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BIOLOGIA PESQUEIRA DOS TUBARÕES MARTELO (SPHYRNA SPP.) NO OCEANO ATLÂNTICO SUDOESTE E EQUATORIAL

NATALIA PRISCILA ALVES BEZERRA

RECIFE,

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Tese apresentada ao Programa de Pós-Graduação em Oceanografia da Universidade Federal de Pernambuco (PPGO-UFPE) como exigência para obtenção do título de Doutor em Oceanografia.

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“Ás vezes, a verdadeira vitória não se pode mostrar, nem a verdadeira coragem é tão visível ou evidente quanto se pensa.”

ERNEST HEMINGWAY

RESUMO

O objetivo principal da presente tese consistiu em gerar informações a respeito das espécies de tubarões martelo do gênero *Sphyrna*, no que concernem as distribuições espaço-temporais de suas capturas, no uso de hábitats preferenciais e na capturabilidade dessas espécies no entorno dos montes submarinos no oceano Atlântico Sul e Equatorial. A fim de obter dados sobre as distribuições espaço-temporais das capturas do *Sphyrna lewini*, *Sphyrna zygaena* e *Sphyrna mokarran* para os anos de 2004 a 2011, foram avaliados 29.418 lançamentos oriundos da frota atuneira estrangeira e nacional que opera com espinhel pelágico no Atlântico Sudoeste e Equatorial. Nesse período, 6.172 tubarões martelo foram capturados, correspondendo a 0,4% do total das capturas da frota atuneira. A captura por unidade de esforço (CPUE) nominal calculada por trimestres apresentou uma tendência de maiores valores próximos as regiões equatorial e sul do Brasil. A média da CPUE nominal foi de 0,12 tubarões/1.000 anzóis. As observações sobre o uso do habitat foram concebidas através da implantação de sete marcas eletrônicas via satélite nos tubarões martelo (*S. lewini*) no entorno do arquipélago de São Pedro e São Paulo (ASPSP). Com as informações dos locais de soltura das marcas e as geolocalizações fornecidas, foi possível inferir que os tubarões monitorados permaneceram nas circunvizinhanças do ASPSP, sugerindo fidelidade ao local. O padrão diário de movimentação vertical dos tubarões indicou a preferência por águas mais aquecidas, superiores a 25° C, e por profundidades de até 150 m. Contudo, a espécie realizou incursões frequentes a maiores profundidades, e ainda todos os mergulhos realizados nas zonas abaixo dos 500 m foram registrados exclusivamente durante o período noturno. A máxima profundidade atingida foi de 728 m, onde a temperatura mínima registrada foi igual a 5,6° C. Assim, os padrões de movimentação vertical indicaram que a espécie frequenta uma grande amplitude de profundidade e temperatura na coluna d’água, entre as zonas epipelágicas e mesopelágicas. Durante os experimentos para a marcação dos tubarões, uma fêmea da espécie *S. zygaena* foi capturada no ASPSP, o que caracterizou uma nova ocorrência para a região e também ampliou a área de extensão para a espécie. Para avaliar a relação entre as capturas dos tubarões martelo e os montes submarinos com o uso de espinhel, foram mensuradas as distâncias dos pontos de capturas e esforços até os montes submarinos mais próximos para o período de 1981 a 2011 no oceano Atlântico Sul e Equatorial. Os tubarões martelo totalizaram 59.556 das capturas para toda a área analisada, com 9.519 indivíduos (16%) capturados em distâncias de até 40 km dos montes submarinos. Devido às espécies de tubarões martelo apresentarem indícios de agregações nos montes submarinos, foi calculada a CPUE nominal e padronizada para as distâncias de 0 a 40 km dos montes submarinos, com maior índice registrado a 10 km dessas formações, onde a CPUE nominal foi de 0,90 tubarões/1.000 anzóis. A medida que as capturas se afastaram dos montes submarinos, o valor da CPUE calculada decresceu, sugerindo que essas formações representam áreas de prováveis agregações para os tubarões martelo.

Palavras-chave: Elasmobrânquios. Captura incidental. CPUE. PSAT. Comportamento. Montes submarinos. Oceano Atlântico Sul.

ABSTRACT

The aim of this thesis was to gather information about the species of hammerhead sharks of the genus *Sphyrna* focus focused on the spatial-temporal distributions of catches, habitat preferences and catchability of these species around seamounts in the South and Equatorial Atlantic Ocean. In order to obtain the spatial and temporal data of the *Sphyrna lewini*, *Sphyrna zygaena* e *Sphyrna mokarran* catches from 2004 to 2011 were analyzed 29,418 longline sets of foreign and national tuna longline vessels chartered in the Southwest and Equatorial Atlantic. In this period, 6,172 hammerhead sharks were caught representing 0.40% of catches. The spatial distribution of the mean catch per unit effort (CPUE) by quarters showed a trend of higher catches near the equatorial region and in southern Brazil. The CPUE mean was 0.12 sharks/1,000 hooks. Observations about habitat use were designed through the deployment of seven satellite electronic tags in the hammerhead shark (*S. lewini*) around of the Saint Peter and Saint Paul Archipelago (SPSPA). According to the release points and geolocations data hammerhead sharks stayed around SPSPA, suggesting local fidelity. The daily pattern of vertical movement of sharks indicates a preference for shallow waters higher than 25° C and for depths up to 150 m. However, the specimens made frequent dives at greater depths with all dives performed below 500 m depth during the night time period exclusively. The deepest diving recorded for 728 m where the minimum temperature was 5.6° C. Scalloped hammerhead sharks covered a wide extension of the water column ranging from the mixing layer to the mesopelagic zone. During the tagging experiments in SPSPA a female of the *Sphyrna zygaena* species was captured. This is the first confirmed occurrence of a smooth hammerhead shark in SPSPA that expanded the geographic range extension for the species. In order to evaluate the relationship between longline catches of hammerhead sharks and seamounts, the catch and effort distances to nearest seamounts were measured. From 1981 to 2011 in the South Atlantic Ocean and Equatorial 59,556 hammerhead sharks were captured in the total area with 9,519 (16 %) at a distance up to 40 km of the nearest seamount. Due to hammerhead shark species show signs of aggregation in seamounts, nominal and standardized CPUE were calculated for the 0-40 km distances of seamounts. The highest CPUE value (0.90 sharks/1,000 hooks) was calculated at 10 km from the seamount. As catches moved away from seamounts, the value of CPUE decreased, suggesting that formations probably like seamount aggregation for hammerhead sharks.

Keywords: Elasmobranchs. Bycatch. CPUE. PSAT. Behavior. Seamounts. South Atlantic Ocean.

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1.1. Introdução Geral

O grupo dos Chondrichthyes, ao qual pertence os tubarões, raias e quimeras, atualmente é composto por cerca de 1.100 espécies, que estão distribuídas em zonas neríticas e oceânicas, com hábitos pelágicos e demersais. Os tubarões compreendem pouco mais de 500 espécies, classificadas em oito ordens e 34 famílias, com ampla variedade morfológica e aspectos biológicos distintos (Compagno et al., 2005). Embora existam diferenças em suas histórias de vida, os tubarões, de modo geral, são espécies *K*-estrategistas, por apresentarem crescimento lento, maturação sexual tardia e reduzida fecundidade (Hoenig & Gruber, 1990; King & Mcfarlane, 2003), características biológicas que os tornam mais vulneráveis à sobrepesca. Juntamente com a degradação ambiental, a mortalidade por pesca é certamente o principal fator de declínio das populações desses predadores de topo de cadeia, que desempenhm um papel de extrema importância para a saúde dos oceanos (Morgan & Burgess, 2007; Morgan & Carlson, 2010; Amandè et al., 2011; Bromhead et al., 2012; Dent & Clarke, 2015; Ruiz et al., 2015).

Além da pesca excessiva, a destruição e consequente perda de alguns dos seus hábitats essenciais, ocasionadas por ações antrópicas em razão dos processos de industrialização e urbanização, tem causado impactos fortemente negativos nas populações de tubarões, afetando não apenas esses predadores de topo, mas toda a cadeia trófica aquática (Stevens et al., 2000; Jackson et al., 2001; Garcia et al., 2008). Em razão disso, cerca de 6% das espécies de tubarões e raias estão em risco de extinção e 26% se encontram vulneráveis à extinção, de acordo com os critérios da IUCN (*International Union for Conservation of Nature*) (Camhi et al., 2009). Segundo os mesmos critérios, os tubarões martelo *Sphyrna lewini* e *Sphyrna* *mokarran* foram considerados como ameaçados de extinção, devido ao declínio populacional de 90% e 80%, respectivamente, nos últimos vinte e cinco anos. Já o S*phyrna zygaena*, foi classificado como vulnerável à extinção (Casper et al., 2005; Baum et al., 2007; Denham et al., 2007).

Os tubarões martelo *S. lewini*, *S. zygaena* e o *S. mokarran* são as três espécies de maior porte do gênero *Sphyrna*, sendo também as mais representativas em número de capturas (Compagno et al., 2005; Bezerra et al., 2016). Essas espécies possuem uma extensa faixa de ocorrência, com distribuição cosmopolita, exibindo preferência por águas tropicais e temperadas, sendo encontradas preferencialmente em ambientes costeiros, semi-oceânicos e, especialmente o *S. lewini*, em ecossistemas insulares (Klimley & Nelson, 1984; Compagno et al., 2005). Por sua vez, a amplitude na diversidade de habitats, faz com que os tubarões martelo sejam explorados pela pesca artesanal e industrial, em virtude do comércio de suas longas nadadeiras (Motta et al., 2005; Clarke et al., 2007; Myers et al., 2007). Indivíduos juvenis de *S. lewini*, por exemplo, tendem a ser mais costeiros, sendo consequentemente mais capturados pela frota artesanal (Vooren, 1997; Lessa et al., 1998). Quando se tornam subadultos, as fêmeas em menores comprimentos do que os machos, migram em direção às regiões oceânicas, tornando-se alvo de captura pela frota pesqueira industrial (Klimley, 1987; Heupel & Simpfendorfer, 2005). Nos últimos anos, em grande parte de suas áreas de ocorrência nos oceanos Atlântico, Pacifico e Índico, foram registrados declínios populacionais que variaram de 60% a 99% para algumas das principais espécies de tubarões martelo (Baum et al., 2003; Dudley & Simpfendorfer, 2006; Denham et al., 2007; Myers et al., 2007). A principal causa desse declínio foi certamente a mortalidade por pesca, advindas de diferentes aparelhos e métodos, tais como espinhel, linha de mão, redes de emalhar, cerco e arrasto (Bonfil, 1994).

Embora a pesca com o uso do espinhel seja considerada uma atividade seletiva, no oceano Atlântico Norte a população de tubarões martelo (*S. lewini*, *S. zygaena* e *S. mokarran*) declinou 76%, enquanto no Atlântico Sul essa redução correspondeu a 61%, em detrimento exclusivo da pesca de espinhel, indicando que essas espécies representaram uma parcela importante no montante das capturas de elasmobrânquios em todo o Atlântico (Kotas 2004, Vooren & Klippel, 2005; Amorim et al., 2011; Baum & Blanchard, 2010; Barreto et al., 2015). No Brasil, apesar da frota espinheleira ter como espécies-alvo os atuns (*Thunnus* sp.) e o espadarte (*Xiphias gladius*), um volume considerável de elasmobrânquios é capturado incidentalmente (*bycatch*) como fauna acompanhante dessa pescaria (Hazin 2006; Frédou et al., 2015), razão pela qual várias medidas mitigadoras têm sido adotadas com o objetivo de reduzir esse impacto sobre os estoques das espécies mais afetadas.

A proibição da prática do *finning*, que é a remoção e a retenção das nadadeiras dos tubarões e posterior descarte do corpo, foi uma das medidas pioneiras executadas pelos órgãos ambientais brasileiros em prol da conservação dos tubarões e raias, já em 1998 (IBAMA, nº 121/1998). Em 2005, foi publicado o Plano Nacional de Ação para a Conservação e o Manejo de Peixes Elasmobrânquios no Brasil, fruto de um exaustivo trabalho da sociedade científica cujo principal objetivo foi trazer subsídios para a implementação de medidas para a conservação do grupo (Lessa et al., 2005). Atualmente, o PAN (Plano de Ação Nacional para a Conservação dos Elasmobrânquios) tem realizado reuniões periódicas com o desafio de avaliar as condições dos estoques, bem como promover medidas que possam evitar o colapso das populações. Uma das resoluções mais expressiva e debatida atualmente para a conservação dos elasmobrânquios no país, foi a publicação da portaria 445 pelo Ministério do Meio Ambiente (MMA), em dezembro de 2014, a qual inseriu 55 espécies de tubarões e raias na lista de espécies ameaçadas de extinção, em várias categorias de ameaça: vulnerável, em perigo e criticamente em Perigo (MMA, nº 445/2014). A partir da sua publicação, houve sucessivas suspensões da lista por mandados judiciais, encontrando-se a mesma, no momento, porém, em vigor, e as espécies ali inseridas retornaram ao seu status de proteção.

Em paralelo às iniciativas nacionais, a ICCAT (*International Commission for the Conservation of Atlantic Tunas*), uma das 5 organizações regionais de gestão da pesca de atuns no mundo (RFMOs), tem adotado diversas medidas de ordenamento voltadas não só para a conservação dos estoques de atuns, mas também da fauna acompanhante ameaçada. A primeira medida inédita da ICCAT destinada especificamente à conservação de uma espécie de tubarão, o tubarão raposa (*Alopias superciliosus*), foi adotada pela Comissão, no ano de 2009, sob a presidência brasileira. Naquele ano, a ICCAT tornou proibida a retenção a bordo, o armazenamento ou a venda de qualquer exemplar de tubarão raposa. Diversas medidas de conservação foram desde então adotadas para os tubarões martelo (*Sphyrna* sp.), mako (*Isurus oxyrinchus*), galha-branca oceânico (*Carcharhinus longimanus*) e o lombo preto (*Carcharhinus falciformis*) (Tolotti et al., 2015). Em relação aos tubarões martelo, já no ano seguinte, em 2010, a ICCAT aprovou uma medida de ordenamento aplicável a todo o gênero *Sphyrna*, com exceção do *Sphyrna tiburo*, proibindo a sua pesca dirigida, retenção a bordo, armazenamento ou venda, exceto em países em desenvolvimento e para consumo interno. Ainda, a exportação de qualquer das partes dos tubarões martelo foi proibida, com vistas a inibir a comercialização de suas nadadeiras (ICCAT, 2010).

A dificuldade no processo de identificação das diferentes espécies de tubarão martelo sempre foi um entrave para o desenvolvimento de pesquisas sobre as mesmas e para a consequente adoção de medidas de conservação específicas para cada espécie, acarretando consequências negativas para as suas diferentes populações. A identificação precisa, não apenas de uma dada espécie, mas até mesmo de estoques diferentes de uma mesma espécie, é um aspecto crucial para uma gestão eficiente da atividade pesqueira com vistas a assegurar a necessária conservação dos estoques explotados, não apenas no caso dos tubarões martelo, mas de outros gêneros, a exemplo do gênero *Carcharhinus*, que sofre a mesma dificuldade (Bornatowski et al., 2014a).

Mesmo diante da problemática para a identificação das espécies, estudos específicos sobre a história de vida do *S. lewini*, *S. mokarran* e *S. zygaena* vêm sendo publicados, trazendo informações biológicas preciosas em relação à reprodução (Hazin et al., 2001; Harry et al., 2011), alimentação (Bornatowski et al., 2007; Vaske et al., 2009; Bornatowski et al., 2014b) e idade e crescimento (Piercy et al., 2010; Coelho et al., 2011; Kotas et al., 2011). Já a literatura relacionada ao aporte de dados relacionados as capturas dos tubarões martelo e suas distribuições espaço-temporais, existe uma tendência de agrupar as informações apenas ao nível de gênero, já que dependem, na maioria das vezes, das bases de dados oficialmente compiladas, as quais dificilmente dispõem das informações individualizadas por espécie (Zeeberg et al., 2006; Mader et al., 2007; Barreto et al., 2015; Bezerra et al., 2016). Além dos estudos que versam a respeito dos aspectos biológicos das espécies, em anos recentes tem crescido o número de trabalhos com o uso de metodologias não letais, as quais, entre outras funções, são capazes de desvendarem caraterísticas ecológicas e comportamentais das espécies estudadas (Musyl et al., 2011). A partir da utilização de dispositivos eletrônicos (acústico e via satélite), tornou-se possível elucidar os padrões de movimentação de espécies altamente migradoras, a exemplo de vários elasmobrânquios. Além de ser um método pouco invasivo e de baixo impacto, com níveis extremamente baixos de letalidade, associados quase sempre ao processo de captura, as marcas eletrônicas têm sido capazes de monitorar remotamente os animais marcados, fornecendo informações inéditas sobre os seus ciclos de vida e movimentos migratórios (Hazin et al., 2013; Thorrold et al., 2014; Afonso & Hazin, 2015; Branco-Nunes et al., 2016).

Pesquisas sobre a movimentação de tubarões martelo com o uso de transmissores eletrônicos têm sido direcionadas principalmente para o *S. lewini*, com os primeiros resultados já tendo sido publicados desde a década de 80 (Klimley & Nelson, 1984), reportando informações especialmente relacionadas aos deslocamentos verticais da espécie em ilhas e montes submarinos (Klimley et al., 1988; Hearn et al., 2010; Ketchum et al., 2014). Essas formações topográficas são zonas com alta produtividade que servem de abrigo, proteção ou moradia para diversos grupos taxonômicos (Worm et al., 2003; White et al., 2007). A possível interação entre os tubarões martelo e os montes submarinos vem sendo objeto de estudo também no Brasil, já há algum tempo (Hazin et al., 2001; Vaske et al., 2009). A partir das interpretações dos dados coletados por transmissores eletrônicos, a exemplo das marcas monitoradas via satélite PSAT (*Pop-up satellite archival tag*), é possível se identificar os hábitats preferenciais e o seu uso pelas diferentes espécies (Klimley et al., 1988; Bessudo et al., 2011; Hoyos-Padilla et al., 2014), além de desvendar padrões migratórios e de deslocamentos verticais, com base nos quais é possível inferir alguns aspectos biológicos da espécie, tais como possíveis zonas de reprodução e de alimentação.

Diante desse contexto, a presente tese foi elaborada na forma de quatro artigos que versam, em seu conjunto, sobre as capturas dos tubarões martelo no Atlântico sudoeste e equatorial, sobre o uso preferencial do hábitat pelo *S. lewini* a partir do monitoramento iniciado no Arquipélago de São Pedro e São Paulo (ASPSP), sobre a ocorrência inédita e a consequente extensão da área de ocorrência para uma espécie do gênero *Sphyrna* no ASPSP, e, por fim, sobre a relação dos tubarões martelo com os montes submarinos no oceano Atlântico Sul e equatorial. Os resultados gerados nessa tese são de caráter inédito para essa região do Atlântico, e visam contribuir com os esforços de conservação já existentes para o gênero *Sphyrna* no Brasil e em toda a bacia atlântica.

1.2. Informações sobre as espécies estudadas

Os tubarões martelo pertencem à ordem Carcharhiniformes, família Sphyrnidae e gênero *Sphyrna*, sendo esse último composto atualmente por nove espécies, entre as quais sete podem ser encontradas no oceano Atlântico Sul: *Sphyrna media* (Springer, 1940), *Sphyrna mokarran* (Rüppell, 1837), *Sphyrna tiburo* (Linnaeus, 1758), *Sphyrna tudes* (Valenciennes, 1822), *Sphyrna zygaena* (Linnaeus, 1758), *Sphyrna lewini* (Griffith & Smith, 1834) e a nova espécie descrita, *Sphyrna gilberti* (Quattro, Driggers III, Grady, Ulrich & Roberts, 2013) (Compagno et al., 2005; Pinhal et al., 2012). As espécies do gênero *Sphyrna* são facilmente distinguidas em decorrência da anatomia peculiar da sua cabeça, que é um atributo incomum às demais espécies de tubarões. Alguns aspectos morfológicos, tais como a coloração da pele e da íris, e o tamanho, posição e formato das nadadeiras, são caraterísticas diagnósticas que diferenciam as diferentes espécies de tubarões martelo entre si. Contudo, a forma, ângulo de curvatura e a presença ou ausência de entalhe na porção cefálica mediana, são os caracteres morfológicos que mais facilmente distinguem as espécies que compõem o gênero Sphyrna (Compagno et al., 2005; Vooren & Klippel, 2005). As espécies *S. lewini*, *S. mokarran* e *S. zygaena* (Fig. 1) são as mais abundantes e as que atingem os maiores comprimentos, sendo também as que mais se assemelham morfologicamente (Bonfil, 1994; Compagno et al., 2005; Vooren & Klippel, 2005).

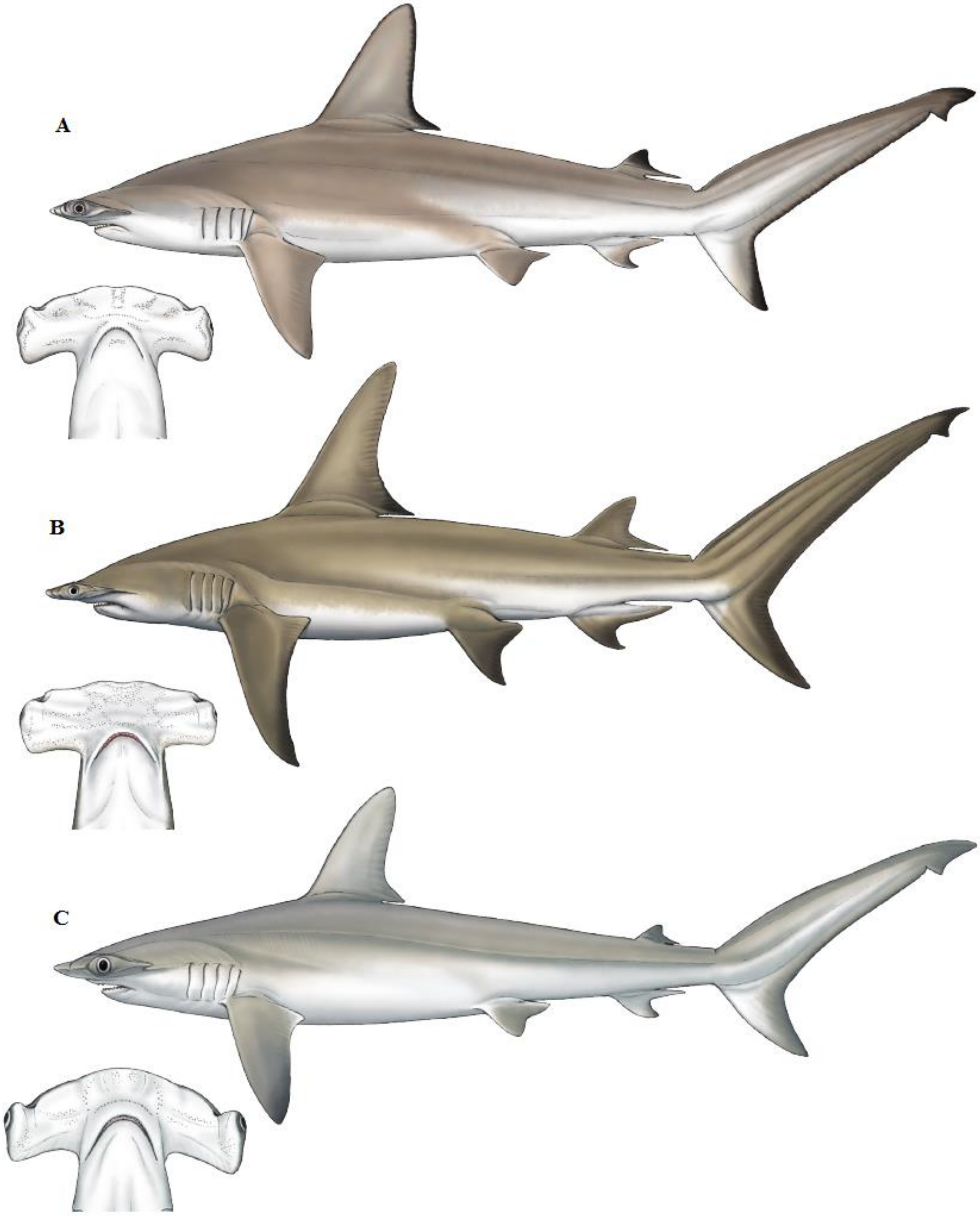

Figura 1: Três espécies de tubarão martelo: A. *Sphyrna lewini*, B. *Sphyrna mokarran* e C. *Sphyrna zygaena*. Note a diferença na curvatura e entalhe mediano em cada cabeça. Fonte: Id Guide Shark Trust, Fondation Ensemble.

