of Experimental Marine Biology and Ecology**, v. 495, p. 24–34, 2017.

HAMMERSCHLAG, N.; GALLAGHER, A. J.; LAZARRE, D. M. A review of shark satellite tagging studies. **Journal of Experimental Marine Biology and Ecology**, v. 398, p. 1–8, 2011.

HAYS, G. C. et al. Key Questions in Marine Megafauna Movement Ecology. **Trends in Ecology & Evolution**, v. 31, n. 6, p. 463–475, 2016.

HAZIN, F. H. V. et al. Occurrences of whale shark (*Rhincodon typus* Smith, 1828) in the Saint Peter and Saint Paul archipelago, Brazil. **Brazilian Journal of Biology**, v. 68, n. 2, p. 385–389, 2008.

HAZIN, F. H. V. et al. Elasmosbrânquios do Arquipélago de São Pedro e São Paulo. In: OLIVEIRA, J.; VIANA, D.; SOUZA, M. (Eds.). . **Arquipélago de São Pedro e São Paulo: 20 anos de pesquisa**. Recife. p. 143–159.

HAZIN, F. H. V et al. Review of a small-scale pelagic longline fishery off northeastern Brazil. **Marine Fisheries Review**, v. 60, n. 3, p. 1–8, 1998.

HEITHAUS, M. R. et al. Long-term movements of tiger sharks satellite-tagged in Shark Bay, Western Australia. **Marine Biology**, v. 151, n. 4, p. 1455–1461, 2007.

HEITHAUS, M. R. et al. Predicting ecological consequences of marine top predator declines. **Trends in Ecology & Evolution**, v. 23, n. 4, p. 202–210, 2008.

HEUPEL, M. R. et al. Sizing up the ecological role of sharks as predators. **Marine Ecology Progress Series**, v. 495, p. 291–298, 2014.

HEUPEL, M. R.; SIMPFENDORFER, C. A. Using acoustic monitoring to evaluate MPAs for shark nursery areas: The importance of long-term data. **Marine Technology Society Journal**, v. 39, n. 1, p. 10–18, 2005.

HEUPEL, M. R.; SIMPFENDORFER, C. A.; HUETER, R. E. Estimation of shark home ranges using passive monitoring techniques. **Environmental Biology of Fishes**, v. 71, p. 135–142, 2004.

HOBBS, J.-P. A. et al. Unique fish assemblages at world's southernmost oceanic coral reefs, Elizabeth and Middleton Reefs, Tasman Sea, Australia. **Coral Reefs**, v. 27, n. 1, p. 15, 2008.

HOOKER, S. K. et al. Making protected area networks effective for marine top predators. **Endangered Species Research**, v. 13, n. 3, p. 203–218, 2011.

HUSSEY, N. E. et al. Aquatic animal telemetry: A panoramic window into the underwater world. **Science**, v. 348, n. 6240, p. 1255642, 2015.

INTERNATIONAL COMMISSION FOR THE CONSERVATION OF ATLANTIC TUNA (ICCAT). **Recommendation by ICCAT on the conservation of silky sharks caught in association with ICCAT fisheries**. Disponível em: <https://www.iccat.int/Documents/Recs/compendiopdf-e/2011-08-e.pdf>. Acesso em: 15 jan. 2020.

JABADO, R. W. et al. Troubled waters: Threats and extinction risk of the sharks, rays and chimaeras of the Arabian Sea and adjacent waters. **Fish and Fisheries**, v. 19, n. 6, p. 1043–1062, 2018.

JACKSON, J. B. C. et al. Historical Overfishing and the Recent Colllapse of Coastal Ecosystems. **Science**, v. 293, p. 629–638, 2001.

JONES, P. J. S.; DE SANTO, E. M. Viewpoint – Is the race for remote, very large marine protected areas (VLMPAs) taking us down the wrong track? **Marine Policy**, v. 73, n. 0, p. 231–234, 2016.

JOUNG, S. J. et al. Age, growth, and reproduction of silky sharks, *Carcharhinus falciformis*, in northeastern Taiwan waters. **Fisheries Research**, v. 90, n. 1–3, p. 78–85, 2008.

