

## Difference in the trophic structure of fish communities between artificial and natural habitats in a tropical estuary

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**Abstract.** The present study tested the hypothesis that artificial habitats (pier and bridge) harbour different fish trophic guilds compared with natural habitats (mangrove roots) and that the trophic structure of fish communities on estuarine artificial habitats resembles adjacent coral reefs. High-definition cameras were used to survey the fish community associated with the different structures over a 6-month period. Benthos was also analysed following the point intercept method on the different habitats. In the estuary, fish abundance was up to threefold higher and species richness twofold higher on artificial structures compared with the natural habitat. Mangrove roots were mainly inhabited by juvenile carnivores, whereas the pier and bridge were mostly inhabited by sessile invertebrate feeders and roving herbivores. A less diverse benthic community was found on mangrove roots, mostly composed of mud and algae. In contrast, benthos at the bridge and pier was more diverse and dominated by sponges, octocorals and oysters. In addition, fish trophic structure from an adjacent coral reef area showed more than 60% similarity with the fish community on the artificial structures surveyed. The results of the present study indicate that artificial hard structures support unique fish communities compared with natural estuarine mangrove habitats.

**Additional keywords:** benthic composition, coral reefs, fish distribution, habitat use, man-made structures.

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### Introduction

Coastal ecosystems, such as coral reefs, seagrass meadows, macroalgae beds and estuaries, are vital for fish communities (Nagelkerken 2000; Syms and Jones 2000; Beck *et al.* 2001; Pereira *et al.* 2010; Chaves *et al.* 2013). In particular, estuaries are one of the most productive coastal habitats, supporting a high abundance of fish that use them for breeding, feeding and as nurseries (Beck *et al.* 2001; Laegdsgaard and Johnson 2001; Able 2005). As important habitats for juvenile fish, estuaries have vital connectivity links with coral reefs and strongly influence fish communities on neighbouring coral reefs (Beck *et al.* 2001; Mumby *et al.* 2004).

The distribution of estuarine fauna (e.g. fish and crustaceans) is associated with a series of abiotic factors, such as salinity, temperature, water turbidity and dissolved oxygen (Cyrus and Blaber 1992; Thiel *et al.* 1995; Feyrer *et al.* 2011). Biotic factors, such as benthic composition, surrounding vegetation and associated fauna, are also important variables influencing fish

abundance and species richness on tropical estuaries (Bottom and Jones 1990; Thiel *et al.* 1995; França *et al.* 2012). However, despite extensive research correlating abiotic and biotic factors with fish distribution in estuaries (Blaber and Blaber 1980; Schaffler *et al.* 2013; Vilar *et al.* 2013), little is known about the effects of artificial structures (e.g. piers and bridges) on fish distribution and the ecological consequences within estuaries (Clynick 2008; Folpp *et al.* 2013). It is unclear whether differences in diversity and community structure exist between natural and artificial structures in estuaries, as well as between different artificial structures (Folpp *et al.* 2013). If artificial structures attract species in estuaries, then their presence can modify the natural community structure. In this context, different patterns of fish trophic structure have already been observed between artificial habitats (e.g. shipwrecks and concrete blocks) and natural tropical and temperate reefs (Arena *et al.* 2007; Honório *et al.* 2010; Fowler and Booth 2013; Simon *et al.* 2013); however, this trend has not yet been investigated in-depth for estuaries.

Since the last century, estuarine systems have become strongly urbanised and the construction of artificial structures such as piers and bridges has increased considerably (Bohnsack 1989). However, the effects of these artificial habitats on the estuarine fish community and adjacent coral reef areas are unknown. According to Emery *et al.* (2006), an oil platform in California has affected the recruitment of a carnivore fish on associated natural ecosystems, with possible long-term consequences on natural communities. An increase in unplanned estuarine artificial habitats may even alter ecosystem function and reduce the resilience of adjacent reef communities (Hughes 1994; Bellwood *et al.* 2004). Therefore, following a recent significant increase in the use of artificial structures in estuaries, it is critical to understand whether artificial structures are playing a different ecological role compared with natural habitats, as well as the effect of these artificial habitats on nearby coral reefs. For example, if the trophic and community structure of fish on estuarine artificial habitats resembles adjacent coral reefs because of migrating roving herbivores (e.g. parrotfish), then this vital ecological function could be reduced on coral reefs and coral–algal phase shifts could be established (Harborne *et al.* 2015). Herbivore fish are fundamental species on coral reefs that help control algae phase shifts, and even a small variation in their abundance and diversity can affect the resilience of tropical reefs (Hughes 1994; Roff and Mumby 2012; Nash *et al.* 2016).

