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Atividade de forrageamento e comportamento alimentar de duas espécies sintópicas de Mullidae (Perciformes) no Arquipélago de Fernando de Noronha, Pernambuco

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Dissertação apresentada ao Instituto de Biologia da Universidade Estadual de Campinas para a obtenção do título de Mestre em Ecologia.

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"Bons naturalistas têm que
ser historiadores".

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Resumo

A família Mullidae (Perciformes) inclui cerca de 50 espécies de peixes distribuídas em áreas tropicais e subtropicais dos Oceanos Índico, Pacífico e Atlântico. Os mulídeos forrageiam no substrato, orientados principalmente por um par de barbilhões. Foi aqui estudada, comparativamente, a atividade de forrageamento e o comportamento alimentar de *Mulloidichthys martinicus* e *Pseudupeneus maculatus*, que vivem em sintopia no Arquipélago de Fernando de Noronha (Pernambuco). Foi também registrado o comportamento de forrageamento de grupos de *P. maculatus* na Reserva Biológica Marinha do Arvoredo (Santa Catarina) e a formação de cardumes mistos sem atividade alimentar por *M. martinicus* em Fernando de Noronha. As duas espécies diferiram em todos os aspectos analisados. *Pseudupeneus maculatus* forrageia sobre três tipos de substrato, preferindo substrato misto composto por areia e algas. *Mulloidichthys martinicus* explora dois tipos de substrato, preferindo substrato arenoso. *Pseudupeneus maculatus* apresenta menor freqüência alimentar, percorrendo menor distância por tempo durante o forrageamento e apresenta repertório comportamental diversificado ao forragear. Adicionalmente, foram registrados indivíduos de *P. maculatus* alimentando-se de plâncton na coluna d'água quando forrageando em grupos, o primeiro registro de planctofagia para a espécie. Foi também estudado um possível caso de mimetismo de proteção entre *M. martinicus* e *Haemulon chrysargyreum* (Haemulidae), que freqüentemente formam cardumes mistos em Fernando de Noronha. *Pseudupeneus maculatus* é aqui caracterizada como mais versátil, na seleção de substrato para forrageio e em seu comportamento alimentar, quando comparada a *M. martinicus*. Apesar de apresentarem diversas características em comum, as espécies de Mullidae geralmente diferem em sua atividade de forrageamento, indicando que sua simples caracterização como fossadores generalizados de substratos não consolidados é inadequada.

Abstract

The goatfishes (Mullidae), include about 50 species distributed in tropical and subtropical Indo-Pacific e Atlantic Oceans. All goatfishes forage on the bottom, primarily oriented by a pair of chemosensorial barbels. The foraging behaviour and activity of *Mulloidichthys martinicus* e *Pseudupeneus maculatus* was studied comparatively at Fernando de Noronha Archipelago two goatfishes syntopic in (Brazil, Pernambuco), where these two species are syntopic. The behaviour of *P. maculatus* when foraging in groups at the Reserva Biológica Marinha do Arvoredo (Brazil, Santa Catarina) and mixed schooling behaviour of *M. martinicus* at Fernando de Noronha was also studied. The two species differed in all analyzed aspects. *Pseudupeneus maculatus* forages over tree substrate types but prefers mixed substrate composed of sand and algae. *Mulloidichthys martinicus* forages over two substrate types, preferring sandy substrate. *Pseudupeneus maculatus* has a lower feeding rate, roams less per given time and displays a more diverse feeding mode repertoire when compared with *M. martinicus*. Moreover, a study of plankton-feeding behaviour by *P. maculatus* when foraging in groups at Fernando de Noronha and the Reserva Biológica Marinha do Arvoredo was made, the first record of plankton-feeding for *P. maculatus*. A presumed example of protective mimicry by *M. martinicus* and *Haemulon chrysargyreum* (Haemulidae), which frequently form mixed schools in Fernando de Noronha, was also studied. *Pseudupeneus maculatus* is here considered as a more versatile bottom forager when compared to *M. martinicus*. Notwithstanding the overall similarity between mullid species, they do differ in their substrate preferences and foraging activity, which indicates that goatfishes can not be characterized simply as generalized soft bottom foragers.

INTRODUÇÃO GERAL

A família Mullidae

A família Mullidae (Perciformes) inclui cerca de 50 espécies de peixes de médio porte (cerca de 10-30cm), distribuídas em áreas tropicais e subtropicais dos Oceanos Índico, Pacífico e Atlântico (Froese & Pauly, 2005). As espécies desta família são encontradas principalmente sobre fundos não-consolidados (lama, areia, cascalho), a maioria delas próximas a recifes, em profundidades de cinco a 140 metros (Munro, 1976).

Durante a fase larval, os mulídeos são exclusivamente planctófagos, porém, após o seu recrutamento no ambiente recifal, sofrem mudanças drásticas e relativamente rápidas, passando a apresentar hábito bentônico. Dentre as mudanças sofridas durante a fase larval, o desenvolvimento de um par de barbilhões quimio-sensoriais logo abaixo da boca é uma das mais marcantes e está diretamente relacionada com o habito bentônico. O par de barbilhões é usado na detecção, captura e manipulação de presas, possibilitando aos mulídeos explorar eficientemente o substrato (Gosline, 1984; McCormick, 1995). Assim, diferente de muitas outras famílias de peixes recifais, que têm representantes tanto bentônicos como planctófagos, todos os mulídeos são carnívoros que forrageiam no substrato (zoobentívoros) quando adultos (Gosline, 1984; McCormick, 1995).

Durante sua atividade alimentar, os mulídeos revolvem e fossam o substrato não consolidado ao redor dos recifes (Gosline, 1984; McCormick, 1995), misturando o sedimento e alterando a topografia e a composição da infauna (Barnes et al., 1993, McCormick, 1995) (Figura 1). Durante essa perturbação do substrato, os mulídeos desenterram e afugentam invertebrados e peixes bentônicos, atraindo a atenção de predadores oportunistas. Estes predadores se associam momentaneamente aos mulídeos,

aproveitando os itens alimentares expostos por sua atividade aumentando, assim, seu sucesso de caça (e.g. Aronson & Sanderson, 1987; Helfman et al., 1997) (Figura 1). Nesta associação, os peixes seguidos (no caso, os mulídeos) são chamados de nucleares e os peixes que se associam ao nuclear, de seguidores. Aparentemente, esta associação é benéfica ao seguidor e geralmente inócua aos nucleares (Aronson & Sanderson, 1987).

Figura 1. *Pseudupeneus maculatus* forrageia revolvendo e fossando o substrato, assim atraindo atenção de predadores oportunistas como o budião (*Halichoeres poeyi*), que se alimenta das presas não apanhadas pelo mulídeo. (Foto: Roberta Martini Bonaldo).

As espécies de Mullidae em geral forrageiam sobre substratos não consolidados e as sintópicas podem se sobrepor no uso de recursos alimentares (e.g. Munro, 1976; McCormick, 1995). Entretanto, espécies sintópicas de Mullidae geralmente apresentam diferentes modos de forragear e exploram diferentes microhábitats e tipos de substrato (e.g. Hobson, 1974; Munro, 1976; McCormick, 1995). De modo geral, há espécies de Mullidae associadas a fundos não consolidados (principalmente arenosos) e espécies associadas a uma maior variedade de substratos, como fundos de algas, “entulho” (amontoados de corais

e conchas danificadas), cascalho ou rochas e corais (McCormick, 1995). Espécies de *Mulloidichthys* forrageiam principalmente sobre substratos não consolidados e geralmente ocorrem em regiões com depósito de sedimento ao redor de recifes (Gosline, 1984; McCormick, 1995). Já as espécies de *Parupeneus* e *Pseudupeneus* são mais versáteis e forrageiam também sobre substratos consolidados, ocorrendo freqüentemente sobre os recifes (Gosline, 1984; McCormick, 1995).

Apesar de todas as espécies de Mullidae forragearem no fundo, com auxílio dos barbilhões, as diferentes espécies podem apresentar repertórios distintos de táticas alimentares. Há espécies que usam cinco táticas alimentares, as mais comuns sendo enterrar o focinho no substrato ou abocar a camada superior do substrato (e.g. Lukoschek & McCormick, 2001). Cada tática alimentar tem impacto distinto no substrato e sua fauna associada (McCormick, 1995; Lukoschek & McCormick, 2001).

Espécies de Mullidae podem ter atividade alimentar exclusivamente diurna, exclusivamente noturna, ou diurna e noturna (Randall, 1967; Hobson, 1974; Gosline, 1984). Quando não estão em atividade alimentar, os mulídeos formam grupos pequenos ou médios (de 4 a 30 indivíduos) e permanecem estacionários na coluna d'água. Os grupos inativos podem ocorrer tanto em grutas e reentrâncias no recife como em águas relativamente abertas (Randall, 1967; Munro, 1976; Gosline, 1984).