Os tubarões martelo são vivíparos placentários, sendo gerados de dois até 42 embriões por gestação, que pode durar até 11 meses (Compagno, 1984). O comprimento total máximo registrado para o *S. lewini* é de 420 cm, com medidas mais frequentes em torno de 370 cm (Compagno, 1984; Compagno, 1998). As fêmeas de *S. lewini* atingem a maturidade sexual por volta dos 240 cm e os machos entre 180 cm e 200 cm de comprimentos totais (CT) (Hazin et al., 2001). O *S. mokarran* é a maior espécie do gênero, com um comprimento total máximo relatado de até 610 cm (Compagno et al., 2005), embora sejam mais comuns os indivíduos atingirem os 400 cm de CT (Compagno, 1984; Bonfil, 1994). Ambos os sexos alcançam a maturidade sexual aos 279 cm (CT) (Harry et al., 2011). Já o *S. zygaena* tem seu comprimento máximo total reportado entre 370 cm e 400 cm (Compagno et al., 2005), embora seja mais comum encontrar indivíduos com 335 cm de CT (Compagno, 1998). Machos e fêmeas dessa espécie maturam entre 210 e 240 cm (CT) (Compagno et al., 2005).

Os cefalópodes parecem ser o item de maior importância na dieta do *S. lewini* e *S. zygaena*, com as lulas da família Cranchiidae e os exemplares de *Histioteuthis* spp., *Hyaloteuthis* spp., *Lolliguncula brevis* e *Doryteuthis* spp. correspondendo às presas mais representativas nos seus conteúdos estomacais (Vaske-Jr et al., 2009; Bornatowski et al., 2014b). Teleósteos, elasmobrânquios e crustáceos também fazem parte da dieta alimentar dessas duas espécies, que são consideradas predadores especialistas, mas que aparentemente não apresentam sobreposição alimentar (Smale, 1991; Bornatowski et al., 2007; Vaske et al., 2009; Bornatowski et al., 2014b). O *S. mokarran* é a espécie cujo hábito alimentar menos se conhece, embora se saiba que os peixes ósseos, cefalópodes e crustáceos correspondem a uma menor parcela de sua dieta. Nos conteúdos estomacais do *S. mokarran* foram encontrados elevados índices de outros elasmobrânquios menores, a exemplo da *Dasyatis americana* com até 1,5 m de largura do disco (Strong et al., 1990; Smale & Cliff, 1998).

2. Capítulo II

2.1. Artigo científico I

Artigo científico publicado no **Journal of Fish Biology**

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VULNERABILITY TO LONGLINE FISHERIES OF THREE HAMMERHEAD SHARK *SPHYRNA* SPECIES IN THE SOUTH-WESTERN AND EQUATORIAL ATLANTIC OCEAN

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ABSTRACT

Catch and effort data from 29 418 longline sets from Brazilian tuna longline vessels operating in the south-western and equatorial Atlantic Ocean between 2004 and 2011 were analysed to investigate the distribution, catch rate and size of three species of hammerhead sharks (*Sphyrna lewini*, *Sphyrna mokarran* and *Sphyrna zygaena*). During that period, 6,172 hammerhead sharks were caught. Among the elasmobranchs, the highest percentage of hammerhead sharks were caught in 2007, when they accounted for 3.90% of the group, while the lowest value of 0.40% was recorded in 2010. In general, the spatial distribution of the mean catch per unit effort (CPUE) by years and quarters showed a trend of higher catches near the equatorial region and in southern Brazil. The nominal mean CPUE was 0.12 *Sphyrna* spp. 1000^{-1} hooks, with the highest value being recorded in 2007 (0.30 *Sphyrna* spp. 1000^{-1} hooks). The standardized yearly CPUE estimated by a generalized linear model assuming a zero inflated negative binomial (ZINB) distribution were not much different from nominal values. Of the 205 sexed specimens, 117 were females and 88 were males, resulting in a sex ratio with a predominance of females (1.30:1.00), although not statistically significant. The total length of females ranged from 1200 to 2800 mm and of males from 1100 to 3100 mm. Juvenile hammerhead sharks represented 82 and 54% of the sexed female and male specimens, respectively.

Keywords: Brazilian fleet; by-catch; Chondrichthyes; CPUE; distribution; elasmobranch

INTRODUCTION

Shark and ray populations are especially susceptible to overfishing due to their biological characteristics, such as low fertility, late sexual maturation and high longevity (Stevens *et al*., 2000; Schindler *et al.*, 2002). Global estimates indicate that, since 2005, the annual landings of Chondrichthyes have remained around 750,000 t, with sharks accounting for about 2/3 of that figure (500,000 t) (FAO, 2014). However, if discards and unreported catches of some species are added, the actual value could possibly be two or even three times greater than that, such as, for example, estimates of 1,4 million t in 2010, for only shark catches (Worm *et al.*, 2013).

Despite the high amount of shark catches worldwide, they are caught mainly as bycatch by pelagic longline fisheries, targeting tunas (*Thunnus sp*.) and swordfish *Xiphias gladius* (Linnaeus 1758) (Amorim *et al.*, 1998; Marin *et al.*, 1998). In Brazil, shark catches represented about 10% of the total catch made by chartered tuna longliners boats, in 2004. This percentage, however, has considerably increased since then, surpassing 30%, in 2009, with the majority of the shark catches being made up by blue sharks *Prionace glauca* (Linnaeus 1758) (Frédou *et al.*, 2015).

In light of the global trend of sharp decline of several shark stocks worldwide, mitigating measures started to be adopted by various nations and international organizations, such as The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the International Commission for the Conservation of Atlantic Tunas (ICCAT). CITES, for instance, included, in 2013, scalloped hammerhead shark *Sphyrna lewini* (Griffith & Smith 1834), smooth hammerhead shark *Sphyrna zygaena* (Linnaeus 1758) and great hammerhead shark *Sphyrna mokarran* (Rüppell 1837) in appendix II, aiming at establishing strict control over their export, in order to minimize their risk of extinction (CITES 2015). ICCAT, on the other hand, adopted, in 2010, a recommendation restricting the landings and trading of any species of the genus *Sphyrna* (except bonnethead shark *Sphyrna tiburo* (Linnaeus 1758)), to enable the recovery of their populations (ICCAT, Rec. 10-08).

In spite of the fact that conservation measures have been implemented for hammerhead sharks worldwide, the scalloped hammerhead and the great hammerhead sharks were classified as endangered, and the smooth hammerhead as vulnerable, in the red list of threatened species of the IUCN (International Union for the Conservation of Nature) (Casper *et al.*, 2005; Baum *et al.*, 2007; Denham *et al.*, 2007). These species are usually found in coastal and semi-oceanic environments, as well as in island ecosystems, and have a cosmopolitan distribution in tropical, subtropical and temperate regions. The three species occur off the Brazilian coast, although the smooth hammerhead is most frequently found below 22º latitude (Compagno, 1984). Hammerhead sharks have been under an increasing fishing pressure worldwide due to its wide distribution and especially to the high commercial value of their large fins. In the South Atlantic Ocean, hammerhead sharks are caught both near coastal environments by artisanal fisheries (Motta *et al.*, 2005), as well as in the open ocean by industrial fishing boats (Mader *et al.*, 2007; Amorim *et al.*, 2011).

Currently, the majority of studies carried out on the genus *Sphyrna* (Rafinesque 1810) have been related to their biological traits (Harry et al., 2011; Bornatowski et al., 2014a) and especially in relation to *S. lewini*, to the use of habitat and migratory movements (Bessudo et al., 2011; Hoffmayer et al., 2013). Few studies, however, have been conducted in order to assess the effect of fishing on *Sphyrna* spp., despite their well-known and significant contribution to the elasmobranchs caught by different fishing gears worldwide, including the south-west Atlantic Ocean (Mazzoleni & Schwingel, 1999; Vooren et al., 2005). Studies on their contribution in the tuna longline fishery, particularly on the spatio-temporal distribution of their catches, are especially scarce. The identification of *Sphyrna* species, however, is crucial for management purposes to elucidate which parts of the different populations of hammerhead species are subject to a higher degree of fishing pressure. In general, the hammerhead shark species are classified as 'hammerhead' in logbooks. For this reason, the data collected from industrial and artisanal fisheries are problematic in many fishery statistics. This situation is common for many shark species (Bornatowski et al., 2014b).

In view of this, the present study compiles information about catch rates, spatio-temporal distribution, length–frequency distribution and sex ratio of the three species of hammerhead sharks (*S. lewini*, *S. zygaena* and *S. mokarran*) caught by the Brazilian tuna longline vessels in the south-west and equatorial Atlantic Ocean, aiming at supporting potential management measures for the conservation of these species.

MATERIALS AND METHODS

The study was conducted in the south-west and equatorial Atlantic Ocean between 10◦ N and 40◦ S and from 5◦ E to 55◦ W (Fig. 2). Catch and effort data from 29,418 longline sets conducted by chartered and national Brazilian tuna longline boats between 2004 and 2011, were analysed to investigate the distribution, catch rate and size of the three species of sphyrnids. Since these three species are morphologically close, however, and misidentification is very likely, all catch data had to be merged. Besides, in many cases, the species was only indicated by its general name, of hammerhead (*Sphyrna* spp.). Fishing logbook data were made available by the Brazilian Ministry of Fisheries and Aquaculture (MPA). Logbooks contain information about the date, latitude and longitude of gear setting and retrieval, individual catches of all species (tunas and like-tunas), the flag of the boat (in the case of chartering) and the number of hooks deployed.

Chartered and national Brazilian tuna longline vessels are separated into two fishing strategies, according to their main target species: swordfish or tunas. The criteria adopted for separating the national fleet into these two fishing strategies was the percentage of the target species in the catches (>50%) confirmed by the MPA website fisheries permit. Whenever the target species could not be identified, the boats were excluded. In the case of chartered vessels, the division of the data set into these two strategies followed previous studies (Tolotti *et al*., 2013). In fishing operations targeting swordfish, gear setting was during the night, using a shallower longline and, very frequently, light sticks and squids as bait. The second strategy, targeting tunas, uses a deeper longline, able to reach to 250m depth, operated mainly during daytime and using small fishes or squid as bait (Araújo *et al*., 2013).

Catch per unit effort (CPUE) was calculated as the number of hammerhead sharks caught 1000^{-1} hooks. Nominal CPUE was calculated by 5° latitude × 5° longitude squares, by quarters and years, to evaluate the spatial and temporal distribution of catches. The spatial distribution of the total effort, including those with zero catches of *Sphyrna* spp., was plotted.

In order to assess whether seasonality, fishing operations and fishing area (Table I) affect annual variability of catches, a standardization of CPUE by generalized linear models (GLM) was made assuming negative binomial and Poisson distributions. Models were constructed by assessing different response variables based on the selection of the smallest AIC (Akaike, 1987). After selecting predictors, the model was structured in the following order: years, areas, fishing operations and quarters. Since the variable of interest (catch per set) showed a clear excess of zeros identified in exploratory analysis, the zero inflated Poisson (ZIP) and zero inflated negative binomial (ZINB) models were tested, evaluating AIC values in the same way (Brodziak & Walsh, 2013). In addition, the Vuong test was performed in order to compare the superiority of the models with non-inflated zero and zero inflated models (Vuong, 1989). As a result, zero inflated models had a better performance because excess zeros could be modelled independently. The statistical analysis was performed with the pscl and mass packages in R (www.r-project.org).

Data on length and sex of hammerhead sharks were collected by observers of the National Observer Programme, on board chartered Brazilian tuna longline vessels. Males and females were classified into immature and mature based on their total length (LT) according to previous studies (mature females > 2400 mm LT; mature males > 2000 mm *LT*) and were plotted in 1° longitude × 1° latitude squares for the spatial distribution (Hazin *et al*., 2001; Harry *et al*., 2011). A χ^2-square test was performed to test differences in sex ratio, while differences in the *LT* frequency distribution of males and females were tested by Kolmogorov–Smirnov test (Zar, 2010). Statistically significant difference was set at $P<0.05$.

Table I: GLM variables for standardized CPUE of hammerhead sharks captured between 2004-2011 in the Southwestern and Equatorial Atlantic Ocean.

Variables	Details
Years	2004 until 2011
Areas	Area 1: North (010° N - 05°S)
	Area 2: Northeast (05°S - 020°S)
	Area 3: South and Southeast (020°S - 040°S)
Quarter	1 st: Jan, Feb e Mar
	2 nd: Apr, May e Jun
	3 rd: Jul, Aug e Sep
	4 th: Oct, Nov e Dec
Fishery operations	Shallow longline (SL) and Deep longline (DL)

RESULTS

Approximate total effort in this study was 48 million hooks, about a fourth of which (26.90%) was deployed in 2005. After this year, effort decreased until 2008 (2 million hooks), increasing again in 2009, up to 2.5 million hooks. In 2010, effort decreased again, reaching the minimum value with just over a million and a half hooks (3.30% of total). Fishing operations with shallow longline had a total effort of about 25 million hooks over eight years, close to half of the total effort. Between 2004 and 2006, fishing effort fluctuated around five million hooks per year, declining in subsequent years. For deep longline fishing operations, total effort was close to 23 million hooks. The greatest effort for this fishing strategy was recorded in 2005, when approximately seven million hooks were used, decreasing thereafter (Fig. 1).

The fishing effort employed by the chartered and national Brazilian tuna longline vessels was concentrated especially between 05°S-05°N of latitude and 040°-025°W longitude. In addition, other two areas of high concentration of effort were: 025º-035ºS/ 055º- 045ºW; and between 15º-25ºS of latitude and 035º-020ºW longitude (Fig. 2).

From 2004 to 2011, approximately one million specimens of tuna and tuna-like species were caught. About one third (320,000 individuals) was caught in 2005, when the highest fishing effort was used, followed by 2004, when 310,000 fish were caught. The year with the lowest effort and catch in number of fish (45,000) was 2010. Reflecting the trends in overall catches, in 2005, the number of elasmobranchs caught was the highest recorded for the period, approaching 63,000. Likewise, the lowest elasmobranch catch was recorded in 2010, when about 9,000 sharks and rays were caught (Fig. 3).

Hammerhead sharks contributed 0.40% of the total number of fish caught between 2004 and 2011. During this period, 6,172 hammerhead sharks were caught by national and chartered boats. The highest relative proportion of hammerhead sharks in the catch was observed in 2007; both in relation to the total number of fish caught (finfish and elasmobranchs) (0.90%), and to the elasmobranch catch (3.90%). The lowest percentages were observed in 2010, when these values were equal to 0.10% and 0.40%, respectively (Fig. 2). The highest number of hammerhead sharks (1,655) was recorded in 2005, while the lowest value was observed in 2010, when only 37 sharks were caught. Shallow longline fishing operations caught more sharks in all years, except in 2010 (Fig. 1). The overall nominal CPUE, averaged for all fishing sets, for the shallow longline fishing, equal to 0.14 sharks/1,000 hooks, was almost twice the value for deep longline fishing (0.08 sharks/1,000 hooks) (Fig. 3). The highest values for both fishing strategies were recorded in 2007: 0.37 sharks/1,000 hooks for the shallow longline, and 0.20 sharks/1,000 hooks for the deep longline (Fig. 4).

The mean CPUEs of hammerhead sharks for 5º x 5º squares, for all years combined showed low values (under 0.20 sharks/ 1,000 hooks) for the majority of the fishing ground. Higher values were observed in three main areas: a) in the equatorial region, in more coastal waters off northern Brazil (05ºN-05ºS/ 040º-050ºW), where the highest CPUE value (8.50 sharks/ 1,000 hooks) was found; b) also in the equatorial region, but far away from the Brazilian coast (0º-05ºS/ 010º-020ºW); and c) off southern Brazil, south of 15ºS, both closer to the coast (20º-35ºS), as well as far away from it, up to 15º-20ºS/ 025º-030ºW (Fig. 5).

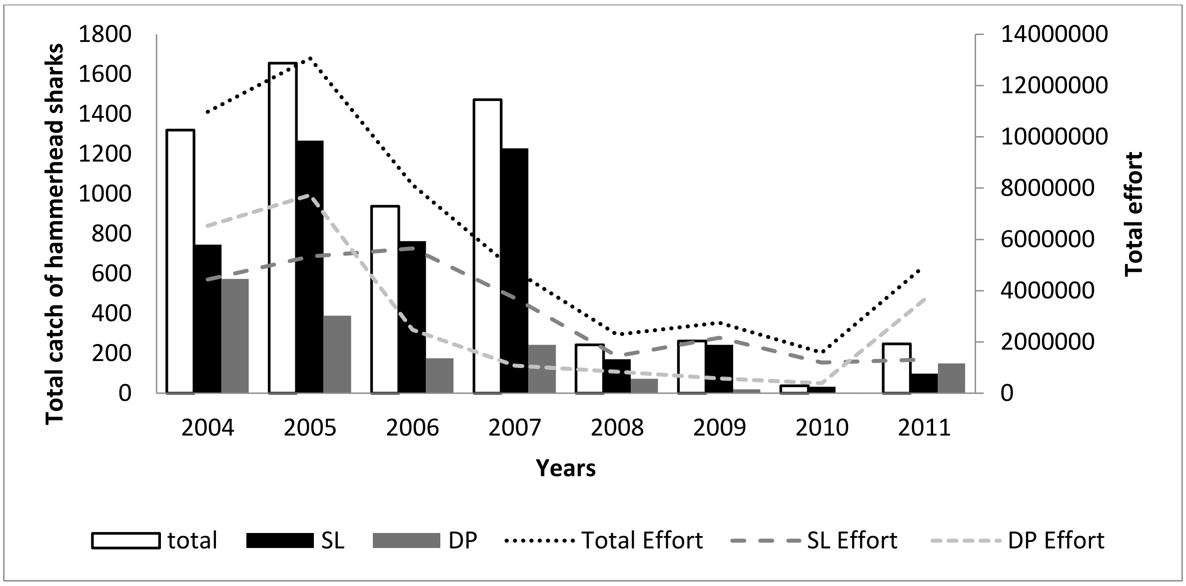

Figure 1: Total number of hammerhead sharks caught per fishing operation of shallow longline (SL) and deep longline (DL), and fishing effort (lines) of Brazilian national and chartered longline boats in the southwestern and equatorial Atlantic Ocean, from 2004 to 2011.

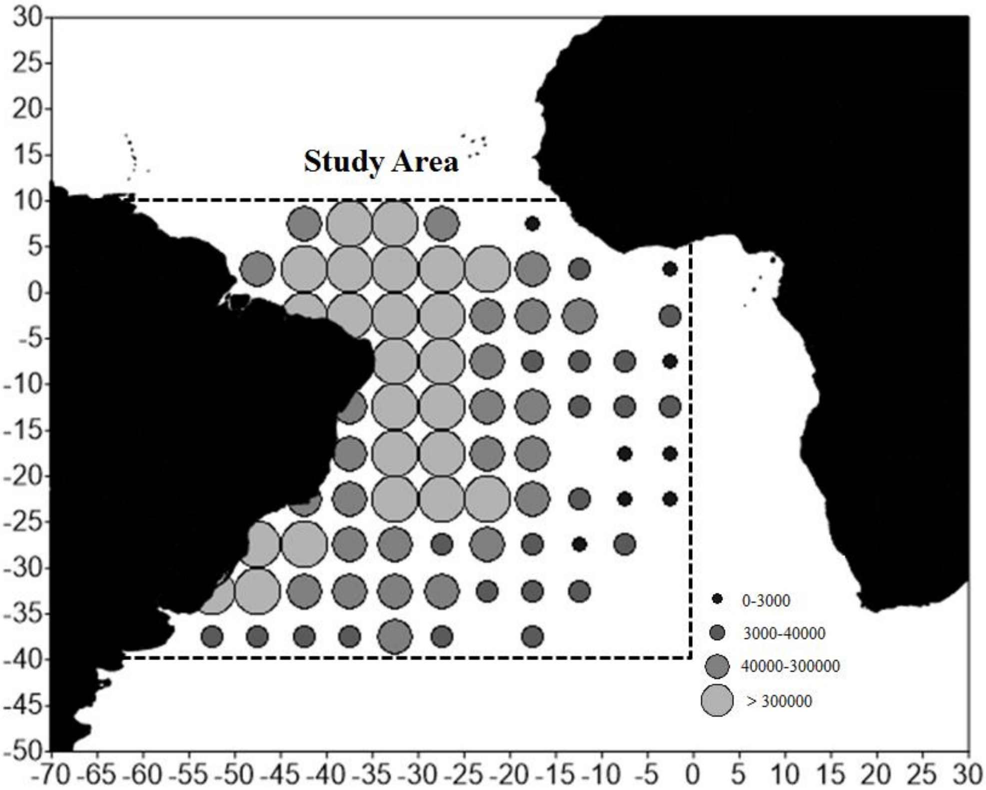

Figure 2: Spatial distribution of fishing effort (number of hooks) of Brazilian national and chartered longline boats between 2004 and 2011 in the Southwestern and Equatorial Atlantic Ocean.

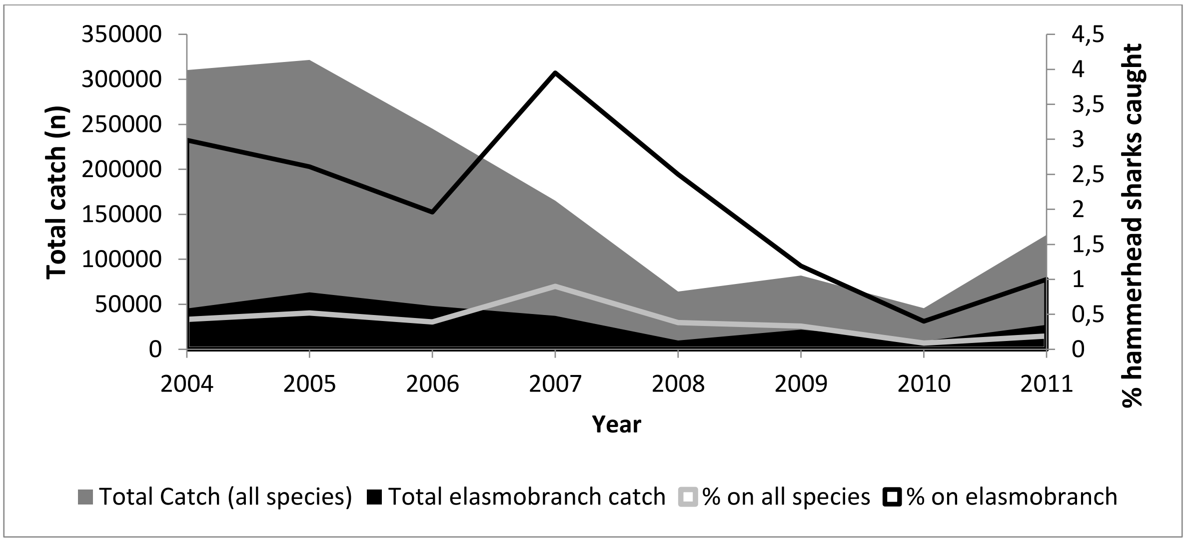

Figure 3: Total catch of all species and of only elasmobranchs, and relative participation (%) of hammerhead sharks, between 2004 and 2011, in the southwestern and equatorial Atlantic Ocean by Brazilian national and chartered tuna longline boats.