JOUNG, S. J.; LIAO, Y. Y.; CHEN, C. T. Age and growth of sandbar shark, *Carcharhinus plumbeus*, in northeastern Taiwan waters. **Fisheries Research**, v. 70, n. 1, p. 83–96, 2004.

KATO, S.; CARVALLO, A. H. Shark tagging in the eastern Pacific Ocean, 1962-1965. In: GILBERT, P. W.; MATHEWSON, R. F.; RALL, J. P. (Eds.). . **Sharks, Skates and Rays**. Baltimore: Johns Hopkins Press., 1967. p. 93–109.

KETCHUM, J. et al. **Shark movements and the design of protected pelagic environments within and beyond the Galapagos Marine Reserve**, 2009.

KINNEY, M. J.; SIMPFENDORFER, C. A. Reassessing the value of nursery areas to shark conservation and management. **Conservation Letter**, v. 2, p. 53–60, 2009.

KOHLER, N. E.; CASEY, J. G.; TURNER, P. A. NMFS cooperative shark tagging program, 1962-93: An atlas of shark tag and recapture data. **Marine Fisheries Review**, v. 60, n. 2, p. 1–87, 1998.

KOLDEWEY, H. J. et al. Potential benefits to fisheries and biodiversity of the Chagos Archipelago/British Indian Ocean Territory as a no-take marine reserve. **Marine Pollution Bulletin**, v. 60, n. 11, p. 1906–1915, 2010.

KYNE, P. M. et al. **Carcharhinus galapagensisThe IUCN Red List of Threatened Species 2019: e.T41736A2954286**. Disponível em: <https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T41736A2954286.e>.

LARA-LIZARDI, F. et al. Shark movements in the Revillagigedo Archipelago and connectivity with the Eastern Tropical Pacific. **bioRxiv**, 2020.

LESSA, R. P. et al. Distribution and abundance of ichthyoneuston at seamounts and islands off North-Eastern Brazil. **Archive Fishery and Marine Research**, v. 47, n. (2/3), p. 239–252, 1999.

LOWE, C. G.; WETHERBEE, B. M.; MEYER, C. G. Using acoustic telemetry monitoring techniques to quantify movement patterns and site fidelity of sharks and giant trevally around French Frigate Shoals and Midway Atoll. **Atoll Res Bull**, v. 543, p. 281–303, 2006.

LUBBOCK, H. R.; EDWARDS, A. J. The fishes of Saint Paul’s Rocks. **Jornal of Fish Biology**, v. 18, p. 135–157, 1981.

LUIZ, O. J.; EDWARDS, A. J. Extinction of a shark population in the Archipelago of Saint Paul’s Rocks (equatorial Atlantic) inferred from the historical record. **Biological Conservation**, v. 144, n. 12, p. 2873–2881, 2011.

MACENA, B. C. L.; HAZIN, F. H. V. Whale shark (*Rhincodon typus*) seasonal occurrence, abundance and demographic structure in the mid-equatorial Atlantic Ocean. **PLoS ONE**, v. 11, n. 10, p. 1–24, 2016.

MCCLENACHAN, L.; COOPER, A. B.; DULVY, N. K. Rethinking Trade-Driven Extinction Risk in Marine and Terrestrial Megafauna. **Current Biology**, v. 26, n. 12, p. 1640–1646, 2016.

MENDONÇA, S. A. et al. Seasonal aggregation and diel activity by the sicklefin devil ray Mobula tarapacana off a small, equatorial outcrop of the Mid-Atlantic Ridge. **Journal of Fish Biology**, v. 93, n. 6, p. 1121–1129, 2018.

MEYER, C. G.; PAPASTAMATIOU, Y. P.; HOLLAND, K. N. A multiple instrument approach to quantifying the movement patterns and habitat use of tiger (*Galeocerdo cuvier*) and Galapagos sharks (*Carcharhinus galapagensis*) at French Frigate Shoals, Hawaii. **Marine Biology**, v. 157, n. 8, p. 1857–1868, 2010.

