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Flight response of the barber surgeonfish, *Acanthurus bahianus* Castelnau, 1855 (Teleostei: Acanthuridae), to spearfisher presence

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When confronted by predators, prey need 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 examined whether the FID was influenced by body and group size; by the heterogeneity of species in groups formation; and the distance to shelter. Significant differences in FID were observed with increasing body size. We found no significant relationship of FID with size or group formation, neither with distance to shelter. 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 support theories suggesting that spearfishers do influence fish behavior. We highlight that future research should focus on the indirect impacts of spearfishing on the structure of marine communities, emphasizing the anti-predator behaviour of juvenile and adult target fishes.

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), a distância à qual 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 se examinar fatores que influenciam nas decisões de fuga. Aqui nós investigamos como a DIF do peixe cirurgião, *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 refúgio. Diferenças significativas na DIF foram observadas com o aumento no tamanho do corpo. Nós não encontramos nenhuma relação significativa da DIF com o tamanho ou formação do grupo, nem com a distância para refúgio. 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 suportam teorias sugerindo que pescadores subaquáticos influenciam no comportamento dos peixes. Nós destacamos que pesquisas futuras devem focar nos impactos indiretos da pesca subaquática na estrutura das comunidades marinhas, enfatizando o comportamento anti-predador de peixes juvenis e adultos alvo 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 behaviour (Abrams, 2000). Prey may adaptively respond to predators by becoming more vigilant and loosing 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 flee or avoiding predators, prey can use their learning acquired with social transmitted information when responding to possible threats (Brown & Laland, 2003; Kelley & Magurran, 2003). Thereby, animals that are target by

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predators can adjust their antipredator behaviour responses, and consequently their flight decisions, according with 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 behaviour, 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 behavioural 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 (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 behaviour 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 behaviour 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 behaviours and the responses may vary among species (Nunes *et al*., 2015).

Some authors (*e.g.* Blumstein, 2006; Stankowich & Coss, 2007) consider that animals frequently respond to anthropogenic disturbance stimuli in the same way they do for natural predators, *i.e.* that preys follow the same economic principles 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 behaviours, with higher FID positively associated with fishing pressure in families that are specially targeted by spear guns.

Spearfishing activity has been linked to have ecological consequences in reef fish depletion, considering abundance and fish size (Meyer, 2007; Frisch *et al*., 2008) 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 the lack of specific management policies to regulate fishing methods (Frisch *et al*., 2008). In this context, the knowledge of fish flight behaviours 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 behaviour 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) larger individuals; (ii) higher number of conspecifics (*i.e.* highest percentage of individuals of *A. bahianus*) and smaller groups; (iii) with distance from a potential shelter and (iv) substrate type.

Material and Methods

Study species. The Acanthuridae are 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 behaviour (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 Ascension and St. Helena, in the South and Central Atlantic (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 behavioural 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 inexperienced spearfishers (Bender *et al*., 2014) 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). Spear gun fishing is popular in this area (Nunes *et al*., 2012) being also the focus of several reef fish studies (Coni *et al*., 2007; Nunes *et al*., 2007a, 2007b; Campos *et al*., 2010; 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 5 m visibility. Rocky reefs are the main physiographic structure in the study sites. These habitats are covered by 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 (Nunes *et al*., 2013), small colonies of scleractinian corals and sand bottom.

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 fish 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 referred 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).