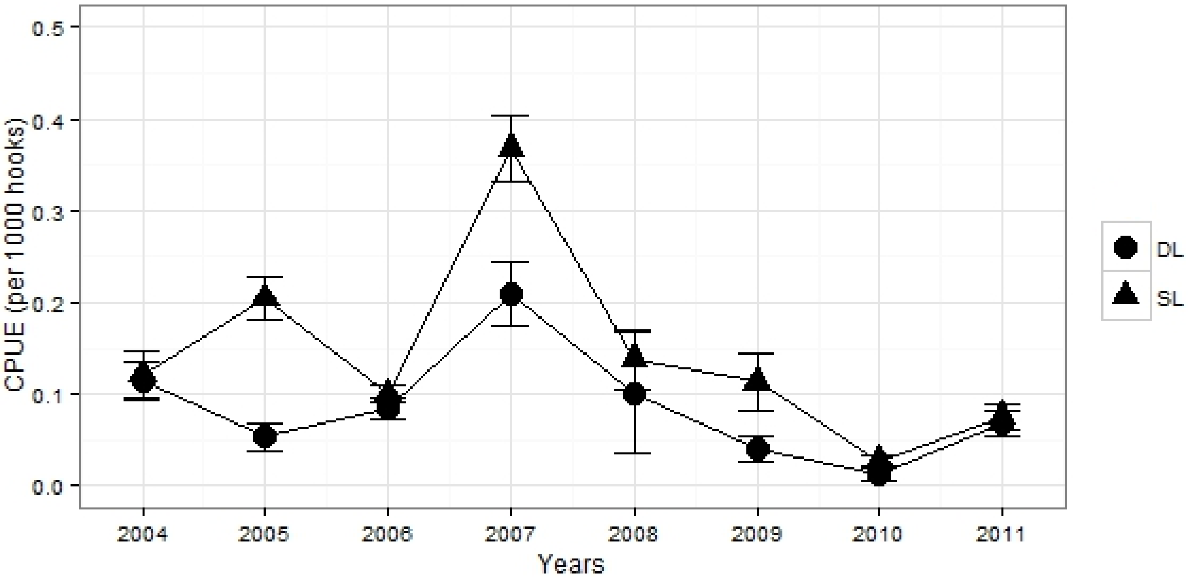

Figure 4: Nominal CPUE of the Shallow longline (SL) and Deep longline (DL) fishing operations for hammerhead sharks caught from 2004 to 2011, by Brazilian national and chartered longline boats, in the southwestern and equatorial Atlantic Ocean. The bars mean standard deviation.

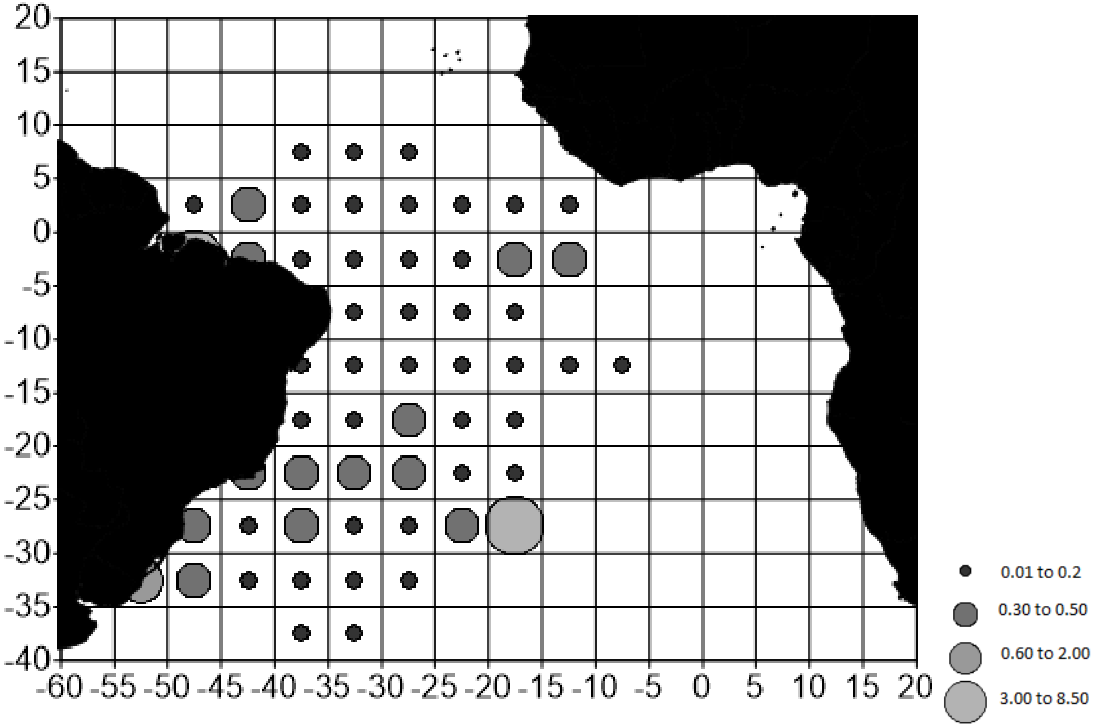

Figure 5: Distribution of the CPUE (number of sharks per 1,000 hooks) for hammerhead sharks caught by Brazilian national and chartered longline boats, in the southwest Atlantic and equatorial Ocean, from 2004 to 2011.

The mean CPUEs of hammerhead sharks for 5º x 5º squares, for all years combined, averaged by quarters of the year, indicated that the higher abundance in the equatorial region, close to the Brazilian coast (05ºN-05ºS/ 040º-050ºW), was more pronounced in the first and second quarters, disappearing thereafter. The second area of higher abundance, also located in the equatorial region but far away from the Brazilian coast, is noticeable in 0º-05ºS/ 010º-020ºW, during the first quarter, and around 05ºN-0º/ 020º-025ºW, during the third quarter. The high CPUE values off southern Brazil, close to the coast, were located from 20º-25ºS, during the first quarter, moving gradually south, to 25º-35ºS, during the second quarter, and from 30-35ºS, during the third and fourth quarters. The higher CPUEs, located off southern Brazil, far away from the coast, also seemed to exhibit a seasonal displacement, moving further south and eastward, from the fourth to the second quarter. The squares with higher CPUEs were respectively located at 20º-25ºS/ 030º-035ºW, during the 1st quarter; at 25º-30ºS/ 020º-030ºW, during the 2nd quarter; and at 20º-25ºS/ 030º-035ºW, during the 3rd quarter. During the 4th quarter it was no longer noticeable (Fig. 6).

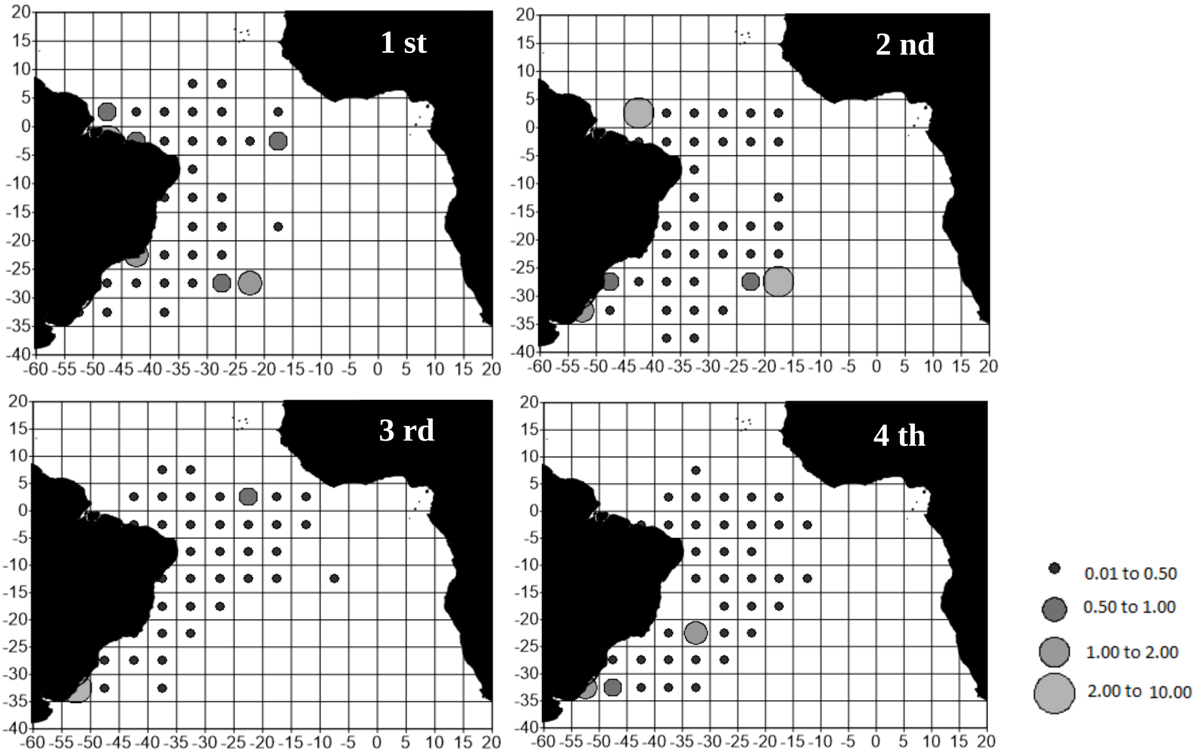

Figure 6: Quarterly distribution of the mean CPUE mean (number of sharks per 1,000 hooks) of hammerhead sharks, caught by Brazilian national and chartered longline boats, in the southwestern and equatorial Atlantic Ocean, from 2004 to 2011.

Results from the Vuong test, which was applied to compare non-inflated zero and zero inflated models for standardization of the CPUE, indicated that zero inflated models were more appropriate (ZINB > BN, p< 2.22e-16; ZIP > Poisson, p< 2.51e-09). The Zero inflated Negative Binomial (ZINB) model was considered the most appropriate due to the lower AIC (20335,4) compared to the ZIP model (AIC value of 27837,7). The ZINB model was able to fit results to variable catch for both, the null generating (zero inflated model) and for non-zero values (count models) that obey the usual negative binomial distribution. The response variables showed statistically significant differences between years, areas, quarters and fishing strategy (DL x SL), in general. Exceptions were found in years 2007 and 2008 and area 3 for the Count models and in 2008, 2010 and 2011 for the zero inflated model. In estimating the Count models, only area 3 had a positive influence over area 1. For the model with zeros, all variables showed negative estimates except for year 2011 and for the fishing operation (Table II).

Table II: Coefficients for CPUE of the ZINB model of hammerhead sharks. Model's estimation standard error (SE) and respective p values.

Count models					Zero Inflated			
Factor	Estimate	SE	Pr(>|z|)		Estimate	SE	Pr(>|z|)	
(Intercept)	-6.68116	0.1813	< 2e-16	***	2.8733	0.1691	< 2e-16	***
2005	-0.47694	0.13673	0.000486	***	-1.0409	0.1435	3.99E-13	***
2006	-0.89874	0.15078	2.51E-09	***	-1.1909	0.1911	4.62E-10	***
2007	-0.08795	0.16429	0.592421		-1.8219	0.2302	2.51E-15	***
2008	-0.11996	0.22044	0.586326		-0.4628	0.2516	0.06592	
2009	-0.91063	0.20105	5.92E-06	***	-0.6749	0.2585	0.00903	**
2010	-2.22047	0.34008	6.61E-11	***	-0.9479	0.5282	0.07271	
2011	-0.49457	0.21078	0.018955	*	0.1289	0.2009	0.52113	
area2	-0.57737	0.15735	0.000245	***	-1.6598	0.2894	9.74E-09	***
area3	0.18456	0.11804	0.117934		-1.0428	0.1613	1.01E-10	***
DL	-0.23929	0.0949	0.011685	*	0.4667	0.1101	2.25E-05	***
2 nd	-0.81442	0.1908	1.97e-05	***	-1.6124	0.2092	1.29E-14	***
3 rd	-0.69616	0.13684	3.63e-07	***	-2.0350	0.1539	< 2e-16	***
4 th	-1.15505	0.13104	< 2e-16	***	-1.6444	0.1498	< 2e-16	***

*significance levels of 10%, ** 5% , *** 1 %

Nominal and standardized CPUEs showed a very similar trend, being rather stable, from 2004 to 2006, around 0.15 sharks /1,000 hooks. In 2007, both jumped to almost twice that figure, reaching the highest value in the series (0.30 sharks /1,000 hooks). After that peak, however, they declined continuously, until 2010, when the lowest value was recorded (0.02 sharks /1,000 hooks), increasing mildly again in 2011, with values close to 0.10 sharks/ 1,000 hooks. The nominal average CPUE for all years combined was 0.12 hammerheads sharks per 1,000 hooks (Fig. 7).

Of the 205 hammerhead sharks that were measured (3.30% of the total), 117 were females and 88 were males, with a sex ratio of 1.30♀:1.00♂. This difference, however, was not statistically significant (χ^2= 2.0; P > 0.05). Total length ranged from 1200 mm to

2800 mm for males and from 1100 mm to 3100 mm for females, but were not significantly different between sexes (K-S=0.18; P > 0.05). The majority of both female and male total length was found between 1600 and 1700 mm (Fig. 8).

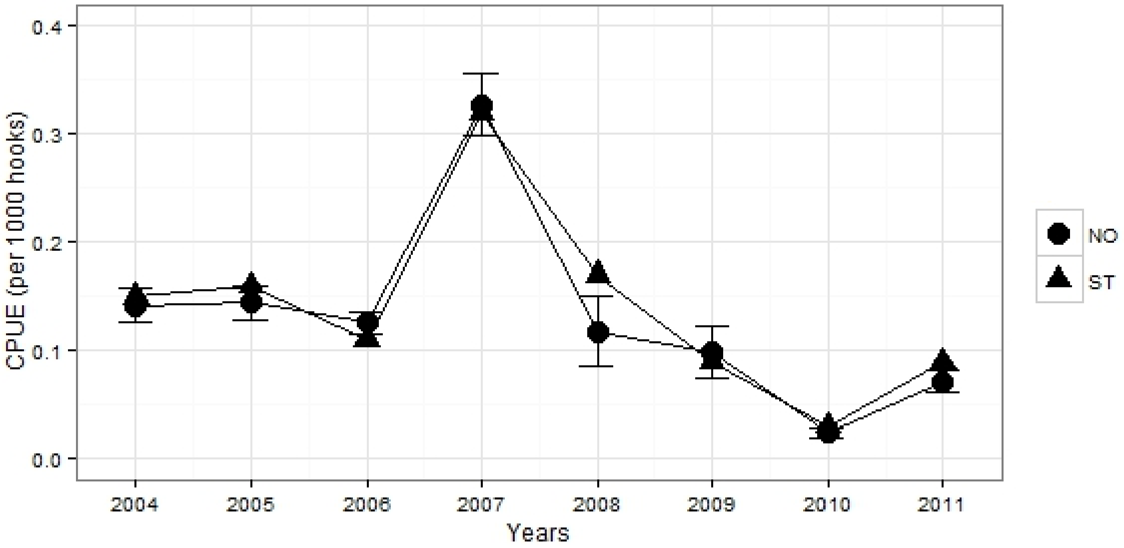

Figure 7: Nominal (NO) and standardized (ST) CPUE of hammerhead sharks caught in the Southwestern and Equatorial Atlantic Ocean by national and chartered longline tuna fleet between 2004 and 2011. The bars mean standard deviation.

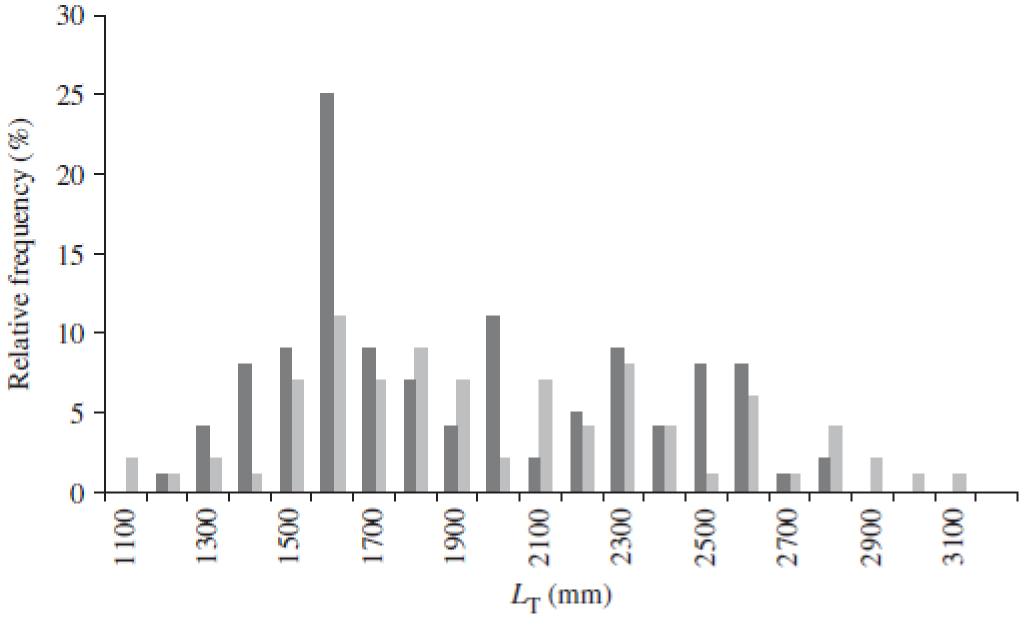

Figure 8: Total length (LT) frequency distribution of (■) female and (□) male *Sphyrna lewini* caught 2004–2011 by Brazilian national and chartered longline boats in the south-western and equatorial Atlantic Ocean (n=205).

Considering the total length at maturity available from the literature (Hazin *et al*., 2001; Harry *et al*., 2011), 97 (82.00%) and 48 (54.00%) of the scalloped hammerhead sharks measured were probably immature. In this study, it was not possible to identify a clear pattern of segregation by sex or by maturity stage. However, adult females seemed to be more abundant near the equatorial region, Trindade and Martin Vaz Islands and southern Brazilian coast, while immature individuals were caught mainly between latitudes from 015ºS to 020ºS. Juvenile males were more common from 10ºS to 05ºN, whilst adult males were caught throughout the area (Fig. 9).

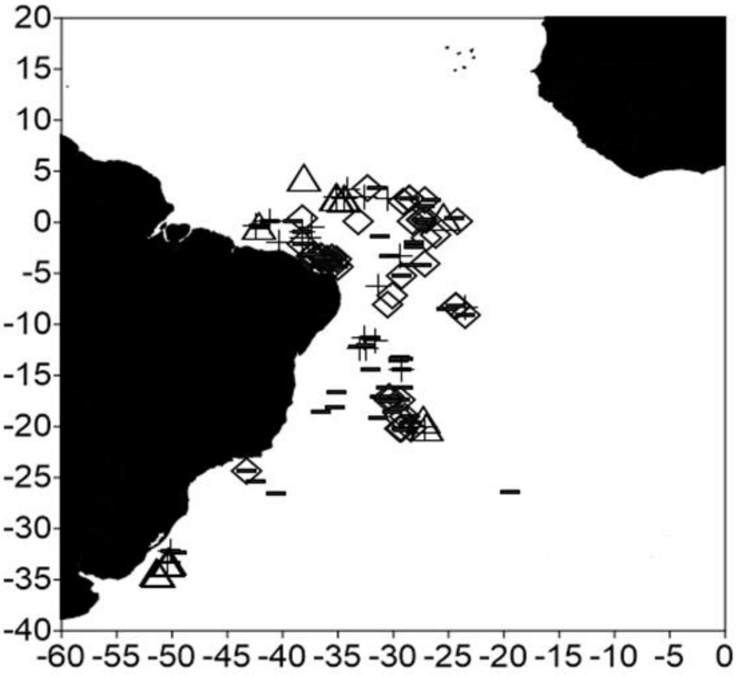

Figure 9: Distribution of male and female hammerhead sharks caught by chartered longline boats, in the southwestern and equatorial Atlantic Ocean, from 2005 to 2011, by maturity stages (◊ immature males, + mature males, ─ immature females and Δ mature females).

DISCUSSION

Seamounts and islands are important oceanic features where fish tend to aggregate due to the oceanographic phenomena that take place in these areas, which enhance productivity and aggregations of marine life (Travassos *et al.*, 1999; Pitcher *et al.*, 2007). Morato *et al.* (2010) found that the catch rate for target species and some bycatch species (elasmobranches) in the tuna longline fishery (swordfish and tunas) was elevated closer to seamounts. In this study, higher fishing effort was found around the Equatorial region where island ecosystems are important. Effort was also concentrated in other areas such as near Trindade and Martin Vaz Islands and off the southern Brazilian coast.

Ever since the tuna longline fishing effort began in the South Atlantic Ocean, in 1956, the number of vessels has been fluctuating. In this study, the reduction of the tuna longline fishing effort, and consequently the catch, was mainly due to a decrease in the number of chartered vessels. However, Frédou *et al.* (2015) found an increase in catches of blue sharks in tuna longline fisheries from 2004 to 2010 and other sharks until 2008 in the South Atlantic Ocean, decreasing in subsequent years, as observed in the present study. Shark catches by longline boats off southeast Brazil represented 49.2% of the total catch, in 2007 and 2008, with the hammerhead sharks (*S. lewini* and *S. zygaena*) representing 6.3% (Amorim *et al.*, 2011). Overall, a low relative contribution (0.40%) of the hammerhead sharks in the tuna pelagic longline fishery in Brazil was found in this study. A situation much different from the trawling fishery in more coastal areas, for instance, which seems to have negatively affected their populations in southern Brazil, with evidence of overfishing, especially in the case of *S. lewini* (Mader *et al.*, 2007; Vooren *et al.*, 2005). In the North Atlantic, likewise, the trawling fishery caught the three hammerhead sharks species, which together represented 42% of the megafauna caught as bycatch (Zeeberg *et al.*, 2006). Incidentally, the decline of the hammerhead sharks stock in that ocean was estimated at around 90% (Baum *et al.*, 2003).

The catches of swordfish and sharks were higher during the period when a shallower longline (1998-2007) in the South Atlantic Ocean was the most used (Barreto *et al.*, 2015). The higher CPUE of hammerhead sharks in the shallow longline found in this study is likely related to their preference for surface waters (Compagno, 1984). However, the frequent vertical movements displayed by the *S. lewini*, including dives of more than 100 m, possibly related to the search for prey in the mesopelagic environment mostly at night (Vaske *et al.*, 2009; Bessudo *et al.*, 2011), renders the hammerhead sharks vulnerable to both fishing strategies.

Off the South Brazilian coast and close to the Rio Grande rise, there is an important fishing area for blue sharks (Carvalho *et al.*, 2011), as well as for hammerhead sharks. Hazin *et al.* (2001) found a higher abundance of hammerhead sharks away from the Brazilian Northeast coast (> 150 km) and closer to seamounts, which are likely an important aggregation area for hammerhead shark populations (Bessudo *et al.*, 2011). The apparent southward migration along the Brazilian coast, from the 1st quarter, when the highest CPUE off southern Brazil is observed around 20^{o}-25^{o}S, to the 3rd and 4th quarter, when the highest catch rates are concentrated off Rio Grande do Sul State (25^{o}-35^{o}S), might be related to the reproductive cycle of the species. According to Vooren *et al.* (2005), pregnant hammerhead sharks approach the coast of southern Brazil during austral summer (4th quarter), while copulation occurs further offshore, on the continental slope, from January to February.

