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Programa de Pós- Graduação em Diversidade Biológica e Conservação nos Trópicos

LARISSA DE JESUS BENEVIDES

COMPORTAMENTO DE FUGA DE PEIXES ALVO DA PESCA-SUB EM RECIFES COM DIFERENTES MANEJOS

MACEIÓ – ALAGOAS

2016

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Dissertação apresentada ao Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos, Instituto de Ciências Biológicas e da Saúde. Universidade Federal de Alagoas, como requisito para obtenção do título de Mestre em CIÊNCIAS BIOLÓGICAS, área de concentração em Conservação da Biodiversidade Tropical.

Orientador: Dr. Cláudio L. S. Sampaio

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DEDICATÓRIA

Ao meu pequeno, porém grande companheiro Gabriel e ao nosso velho, porém jovem amigo Thiony (in memoriam).

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RESUMO

Uma fuga mal sucedida, por um animal sob ameaça de predação, representa a morte e perda de todo *fitness* que poderia ser adquirido no futuro. Entretanto, mesmo presas que não sofreram qualquer tipo de injúria com o ataque de um predador, podem ter substanciais custos para realizar atividades que elevem seu *fitness*. Dessa forma, o nível do risco de predação imposto por um predador é capaz de moldar as decisões de fuga e, consequentemente, o comportamento do indivíduo no seu habitat. Este estudo objetivou investigar o comportamento de fuga de peixes recifais com diferentes *status* de captura por pescadores subaquáticos, e, como a percepção do risco desses animais dar-se em áreas marinhas com distintas atividades antrópicas. Para isso, foram realizadas medições da Distância Inicial de Fuga (DIF) e avaliada a influência de diferentes fatores nas decisões de fuga de indivíduos de *Epinephelus adscensionis, Acanthurus bahianus* e *Chaetodon striatus*. As coletas foram realizadas em áreas de pesca e turismo ao longo da costa do nordeste do Brasil, nas cidades de Tamandaré - PE, Maragogi - AL, Maceió - AL, e Salvador - BA. Os resultados destacam que a DIF de *A. bahinaus* é influenciada pelo tamanho do corpo e tipo de substrato. Além disso, a DIF das três espécies foi influenciada pelo *status* de proteção da área marinha, mas diferenças entre as áreas de turismo e pesca foram encontradas apenas para *E. adscensionis.* Assim, esse estudo evidencia que os peixes recifais reagem à abordagem do pescador-sub assim como reagem aos seus predadores naturais, mantendo-se mais alerta onde o nível de distúrbio, ou o risco de captura, é elevado. Esse conhecimento pode ser utilizado para avaliar o efeito de atividades antrópicas, como pesca e mergulho recreativo, no comportamento antipredatório de peixes recifais e, a partir disso, reduzir os efeitos deletérios dessas atividades a nível de populações e comunidades. Com as medidas das DIFs é possível inferir o quanto os peixes estão alerta à presença humana, e, a partir daí, estimar distâncias mínimas de aproximação do mergulhador antes de iniciar uma pertubação, ou indicar áreas marinhas onde atividades antrópicas devem ser limitadas ou banidas.

Palavras-chave: Distância Inicial de Fuga, Pesca-subaquática, Área Marinha Protegida, Brasil.

ABSTRACT

An unsuccessful escape, by an animal under threat of predation, represents death and the loss of all fitness that could be acquired in the future. However, even prey that suffers a non-lethal injury with the attack of a predator may have substantial costs to carry out activities that increase your fitness. Therefore, the level of predation risk imposed by a predator is able to shape the escape decision and, therefore, the individual behavior in their habitat. This study aimed to investigate the escape behavior of reef fish with different capture status by spearfisher, and, how is the perception of these animals to the risk of capture in marine areas with distinct anthropic activities. For this, were made the Flight Initiation Distance (DIF) measurements of *Acanthurus bahianus, Epinephelus adscensionis*, and *Chaetodon striatus*, and evaluated the influence of distinct factors on escape decisions. Underwater surveys were performed on fishery and tourism sites along the northeastern coast of Brazil, in the cities of Tamandaré - PE, Maragogi - AL, Maceió - AL, e Salvador - BA. The results highlighting that FID of *A. bahianus* is influenced by body size and substrate type. Besides that, the DIF of three study species was influenced by the protection status of the marine area, but differences between tourism and fishery sites was just found for *E. adscensionis*. Thereby, this study points that reef fish react to spearfisher approach as they react to their natural predators, keeping alert where the disturb, or the risk of capture, is elevated. This knowledge can be used for assessing the effect of anthropic activities, as fishing and diving, on the antipredator behavior of reef fish and thus, develop strategies to reduce the deleterious effects on individual, population or community level. With FID's measures, it is possible to say how much reef fish are alert with human presence and, thenceforth, estimate minimal distances of a diver approach before start a disturbance, or indicate areas where anthropic activities should be reduced or banned.

Keywords: Flight Initiation Distance, Spearfishing, Marine Protected Area, Brazil.

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SUMÁRIO

1. APRESENTAÇÃO

Alterações nos comportamentos antipredatórios de peixes recifais podem ser resultantes do impacto da predação humana em espécies alvo. Dessa forma, o monitoramento do comportamento de fuga de peixes, por meio de medições da Distância Inicial de Fuga, pode representar uma importante ferramenta para identificar e avaliar o resultado de tais mudanças ocasionadas por distúrbios antrópicos. Baseado nesse breve contexto, a presente dissertação discute a influência de efeitos não letais do pescador-subaquático no comportamento de fuga de peixes recifais, e, como essa percepção do risco de predação é expressa em áreas marinhas protegidas com distintas atividades de manejo, no Nordeste do Brasil. A dissertação se inicia com uma revisão de literatura onde são expostas as bases conceituais sobre a pesca-sub; o manejo em áreas marinhas protegidas; e a utilização do comportamento na conservação das espécies, incluindo o uso do método da Distância Inicial de Fuga.

A segunda parte da dissertação consiste no manuscrito intitulado: “Flight response of Barber Surgeonfish, *Acanthurus bahianus* Castelnau, 1855 (Teleostei: Acanthuridae), to spearfisher presence”, onde o objetivo central foi investigar como o *A. bahianus* responde à presença do pescador-sub, por meio da DIF, em uma área de pesca no litoral do estado da Bahia. Em sequência, o manuscrito intitulado: “Flight decisions of reef fishes subject to different status of capture and human disturbance” representa o terceiro e principal capítulo dessa dissertação. Nesse capítulo, a percepção do risco de predação foi investigada em peixes recifais com diferentes *status* de captura pela pesca-sub, em áreas pertencentes e não pertencentes à uma área marinha protegida, através de um cenário de atividades de pesca e turismo. Ao final da dissertação encontra-se uma conclusão geral, onde são brevemente resumidos os resultados e implicações dessa pesquisa, e são apresentadas sugestões para futuras ações relacionadas com o manejo em áreas marinhas. Assim, essa dissertação fornece informações inéditas para a conservação de peixes recifais que habitam áreas frequentemente afetadas por distúrbios antrópicos.

2. REVISÃO DA LITERATURA

2.1. Pesca-sub

A degradação global dos ecossistemas marinhos devido à sobrepesca é bem documentada (JACKSON et al. 2001; MYERS e WORM, 2003; FRISCH et al. 2012), e as consequências da depredação de peixes no ambiente recifal vêm sendo discutidas em estudos que apontam uma redução na abundância e no tamanho destes animais, ocasionados por essa atividade (JOUVENEL e POLLARD, 2001; MEYER, 2007; FRISCH et al. 2008). A caça ou pesca subaquática, ou pesca-sub, é um popular método de captura de animais marinhos, especialmente peixes. Essa pesca pode ser esportiva, recreativa ou comercial, sendo uma importante e crescente atividade em áreas tropicais e temperadas ao redor do mundo (ENNIS, 2011; DIOGO e PEREIRA, 2013; MUTTAQIN et al. 2013). A pesca-sub é conduzida em águas superficiais, através do mergulho livre, e em águas mais profundas, neste último caso com o uso de equipamentos para mergulho SCUBA, como cilindros de ar comprimido (DALZELL, 1996; FRISCH et al. 2008; LINDFIELD et al. 2014).

Devido às armas usadas para captura (*e.g.* arpões, arbaletes, armas pneumáticas), esse tipo de pesca é considerado seletivo, tanto em relação às espécies quanto ao tamanho dos indivíduos capturados (DALZELL, 1996; HARPER et al. 2000). Essa seletividade pode representar uma ação menos danosa para alguns organismos por minimizar impactos diretos em espécies não alvo de pescarias (*e.g.* por *bycatch*) (FRISCH et al. 2008). Todavia, a pesca-sub é tida como método de captura bastante eficiente. Em termos de CPUE (Captura por Unidade de Esforço) essa modalidade de pesca é observada como mais efetiva (*i.e.* possui maior rendimento) do que outros métodos, como a pesca de linha e, por isso, pode ter elevada capacidade destrutiva nos estoques pesqueiros (GILLETT e MOY, 2006; MEYER, 2007).

A retirada de espécies chaves (*i.e.* espécies pertencentes a grupos funcionais de destacada importância no ecossistema recifal), como peixes herbívoros e predadores de topo, induz alterações na estabilidade ecossistêmica nesse ambiente (CINNER et al. 2009). Por exemplo, peixes herbívoros (*e.g.* pastadores e raspadores/escavadores) possuem papel ecológico fundamental nos recifes devido à suas atividades alimentares que ajudam a prevenir ou reverter o estabelecimento e crescimento de comunidades algais que impedem o recrutamento de corais (GREEN e BELLWOOD, 2009). Assim, a remoção dessas espécies pode comprometer a resiliência dos recifes de corais (CINNER et al. 2009). Adicionalmente, a sobrepesca de predadores de topo pode desencadear alterações no controle *top-down,* de grandes carnívoros para mesopredadores, elevando a mortalidade de níveis tróficos inferiores (HEITHAUS et al. 2008; GODOY et al. 2010).

Por outro lado, a retirada de predadores naturais, além dos efeitos na abundância, pode ter também efeitos indiretos no comportamento de espécies presas, por alterar a percepção do risco de predação desses animais (MADIN et al. 2010). Embora estudos anteriores não tenham encontrado mudanças significativas do efeito das armas utilizadas pela pesca-sub no comportamento de alguns peixes recifais (JANUCHOWSKI-HARTLEY et al. 2012), mudanças no comportamento antipredatório dessas espécies podem ser ocasionadas pelo reconhecimento dos pescadores-sub como um predador, primordialmente pelas espécies alvo (GUIDETTI et al. 2008; JANUCHOWSKI-HARTLEY et al. 2011). Contudo, espécies não alvo podem também demonstrar medo à esses mergulhadores, e isso pode ter impactos indiretos ainda não estimados para o ecossistema marinho (TRAN et al. 2016).

A global popularidade da pesca subaquática, em parte devido à sua importância econômica para a sustentabilidade de pescadores locais, tem emergido juntamente com sinais de sobre-explotação dos recursos marinhos (FRISCH et al. 2012). Entretanto, embora haja uma crescente busca pelo conhecimento dos efeitos da prática da pesca-sub (MEYER, 2007; LLORET et al. 2008; ROCKLIN et al. 2011; LINDFIELD et al. 2014), tanto comercial quanto esportiva (COLL et al. 2004), ainda são reduzidas as políticas públicas específicas para manejar este método de pesca (FRISCH et al. 2012). No Brasil, a pesca subaquática é praticada ao longo de toda a costa (TEIXEIRA et al. 2004; TUBINO et al. 2007; NUNES et al. 2012) e em ilhas oceânicas (PINHEIRO et al. 2010; GUABIROBA Jr, 2014), havendo forte histórico de competições estaduais, nacionais e internacionais (Sampaio, com. pess.). Entretanto, são escassas as informações que tratem da real magnitude das alterações causadas nas assembleias de peixes recifais, e nas espécies que direta ou indiretamente são afetadas por ela. Adicionalmente, a falta de registros disponíveis sobre os desembarques, incluindo espécies alvo, tamanhos e pesos (NUNES et al. 2012), pode ser umas das principais causas para as falhas nas estratégias de gestão da pesca-sub em áreas marinhas.

2.2. Manejo em áreas marinhas

A criação de áreas protegidas, ou Unidades de Conservação (UCs), é uma estratégia essencial para conservar a biodiversidade e conter os processos de degradação ambiental (PRATES et al. 2007). Nos oceanos em todo o mundo, a criação de Áreas Marinhas Protegidas (AMPs), por exemplo, tem sido considerada como uma solução para mitigar os impactos causados pela pesca e outras atividades antrópicas (RUSS e ALCALA, 2011). AMPs são frequentemente vistas como ferramentas chaves para preservar ou restaurar a biodiversidade marinha, protegendo espécies exploradas e evitando a destruição do habitat por meio de dois objetivos centrais; manejo e conservação (CÔTÉ et al. 2001; HALPERN, 2003). Para corresponder às propostas de manejo, as AMPs permitem atividades em algumas áreas, com o uso extrativo ou não, e restringem o acesso a outras (ROCKLIN et al. 2011). Áreas com acesso restrito e onde a pesca é proibida, chamadas reservas marinhas, tem mostrado significativo aumento na densidade populacional, tamanho e biomassa de peixes alvo da pesca dentro de suas fronteiras (ASHWORTH e ORMOND, 2005; BRUCE et al. 2012). Além disso, reservas marinhas podem beneficiar áreas além de seus limites, promovendo o *spillover* (*i.e.* exportação de biomassa) de adultos e jovens e, consequentemente, repovoando e favorecendo a captura nas áreas pescadas através da emigração das espécies (GELL e ROBERTS, 2003; RUSS et al. 2003; FRANCINI-FILHO e MOURA, 2008).

Por outro lado, para alcançar os objetivos da conservação, as AMPs preservam espécies, comunidades e o ecossistema por regular a exploração dos recursos marinhos (RUSS e ALCALA 2011) e por manter populações viáveis de espécies nativas dentro de suas delimitações (HALPERN e WARNER, 2003). Adicionalmente, peixes protegidos da pesca, dentro das AMPs, são favorecidos pela redução da predação pelo homem e podem demonstrar alterações em seu comportamento. Se a proteção for absoluta, peixes que não possuem ampla distribuição no habitat devem responder diferentemente aos pescadores e aos humanos não associados à pesca, mantendo-se mais cautelosos a essa abordagem fora dos limites das AMPs, onde o risco de captura é mais elevado (JANUCHOWSKI-HARTLEY et al. 2013). Entretanto, na costa do Brasil, as áreas marinhas mostram evidente desproporcionalidade quanto às categorias de manejo. Considerando os três Grandes Ecossistemas Marinhos, a Plataforma Norte possui maior área sob proteção (13%), a Costa Leste possui menos do que 1.3% de sua área marinha preservada, enquanto a Plataforma Sul possui a menor área protegida (< 0.4%) (SCHIAVETTI et al. 2013). Essa desigual divisão chama atenção quando são comparados com os principais *hotspots* para os peixes recifais (*i.e.* áreas com alta riqueza, endemismo, espécies ameaçadas, espécies alvo e grupos funcionais), que se encontram inseridos nas regiões nordeste e sudeste (Costa Leste e Plataforma Sul) do Brasil (VILA-NOVA et al. 2014).