MOLINA, J. M.; COOKE, S. J. Trends in shark bycatch research: Current status and research needs. **Reviews in Fish Biology and Fisheries**, v. 22, n. 3, p. 719–737, 2012.

MORA, C. et al. Coral reefs and the global network of marine protected areas. **Science**, v. 312, n. 5781, p. 1750–1751, 2006.

MUCIENTES, G. R. et al. Sexual segregation of pelagic sharks and the potential threat from fisheries. **Biology Letters**, v. 5, n. 2, p. 156–159, 2009.

MUSYL, M. K. et al. Performance of pop-up satellite archival tags. **Marine Ecology Progress Series**, v. 433, p. 1–28, 2011.

MYERS, R. A. et al. Cascading Effects of the Loss of Apex Predatory Sharks from a Coastal Ocean. **Science**, v. 315, n. March, p. 1846–1850, 2007.

MYERS, R. A.; WORM, B. Extinction , survival or recovery of large predatory fishes. **The Royal Society**, v. 360, n. January, p. 13–20, 2005.

NIELSEN, A.; SIBERT, J. R. State-space model for light-based tracking of marine animals. **Canadian Journal of Fisheries and Aquatic Sciences**, v. 64, p. 1055–1068, 2007.

NMFS. **Final Amendment 3 to the Consolidated Atlantic Highly Migratory Species Fishery Management Plan. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Sustainable Fisheries, Highly Migratory Species Manaagement DiviSilver Spring, MD. Public Document. pp. 632**, 2010.

NMFS. **SEDAR 21 Stock Assessment Report. HMS Dusky Shark. SEDAR, 4055 Faber Place Drive, Suite 20, North Charleston, SC 29, 405.**, 2011.

OLIVEIRA, G. M.; EVANGELISTA, J. E. V; FERREIRA, B. P. **Considerações sobre a biologia e a pesca no Arquipélago de São Pedro e São Paulo. Boletin Técnico Científico do CEPENE 5, 31-52**. 1997.

OLIVEIRA, L. P. P. **Abundância relativa e uso do habitat por tubarões do gênero *Carcharhinus* (*C. falciformis, C. galapagensis e C. obscurus*) no Arquipélago de São Pedro e São Paulo - Brasil**. Universidade Federal de Pernambuco, 2017.

OLIVER, S. et al. Global patterns in the bycatch of sharks and rays. **Marine Policy**, v. 54, p. 86–97, 2015.

PAIVA, M. P.; LE GALL, J.-Y. Catches of tunas and tuna like fishes in the longline fishery areas off the cost of Brazil. **Arquivos de Ciências do Mar**, v. 15, n. 1, p. 1–18, 1975.

PAPASTAMATIOU, Y. P. et al. Distribution and diet of four species of carcharhinid shark in the Hawaiian Islands : evidence for resource partitioning and competitive exclusion. **Marine Ecology Progress Series**, v. 320, p. 239–251, 2006.

PAPASTAMATIOU, Y. P. et al. Long-term movement patterns and trophic ecology of blacktip reef sharks (*Carcharhinus melanopterus*) at Palmyra Atoll. **Journal of Experimental Marine Biology and Ecology**, v. 386, n. 1–2, p. 94–102, 2010.

PAPASTAMATIOU, Y. P. et al. Movements and foraging of predators associated with mesophotic coral reefs and their potential for linking ecological habitats. **Marine Ecology Progress Series**, v. 521, p. 155–170, 2015.

PAZMIÑO, D. A. et al. Strong trans-Pacific break and local conservation units in the Galapagos shark (*Carcharhinus galapagensis*) revealed by genome-wide cytonuclear markers. **Heredity**, v. 120, n. 5, p. 407–421, 2018.

PAZMIÑO, D. A. et al. Introgressive hybridisation between two widespread sharks in the east Pacific region. **Molecular Phylogenetics and Evolution**, v. 136, n. March, p. 119–127, 2019.