Mathematical models that aim to assess spatiotemporal indicators that possibly influence catch rates are essential to more adequately estimate the fishing trend (Minami *et al.*, 2007). In the GLM model, the Poisson distribution was not appropriate due to overdispersion with a variance that exceeded the mean. The model assumed was thus the ZINB, which better fitted the high amount of zero catches of hammerhead sharks than ZIP and, for this reason, has been commonly used for bycatch species (Welsh *et al*., 1996; Brodziak & Walsh, 2013; Hazin *et al.*, 2013).

The nominal CPUE values were close to the standardized CPUE indices, demonstrating that either the model was not able to compensate for the main factors affecting the CPUE or that the nominal CPUE already closely reflects the actual abundance of the hammerhead sharks. A similarity between nominal and standardized

CPUE estimates for oceanic whitetip *Carcharhinus longimanus* (Poey 1861) was also reported by Tolotti *et al.* (2013), who speculated the possible reasons for the trend being the relatively short time series or a lack of homogeneity in the variables in the model. The highest CPUE observed in 2007 might have resulted from the majority of sets occurring in latitudes greater than 20ºS, where the abundance of the species seems to be higher, as well as oceanic productivity (Peterson & Stramma, 1991; Carvalho *et al.*, 2011).

Based on CPUEs values, from 1972 to 2003, off the North Carolina coast, Myers *et al.* (2007) estimated a decline of hammerhead shark populations between 98% and 99%, for *S. lewini* and *S. zygaena*, respectively. Berkeley & Campos (1988) found a CPUE value of hammerhead sharks calculated from catch and effort longline data from southeastern United States, during 1981 to 1983, of 13.37 sharks per 1,000 hooks. Comparatively, Beerkircher *et al.* (2002) in the same region (southeastern US) from 1992 to 2000 found a mean CPUE for hammerheads of 0.48 sharks per 1,000 hooks, close to the value observed in this study, suggesting a sharp decline in the biomass of the fished stock. A similar situation was also reported in the South Atlantic Ocean where the '90s high CPUE rates could have caused the depletion of hammerhead shark stocks (Barreto *et al.*, 2015).

Juvenile female hammerhead sharks migrate from the nursery and growth areas to offshore waters at smaller sizes than males to find pelagic prey to increase feeding success and accelerate growth (Klimley, 1987). Just as the present results found, , White *et al.* (2008) and Hazin *et al.* (2001) reported that most hammerhead sharks caught by longline boats were juvenile females probably due to their earlier migration from coastal to pelagic zones (Hoyos-Padilla *et al.*, 2014), a trend that may lead to a decline of biomass over time. In December 2014, to mitigate the bycatch of hammerhead sharks in Brazil, the *S. lewini* and *S. zygaena* were considered as "critically endangered" and *S.mokarran* as “endangered” (MMA, 2014), by the Directive 445, prohibiting their boarding and landing in the entire country. Currently, however, these species are unprotected because the directive was suspended due to a legal suit. Despite the apparently minor impact of the tuna longline fishery on hammerhead species, efficient management strategies are important to ensure the long-term sustainability of the species. The use of deeper longlines and circle hooks instead of J hooks, are example of measures that might be adopted not only to reduce the catches of hammerhead sharks, but to mitigate the impact of longline fisheries on all elasmobranchs caught (Pacheco *et al.*, 2011).

This study reports information about the hammerhead sharks caught in the Southwestern and Equatorial Atlantic Ocean by national and chartered longline boats. It is fundamental, however, that all hammerhead species be recorded individually in the future, so that more specific analysis can be properly conducted. The genetic techniques, such as DNA barcoding, may be used to identify species during landings, for example (Bornatowski *et al.*, 2014b). Considering, however, the worldwide distribution of hammerhead sharks, and their presence in different environments during their lifecycle, it is necessary to envisage and implement efficient international measures for the conservation of these fragile species, considering the intrinsic characteristics of each population.

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3. Capítulo III

3.1. Artigo científico II

Artigo científico a ser encaminhado para a **Plos One Journal**

Evidences of local fidelity and diving behavior of scalloped hammerhead shark (*Sphyrna lewini*) off the Saint Peter and Saint Paul Archipelago, Brazil

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Abstract

Due to increasing concern to use non-lethal investigations methods to elucidate behavioral aspects of endangered species, seven scalloped hammerhead sharks (*Sphyrna lewini*) were tagged with satellite tags around of the Saint Peter and Saint Paul Archipelago (SPSPA). The transmitters were used to bring light about the vertical displacement patterns and the horizontal migration behavior. For this purpose, the distribution ranges and the daily movement patterns of the hammerhead sharks were analyzed. The tags were preformatted to archive data at 60s intervals of 14 bins with a release time of 70 or 120 days. Sharks were tagged between October 2010 to May 2014. Although the tags were programmed to remain attached for more time, the first two tags were prematurely released after 7 and 5 days of monitoring, respectively and one shark never transmitted data. According to the deployment and pop-up information, as well as geolocation performed by tags, all sharks remained in the SPSPA surroundings during the monitoring period. Yet, no hammerhead sharks migrated to inshore direction suggesting a local fidelity. Regarding the vertical movement, all sharks dove to depths greater than 150 m and water temperatures above 25° C. The deepest diving recorded for 728 meters on two occasions during nighttime where the minimum temperature was 5.6° C. The mean diving speeds for descent and ascent were 0.50 and 0.32 $m.s^{-1}$ respectively with descent rates were always faster than ascent rates. Scalloped hammerhead sharks covered a wide extension of the water column ranging from the mixing layer to the mesopelagic zone. This study highlights the potential information for the understanding of the scalloped hammerhead shark movement patterns to a better management of this species.

Keywords: movement, PSAT, oceanic island, Satellite telemetry, Atlantic ocean

Introduction

The search for information related to fish behavior in their habitat is an essential key to understanding their life history, enabling the approval of efficient measures that contribute to the conservation of species and ecosystems (Hayes et al. 2009, Jorgensen et al. 2012). However, tracing the life history of the species is very complex, especially for those which perform great migrations or have the ability to inhabit a variety of ecosystems, making it essential to gain knowledge about the environment and behavior of the species (Heupel et al. 2007). This task is particularly difficult for migratory sharks because of the various factors that are thought to influence their habitat use and spatial distribution such as age, sex or food availability (Klimley 1987, Hoyos-Padilla et al. 2014, Vandeperre et al. 2014). As apex predators, sharks play a key role in maintaining the ecosystem equilibrium as top-down controllers of marine food webs, and their progressive loss in the world’s oceans in the last decades is thought to be causing deleterious cascading effects in the entire marine ecosystem (Libralato et al. 2006, Ruiz et al. 2015). Better understanding their migrations, habitat use, and Essential Fish Habitats (EFH) are becoming crucial elements for their global conservation.

The scalloped hammerhead shark (*Sphyrna lewini*) is bounded between the latitudes of 40° N and 40° S, with a cosmopolitan distribution, and preference for tropical and temperate waters. This species has a wide distribution in coastal and oceanic habitats, occurring also in island ecosystems (Compagno 1984, 2005). Several studies have shown declines in scalloped hammerhead shark populations, possibly due to global shark fin trade (Baum & Blanchard 2010, Barreto et al. 2015, Bezerra et al. 2016). High rates of incidental or targeted catches, including the illegal practice of finning are factors that contribute to increase the vulnerability of the species, resulting in drastic reductions of some populations in a short period of time (Stevens et al. 2000, Harrington et al. 2005, Zeeberg et al. 2006). The International Union for the Conservation of Nature (IUCN) Red List, classified the scalloped hammerhead shark as Endangered due to their drastic population decline in the past twenty years, primarily because of overfishing (Baum et al. 2007). Following IUCN decision, the International Commission for the Conservation of Tuna in the Atlantic (ICCAT) approved an endorsement in 2010 prohibiting the onboard possession, landing and trade of any species of the genus *Sphyrna* (except *Sphyrna tiburo*). ICCAT recommended further studies on the biological and ecological aspects of these species in order to identify nursery areas and potential migration routes (ICCAT 2010). *S. lewini* was included in appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 2013 (March 2013, CoP16). In Brazil, it was classified as Critically Endangered in 2014 (Directive Nº 445/ Ministry of the Environment) and of its boarding or selling prohibited in national territory. Shortly later, however, this directive was suspended by judicial decision but in the present moment the directive is valid.

The behavior of migratory sharks in the wild has been increasingly investigated using various types of electronic tags, most notably Pop-up Satellite Archival Transmitting tags (PSATs) (Bessudo et al. 2011b, Hammerschlag et al. 2011, Musyl et al. 2011, Queiroz et al. 2016). These tags collect information on both the animal's vertical and horizontal displacements, elucidating researchers about key aspects of their spatial ecology such as the fine scale vertical habitat use or the broad scale regional residency and migrations. PSATs and ultrasonic telemetry were used before to study the behavior of scalloped hammerhead sharks in the central Eastern Pacific, in the Gulf of California (Jorgensen et al. 2009) and around the Malpelo/Cocos/Galapagos oceanic islands (Bessudo et al. 2011b, Hoyos-Padilla et al. 2014). These studies pointed towards a shark behavioral pattern whereby adults spend prolonged periods around these areas during which they move away from the islands at night to perform large vertical displacements ('dives'), presumably to feed, only to come back during the day to the island shelves. and daily movements of departure and return the island. Vertical migration has been analyzing showing preference for thermocline water with deeper dives far and surface dives near from the islands (Bessudo et al. 2011a, Ketchum et al. 2014a).

Islands and seamounts are important area to assemblages of pelagic species concentrating more than coastal areas and open ocean (Morato et al. 2010). The ocean currents systems interaction with the rough ocean topography causes upwelling contributing to the primary productivity increase (Hekinian 1982, Hekinian et al. 2000). The Saint Peter and Saint Paul Archipelago (SPSPA) is a group of small Brazilian oceanic islands used by several marine species for protection, reproduction and feeding (Vaske et al. 2003, Vaske et al. 2005, Vaske et al. 2006, Bezerra et al. 2013, Viana et al. 2013, Santos et al. 2014). Yet, the area is host to a very diverse fish assemblage, including species which are believed to be permanent or partially resident, and other for which it plays the role of a resting site along their migratory route (Lessa et al. 1999, Bezerra et al. 2011, Mendonça et al. 2012, Macena & Hazin 2016).

The scalloped hammerhead shark generally aggregates in large numbers in islands (Kimley & Nelson 1984, Hearn et al. 2010, Bessudo et al. 2011 a) but in SPSPA only solitary specimens are sighted. Two species of hammerhead shark were recorded to date in SPSPA, *S. lewini* and more recently *S. zygaena* (Lubbock & Edwards 1981, Bezerra et al. 2017). The archipelago lies right at the equator, thus being located at a double crossroads for oceanic, migratory species with potential implications for their (spatial) management, most notably that of international organizations such as ICCAT: that between the north and south Atlantic, but also that between the east and west south Atlantic. However, the function and importance of this singular insular ecosystem in the life history of hammerhead and other oceanic sharks, and the degree of connectivity with other oceanic and coastal habitats for the populations of these species along the latitudinal and longitudinal cross basin axes, remain unanswered questions. This study aimed to shed light on these questions by investigating, for the first time in the south Atlantic, the vertical and horizontal movements of scalloped hammerhead sharks at the SPSPA.

Material and Methods

Ethics Statement

The experiments were conducted with the permission and approval by Instituto Chico Mendes de Conservação da Biodiversidade (number 50119-1) of the Brazilian Ministry of Environment. Scalloped hammerhead sharks capture and tagging methods were pre-approved by the Commission of Ethics on the Usage of Animals from the Federal Rural University of Pernambuco (license no. 054/2013; protocol no. 23082.022567/2012).

Study Area

The Saint Peter and Saint Paul Archipelago (SPSPA) is the smallest Brazilian oceanic island ecosystem, located on the transform fault of the Mid- Atlantic Ridge (0°55'02 "N, 029°20'42" W) (Fig. 1). It is included in a Marine Protected Area, which also comprises the Fernando de Noronha Archipelago and the Biological Reserve of Atol das Rocas. Its geographical position, almost in the middle of the Atlantic Ocean, lying about 530 nm from Natal- RN, in Brazil, and 985 nm from Guine-Bissau, in Africa, is highly strategic, from the scientific, ecologic, economic and political point of view (Mabessoone & Coutinho 1970).

Transmitter programming and tagging procedures

Seven scalloped hammerhead sharks were tagged between October 2010 and May 2014. Sharks HS 1 and HS 2 were tagged at a distance of approximately 5 nm from SPSPA, while HS 3, HS 4, HS 5, HS 6 and HS 7 were tagged at around a mile from it. All sharks were tagged on the east side of the SPSPA. The sharks were captured with a small longline consisting of a main polyamide monofilament cable (300 mm), with 16 to 25 secondary lines (200 mm monofilament), using circle hooks (size 16/0 or 17/0). The soaking time of the gear was approximately 4 hours, during night time, in two sets (7h-11h PM and 0h-4h AM).

The two first sharks tagged were placed on the boat deck with eyes covered and a seawater tube placed inside their mouth to improve oxygenation and reduce stress. For the remaining sharks, the tagging was conducted directly in the water, with the assistance of an inflatable boat next to the fishing vessel. All tagging procedures lasted no more than 5 minutes. The tags of the first two specimens were fixed in the muscle at the base of the first dorsal fin, with a stainless steel dart. For all other sharks the tag was looped on the first dorsal fin at mid-height, at approximately 5 cm from the anterior region, by a monofilament cable coated with pvc, producing a loop that joined the cable with the tag on the fin. This methodology has been applied successfully with other sharks in the same area (Hazin et al. 2013). All scalloped hammerhead sharks were sexed and measured for total length (TL).

Six satellite transmitters (PSAT, MK10 model) manufactured by Wildlife Computers, WA, USA, were used to obtain the horizontal and vertical movements of tagged scalloped hammerhead sharks (HS1, HS2, HS3, HS5, HS6, and HS7). These tags have a resolution of 0.05°C and 0.5 m of temperature and depth, respectively.

Additionally, one scalloped hammerhead shark (HS4) was tagged with a satellite-linked transmitter SPOT (Smart Position and Temperature) but never reported any data.

The PSATs were programmed to collect and store data every second, summarized in 14 intervals (or bins) of temperature and depth (ranges described in Fig 3), providing histograms of data for every 3 hours. The ranges covered by the 14 bins were predetermined from behavioral characteristics related to the previously discussed preference for certain depths and temperatures of the species (Klimley et al. 1988, Jorgensen et al. 2009, Bessudo et al. 2011b). Three PSAT were pre-programmed to collect data for 70 days and the other three for 120 days. The data received were decoded with WC-DAP® (*Data Analysis Programs*) and WC-GPE® (*Global Position Estimator*) software, provided by the manufacturer.

Vertical distribution

Depth and temperature data from day and night periods were analyzed to identify diving behavior patterns. Since geolocations were from the equatorial region, where day and night have similar time, crepuscular periods (dawn and dusk) were not considered. In order to assess possible differences between the times spent at depths and temperature ranges in daily period was applied a Kolmogorov–Smirnov test (K-S) for day (5h - 17h) and night (17h-5h).

Only the sharks HS 3, HS 5, HS 6 and HS 7 had *time series* function available in their tags. The time series collected temperature and pressure data every 10 minutes in 10-day cycles (10 days collecting data and 10 days off) producing 288 depth and temperature readings every 24 hours. In order to analyze the diving behavior, the depth data were sectioned in four intervals: mixed layer (0 to 50 m), thermocline (50 to 150 m), maximum biomass layer (150 to 350 m) and maximum depth layer (350 to 700 m).

Thermocline and maximum biomass layer (MBL) intervals were defined based on the literature for SPSPA (Travassos et al. 1999, Irigoien et al. 2014). The Kolmogorov–Smirnov test was performed to identify whether statistical differences between the depths experienced by these four sharks were significant.

Individual diving behavior was assessed by visual inspection, considering a full dive when the shark exceeded the thermocline depth limits and were followed by a return to the mixed layer or thermocline zone. The mean speed of the dives ($m.s^{-1}$), with ascent and descent rates, and their duration were also calculated. Only the dives with no missing data were used. The Student's t test was applied to analyze the differences between the descent and ascent speeds.

Horizontal distribution

Raw geolocation estimates were calculated using the WC-GPE©. For all sharks, 212 Argos location readings were performed but only 37 light level curves were suitable for the processing of the geolocation according to luminosity. Daily positions with estimates of the most probable track were calculated using the Kalman filter KFTRACK (Nielsen & Siebert 2007, Lam et al. 2008), from raw geolocation estimates. The most probable track was also inferred using sea-surface temperature (SST) data (UKFSST; Lam et al. 2008), by comparing the SST readings from the tag with the remotely sensed SST data relative to each location point in order to refine the tracking (Nielsen et al. 2006, 2012). The SST mean data were downloaded from the National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory repository. Due to the minimal SST variation around the equatorial region the model including SST did not converge and therefore not was used. All statistical analyses were performed using R programing (R Development Core Team 2015).

Results

Monitoring and performance of PSAT

Five out of the seven tagged sharks were females measuring between 219 cm and 260 cm TL, the remaining two sharks being males of 210 and 215 cm TL (Table 1). The PAT tag retention time spanned from 5 to 120 days (mean= 73.6 days, S.D. ±55.8, n=6) as two tags prematurely released from the shark (HS1 and HS2). The SPOT tag on HS4 never transmitted.

Table 1: Summary of the satellite tag deployments of seven scalloped hammerhead sharks specimens monitored from SPSPA.

					TAGGING			**POP-UP**			
Shark	**Type**	**TL (cm)**	**Sex**	**Days expected**	**Date**	**Lat.**	**Long.**	**Date**	**Lat.**	**Long.**	**Days at liberty**
HS 1	Mk10	250	F	70	10/08/2010	0.863	-29.28	10/14/2010	0.935	-29.294	7
HS 2	Mk10	260	F	70	10/06/2010	0.858	-29.317	10/10/2010	1.27	-28.594	5
HS3	Mk10	200	F	70	03/28/2012	0.918	-29.336	06/10/2012	0.845	-29.423	70
HS 4	SPOT	250	F	70	05/13/2013	0.858	-29.31	-	-	-	-
HS 5	Mk10	210	M	120	04/13/2014	0.858	-29.317	08/15/2014	1.15	-31.012	120
HS 6	Mk10	219	F	120	04/13/2014	0.858	-29.317	08/15/2014	1.019	-32.092	120
HS 7	Mk10	205	M	120	05/06/2014	0.858	-29.317	09/11/2014	-0.327	-25.961	120

Horizontal movements

A comparison of the release and pop up locations for each of the six PSAT tagged sharks show that these were very close to each other, indicating that the sharks most possibly remained in the surroundings of SPSPA during the time they were monitored. Furthermore, whenever the monitoring period was long enough to calculate geolocations (i.e. for sharks HS3, HS5, HS6 and HS7), these confirmed that the animals remained in the broad vicinity or region of the archipelago and did not move widely (Fig. 1). However, an inspection of the tracks also suggests that some sharks moved away from the archipelago in a southerly or easterly direction after tagging only to return to SPSPA vicinities. Due to missing data, it was not possible to calculate the velocity between locations.

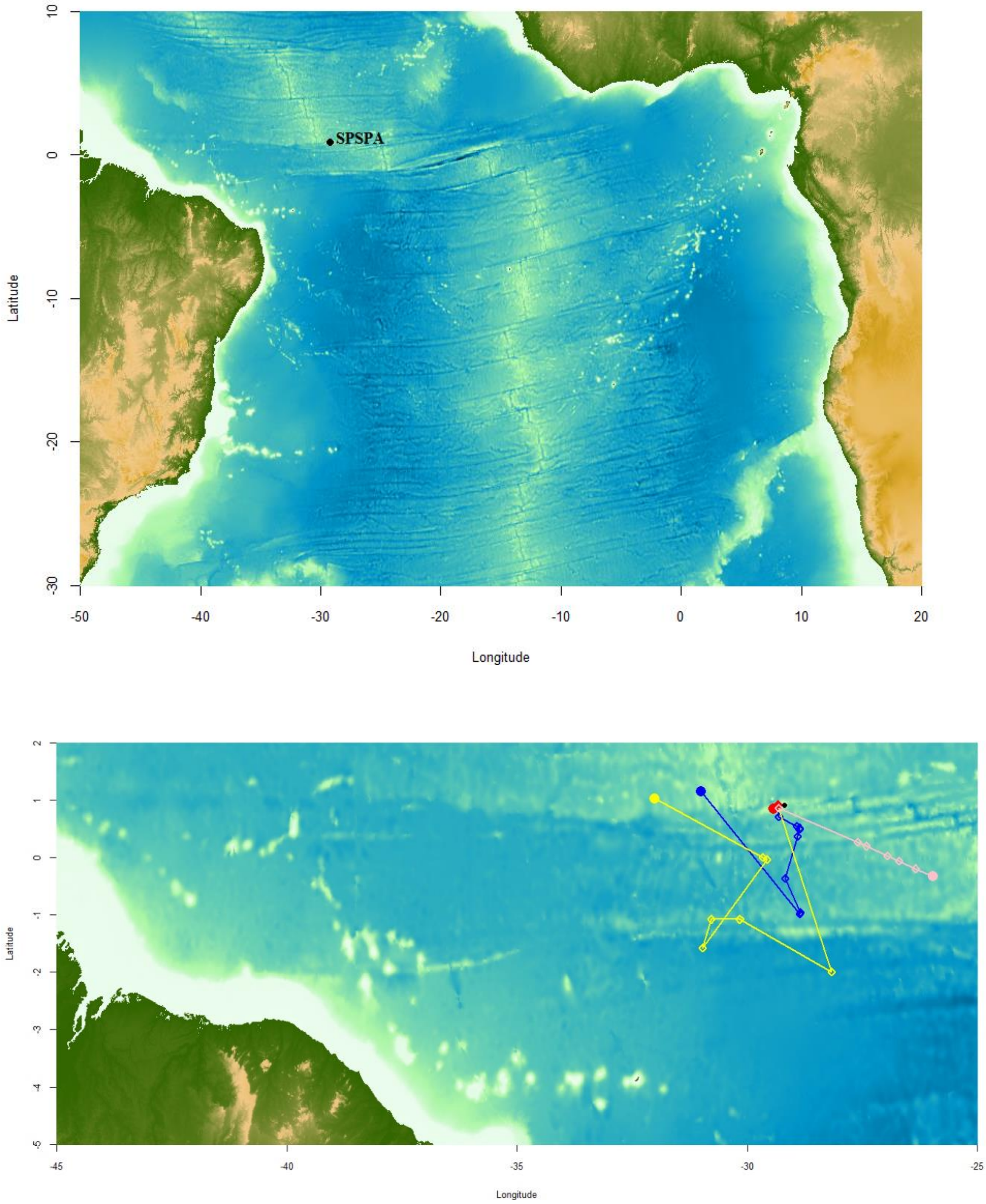


Figure 1: Location of the Saint Peter and Saint Paul archipelago (SPSPA) (Up) and most probable track of scalloped hammerhead sharks from the SPSPA (Down). The black dot represents the SPSPA and diamonds represent HS 3 (red), HS 5 (blue), HS 6 (yellow) and HS 7 (pink). Circles represent the end of the track.

Depth and temperature distribution

The daily vertical movements of all sharks monitored obtained from three-hour binned data showed that the sharks had a clear preference for warm waters, above 22°C, and for depths above 150 m (Fig. 2). All sharks spent long periods of time at depths between the surface and 150 m, both during the day (98%) and at night (90%), with temperatures higher than 22ºC for most of the the day (66%) and night (60%). However, despite this preferred range, the six monitored sharks frequently conducted incursions at depths exceeding 150 m, with the wider vertical range occurring during the night. The K-S test indicated no significant difference between depth (D= 0.3571, p-value= 0.3433) and temperature (D= 0.2857, p-value= 0.6355) utilization, during day and night diel periods. Only HS3 and HS5 dived below 700 m depth (Fig. 3). HS3 reached a maximum depth of 728 m twice (05/17/2012 and 06/05/2012), at temperatures of, at least, 5.6°C. HS 5 made the deepest dive recorded of this study, reaching 736 m, a depth where the temperature was also 5.6°C (08/10/2014).