Na costa do nordeste brasileiro, Área de Proteção Ambiental Costa dos Corais (APACC) estabelece diferentes usos das áreas marinhas (diretos ou indiretos), criados a partir de demandas locais e por distintos instrumentos legais de regulamentação. Um dos principais instrumentos de gestão desta UC é o zoneamento, que representa o ordenamento territorial para manejo das unidades, estabelecendo usos diferenciados para cada zona, de acordo com seus objetivos (*e.g.* proteção, monitoramento, pesquisa, uso, etc.) (ICMBIO, 2013). Dessa forma, na APACC, sete zonas apresentam distintas estratégias de manejo, dentre elas estão: Zona de Uso Sustentável (destinada ao uso geral, mas sujeita às normas gerais da unidade); Zona Exclusiva de Pesca (destinada ao uso dos recursos pesqueiros por pescadores profissionais); Zona de Visitação (destinada ao uso turístico empresarial ou de base comunitária) (ICMBIO, 2013). Uma corrente discussão ligada a essas áreas protegidas refere-se ao estabelecimento das AMPs, o qual é raramente seguido por um bom manejo. Muitas delas são apenas "*paper parks*", que existem oficialmente, mas a falta de eficácia na fiscalização contra danos e/ou exploração por seres humanos faz com que os objetivos da proteção não sejam alcançados na prática (FLOETER et al. 2006). Isso significa que algumas AMPs podem ser enganosos indicadores de uma conservação efetiva (MORA et al. 2006).

Para que a proteção anunciada pelas AMPs seja efetiva, é necessário que o local escolhido para criação dessas áreas seja favorável à aplicação das técnicas de manejo, as quais são necessárias para cumprir os objetivos pré-determinados, seja a gestão da pesca ou a proteção das populações nativas (BOTSFORD et al. 2003). Diferenças no tamanho das AMPs, nas zonas de amortecimento (KRAMER e CHAPMAN, 1999; HALPERN, 2003), idade de estabelecimento (MOLLOY et al. 2009), ausência de infraestrutura e recursos humanos nas reservas marinhas (GERHARDINGER et al. 2011), também são fatores que influenciam na segurança oferecida pelas mesmas, fazendo com que a recuperação de algumas populações possa levar décadas (MOLLOY et al. 2009). Adicionalmente, a efetividade da reserva também pode variar com a resposta das diferentes espécies à proteção (MOLLOY et al. 2008). Por exemplo, espécies de predadores (geralmente as mais exploradas) são susceptíveis à proteção, enquanto espécies presas podem sofrer devido à cascata trófica resultante do aumento de seus predadores dentro da reserva (CÔTÉ et al. 2001; GRAHAM et al. 2003). Nessa perspectiva, as distintas respostas comportamentais das espécies exploradas podem indicar como estas estão reagindo à proteção oferecida pela AMP e como os distúrbios causados pela pesca estão sendo refletidos no ambiente marinho.

2.3. Comportamento e conservação

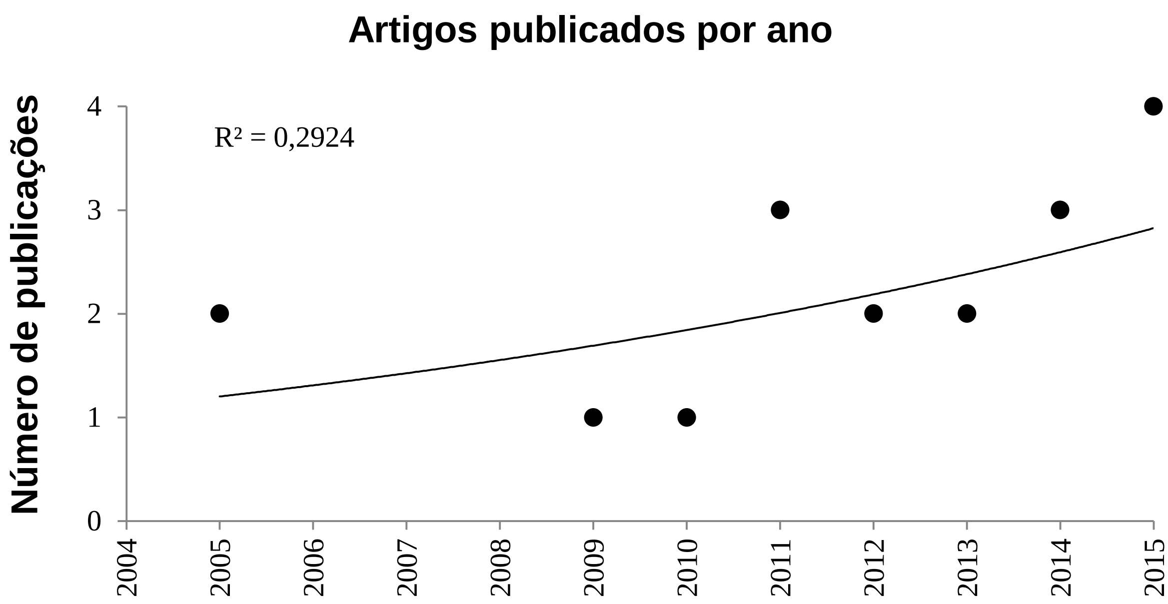
A aplicação do conhecimento sobre o comportamento animal para resolver problemas de conservação da vida selvagem é um campo relativamente novo, conhecido por ‘comportamento de conservação’, que objetiva investigar aspectos comportamentais chaves que possam prevenir ou evitar a perda da biodiversidade (BLUMSTEIN e FERNÁNDEZ-JURICIC, 2010; BERGER-TAL et al. 2011). Embora os avanços teóricos na compreensão do comportamento animal ainda sejam alvo de críticas, quanto a sua contribuição prática para a conservação de populações animais (CARO, 2007), relevantes publicações têm explorado e destacado as principais conexões entre as ciências comportamentais e da conservação (SUTHERLAND, 1998; BLUMSTEIN, 2000; BUCHHOLZ, 2007). Dessa forma, estudos comportamentais podem contribuir para solucionar questões em diferentes contextos, como por exemplo, na conservação *ex situ*, reintroduções e translocações, além de impactos antrópicos (SUTHERLAND, 1998; BLUMSTEIN e FERNÁNDEZ-JURICIC, 2010).

Atividades antrópicas, em geral, causam distúrbios e podem fazer com que espécies apresentem diferentes respostas em relação ao tipo de estímulo a qual ela é submetida. Essas respostas podem ser de significativa importância para identificar os mecanismos comportamentais que direcionam um dos pressupostos assumidos pela ‘hipótese das perturbações de risco’ (*risk-disturbance hypothesis*) (FRID e DILL, 2002; FERNÁNDEZ-JURICIC et al. 2003). Essa hipótese assume que os animais reagem aos humanos de maneira similar àquela que reagem aos predadores naturais – se tornam alerta e eventualmente fogem, caso o custo da aproximação seja maior do que o benefício de continuar com atividades que elevem seu *fitness* (*i.e.* valor reprodutivo), como exploração de recursos no ambiente (FRID e DILL, 2002). Dessa forma, as consequências da presença humana no comportamento dos animais, *e.g.* no aumento da vigilância, devem reduzir o tempo de forrageamento e, consequentemente, o sucesso reprodutivo dos indivíduos (BURGER, 1994; MORRIS e DAVIDSON, 2000; FERNÁNDEZ-JURICIC e TELLERÍA, 2000), podendo desencadear mudanças em nível de populações e comunidades.

Nesse contexto, alguns métodos baseados em experimentos “estímulo-resposta” têm sido aplicados para examinar distâncias de escape de algumas espécies e, por exemplo, usados para determinar áreas de amortecimento (*Buffer zone*) que possam minimizar os distúrbios relacionados às atividades antrópicas (RODGERS e SCHWIKERT, 2002). Esses métodos consistem na estimativa de distâncias mínimas de abordagem na qual os animais revelam medo aos humanos e são mensurados por meio da Distância de Alerta (distância entre o observador e o animal quando este último se torna alerta) (FERNÁNDEZ-JURICIC et al. 2001; FERNÁNDEZ-JURICIC et al. 2005) e Distância Inicial de Fuga (DIF – distância entre o predador e a presa quando esta última foge) (LIMA e DILL, 1990; BLUMSTEIN, 2003). A DIF está atrelada à decisão da presa de escapar ou não do predador, balanceando entre os benefícios de reduzir a probabilidade de captura contra os custos de abandonar a fonte de recursos e gastar energia ao escapar (YDENBERG e DILL, 1986). Essas decisões econômicas da fuga (EEM - *economic escape model*) impulsionaram estudos que direcionaram a atenção para a ampla variedade de fatores que influenciam nos comportamentos de fuga, ou antipredatórios, em diferentes taxa (STANKOWICH e BLUMSTEIN, 2005; COOPER e BLUMSTEIN, 2015). Dentre esses trabalhos, destacam-se aqueles realizados em: (i) aves (FERNÁNDEZ-JURICIC et al. 2004; BLUMSTEIN, 2006; WESTON et al. 2012), (ii) répteis (*e.g.* lagartos) (COOPER, 2009; COOPER e STANKOWICH, 2010), (iii) mamíferos (*e.g.* ungulados, marsupiais e roedores) (STANKOWICH, 2008; BLUMSTEIN et al. 2009), (iv) anfíbios (MARTÍN et al. 2005; BATEMAN e FLEMING, 2014), e mais recentemente com os (v) peixes (DOMENICI, 2010; JANUCHOWSKI-HARTLEY et al. 2012).

A utilização da abordagem humana para avaliar diferentes componentes da distância de fuga tem respondido questões associadas às variações na tolerância dos animais aos distúrbios antrópicos, como atividades relacionadas ao ecoturismo, caça e pesca (BLUMSTEN et al, 2005; STANKOWICH, 2008; TRAN et al, 2016). Em geral, observa-se que o nível de visitação humana, ambos no ambiente terrestre e marinho, é capaz de moldar o comportamento de cautela das diferentes espécies e pode está correlacionado com características do indivíduo (*e.g.* morfológicas, fisiológicas, ontogenéticas), do ambiente (características físicas, políticas de manejo) e com interações sociais (SAMIA et al. 2015; CAMP et al. 2012; FEARY et al. 2011). Na última década, houve um crescimento no número de estudos realizados com peixes (Fig. 1) que tem examinado diferentes aspectos do comportamento (*e.g.* interações de limpeza, sociais, antipredatórias, habilidade locomotora, entre outros) para avaliar a influência da presença humana na biologia dos indivíduos, em especial nas decisões de fuga em respostas ao risco de predação. Esses trabalhos têm gradualmente têm deixado evidente sua relevância (Fig. 1; Tabela 1) e fornecido informações úteis sobre a utilização da distância inicial de fuga como ferramenta para acessar a percepção do risco desses animais, a efetividade de manejo de áreas marinhas e a sensibilidade dos peixes à atividade de pesca.

No Brasil, estudos com comportamento de fuga em peixes recifais, especificamente com o uso da DIF, são mais recentes (NUNES et al. 2015; BENEVIDES et al. 2016) e escassos, o que chama a atenção para a necessidade de se ampliar o conhecimento dessa área na costa brasileira.



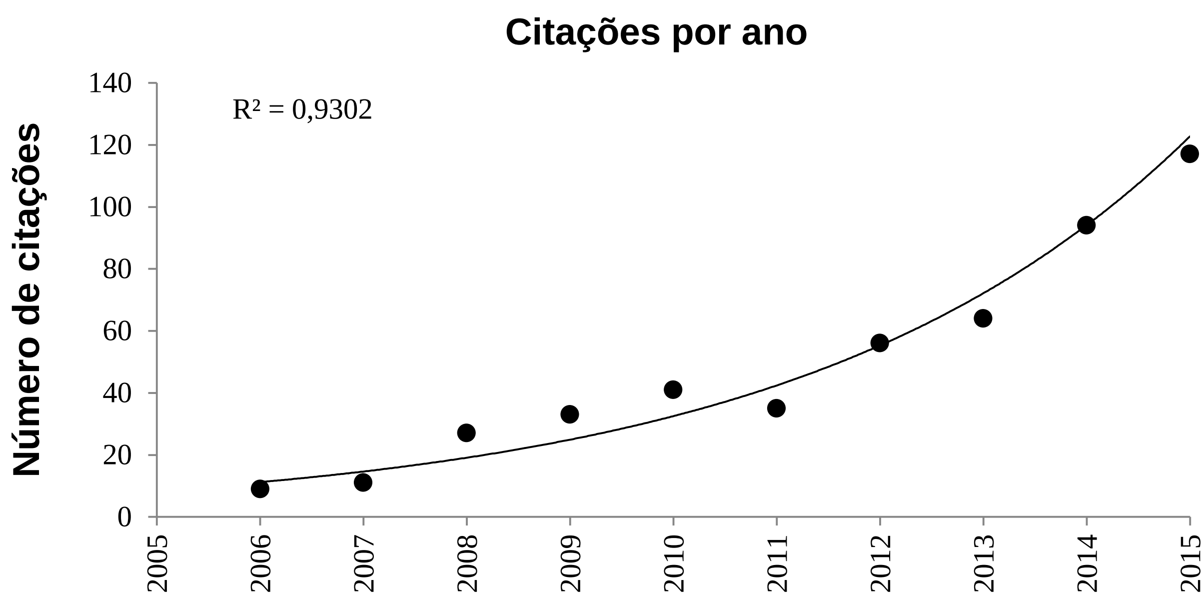


Figura 1. Análise de citações baseada em pesquisa conduzida no *Web of Science*, mostrando o número de artigos e citações sobre o comportamento de fuga dos peixes entre 2000 e 2015. A pesquisa foi realizada utilizando os termos "*Fish Behavior*" e "*Flight Initiation Distance*".

Tabela 1. Sumário de estudos com peixes, baseado na pesquisa realizada no *Web of Science* utilizando os termos "*Fish Behavior*" e "*Flight Inition Distance*", entre os anos 2000 e 2015.