PIKITCH, E. K.; CAMHI, M. D.; BABCOCK, E. A. Introduction to sharks of the open ocean. **Sharks of the Open Ocean. Biology , Fisheries and Conservation**, p. 3–13, 2008.

PINHEIRO, H. T. et al. Fish biodiversity of the Vitória-Trindade seamount chain, southwestern Atlantic: an updated database. **PLoS ONE**, v. 10, n. 3, p. 1–17, 2015.

POIZAT, G.; BARAN, E. Fishermen's knowledge as background information in tropical fish ecology: A quantitative comparison with fish sampling results. **Environmental Biology of Fishes**, v. 50, n. 4, p. 435–449, 1997.

QGIS DEVELOPMENT TEAM. **QGIS geographic information system. Open Source Geospatial Foundation Project**. 2016.

QUEIROZ, N. et al. Convergent foraging tactics of marine predators with different feeding strategies across heterogeneous ocean environments. **Frontiers in Marine Science**, v. 4, p. 1–15, 2017.

R CORE TEAM. **R: A language and environment for statistical computing (Version 3.6.2) R Foundation for Statistical Computing: Vienna, Austria**. 2019. Disponível em: <http://www.r-project.org/>.

REYNOLDS, J. D. et al. Biology of extinction risk in marine fishes. **Proceedings of the Royal Society B**, v. 272, n. 1579, p. 2337–2344, 2005.
ROBERTS, C. M. Selecting marine reserve locations: optimality versus opportunism. **Bulletin of Marine Science**, v. 66, n. 3, p. 581–592, 2000.

ROFF, G. et al. Decline of coastal apex shark populations over the past half century. **Communications Biology**, v. 1, n. 223, p. 1–11, 2018.

SECRETARIA DA COMISSÃO INTERMINISTERIAL PARA OS RECURSOS DO MAR (SECIRM). **Proposta para ordenamento de atividade pesqueira**. Brasília, DF: Marinha do Brasil, 2012.

SHIPLEY, O. N. et al. Horizontal and vertical movements of Caribbean reef sharks (*Carcharhinus perezi*): conservation implications of limited migration in a marine sanctuary.

Royal Society Open Science, v. 4, n. 2, 2017.

SIMPFENDORFER, C. A. et al. The importance of research and public opinion to conservation management of sharks and rays: a synthesis. **Marine and Freshwater Research**, v. 62, n. 6, p. 518–527, 2011.

SIMPFENDORFER, C. A.; DULVY, N. K. Bright spots of sustainable shark fishing. **Current Biology**, v. 27, n. 3, p. R97–R98, 2017.

SMINKEY, T. R.; MUSICK, J. A. Age and growth of the sandbar shark, *Carcharhinus plumbeus*, before and after population depletion. **Copeia**, v. 1995, n. 4, p. 871–883, 1995.

SMITH, H. G. et al. A biological survey of St. Paul's Rocks in the equatorial Atlantic Ocean. **Biological Journal of the Linnean Society**, v. 6, n. June, p. 89–96, 1974.

SMITH, S. E.; AU, D. W.; SHOW, C. Intrinsic rebound potentials of 26 species of Pacific sharks. **Marine Freshwater Research**, v. 49, p. 663–678, 1998.

SNODGRASS, R. E.; HELLER, E. Shore fishes of the Revillagigedo, Clipperton, Cocos and Galapagos Islands. **Proceedings of the Washington Academy of Sciences**, v. 6, p. 333–427, 1905.

SOARES, M. DE O.; LUCAS, C. C. Towards large and remote protected areas in the South Atlantic Ocean: St. Peter and St. Paul´s Archipelago and the Vitória-Trindade Seamount Chain. **Marine Policy**, v. 93, n. February, p. 101–103, 2018.

SOLER, G. A.; BESSUDO, S.; GUZMÁN, A. Long term monitoring of pelagic fishes at Malpelo Island, Colombia. **LATIN AMERICAN JOURNAL OF CONSERVATION**, v. 3, n. 2, p. 28–37, 2013.

SOTO, J. M. R. Annotated systematic checklist and bibliography of the coastal and oceanic fauna of Brazil. I. Sharks. **Mare Magnum**, v. 1, n. 1, p. 51–120, 2001.