Área de estudo

O Arquipélago de Fernando de Noronha se situa a cerca de 400km da costa nordeste do Brasil. O arquipélago é formado por 21 ilhas e ilhotas, sendo que a maior delas (Fernando de Noronha) tem cerca de 10km de comprimento e 27km^2 (Figura 2) (Linsker, 2003; www.noronha.pe.gov.br). O arquipélago tem origem vulcânica e está situado sobre o pico de uma montanha submersa cuja base está à cerca de 4.500m de profundidade. Assim, a costa do arquipélago apresenta declive acentuado e a poucos metros da costa a profundidade pode ultrapassar os 100m (Linsker, 2003).

Os recifes de Fernando de Noronha são compostos principalmente por rochas cobertas por algas pardas e sedimento. A costa noroeste da ilha, denominada "Mar de Dentro" apresenta mar calmo durante os meses de maio a novembro e é onde foi feita a maioria das observações do presente estudo. Na costa sudeste, conhecida como "Mar de Fora", o mar é batido durante a maior parte do ano, ficando relativamente calmo durante os meses de novembro a abril (Linsker, 2003).

A principal área de estudo está localizada na Praia da Conceição, no "Mar de Dentro" (Figura 2b, 3). Esta área é composta por recife rochoso e planície arenosa adjacente. Nas áreas de costão rochoso predominam quatro tipos de substrato: 1) algas pardas (*Dictyota* sp., *Dictyopteris* sp. e *Sargassum* sp.; 2) misto de algas e areia (composto principalmente por areia, algas coralináceas, algas verdes calcificadas e *Dictyota* sp.); 3) arenoso e 4) rochoso e coralíneo (Figura 4). A profundidade varia de um a 10m, a temperatura é constante ao longo do ano, variando ente 27-28^{o}C e a visibilidade subaquática pode variar entre 5-25m.

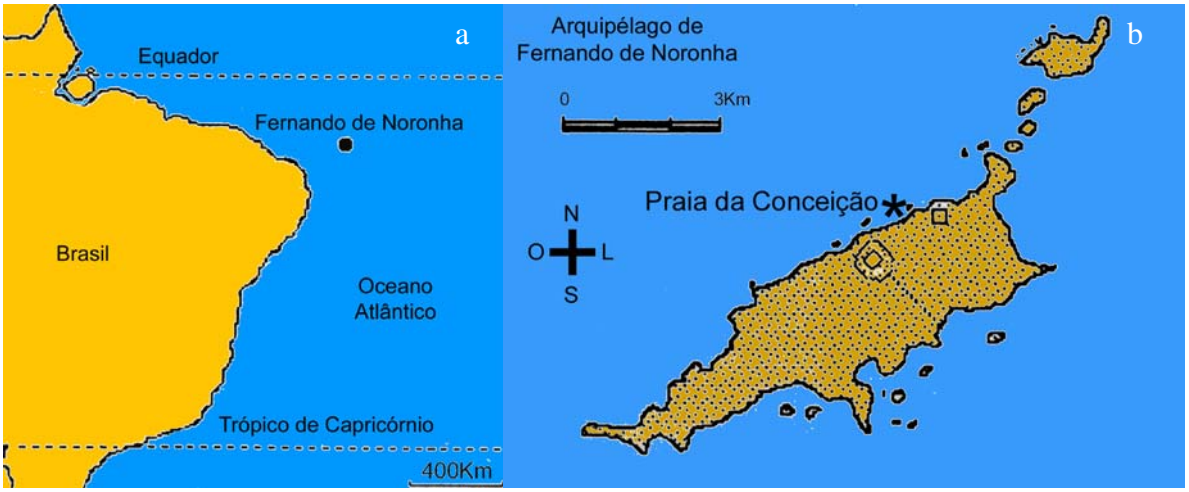

Figura 2. Localização do Arquipélago de Fernando de Noronha (03°54'S, 32°25'W) no Atlântico Ocidental (a) e mapa do arquipélago (b). A principal área de estudo, Praia da Conceição, está marcada com "*" no mapa do arquipélago.

Figura 3. Costão rochoso da Praia da Conceição, Fernando de Noronha, principal área de estudo.

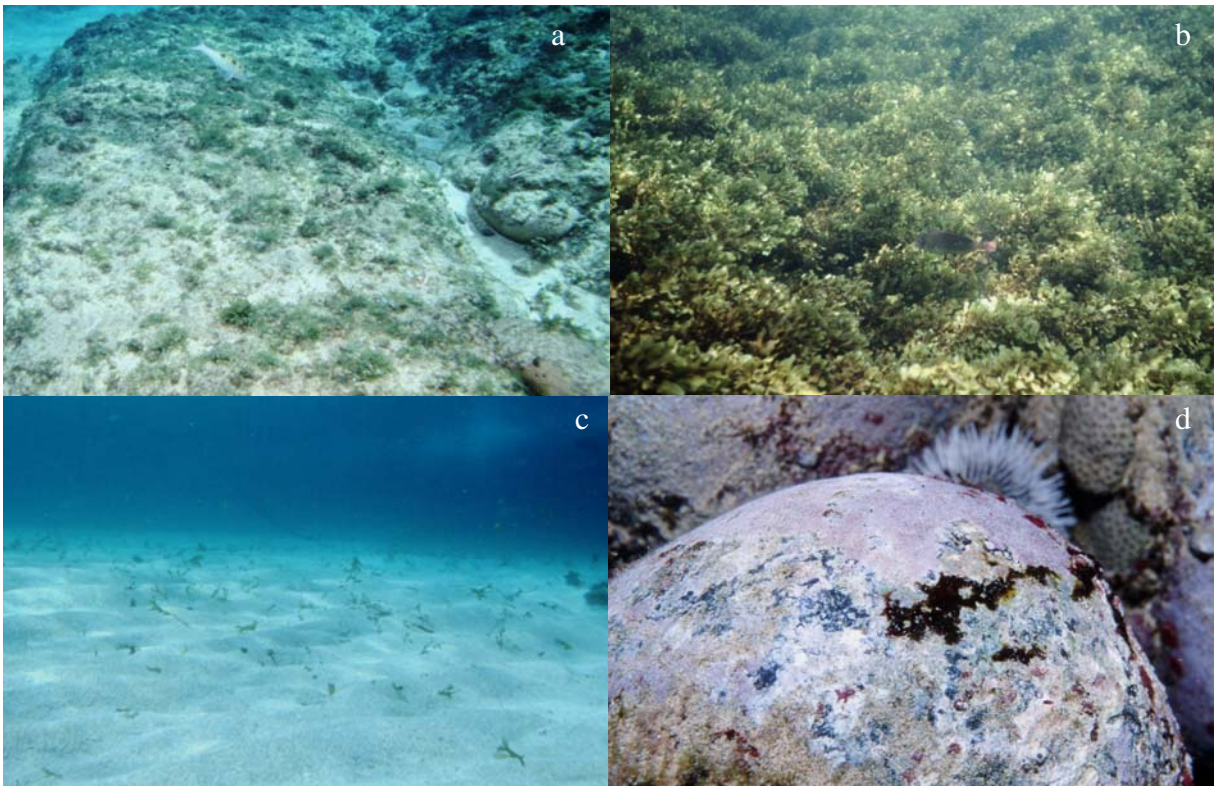

Figura 4. Os quatro tipos de substratos estudados na Paia da Conceição: misto (a), algas pardas (b), arenoso (c) e rochoso (d).

Foram também feitas observações e registros em vídeo e fotográficos em outras regiões do arquipélago, como Porto de Santo Antônio, Praia do Sancho (no "Mar de Dentro") e Baía do Sueste (no "Mar de Fora"). As observações no Porto de Santo Antônio foram feitas em um naufrágio a cerca de 6-8m de profundidade. Na Praia do Sancho, as observações se concentraram na costa sul, entre 5-12m de profundidade e, na Baía do Sueste, na costa norte entre um e dois metros de profundidade. Em todas as áreas de estudo o fundo era semelhante, principalmente composto por algas pardas e fundo arenoso adjacente ao recife.

Espécies estudadas

Em Fernando de Noronha (Pernambuco), ocorrem duas espécies sintópicas de Mullidae, *Mulloidichthys martinicus* e *Pseudupeneus maculatus* (Figura 5). *Mulloidichthys martinicus* ocorre no Atlântico Ocidental, da Flórida ao Rio de Janeiro, apresenta atividade alimentar diurna e noturna e pode forragear solitária ou em pequenos a grandes grupos (Randall, 1967; Munro, 1976; Aronson & Sanderson, 1987; Carvalho-Filho, 1999). *Pseudupeneus maculatus* ocorre no Atlântico Ocidental, de Nova Jersey a Santa Catarina, apresenta atividade alimentar diurna e forrageia solitária ou em pequenos grupos (Starck & Davis, 1966; Munro, 1976; Carvalho-Filho, 1999). Ambas são espécies recifais, freqüentemente encontradas sobre fundo de areia e cascalho (Starck & Davis, 1966; Munro, 1976; Carvalho-Filho, 1999).