Revista	Fator de impacto	Ano de Publicação	Autores
Biological Conservation	4.036	2015	Januchowski- Hartely *et al.*
Plos One	3.534	2015	Titus *et al.*
Plos One	3.534	2015	Wilson *et al.*
Marine Biology	2.393	2015	Nunes *et al.*
Methods in Ecology and Evolution	5.322	2014	Lindfield *et al.*
Animal Behaviour	3.068	2014	Binning *et al.*
Aquatic Conservation	1.756	2014	Januchowski- Hartely *et al.*
Ecology Letters	13.420	2013	Januchowski- Hartely *et al.*
Behavioral Ecology and Sociobiology	3.049	2013	Lyons
Marine Ecology Progress Series	2.640	2012	Januchowski- Hartely *et al.*
Aquaculture	1.828	2012	D'Ana *et al.*
Conservation Biology	4.320	2011	Feary *et al.*
Plos One	3.534	2011	Januchowski- Hartely *et al.*
Animal Behaviour	3.068	2011	Miller *et al.*
Animal Behaviour	3.068	2010	Sirot
Canadian Journal of Zoology	1.346	2010	Krause *et al.*
Behavioral Ecology and Sociobiology	3.049	2009	Gotanda *et al.*
Proceedings of the Royal Society B - Biological Sciences	5.683	2005	Stankowich & Blumstein
Behavioral Ecology	3.177	2005	Semeniuk & Dill

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3. FLIGHT RESPONSE OF BARBER SURGEONFISH, *ACANTHURUS BAHIANUS* CASTELNAU, 1855 (TELEOSTEI: ACANTHURIDAE), TO SPEARFISHER PRESENCE

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Abstract

When confronted by predators, prey needs to make an economic decision between continuing their current activity or flee. Flight Initiation Distance (FID), the distance at which an organism begins to flee an approaching threat, has been used to indicate an animal's fearfulness level and a way to examine factors influencing escape decisions. Here we investigated how the FID of the Barber Surgeonfish, *Acanthurus bahianus,* responds to the presence of spearfishers in a fishing site in northeast Brazil. Specifically, we investigated whether the FID was influenced by the body and group size; by the heterogeneity of species in group formation; by the distance to shelter and substrate type. FID was positively and significantly correlated to fish body size. We found no significant relationship of FID with size or group formation, neither with distance to the shelter, but preferences in forming groups with *A. bahianus* were seen among some species, and a higher FID was associated with less sheltered substrates. Results obtained here suggest that spearfisher's presence do influence in *A. bahianus* behavior. We highlight that future research should focus on the indirect impacts of spearfishing on the structure of marine communities, emphasizing the antipredator behavior of juvenile and adult target fishes.

Resumo

Ao serem confrontadas por predadores as presas precisam tomar decisões econômicas, escolhendo entre continuar com sua atividade atual ou fugir. Distância Inicial de Fuga (DIF), distância em que um organismo começa a fugir de uma ameaça que se aproxima, tem sido utilizada para indicar o nível de medo do animal e um modo para examinar fatores que influenciam nas decisões de fuga. Aqui nós investigamos como a DIF do Cirurgião Barbeiro, *Acanthurus bahianus*, responde à presença de pescadores subaquáticos em uma tradicional área de pesca no nordeste do Brasil. Especificamente, investigamos se a DIF foi influenciada pelo tamanho do corpo e do grupo; pela heterogeneidade das espécies na formação de grupos; e pela distância para o refúgio e pelo tipo de substrato. DIF foi positiva e significativamente relacionada ao tamanho do corpo do peixe. Nós não encontramos nenhuma relação significativa da DIF com o tamanho ou formação do grupo, nem com a distância para o refúgio, mas preferências na formação de grupos com *A. bahianus* foram observadas entre algumas espécies, e maiores DIF foram associadas com substratos menos abrigados. Resultados obtidos aqui sugerem que a presença de pescadores subaquáticos influencia o comportamento *A. bahianus*. Nós destacamos que pesquisas futuras devem focar nos impactos indiretos da pesca subaquática sobre a estrutura das comunidades marinhas, enfatizando o comportamento antipredator de peixes juvenis e adultos alvos da pesca.

Keywords: Antipredator behaviour, Brazil, Flight Initiation Distance, Rocky reefs, Spearfishing.

Introduction

Risk perception in animals can be a result of the evolution of prey defensive traits in response to predator hunting behavior (Abrams, 2000). Prey may adaptively respond to predators by becoming more vigilant and losing foraging opportunities; remaining inactive and increasing the risk of capture (Brown et al., 2001), or by moving away (flee) from an approaching threat (Dill, 1974). Additionally, in making decisions toward fleeing or avoiding predators, prey can use their learning acquired with socially transmitted information when responding to possible threats (Brown & Laland, 2003; Kelley & Magurran, 2003). Thereby, animals that are target by predators can adjust their anti-predator behavior responses, and consequently their flight decisions, according to their first perceptions of a probable risk (Ydenberg & Dill, 1986).

The main metric used to test risk perception and escape responses in wild animals is known as Flight Initiation Distance or FID. This index estimates the shorter distance at which the prey begins to flee from the predator approach (Ydenberg & Dill, 1986; Cooper & Frederick, 2007). FID has been used to examine the vigilance levels in a number of taxa, including birds (Blumstein, 2006), ungulates (Stankowich, 2008), lizards (Cooper, 2009), anurans (Bateman & Fleming, 2014), and fishes, which have been specially studied in the context of fishing (Feary *et al.* 2011; Januchowski-Hartley *et al.* 2012). Variations in life history traits such as reproductive value, age at maturity and body size can affect the antipredator behavior, and consequently how species will escape from particular threats (Blumstein, 2006). Large-bodied species might be more vulnerable since they are generally less agile (Witter et al., 1994), and so could have higher detection abilities, which may select for greater flight initiation distance (Blumstein *et al.* 2005; Blumstein, 2006). Likewise, predator characteristics (*e.g.* approach speed and predator size) are predicted to increase prey flight distances (Cooper, 2006; Stankowich & Coss, 2007; Cooper & Stankowich, 2010). However, other variables may also modulate the escape performance to avoid predation in fishes, including physiology/biomechanics and behavioral ecology (Domenici *et al.* 2007; Domenici, 2010; Marras *et al.* 2011).

Group size or distance to shelter, which are factors related to perceived risks and the cost of escaping, may also result in different effects on prey flight decisions (Stankowich & Blumstein, 2005). Fishes in shoals, taking advantage of the vigilance of other group members, might avoid predators to close approach, which can result in greater FID (F. A. Januchowski-Hartley et al., 2011). Furthermore, within shoals individuals are also benefited from social learning, allowing more rapid and efficient responses to a known or novel predator (Magurran, 1990; Hoare & Krause, 2003). The communication network of behavior is propagated by neighbours in groups and has been revealed as a process of complex information transfer (Rosenthal et al., 2015). The sharing of acquired information within the groups could be facilitated by conspecific members, although mixed groups could also increase information diversity (Sakai & Kohda, 1995; Hoare & Krause, 2003).

Heterospecific associations have been reported in surgeonfishes, and the major functionality of such groups could be enhanced feeding and decreased predation levels (Barlow, 1974; Alevizon, 1976; Itzkowitz, 1977; Reinthal & Lewis, 1986; Baird, 1993). Nonetheless, there is a shortage of recent studies that strengthen the advantages for fish escape behavior when in mixed groups (Semeniuk & Dill, 2006). Additionally, the effect of the distance from a possible refuge on FID is reported by Gotanda *et al.* (2009) and it is expected to be lower when the prey is closer to a shelter (*e.g.* rocky crevice). In this context, habitats with greater structural complexity (*i.e.* presence of rocky and coral reefs) can act distinctively on antipredator behaviors and the responses may vary among species (Nunes et al., 2015).

Some authors (*e.g.* Stankowich & Coss, 2007; Blumstein, 2006) consider that animals frequently respond to anthropogenic disturbance stimuli in the same way that they do for natural predators, *i.e.* preys follow the same economic principles that they use when encountering natural predators (Frid & Dill, 2002). Equally, the study of Januchowski-Hartley *et al*. (2011) has highlighted some changes on fish flight behaviors, with higher FID positively associated with fishing pressure in families that are specially targeted by spear guns. Spearfishing activity has been linked to having ecological consequences in reef fish depletion, considering abundance and fish size (Frisch *et al.* 2008; Meyer, 2007) and the shift on top-down control from large carnivorous toward herbivorous and omnivorous species (Godoy *et al.* 2010). Nevertheless, evaluating the magnitude of changes caused by this activity in marine ecosystems represents a challenge, greatly due to the lack of specific management policies to regulate fishing methods (Frisch *et al.* 2008). In this context, the knowledge of fish flight behaviors can have important implications for fishing sustainability and regulation practices since fishes may show distinct approach distances (*i.e*. lower or higher FIDs) depending on target species, protection status in fished areas or the fishing intensity (Januchowski-Hartley *et al*. 2012). Here we aim to investigate the flight behavior of a tropical reef fish, the Barber Surgeonfish, *Acanthurus bahianus* Castelnau, 1855, in the presence of a spear gun diver on a popular fishing site in Northeast Brazil. We tested whether FID would be positively correlated with: (i) individual size; (ii) number of conspecifics (*i.e.* the highest percentage of individuals of *A. bahianus*) in the group and group size; (iii) with distance from a potential shelter and (iv) substrate type.

Materials and Methods

Study species

The Acanthuridae family is distributed in tropical and subtropical seas worldwide and comprises six genera and 80 species of Roving Herbivorous reef fishes (RHs), commonly known as surgeonfishes (Nelson, 2006). These roving herbivorous fishes feed primarily on filamentous benthic algae and detritus (Dias *et al.* 2001; Francini-Filho *et al.* 2010) and exhibit wide interspecific variation, in general, ecology and social behavior (Risk, 1998; Alwany *et al.* 2005). The Barber Surgeonfish, *Acanthurus bahianus* (Acanthuridae) was the target species studied. It is found in tropical and subtropical waters of the Brazilian coast, from Parcel Manuel Luiz to Santa Catarina, including the Oceanic Islands of Fernando de Noronha, Atol das Rocas and Trindade, offshore Brazil, and in South and Central Atlantic islands of Ascension and St. Helena (Sampaio & Nottingham, 2008; Bernal & Rocha, 2011).

Juveniles and adults of *A. bahianus* are locally abundant in shallow waters (Dias *et al.* 2001; Rocha *et al*. 2002; Francini-Filho *et al.* 2010) and commonly targeted by spearfishers on south Atlantic coral reefs. Moreover, surgeonfish are known to exhibit behavioral changes as a result of fishing (Smith *et al.* 1989; Januchowski-Hartley *et al.* 2011, 2013, 2014). Although not yet considered as fishery target species in some sites on the east coast of Brazil (Floeter *et al.* 2006), *Acanthurus* spp. are caught by spearfishers (Bender *et al.* 2014; Author´s pers. obs.) and exported to international markets from northeast Brazil (Lessa & Nóbrega, 2000). Between 1996 and 2008, 3,335.49 metric tons of fish were caught and freshly exported for human consumption in the State of Rio Grande do Norte, northeastern Brazil, to the United States and the European Community, where *Acanthurus* spp. represented 8.64% of the total (Cunha *et al*. 2012).

Study site

We measured flight initiation distance (FID) of *Acanthurus bahianus* during four days in October 2014, totaling 16 hours of sampling effort, at randomly selected points distributed along the rocky reefs of Porto da Barra (13°23'S 38°55'W), in southeast of Todos os Santos Bay (TSB), in Salvador, Bahia, Brazil (Fig. 1). Speargun fishing is popular in this area (Nunes *et al.* 2012; Author's pers. obs.) being also the focus of several reef fish studies (Coni *et al*. 2007; Nunes *et al*. 2007a, 2007b; Campos *et al*. 2011; Nunes *et al*. 2013) due to the easy access, high species richness, and shallow and clear waters.

Underwater surveys were performed at a maximum of 4 m depth and mean of 5 m visibility. Rocky reefs are the main physiographic structure in the study sites. These habitats are formed by superposition of granite boulders and characterized by a high density of holes (Ferreira *et al.* 2001). Nonetheless, they represent a less complex environment than coral reefs, which are composed by builder organisms forming a tridimensional complexity reef (Nunes *et al.* 2015). In this area, rocky reef substrates are predominantly composed of turf, soft coral, sea urchins, zoanthids, sponges, small colonies of scleractinians corals and sand bottom (Nunes *et al*. 2013)

Data collection

Two snorkeling divers conducted the underwater surveys. Prior to FID measurement, we estimated the total length (TL) (cm) of each target individual and the number of fishes in each group (max. radius 1 m distance). To study the heterogeneity and preferences of other species to form groups with *A. bahianus*, we identified the species present in the group and estimated the density of the species at the study site. For this, we performed 34 stationary visual censuses (adapted from Bohnsack & Bannerot, 1986) with 4 m radius and 5 min duration (after Nunes *et al.* 2013).

The distance (cm) to the nearest potential shelter was measured as the distance between the locations which the target fish started to flee from the observer's approach, and the closest ledge, hole, or vertical structure capable of providing visual isolation (Gotanda *et al.* 2009). Furthermore, each type of substrate (sand, turf, soft coral, sea urchin, zoanthids or sponges) at the site of observation (max. radius 1 m distance) had its coverage percentage visually estimated, once different substratum composition may offer different resources, *e.g.* shelter, to reef fishes (Krajewski *et al.* 2010).