The detailed analysis of the diving behavior of four sharks whose tags had the time series function suggested that males and females might use the depths differently, since females spent more time into the mixed layer (0-50 m) and males inside the thermocline (50-150 m) (Tab. 2), although the difference, was not significant (K-S test: D = 0.5, p-value = 0.7714).

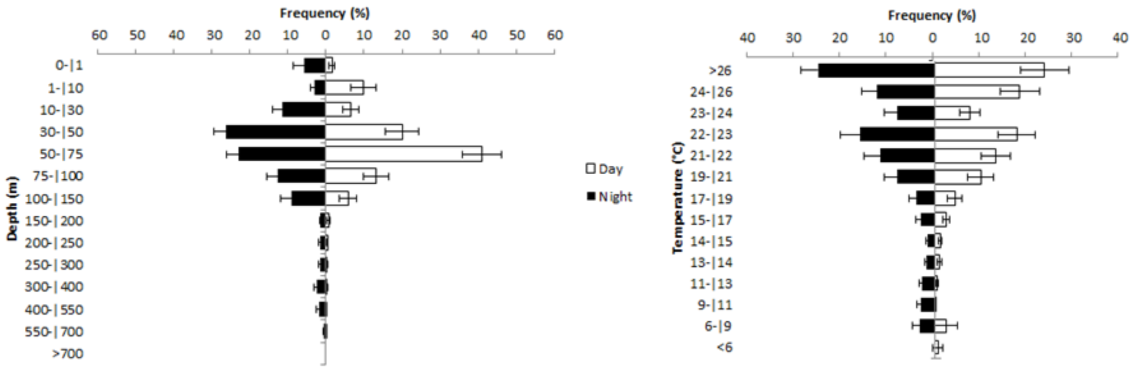
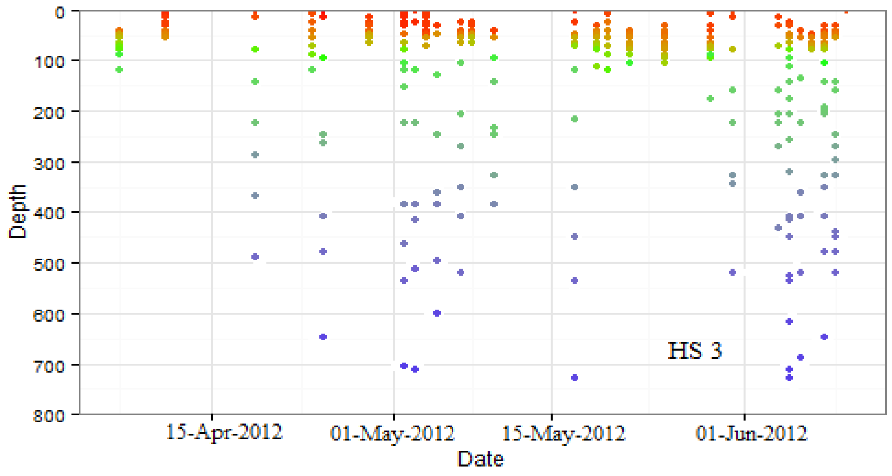


Figure 2: Time at depth (TAD; left) and temperature (TAT; right), from 3-hour bins, for six scalloped hammerhead sharks (HS1; HS2; HS3; HS5; HS6; HS7) monitored from the SPSPA. Black and white bars indicate night and day, respectively.



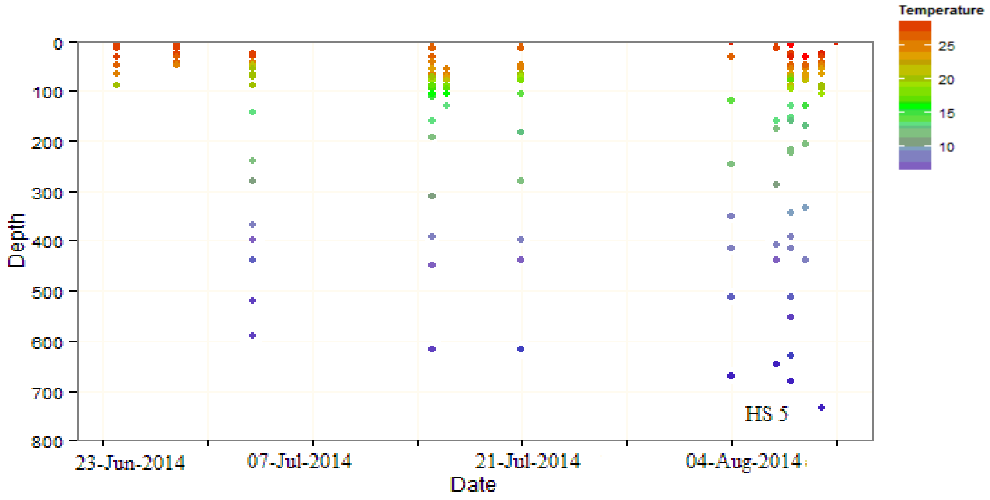


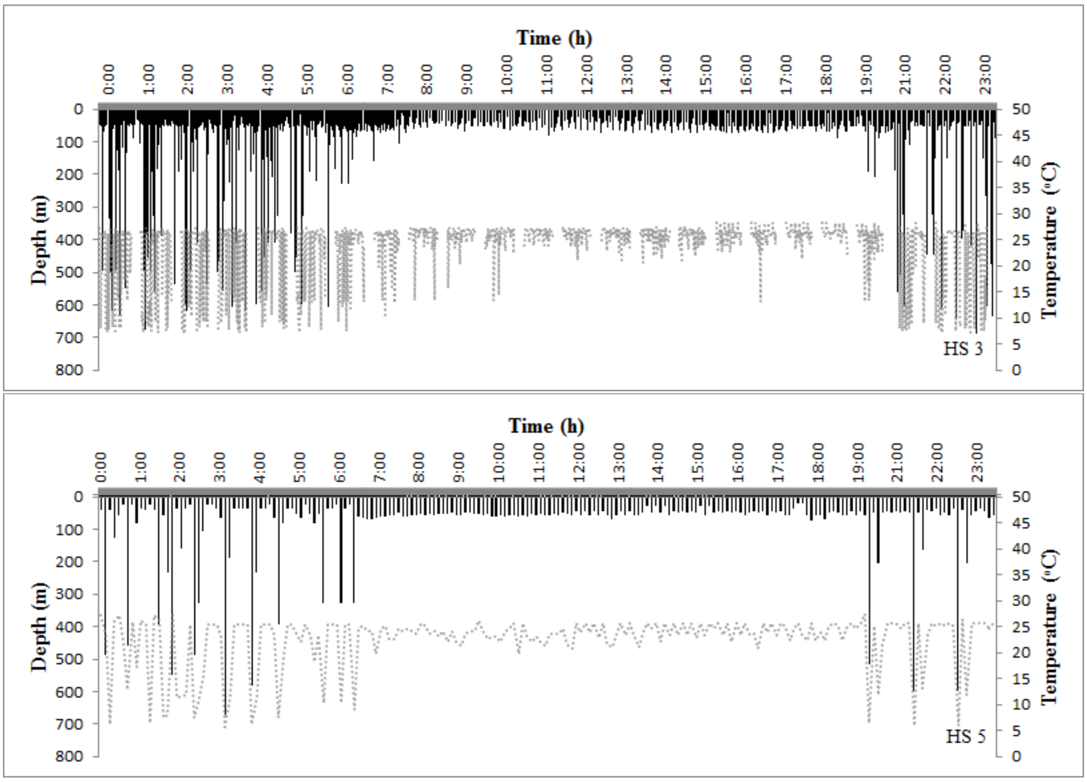
Figure 3: Profiles of depth and temperature (PDT), recorded for scalloped hammerhead sharks HS3 and HS5, from the SPSPA. The PDTs correspond to the data summarized every 3 hours, containing eight readings of depth and sixteen readings of temperature.

Table 2: Percentages of time-at-depth for day, night and total of the dives. Mixed layer (0 to 50 m), thermocline (50 to 150 m) maximum biomass layer (150 to 350 m) and maximum depth layer (350 to 700 m) ranges were represented.

	HS 3			HS 5			HS 6			HS 7		
Depth	**Total**	**Day**	**Night**	**Total**	**Day**	**Night**	**Total**	**Day**	**Night**	**Total**	**Day**	**Night**
0-50	48.4	51.4	46.0	33.5	24.5	50.0	58.5	54.0	61.9	35.2	31.6	38.4
50-150	41.3	46.3	37.5	60.6	73.7	36.4	39.0	44.6	34.8	56.5	62.2	51.5
150-350	4.3	2.3	5.9	3.2	2.1	6.0	1.5	3.6	4.2	5.5	5.9	5.3
350-700	5.7	0.0	10.5	2.3	0.0	7.6	1.0	0.0	1.7	2.8	0.3	4.7

The time series function allowed a detailed delineation of the daily vertical migration, which helped to identify circadian cycles. During the day, all sharks remained in the shallow layers of the water column swimming in waters up to 347 m (mean= 54 m) and experiencing temperatures above 11.6° C (mean= 23.9° C). All dives below 347 m (mean= 93 m) frequently occurred at night with a minimum temperature of 5.6°C (mean=10.4°C) (Fig. 4). The vertical movements indicated that the scalloped hammerhead shark is able to move into a wide range of temperature and depth, between the epipelagic and mesopelagic zones. However, a notable preference for water over 150 m depth has been demonstrated with deeper dives occurring especially during the night. Only one single deep diving (below to 600 m) was recorded in the daytime (6:20 am), by HS7 (Figs. 4 and 5). The diving behavior observations by visual inspection showed that deep dives (>500 m) occurred consecutively. Usually after a deep dive the sharks returned to the mixed layer and thereafter performed another deep dive (Fig. 5).

The total diving time estimated was 10 to 40 minutes, with mean speed of 0.80 m.s^{-1}. The mean diving speeds for descent and ascent were 0.50 and 0.32 m.s^{-1}, respectively. The descent rates were always faster than ascent rates, although the differences were not statistically significant (Student's t test, $p > 0.05$). Descent and ascent diving rates were proportionally faster when greater depths were reached (Fig. 6).



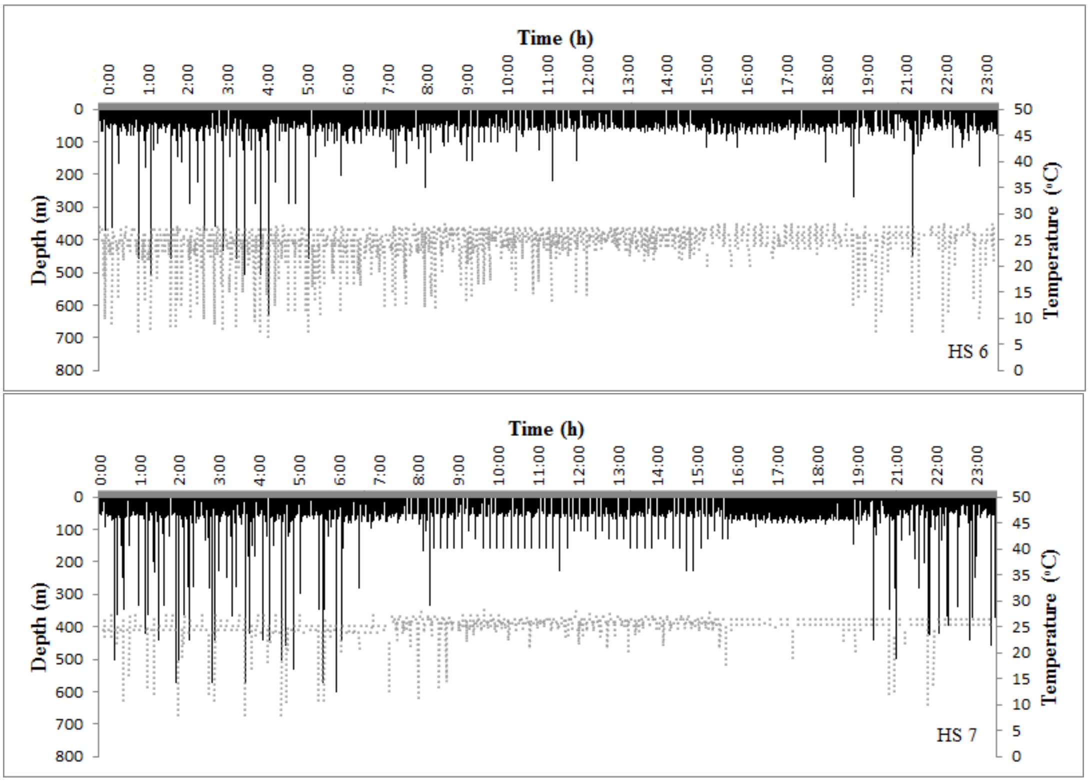
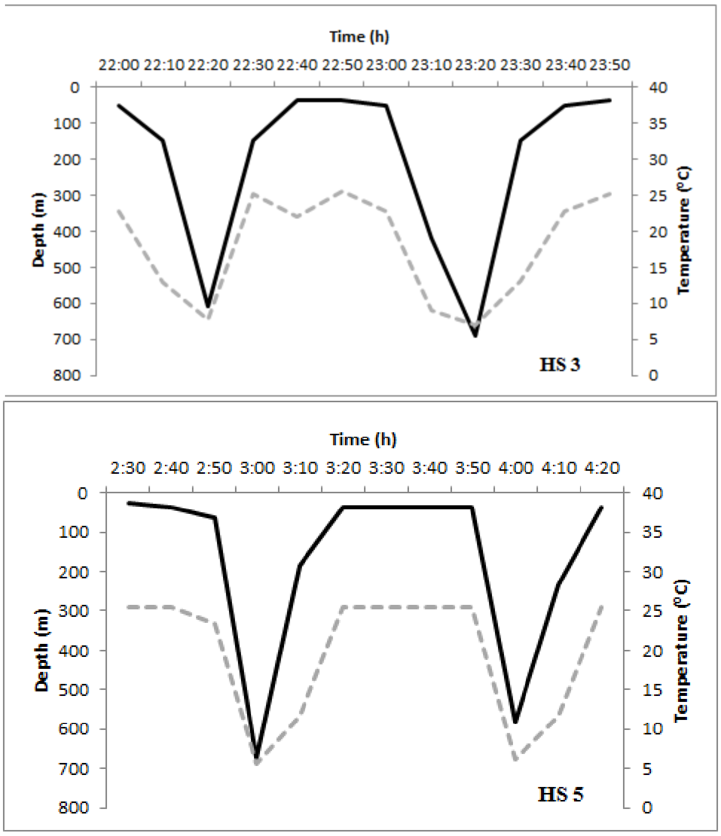


Figure 4: Vertical movement of four scalloped hammerhead shark (HS 3, HS 5, HS 6 and HS 7) with resolution of 10-minute from time series function. Black lines represent depth and grey lines are temperature.



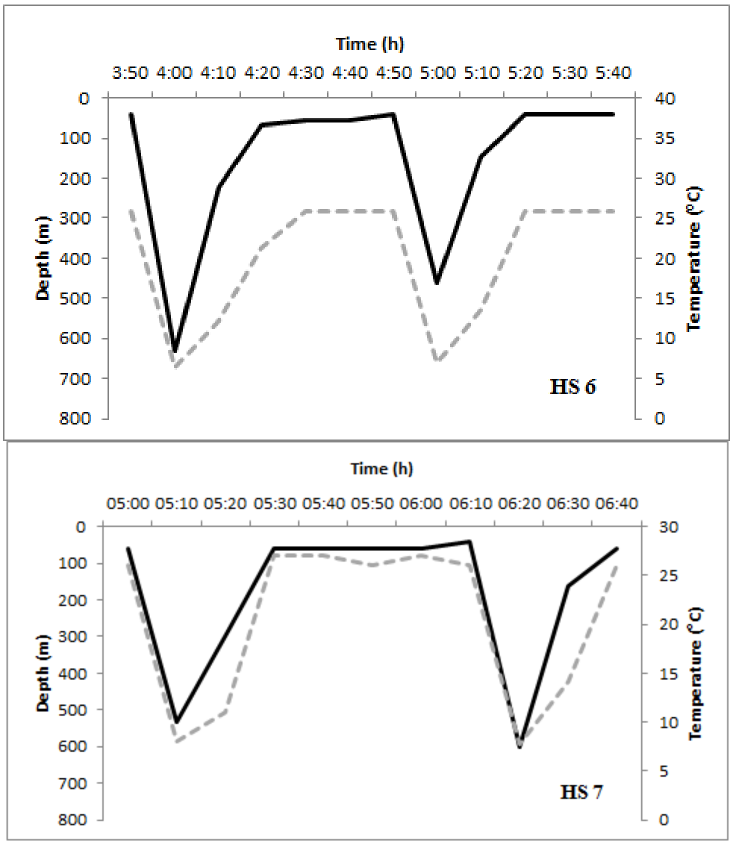


Figure 5: Details of deep diving behavior. Solid black and dashed gray lines represent depth and temperature, respectively.

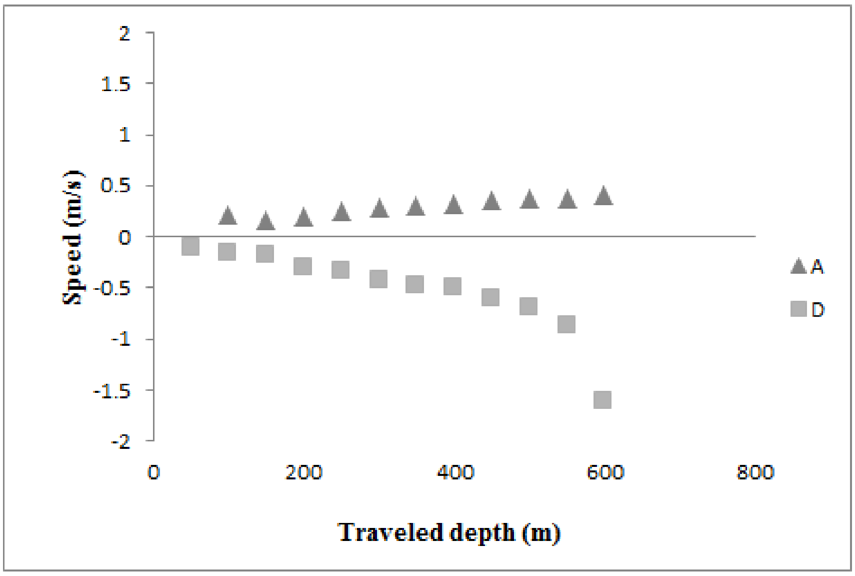


Figure 6: Ascent (A) and descent (D) movements rates of tagged scalloped hammerhead sharks. The triangles represent descent and squares are ascent rates.

Discussion

The use of satellite tags in the scalloped hammerhead shark is unprecedented on Equatorial Atlantic Ocean. This technology was only used recently on the species worldwide and for this reason the attachment methods of the tags needs to be experimented and discussed carefully to enhance the success of retention and survival of the shark (Bessudo et al. 2011b, Hoffmayer et al. 2013). In the present study, the short period of tag retention to the sharks (HS1 and HS2) was similar to those observed by Bessudo et al. (2011b) with scalloped hammerhead sharks. The premature release might be related to several reasons and is commonly observed in other shark species (Kerstetter et al. 2004, Hayes et al. 2007, Meyer et al. 2010, Hammerschlag et al. 2011, Afonso & Hazin 2015). The most probable cause for these two sharks (HS1 and HS2) was the onboard tagging method, since it differed significantly from the sharks tagged directly on the water (Kerstetter et al. 2004, Musyl et al. 2011). The stress during the tagging procedure onboard may be the cause of sharks disease and consequent premature releases.

The six scalloped hammerhead shark did not swim great distances from SPSPA, spending most of the time near the archipelago, especially HS3. Despite the movements away from the island, the release points were close to SPSPA in all cases, indicating potential evidence of fidelity to the area. Daily movements in which the scalloped hammerhead sharks moved away from the archipelago during the night and returned in the daytime were described for other regions; including results indicating the preference of the species for specific locals of certain islands (hotspots) where large marine life aggregation generally occur (Klimley & Nelson 1984, Klimley & Butler 1988, Hearn et al. 2010, Bessudo et al. 2011a, Ketchum et al. 2014a). Due to the geolocation limitations, in the present study this pattern could not be confirmed, but the use of the SPSPA as a refuge area, where the scalloped hammerhead sharks return periodically, is not only entirely plausible but likely.

In Galapagos Marine Reserve the migrations between the islands have been associated with abiotic factors, such as ocean currents and seasons, as well as with distinct individual behavior (Ketchum et al. 2014a, b). The scalloped hammerhead sharks tagged there, however, did not migrate towards the continent, despite their various movements in different directions, probably related to the different seasons they were tagged. Likewise, all sharks tagged in the vicinity of SPSPA returned to the archipelago, within different timeframes. The most likely reason for this behavior is a lonely prey searching, away from SPSPA at night, returning at dawn to aggregate in schools using the archipelago as a reference point (Dagorn et al. 2000, Fréon & Dagorn 2000). The use of geomagnetic field as a geographical reference by scalloped hammerhead sharks was described by Klimley (1993), indicating that directional movement is probably an effect of the island topography.

The tagged sharks spent most of the time in the island vicinity, a behavior that might be related to the high productivity of this insular ecosystem, particularly when compared to the strong oligotrophic waters of the equatorial Atlantic Ocean surrounding it. SPSPA probably serves not only as a feeding and reproduction ground, but also as a shelter from predation, to several species as already observed by various authors (Klimley & Butler 1988, Heupel & Hueter 2002, Vaske et al. 2003, Vaske et al. 2005, Vaske et al. 2006, Morato et al. 2010, Bezerra et al. 2013, Viana et al. 2013). Local upwelling and turbulence resulting from the interaction with marine currents promote the vertical transport of nutrients that may be retained close to the islands, contributing significantly to food availability and aggregation of marine organisms (Worm et al. 2003, White et al. 2007).

In Malpelo and Cocos Islands, both during day and night, the scalloped hammerhead sharks remained predominantly in warm waters, at depths up to 100 m, never reaching 1,000 m (Bessudo et al. 2011 a,b). Their thermal preference was modified according to the seasonal variation of the thermocline depth. This preference was similar to the ones observed presently.

Incursions to great depths are probably associated to prey searching, due to the species capacity to forage on mesopelagic zone and its preference for oceanic cephalopods, such as *Chiroteuthis sp.* and *Vampyroteuthis infernalis*, known to occur at depths of 300 m (Smale & Cliff 1998, Vaske et al. 2009). Depths below 350 m have already been considered the range of high biomass in the SPSPA surroundings and could possibly explain some of the dives of the species in that area, due to intraspecific and interspecific competition and overlapping feeding niches (Heupel et al. 2007, Vaske et al. 2009, Heithaus et al. 2013, Bornatowski et al. 2014, Irigoien et al. 2014). Diving to deep waters for trophic reasons have also been described for other sharks (Bonfil et al. 2010, Cartamil et al. 2011, Afonso & Hazin 2015, Howey-Jordan et al. 2013, Tyminski et al. 2015).