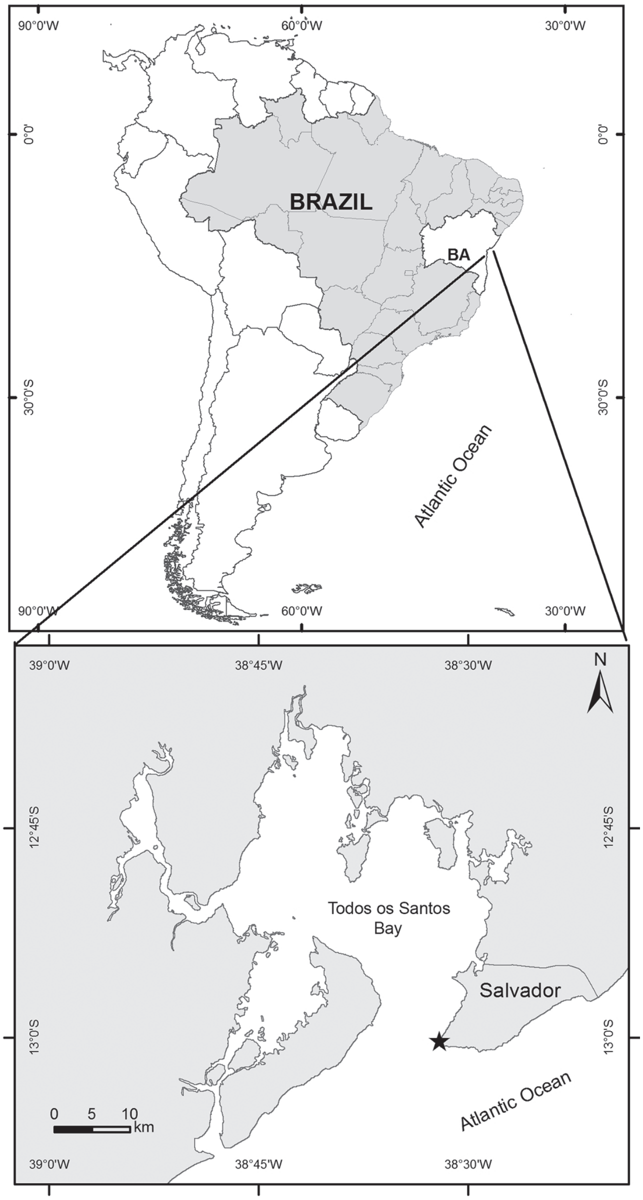

Fig. 1. Location of the study area at the Porto da Barra (black star), Salvador, Bahia, Brazil.

The distance (cm) to the nearest potential shelter 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). 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.

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 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 three continuous covariates: the influence of size of target fish (TL), group size and distance of shelter, and one categorical variable: substrate type, on FID of *A. bahianus*. Tukey's test was used to identify differences in FID.

We used a T-test to compare the FID between interspecific and mono specific shoals. One-way analysis of variance (ANOVA) was performed to investigate whether there were differences in FID in different levels of specificity of groups in the absence of *Acanthurus bahianus*, *i.e.* the percentage of individuals of other species in each group (0-30%, 31-60%, > 60%). Additionally, an electivity index, Ivlev's, was used to identify the group formation preferences.

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 show low preference, or rejection, while values close to 1 indicate 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 analyses were performed considering a significance level $\alpha \leq 0.05$.

Results

Body size, group size and distance to shelter. We 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 significant differences in FID between some of the variables ($p < 0.001$). We found a significant and positive correlation between FID and body size, with an increase in FID in large-bodied individuals (Fig. 2b).

Table 1. Analysis of covariance (ANCOVA) results testing the influence of fish size, group size, distance of shelter and 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		

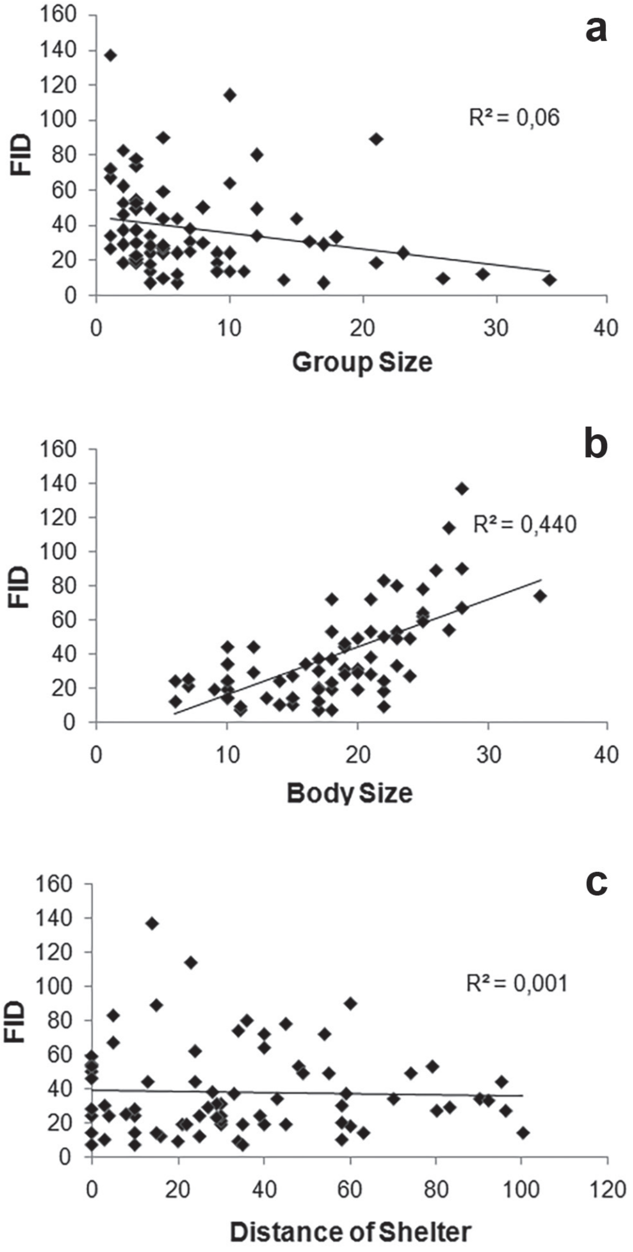

Fig. 2. Flight Initiation Distance (cm) plotted against Group size (a), Body size (cm) (b), and Distance of shelter (cm) (c) for *Acanthurus bahianus*.

There was no significant difference between FID and group size or in distance to a potential shelter (Table 1). However, FID varied between the main substrates (ANCOVA; *F* = 3.95, *p* = 0.028) (Table 1) with greater flight distances observed where there was a higher percentage of sand substrate (Fig. 3).