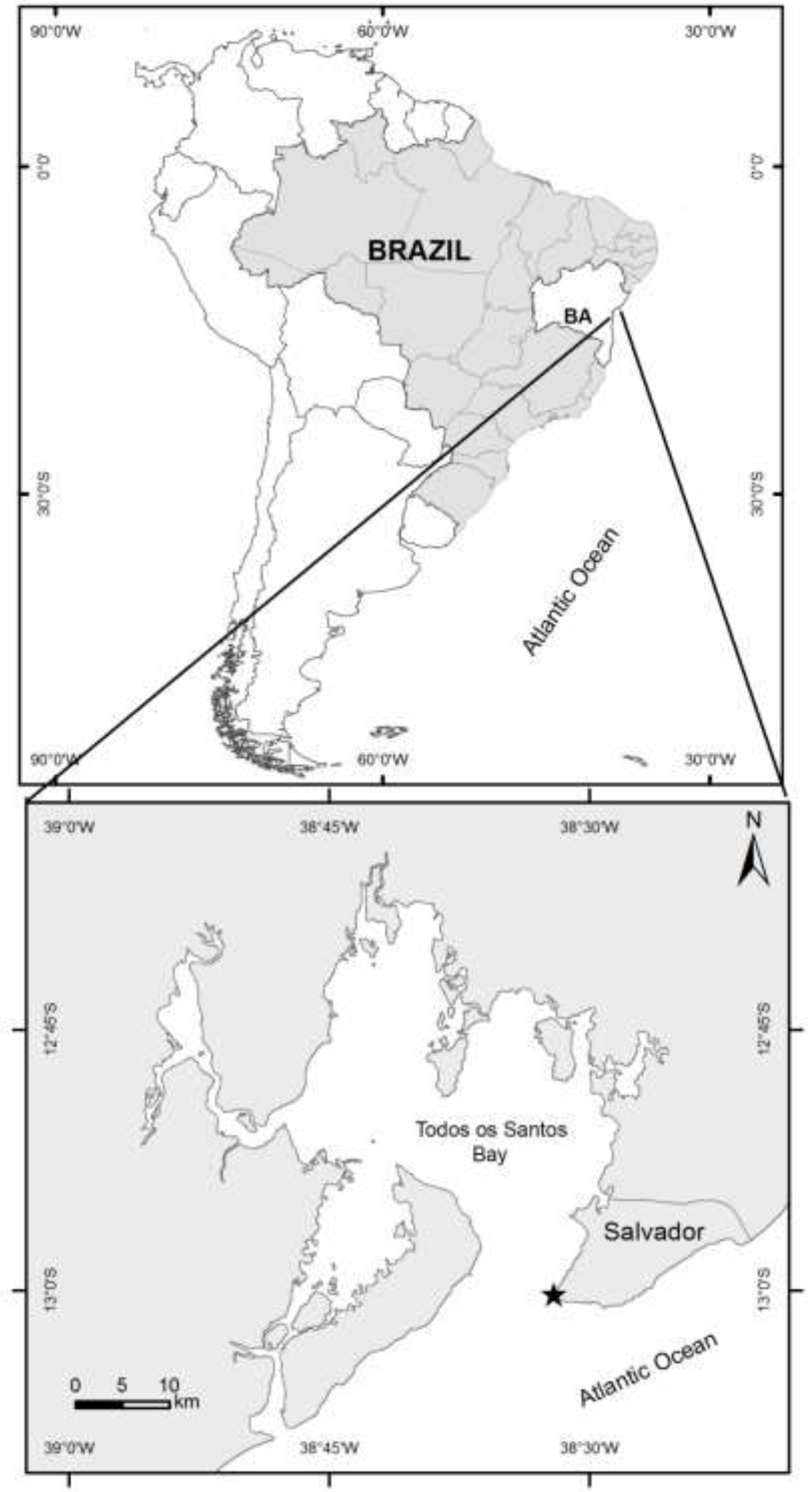

Figure 1. Location of the study area at the Porto da Barra (black star), Salvador, Bahia, Brazil.

Flight initiation distance

The same diver measured the FID of *A. bahianus* individuals. A potential target fish was first identified from the surface. A diver would then descend to the same depth as the targeted fish and swim towards the fish at a constant speed (Januchowski-Hartley *et al.* 2011, 2012). The diver was dressed in a spearfishing camouflaged wetsuit and reproduced spearfisher behavior, remaining approximately 3 m far, holding the spear gun horizontally in front of the face and pointing directly to the targeted fish. When the fish fled, the diver placed a marker on the substrate directly below the point where their hand was holding the gun at the moment of flight, and then a second marker was left on the substrate directly below the location of the fish when it fled (Januchowski-Hartley *et al.* 2011, 2012). The distance (cm) between these markers was measured using a graduated tape.

The spear gun used in the survey was 46 cm and this distance was therefore subtracted from the measurements to obtain the FID. To avoid recording fishes from the same group in quick succession, the diver immediately moved at least 5 m away after each observation (Nunes *et al.* 2013).

Data analysis

FID data was tested for normality through Shapiro-Wilk W test (W = 0.9296; p = 0.08) and homogeneity of variance was determined using Levene's test (F (1.72) = 0.293; p = 0.589). Analysis of covariance (ANCOVA) was used to investigate if FID of *A. bahianus* was influenced by the substrate type and by three covariates: the size of target fish (TL), group size and distance of shelter. Tukey's test was used to identify where FID differed between main substrates. To compare the FID between interspecific and monospecific shoals we used a T-test. Furthermore, one-way analysis of variance (ANOVA) was performed to investigate whether there were differences in FID in different levels of specificity of groups of *Acanthurus bahianus*, *i.e.*, the percentage of individuals of other species in each group (0-30%, 31-60%, > 60%).

Additionally, we used an electivity index Ivlev's to identify which species found in groups with *A. bahianus* show preferences for this formation. Ivlev's was calculated using the formula: $E_i = (r_i - n_i)/(r_i + n_i)$, where E_i is the value of electivity for the selection of species *i* in group formation with *A. bahianus*; r_i is the percentage of encounters of species *i* with *A. bahianus* and n_i is the relative density of species *i* in area. Electivity index varied from -1 to 1. Values close to -1 shows low preference or rejection while values close to 1 indicate a high preference for a group formation with *A. bahianus* (Krebs, 1989). T-test and ANCOVA were performed in StatSoft STATISTICA, version 8.0, and all data analyzes were performed considering a significance level $\alpha < 0.05$.

Results

Body size, group size and distance to shelter

Was measured the FID of 74 Individuals of *A. bahianus,* which ranged from 6 to 30 cm TL and were solitary or present in groups ranging from 2 to 34 individuals. The results of Analysis of covariance (Table 1) showed that there was just a significant correlation between FID and body size, with no correlation in FID of *A. bahianus* with group size and distance to a potential shelter (Fig. 2b). However, FID varied according to substrate type (ANCOVA; $F = 3.95$, $p = 0.028$) (Table 1) with greater flight distances observed where there was a higher percentage of sand substratum (Fig. 3).

Table 1. Analysis of covariance (ANCOVA) results testing the influence of fish size, group size, the distance of shelter and the substrate on Flight Initiation Distance of *Acanthurus bahianus*. SS = Sum of squares; Df = Degree of freedom; MS = Mean of squares. *Significant difference.

	SS	Df	MS	F	p
Group size	501.22	1	501.221	1.597	0.214
Body size	9400.60	1	9400.604	29.95	0.000*
Distance of shelter	31.98	1	31.981	0.101	0.751
Substrate	2479.94	2	1239.972	3.951	0.028*
Error	10983.86	35	313.825		

Composition and preference in a group formation

Differences between FID of interspecific and monospecific shoals were not found (t = 0.049; df = 66.00; p = 0.619). Furthermore, the species composition in groups did not significantly affect the FID of *A. bahianus* (One-way ANOVA; F= 0.097, p = 0.908) based on three categories of mixed groups of species (mean ± S.D.): 0-30% Low (39.4 ± 28.1); 31-60% Medium (37.5 ± 27.3); > 60% High (36.6 ± 23.5). On the other hand, Ivlev's electivity index showed that 3 out of 11 species had a strong preference for group formation with *A. bahianus*: *Acanthurus chirurgus*, *Halichoeres poeyi* and *Acanthurus coeruleus,* in order of preference, respectively. Two species showed no preferences: *Stegastes fuscus* and *Sphoeroides spengleri* (Fig. 4).

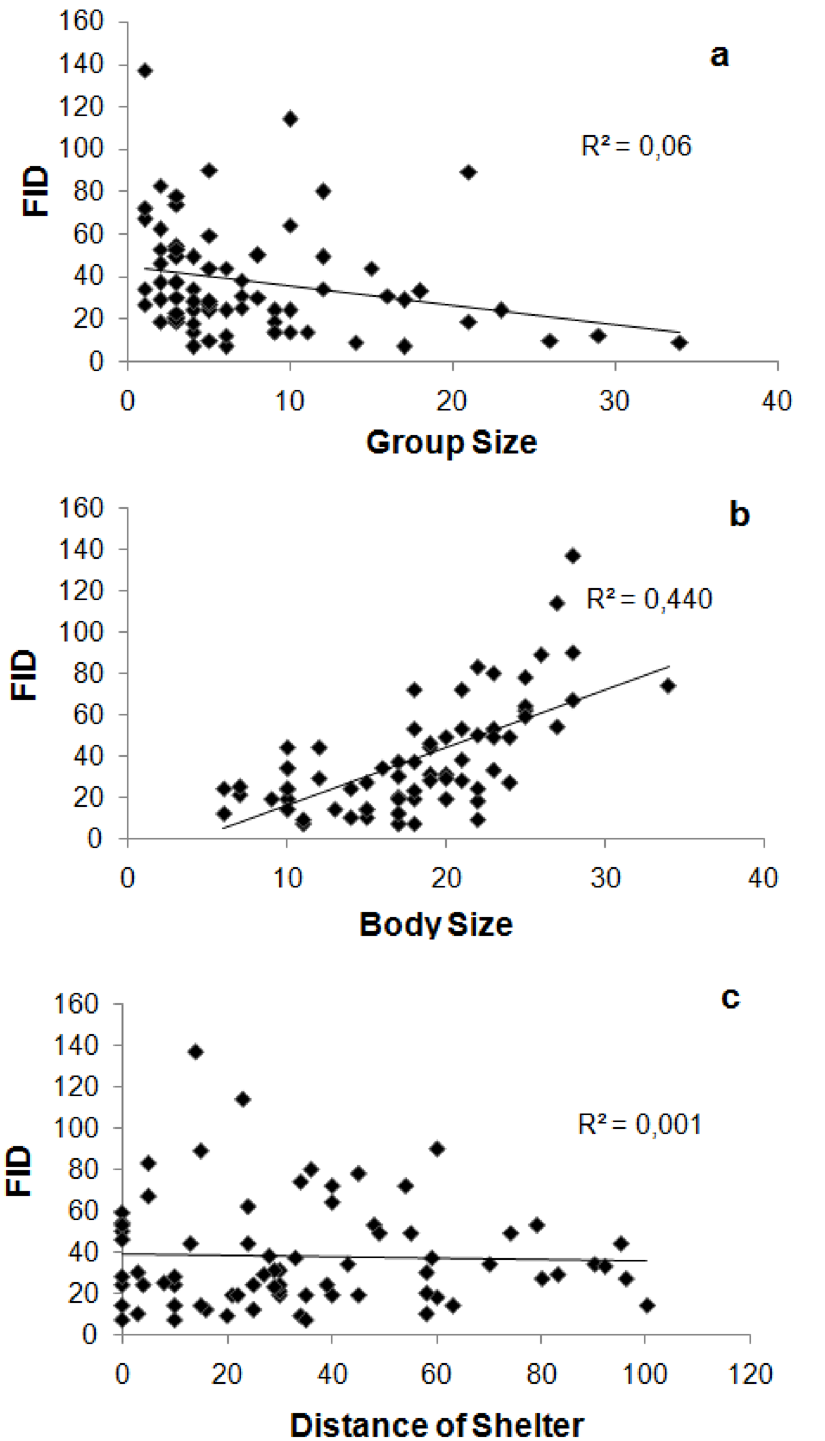

Figure 2. Flight Initiation Distance (cm) plotted against Group size (a), Body size (cm) (b) and Distance of shelter (cm) (c) for *Acanthurus bahianus*.

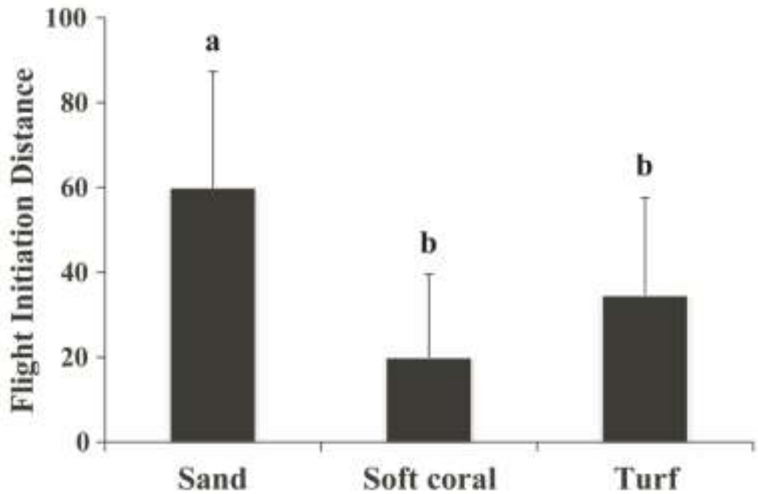

Figure 3. Flight Initiation Distance (cm) (mean ± S.D.) for *Acanthurus bahianus* in the main substrates found at the study site. Different letters mean significant differences – $p < 0.05$.

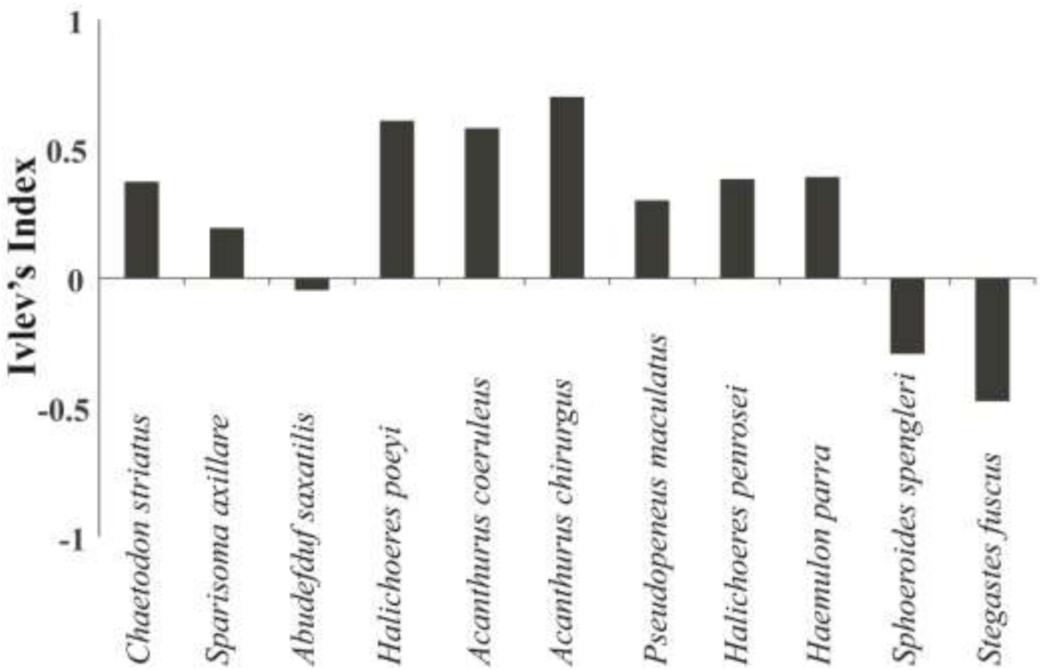

Figure 4. Results of Ivlev's index showing the preference of *Acanthurus chirurgus, Acanthurus coeruleus* and *Halichoeres poeyi*; and the rejection of *Stegastes fuscus* and *Sphoeroides spengleri* to form groups with *Acanthurus bahianus.*

Discussion

We investigated FID of *A. bahianus* when confronted with a spearfisher. Our results indicate that: (i) body size significantly influence FID, with smaller individuals having lower FID than larger ones; (ii) size and group composition did not affect the escape response of *A. bahianus*, albeit congeneric species of *Acanthurus,* and *H. poeyi* had revealed preferences in form groups with *A. bahianus*; and (iii) despite the distance to shelter having no influence on FID, escape responses varied between main substrate types.