As hammerhead sharks have a preference for warmer waters, after performing a deep dive, the shark would return to the thermocline to warm up before doing another deep dive. This daily movement of frequent diving between surface and great depths, called a *yo yo* diving pattern (Klimley et al. 2002, Bessudo et al. 2011b, Nakamura et al. 2011, Holmes et al. 2014, Afonso & Hazin 2015), also detected in this study, might have a metabolic reason. Thermoregulation requirements to maintain body temperature, prey searching and navigation are some of the factors that might explain this diving behavior (Weihs 1973, Hight & Lowe 2007, Bonfil et al. 2010, Campana et al. 2011, Thums et al. 2012).

The apparently shallower distribution of females in relation to males might also have a physiological reason. Judging from their size, all tagged females in the present study were likely adults and could, therefore, be using the warmer waters of the mixed layer to save energy and/or accelerate the ovulation/fertilization process, as demonstrated for other shark species (Hazin et al. 2000, Hight & Lowe 2007, Nosal et al. 2014).

The majority of the dives displayed by the six sharks on the mesopelagic zone occurred during the night, contrasting with the pattern commonly described for other shark species, which remain in deep waters during the day moving to shallow waters searching for food at night (Sims et al. 2005, Cartamil et al. 2010, 2011, Queiroz et al. 2012). The inverse behavior observed for the scalloped hammerhead shark may be a response to a smaller competitiveness for prey in deeper waters, during these times of the day (Jorgensen et al. 2009, Bessudo et al. 2011b). Furthermore, the descent speed was greater than the ascent movement (fast-down and slow-up), suggesting that sharks might be feeding during their return to shallow waters, a pattern also reported by Hoffmayer et al. (2013) for the species. This behavior is also common for other shark species, such as *Prionace glauca*, *Alopias vulpinus*, *Alopias superciliosus*, *Isurus oxyrinchus* and *Carcharhinus longimanus* (Carey & Scharold 1990, Nakano et al. 2003, Abascal et al. 2011, Cartamil et al. 2011, Howey-Jordan et al. 2013).

In the Wolf Island, incursions to depths between 100 and 300 m also occurred during the night, coinciding with the time in which the scalloped hammerhead shark swam away from the island (Hearn et al. 2010). Despite the geolocation data do not allow to confirm such movements in SPSPA, it is probable that the scalloped hammerhead sharks also move away from SPSPA during the night.

The vertical movements described for the scalloped hammerhead sharks in other oceanic islands were observed in the present study, despite the reduced number of tags used. Unfortunately, the data on the horizontal movements of scalloped hammerhead sharks were not sufficient to identify the existence of distinctive patterns, but they do suggest a temporal local fidelity of the species to the SPSPA. In order to elucidate the specific area of use of the scalloped hammerhead sharks in SPSPA more studies using satellite and acoustic telemetry are needed. The present information on the movements of scalloped hammerhead sharks in the equatorial Atlantic Ocean indicates that the specimens remained near SPSPA for at least four months. The SPSPA, together with the Biological Reserve of Atol das Rocas and Fernando de Noronha Archipelago, are included in the Marine Protection Area of Fernando de Noronha. The use of SPSPA by the scalloped hammerhead shark highlights the importance of the adoption of conservation measures for the species in this insular ecosystem. It also emphasizes the great importance of these insular oceanic ecosystems to several other marine species which depend on them for their life cycles and ultimate survival.

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4. Capítulo IV

4.1. Artigo científico III

Nota científica publicada na **Latin American Journal of Aquatic Research**.

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FIRST RECORD OF THE SMOOTH HAMMERHEAD SHARK (*SPHYRNA ZYGAENA*) IN SAINT PETER AND SAINT PAUL ARCHIPELAGO: RANGE EXTENSION FOR THE EQUATORIAL REGION

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ABSTRACT. A smooth hammerhead shark (*Sphyrna zygaena*) was found in Saint Peter and Saint Paul Archipelago in May 2015. This is the first confirmed occurrence of a smooth hammerhead shark in an equatorial oceanic island and suggests a geographic range extension for the species.

Keywords: *Sphyrna zygaena***,** Sphyrnidae, new occurrence, oceanic island, equatorial Atlantic.

From all eight known shark orders, Carcharhiniformes presents the highest species diversity, including the smooth hammerhead shark (*Sphyrna zygaena* (Linnaeus, 1758)), which belongs to the Sphyrnidae family. Currently, the genus *Sphyrna* is composed by nine species, with six of them occurring in Brazilian waters: *Sphyrna media*, *Sphyrna mokarran*, *Sphyrna tiburo*, *Sphyrna tudes*, *Sphyrna lewini*, *S. zygaena* (Compagno, 1984), as well as the new species *Sphyrna gilberti* (Pinhal *et al.*, 2012).

The species comprising this genus are mainly distinguished due to the presence or absence of notches in the cephalic region, as well as other morphological aspects such as the size and position of fins, for example (Compagno *et al.*, 2005; Vooren *et al.*, 2005;

Navia & Mejía-Falla, 2011). Among the species of *Sphyrna* commonly captured in Brazil, *S. zygaena*, *S. mokarran* and *S. lewini* are the largest and the ones that show a higher degree of morphological similarity. These three species are cosmopolitan, inhabit oceanic and coastal regions of tropical, subtropical and temperate seas, and are present along the entire coast of Brazil, with the exception of *S. zygaena* which is distributed mainly in latitudes greater than 20ºS (Casper *et al*., 2005; Compagno *et al*., 2005).

In the Southeast and South regions of Brazil, the smooth hammerhead shark is caught near the coast using trawls and gill nets, and offshore in pelagic longline fisheries (Vooren *et al*., 2005; Amorim *et al*., 2011). Despite the general view that the area of occurrence for the species is limited to high latitudes, a smooth hammerhead shark (Fig. 1) was captured in the Saint Peter and Saint Paul Archipelago (SPSPA) (Fig. 2), a Brazilian group of oceanic equatorial islands. The SPSPA (0°55'02"N, 029°20'42"W) is formed by a group of small islands between the South American and African continents and Southern and Northern hemispheres, located about 1,100 km from the coast of Brazil and 1,700 km from the coast of Guinea-Bissau, Africa.

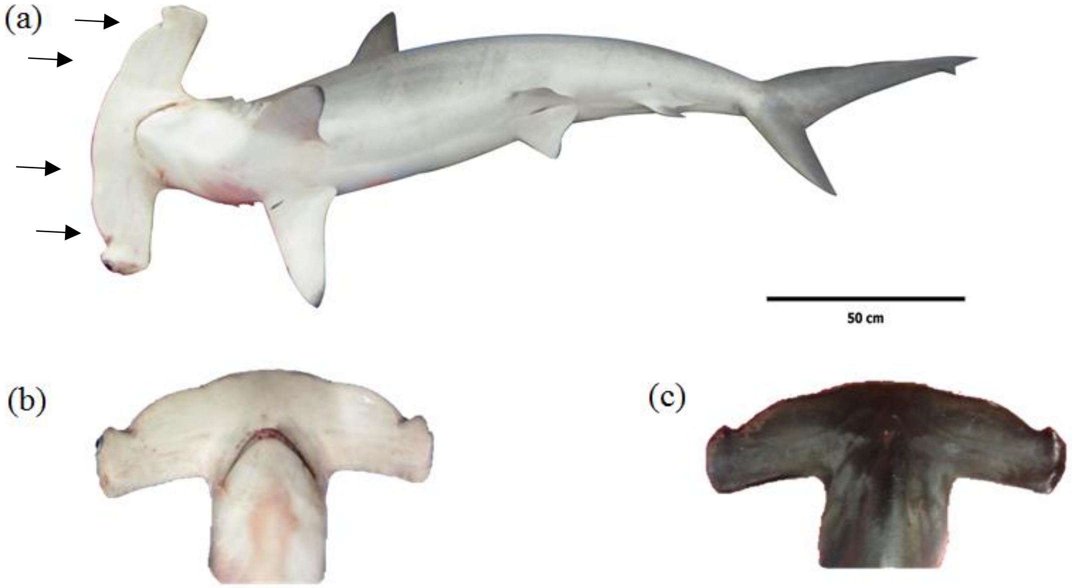

Figure 1. a) Female of Smooth hammerhead shark caught in Saint Peter and Saint Paul archipelago. (→ Four notches), b) Ventral and (c) dorsal head view.

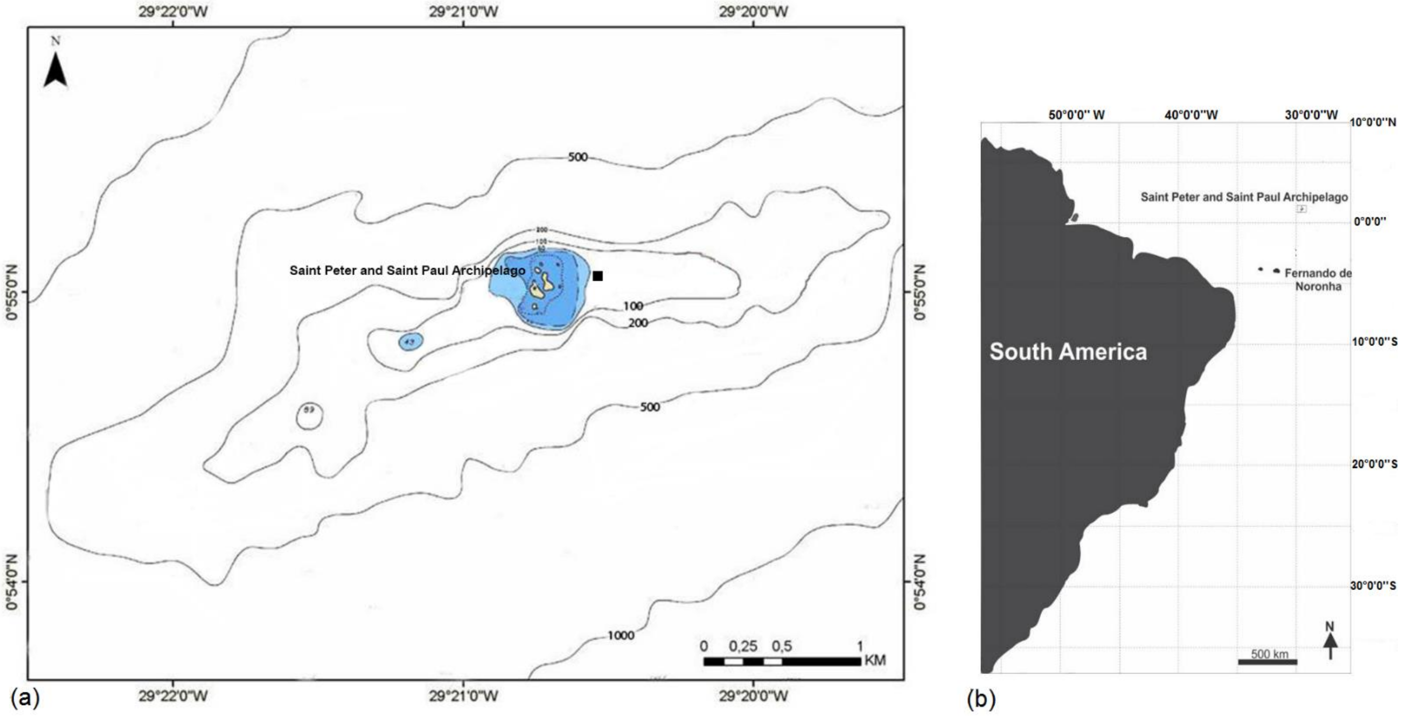

Figure 2. New occurrence location of the smooth hammerhead shark: Saint Peter and Saint Paul archipelago (SPSPA). a) Capture area (■) in SPSPA and b) SPSPA location.

A female *S. zygaena* was captured in 15 May 2015, during shark fishing operations for telemetry studies. The shark was caught in the eastern part of the archipelago on a drum line composed of 16 circle hooks size 16, using flying fish (*Cheilopogon cyanopterus*) as bait. Unfortunately the shark did not survive the capture procedure. The smooth hammerhead shark was easily identified by the following key diagnostic features: head arched with four notches and without a median indentation; first dorsal fin moderately high, with second dorsal and pelvic fins low; pelvic fins not falcate; and lower caudal fin lobe without a dark blotch on it. The shark was eviscerated and measured right after it was landed, presenting the following measurements: 226 cm total length (L_T), 173 cm fork length, 157 cm precaudal length and 57 cm interdorsal space. The total and eviscerated weights were 49.2 kg and 46.1 kg, respectively. The gonadal macroscopic analysis showed the female smooth hammerhead shark was developing by Stehmann (2002) maturity scale, although Vooren *et al*. (2005), in the Southern region of Brazil, have registered adult females with shorter lengths (between 198 cm and 210 cm L_T) than the one described in this study.

The degree of stomach repletion was 25% with the presence of unidentified cephalopod tissues and some beaks. Cephalopods are commonly an important diet item for this species (Rogers *et al*., 2012; Galván-Magaña *et al*., 2013; Bornatowski *et al*., 2014). The specimen is kept in the biological collection of the Oceanography Fisheries Laboratory of the Federal Rural University of Pernambuco, Brazil. *S. zyganea* is the second hammerhead shark species to be reported for the SPSPA, however, the occurrence of the other species, *S. lewini,* in the archipelago is considered common (Lubbock & Edwards, 1981; Vaske-Jr. *et al*., 2005). Bezerra *et al*. (2016) reported significant catches of hammerhead sharks around the archipelago, yet, it was not possible to identify the different species in order to confirm the presence of *S. zygaena* in the area. A possible occurrence of a smooth hammerhead shark near the equatorial region was listed by Soto (2001), in the Fernando de Noronha Archipelago. Nonetheless, according to the author, the record requires confirmation. Smooth hammerhead sharks may seek shelter and food in island ecosystems, such as scalloped hammerhead sharks, which usually form aggregations in these environments (Hearn *et al*., 2010; Bessudo *et al*., 2011; Ketchum *et al*., 2014).

In almost 20 years of intense monitoring around the SPSPA, however, the smooth hammerhead shark had never been reported. The species of the genus *Sphyrna* are usually identified in longline fishing logbooks only as "hammerhead", which hinders the understanding of their geographic distribution, abundance, and importance in fisheries catches, thus contributing to a higher risk for these species (Gallagher *et al*., 2014). This study confirms the presence of the smooth hammerhead shark in the Atlantic equatorial zone, indicating a possible range extension for the species. Delimiting the occurrence area of the species is extremely important to decide effective management and conservation measures for smooth hammerhead sharks, which are classified as vulnerable in the IUCN (International Union for the Conservation of Nature) Red List of Threatened Species (Casper *et al*., 2005).

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5. Capítulo V

5.1. Artigo científico IV

Artigo científico a ser encaminhado para o
Journal of Fishery Research

Capturas incidentais dos tubarões martelo na pesca de espinhel no entorno dos montes submarinos no oceano Atlântico Sul e Equatorial

Natalia P. A. Bezerra, Fábio H. V. Hazin & outros

Abstract

In general, seamounts are biologically important due to their higher biological productivity, attracting an abundant marine life. The species found on the seamounts are of the different taxonomic levels creating productive fishing areas. In the present study, 2,394 seamounts were evaluated in the South and Equatorial Atlantic Ocean in terms of distance from the catch to the nearest seamount. Between 1981 and 2011, the hammerhead sharks totaled 59,556 catches in the total area, with 9,519 in a distance up to 40 km of the nearest seamount. The total effort was 146 million hooks and about 30 million of them (21%) were deployed close to the seamounts. Since hammerhead sharks tend to aggregate around seamounts, the nominal and standardized catch per unit effort (CPUE) was calculated for distances from 0 to 40 km. The CPUE rates substantially increased the closer the hooks were to the seamount. Near the seamounts, the maximum CPUE value was in 10 km (0.90 sharks/1,000 hooks) and the lowest value was in 40 km (0.23 sharks/1,000 hooks). The CPUE of hammerhead sharks showed a significant difference among seamounts areas with higher CPUE rates in southern Brazil near the Rio Grande rise (8.56 – 11.00 sharks/1,000 hooks). These results indicate that marine protected areas might be an efficient tool to protect endangered sharks species that aggregate on seamounts.

Keywords: CPUE, apex predators, seamount conservation, aggregation, South Atlantic Ocean

Introdução

Juntamente com a plataforma continental, áreas de ressurgência e ecossistemas insulares, os montes submarinos se incluem entre os locais de maior produtividade dos oceanos (Longhurst et al., 1995; Hyrenbach et al., 2000; Klimley et al., 2005; Sigman e Hain, 2012). Embora as definições do termo monte submarino venham sendo modificadas ao longo dos anos, a mais tradicional define os montes submarinos como elevações que soerguem do assoalho oceânico, cujo cume não ultrapassa o nível do mar (Menard, 1964). Ainda, na definição geológica convencional, apenas as formações superiores a 1.000 m de altura são classificadas como montes submarinos, embora feições intermediárias entre 100 m e 1.000 m de altura possam ser classificadas como montes submarinos menores, sendo atribuído o termo "knoll" para tais estruturas (Rogers, 1994; Yesson et al., 2011). Os montes submarinos são predominantemente de origem vulcânica, sendo encontrados tanto isolados, como formando longas cadeias na expansão do assoalho oceânico (Clark et al., 2010; Staudigel e Clague, 2010; Wessel et al., 2010). A dimensão espacial e conformidade dessas estruturas podem apresentar formas variadas, embora geralmente possuam forma cônica, e estão intimamente sujeitas à dinâmica entre as fraturas onde estão localizadas (Murray, 1941; Wessel, 2007).

Nos censos globais mais recentes, Kim e Wessel (2011) identificaram 33.096 montes submarinos, embora algumas estimativas indiquem que esse número pode alcançar os 100.000 (Wessel et al., 2010). Com uma extensão de 28,8 milhões de km^2, ocupando, portanto, uma área equivalente a América do Sul, os montes submarinos foram reconhecidos recentemente como um dos maiores biomas do planeta (Etnoyer et al., 2010). Em razão disso, nos últimos anos, estudos multidisciplinares vêm sendo desenvolvidos com o objetivo de se compreender melhor as dinâmicas peculiares dos montes submarinos (Pitcher et al., 2007; Kvile et al., 2014; Morato et al., 2015).

Por se tratarem de formações geológicas extensas em regiões oceânicas e devido às características batimétricas e oceanográficas intrínsecas a cada estrutura, os montes submarinos são capazes de agregar uma elevada biodiversidade (*hotspots*) em diferentes níveis da cadeia trófica (Hazin et al., 1998; Fréon e Dagorn 2000; Hazin et al., 2001; Morato et al., 2008). Assim, levantamentos sobre a biodiversidade dos montes submarinos vêm sendo realizados a fim de elucidar os processos ecológicos que ali se desenvolvem, bem como identificar locais com potencial para agregação de vida marinha nos diferentes oceanos (Lessa et al., 1999; Morato et al., 2009, 2010a; Pinheiro et al., 2015). Cerca de 800 espécies de peixes já foram confirmadas como associadas aos montes submarinos no Pacífico ocidental (Froese e Sampang, 2004; Morato et al., 2006), com um relevante grau de endemismo que pode variar de 10 a 50% para espécies de peixes, a depender do local e dimensão dessas estruturas (Parin et al., 1997; Sampaio et al., 2006; Morato e Clark, 2007; Vaske et al., 2008).

Os recursos pesqueiros dos montes submarinos começaram a ser explorados por embarcações oriundas da antiga União Soviética e do Japão ainda na década de 60. No oeste do oceano Atlântico Sul, as prospecções pioneiras aos montes submarinos datam do início dos anos 80, especialmente na cadeira Vitória-Trindade e na elevação do Rio Grande (Clark et al., 2007). Com os avanços tecnológicos, as localizações dos montes submarinos estão cada vez mais conhecidas, aumentando a vulnerabilidade à pesca das comunidades de organismos aquáticos que vivem nessas formações (Clark e Koslow, 2007). A fauna que habita os montes submarinos é composta por diversos grupos taxonômicos, tais como os peixes, cetáceos, aves e tartarugas marinhas, além de organismos bentônicos (Yen et al., 2004; Morato et al., 2008; Amorim et al., 2009; Maxwell et al., 2012). Algumas espécies desses grupos são capazes de utilizar os montes submarinos como área de alimentação, reprodução e/ou como um geo-referencial de localização em suas rotas migratórias (Klimley, 1993; Pitcher e Parrish, 1993; Bull et al., 2001; Vaske et al., 2009). Grandes peixes pelágicos, como os atuns, agulhões e tubarões, são em geral considerados como espécies visitantes nos montes submarinos, embora algumas dessas formações se constituam em áreas importantes de agregação (*hotspot*) para essas espécies de grande interesse comercial (Myers et al., 2000; Worm et al., 2003; Hearn et al., 2010, Morato et al., 2009,2010b).

Em razão disso, os montes submarinos vêm sendo submetidos a um esforço de pesca crescente, desenvolvido por diferentes países e artes de pesca, com impactos negativos potencialmente significativos, não somente sobre as populações das espécies-alvo, mas também sobre a fauna acompanhante (Dagorn et al., 2000; Morato et al., 2006; Watson et al., 2007; Ruiz et al., 2016). Na pesca com o uso de espinhel pelágico, por exemplo, que tem como espécies-alvo os atuns e afins, é muito comum a captura de tubarões de forma incidental (*bycatch*). De acordo a ICCAT (Comissão Internacional para Conservação do Atum no Atlântico), uma organização regional de ordenamento pesqueiro (OROP) de atuns e afins no Atlântico, a albacora laje (*Thunnus albacares*), o espadarte (*Xiphias gladius*) e o tubarão azul (*Prionace glauca*) são as espécies mais abundantes em número de capturas no oceano Atlântico Sul (Frédou et al., 2015; ICCAT, 2015). Tendo em vista que a maioria das espécies-alvo da pescaria com espinhel pelágico estão associadas aos montes submarinos, o esforço de pesca empregado nestas áreas pode acarretar em um declínio importante de algumas espécies não-alvo, a exemplo dos tubarões (Morato et al., 2010a).

Por sua história de vida, as populações de tubarões são especialmente vulneráveis à mortalidade por pesca, por apresentarem reduzida fecundidade, crescimento lento e baixa resiliência (Schindler et al., 2002; King e Mcfarlane, 2003). Para algumas espécies de tubarões, as suas relações intrínsecas com os montes submarinos já foram documentadas. No Pacífico ocidental, tubarões mako (*Isurus oxyrinchus*) e lombo preto (*Carcharhinus falciformis*) estão presentes nas proximidades dos montes submarinos possivelmente para se alimentarem no processo migratório (Morato et al., 2010a). Estudos no oceano Atlântico equatorial identificaram uma associação positiva das espécies do gênero *Carcharhinus* e do tubarão martelo (*Sphyrna lewini*) com os montes submarinos presentes nesta região (Hazin et al., 1998, 2001).

Embora estudos sobre a capturabilidade nos montes submarinos do oceano Pacífico indiquem que o número de capturas em torno dessas formações é superior às áreas adjacentes de oceano aberto (Fonteneau, 1991; Campbell e Hobday, 2003; Morato et al., 2010a), ainda existe uma grande escassez desse tipo de informação para o oceano Atlântico Sul e Equatorial. Nesse contexto, o objetivo do presente estudo foi reportar dados de captura dos tubarões martelo (*Sphyrna* spp.) em relação às distâncias dos montes submarinos, assim como fornecer informações de captura por unidade de esforço (CPUEs) dos tubarões martelo no entorno dos mesmos, no intuito de identificar áreas de prováveis agregações, com base nas quais possam ser desenvolvidas medidas espaciais de conservação, em particular para a o uso do espinhel, de modo a evitar depleções locais.

Material e Métodos

Os montes submarinos avaliados no presente estudo foram provenientes do trabalho de Kim e Wessel (2011), que geraram um banco de dados com as suas localizações. Censos com estimativas globais dos montes submarinos são possíveis devido ao uso de satélites orbitais, estimando-se o tamanho dessas feições a partir do gradiente de gravidade vertical (VGG- Vertical Gravity Gradiente). Dos 24.643 montes submarinos reportados por Kim e Wessel (2011), 2.394 foram avaliados no presente estudo, tendo sido removidos dessa base de dados as ilhas que por ventura foram incorporadas de forma incorreta. Os 2.394 montes submarinos estudados apresentam dimensões variadas, localizando-se, sobretudo, na porção sul e equatorial do oceano Atlântico, entre as latitudes de 10ºN e 40ºS e longitudes de 45ºW e 15ºE (Fig. 1).