Figura 5. *Mulloidichthys martinicus* (a) e *Pseudupeneus maculatus* (b) têm ampla distribuição no Atlântico Ocidental, sendo sintópicos em diversos locais de Fernando de Noronha.

Não há estudos sobre seleção de substrato para forrageio pelas duas espécies, porém, *P. maculatus* parece forragear exclusivamente em substrato arenoso no Caribe (Itzkowitz, 1977; Aronson & Sanderson, 1987; J.P. Krajewski & R.M. Bonaldo obs. pess.).

Mulloidichthys martinicus e *P. maculatus* alimentam-se de presas semelhantes (e.g., poliquetas, caranguejos, camarões, moluscos bivalves), mas apresentam diferenças nas proporções volumétricas de itens alimentares consumidos, quando em simpatria (Randall, 1967). Ainda, *M. martinicus* alimenta-se de maior variedade de itens sendo, plausivelmente, menos seletivo na escolha de itens alimentares que *P. maculatu*s (Randall, 1967; Munro, 1976). Há um único registro de zooplâncton na dieta de *M martinicus* no Caribe (Sierra *et al.*, 1994), porém sem maiores comentários.

OBJETIVOS

O presente estudo examina comparativamente a atividade de forrageamento e comportamento alimentar de *M. martinicus* e *P. maculatus*, espécies sintópicas em Fernando de Noronha. No primeiro capítulo, são examinadas as proporções de investidas em diferentes tipos de substratos, a freqüência alimentar, a duração das investidas no substrato e as táticas alimentares cada espécie. No segundo capítulo, são apresentados os primeiros registros de planctofagia para *P. maculatus* e um dos únicos registros de planctofagia em Mullidae, feitos em Fernando de Noronha (Pernambuco) e na Reserva Biológica Marinha do Arvoredo (Santa Catarina). No terceiro capítulo, é apresentado um possível exemplo de mimetismo de proteção entre *M. martinicus* e *Haemulon chrysargyreum* (Haemulidae) em Fernando de Noronha.

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Capítulo 1

Foraging activity and behaviour of two syntopic goatfish species (Perciformes: Mullidae) at Fernando de Noronha Archipelago, tropical West Atlantic

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Abstract

The goatfishes (Mullidae) include about 50 specialized bottom forager fish species. The foraging activity of the yellow goatfish, *Mulloidichthys martinicus*, and the spotted goatfish, *Pseudupeneus maculatus*, was studied comparatively at Fernando de Noronha Archipelago, off northeast Brazil, tropical West Atlantic, where they are syntopic. *Pseudupeneus maculatus* fed over a larger variety of substrate types, had lower feeding rate, roamed more per given time, spent less time in a feeding event, and displayed a more diverse repertoire of feeding modes than *M. martinicus*. The differences in the foraging activity and behaviour between the two species possibly minimize potential resource overlap between them, as recorded for other syntopic mullids. *Pseudupeneus maculatus* had lower feeding rate probably because it fed on larger items. Additionally, it roamed over greater distance per time possibly because it foraged over a greater variety of substrate distributed over a larger area than that used by *M. martinicus*. Notwithstanding the overall similarity between the mullids in general, they do differ in their substrate preferences and foraging activity, which indicates that these fishes should not be simply considered generalized soft bottom foragers.

Key words: *Mulloidichthys martinicus, Pseudupeneus maculatus*, foraging behaviour, oceanic island.

Introduction

Goatfishes (Perciformes: Mullidae) include about 50 species distributed in tropical and subtropical seas. All goatfishes are zoobenthivores and forage mainly over soft sediments (sand and mud) around reefs, oriented mostly by their tactile and chemosensorial barbels (Gosline, 1984; McCormick, 1993, 1995; Platell et al., 1998). During their foraging, the goatfishes disturb the substrate and, thus, change the bottom topography and the distribution of invertebrates associated to soft sediments (McCormick, 1995). Additionally, as a consequence of their foraging mode, the goatfishes act as nuclear species and are frequently followed by other carnivore reef fishes that catch small preys flushed during their substrate disturbance (Gosline, 1984; Aronson & Sanderson, 1987).

The goatfishes are common and abundant in tropical and sub-tropical shallow reefs (Platell *et al.,* 1998) and two or more goatfish species frequently occur in the same reef (Gosline, 1984; Golani, 1994; McCormick, 1995). Despite their overall similarity, co-occurring goatfish species usually differ in their foraging substrate and feeding modes (Gosline, 1984; Golani, 1994; McCormick, 1995; Platell *et al.*, 1998). Such differences are believed to minimize food overlap between co-occurring goatfishes (Labropoulou & Eleftheriou, 1997).

Two species of goatfishes, the yellow goatfish, *Mulloidichthys martinicus* (Cuvier), and the spotted goatfish, *Pseudupeneus maculatus* (Bloch) are syntopic at Fernando de Noronha Archipelago, off northeast Brazil, tropical West Atlantic. The yellow goatfish is a common reef species in the Western Atlantic and ranges from Florida to South-eastern Brazil (Carvalho-Filho, 1999; Humann & DeLoach, 2002). It feeds both at daytime and night (Randall, 1967; Munro, 1976; Aronson & Sanderson, 1987) and forages either solitarily or in groups (Carvalho-Filho, 1999). The spotted goatfish also is a common reef fish species in the

Western Atlantic and ranges from New Jersey to South Brazil (Carvalho-Filho, 1999; Humann & DeLoach, 2002). It feeds only during the day, either solitary or in small groups (Starck & Davis, 1966; Munro, 1976).

Mulloidichthys martinicus and *P. maculatus* feed on similar items, but *P. maculatus* generally has, in its stomach, a higher volumetric content of mobile preys, such as crabs and shrimps, and also feeds on small fishes (Randal, 1967). The relative high proportion of mobile and large prey in the stomach content of the spotted goatfish is possibly related to the fact that all species within the genus *Pseudupeneus* have strong jaw teeth, as well as a relatively long snout, both features apparently suited to catch large and active prey (Gosline, 1984).

The foraging activity of *M. martinicus* and *P. maculatus* was studied comparatively at Fernando de Noronha Archipelago. The present study addressed the five following questions: 1) Do the two species use the same foraging substrate? 2) Do their feeding rates differ? 3) Are there differences in the distance travelled per given period while foraging? 4) Does the time spent in a feeding event differ between the two species? 5) Do their feeding modes differ?

Materials and methods

The study was conducted at the Fernando de Noronha Archipelago (03°50' S; 32°25' W), 345km off north-eastern Brazil, from June to July 2002 and June 2003. The main study site was an area of about 200 X 30 m at the Praia da Conceição, on the west side of Fernando de Noronha main island. The bottom was composed of rocky reefs covered mostly by brown algae (*Dictyota* sp., *Dictyopteris* sp., and *Sargassum* sp.), mixed substrate (composed mostly with sand and an assemblage of corallinaceous and green calcified algae, as well as *Dictyota* sp) and adjacent sandy areas. During the study the depth ranged 1-12 m, visibility ranged 8-30 m and water temperature was 27-28°C.

The foraging activity of the two goatfishes was observed over 55 non-consecutive days while snorkelling and scuba-diving. During observational sessions of 60-150 min, "focal animal" and "all occurrences" samplings (Lehner, 1979) were used in a total of 640 min of direct observation. All observations were conducted at daytime from 0930h to 1730h.

Selection of foraging substrate and feeding rates of the two species were assessed by following individuals for periods of 3 to 5 min and counting the number of feeding events on four substrate types: 1) brown algae; 2) mixed (algae and sand); 3) sandy, and 4) hard substrate (rocks and stony corals). Each feeding event started when the goatfish's mouth or snout touched the substrate and ended when it left the substrate. The distance travelled per given time was assessed by following foraging individuals for 3 to 5 min and measuring the distance the fish moved within this time. Individuals were not followed over successive periods to avoid the risk of biased samples (Birkeland & Neudecker, 1981). Data used for substrate selection comparisons was collected in June 2003 and at the same study site, and therefore the substrate availability was the same for all individuals studied. Data on feeding rates and distance travelled per time was collected in June and July 2002 and June 2003 at the same study site, using similar observational times for the two species in the consecutive years.

The relative abundance of the four foraging substrate types was assessed by video recording eight 30 x 1.5 m transects (modified from Birkeland & Neudecker, 1981). Transects started on the rocky shore and ended on the sandy area where the two goatfishes were still recorded feeding. Still frames were taken from the video recordings and the availability of the four substrates types considered was thus estimated (brown algae, sand, mixed and hard substrate).