SOTO, J. M. R.; MACENA, B.; HAZIN, F. H. V. **Novas informações sobre a presença do tubarão-das-galápagos, *Carcharhinus galapagensis* (Snodgrass & Heller, 1905) (Carcharhiniformes, Carcharhinidae), no Arquipélago São Pedro e São Paulo**. VII Reunião da Sociedade Brasileira para o Estudo dos Elasmobrânquios - SBEEL. Anais. **Anais**...Rio Grande/RS: 2011.

SPEED, C. W. et al. Complexities of coastal shark movements and their implications for management. **Marine Ecology Progress Series**, v. 408, p. 275–293, 2010.

SPEED, C. W.; CAPPO, M.; MEEKAN, M. G. Evidence for rapid recovery of shark populations within a coral reef marine protected area. **Biological Conservation**, v. 220, n. December 2017, p. 308–319, 2018.

STEVENS, J. et al. The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems. **ICES Journal of Marine Science**, v. 57, n. 3, p. 476–494, 2000.

TOPELKO, K. N.; DEARDEN, P. The Shark Watching Industry and its Potential Contribution to Shark Conservation. **Journal of Ecotourism**, v. 4, n. 1, p. 108–128, 2005.

TREMBLEY-BOYER, L.; BROUWER, S. **Review of available information on non-key shark species including mobulids and fisheries interactions.**EB-WP-08. Western Central Pacific Fisheries Commission. Scientific Committee Twelfth Regular Session. Bali, Indonesia 3–11 August 2016, , 2016.

VASKE JR, T. et al. A checklist of fishes from Saint Peter and Saint Paul Archipelago, Brazil. **Journal of Applied Ichthyology**, v. 21, p. 75–79, 2005.

VASKE JR, T. et al. The commercial fishery of pelagic fishes off the Saint Peter and Saint Paul Archipelago, Brazil. **Tropical Oceanography**, v. 36, n. 1–2, p. 47–54, 2008.

VASKE JR, T.; VOOREN, C. M.; LESSA, R. P. Feeding strategy of yellowfin tuna (*Thunnus albacares*), and wahoo (*Acanthocybium solandri*) in the Saint Peter and Saint Paul Archipelago, Brazil. **Boletim do Instituto de Pesca**, v. 29, n. 1, p. 173–181, 2003.

WASS, R. C. **A comparative study of the life history, distribution and ecology of the sanddbar shark and the gray reef shark in Hawaii**. PhD dissertation, University of Hawaii, Honolulu, 1971.

WENG, K. C. et al. Migration of an upper trophic level predator, the salmon shark *Lamna ditropis*, between distant ecoregions. **Marine Ecology Progress Series**, v. 372, p. 253–264, 2008.

WETHERBEE, B. M.; CROW, G. L.; LOWE, C. G. Biology of the Galapagos shark, *Carcharhinus galapagensis*, in Hawai'i. **Environmental Biology of Fishes**, v. 45, p. 299–310, 1996.

WHITE, T. D. et al. Assessing the effectiveness of a large marine protected area for reef shark conservation. **Biological Conservation**, v. 207, p. 64–71, 2017.

WICKHAM, H. **ggplot2: elegant graphics for data analysis.** Disponível em: <https://cran.r-project.org/package=ggplot2>.

WOOD, L. J. et al. Assessing progress towards global marine protection targets: shortfalls in information and action. **Oryx**, v. 42, n. 3, p. 340–351, 2008.

WORM, B.; LOTZE, H. K.; MYERS, R. A. Predator diversity hotspots in the blue ocean. **Proceedings of the National Academy of Sciences**, v. 100, n. 17, p. 9884–9888, 2003.

ANEXO A - QUESTIONÁRIO APLICADO AOS PESCADORES DO ARQUIPÉLAGO DE SÃO PEDRO E SÃO PAULO.

