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Are Ehippid Fish a “Sleeping Functional Group”? – Herbivory Habits by Four Ehippidae Species Based on Stomach Contents Analysis

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1. Introduction

Ehippidae fish are commonly classified as being omnivorous, though tending to carnivore habits fishes (Burgess, 1978; Heemstra, 2001; Kuitert & Debelius, 2001). The group is broadly distributed in sub-tropical and tropical coastal regions, comprising eight genera and 16 species (Nelson, 2006), where the larger genera are *Platax*, with five species described all from the Indo-Pacific (Kishimoto et al., 1988; Nakabo, 2002), and *Chaetodipterus*, with three species: one occurring in the eastern Pacific; and two reported from the Atlantic Ocean (Burgess, 1978).

The literature concerning feeding habits and feeding behavior of ehippid fish is still very scarce. Recent studies, however, show that the trophic classification of the group is controversial. Depending on the ontogenetic stage, and on specific environmental conditions, juvenile *Platax orbicularis*, were observed to switch from mainly herbivorous habits, during daylight, to carnivorous habits at night (Barros et al., 2008; 2011). Other studies based solely on stomach contents have identified mostly plant material in the stomachs of individuals at the same growth stage (Nanjo et al., 2008). Zooplankton consisted in the main food item identified in stomachs belonging to juveniles of another *Platax* species, *P. boersii* (Nanake et al., 2011). The latter is generally classified as carnivores, feeding mainly on benthic prey. All five *Platax* species are known from the Indo-Pacific, yet recent studies have reported sporadic occurrences in the Mediterranean Sea, indicating the group invasive potential (Bilecenoglu & Kaya, 2006; Golani et al., 2011).

Misleading information regarding diet and feeding habits of *Chaetodipterus* species are also reported in the available literature. While *C. faber* sampled from the coast of South Caroline, in

the US, were observed to feed mainly on hydroids (Hayse, 1990), those from north-eastern Brazil showed preference for a more herbivorous, algae-rich diet (Bittencourt, 1980; Couto & Vacancelos Filho, 1980), yet none of these reports exclude other food sources in their results.

Moreover, Bellwood et al. (2006) have suggested ephippid fish as belonging to a “sleeping functional group”, where individual fish have the potential to explore algae-rich substrates for food, such as phase-shifted corals, helping with the recovering process of the latter environments, via removing the thick algae layer from whitened corals, as the observed in a few adult individuals of *P. pinnatus* at the Great Reef Barrier, Australia. The authors have suggested the entire Family Ephippidae might play such a role in damaged coral reef environments, including the genus *Chaetodipterus* in Atlantic coastal waters.

The present review aims to verify if ephippid fish should be classified as a potential functional group, examining both the available literature on Ephippid fish, as well as original data on the stomach contents of juveniles and adults of five ephippid species from four locations in Japanese and Brazilian coastal waters. Feeding plasticity, feeding behavior and the Group potential on playing a functional role on these coastal environments are discussed.

2. Feeding plasticity and trophic classification of Ephippid fish

Despite being a relatively small group, information on feeding habits, feeding behavior and diet of the Ephippidae is quite limited, being available mostly from technical reports based on trawl samples or bycatch material. As both methods are often limited in sample number, the resulting literature is then sparse and confusing: While there is plenty of information on trophic habits of the two main genera, *Platax* and *Chaetodipterus*, there are a number of incongruences on such reports. Furthermore, detailed information regarding the remaining genera is rare, virtually absent in the literature. In Table 1 we summarize the state of the art concerning the available knowledge on the trophic classification of the Ephippidae.

Establishing a general classification for an entire fish group is always controversial, as feeding habits may rely on several biological aspects of a given species, as ontogenetic stage, habitat conditions during settlement, etc., according to both morphological and environmental constraints for particular sizes (Gerking, 1994; Diana, 1995; Russo et al., 2008). Even for the closely related group Acanthuridae (Holcroft & Wiley, 2008), sister-group of the Ephippidae, and generally known as an herbivore group, a few species have a mixed diet, based on both zooplankton and algae (Choat et al., 2004).