About two hours of foraging activity of the two goatfishes were video-recorded and photographed at four different sites in the archipelago. In all sites the bottom was similar to

that of Praia da Conceição. A total of 128 feeding events of 19 individuals of *M. martinicus* and 118 feeding events of 21 individuals of *P. maculatus* were analyzed. Time spent during each feeding event was estimated by analyzing the video records frame by frame. Time average spent in each feeding event was calculated for each individual recorded, and the total mean between all individuals was calculated for each species. The feeding modes of the two goatfish species were quantified analyzing the video records and photographs, and a name for each mode is here proposed.

Results

Mulloidichthys martinicus and *P. maculatus* differed in all studied features (Figures1 and 2 and Table I). *Mulloidichthys martinicus* fed over sandy and mixed (algae and sand) substrate, but preferred sandy bottom, whereas *P. maculatus* fed over sandy, mixed and brown algae substrate, but preferred mixed substrate (Figure 1). Both species were also recorded to feed on rubble substrate (composed of pieces of dead calcified algae of about 2-20 mm, and sand) at study sites other than the main site at the Praia da Conceição.

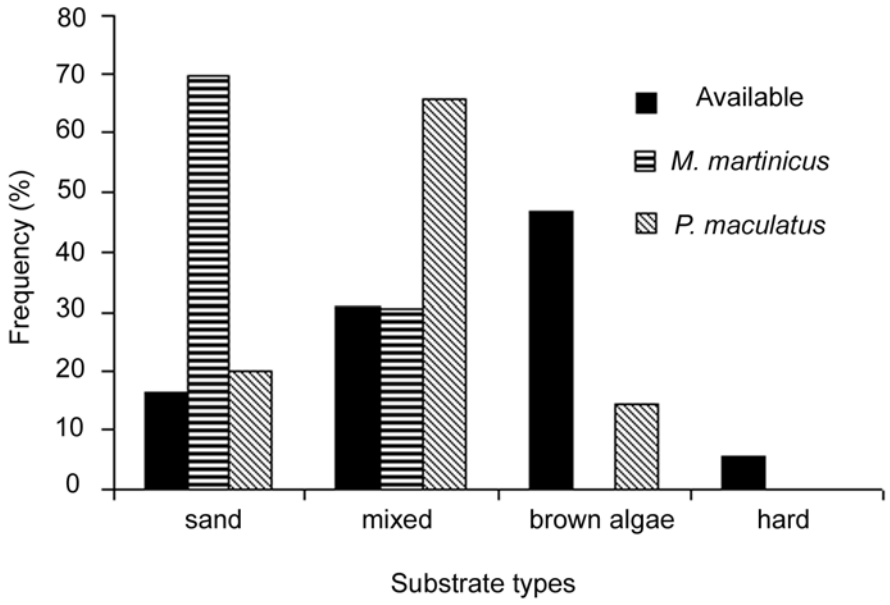

Figure 1. Frequency of feeding events of *Mulloidichthys martinicus* and *Pseudupeneus maculatus* on each substrate type, and the actual relative abundances of those substrates at Fernando de Noronha Archipelago.

Mulloidichthys martinicus had higher feeding rate, roamed less per given time, and spent more time during each feeding event than *P. maculatus* (Table I).

Table I. Comparisons between *Mulloidichthys martinicus* and *Pseudupeneus maculatus* at Fernando de Noronha Archipelago: Student t test for feeding rates and distance roamed per time and Mann-Whitney for time spent during each feeding event. The parentheses indicate the total number of bouts for feeding rate and distance roamed per time data and number of individuals for time spent in each feeding event data.

	M. martinicus	***P. maculatus***	**p**
Feeding rate	3.42	1.99	<0.0001
(feeding events/min)	(n=30)	(n=53)	
Distance roamed per time	2.99	5.39	<0.0001
(m/min)	(n=26)	(n=33)	
Time spent in each feeding event	1.56	0.61	<0.0001
(s)	(n=17)	(n=16)	

The feeding modes displayed by the two species were here classified into six categories (Figure 2) (modified from McCormick, 1995): 1) excavate: burrowing with snout, the body axis usually more than 30^{o} relative to substrate; 2) push: moving the snout against the substrate dislodging it horizontally, the body axis usually less than 20^{o} relative to substrate; 3) drift: barbels actively pushing the top layer of the sediment; 4) bite: capture of prey using only jaws' movement; 5) pursuit: short distance chase (about 5 -30cm) of a mobile prey flushed during the substrate disturbance; 6) ambush: striking a prey after remaining stationary for 1 to 5 sec camouflaged on the substrate.

Pseudupeneus maculatus displayed the six feeding modes, whereas *M. martinicus* displayed four of them: excavate, push, drift and bite. The two species additionally differed in the frequency that they displayed each feeding mode, since *M. martinicus* mostly pushed and excavated, whereas *P. maculatus* mostly bit and drifted (Figure 3).

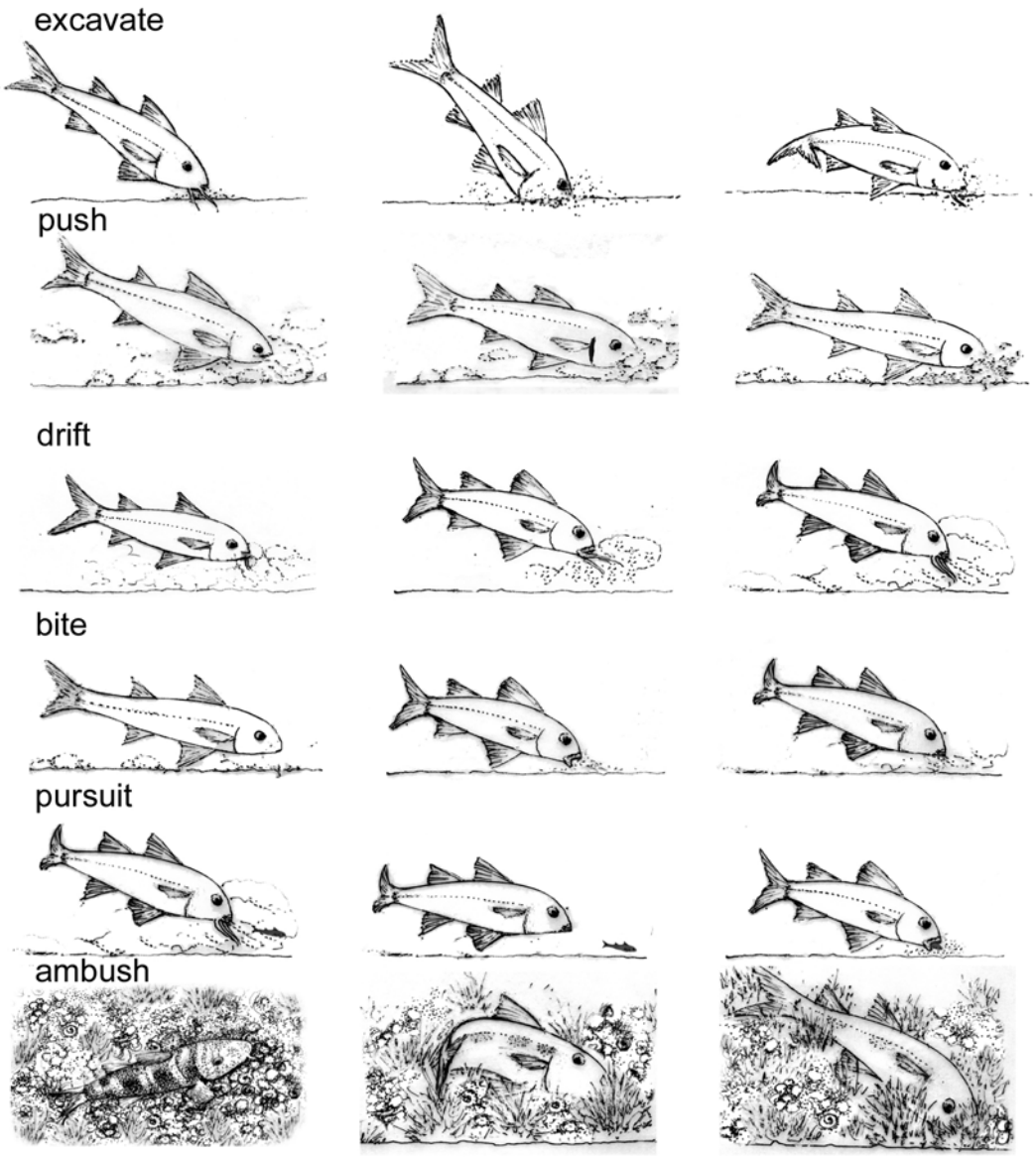

Figure 2. A hypothetic goatfish displaying the six feeding modes (from the left to the right) recorded for *Mulloidichthys martinicus* and *Pseudupeneus maculatus* at Fernando de Noronha Archipelago. The former species displayed only excavate, push, drift and bite, whereas the latter one displayed all modes. Based on video frames and photographs.