A fim de avaliar se a variação interanual (anos), as distâncias dos montes submarinos (km), a estratégia de pesca, as áreas de pesca (5) e as fases lunares (4) exerceram algum tipo de influência sobre a variabilidade das capturas no entorno dos montes submarinos (Tab. 1), a captura por unidade de esforço (CPUE) foi calculada através de modelos lineares generalizados (GLM), com base nas capturas em número, considerando-se o esforço como offset no modelo. As informações de captura em número, esforço de pesca, estratégia de pesca e suas distribuições espaço-temporais, entre o período de 1981 até 2011, foram obtidos de 82.947 lançamentos, das embarcações nacionais e estrangeiras arrendadas, disponíveis no Banco Nacional de Dados da Pesca de Atuns e Afins no Brasil (BNDA) do extinto Ministério da Pesca e Aquicultura (MPA).

As distâncias entre os locais de lançamento do espinhel para a captura dos tubarões martelo (*Sphyrna* sp.) até o monte submarino mais próximo foram calculadas através da lei esférica simples de cossenos no programa ArcGis versão 10. Apenas os dados com resolução espacial de 1º foram utilizados para calcular a distância entre a captura e o monte submarino e, assim, dados aquém desta resolução foram excluídos da base de dados. De acordo com estudos pretéritos, as espécies do gênero *Sphyrna* apresentam uma significativa associação com os montes submarinos (Kimley, 1993; Hazin et al., 2001; Bessudo et al., 2011). Por isso, a influência dos montes submarinos nas capturas de tubarões martelo foi investigada até a distância de 40 km, sendo esse o perímetro máximo delimitado por Morato et al. (2008, 2010a) como o raio de influência dos montes submarinos.

A análise da variação interanual da CPUE, nominal e padronizada, para os anos de 1981 a 2011, considerou apenas as distâncias de até 40 km do monte submarino. Já a

CPUE nominal e padronizada por faixa de distância do monte submarino (0-10km, 10-20km, 20-30km e 30-40km) considerou também os lances realizados além dos 40 km (>40km), ou seja, fora do raio de influência dos montes submarinos.

Foram consideradas duas estratégias de pesca distintas, a depender da espécie-alvo da pescaria: o espadarte (*Xiphias gladius*) (SL-“shallow longline”= espinhel raso) ou os atuns (*Thunnus sp.*) (DL- “deep longline”= espinhel profundo). Para a segmentação da frota nacional em duas estratégias de pesca, o critério adotado foi o percentual preponderante de ocorrência da espécie-alvo no montante das capturas de cada embarcação (espadarte x atuns). Os barcos estrangeiros foram segregados também em duas estratégias com base em estudos pretéritos (Tolotti et al., 2013; Bezerra et al., 2016; comunicação pessoal). A divisão das estratégias de pesca está relacionada, entre outros aspectos, com a espécie-alvo e consequente profundidade de atuação do aparelho de pesca que alcança águas mais profundas para a captura de atuns, enquanto que na pesca do espadarte não excede aos 100 m de profundidade (Araújo et al., 2013).

Foram testadas as distribuições de Poisson, Poisson inflado de zeros (ZIP) e binomial negativa inflada de zeros (ZINB) para a padronização da CPUE anual (1981 a 2011) e por intervalo de distância do monte submarino (de 0 a 40 km, e >40 km). A estrutura do modelo foi construída através da avaliação das diferentes variáveis-resposta com base na seleção do menor Critério de Informação de Akaike (AIC) (Akaike, 1987) e dos resíduos gerados, resultando no modelo estruturado na seguinte ordem: ano, área, período lunar e estratégia de pesca e distância ao monte submarino. O teste *Vuong* foi aplicado para comparar a superioridade dos modelos inflados ou não de zeros.

A fim de avaliar a distribuição espacial das capturas, a CPUE nominal dos tubarões martelo foi calculada para cada quadrante de 5º x 5º de latitude e longitude, incluindo aqueles onde ocorreram esforço, mas não houve capturas. Todas as análises estatísticas foram realizadas no programa R (R Development Core Team, 2013).

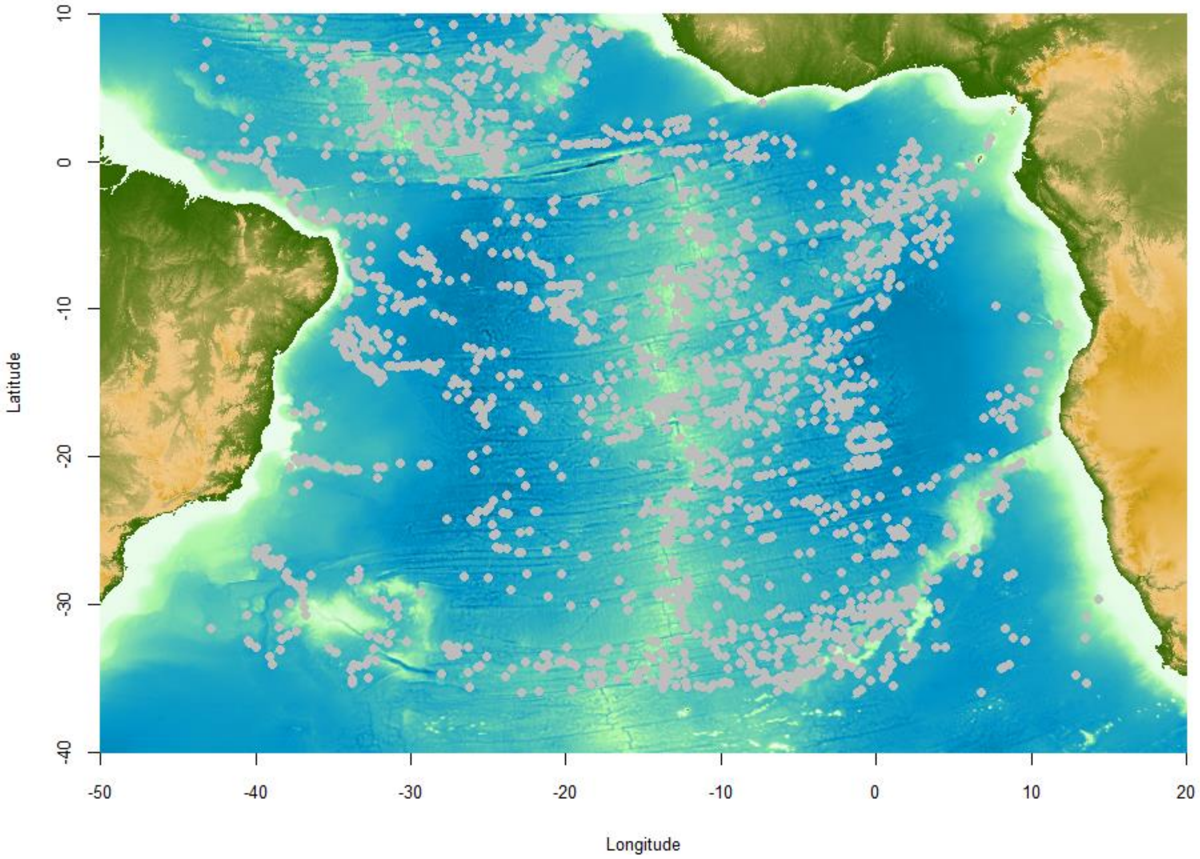

Figura 1: Localização dos 2.394 montes submarinos avaliados no presente estudo, descritos no censo global realizado por Kim e Wessel (2011).

Tabela 1: Detalhes das variáveis explicativas utilizadas nos GLMs.

Data	**Description**
Year	Years between 1981 and 2011
Areas (latitudes)	Area 1: 40^{o}S- 30^{o}S; Area 2: 30^{o}S- 20^{o}S; Area 3: 20^{o} 10^{o}S; Area 4: 10^{o}S- 0^{o} and Area 5: 0^{o}- 10^{o} N
Moon phases	New,Waxing, Full and Waning
Strategy	Shallow longline (SL) and deep longline (DL)
Distance to seamount (km)	Capture local to the nearest seamount

Resultados

A distribuição geográfica do esforço de pesca no entorno dos montes submarinos com distância de até 40 km esteve preponderantemente concentrada a oeste do oceano Atlântico Sul, sobretudo em latitudes acima dos 15°S e longitudes inferiores a 20°W (Fig. 2).

Das 59.556 capturas de tubarões martelo entre os anos de 1981 a 2011, 9.519 exemplares (16%) foram capturados no raio de até 40 km dos montes submarinos, com esforço total para este período de aproximadamente 146 milhões de anzóis, dos quais cerca de 30 milhões de anzóis (21% do esforço total) foram empregados nessa distância. A variação anual do número de exemplares capturados foi, em geral, proporcional à variação do esforço de pesca aplicado, tanto se considerada toda a área, como também no entorno dos montes submarinos, com algumas exceções, a exemplo do ano de 2002, quando, mesmo após uma redução no esforço de pesca (menor em ~ 11 milhões de anzóis, em relação à 2001), foram contabilizadas 7.470 capturas, maior índice registrado para toda a série temporal analisada (Fig. 3).

A CPUE nominal anual calculada para as capturas com até 40 km de distância dos montes submarinos variou de 0,01 (1992) a 3,25 tubarões (2002) por 1.000 anzóis, com o valor médio de 0,35 tubarões/1.000 anzóis (Fig. 4a e b).

Os resultados do teste *Vuong* indicaram que o modelo com zero inflado apresentou uma correlação positiva quando comparado ao modelo não inflado de zeros (Modelo inflado de zero> Modelo não inflado de zero, $p< 2.22e-16$). Esse fato se deve a uma característica da variável resposta (captura), que possui um elevado índice de zeros (Fig. 1 suplemento). Os valores de AIC gerado para o ZIP (185.769) foi superior ao calculado pelo ZINB (61.993), o que, juntamente com a análise dos resíduos (Fig. 2 e 3 suplemento), indicou que o modelo ZINB se ajustou melhor aos dados.

A CPUE anual padronizada pelo ZINB variou de 0,01 (1986) a 2,50 (2002) tubarões/ 1.000 anzóis com média de 0,27 tubarões/1.000 anzóis, valor inferior à média da CPUE nominal calculada (Fig. 4 a e b).

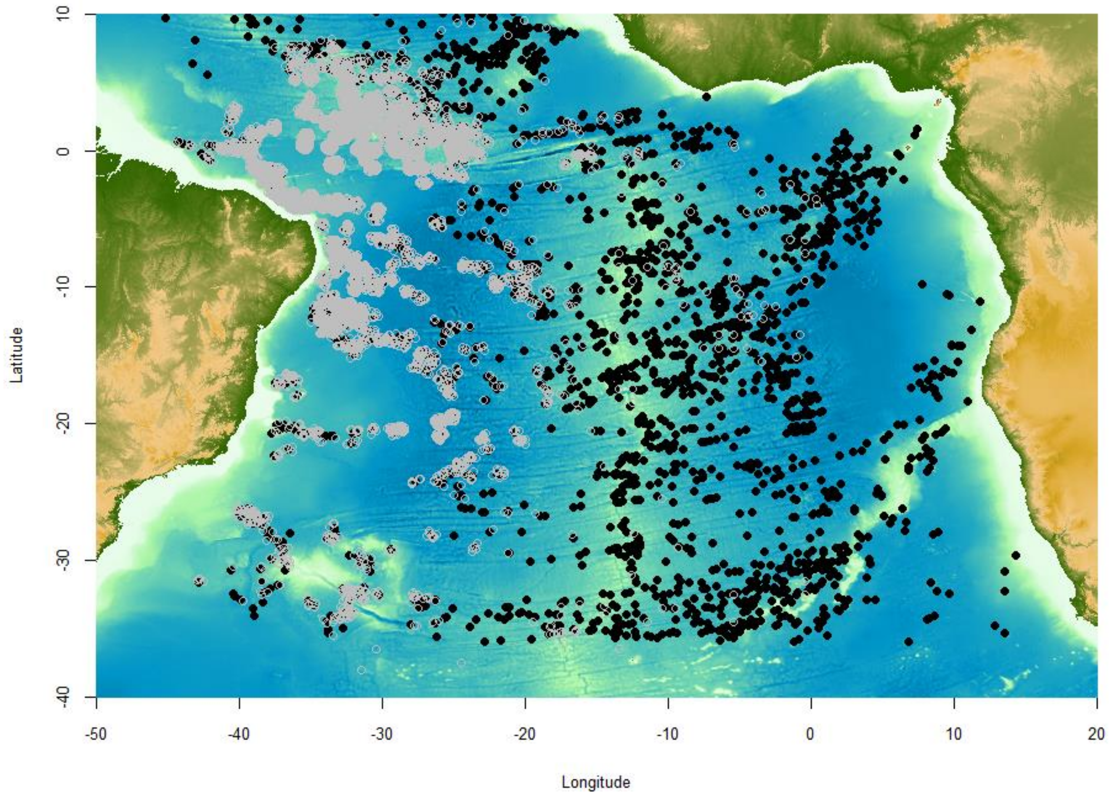

Figura 2: Distribuição espacial do esforço de pesca (cinza) a uma distância máxima de 40 km do monte submarino (preto) mais próximo, empregado pela frota atuneira estrangeira e nacional no oceano Atlântico Sul e Equatorial de 1981 a 2011.

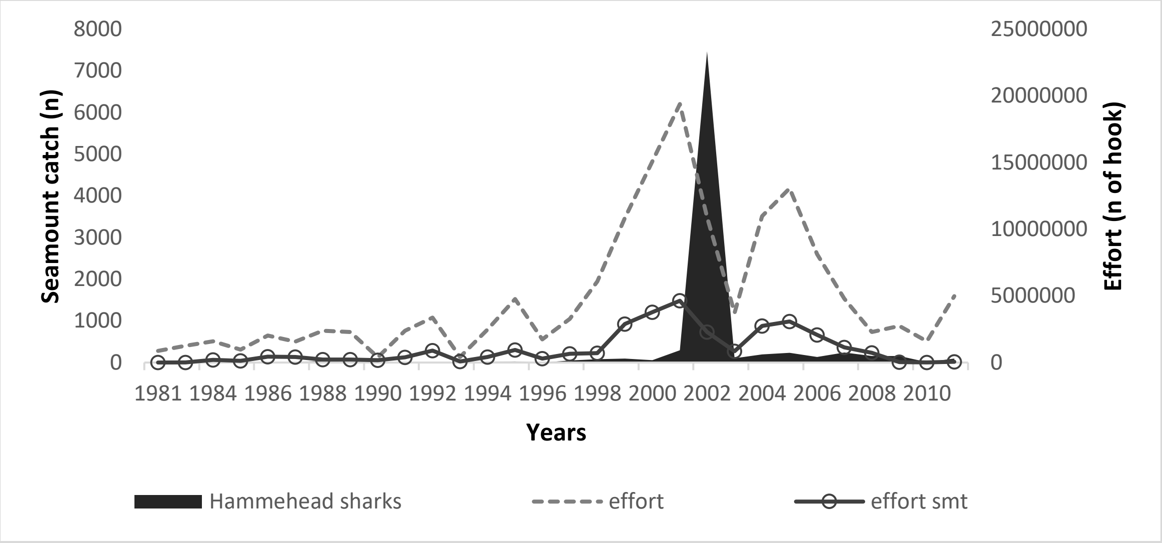

Figura 3: Total do esforço (effort), esforço nos montes submarinos (effort smt) e número de exemplares capturados de tubarões martelo (*Sphyrna* spp.) nas circunvizinhanças dos montes submarinos (distância de até 40 km) pela frota atuneira nacional e estrangeira entre o período de 1981 a 2011 no oceano Atlântico Sul e Equatorial.

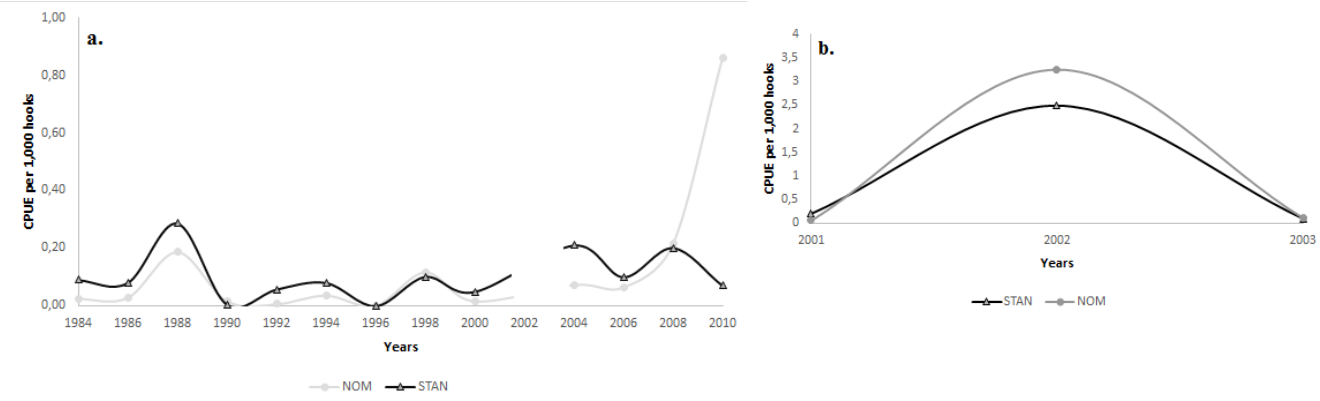

Figura 4: **a.** Variação anual da captura por unidade de esforço nominal (NOM) e padronizada (STAN) para os tubarões martelo capturados a até 40 km de distância do monte submarino, para o período de 1981 a 2011 (exceto para 2002), no oceano Atlântico Sul e Equatorial. **b.** Detalhe da CPUE para o ano de 2002.

Os índices da CPUE nominal dos tubarões martelo, calculada em intervalos de 10 km para as capturas que distaram de 0 km a 40 km dos montes submarinos, variou de 0,90 a 0,23 tubarões martelo para cada 1.000 anzóis, com o maior percentual registrado a até 10 km e o menor, entre 30 km e 40 km de distância dos montes submarinos. A CPUE nominal decresceu de forma linear, à medida que as capturas ficaram mais distantes dos montes submarinos até os 40 km de distância das formações. O valor da CPUE registrada fora do entorno dos montes submarinos (> 40 km) foi de 0,40 tubarões/1.000 anzóis (Fig. 5).

A padronização da CPUE para os tubarões martelo nas diferentes distâncias dos montes submarinos entre 0 km e 40 km e na área fora desse perímetro (> 40 km) foi realizada com o modelo binomial negativo inflado de zeros. Para as distâncias de 0 km a 40 km dos montes submarinos, a padronização da CPUE gerou valores entre 0,36 e 0,39 tubarões por 1.000 anzóis, enquanto que para toda a área fora do raio de influência proposto (> 40 km), a CPUE padronizada correspondeu a 0,15 tubarões/1.000 anzóis (Fig. 5).

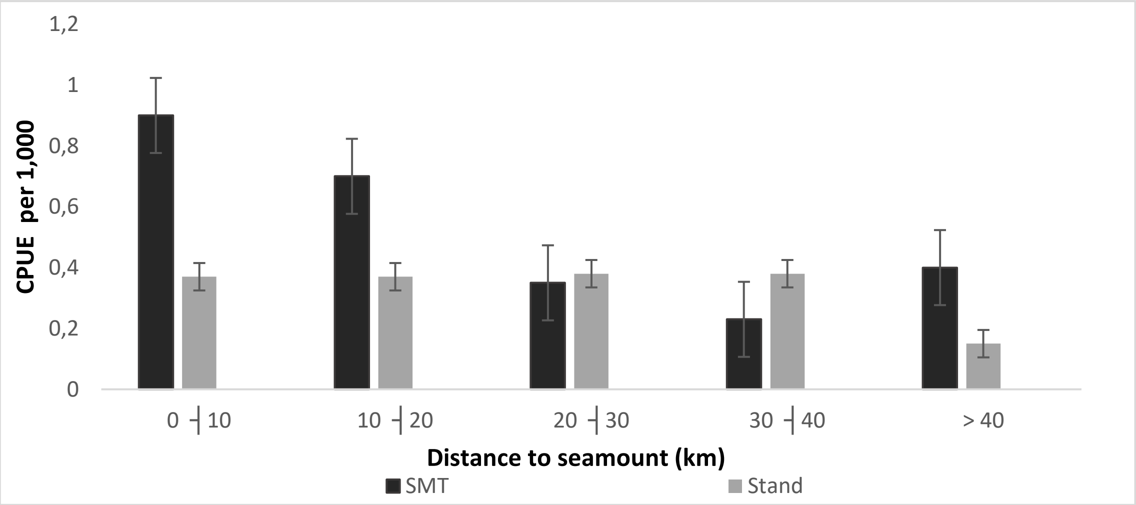

Figura 5: Captura por unidade de esforço nominal (SMT) e padronizada (Stand) dos tubarões martelo calculada a cada 10 km, em distâncias que variaram de 0 a 40 km dos montes submarinos mais próximos e na área fora do raio de influência

dessas estruturas (> 40 km) no oceano Atlântico Sul e Equatorial, entre os anos de 1981 a 2011. As barras correspondem ao erro padrão.

Os coeficientes do modelo demostraram que os fatores ano, área, fase lunar e distância ao monte submarino apresentaram diferenças estatisticamente significativas, embora o erro calculado no modelo com as capturas zero tenha sido elevado, possivelmente devido ao ano de 1981 apresentar poucas capturas iguais a zero (Tab. 2).

Os índices relativos à distribuição geográfica da CPUE nominal dos tubarões martelo oscilaram de 0,01 a 11,0 tubarões/1.000 anzóis. As áreas com as mais elevadas CPUE foram localizadas no extremo sul, entre 27,5°S e 37,5°W e 27,5°S e 32,5°W, com valores de 11,0 e 8,56 tubarões por 1.000 anzóis, respectivamente. Os menores valores de CPUE, por sua vez, embora mais dispersos, foram observados em maior número na porção norte do Atlântico Sul: 2,5°N e 32,5°W (0,01 tubarões/1.000), 12,5°S e 7,5°W (0,01 tubarões/1.000), 7,5°S e 17,5°W (0,03 tubarões/1.000), 7,5°S e 22,5°W (0,03 tubarões/1.000) (Fig. 6).

Tabela 2: Coeficientes das estimativas dos parâmetros (estimate), erro-padrão (SE) e os valores *p* (P) para o modelo negativo binomial inflado de zeros (ZINB) para as capturas de tubarões martelo (Significance levels: *10%, **5%, ***1%).