According to the literature, a general classification for the trophic habits of ephippid fish is a difficult, almost impossible task. This is especially due to the contrasting information on some taxa, indicating a very plastic diet, which may include both animal and plant-based food sources, as well as different behavioral strategies, even in supposedly specialized species, such as those of the genus *Platax* (Bellwood et al., 2006; Barros et al., 2008, 2011). Detritivorous habits by *P. boersii* and *R. pentanemus* are also strong evidences

supporting feeding plasticity: late juveniles and adults of *P. boersii* are commonly observed to chase the green turtle *Chelonia mydas* to feed on their algae-rich faeces, (B. Barros, per. obs.); and *R. pentanemus* were reported to feed on sewage material (Robins et al., 1991).

Taxon	Occurrence	Trophic classification	References
<i>Chaetodipterus faber</i>		Omnivore*	Bittencourt (1980) Couto & Vasconcelos Filho (1980) Hayse (1990)
<i>Chaetodipterus lippei</i>	Eastern Atlantic	-	-
<i>Chaetodipterus zonatus</i>	Eastern Pacific	Carnivore	Schneider (1995) de La Cruz Agüero et al. (1997)
<i>Ehippus goreensis</i>	Eastern Atlantic	Carnivore	Allen (1981) Desoutter (1990)
<i>Ehippus orbis</i>	Indo-West Pacific	Carnivore	Masuda et al. (1984) Maugé (1984) Kuronuma & Abe (1988) Lieske & Myers (1994)
<i>Paraseptus panamensis</i>	Eastern Pacific	-	-
<i>Platax batavianus</i>	Indo-West Pacific	-	-
<i>Platax boersii</i>	Indo-West Pacific	Omnivore**	Kuiter & Debelius (2001)
<i>Platax orbicularis</i>	Indo-West Pacific	Omnivore*	Myers (1991) Kuiter & Debelius (2001) Barros et al. (2008, 2011)
<i>Platax pinnatus</i>	Indo-West Pacific	Carnivore*	Kuiter & Debelius (2001) Bellwood et al. (2006)
<i>Platax teira</i>	Indo-West Pacific	Carnivore	Myers (1991)
<i>Proteracanthus sarissophorus</i>	Western-Central Pacific	-	-
<i>Rhinoprenes pentanemus</i>	Western-Central Pacific	Herbivore**	Robins et al. (1991)
<i>Tripteronodon orbis</i>	Western Indian	Carnivore	Fischer et al. (1990)
<i>Zabidius novemaculeatus</i>	Indo-Pacific	-	-

Table 1. List of all 15 Ehippididae species (following Nelson, 2006), with their respective trophic classification, according to the available literature. Single asterisks indicate dubious literature regarding trophic habits, suggesting both herbivorous and carnivorous habits by these species. Double asterisks indicate detritivorous habits as well. Hyphens indicate no available data on diet or feeding habits.

Morphological attributes of the cranial anatomy of *Platax* and *Chaetodipterus*, are similar to those of Family Scaridae, with very specialized swelling of ethmoid, frontals and supraoccipital bones, shortening of the lower jaw, and short dentary and articular bones, which provide great biting power (Gregory, 1933). Browsing activities over algae turfs by juvenile *P. orbicularis* were also observed to feed on algae similar to the feeding manner of the Scaridae (Barros et al., 2008).

3. Stomach contents and herbivorous habits by Ehippidae species

In this section, original data on four Ehippidae species are compared with information from the literature, to clarify the importance of herbivory for the species studied. Point surveys were held in Japanese and Brazilian waters, in order to compare diet and feeding habits of the Ehippidae occurring in the Pacific and Atlantic. Sampling was due to mid-summer 2005 to early winter 2006, in Japan, and from early summer 2008 to mid-winter 2010 in Brazil.

3.1. Sampling sites

Field sampling activities were held in the reefs off the Okinawa Archipelago, Japan (JPN); and in four sites along the Western Atlantic, all in the Brazilian coast (BR) (Fig. 1). Methods for capturing fish samples varied according to the surveyed location, using nets, spearfishing, line and hook, and direct acquisition from employed fishermen or from local markets. In Brazil, most sampling sites consisted in estuarine environments (Curuçá, Bragança and some samples from Caravelas). The Table 2 summarizes sampling activities in each of the surveyed locations, detailing respective methodologies as employed.