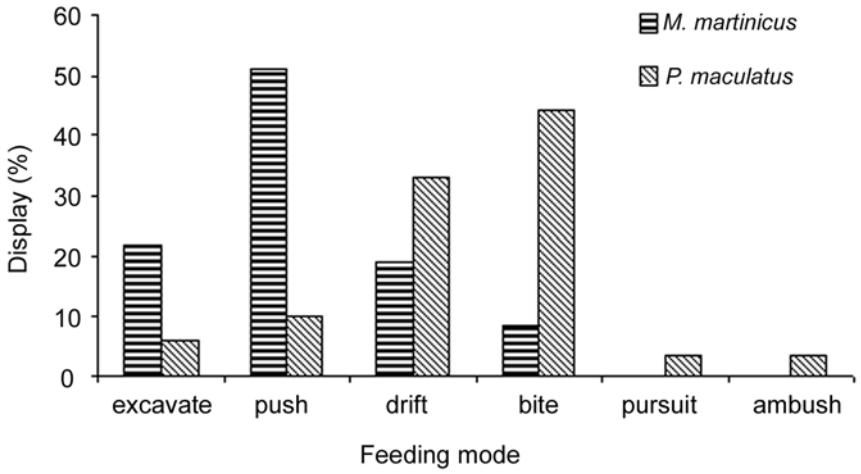

Figure 3. Frequency of each feeding mode by *Mulloidichthys martinicus* and *Pseudupeneus maculatus* at Fernando de Noronha Archipelago.

Discussion

All goatfish exploit the bottom, especially soft substrates, using their barbels and snout (Gosline, 1984; McCormick, 1995). Thus, sympatric species have the potential to overlap in food resources use. However, in spite of their overall similarity of feeding habits, goatfish species usually differ in the substrate they forage and in their feeding modes (Gosline, 1984; Golani, 1994; McCormick, 1995; Platell *et al.*, 1998). In the present study, *M. martinicus* and *P. maculatus* differed in all analyzed features. In the Caribbean, these two goatfish species are known to occur at different depths (Munro, 1976). The differences in foraging activity and depth distribution of both species may minimize the food resource overlap between them where they live in sympatry. Additionally, *M. martinicus* and *P. maculatus* differ in their activity period, since the former is known to feed at night as well (Randall, 1967; Munro, 1976). However, differences in activity period may not be very important to avoid food resource overlap because the consumption of one food resource at night at a given site reduces its availability during the day at this site (Schoener, 1974).

Although goatfish species usually differ in their feeding activity, which is regarded as a mechanism of avoid resource overlap and competition, data from the present study do not necessarily points that differences in foraging behaviour of *M. martinicus* and *P. maculatus* is a mechanism to minimize competition (Connel, 1980). Differences between these two species may also have resulted from past competition or simply by differences arisen during their speciation (Connel, 1980).

Even though there is no study that examines foraging substrate use by *M. martinicus* or *P. maculatus*, in the Caribbean these two species seem to feed almost exclusively over sandy bottoms (Itzkowitz, 1977; Aronson & Sanderson, 1987; Krajewski & Bonaldo pers. obs.). The present study findings for *M. martinicus* are similar to those obtained in the Caribbean (Aronson & Sanderson, 1987), since it foraged only over soft substrates (sandy, mixed, and rubble) mainly composed of sand. On the other hand, in this study *P. maculatus* foraged over a wider range of substrate types than in the Caribbean (Itzkowitz, 1977; Aronson and Sanderson, 1987; Krajewski and Bonaldo, pers. obs.), especially in Jamaica, where this goatfish was recorded to forage exclusively on sandy substrate (Itzkowitz, 1977). Additionally, part of the brown algae substrate in our main study site is located in very shallow waters (about 5 to 40 cm deep) and may be inaccessible for *P. maculatus* during low tides and under the impact of waves. Thus, the preference for brown algae substrate here recorded for *P. maculatus* may be underestimated and this substrate may be more used for foraging by this goatfish than observed in the present study. These results indicate that *P. maculatus* and species of the closely related genus *Parupeneus* (Gosline, 1984; McCormick, 1995) have the potential to forage mostly in reef areas and are not sandy bottom specialists. Perhaps *P. maculatus* is known as foraging almost exclusively on soft substrates in some areas of the Caribbean because many coral reefs are present there, and algal cover is not as abundant as it is at Fernando de Noronha (J. P. Krajewski and R. M.

Bonaldo per. obs.). Similar questions related to bottom differences in the Caribbean and on Brazil's coast were raised about the cleaning role of the french angelfish, *Pomacanthus paru* (Bloch), in these two regions (Sazima *et al.,* 1999).

Species of the genera *Pseudupeneus* and *Parupeneus* are believed to feed on larger and more mobile preys when compared with other goatfish species (Gosline, 1984). *Pseudupeneus maculatus* is known to feed on more mobile and larger preys than *M. martinicus* (Randal, 1967). In the present study, *P. maculatus* was occasionally observed mouthing and ingesting large preys (up to 4 cm total length) such as fishes and crustaceans. Thus, *P. maculatus* probably had lower feeding rate when compared with *M. martinicus* due to its feeding on large food items in a higher proportion. The present study indicates that the yellow goatfish feeds continuously on small preys, whereas the spotted goatfish feeds on larger preys, thus in lesser amount.

Pseudupeneus maculatus foraged over three substrates types that altogether span about 93% of the total area of the study site, whereas the substrates used by *M martinicus* span about 47% of the same site (Fig. 1). The yellow goatfish probably roamed for lesser distances because the substrate it used was concentrated on the sand flat.

The lesser time spent in each feeding event by *P. maculatus* possibly is related to the ability of species of the genera *Pseudupeneus* and *Parupeneus* to catch large and mobile preys using their strong teeth and long snout. These may help goatfishes of the two genera immobilise and ingest preys quickly and, thus, they do not spend time immobilising preys pushing them against the substratum as *M. martinicus* have to do. This suggestion seems supported by the feeding modes displayed by the two goatfishes here studied. Whereas *M. martinicus* fed frequently burrowing its snout into the soft bottom, *P. maculatus* displayed a variable feeding repertoire and frequently caught either immobile or mobile preys using quick bites only.

In spite of their overall similarity in feeding behaviour, each goatfish species seem to have its particular way to explore the bottom. Some species are most often associated to soft bottoms and usually use their snout and barbels to excavate and search for buried preys, whereas other species forage on a wide range of bottom types and display a variable feeding repertoire (Gosline, 1984; McCormick, 1995). In the present study, *M. martinicus* was mostly associated with soft bottoms and displayed feeding modes similar to that commonly used by other soft-sediment specialists, such as several *Mulloidichthys* species from the Pacific (Gosline, 1984; McCormick, 1995; Randall *et al.*, 1997). On the other hand, *P. maculatus* displayed a variable feeding repertoire, similarly to other reef species of the genera *Pseudupeneus* and *Parupeneus* (Gosline, 1984; McCormick, 1995). Additionally, the spotted goatfish displayed two feeding modes (pursuit and ambush) which are not recorded for any other goatfish species (Gosline, 1984; McCormick, 1995). While ambushing, the colour of the spotted goatfish matched that of the substrate it hunted over, working as a camouflage to disguise the predator. The colours most often displayed by *P. maculatus* (light brown with yellow and dark brown spots) are similar to those of the brown algae substrate, abundant in all study sites, which may facilitate this goatfish's camouflage during ambush and increase its hunting success on visually guided and quickly fleeing prey.

Differences in the frequency of feeding modes between the two species indicate that each of them has a different impact and disturbance on the substrate and the hidden prey. *Mulloidichthys martinicus* caused greater disturbance in soft sediments than *P. maculatus*, which, additionally, cause even greater disturbance while foraging in large groups.

Overall, *Pseudupeneus maculatus* may be characterized as a versatile bottom predator that forages both on soft and hard substrates. Additionally, the spotted goatfish is known to feed on zooplankton while foraging in groups (Krajewski & Bonaldo, submited), which

supports its characterization as a versatile predator. On the other hand, *M. martinicus* seems to be a soft bottom specialist, even if recorded to feed on zooplankton in the Caribbean (Sierra *et al*., 1994).

The present study and other recent findings indicate that goatfishes can not be simply characterized as soft bottoms specialists (Gosline, 1984, McCormick, 1995). Different species of goatfishes may have different impacts on soft, algae and hard bottom types and the associated organisms, either by differential consumption or disturbance. Additionally, goatfishes are ubiquitous nuclear species, and are followed by a number of generalist predators (Aronson & Sanderson, 1987, Soares & Barreiros, 2003, Sazima et al., 2005). Thus, differences in the foraging behaviour and activity of goatfishes may also lead to differences in the species that associate with each goatfish species, and in the possible benefits gained by the follower species.