Research conducted on estuaries normally involves the direct collection and subsequent analyses of fish specimens (Dahlberg and Odum 1970; de Moura *et al.* 2012). Based on the nursery hypothesis (Beck *et al.* 2001; Sheaves *et al.* 2015), estuaries contribute substantially to the establishment of the adult population of several marine species because of higher numbers of juveniles; consequently, extensive collection using drag nets could be potentially damaging for post-settled juvenile fish. The use of remote cameras analysing fish communities has grown extensively because of easier logistic use, reduced observer bias and the possibility to check images as many times as necessary by different observers (Willis and Babcock 2000; Willis *et al.* 2000). Therefore, remote cameras have been used efficiently to access fish communities on coral reefs (Dunlap and Pawlik 1996; Bellwood and Fulton 2008; Burkepile and Hay 2011; Longo and Floeter 2012) and temperate areas (Watson *et al.* 2005, 2010), although they have rarely been used in estuarine studies because of poor visibility conditions.

The aim of the present study was to analyse differences in fish trophic structure between natural (mangrove roots) and artificial (pier and bridge) habitats in a tropical estuary, using remote cameras. A previous pilot study (P. H. C. Pereira, pers. obs.) in the area indicated that a large number of juvenile carnivores (e.g. *Lutjanus* spp.) were associated with mangrove roots, whereas sessile invertebrates feeders (*Pomacanthus* spp.) and roving herbivores (*Acanthurus* spp. and *Sparisoma* spp.) were more often recorded around the artificial structures. Consequently, in the present study we tested the hypothesis that fish trophic guilds could be distinctly associated with natural and artificial structures in a tropical estuary. The benthic community and substratum composition were also analysed in

the different structures to correlate data with fish community. We predicted that estuarine sites with more complex benthic cover (e.g. octocorals and sponges) could present higher fish abundance and species richness. In addition, an adjacent coral reef area located near the estuary, ~2.3 km east of the estuary entrance, was analysed. The trophic composition of the fish community from this adjacent coral reef area was compared with the natural and artificial estuarine structures to better understand similarities among fish communities from the estuary and coral reefs.

## Materials and methods

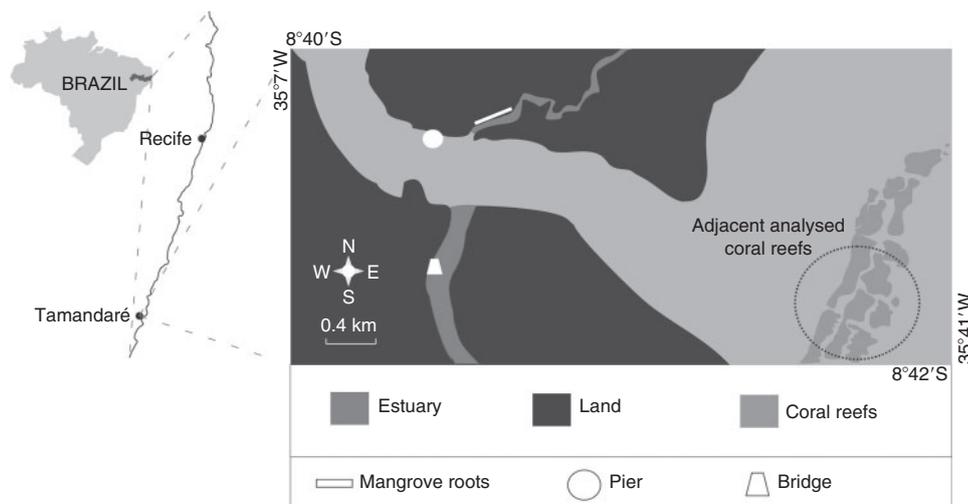
### Study area

The study was conducted in the estuary of Rio Formoso (8°39'45"S and 35°06'15"W), located 92 km south of Recife, capital of Pernambuco state, north-east Brazil. This estuary is formed by the confluence of the Formoso, Ariquindá and Passos rivers. Natural structures (mangrove roots) and two artificial structures (pier and bridge) were chosen as sampling sites (Fig. 1). The pier and bridge represent the unique artificial structures within this estuary. The sampling sites were located in the mid-estuary region, all of which is part of the Guadalupe Marine Protected Area (de Paiva *et al.* 2009).