UNIVERSIDADE FEDERAL DE PERNAMBUCO
DEPARTAMENTO DE OCEANOGRAFIA
PROGRAMA DE PÓS-GRADUAÇÃO EM OCEANOGRAFIA

(1) Responsável: ______________________________

(2) Ficha ________ (3) Local: _______________ (4) Data: ______________

(5) Nome/apelido: ____

(6) Idade: _____

(7) Escolaridade: ____

(8) Funções que ocupa/ocupou na pesca: ________________

(9) Anos na atividade: _______________________

(10) Há quanto tempo você pesca ou pescou no ASPSP?

____

(11) Passou algum período sem pescar na região do ASPSP? Caso sim, qual?

____

(12) Reconhece alguma desses animais (Imagens)?

(1)	(2)	(3)
(4)	(5)	(6)
(7)	(8)	(9)

(13) Você encontra algum desses tubarões no entorno do ASPSP? Caso sim, qual(is)? Sim/Não.

____

(14) Costumavam capturar algum desses tubarões quando a pesca era permitida? Se sim, qual(is)? Sim/Não.

____

(15) Você percebeu alguma mudança na quantidade de tubarões no ASPSP ao longo dos anos? Caso sim, mudou como? A partir de que ano você observou essa mudança?

Animal	Teve Mudança?	Ano(s)
	Não/Aumentou/Diminuiu	
	Não/Aumentou/Diminuiu	
	Não/Aumentou/Diminuiu	
	Não/Aumentou/Diminuiu	

(16) Teve algum ano/período que você **NÃO** observou algum desses tubarões? Se sim, qual(is) animal(is)? Qual(is) ano(s)? Sim/Não

Animal:						
Ano:						

(17) Em geral, em qual **época** do ano se observa MAIS e MENOS tubarões aqui no ASPSP? Por quê?

Mais comum											
JAN	FEV	MAR	ABR	MAI	JUN	JUL	AGO	SET	OUT	NOV	DEZ
Motivo:											
Menos comum											
JAN	FEV	MAR	AB R	MAI	JUN	JUL	AGO	SET	OU T	NOV	DEZ
Motivo:											

18) Em geral, qual é o MELHOR e PIOR **horário** do dia para encontrar os tubarões? Por quê?

Melhor	Pior

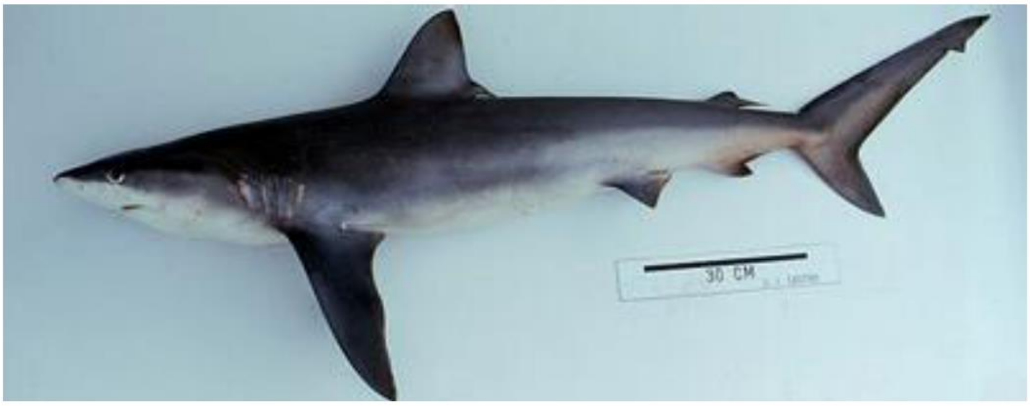
(19) Tem algum local/ponto no entorno do arquipélago onde você encontra esse(s) animal(is) com mais frequência? Caso sim, você poderia apontar no mapa? Sim/Não