Sampling site	Taxon	SL range (cm)	N	Methods
Okinawa (JPN)	<i>P. boersii</i>	8.54 ± 1.07	17	Employed fishermen, using several net types and hook-and-line; local fish market for all samples from Japanese waters
	<i>P. pinnatus</i>	18.33 ± 2.92	3	
	<i>P. teira</i>	17.20 ± 2.42	3	
Curuçá (BR)	<i>C. faber</i>	18.61 ± 1.14	33	Cast nets; gill nets, hook-and-line
Bragança (BR)	<i>C. faber</i>	15.42 ± 0.91	56	Local fish market
Natal (BR)	<i>C. faber</i>	9.03 ± 1.73	4	Hook-and-line
Caravelas (BR)	<i>C. faber</i>	11.86 ± 1.02	42	Gill nets; spearfishing; hook-and-line
TOTAL	-	-	158	-

Table 2. The four analyzed Ehippidae species, with regards to the methods as employed due to each sampling site. Standard size (SL) is provided as average values ± standard deviation. Wherever spearfishing was employed, samples were primarily targeted in the head, in order to cause the less damage to the stomach contents as possible.

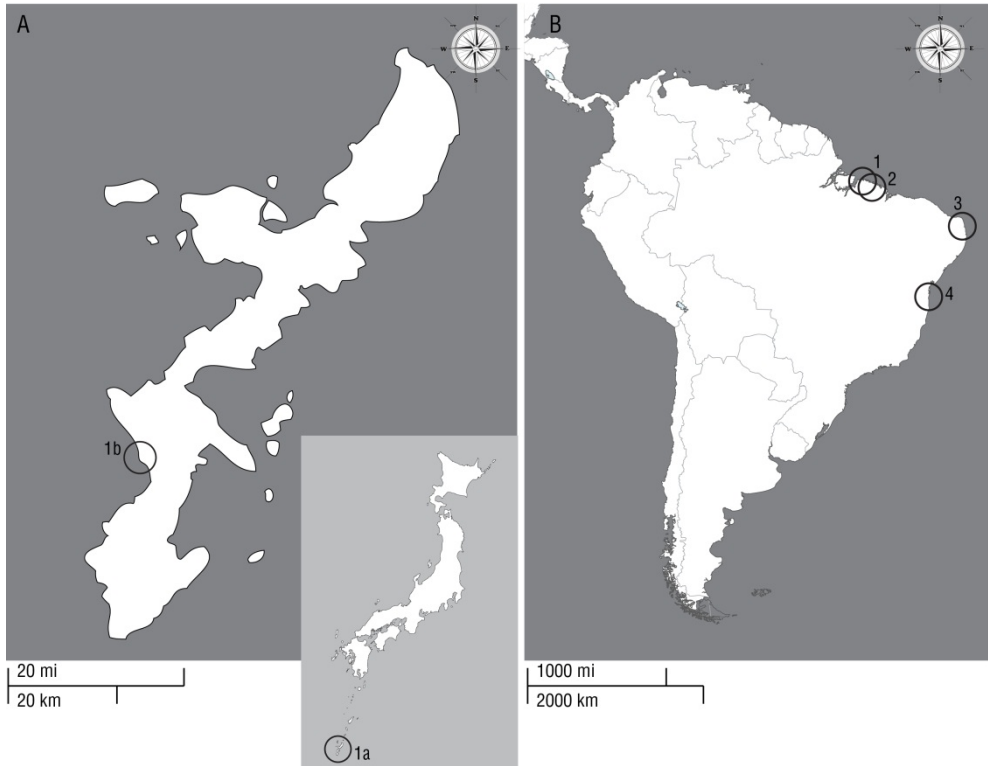


Figure 1. Sampling sites for the present study, where in (A) is the city of Chatan, Okinawa, Japan (1a-b); and (B) are sites as sampled in Brazil, in the cities of (1) Curuçá, (2) Bragança, (3) Natal and (4) Caravelas, in the states of Pará (1-2), Rio Grande do Norte (3) and Bahia (4), respectively.