Greater FID was often associated with larger body size, which could be attributed to spearfisher preferences in targeting larger fishes (Januchowski-Hartley *et al.* 2011), however, this relation may also be alternatively explained. Large-bodied species can be correlated with age at maturity or age at the first reproduction and this life history traits could affect the fearfulness, making species reduce the risk-taking (Blumstein, 2006). In the same way, the reproductive value strongly supports explaining the increase in FID with body size in parrotfishes (Gotanda et al., 2009). Furthermore, experience or social learning related to predator attacks may provide an opportunity for learned escape responses in adult fish (Kelley & Magurran, 2003).

Although a relationship between FID and group size has not been found here, previous studies have shown that fishes can perform coordinated shoaling behavior on different shoal sizes in response to increased predation risk (Magurran & Pitcher, 1987). Nevertheless, the relationship between group size and escape distance is controversial and may generate contrasting results due to variables related to shoaling (*e.g.* variables affecting vigilance) (Roberts, 1996). For instance, Semeniuk & Dill (2005) found longer reaction distances in groups than in solitary individuals of cowtail stingray, *Pastinachus sephen*. Similarly, Januchowski-Hartley *et al.* (2011) observed an increase of FID with growth on group size for Acanthuridae. The latter study suggested that this result could indicate an independent anti-predation response to variation in fishing pressure. One possible explanation for this group effect is the ‘many-eyes hypothesis’ (Pulliam, 1973), which states that as the group size increases, there are more eyes scanning the environment for predators (Lima, 1995). Thus, the earlier collective detection of a predator attack (Magurran, 1990) may result in a higher FID. In conformity with this prediction, Wolf (1987) reports that juveniles of a sister species of Barber Surgeonfish, *Acanthurus tractus* (see Bernal & Rocha, 2011) can benefit from having more time to forage instead of vigilance when in schooling groups than solitary ones.

Living in conspecific or heterospecific aggregations can facilitate social learning of antipredator behavior through chemical and visual cues (Griffin, 2004; Lönnstedt & McCormick, 2011). Monospecific grouping may provide foraging and anti-predator benefits, however, mixed groups can be more advantageous since they create less resource competition and provide better detection of potential threats (Sakai & Kohda, 1995; Semeniuk & Dill, 2005, 2006). In this study, *A. bahianus* has not shown differences in FID due to mono or mixed groups, but assuming that species can learn that spearfishers represent a potential threat, it is possible that the preference of species found here to form groups with Barber Surgeonfish could reinforce appropriate antipredator responses. Barber Surgeonfishes are often accompanied by *A. chirurgus* and *A. coeruleus* (Dias *et al.* 2001) and the relative frequencies of each species in a group can vary with size classes. This allows mixed groups to exploit territories with high resource quality (*i.e.* higher biomass and algal diversity) (Wolf, 1987; Ferreira *et al.* 1998).

Similarly, the willingness of *Halichoeres* species to form groups with roving herbivores, such as surgeonfish is well known, and can be explained by the associated decrease in predation risk and an increase in foraging opportunities (Alevizon, 1976; Dias *et al.* 2001; Nunes *et al.* 2013). Furthermore, *Halichoeres* spp. are often observed (including on our study site) engaged in cleaning activities with regular client fish such as *A. bahianus* (Sazima *et al.* 1998; Coni *et al.* 2007). Groups of Barber Surgeonfish can consume large amounts of algal biomass from damselfish (*Stegastes fuscus*) territories (Lawson *et al.* 1999; Dias *et al*. 2001). This antagonistic behavior explains the lack of association between *S. fuscus* and *A. bahianus*, despite the very high abundance of Brazilian damselfish (Ferreira *et al*. 1998; Osório *et al*. 2006). The bandtail puffer, *Sphoeroides spengleri*, a common local species that feeds opportunistically on fish (Randall, 1967) is also avoided, perhaps due to the risk of bites.

To have refuge into crevices or undersurface of boulders is apparently effective for some species (*e.g.* mugilids) in order to combat the attacks by large predators

(Guidetti *et al*. 2008). The assumption that flight initiation distance is associated with structural complexity is supported by other studies, where Labridae fish showed a decrease on FID in structurally higher habitats (Nunes et al., 2015), however, the relationship between FID with distance to for *A. bahianus* was not significant. The natural physical structure of rocky reefs, mainly determined by their density of holes, are less complex than coral reefs are (Ferreira *et al.* 2001; Floeter *et al.* 2004) and it is possible that *A. bahianus* does not consider the available crevices and overhangs as potential shelters capable of providing protection from predation. In contrast, we found higher FID associated with more homogeneous substrates (*i.e.* sand bottom). Possibly, larger individuals of *A. bahianus* that were foraging in these points preferred to avoid taking the risk of a close approach from the spearfisher and escaped as soon as the threat was detected.

Acanthurids are abundant and important members of the reef community, playing significant ecological roles in coral reef resilience. They graze epilithic algal turfs and limit the establishment and growth of macroalgae that can kill coral colonies by preventing recruitment (Green & Bellwood, 2009). Fishing for *Acanthurus* spp. in Brazil has been described by many authors (*e.g.* Ribeiro, 2004; Nóbrega & Lessa, 2007; Cunha *et al.* 2012) and goes back for more than a decade in the artisanal fisheries of states in the “Hump of Brazil”. They are also under increasing threat as a result of fishing for multiple uses (Sampaio & Rosa, 2005; Sampaio & Nottingham, 2008; Cunha *et al.* 2012). Reduction in population numbers of medium-large herbivore species such as *A. bahianus* by spearfishing might result in a significant loss of ecosystem functions (Green & Bellwood, 2009; Burkepile & Hay, 2011; Bonaldo *et al.* 2014). Additionally, an increase in wariness in target species such as *A. bahianus* may reduce fishing success and make fishers shift their preferences. This could affect the antipredator behavior of (currently) non-target species and increase their sensitivity to spearfisher disturbance.

In conclusion, our study strongly suggests an evidence that *A. bahianus* alters their perception of predation risk with increased body size or when in areas of low physical complexity. However, the relationship between FID and group composition is not yet completely understood: FID does not seem to be influenced by group composition *per se,* but the preferences in group formation show clear selectivity for living in specific shoals. We highlight that future research should focus on the fish preferences in group formation, *e.g.* aggregations in mixed or single species shoals, and on indirect impacts of spearfishing on the structure of marine communities, emphasizing in considering aggregation behaviors and the social learning of juvenile and adult fishes as an important tool to avoid predation.

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4. **FLIGHT DECISIONS OF REEF FISHES SUBJECT TO DIFFERENT STATUS OF CAPTURE AND HUMAN DISTURBANCE**

To be submitted

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Abstract

Understanding how fish make decisions to escape from human approach has a crucial role for elucidating conflicts of human activities in marine ecosystems. Nevertheless, its importance in conservation practice is still underestimated. We investigated if the risk perception differs between three reef fish species with a distinct history of capture by spearfishers, inside and outside one marine protected area (MPA) across fishery and tourism activities scenarios. We measured the flight initiation distance (FID) of reef fish and estimated fish size, group size and distance to the refuge. These variables were used in a permutational multivariate analysis of variance (PERMANOVA) and pairwise comparisons, for assessing the effects of protection and spearfishing or tourism activities on reef fish's FID, in the northwest of Brazil. Fish's FID was significantly influenced by protection status of marine areas, but differences between fishery and tourism areas were only found in FID of the species with a major history of capture. The results evidence that changes in flight distances of reef fishes have been not associated only with spearfishing, but also might be influenced by recreational activities in marine areas. This study highlights that the knowledge of how fishes deal with human presence in their habitat can help improve management policies and so should receive more attention. With FID's measures, it is possible to say how much reef fish are alert with human presence and thenceforth estimate minimal distances to approach fish before affecting their activities or indicate areas where anthropic activities should be reduced or banned.

Resumo

Compreender como os peixes tomam decisões para escapar da abordagem humana tem um papel crucial para elucidar conflitos de atividades antrópicas no ecossistema marinho. Entretando, sua importância na prática da conservação ainda é subestimada. Nós investigamos se a percepção do risco difere entre três espécies de peixes recifais com distintos históricos de captura por pescadores-sub, dentro e fora de uma área marinha protegida (AMP), ao longo de um cenário de atividades de pesca e turismo. Nós medimos a distância inicial de fuga (DIF) de peixes recifais e estimamos o tamanho do corpo, tamanho do grupo e a distância para refúgio. Essas variáveis foram usadas em uma permutacional análise de variância (PERMANOVA) e comparações par-a-par, para avaliar os efeitos da proteção e das atividades de pesca-sub ou turismo na DIF de peixes recifais, no nordeste do Brasil. A DIF dos peixes foi significativamente influenciada pelo *status* de proteção das áreas marinhas, mas diferenças entre as áreas de turismo e pesca foram encontradas apenas na DIF da espécie com maior histórico de captura. Os resultados evidenciam que mudanças na distância de fuga de peixes recifais tem sido associadas não apenas com a pesca-sub, mas também podem ser influenciadas por atividades recreativas em áreas marinhas. Esse estudo destaca que o conhecimento de como os peixes lidam com a presença humana em seu habitat pode ajudar a melhorar as políticas de manejo e, por isso, devem receber mais atenção. Com as medições das DIFs, é possível dizer o quanto peixes recifais estão alerta à presença humana e, a partir daí, estimar distâncias mínimas para se aproximar dos peixes antes de afetar suas atividades ou indicar áreas onde as atividades antrópicas devem ser reduzidas ou proibidas.

Keywords: Flight Initiation Distance; Marine Protected Area; spearfishing impact; tourism; target fishes; non-target fishes

Introduction

The risk of being preyed, or the probability of an individual be killed by a predator, can be behaviorally influenced by decisions of when and how to escape from predator (Lima and Dill, 1990). Such decision may reflect in trade-offs between the costs of predation and benefits to be engaged in other activity (Ydenberg and Dill, 1986). Thus, even preys that suffer no injuries with predatory encounters may incur relevant costs in their fitness, for example reducing foraging or reproductive activity (Cooper and Blumstein, 2015). The predictions about the effects of predation risk with natural predators in wildlife have been extended to human as a predator, as assumed by risk-disturbance hypothesis (Frid and Dill, 2002). Negative effects caused by human disturbance has been reported in numerous studies with terrestrial vertebrate taxa, as birds, mammals and lizards (Beale and Monaghan, 2004; Samia et al., 2015; Stankowich, 2008), which seek to understand how different impacts affect individuals, population or communities, to achieve better management strategies.

In marine ecosystems, the accelerated increase of recreational activities, such as diving, has contributed with deleterious effects on benthic communities (*e.g.* changes in coral morphologies and abundance of herbivorous reef fishes) (Gil et al., 2015), beyond trigger antipredator behavioral changes by modify specific responses to natural predators (Geffroy et al., 2015). In addition, another noteworthy anthropogenic disturbance in marine biodiversity is overfishing. Fishing is responsible for substantial changes in fished populations over the centuries (Jackson, 2001), shaping the trophic composition, abundance, diversity, and influencing the behavior of reef fish assemblages (Januchowski-Hartley et al., 2011; Mora et al., 2011; Pereira et al. 2016).

For instance, fish when exposed to fishing with dip net (Yue et al., 2004), or spearfishing (Januchowski-Hartley et al*.,* 2015), can exhibit an increase of their wariness due to the association with a threat. These behavior responses are often related to the initial perception of danger. Therefore, there is a range of attributes of both fishes (*e.g.* body size; crypsis; sociability) and environment (*e.g*. distance to cover or refuge disponibility; turbidity) (Abrahams, 1995; Gotanda et al., 2009; Semeniuk and Dill, 2005) that might act in how these animals make economic decision to fleeing from predation (Ydenberg and Dill, 1986). Previous studies have made use of the FID (Flight Initiation Distance – the distance at which prey species will allow a predator approach before fleeing) for assessing fish wariness in light of predation (Gotanda et al., 2009; Januchowski-Hartley et al., 2014; 2015). Longer escape distances mean that the individuals are more alert for an earlier detection of capture risk. In contrast, individuals that show short distances prefer to give up more time for activities that increase fitness, such as feeding, or are less alert for predator detection (Ydenberg and Dill, 1986). Thereby, FID represents an important metric to assess the individual and species decision modified by experience with predation. A growing literature on fish's FID indicates that flight behavior can be different in response to the human stimulus in marine protected and unprotected areas (Gotanda et al., 2009; Feary et al., 2010; Januchowski-Hartley et al., 2013).

Marine protected areas (MPA) are established as a tool for the management of marine ecosystems with restricted human activities (Baskett and Barnett, 2015). Specifically, beyond safeguard fishes and other organisms, the marine reserves functions include preserving the economic value of fisheries, enhancing fishery yield beyond their boundaries (either through fish larvae recruitment or adult spillover effect) (Russ and Alcala, 2011). However, in Brazillian coast, the management failures and problems with a bureaucratic network of the administrative system, represents some of the major flaws identified in MPAs (Gerhardinger et al., 2011). These gaps reflect a frail protection observed in the Brazilian marine environment and in unequal distribution of MPAs, when considered the protection categories and proportion of protected environments (Magris et al., 2013; Schiavetti et al., 2013). Additionally, for reef fishes, there is still a mismatch between MPAs and their hotspots (areas with high richness, endemism and/or number of species under threats) (Vila-Nova et al., 2014), which may difficult an adequate protection for fish communities.

Thereby, understand how which the perception of predation risk by reef fish may have important implication in evaluating anthropogenic disturbances and to developing strategies for conservation of overexploited species, especially along the Brazilian coast. In this context, this study investigated how the risk perception of three reef fish species with a distinct history of capture by spearfishers, differs between protected and unprotected reefs with differents management categories of use: tourism and fishery. To explore these questions, we used the FID measures and hypothesized that if fishes are capable of differentiating a spearfisher’s threat inside and outside of MPA, so they also can demonstrate differences in flight behavior between fishery and tourism areas, with less wariness behavior and smaller FIDs in tourism sites.

Methods

Study site

The Costa dos Corais - Marine Protected Area was created in 1997 and represent the first federal conservation area to protect the coastal Brazilian reefs in the northeastern coast. It is the largest MPA in the country encompassing two states, from the city of Tamandaré, south of Pernambuco, to the Paripueira at north of Alagoas

(Ferreira et al., 2001). The management of natural resources are the main goals of Costa dos Corais, through the regulation of ecological, scientific and cultural tourism; and the artisanal, commercial, subsistence and amateur fishing activity (ICMBIO, 2013).