____

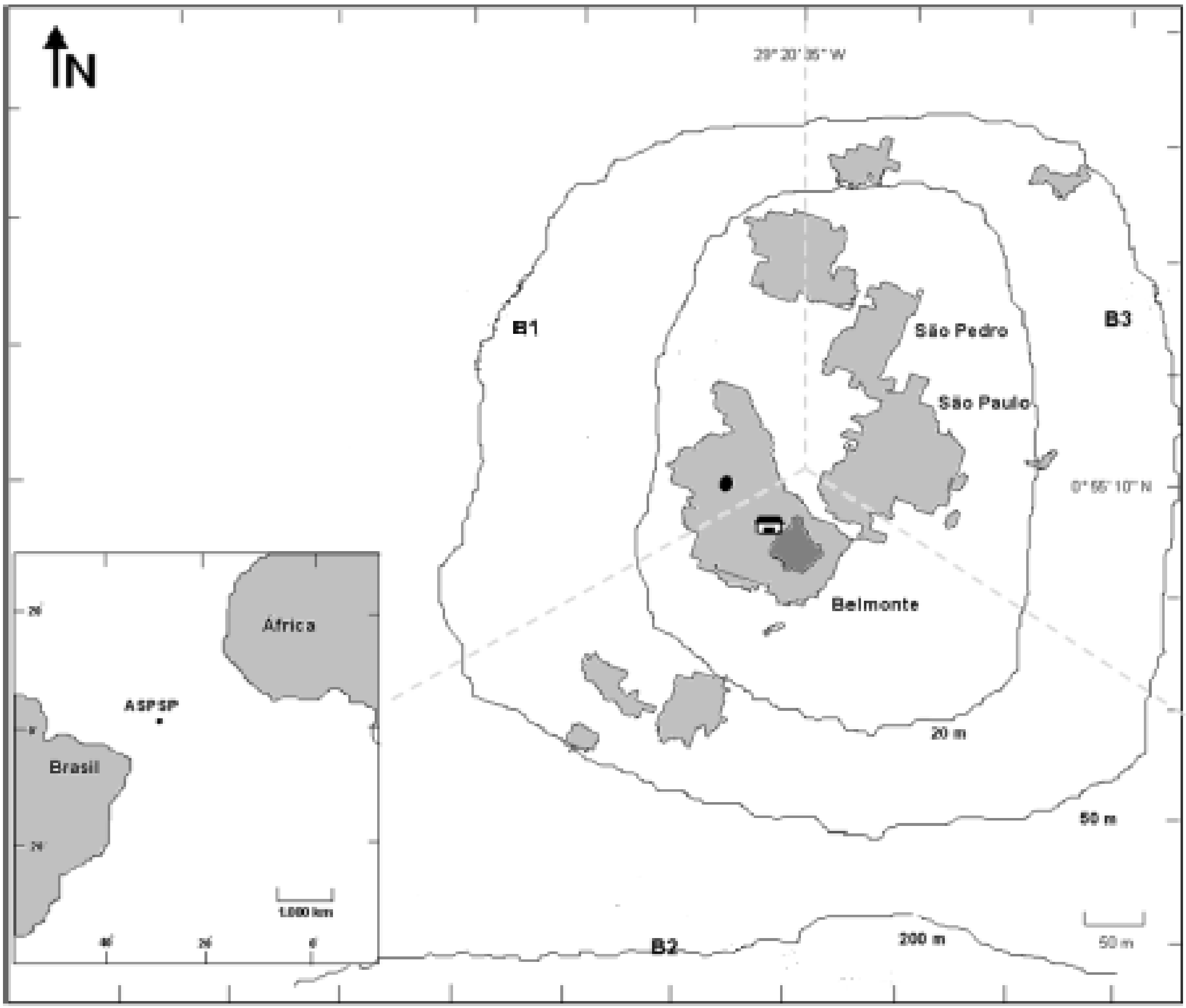
(20) Como você definiria a atual situação dos tubarões no ASPSP?

____

ANEXO B - IMAGENS DOS *Carcharhinus spp.* UTILIZADAS DURANTE A APLICAÇÃO DOS QUESTIONÁRIOS.


30 CM

ANEXO C - MAPA UTILIZADO PARA DEFINIR AS ÁREAS DE MAIOR AVISTAMENTO DOS TUBARÕES.



Fonte: Macena, 2010