3.2. Stomach contents analysis

Samples were placed in ice soon after capture, and stocked frozen until analysis, when we proceeded with dissection of stomachs, by cutting above the cardiac sphincter (esophagus) and below the pyloric sphincter (large intestine). An incision was made along the longitudinal axis, with contents removed with pincers, followed by rinsing the inner cavity with 70% ethanol. After rinsing and sorting, contents were identified to the lowest possible taxon. We proceeded with the analysis, using the protocol as adapted from Lima-Junior & Goitein (2001), which consists basically in calculating an index for Absolute Importance (AI) for each food item (*i*) present in a given sample.

The absolute importance index AI_i was calculated for each food item by multiplying the frequency of occurrence Fi (%) by the volumetric analysis index Vi observed in the fish diet. Fi (%) was obtained by the formula

$$F_i (\%) = 100n_i/n$$

where n_i was the number of stomachs filled with food item i , and n the total number of stomachs sampled. V_i was given by the standard weight of all samples. For each food item i , points were ascribed using integers according to the degree of fullness and degree of importance of food item i , following the formula

$$M_i = \sum i/n$$

where M_i is the mean of ascribed points for i . After assessing M_i values, V_i can be calculated as

$$V_i = 25M_i$$

where 25 is a constant of multiplication.

The results were compared with those available in the literature, to any of the surveyed species, plus relevant data on herbivory activities by any Ehippidae. Information on diet and feeding habits by juvenile *P. orbicularis* was also included, due to the particularity of switching feeding behaviors from herbivory to carnivory within a day (Barros et al., 2008), yet adult fish were neither observed nor sampled during our survey in Japan.

Our results for both *Platax* and *Chaetodipterus* are summarized in Table 3. The main food item found in the stomach contents of all 23 *Platax* individuals was green algae, found in > 90% of the stomachs, with extremely high AI values, contrast to what is generally expected, as all targeted species are supposed to feed mainly on animal prey (Hayse 1990, Kuitert and Debelius 2001, Randall 2005a). Instead, animal prey consisted only in a minor food items, all with lower AI values. Similarly, *C. faber* presented green algae was the most frequently observed food item; in the three sampling sites surveyed (average AI = 2741.87 ± 83.92), yet AI levels were slightly lower than those observed for *Platax* fish; and animal food was observed more often, with substantive AI values, considering all-pooled data. However, underwater *in situ* observations using SCUBA at Caravelas suggest consumption of green algae by *C. faber* as being an incidental first step when reaching for benthic prey sheltered in the algae cover (Barros et al., in preparation). Furthermore, benthonic prey, mainly unidentified gastropod shell fragments, were observed for both genera in considerable minor frequencies rather than other food items.

The greatest evidence for feeding on benthic animal prey were shell fragments, polychaetes and bryozoa, frequently observed in the stomach contents of all four species. Sand fragments as found in stomachs of both Brazilian and Japanese samples would also indicate feeding on a benthic environment, but it is not necessarily an excluding factor, as sand grains occasionally occur on weeds from shallow or turbulent environments.

Our data contrast with the most as available in the literature regarding trophic classification of the Ehippidae. While most of the literature dealing with *Platax* species classifies all five species as carnivores (Table 1), the diet of all three *Platax* species studied

in Japan is mostly algae (Table 3). Juvenile *P. orbicularis* were also observed feeding predominantly on algae turfs from hard substrates in high frequencies during the daylight, and were mostly zooplanktivores at night (Barros et al., 2008). Regardless, all available literature on *Platax* fishes refers to carnivorous habits combined with other food sources (Table 1). The Atlantic spadefish *C. faber* is referred as mainly carnivore by Hayse (1990), yet previous studies show different dietary patterns, relying on herbivory (Bittencourt, 1980; Couto & Vasconcelos Filho, 1980). Our results present a more plastic diet for this particular species, making it difficult to predict which food source is predominant for its trophic classification.