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Capítulo 2

Plankton-picking by the goatfish *Pseudupeneus maculatus* (Mullidae), a specialized bottom forager

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Abstract

The goatfishes (Mullidae) include about 50 specialized bottom forager fish species. Juveniles and adults of the spotted goatfish *Pseudupeneus maculatus* were recorded feeding on plankton on rocky reefs off Southern and Northeastern Brazil, respectively.

Key words: benthic foraging, plankton feeding, zooplankton, opportunistic behavior, Western Atlantic

Plankton-feeding is a widespread foraging mode among reef fishes (Hobson, 1991). Some species feed on plankton only during their larval and early juvenile stages, while others remain obligate planktivores when adults (Hobson, 1991). Fishes specialized for picking zooplankton generally have protrusible jaws and short bodies, and typically form aggregations in the water column in areas where zooplankton is abundant (Hobson & Chess, 1978, 1986; Hobson, 1991). Some bottom-foraging reef fish are reported to feed on plankton or particulate food occasionally and under particular circumstances (e.g. Glasby & Kingsford, 1994; Sazima & Sazima, 2001; Sazima *et al*., 2003).

The goatfishes (Mullidae) include about 50 specialized bottom-foraging fishes that use their well developed chemo-sensorial barbels to probe and disturb the substrate while feeding (Munro, 1976; McCormick, 1995). Differently from several other reef fish families that have strong benthic association (e.g., damselfishes, wrasses, snappers, and groupers) and include both bottom and plankton-foraging species, no goatfish is known as primarily planktivorous when adult (McCormick, 1995).

The goatfishes are reported as plankton-eaters only during their larval stage, and after a drastic and quick change during their settlement they develop a set of features that seems to

constrain them to a benthic foraging habit (Gosline, 1984; McCormick, 1993, 1995). However, there is a report on zooplankton in the diet of the yellow goatfish, *Mulloidichthys martinicus* (Cuvier) from Cuba (Sierra *et al.*, 1994), and a record of foraging in the water column by the goatfish *Parupenes barberinus* (Lacepède) in Australia (Lukoschek & McCormick, 2001), both records without further comments.

Groups of the spotted goatfish, *Pseudupeneus maculatus* (Bloch), were recorded feeding on plankton on the rocky reefs of the Marine Biological Reserve of Arvoredo (about 27°17'S, 48°18W), on the coast of Santa Catarina, southern Brazil, and at Fernando de Noronha Archipelago (03°50'S, 32°25'W), about 345 km off northeast Brazil. The observations at the Marine Biological Reserve of Arvoredo were conducted in February 2004, the depth at the study site was 5-15 m and horizontal visibility was 4-10 m. The plankton-feeding behaviour of groups of juvenile spotted goatfish was observed and photographed during eight scuba-diving sessions totalling eight hours. The observations at Fernando de Noronha Archipelago were conducted in June 2003 and the depth was 15 m and horizontal visibility 30 m. A mixed group of *P. maculatus* and the damselfish *Abudefduf saxatilis* (Linnaeus) was video recorded while they foraged on suspended particles and zooplankton.

At the Marine Biological Reserve of Arvoredo a total of 13 groups of juvenile spotted goatfish were recorded. Each group was composed of 12-16 individuals of 5-10 cm total length (L_T), most larger than 7 cm L_T. All groups were constantly feeding on the bottom over brown algae substrate and the plankton-picking foraging was recorded when the individuals suddenly rose up to one m from the bottom and started to pick small crustaceans in the water column (Fig. 1). The fishes spent about 4-10 s feeding on plankton before they resumed their habitual bottom-feeding. During the plankton-feeding the fish protruded their jaws with their barbels retracted and swam back and forth to pick off

individual plankters. In all instances of plankton-feeding a cloud of small crustaceans was visible. No adult individuals of the spotted goatfish were recorded feeding on plankton at the Marine Biological Reserve of Arvoredo, most were foraging solitarily on the bottom.

Figure 1. A group of juvenile, recently settled goatfish, *Pseudupeneus maculatus*, rising in the water column to feed on plankton. The white spots in the water column are due to the flash light reflected on the zooplankton.

At Fernando de Noronha Archipelago a mixed group of about 10 *P. maculatus* of 15-20 cm L_T and 33 *A. saxatilis*, was recorded. The group was feeding on the bottom and plankton-feeding was recorded when the goatfish started to pick small crustaceans about 2-5 cm above a brown algae agglomerate that was floating about 20-30 cm above the sandy bottom (Fig. 2). The plankton-picking lasted about 15 s and was displayed by six out of the 10 individuals. During plankton-feeding the fishes protruded their jaws with their barbels retracted and swam back and forth picking off individual plankters and other particles in the water column. A copy of the video records is deposited as a voucher in the Museu de História Natural of the Universidade Estadual de Campinas (ZUEC tape #21)

Figure 2. A mixed group of the goatfish *Pseudupeneus maculatus* and the damselfish *Abudefduf saxatilis*. The goatfish are feeding on drifting crustaceans, close to the bottom. Note the protruded mouth of the individual on the left side of the picture (taken from a video frame).

When goatfish settle, they go through a drastic and quick morphological and colour change. Pelagic goatfish are usually silvery and change to adult colour shortly after settlement. The chemosensorial barbels also change drastically during settlement, and they are recorded to increase up to 52% in length in a 12h-period (McCormick, 1993). The barbels are not used during the larval phase, but are frequently used to detect and manipulate prey once the fish is settled (McCormick, 1993). Also, goatfishes are recorded to change behaviour from schooling with other fish species under drifting debris before and during settlement, to foraging in small groups or solitarily on the bottom after settlement (MacCormick, 1993). For the spotted goatfish, the metamorphosis from pelagic larva to benthic adolescence occurs when the fish is about 41mm standard length (L_S), but may be

delayed until 61 mm L_S (Munro, 1976). All individuals observed foraging on plankton at the Marine Biological Reserve of Arvoredo were certainly post settlement, since they were constantly foraging on the bottom and had chemosensorial barbels and colour similar to that of adults (Figure 1). Since all individuals observed were about 5-10 cm L_T, they must be considered recently settled and this proximity to their larval phase may have favoured the occurrence of plankton-feeding behaviour, as these fish displayed this behaviour in the larval stage not long before the phase recorded here. The much higher frequency of foraging in the water column by small individuals (< 12 cm L_T) of *P. barberinus* when compared with medium and large (> 12 cm L_T) ones (Lukoschek & McCormick, 2001) lends support to this latter suggestion.

The spotted goatfish seldom swims in open water, and even when it spawns, it generally rises a shorter distance more quickly in the water column than other reef fishes, a strategy believed to be a predator avoidance behaviour (Colin & Clavijo, 1978). The closeness of the drifting crustaceans and the bottom, in both our records, may have favoured the plankton-feeding behaviour, since the spotted goatfish could feed on the plankton without having to rise too far from the substrate and thus be exposed to predators. Additionally, as the plankton was close to the substrate, the goatfish could perceive it as an alternative and rich food resource (Norrbin & Bamstedt, 1984) during their usual bottom-feeding.

The foraging in groups may also have contributed to the plankton-picking behaviour. In the example where the spotted goatfish was feeding together with *A. saxatilis*, the fish group seems to have chased the small crustaceans and concentrated them over the brown algae mass. This likely helped the goatfish perceive the drifting crustaceans during their usual bottom-feeding. Additionally, when foraging in groups the fish are safer from predators (Brock & Riffenburgh, 1960), so they may be more prone to rise in the water column. Even a solitary goatfish could pick off plankters where plankton is abundant and

close to the bottom in reef areas that provide shelter against predators (Colin & Clavijo, 1978).

The goatfishes suffer a major change during their settlement and develop a set of features that seems to constrain them to benthic foraging (Gosline, 1984; McCormick, 1993, 1995). Even if they exhibit several features exclusive to bottom-foragers, the goatfishes have protrusible jaws, a characteristic shared with specialized plankton-picking fish species (Hobson, 1991). The protrusible jaws seem to be the main feature of the spotted goatfish that enables it to feed on plankton and drifting particles, and several other bottom-foraging species with protrusible jaws are likely candidates to feed occasionally on plankton. The records of feeding in the water column by *P. barberinus* (Lukoschek & McCormick, 2001), plankton-picking by the bottom-foraging butterflyfish *Chaetodon striatus* (Linnaeus) (Sazima & Sazima, 2001) and dolphins' offal picking by chub, *Kyphosus sectatrix* (Linnaeus), and doctorfish, *Acanthurus chirurgus* (Bloch), (Sazima *et al.*, 2003) lend support to our suggestion. Small groups of the barber goby, *Elacatinus figaro* (Sazima *et al.*, 1996), were also recorded by us picking off plankton about 50 cm above the bottom in Rio de Janeiro, Southeastern Brazil. This goby is a specialized, station-based cleaner that may feed over the substrate (Sazima *et al.*, 1996). There was a plankton bloom on the occasion, which further strengthens our suggestion about particulate-feeding by bottom-foraging fishes when plankton is abundant, even if it is an ephemeral resource (see also Sazima & Sazima, 2001).