Mangrove sites are located on the Formoso River where the associated mangrove vegetation is composed of *Rhizophora mangle*, *Laguncularia racemosa*, *Avicennia shaueriana* and *Conocarpus erectus*, with 60% of the vegetation community relative abundance made up of *R. mangle* (de Paiva *et al.* 2009). The average depth of the mangrove area is 2.0 m in the central region and 0.5 m at the margins. The natural substratum is composed primarily of *R. mangle* roots covered by barnacles and oysters, mainly *Crassostrea rhizophorae*, surrounded by muddy sediment. Data sampling was randomly performed in a 400-m lateral stretch of mangrove, never repeating sampling at the same site.

The artificial structures were also located on the Formoso River. The pier is the biggest in Pernambuco state and receives an average number of 600 visitors per day, being used mostly by tourists and local fisherman. It is 300 m long and is made up of numerous square wood pillars (~30 × 30 cm), reaching an average depth of 2.5 m and surrounded by a sandy–muddy sediment. The benthic community on the pier's supporting pillars is composed primarily of octocorals, sponges and small amounts of algae. The bridge is 220 m long and is supported by eight 2-m diameter concrete columns (four next to each river margin), reaching an average depth of 3.0 m. The columns and adjacent substratum are covered with oysters, barnacles, octocorals, sponges and leftover wood from the construction.

An adjacent coral reef area located ~2.3 km east of the estuary entrance was also analysed to compare the trophic structure of the fish community on natural coral reefs with the natural and artificial structures in the estuary. The reef area is characterised as having shallow reefs (depth range of 5 m). It is covered by macroalgae species, hermatypic corals (*Favia gravida*, *Montastrea cavernosa*, *Mussismilia* spp. and *Porites astreoides*) and hydrocoral colonies of *M. alcicornis* and *M. braziliensis* (Ferreira *et al.* 2004; Pereira *et al.* 2014).



**Fig. 1.** Map of the study site highlighting the different sampling structures (artificial, pier and bridge; natural, mangrove roots), as well as the adjacent coral reef.

## Data collection

### Fish community

Sampling was conducted in the estuary twice a month between November 2013 and May 2014 (between 0600 and 0900 hours). GoPro Hero 2 HD cameras (120 frames  $s^{-1}$ ), mounted separately on tripods, were used for sampling. Although video cameras have rarely been used to survey fish communities in estuaries because of poor water visibility, remote cameras were selected as the sampling technique in the present study once the visibility of this estuary was confirmed to be good and estimated to be  $\sim 2.5$  m during the sampling months (P. H. C. Pereira, pers. obs.; also see the Supplementary material to this paper). Fourteen samples were collected at each natural and artificial habitat, always sampling in different areas and never repeating sampling at the same site (sampling sites were located at least 50 m apart). Thus, 42 video samples, of 15 min duration each, were collected in the estuary. All video recordings started 5 min after camera deployment to avoid effects from the diver and placement of the camera. Remote video footage was analysed using Windows Media Player version 8.1 (Microsoft, Bellevue, WA, USA). The concept of maximum number of individuals of each species (MaxN; i.e. the maximum number of individuals of a species observed in a single frame) was applied during video sample analysis. The use of MaxN has been proven to be a reliable and robust method for monitoring relative fish abundance in a variety of inshore marine environments (Willis *et al.* 2003; Stobart *et al.* 2007; Folpp *et al.* 2013). Detailed reviews of the use of MaxN as an estimator of relative abundance and its effectiveness have been reported previously (Cappo *et al.* 2006).

Previous studies have shown that estuarine habitats, such as mangroves and seagrass meadows, are critical for the life cycle of some reef fish species (Mumby *et al.* 2004). Therefore, we expected to record coral reef fish species associated with the estuarine habitats studied in their juvenile phase. These reef fish are normally only found in the estuarine natural habitats during the juvenile life phase, and adult populations are not established

in estuaries. Similar to methods used in the estuary, fish community data from an adjacent coral reef was obtained twice a month between December 2013 and May 2014 using two GoPro Hero 2 HD cameras. In all, 14 video samples were obtained during low tide on the adjacent coral reef to compare the trophic structure of fish communities between coral reefs and natural (mangrove roots) and artificial (pier and bridge) estuarine habitats.