The present study was conducted in eight reefs with multiple uses; two tourism and two fishery sites, inside (at cities Tamandaré – PE and Maragogi – AL) and outside (at city Maceió – AL) Costa dos Corais - MPA (Fig.1). Between the tourist activities practiced at study sites, the focus is on the recreational diving, including snorkeling or guided dive, and tours with sail or motor boats. In sites where fishing activity is realized, spearfishing is the main catch method practiced on the reefs. Fishing and tourism areas were selected according to literature (Pereira et al. 2014; ICMBIO, 2013), information provided by fishermen and boat tourism drives, and personal observations of authors. Thereby, observations were conducted in following sites: (i) tourism; tide pools in front of *São Pedro* church at Tamandaré - PE; *Galés de Maragogi* at Maragogi - AL and *Pajuçara* tide pools at Maceió – AL; (ii) fishery; *Caieiras* at Tamandaré - PE; *Navio* at Maragogi – AL and *Ponta Verde* tide pools at Maceió – AL. Underwater surveys were performed in habitats that comprised a diversity of substrate, including algal beds, sand bottom, and the most common, the coral reefs, with depth ranging from 0.5 to 6m and with mean visibility value of 5m.

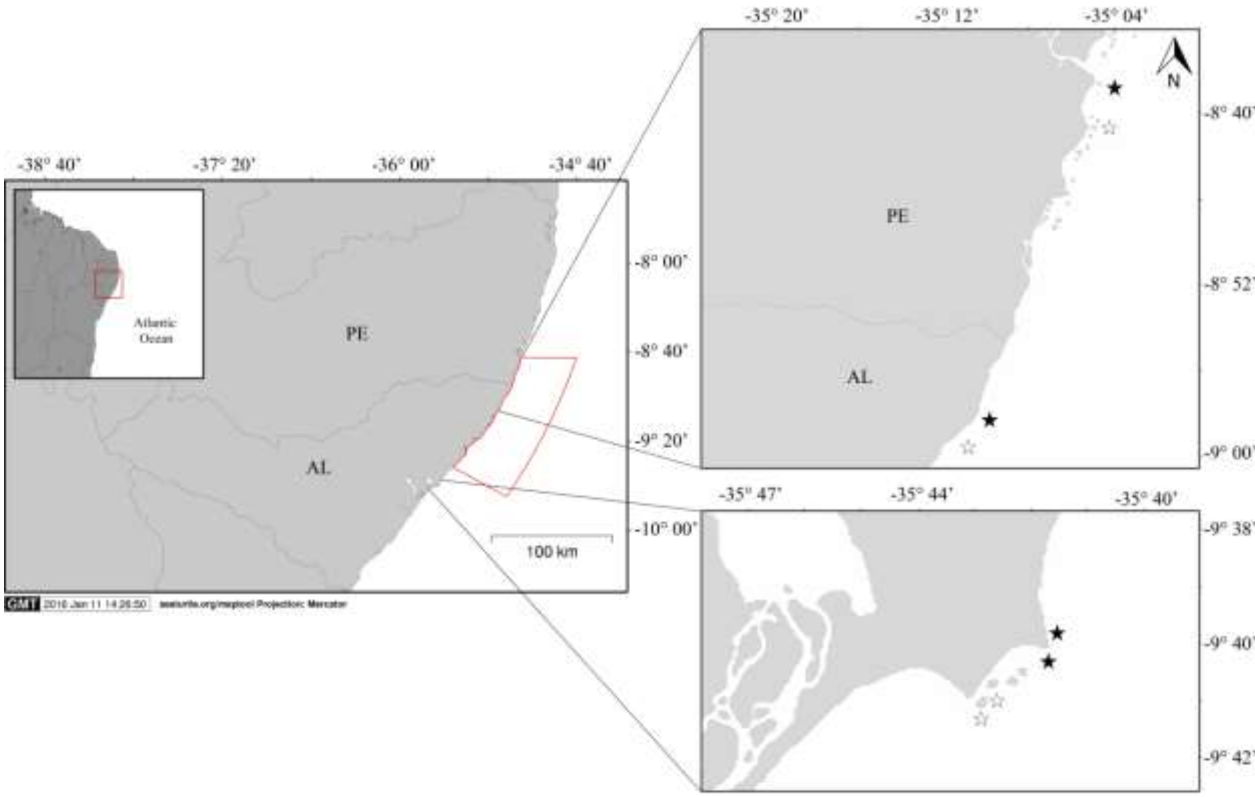

Figure 1. Location of the study area, fishery (filled stars) and tourism (empty stars) areas at cities: Tamandaré – PE, Maragogi and Maceió – AL, in the Northeastern Brazil. The red line represents the limits of Costa dos Corais Marine Protected Area.

Study species

The rock hind, *Epinephelus adscensionis* (Osbeck, 1765), is a species with wide-range distribution, know from both sides of the Atlantic Ocean. It is reported in the western Atlantic from Bermuda, Massachusetts to Florida, Gulf of Mexico, and Caribbean to southern Brazil (including Abrolhos, Fernando de Noronha, Trindade islands) (FAO, 2002). A resident of rocky reefs and usually solitary, juveniles are commonly associated with macroalgal beds (Chaves et al., 2013). The rock hind feeds mainly on crabs and fishes (Randall, 1967), and are characterized as ambush predator with low mobility and high camouflage capability (Pereira, 2014). Caught with hook-and-line and spears, *E. adscensionis* was selected for this study based on their status of target species by local fisheries. Although commonly captured like other groupers, the rock hind is listed by Red List as 'Least Concerned' because it is widespread and abundant in many parts of its range, even in fished areas (Rocha et al., 2008). Nevertheless, in the northeastern Brazil, it does not ease to see the rock hind and maybe it is due to the potential withdrawal of this species by local fishers (Authors pers. obs.).

Beyond *E. adscensionis*, the barber surgeonfish, *Acanthurus bahianus* Castelnau, 1855, was the target species studied. It is found in tropical and subtropical waters of the Brazilian coast, from Parcel Manuel Luiz to Santa Catarina, including the Oceanic Islands of Fernando de Noronha, Atol das Rocas and Trindade, offshore Brazil, and Ascension and St. Helena, in the South and Central Atlantic (Sampaio and Nottingham, 2008; Bernal and Rocha, 2011). In the northeast portion of its range, *A. bahianus* is subject to fishing pressure, caught mainly in traps, gill nets and spears (Bender et al. 2014; Author´s pers. obs.), this species is becoming an important member of the subsistence fisheries and also exported to international markets (Lessa and Nóbrega, 2000). However, in some sites on the east coast of Brazil, they are not yet considered as fishery target species (Floeter et al., 2006). There is no consistent information until the present time indicating that this species is declining due fishing in its range of distribution and, therefore, it is also listed as ‘Least Concern’ in Red List (Choat et al., 2012).

The barber surgeonfish have varying degrees of habitats utilization, inhabiting coral reefs and inshore rocky areas with a mixed sand substrate (Dias et al., 2001). Juveniles and adults are locally abundant in shallow waters and grazes on different species of benthic algae, occasionally on seagrass and on the film algae on the surface of sand undisturbed (Francini-Filho et al., 2010). Individuals of *A. bahianus* are found lonely (sometimes in territorial activities) or in roaming feeding schools, which occurs primarily in adults, with small juveniles never participating of large or dense schools (Choat et al., 2012).

The butterflyfish, *Chaetodon striatus* Linnaeus, 1758, was selected for this study as non-target and control fish species. Although it is occasionally traded in aquarium shops, fishing is not considered a threat. This species is widely distributed in the Caribbean from Florida and Gulf of Mexico to Rio de Janeiro, Brazil. Also been recorded wandering on the north to New Jersey, in the eastern Atlantic and Bermuda (FAO, 2002;

Sampaio and Nottingham, 2008). Butterflyfish are relatively common in rocky and coral reef areas with juveniles being more common in grass beds. Its diet is diverse but feeds basically on small benthic invertebrates (Liedke et al., 2016). The *C. striatus* are a monogamous species, seen frequently as pairs (Whiteman and Côté, 2004), but adults may form plankton-feeding aggregations of up to 20 individuals, and occasionally clean other reef fishes which join the group, such as grunts, parrotfishes and surgeonfishes (Sazima and Sazima, 2001).

Data collection

Data were collected from February to September 2015. The same snorkel diver, dressed in a camouflaged wetsuit and reproducing spearfisher behavior, conducted the underwater surveys and identified target individual on the surface in order to obtain flight initiation distances measurement. Fish size, group size, and distance to the refuge, was recorded as predictors variables. Thus, prior to FID approach, the total length (TL) (cm) of each target individual and the number of fishes on the group (max. radius 1 m distance) was visually estimated. For the FID measurement, the snorkeler remaining approximately 3 m far holding the spear gun horizontally in front of the face and pointing directly to the targeted fish. When fish escaped, the snorkeler dropped a marker on the substrate directly below the point where their hand was holding the gun at the moment of flight, and then a second marker was left at the point where the fish was when it fled (Januchowski-Hartley *et al.* 2011). The distance (cm) between these markers represent the FID and it was measured using a graduated tape. The flight was considered when fish moved away from the snorkeler with an increased speed (Gotanda et al., 2009), or if sudden changed their direction.

Before FID estimates, the distance (cm) to the nearest potential refuge was measured as the distance between the location which the target fish started to flee from the observer’s approach, and the closest ledge, hole, or vertical structure capable of providing visual isolation (Gotanda et al., 2009). The spear gun used in the survey was 70 cm and this distance was subtracted from the FID measurements to obtain the correct distance between fish and the beginning of spear. To avoid recording fishes from the same group in quick succession, the snorkeler immediately moved at least 10 m away after each observation.

Statistical analysis

In order to test whether the FID significantly differ between the management status of the marine areas (inside and outside MPA) and its multiple uses (tourism and fishery), a permutational multivariate analysis of variance (PERMANOVA) was performed in each species separately. The covariates; body size, group size, and distance to the refuge, were included in each design due to the possible influence on response variable of the model. The PERMANOVA analysis was based on a Euclidean resemblance matrix.

The PERMANOVA results that differed significantly were submitted a posthoc pairwise comparisons for assessing differences in FID as a function of the developed activity in marine areas (tourism/ fishery). Next, was analyzed the effect of the continuous covariables in FID using linear regression analysis. PERMANOVA analysis was performed in Primer 6+, with data FID 4th–root transformed, and linear regression was conducted in StatSoft STATISTICA version 10. In all analysis was considered a significant level $\alpha < 0.05$.

Results

Were obtained approximately 15 measures of FID for each species studied, in each sample area, totaling 372 flight initiation distances observations. For *Epinephelus adscensionis*, the PERMANOVA results revealed significant differences in fish FID between (i) 'protection status' (inside/ outside Costa dos Corais - MPA) (pseudo-F = 5.69; $p = 0.01$) and between (ii) 'categories of use' (touristic/ fishery sites) (pseudo-F = 4.79; $p = 0.02$). However, there were no significant interactions between these factors. Therefore, the pairwise test for ‘categories of use’ showed that FID varied among touristic and fishery areas, but it didn't show in which protection status belong these differences. Nonetheless, through the median values of *E. adscensionis* FID were observed greatest escape distances in fishing areas outside MPA, and lowest in touristic areas inside MPA (Fig. 2a). Additionally, when compared only the protection status, higher median FID were observed in reefs outside MPA (Fig. 2b). When linear regression analysis was conducted, the flight initiation distance of *E. adscensionis* had a relation with distance to refuge in fishing areas inside and outside MPA (R^2 = 0.173; p = 0.002/ R^2 = 0.158; p = 0.018) (Fig. 3a; b), and with group size outside MPA in fishing areas (R^2 = 0.160; p = 0.03) (Fig. 4).

FID of the *Acanthurus bahianus* only significantly differed between 'protection status' (pseudo-F = 4.71; p = 0.02) and, although the medians had been the same for this treatment, the percentiles showed a tendency on FID data to be higher in reefs outside MPA (Fig. 5). The results of linear regression showed that *A. bahianus* FID was positively related with group size in touristic areas outside MPA (R^2 = 0.216; p = 0.002) (Fig. 6), and with distance to refuge in touristic areas inside MPA (R^2 = 0.192; p = 0.008) (Fig. 7). Similarly, the PERMANOVA results showed that FID of *Chaetodon striatus* significantly varied between 'protected status' (pseudo-F = 5.88; p = 0.01), and higher medians were observed in reefs outside Costa dos Corais - MPA (Fig. 8). With linear regression analysis, just distance to the refuge showed a significant relation with *C. striatus* FID in fishing areas outside MPA (R^2 = 0.216; p = 0.019) (Fig. 9). Thus, for *A. bahianus* and *C. striatus*, the PERMANOVA analysis suggests that within the factor 'categories of use' the FID are similar between touristic and fishery areas, in both sites inside and outside MPA. The other variable presented in models, body size, had non-significant effects on FID of any species.