Additionally, facultative planktivorous fishes are recorded to increase their ingestion of drifting particles when there is a bloom of highly nutritious particles in the water column (MacCormick, 2003; Pratchett *et al.,* 2001). There is evidence that supplementary food, especially coral propagules, increases growth, improves nutritional and physiological condition and increases reproductive success (McCormick, 2003; Pratchett *et al*., 2001).

Similarly, bottom-foraging fishes that occasionally feed on dolphins' offal may obtain a high amount of protein, since the dolphin offal is composed mainly of partially digested fish and squid and live roundworms (Silva-Jr *et al.*, 2004, 2005). This protein gain should be especially advantageous to herbivorous fish (Wilson, 2002; Wilson *et al.*, 2003), which usually consume food with low protein content (Choat, 1991). This may explain why the only bottom foragers recorded feeding on dolphin offal are herbivores (Sazima *et al*., 2003). Therefore, it seems that bottom foraging individuals may change their usual feeding behaviour to take advantage of rich and ephemeral food resources, such as lipid-rich coral propagules (McCormick, 2003; Pratchett *et al*., 2001), protein-rich dolphin offal (Sazima et al. 2003; Silva-Jr *et al.*, 2004, 2005) and energy-rich plankton (Norrbin & Bamstedt, 1984; this study).

The benefit of eating drifting particles by bottom foraging fishes may cause a "dilemma" in terms of predation: risk in the water column versus feeding on a nutritious food. This dilemma may be lessened by feeding on drifting particles only in "safe situations", such as when in groups and close to the bottom (Brock & Riffenburgh, 1960; Lukoschek & McCormick, 2001).

The picking of drifting particles by bottom foragers is probably restricted to particular circumstances that favour an abundance of such particles, such as mass spawning of reef invertebrates (McCormick, 2003; Pratchett *et al*., 2001), voiding of faeces and vomit by fishes and marine mammals (Arbuto-Oropeza, 2000; Sazima *et al.*, 2003), disturbance of soft substrates (Glasby & Kingsford, 1994), and occasional plankton blooms.

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Capítulo 3

The association of the goatfish *Mulloidichthys martinicus* with the grunt *Haemulon chrysargyreum*: an example of protective mimicry

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Abstract

A presumed example of protective mimicry between the yellow goatfish, *Mulloidichthys martinicus* (Mullidae) and the smallmouth grunt, *Haemulon chrysargyreum* (Haemulidae) is described from Fernando de Noronha Archipelago, NE Brazil. The goatfish and the grunt share a similar overall shape and colour pattern. We found that these two species regularly form mixed schools around reefs. Additionally, when chased small groups of yellow goatfish join schools of smallmouth grunts and behave like them. The colour and shape resemblances between the two species enable their mixed schooling, and enhance the protection against visually oriented predators for both of them. Thus, we suggest that the protective association herein reported for the goatfish and the grunt may be considered as a "social mimicry", since neither species is venomous, poisonous or strongly armed. Furthermore, we suggest that additional instances of social mimicry may involve the yellow goatfish and other striped *Haemulon* species.

Key words: Protective mimicry, social mimicry, mixed schooling, *Mulloidichthys martinicus*, *Haemulon chrysargyreum.*

Resumo

Descrevemos aqui um possível exemplo de mimetismo de proteção entre o saramunete *Mulloidichthys martinicus* (Mullidae) e a xira *Haemulon chrysargyreum* (Haemulidae), no Arquipélago de Fernando de Noronha, Nordeste do Brasil. O saramunete e a xira são semelhantes entre si, no padrão de coloração e no formato do corpo. Observamos que estas duas espécies formam cardumes mistos regularmente, ao redor de recifes. Quando perseguidos, pequenos grupos isolados de saramunetes se associam aos cardumes de xira e se comportam de modo semelhante às xiras. As semelhanças de formato e coloração entre as duas espécies provavelmente facilitam a formação de cardumes mistos e aumentam a proteção contra predadores visualmente orientados, para ambas as espécies. Assim, acreditamos que a associação protetora entre o saramunete e a xira pode ser considerada como um tipo de "mimetismo social", uma vez que nenhuma destas espécies é venenosa, peçonhenta ou tem fortes estruturas mecânicas de defesa. Sugerimos, ainda, que exemplos adicionais de mimetismo social possam envolver o saramunete e outras espécies listradas de *Haemulon*.

Palavras chave: Mimetismo de proteção, mimetismo social, cardumes mistos, *Mulloidichthys martinicus*, *Haemulon chrysargyreum.*

Introduction

Grunts (Haemulidae) are mostly nocturnal benthic feeders which during the day are found in size-variable, inactive schools around reefs primarily for protection from incoming open water predaceous fishes (Randall 1967, 1996). Grunts form a regular component of shallow water reef fish communities in the tropical Western Atlantic(Randall 1967, Ehrlich & Ehrlich 1972). The smallmouth grunt, *Haemulon chrysargyreum*, is a common reef species in the Western Atlantic (Humann & DeLoach 2002) but restricted to oceanic islands in Brazil (Rocha & Rosa 1999). It forages mostly at night and forms large inactive schools around shallow reefs during the day (Randall 1967). The yellow goatfish, *Mulloidichthys martinicus* (Mullidae), forages over sandy bottom both during day and night (Randall 1967, 1996; Munro 1976). The goatfish also forms inactive schools around reefs during the day, but generally with much fewer individuals than the grunt's schools (pers obs.).

Heterotypic schools of yellow goatfishes and grunts, mostly species of the genus *Haemulon*, are widespread in the tropical Western Atlantic (Ehrlich & Ehrlich 1972). The fishes within these mixed schools seem to gain protection against predators by increasing the numbers of individuals that are similar in shape and colour pattern and thus have the potential to confuse visually hunting fishes (Ehrlich & Ehrlich 1972). This mixed schooling is called social mimicry (Moynihan 1968, Randall & McCosker 1993), synergic inviting mimicry (Vane-Wright 1976), or school oriented mimicry (Dafni & Diamant 1984). In all cases the similarity between the fish species that compose the mixed school probably facilitates schooling and enhances the school cohesion. Although grunt-goatfish mixed schools are a common sight in the tropical Western Atlantic, there are no reports on the behaviour of these fishes during the group formation, and under which circumstances these mixed groups are formed.

At the Fernando de Noronha Archipelago, off NE Brazil, the yellow goatfish and the smallmouth grunt are regularly found in inactive mixed schools around the reefs. Herein we report on the behaviour of the schools formed by the smallmouth grunt and the yellow goatfish only, as well as mixed schools of both species. We suggest that the resemblance and the association between these two fish species is an example of protective social mimicry. Furthermore, we surmise that this form of protection may be widespread among goatfishes and similarly looking, schooling other fish species anywhere.

Materials and methods

The study was conducted at the Fernando de Noronha Archipelago (03°50' S; 32°25' W), 340km off north-eastern Brazil, in June and July 2002 and June 2003. We observed, video-recorded and photographed the behaviour of 10 schools of smallmouth grunt, 13 groups of yellow goatfish and 17 mixed schools of the two species, totalling 36 hours of scuba-diving. Additionally, to simulate a chasing predator, we threatened (by swimming straightforward towards the fishes) seven schools of about 10-50 yellow goatfish that were inactive and sheltered in the reef, and three groups of about 4-10 ones that were foraging on the sandy bottom in the open. We chased the groups to induce them to swim into open water and recorded the behaviour of each group. During the study the depth ranged 4-15 m and horizontal visibility ranged 10-30 m. Size of fishes is given as total length (TL) estimates.

Results

Mulloidichthys martinicus and *Haemulon chrysargyreum* have a similar resemblance in overall shape and colour pattern (Figure 1). At the study site the yellow goatfish formed

schools of about 4-50 individuals, and the grunt usually formed schools of about 40-1000 individuals. The monotypic inactive groups of yellow goatfishes were found sheltered under ledges or in crevices in the reef, or were foraging on the sandy bottom in the open. On the other hand, monotypic schools of the smallmouth grunt were always found inactive in the water column in the open. The yellow goatfishes while in the water column in the open were always mixed within the larger schools of inactive smallmouth grunts (Figure 1). Within the mixed school, the yellow goatfish hovered in a head-down, oblique posture similar to that displayed by the grunts within the school (Figure 2). The yellow goatfish and smallmouth grunts that we recorded mixed together were of similar size class (15-20 cm TL) and in only one small mixed school the yellow goatfish outnumbered (by about 10 individuals) the smallmouth grunt. Although the yellow goatfish appears to be a conspicuous fish when solitary or in small groups, its colour pattern renders it inconspicuous while schooling along with the smallmouth grunt (Figure 1). Experimentally chased groups of yellow goatfish immediately joined the schools of the smallmouth grunt when the former fish were induced to flee into open water (Figure 3).