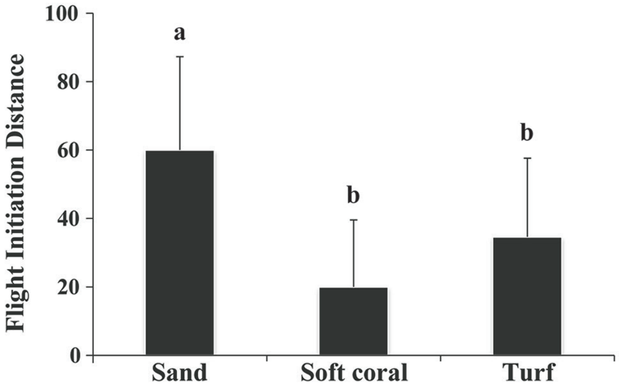

Fig. 3. Flight Initiation Distance (cm) (mean ± S.D.) for *Acanthurus bahianus* in the main substrates found at the study site. Different letters means significant differences – p < 0.05.

Composition and preference in a group formation. 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 species groups (mean ± S.D.): 0-30% Low (39.4 ± 28.1); 31-60% Medium (37.5 ± 27.3); > 60% High (36.6 ± 23.5). Furthermore, there were no differences between FID of interspecific and mono specific shoals (t = 0.0499; df = 66.00; *p* = 0.619).

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).

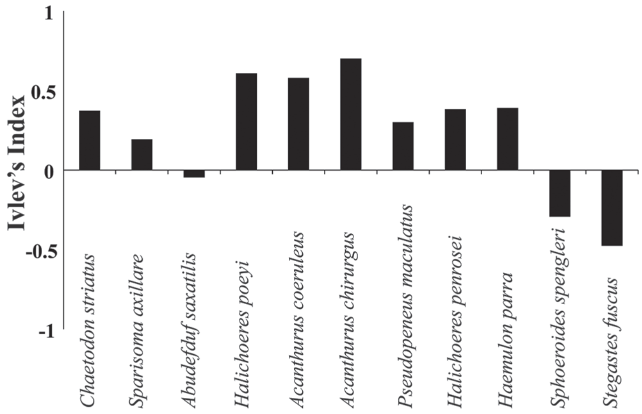

Fig. 4. Results of Ivlev's index showing the preference of *Acanthurus chirurgus, Acanthurus coeruleus* and *Halichoeres poey*; and the rejection of *Stegastes fuscus* and *Sphoeroides spengleri* to form groups with *Acanthurus bahianus.*

Discussion

We investigated FID of *Acanthurus 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* were seen in groups with *A. bahianus*; and (iii) despite the distance to shelter having no influence on FID, escape responses varied between main substrate types (Table 1).

Greater FID was often associated with larger body size (Fig. 2b), which could be attributed to spearfisher preferences in targeting larger fishes (Januchowski-hartley *et al.*, 2011), however our observations may also be alternatively explained. Large-bodied species can be correlated with age at maturity or age at the first reproduction and these 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). Furthemore, experience or social learning related to predator attacks may provide an opportunity for learnt escape responses in adult fish (Kelley & Magurran, 2003).

Although a relationship between FID and shoal size has not been found here, previous studies have shown that fishes can perform coordinated shoaling behaviour on different shoal sizes in response to increased predation risk (Magurran & Pitcher, 1987). 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 and the individual perception of safety in groups (Magurran, 1990) may result in a lower 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.

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.

Living in conspecific or heterospecific aggregations can facilitate social learning of antipredator behaviour through chemical and visual cues (Griffin, 2004; Lönnstedt & McCormick, 2011). Monospecific grouping may provide foraging and anti-predator benefits, however mixed-species groups are probably more advantageous, since they create less resource competition and provide significant benefits such as confusing predators by preventing them to focus on a particular individual, an earlier detection of potential threats and greater flight distances to predators (Semeniuk & Dill, 2005, 2006). To illustrate, studies of heterospecific schooling have indicated that associations of Rusty Angelfish, *Centropyge ferrugatus*, with mixed-species groups provide an antipredatory and foraging benefit (Sakai & Kohda, 1995).

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 (Fig. 4) could mutually 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 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 behaviour explains the lack of association between *S. fuscus* and *A. bahianus* (Fig. 4), 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, possibly due the risk to be bite or other antagonistic behavior.

To have refuge into crevices or undersurface of boulders is apparently effective for some species (*e.g.* sea breams) 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 rocky reefs for *A. bahianus* was not significant (Table 1; Fig. 2c). The natural structure and physical complexity 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 homogenous substrates (*i.e.* sand bottom) (Fig. 3). Possibly, because no shelter was available in these points, *A. bahianus* preferred 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 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 antipredator behaviour of (currently) non-target species and increase their sensitivity to spearfisher disturbance.

In conclusion, our study provides 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 shows 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 behaviours and the social learning of juvenile and adult fishes as an important tool to avoid predation.

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