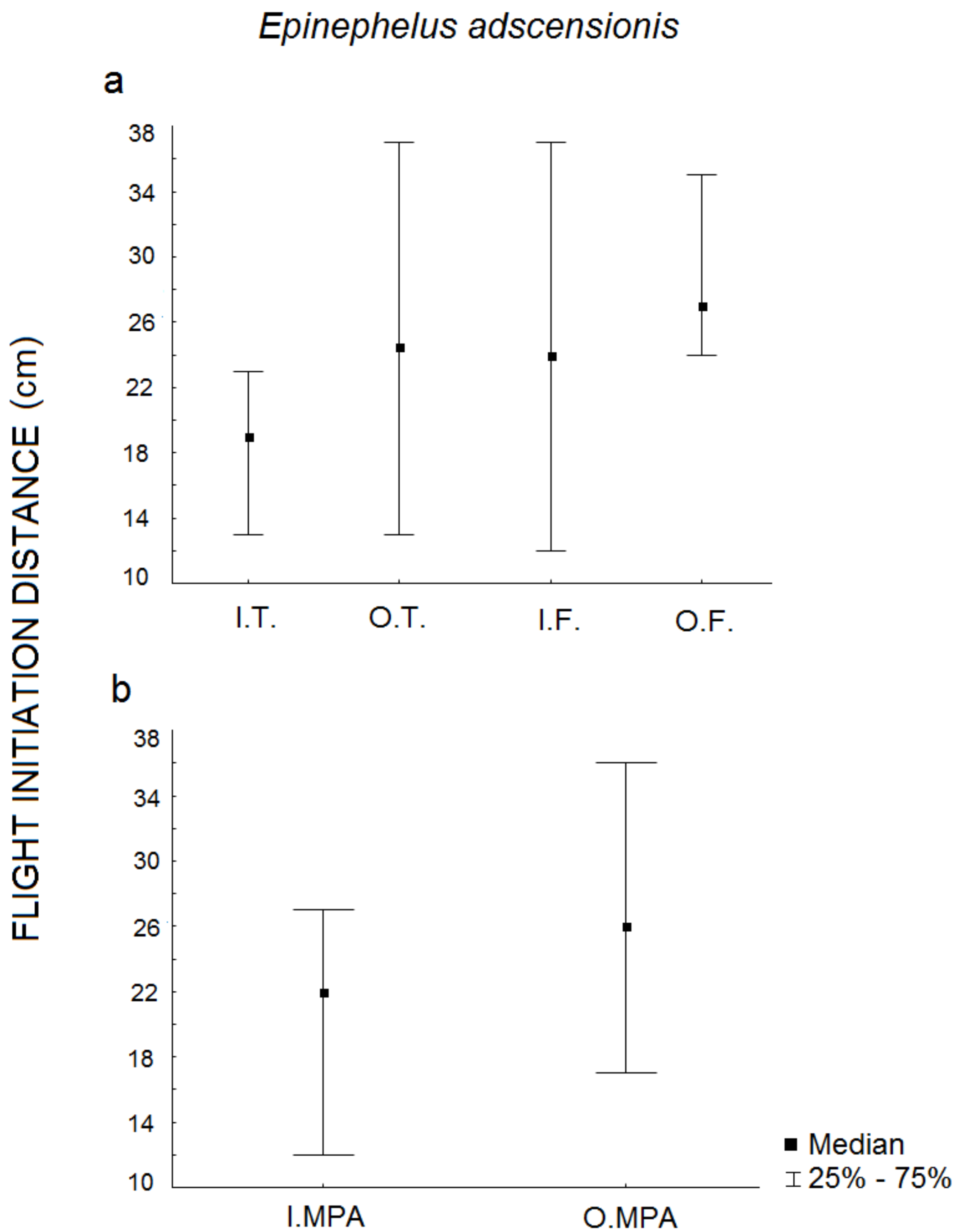

Figure 2. Flight Initiation Distance (FID) (cm) of *Epinephelus adscensionis*: (a) different categories of use of areas; (b) protection status. I.T.: Inside Costa dos Corais – MPA in Touristic areas; O.T.: Outside Costa dos Corais – MPA in Touristic areas; I.F.: Inside Costa dos Corais – MPA in Fishing areas; O.F.: Outside Costa dos Corais – MPA in Fishing areas. I.MPA: Inside Costa dos Corais - MPA; O.MPA: Outside Costa dos Corais – MPA. Dots represent medians and bars represent the percentiles.

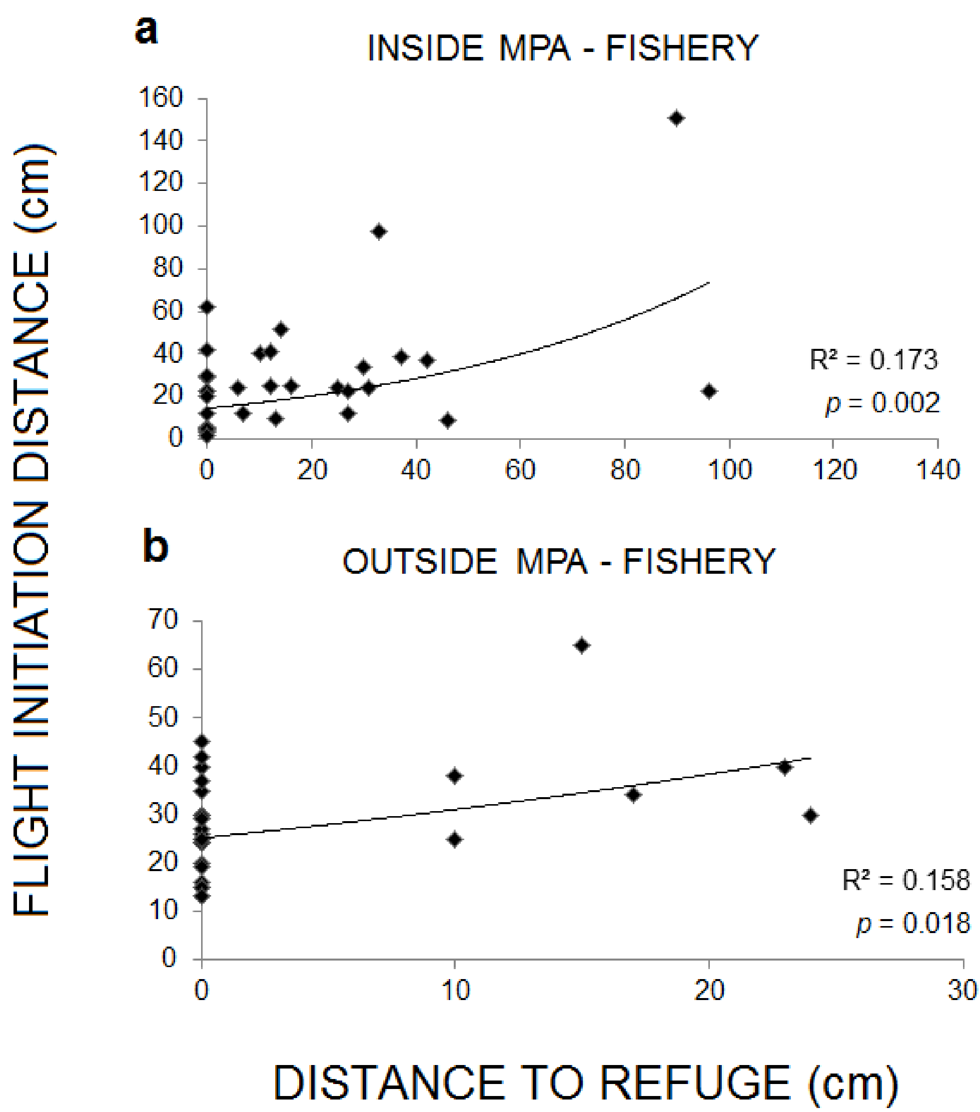

Figure 3. Flight Initiation Distance (FID) (cm) plotted against Distance to Refuge for *Epinephelus adscensionis,* inside (a) and (b) outside Costa dos Corais – MPA in fishing areas.

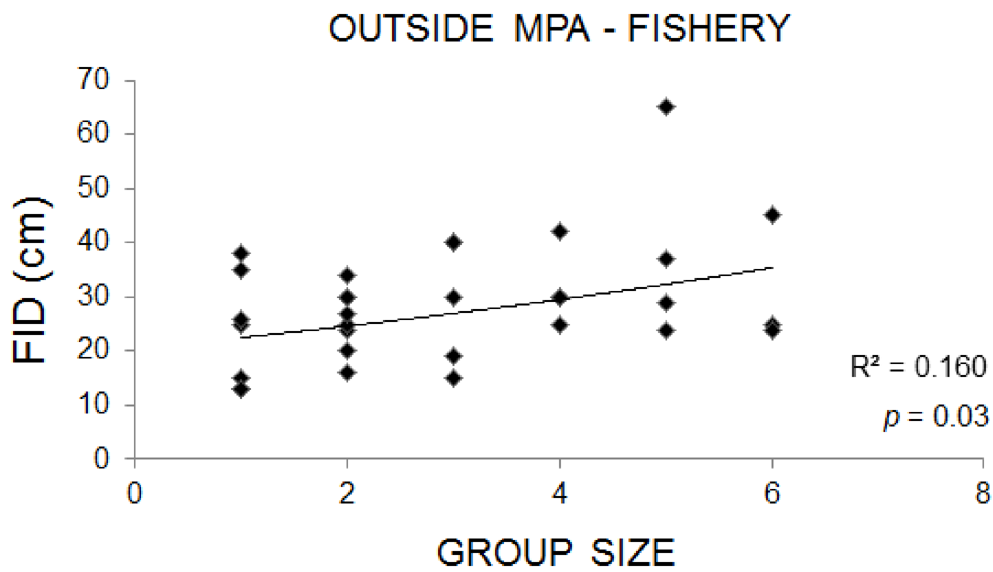

Figure 4. Flight Initiation Distance (FID) (cm) plotted against Group Size for *Epinephelus adscensionis,* outside Costa dos Corais – MPA in fishing areas.

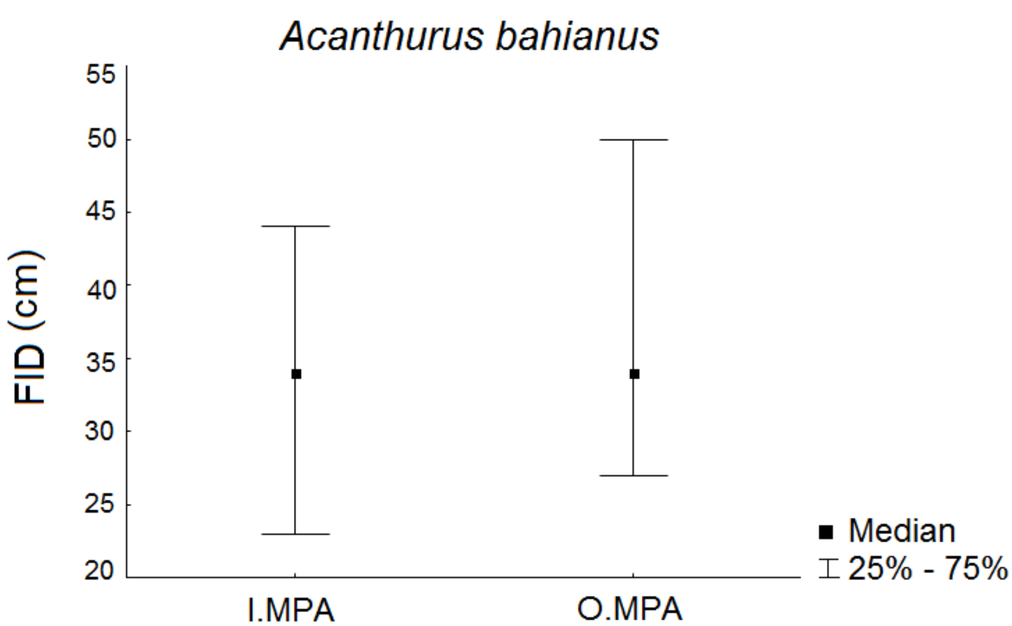

Figure 5. Flight Initiation Distance (FID) (cm) of *Acanthurus bahianus* for protection status. I.MPA: Inside Costa dos Corais - MPA; O.MPA: Outside Costa dos Corais – MPA. Dots represent medians and bars represent the percentiles.

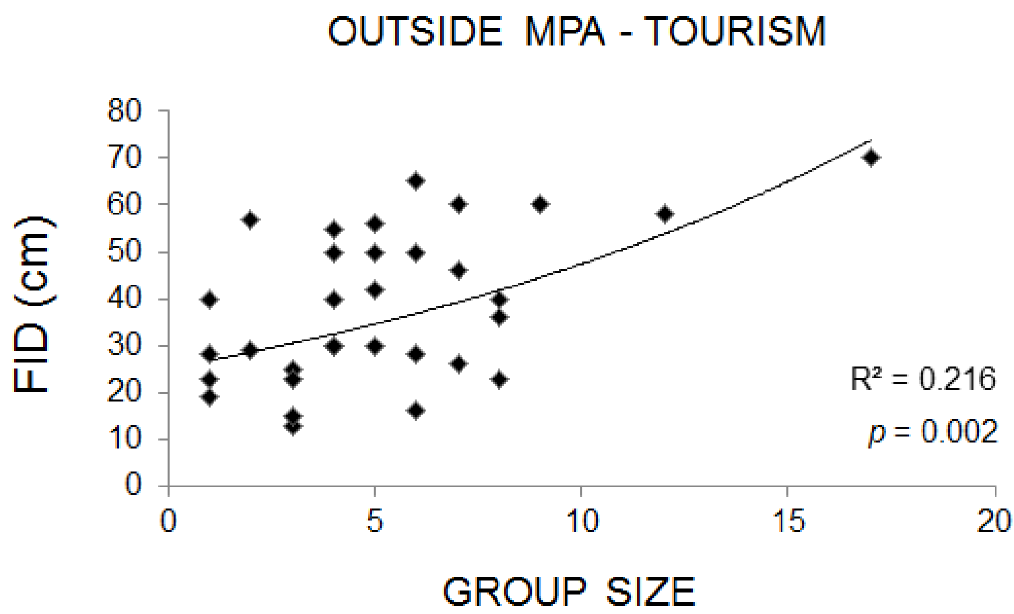

Figure 6. Flight Initiation Distance (FID) (cm) plotted against Group Size for *Acanthurus bahianus*, outside Costa dos Corais – MPA in touristic areas.

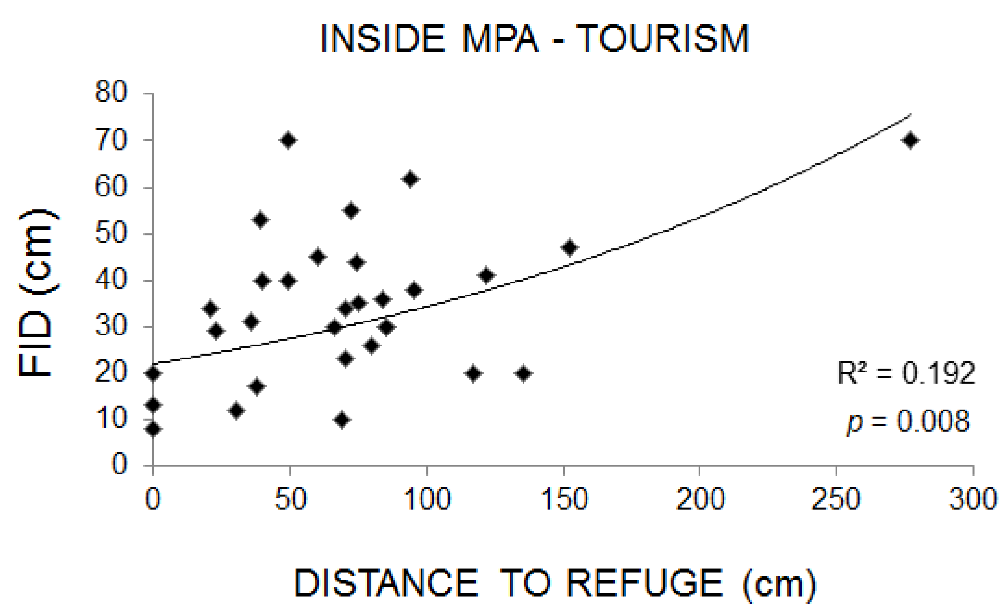

Figure 7. Flight Initiation Distance (FID) (cm) plotted against Distance to Refuge (cm) for *Acanthurus bahianus*, inside Costa dos Corais – MPA in touristic areas.