4. Functional role vs. feeding plasticity in Ehippidae

4.1. Effects of herbivore functional groups on habitat

Herbivory by fishes is a wide-ranging subject, and aspects of behavioral ecology and diet have been addressed since early records (Hiatt & Stratsburg, 1960; Jones, 1968; Borowitzka, 1981; Lewis, 1985), whereas functional ecology has been approached more recently (Bellwood et al., 2002; Bonaldo et al., 2011; Kopp et al., 2012). Efforts concerning herbivory by fishes have been made available in the literature, especially those regarding herbivory in recovery from damage (Bellwood et al., 2004; Ctanovic & Bellwood, 2009; Green & Bellwood, 2009). Intense herbivory activity reduces competition for space between corals and algae, herbivorous fish are widely recognized as a critical functional group on coral reefs. Herbivore fish families such as Acanthuridae and Scaridae are most prominent in this functional group, due to their broad distribution over tropical regions and their dense populations in such habitats (Francini-Filho et al., 2010), although many other fish groups dwelling coral reef environments may play a similar role (Ctanovic & Bellwood, 2009).

4.2. Herbivory by Ehippidae

General biology of ehippid fish is still a matter of controversy. Juveniles of the most species are cryptic, usually mimetic, dwelling coastal environments, and generally solitary, whereas adults usually form huge shoals, migrating over long distances, in up to 30m deep environments (Kuitert & Debelius, 2001; Nakabo, 2002). While there are a few reports focusing on juvenile mimic biology (Breder, 1942; Randall, 2005b; Barros et al., 2008; 2011), studies concerning adult biology, especially behavioral ecology, are rare. Why do adult fish form such shoals is therefore unknown, yet some authors suggest migratory shoaling as for reproductive reasons (Kuitert & Debelius, 2001). In coastal environments, such as coral reefs and estuaries, late juveniles and adults of the genera *Platax* and *Chaetodipterus* are usually observed solitary, in pairs or small aggregates (B. Barros, personal observation; Bellwood et al., 2006; Ctanovic & Bellwood, 2009), while mimic juveniles are usually observed solitary (Barros et al., 2008).

Species	Sampling Site (N)	Main food items observed	Fi (%)	Vi	AIi
<i>P. boersii</i>	OKN (17)	Algae	94.17	35.60	3352.86
		Copepoda	23.66	51.79	1225.47
		Mysida	15.92	44.86	714.28
		Teleostei	6.11	18.83	115.06
		Sand fragments	48.79	41.35	2017.51
<i>P. pinnatus</i>	OKN (3)	Und.	38.26	10.93	418.09
		Algae	92.25	42.32	3904.14
		Pine seed	33.33	55.66	1855.06
		Copepoda	18.92	29.84	564.67
		Gastropoda (shell fragments)	23.42	5.18	121.45
<i>P. teira</i>	OKN (3)	Sand fragments	73.04	12.93	944.78
		Algae	90.81	54.53	4952.14
		Sand fragments	75.00	13.63	1022.03
<i>C. faber</i>	CUR (33)	Und.	11.41	22.43	255.94
		Algae	56.95	43.93	2501.81
		Porifera	21.73	6.52	141.67
		Bryozoa	13.04	3.26	42.53
		Polychaeta	13.04	29.56	386.56
		Annelida	13.04	3.26	141.67
		Bivalvia	17.39	4.34	75.47
		Teleostei	13.04	7.60	99.24
		Sand fragments	56.52	34.62	1956.72
		Und.	35.28	14.55	513.32
<i>C. faber</i>	BRA (56)	Algae	60.23	52.50	3162.07
		Hydrozoa	6.03	10.75	64.82
		Bryozoa	18.00	30.50	549
		Oligochaeta	2.13	0.50	1.065
		Polychaeta	44.20	22.50	994.50
		Bivalvia	2.00	0.75	1.50
		Crustacea	20.05	15.00	300.75
		Teleostei	58.12	12.15	706.52
		Und.	43.94	66.14	2906.19
		Algae	53.92	31.55	1701.18
<i>C. faber</i>	NAT (4)	Porifera	38.60	17.91	691.32
		Polychaeta	45.73	39.55	1808.62
		Und.	67.03	35.12	2354.09
<i>C. faber</i>	CAR (42)	Algae	93.11	38.69	3602.42
		Polychaeta	77.68	18.04	1401.41
		Crustacea	47.85	22.34	1069.16
		Copepoda	32.23	29.81	960.79
		Isopoda	32.30	20.68	667.94
		Teleostei	7.38	17.17	126.72
		Sand fragments	73.15	24.56	1796.67
Und.	84.25	35.87	3022.04		