Figure 1. The yellow goatfish (*Mulloidichthys martinicus*) is difficult to tell apart from the smallmouth grunt (*Haemulon chrysargyreum*) while in mixed schools and viewed under natural light.

Figure 2. The yellow goatfish adopts similar posture and behaviour while in a mixed school with the smallmouth grunt. Note overall resemblance in shape and pattern between the two species even under artificial light.

Figure 3. A previously inactive group of yellow goatfish (lower fish) joins a smallmouth grunt school when chased by a would be predator (in this case a diver).

Discussion

We regard the association of the yellow goatfish with the smallmouth grunt as an example of protective mimicry, so called social mimicry (Moynihan 1968, Randall & McCosker 1993), synergic inviting mimicry (Vane-Wright 1976), and school oriented mimicry (Dafni & Diamant 1984), since for all these categories a defensive function was indicated. Our assumption is based in the fact that these two species are similar in shape and colour pattern and that they form mixed schools. Additionally, when threatened, the yellow goatfish always joined the larger schools of smallmouth grunt and behaved like them. The case herein reported cannot be regarded as an example of Batesian or Müllerian mimicry (Vane-Wright 1976), since the two fish species are neither venomous nor poisonous, and do not appear to display any other feature which would deter or confound potential predators (Dafni & Diamant 1984, Randall 1996, Froese & Pauly 2004).

This mixed schooling behaviour may be considered as advantageous for both the smallmouth grunt and the yellow goatfish since their overall numbers increase while

mixing, and thus confuse visually hunting predators when targeting on its prey. However, as the goatfish is generally less abundant than the smallmouth grunt (pers obs.), the association much likely is more advantageous to the yellow goatfish than to the smallmouth grunt. Moreover, the goatfish forage on sandy bottoms away from reef shelters and thus they must rely on swimming off into open water as a form of defence against potential predators (Gosline 1984). Therefore, we regard the large smallmouth grunt schools as very important and predictable refuges for the yellow goatfish while fleeing in open water. We predict that the yellow goatfish would join schools of other striped grunt species along the Brazil's coast, *Haemulon squamipinna* in Northeast Brazil and *H. aurolineatum* anywhere on the coast being likely candidates for such mixed associations.

Since the genus *Haemulon* is restricted to the New World (both in the Atlantic and Pacific), whereas *Mulloidichthys* is widespread in warm seas (Allen & Robertson 1994), it would be of interest to check which additional genera and/or species these goatfishes associate with. For instance, the Indo-Pacific *Mulloidichthys mimicus* joins schools of the very similar lutjanid *Lutjanus kasmira* during the day (Allen et al. 2003, Froese & Pauly 2004). The yellow-striped goatfishes *M. flavolineatus* and *M. manicolensis* display a colour pattern similar to that of the schooling caesionids *Pterocaesio chrysozona* and *P. digramma* (Froese & Pauly 2004), also from the Indo-Pacific, and perhaps represent additional instances of social, protective mimicry.

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DISCUSSÃO GERAL

Pseudupeneus maculatus pode ser caracterizada como uma espécie mais versátil e generalista na escolha de substrato para forrageio que *M. martinicus*. Como outras espécies de *Pseudupeneus* e *Parupeneus* (Gosline, 1984; McCormick, 1995), *P. maculatus* parece ter potencial para forragear freqüentemente sobre áreas recifais tanto com cobertura de areia e algas, como também sobre cobertura de algas pardas. Ainda, a menor freqüência alimentar e o maior repertório de táticas alimentares de *P. maculatus* parecem estar relacionados à inclusão de presas relativamente grandes e móveis em sua dieta, o que reforçaria ainda mais a versatilidade desta espécie.

Pseudupeneus maculatus apresenta ampla variedade de táticas alimentares, sendo que algumas delas, como perseguição e tocaia, aparentemente não estão registradas para nenhuma outra espécie de Mullidae (q.v. Gosline, 1984; McCormick, 1995; Lukoschek & McCormick, 2001). Foram ainda observados grupos de juvenis e adultos de *P. maculatus* alimentando-se de plâncton, uma tática alimentar aparentemente rara e inesperada entre espécies de Mullidae (Sierra *et al.*, 1994, McCormick, 1995, Lukoschek & McCormick, 2001). A ampla distribuição e a grande abundância de *P. maculatus* em sua área de ocorrência (Carvalho-Filho, 1999; Froese & Pauly, 2005) podem estar relacionadas à versatilidade da espécie durante a alimentação e à sua capacidade de forragear sobre uma ampla variedade de substratos.

O presente estudo indicou diferenças na seleção de substrato para forrageio de *P. maculatus* quando comparado com estudos feitos no Caribe, onde a espécie parece forragear principalmente sobre substrato arenoso (Itzkowitz, 1977; Aronson & Sanderson, 1987; J.P. Krajewski & R.M. Bonaldo obs. pess.). Particularmente na Jamaica, *P. maculatus* parece alimentar-se exclusivamente sobre substrato arenoso (Itzkowitz, 1977). No Caribe, os recifes parecem estar constituídos por, basicamente, de uma parte sólida

composta principalmente de corais, e áreas de substrato arenoso ao redor (J.P. Krajewski & R.M. Bonaldo obs. pess.). Assim, o fato de *P. maculatus* aparentemente forragear somente em substrato arenoso no Caribe deve estar relacionado à ausência de outros substratos em que a espécie é capaz de forragear na região. Em recifes do Caribe onde há cobertura abundante de algas, ou algas e areia, é esperado que *P. maculatus* também forrageie nestes substratos e não fique restrito a áreas de substrato arenoso.

Mulloidichthys martinicus pode ser caracterizada como uma espécie menos versátil que *P. maculatus*, forrageando principalmente sobre substrato arenoso. As táticas alimentares apresentadas por *M. martinicus* são conhecidas para outras espécies de Mullidade e, apesar de terem sido classificadas como quatro táticas distintas, apresentam semelhança e derivam basicamente do comportamento de enterrar o focinho no substrato (Gosline, 1984; McCormick, 1995; Lukoschek & McCormick, 2001). Assim, *M. martinicus* parece ter impacto sobre a fauna associada a substrato arenoso, atingindo profundidades de até cerca de 5cm (McCormick, 1995; Lukoschek & McCormick, 2001). Como outras espécies do gênero, *M. martinicus* alimenta-se de presas relativamente pequenas e sedentárias (e.g. Randall, 1967; Gosline, 1984), apresentando maior freqüência de investidas no substrato que *P. maculatus*.

Mulídeos não apresentam defesas físicas e químicas contra predadores (Gosline, 1984; McCormick, 1995; Lukoschek & McCormick, 2001). Assim, acredita-se que o único modo dos mulídeos escaparem de predadores seja fugir nadando rapidamente na coluna d'água (McCormick, 1995; Lukoschek & McCormick, 2001). O comportamento alimentar de algumas espécies de Mullidae de evitar enterrar o focinho até a altura do olho em substrato arenoso e forragear em grupos parece estar relacionado a uma maior detecção e proteção contra predadores (Lukoschek & McCormick, 2001). No presente estudo, é relatado um possível caso de mimetismo de proteção entre *M. martinicus* e *H.*

chrysargyreum (Haemulidae). *Mulloidichthys martinicus* aproveita os grandes cardumes de *H chrysargyreum*, abundantes na área de estudo, para confundir e evitar predadores potenciais. Este tipo de defesa parece ser especialmente importante para *M. martinicus*, que forrageia em áreas abertas e apresenta atividade alimentar tanto diurna como noturna (Randall, 1967; Munro, 1976). Assim, o mimetismo de proteção é usado por indivíduos de *M. martinicus* que estão inativos durante o dia e se abrigam entre os cardumes de *H chrysargyreum* e por indivíduos que estão forrageando e, ao se sentirem ameaçados, buscam momentaneamente a proteção entre os cardumes.

Mulloidichthys martinicus e *P. maculatus* diferiram em todos os aspectos estudados de seu comportamento e atividade alimentar. Estes resultados, juntamente com resultados de estudos recentes sobre outras espécies de Mullidae (e.g. McCormick, 1995; Lukoschek & McCormick, 2001), indicam que mulídeos não são simplesmente fossadores generalistas de substrato não consolidado. Espécies de Mullidae podem forragear sobre uma grande variedade de substratos do recife, tendo impacto também na fauna associada a algas.

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