To test for differences in fish trophic composition between natural or artificial structures and adjacent coral reefs, fish species were grouped into eight major trophic categories adapted from Ferreira *et al.* (2004). The following categories are based on the main diet of the species: territorial herbivores (TERH); roving herbivores (ROVH); mobile invertebrate feeders (MIF); sessile invertebrate feeders (SIF); carnivores (CAR); piscivores (PIS); planktivores (PLK) and omnivores (OMN; see Table 1). Inclusion of species in these categories was based on the available information from the literature (e.g. Randall 1967; Ferreira *et al.* 2004). In order to improve discussion quality regarding ontogenetic changes in habitat use, fish were also categorized according to life phase as juveniles and adults based on size and patterns of colouration (Humann and Deloach 2002). In addition, cryptobenthic species, such as Blenniidae and Gobiidae, were excluded from the analyses given the difficulties in sampling and identifying those cryptic species with cameras.

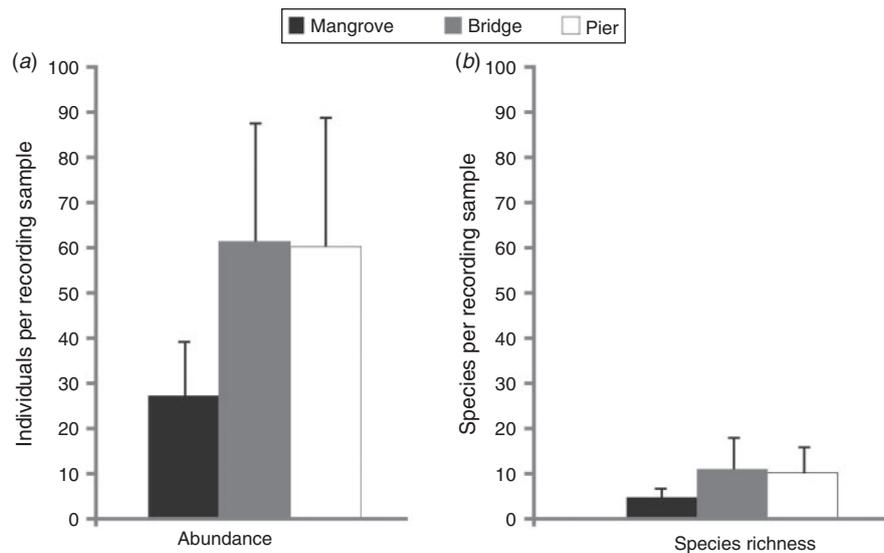
### Benthic community and substratum composition on natural and artificial structures

The benthic community and substratum composition of the natural and artificial structures were analysed during low tide using the point intercept transect method. This method consists of a 25-m transect belt in which the diver registered the substratum type at 20-cm intervals: 26 belt transects were obtained at the bridge, and 14 transects were obtained for the horizontal profile and 12 transects were obtained for the vertical profile distributed on the three main bridge pillars. Similar

**Table 1. Fish families and species recorded in all three different artificial and natural habitats**

Trop., trophic guilds; TERH, territorial herbivores; ROVH, roving herbivores; MIF, mobile invertebrate feeders; SIF, sessile invertebrate feeders; CAR, carnivores; PIS, piscivores; PLK, planktivores; OMN, omnivores; MaxN, maximum number of individuals of a species observed in a single frame of remote video footage