Count model coefficients					**No count model coefficients**			
Parameter	Estimate	Std. Error	Pr(>|z|)		Estimate	Std. Error	Pr(>|z|)	
(Intercept)	-12.270	0.604	< 2e-16	***	-9.017	942.3	< 2e-16	***
1982	1.369	0.664	0.039	*	2.357	920.7	0.798	
1983	0.878	0.660	0.183		-7.392	928.6	0.426	
1984	2.568	0.672	0.001	***	-2.873	909.8	0.752	
1985	-0.254	0.776	0.743		-9.378	920.7	0.422	
1986	0.201	0.840	0.811		-1.313	922.6	0.235	
1987	0.029	0.696	0.965		-1.953	909.0	0.071	.
1988	3.264	0.637	3.06e-07	***	-7.520	876.5	0.390	
1989	0.904	0.640	0.157		-2.320	909.0	0.017	*
1990	3.006	0.641	0.002	**	2.091	846.1	0.983	
1991	1.385	0.617	0.024	*	-1.985	894.5	0.026	*
1992	0.572	0.659	0.386		-2.052	985.1	0.037	*
1993	0.005	0.934	0.995		-2.358	922.6	0.123	
1994	-0.345	0.662	0.602		-3.926	909.0	0.026	*
1995	1.743	0.619	0.004	**	-1.226	889.2	0.167	
1996	2.333	0.650	0.003	***	-6.361	917.7	0.488	
1997	1.347	0.614	0.028	*	-1.490	913.6	0.102	
1998	2.158	0.600	0.001	***	-1.010	882.9	0.252	
1999	1.024	0.600	0.087	.	-1.351	880.7	0.125	
2000	0.101	0.591	0.863		-3.877	882.2	1.49e-05	***
2001	3.345	0.591	1.54e-08	***	-6.823	881.1	0.438	
2002	6.164	0.590	< 2e-16	***	-4.570	871.6	0.600	
2003	3.243	0.600	6.57e-08	***	-1.273	880.9	0.154	
2004	2.307	0.587	8.60e-05	***	-1.361	868.3	0.117	
2005	2.339	0.588	7.11e-05	***	-1.522	871.2	0.137	
2006	1.784	0.589	0.002	**	-1.522	878.8	0.083	.
2007	3.171	0.591	8.15e-08	***	-5.093	877.7	0.561	
2008	2.678	0.612	1.21e-05	***	-9.504	918.3	0.917	
2009	4.470	0.668	2.30e-11	***	-2.010	280.0	0.992	
2010	3.908	0.831	2.56e-06	***	-1.993	440.6	0.996	
2011	3.952	0.676	5.05e-09	***	-2.025	234.7	0.984	
latitude	0.002	0.003	0.437		8.760	590.8	< 2e-16	***
longitude	-0.048	0.003	< 2e-16	***	-6.828	670.8	< 2e-16	***
Waxing	0.780	0.064	< 2e-16	***	2.330	145.4	< 2e-16	***
Full	-0.217	0.064	0.001	***	-1.451	97.74	0.137	
Waning	-0.147	0.063	0.020	*	3.653	96.52	0.705	
JAP	0.107	0.063	0.092	.	1.402	94.72	0.138	
Distance_smt	-0.049	0.062	0.001	***	8.760	590.8	< 2e-16	***

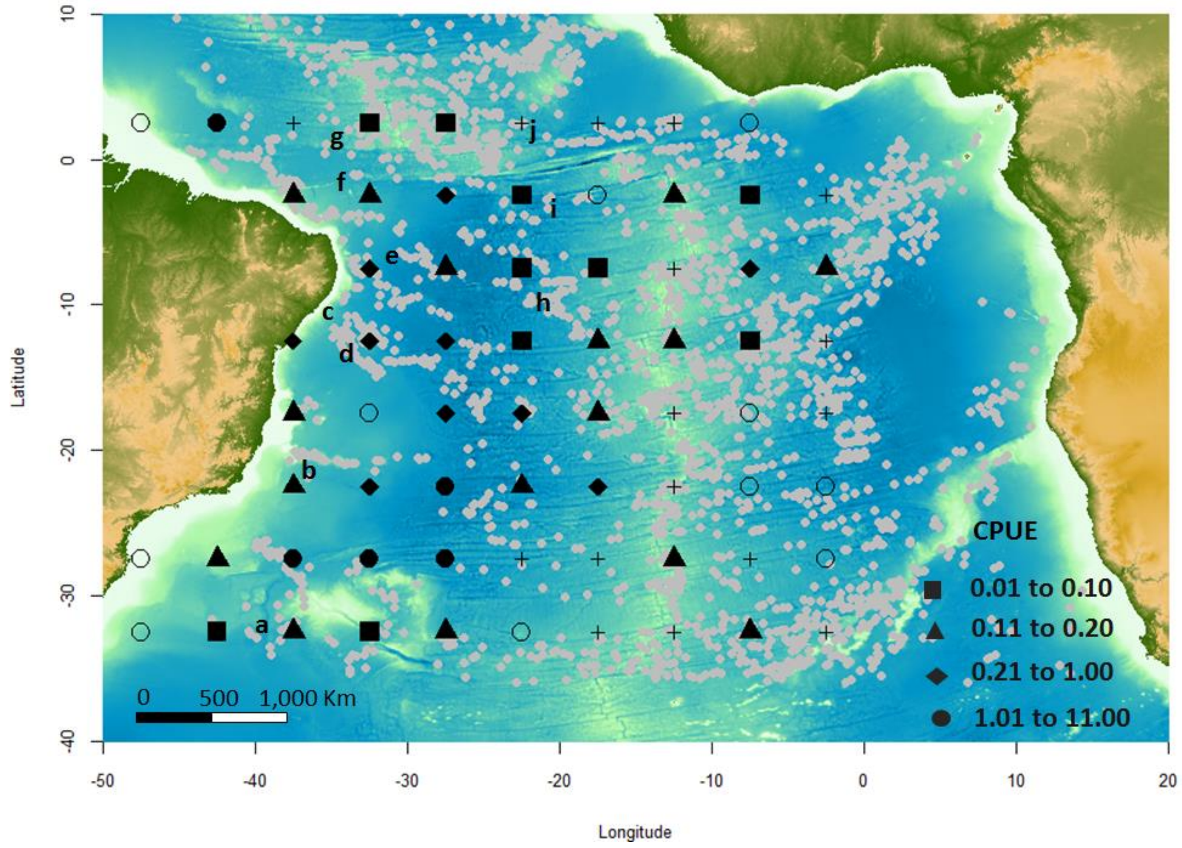

Figura 6: Distribuição espacial da CPUE nominal (tubarão/1.000 anzóis) dos tubarões martelo no oceano Atlântico Sul e Equatorial entre o período de 1981 a 2011. As áreas sinalizadas correspondem as seguintes feições geológicas: a. Elevação do Rio Grande, b. cadeia Vitória-Trindade, c. Montes submarinos da Bahia, d. Stocks e Grol montes submarinos, e. cadeia do Norte e montes submarinos de Pernambuco, f. cadeia de Fernando de Noronha e elevação do Ceará, g. elevação do norte, h. zona de fratura Bode verde, j. zona de fratura de São Paulo e i. Romanche zona de fratura (Skolotnev et al., 2012 a,b). O sinal + corresponde ao local onde ocorreu esforço até 40 km de distância de um monte submarino, mas que não houve captura, e o sinal O as áreas onde não ocorreu esforço de pesca no entorno dos montes submarinos (até 40 km).

Discussão

Algumas espécies de peixes que despertam o interesse da pesca comercial costumam formar grandes cardumes nos montes submarinos (Klimley, 1993; Holland et al., 1999; Morato et al., 2006; Morato et al., 2008; Ferreira et al., 2011; Morato et al., 2010b). Essas agregações ocorrem devido à elevada produtividade primária desses locais, que em parte são ocasionadas por mecanismos de retenção hidrográfica, tais como redemoinhos e pontos de ressurgência, em função dos efeitos da topografia desses ambientes (Rogers, 1994; Travassos et al., 1999). A migração circadiana do zooplâncton, por outro lado, pode resultar na retenção desses organismos na porção superior dos montes submarinos no momento em que eles retornam para as regiões mais profundas (*zooplankton trapping*) (Genin et al., 1988; Genin, 2004), o que também impulsionaria o aumento da produtividade em um ambiente geralmente circundado por águas oligotróficas (Boehlert e Genin, 1987; Genin, 2004). Assim, a biomassa gerada no entorno dos montes submarinos é capaz de sustentar organismos de níveis tróficos superiores, que podem ser visitantes, tais como mamíferos marinhos, alguns elasmobrânquios e tartarugas marinhas, ou residentes por longos ou curtos períodos, a exemplo dos atuns e dos peixes do gênero Beryx que possuem importância comercial, denominados por Morato e Clark (2007) de peixes gregários de montes submarinos (*seamount-aggregating fishes*).

Por se tratarem de formações únicas em ambientes oceânicos, os montes submarinos vêm sendo cada vez mais alvo de estudos não apenas devido às suas características biológicas peculiares, mas também em decorrência do aumento da vulnerabilidade dessas estruturas em razão das atividades de pesca que têm incidido de forma crescente sobre as mesmas (Althaus et al., 2009; Clark, 2009; Clark e Rowden, 2009).

A pesca de atuns e afins com espinhel no Atlântico Sul realizada por embarcações sediadas no Brasil atingiu seus maiores níveis de atividade entre os anos de 1998 e 2008, quando até 100 barcos chegaram a operar (Barreto et al., 2015). Esse intervalo de 10 anos foi também o período com os valores mais elevados de esforço de pesca e capturas no entorno dos montes submarinos para todo o período analisado. Segundo os mesmos autores, entre 1998 e 2008, os tubarões representaram uma parcela extremamente importante nas capturas com o uso do espinhel pelágico no Atlântico Sul, incluindo os tubarões martelo. Os maiores índices de CPUE do tubarão martelo no trabalho citado, porém, ocorreram nos anos de 1996 e 1997, resultado que difere do apresentado neste estudo, sugerindo que a CPUE anual no entorno dos montes submarinos possui uma variabilidade diferente da CPUE convencional, possivelmente devido à influência dessas formações. O índice de CPUE mais elevado no ano de 2002 foi certamente o resultado de algumas dessas agregações pontuais, já que apenas 0,7% dos lances realizados naquele ano (14), responderam por mais de 55% das capturas totais das espécies de tubarão martelo. Todos esses 14 lances ocorreram em distâncias muito próximas de montes submarinos da região equatorial e da elevação de Rio Grande. Em razão dessa forte concentração das capturas, o índice calculado da CPUE padronizada não conseguiu compensar adequadamente o desvio da CPUE em 2002 para a série temporal analisada.

Vários autores já demonstraram que os tubarões martelo costumam formar agregações em montes submarinos (Klimley e Butler, 1988; Hearn et al., 2010; Bessudo et al., 2011), razão pela qual se tornam muito mais vulneráveis às pressões pesqueiras nesses locais (Klimley et al., 1988; Baum e Blanchard, 2010; Bessudo et al., 2011; Queiroz et al., 2016). Essa tendência já foi constatada no Brasil, a partir de dados de pesca com rede de emalhe nas imediações de montes submarinos na costa nordeste (Hazin et al., 2001). Os resultados aqui obtidos confirmam essa tendência, já que a CPUE nominal calculada para a faixa de distância mais próxima dos montes submarinos (até 10km), igual a 0,90 tubarões/1000 anzóis) foi quase 4 vezes superior à obtida na faixa entre 30 km e 40 km (0,23 tubarões/1000 anzóis). Na padronização da CPUE por faixa de distância dos montes submarinos, diferentemente da CPUE nominal, os valores próximos (0-40 km) e distantes (>40 km) dos montes submarinos foram bastante semelhantes, indicando que o modelo conseguiu compensar adequadamente o sinal resultante da proximidade dos montes submarinos.

A influência do relevo submarino na distribuição das espécies de elasmobrânquios não está restrita apenas aos tubarões martelo. No estudo que avaliou a CPUE de tubarões no nordeste do Brasil, por exemplo, Hazin et al. (1998) identificaram que os maiores índices de captura do tubarão azul foram registrados na área sem influência dos montes submarinos, enquanto a tendência oposta foi observada para os *Charcharhinus* sp. Já Morato et al. (2010a), por sua vez, não detectaram influência dos montes submarinos para as capturas dos tubarões azuis, enquanto que para os tubarões lombo-preto (*Carcharhinus falciformis*) a probabilidade de captura aumentou na medida em que o esforço de pesca se aproximou dos montes submarinos.

Os montes submarinos possuem assinaturas geomagnéticas distintas que possivelmente são detectáveis por espécies migradoras, tais como os tubarões martelo, sendo provável, portanto, que funcionem como um referencial geográfico nos processos de migração (Klimley, 1993; Barckhausen et al., 1998; Holland et al., 1999). Além disso, os tubarões martelo podem permanecer longos períodos formando agregações no entorno dos montes submarinos, com movimentos circadianos de saídas e retornos a essas estruturas (Klimley, 1993; Bessudo et al., 2011; Ketchum et al., 2014). Ademais, os montes submarinos também são áreas de agregação alimentar para espécies de diversos níveis da cadeia trófica, tornando esse ecossistema capaz de sustentar grandes predadores de topo (Forges et al., 2000; Arístegui et al., 2009; Pinheiro et al., 2016), ou podem servir de locais para agregações reprodutivas (Hazin et al., 2001). A influência exercida pelas distâncias das capturas aos montes submarinos foi descrita também para espécies de peixes ósseos pelágicos, tais como agulhões e atuns, resultando em uma relação similar ao que ocorreu no presente estudo, com uma tendência de aumento da CPUE quanto mais próxima do monte submarino (Fonteneau, 1991; Morato et al., 2010a).

No Atlântico Sul, áreas no entorno da elevação do Rio Grande já haviam sido sugeridas como possíveis locais de agregação para os tubarões martelo em função dos altos valores de CPUE registrados nas suas imediações (Bezerra et al., 2016), corroborando os resultados encontrados no presente estudo. Da mesma forma, Carvalho et al. (2011) sugeriram que essa formação também é um local importante de captura para o tubarão azul. A elevação do Rio Grande possui profundidades mais rasas que 1.000 m, enquanto o assoalho oceânico no seu entorno possui profundidades médias de 4.000m, existindo várias hipóteses a respeito de sua origem geológica (Mohriak et al., 2010). Essa área recebe a influência direta das águas sub-antárticas, que são extremamente frias e ricas em nutrientes, o que acarreta em uma maior produtividade primária na região (Ciotti et al., 1995). Apesar da evidente influência dos montes submarinos no aumento da abundância relativa de algumas espécies, estudos demonstraram que nem todas as formações apresentam o mesmo potencial de agregação (Morato et al., 2010 a,b), com esse efeito sendo mais acentuado em formações cujo cume se situava em profundidades menores que 400 m (Morato et al., 2008; Hazin et al., 1998), evidenciando que a topografia dessas estruturas pode interferir diretamente na agregação de espécies.

Devido às altas taxas de biodiversidade nos montes submarinos, que também se constituem em “hotspots” para a pesca, algumas dessas estruturas têm recebido prioridade de conservação através da criação de áreas marinhas protegidas (AMP), sobretudo nos oceanos Pacífico e Índico (Hyrenbach et al., 2000; Warner et al., 2012). O principal objetivo na criação das AMP é minimizar os impactos da atividade pesqueira que incidem nessas estruturas, regulamentando o tipo de exploração exercida na área (FAO, 2011; Frey e deVogelaere, 2014). Tradicionalmente, a maior parte das unidades de conservação são terrestres. No Brasil, por exemplo, as UCs marinhas correspondem a apenas 1,5% de todo o território marinho brasileiro (Hoekstra et al., 2005; Briscoe et al., 2016). Assim, por serem um dos maiores biomas do planeta, os montes submarinos deveriam receber elevada prioridade para a conservação no Atlântico a partir da criação de UCs marinhas, com a possibilidade de exclusão de pesca, particularmente aqueles que apresentam altos índices de captura de tubarões resultante de agregações, a fim de que essas populações sejam reestabelecidas e mantidas.

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Suplementos

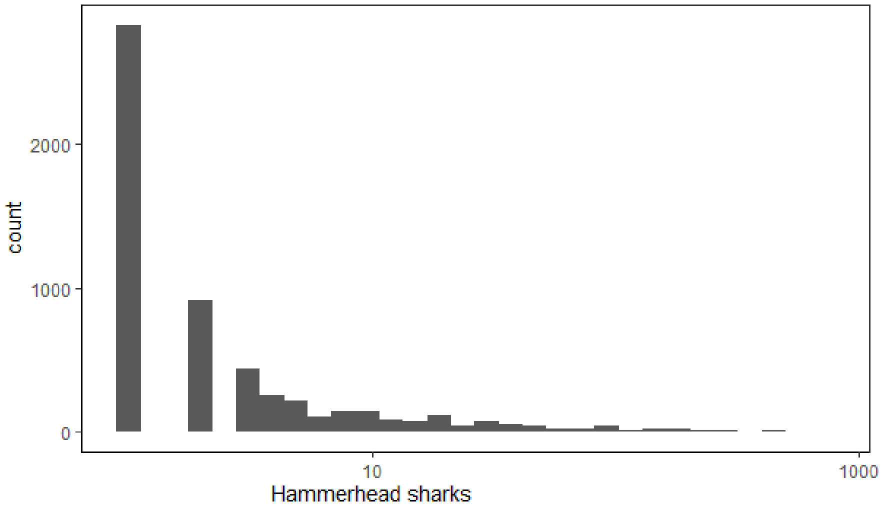

Figura 1: Valores acumulados da variável resposta (captura) de tubarões martelo capturados entre 1978 e 2011 no oceano Atlântico Sul e Equatorial.

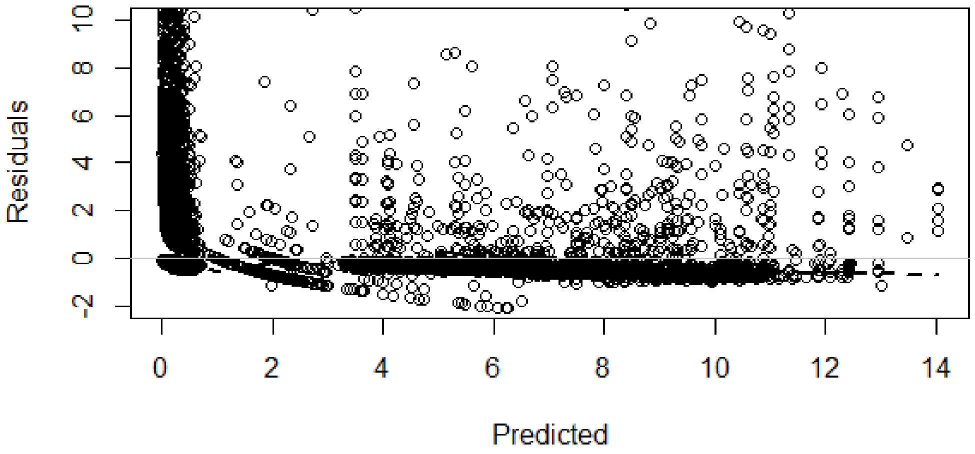

Figura 2: Distribuição dos resíduos do modelo de Poisson inflado de zeros (ZIP).

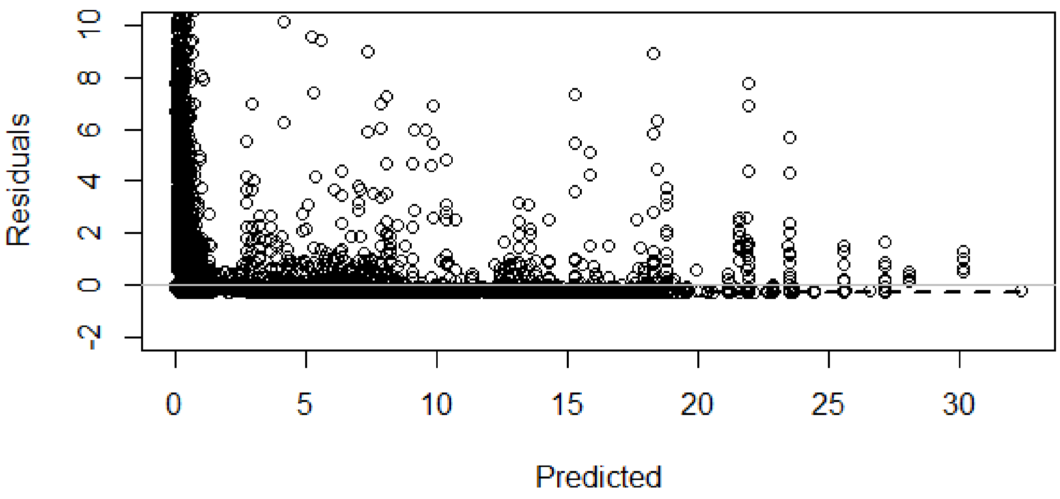

Figura 3: Distribuição dos resíduos do modelo da negativa binomial inflado de zeros (ZINB).

6. Capítulo VI

6.1. Considerações Finais

Os resultados apresentados nesta tese contribuem com dados relevantes e inéditos a respeito da biologia pesqueira dos tubarões martelo (*Sphyrna* spp.), especialmente na porção sudoeste e equatorial do oceano Atlântico. Com as informações geradas, foi constatado que apenas uma pequena parcela do montante geral das capturas foi atribuída aos tubarões martelo entre os anos de 2004 a 2011. Entretanto, diante de um estoque que já se encontra deveras explotado, quaisquer índices de captura, por mais reduzidos que sejam, podem afetar negativamente as populações de tubarões. Se faz imprescindível, também, que os tubarões martelo sejam identificados a nível de espécie, de modo a garantir um modelo de gestão eficiente para as distintas espécies capturadas pelas frotas artesanal e/ou industrial. Identificamos ainda que as taxas de captura estão fortemente associadas aos locais onde ocorreram os esforços, por isso sugerimos que as áreas com maiores índices de CPUE para os tubarões martelo sejam zonas de exclusão pesqueira, de modo a mitigar as capturas incidentais. Fisiologicamente, os tubarões martelo são um grupo extremamente frágil, e por consequência, os animais capturados incidentalmente e posteriormente devolvidos ao mar na forma de "descarte" apresentam uma baixa taxa de sobrevivência, o que acarreta na depleção dos estoques.

Nos experimentos para a implantação dos transmissores via-satélite nos tubarões martelo no arquipélago de São Pedro e São Paulo (ASPSP), o tempo de imersão do material de pesca e o local onde o animal foi contido para a marcação influenciaram diretamente na sobrevivência dos animais. Os cinco últimos exemplares receberam os transmissores dentro da água, ou seja, os animais não foram embarcados para o procedimento de marcação, e ainda, o tempo de imersão do material de pesca foi reduzido, fatores estes que contribuíram para o sucesso da sobrevivência dos espécimes, e por consequência, do monitoramento. Os resultados também demostraram que os exemplares marcados no ASPSP realizaram a sua migração nas adjacências da ilha, o que aponta uma possível fidelidade ao local. O ASPSP é uma área de proteção ambiental (APA) com atividade pesqueira permitida, assim, diante desse novo aporte de informações, sugerimos que medidas sejam deliberadas a fim de proibir a pesca com o uso de espinhel pelágico nas adjacências do ASPSP, como forma de proteção para as espécies ali possivelmente residentes.

Embora as atividades de pesquisas no ASPSP já existam há quase duas décadas, constantemente são reportadas novas ocorrências de espécies pertencentes a diversos grupos taxonômicos. A espécie *S. zygaena* foi recentemente capturada na região onde antes só havia o registro do *S. lewini*, o que remete a extrema importância dos ecossistemas insulares para as espécies do gênero *Sphyrna*, e a necessidade de que o ASPSP continue sendo objeto de pesquisas.

Ainda, a relação entre os tubarões martelo e os montes submarinos foi aprofundada a partir dos resultados gerados pelas CPUEs calculadas em diferentes configurações, sugerindo que os montes submarinos do oceano Atlântico Sul e Equatorial exercem influência para a agregação dessas espécies. Apesar dos montes submarinos serem áreas atrativas para a indústria pesqueira devido a agregação de espécies com grande potencial econômico, nós propomos que na área onde foi registrado o maior índice de CPUE, no entorno da na elevação do Rio Grande, os esforços pesqueiros sejam empregados fora dessa região.

Apesar das importantes contribuições contidas nesta tese, o conhecimento sobre as espécies de tubarões martelo ainda precisa ser melhor aprofundado na porção sul do oceano Atlântico, sendo, portanto, imprescindível que maiores esforços de pesquisa sejam empregados tanto envolvendo os aspectos biológicos, como os ecológicos e comportamentais dessas espécies.

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