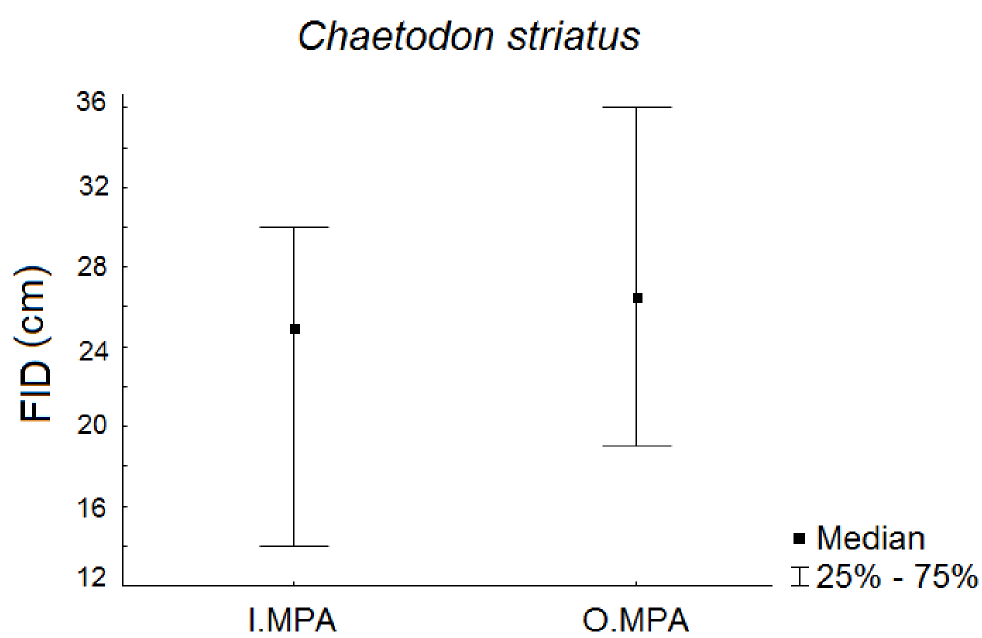

Figure 8. Flight Initiation Distance (FID) (cm) of *Chaetodon striatus* for protection status. I.MPA: Inside Costa dos Corais - MPA; O.MPA: Outside Costa dos Corais – MPA. Dots represent medians and bars represent the percentiles.

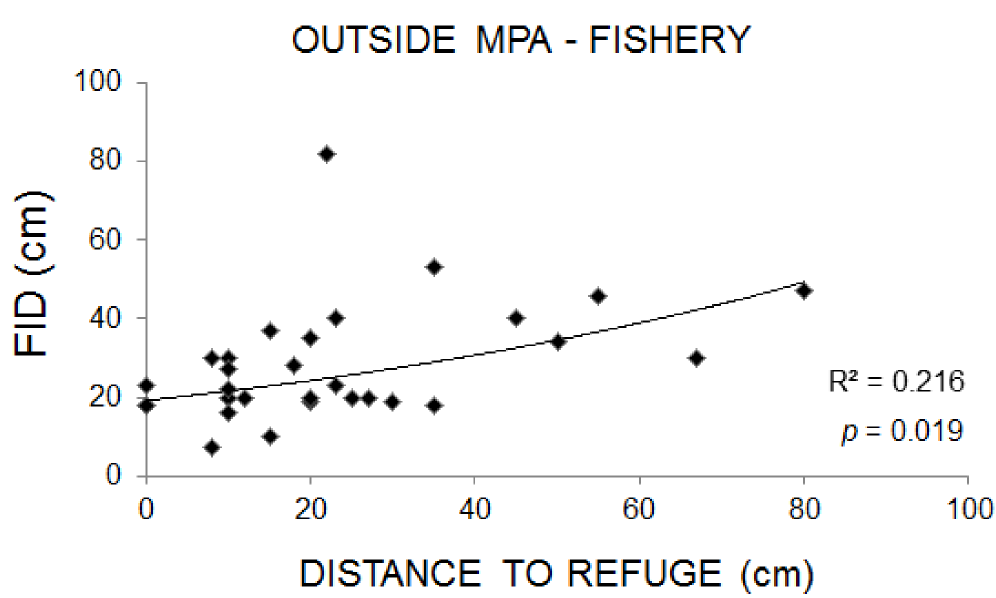

Figure 9. Flight Initiation Distance (FID) (cm) plotted against Distance to Refuge (cm) for *Acanthurus bahianus*, outside Costa dos Corais – MPA in fishing areas.

Discussion

The present study demonstrates that protection status in the marine areas at northeastern Brazil has a strong influence on risk perception of reef fish. All species examined showed significant differences in escape distances between areas inside and outside Costa dos Corais - MPA, with the longer distances observed outside the protection, suggesting this is the likely influence on fish FID. The *Epinephelus adscensionis* was more sensitive to spearfisher approach than *Acanthurus bahianus* due they significant differences exhibited on FID between touristic and fishery areas. These findings corroborate with history capture of both species, being *E. adscensionis* more commonly caught than the *A. bahianus*, and consequently with a probable increase in wariness at non-protected reefs. Thus, evidencing that *E. adscensionis* is able to recognize a threat posed by the presence of spearfisher, keeping alert to the risk of capture where the fishing pressure is more intense and less alert where the chances of capture are lesser, inside MPA.

Within the MPA, individuals of *A. bahianus* were slightly less cautious, and outside these areas the flight was initiated at a greater distance from the spearfisher approach. Previously studies have highlighted equivalent results on individuals of Acanthuridae family, where the FID changes were related to an increase in the gradient of fishing pressure from inside to outside of marine reserves (Januchowski-Hartley et al., 2013; 2015), and in temporarily protected areas (Januchowski-Hartley et al., 2014). However, when FID of *A. bahianus* was compared between areas of tourism and fishery, no significant differences were found. This similarity may indicate an overlap of these activities within its boundaries. It implies that possible flaws on monitoring strategies of tourism and fishing activities, regardless the protection status, leave gaps for the spearfisher and recreational diver act in both areas. Consequently, the sum of these activities and the high rate of human visitation in the same area might be responsible for the negative and conflicting effects seen on the antipredator behavior of the surveyed species. Therefore, *A. bahianus* can be responding to the risk of predation caused by the human presence in a similar way, either by recreational fisherman or recreative divers, which on many occasions are observed chasing fish (Author´s pers. obs.).

This last assumption is supported by results of escape distances observed for *Chaetodon striatus*, which showed a similar trend as the barber surgeonfish in keeping larger FIDs in unprotected sites outside the MPA, but no significant difference between the touristic and fishery areas. Nevertheless, it is a surprising finding from this study, since it was not expected that the butterflyfish identified the spearfisher as a possible threat because it rarely occurs in fishery catches (Sampaio, pers. obs.). Furthermore, this result contrasts with reported by Januchowski-Hartley et al. (2013), where individuals of the non-target family, Chaetodontidae, showed no variation in FID across the boundaries of a reserve. On the other side, the butterflyfish's behavior may also have been related to cognitive abilities. Many fish are able to learn a recognize a predator by alarm cues for danger, like olfactory signs (*e.g.* chemical cues released when another fish is injured or captured) and visual traits of predator (Kelley and Magurran, 2003). Thus, flight responses of *C. striatus* can result from indirect experience (*i.e.* social learning) with predatory events of other target species (Brown and Laland, 2003).

There is a second and alternative explanation for the FID results across categories of use of areas. Significant relationships were found between group size and the distance to refuge with FID. Thus, these variables related to individual flight decisions may have influenced the fish escape distances in some areas of tourism and fishing. Because of many predators have target a single individual, then how higher being the number of members in a group, greater will be the number of vigilant individuals (*many eyes hypothesis*) (Lima, 1995), and lower will be the individual predation risk (*risk dilution effect*), due to the early detection of the threat (Magurran, 1990). Consequently, antipredator responses may vary depending on the group size and it can be reflected on the escape distances. Thus, FID is expected to be higher in groups than solitary individuals (Semeniuk and Dill, 2005), as was observed for the target species, *E. adscensionis* and *A. bahianus* in the fishery and touristic areas outside the protection, respectively.

Fishes targeted by spearfishing can also change their refuge use, swimming near the shelter in protected reefs or escaping into open water reefs (Guidetti et al., 2008). Additionally, habitats with different structural complexities (*i.e.* rocky or coral reef) can act distinctly in antipredator behavior of these animals (Nunes et al., 2013). In this sense, differences in the physical structure of the available habitats in touristic and fishery areas might have been responsible for the positive relationship of FID with distance to refuge observed in all species. That is, when an individual was more distant from the refuge, it fled to great distances from the diver approach than when it was closer to a shelter. The body size showed no significant relationship with any species, although other studies have reported an increase in fish flight distance with the size of individuals (Benevides et al., 2016; Gotanda et al., 2009; Januchowski-Hartley et al., 2011).

In general, our findings are consistent with previous research regarding the effects of spearfishing on flight behavior of target species, with increased FID at high levels of fishing compared to the protection of MPAs (Feary et al., 2010; Gotanda et al., 2009; Januchowski-Hartley et al., 2015). However, our results differ in some important details. The escape distances recorded for the non-target species, *C. striatus*, suggests the existence of conflicting use in Brazilian MPAs, such as previously registered by others authors (Floeter et al., 2006) including the Costa dos Corais – MPA (Gerhardinger et al., 2011), once these fishes demonstrated some wariness from observer approach when they was not inside MPA.

Spite of recreational activities (fishing and diving) being an efficient way to connect humans to the natural environment while promoting the local economy, the disorderly use and intense exposure to humans has increasingly triggered negative effects on marine populations in Brazilian reefs (Albuquerque et al., 2014; Bender et al., 2014; Giglio et al., 2015). From the perspective of the detection of predation risk by animals, human approach is capable to create fear and shape the perceptions of individuals about their habitat, making them optimize their behavior to keep the proper use of resources (Blumstein et al., 2005; Brown et al., 2001; Fernández-Juricic and Tellería, 2000). Nonetheless, this may have a high energy cost for species. These behavioral changes, induced by needs to adapt an unfavorable situation, directly interfere in decisions that can increase or reduce their fitness (Burger, 1994; Frid and Dill, 2002). For instance, assuming that spearfishing, or recreational diving, is affecting the reef fishes decisions to avoid the risk of capture, then this disorder can interfere on species trade-off between increasing the time of surveillance and maintain essential functions to ensure its energy needs (*e.g.* foraging), or their reproductive success (*e.g.* mating) (Frid and Dill, 2002).

Behavioral decisions of target and non-target species to maximize its fitness against the predation risk, may have a strong effect on population level (*e.g.* reduction in food consumption can reduce the growth and fertility, influencing the abundance and recruitment); and the community level (*e.g.* habitat changes may influence the richness and composition) (Dill, 1987). It highlights the continuous needs to understanding how the risk perception, induced by human encounters in reef environment, can represent a potential strength capable of affecting the behavior and have indirect consequences in ecological relationships between species.

In conclusion, the knowledge of how fish deal with disturbances, and how the perception of human presence in their habitat is, should be treated more carefully. This study gives important insights to conservation and can help driven future management politics in marine environmental, through the utilization of Flight Initiation Distance as a tool for monitoring of anthropic recreational activity impact on the behavior of reef fishes. We suggest that FID comparisons are making with others key behavior and at no-take areas, since within this sites the species may show how are they behavior without human disturbance. In addition, different treatments assessing the effect of spearfisher, snorkeler and scuba diver, will support the distinctive influence of this activities on fish behavior and on effective management.

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5. CONCLUSÕES

O presente trabalho descreve como o conhecimento do comportamento antipredor dos peixes pode ser (e tem sido) usado para ajudar a conservar e manejar espécies ameaçadas pela atividade pesqueira. O monitoramento do comportamento de fuga em peixes recifais pode ser útil para o manejo de populações e comunidades, uma vez que, esses animais podem alterar sua percepção do risco de acordo com variações no *status* de captura da espécie e com a intensidade de distúrbio antrópico a qual estão sujeitos em seus habitats. Os resultados dessa pesquisa sugerem que características individuais (*e.g.* tamanho do corpo) e características físicas do ambiente (*e.g.* tipo de substrato) podem influenciar a maneira pela qual os indivíduos de *Acanthurus bahianus* percebem e tomam a decisão de fugir da aproximação de pescadores-sub. Além disso, foi observado que *A. bahianus* possui clara seletividade em viver em grupos mistos para, além de outros benefícios, evitar o risco de captura. Entretanto, ainda são necessários novos estudos para investigar até que ponto *A. bahianus* escolhe viver em grupos heterogêneos para elevar suas vantagens antipredatórias e ao mesmo tempo não gastar energia com disputas por recursos alimentares com as outras espécies.

Adicionalmente, os resultados destacam que o risco de predação pela presença humana no ambiente recifal, através das atividades de pesca e/ou turismo recreativo, pode alterar diretamente o comportamento de fuga de peixes com distintos históricos de captura pela pesca-sub (*Epinephelus adscensionis* e *A. bahianus*), e indiretamente peixes recifais não-alvo de pescarias (*Chaetodon striatus*). Essas descobertas chamam atenção para a gestão em áreas marinhas protegidas, as quais são de fundamental importância para conservar o comportamento natural das espécies, mas que para isso, precisam funcionar adequadamente e reduzir, ou banir, o desenvolvimento desordenado de atividades antrópicas nos recifes.

Dessa forma, essa dissertação evidencia a necessidade de se ampliar o conhecimento de como os peixes estão reagindo comportamentalmente aos distúrbios causados pela presença de pescadores e mergulhadores no ambiente recifal. O aumento da vigilângia desses animais frente à presença de mergulhadores pode fazer com que eles gastem menos tempo se alimentando, reduzindo assim seu *fitness* (*i.e.* valor reprodutivo) e, consequentemente, a sobrevivência e o sucesso reprodutivo da espécie. Nesse sentido, alterações do comportamento de fuga podem refletir negativa e gradualmente em toda comunidade recifal, e, por essa razão, as consequências dessas mudanças precisam receber mais atenção.

A utilização das medições da Distância Inicial de Fuga para monitorar o impacto que a presença de mergulhadores pode causar no comportamento de peixes recifais, representa uma ferramenta acessível, por ser de baixo custo e prática para ser executada. Sugere-se que futuras pesquisas busquem responder se a presença de mergulhadores, sejam pescadores-sub ou não, está alterando não apenas o comportamento de fuga de peixes recifais, mas também o desenvolvimento de outros comportamentos vitais para o equilíbrio do ecossitema recifal, como por exemplo, atividades de limpeza, antagonismos e forrageamento. Por fim, esse estudo fornece uma nova abordagem para contribuir com a resolução de problemas de conservação e manejo nas áreas marinhas, em especial brasileiras, utilizadas para a gestão da pesca e turismo recreativo.