Table 3. Stomach contents as observed in the four locations analysed, where *Fi* means "Frequency of occurrence"; *Vi* means "Volumetric Index"; *AIi* means "Absolute Importance Index"; Und. means "undetermined"

Gerking (1994) has stated that no adult herbivorous fish are obligate plant eaters, selectively excluding all animal food from the diet, as larval herbivorous fish are often recorded to feed on algae plankton for an initial short period, then switching into zooplanktivory. After having developed all morphological and physiological characters, fish do shift back into herbivorous habits. However, for those groups usually classified as herbivorous, animal food items in the gut contents are considered rare, and often referred as incidentally ingested while fish are grazing. Despite our present results suggest herbivory as a major foraging tactic for all analyzed species, considering all-pooled data, animal protein input is still as important as algae ingestion, especially for *C. faber* sampled in the Brazilian coast. Although potentially eligible as a "sleeping functional group", the combination of herbivory and recovery of phase-shifted corals may be independent phenomena, as observed by Bellwood et al. (2006), when three adult *P. pinnatus* were observed foraging on a substantial layer of *Sargassum* algae from whitened coral reef in a considerably short time, when major herbivory activity by other fish groups was expected.

Although no field observations of feeding were made in Japan, our results for *Platax* from the Okinawan archipelago might be subjected to a similar phenomenon as that observed for *P. pinnatus* in the great reef barrier, considering the actual status of the reefs in the Okinawa archipelago, which at least two mass bleaching events were registered for the last ten years due to the global seawater warming, and several coral reefs colonies have been reported to experience phase shift (Loya et al., 2001, Nadaoka et al., 2001, Suefuji & van Woesik 2001, Bena et al., 2004). Algal ingestion by *C. faber* as observed in Brazil, however, might solely indicate feeding plasticity in both diet and behavior. Moreover, feeding plasticity in ehippid fishes may also be a strategy developed during early growth stages, as reported for juvenile *P. orbicularis* (Barros et al., 2008; 2011) The invasive potential of some species may indicate that the group is highly adaptable to novel food sources (Bilecenoglu & Kaya, 2006; Golani et al., 2011). In such cases, a plastic diet combined with plastic feeding behavior would favor the group while migrating to new areas.

5. Conclusions

Even for a limited number of individuals for both genera, our results suggest herbivory as the main feeding habits of ehippid fish, conflicting with the reports of a more carnivorous diet. Unless batfishes and spadefishes have been misclassified as carnivores, our data seems to be exceptional. Our results as presented here, supported by morphological data (Gregory, 1933) and behavioral data on both *Platax* (Barros et al., 2008) and *Chaetodipterus* (Barros et al., in preparation) indicate strong evidence of diverse dietary patterns, where plant material plays a major role.

Despite adult *C. faber* having a more plastic diet, herbivore habits definitely figure among the main strategies as used by that species, even if incidentally while reaching for benthic prey (Barros et al., in preparation). Adult batfishes of genus *Platax*, however, presented a consistent pattern where herbivory figures undoubtedly among the main energy input, with AI values three times as higher as all other food categories observed. Even so, *Platax* species

are often observed solitary, in pairs, or small groups in shallow coral reef environments (Ctanovic & Bellwood, 2009; B. Barros, per. obs.). A bigger population would be expected for larger impacted areas, with phase-shifted corals. Conversely, *Chaetodipterus* are more common in estuarine environments (Heemstra, 2001), being particularly rare in the adjacent coral reefs of the surveyed area in the Brazilian coast (B. Barros, per. obs.).

To corroborate the predictions of Bellwood et al. (2006), we strongly recommend further *in situ* investigations focusing on foraging activities of both *Platax* and *Chaetodipterus* in reefs in the Pacific and Atlantic, as any other Family potentially eligible as functional groups occasionally dwelling both areas.

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