Family	Species	Trop.	Mangrove		Bridge		Pier	
			Total (n)	MaxN	Total (n)	MaxN	Total (n)	MaxN
Acanthuridae	<i>Acanthurus bahianus</i>	ROVH	0	0	0	0	7	0.50
	<i>Acanthurus chirurgus</i>	ROVH	8	0.57	5	0.36	4	0.29
	<i>Acanthurus coeruleus</i>	ROVH	0	0	1	0.07	22	1.57
	<i>Acanthurus</i> spp.	ROVH	0	0	4	0.29	14	1.00
Apogonidae	<i>Apogon americanus</i>	PLK	0	0	0	0	3	0.21
Carangidae	<i>Carangoides bartholomaei</i>	PIS	3	0.21	0	0	1	0.07
	<i>Caranx latus</i>	PIS	0	0	1	0.07	0	0
	<i>Oligoplites</i> spp.	MIF	0	0	6	0.43	0	0
Centropomidae	<i>Centropomus</i> spp.	CAR	83	5.93	4	0.29	68	4.86
Chaetodontidae	<i>Chaetodon striatus</i>	SIF	2	0.14	8	0.57	7	0.50
Clupeidae	–	PLK	0	0	30	2.14	0	0
Engraulidae	–	PLK	0	0	22	1.57	0	0
Epinephelidae	<i>Cephalopholis fulva</i>	PIS	0	0	2	0.14	7	0.50
	<i>Epinephelus adscensionis</i>	PIS	0	0	5	0.36	5	0.36
Gerreidae	<i>Diapterus</i> spp.	MIF	0	0	5	0.36	5	0.36
	<i>Eucinostomus</i> spp.	MIF	12	0.86	2	0.14	1	0.07
	<i>Eucinostomus melanopterus</i>	MIF	3	0.21	0	0	0	0
	<i>Eugerres</i> spp.	MIF	0	0	9	0.64	3	0.21
	<i>Gerres cinereus</i>	MIF	0	0	2	0.14	1	0.07
Haemulidae	<i>Anisotremus virginicus</i>	MIF	0	0	4	0.29	6	0.43
	<i>Haemulon aurolineatum</i>	MIF	0	0	28	2.00	4	0.29
	<i>Haemulon parra</i>	MIF	1	0.07	36	2.57	37	2.64
	<i>Haemulon</i> spp.	MIF	13	0.93	51	3.64	8	0.57
Hemiramphidae	<i>Hemiramphus</i> spp.	OMN	1	0.07	0	0	0	0
Holocentridae	<i>Holocentrus adscensionis</i>	MIF	0	0	1	0.04	3	0.21
Labrisomidae	<i>Labrisomus</i> spp.	MIF	0	0	0	0	1	0.07
Lutjanidae	<i>Lutjanus alexandrei</i>	CAR	28	2.00	2	0.14	3	0.21
	<i>Lutjanus synagris</i>	CAR	2	0.14	2	0.14	3	0.21
	<i>Lutjanus jocu</i>	CAR	3	0.21	8	0.57	4	0.29
	<i>Lutjanus</i> spp.	CAR	3	0.21	5	0.36	1	0.07
Mugilidae	<i>Mugil curema</i>	OMN	0	0	1	0.07	0	0
	<i>Mugil rubrioculus</i>	OMN	4	0.29	0	0	0	0
	<i>Mugil</i> spp.	OMN	1	0.07	2	0.14	0	0
Mullidae	<i>Pseudupeneus maculatus</i>	MIF	0	0	0	0	5	0.36
Muraenidae	<i>Gymnothorax vicinus</i>	CAR	0	0	0	0	1	0.07
Ophichthidae	<i>Myrichthys ocellatus</i>	CAR	0	0	0	0	1	0.07
Ogcocephalidae	<i>Ogcocephalus vespertilio</i>	MIF	0	0	0	0	1	0.07
Ephippidae	<i>Chaetodipterus faber</i>	SIF	0	0	30	0.214	62	4.43
Pomacanthidae	<i>Pomacanthus paru</i>	SIF	2	0.14	1	0.14	13	0.93
Pomacentridae	<i>Abudefduf saxatilis</i>	OMN	3	0.21	3	0.21	49	3.50
Pomacentridae	<i>Stegastes fuscus</i>	TERH	5	0.36	17	1.21	33	2.36
	<i>Stegastes variabilis</i>	TERH	2	0.14	8	0.57	7	0.50
Scaridae	<i>Sparisoma axillare</i>	ROVH	0	0	13	0.93	11	0.79
Sciaenidae	<i>Bairdiella ronchus</i>	MIF	0	0	59	4.21	5	0.36
Sparidae	<i>Archosargus rhomboidalis</i>	MIF	0	0	4	0.29	5	0.36
Sphyaenidae	<i>Sphyaena barracuda</i>	PIS	0	0	4	0.29	0	0
Serranidae	<i>Rypticus saponaceus</i>	CAR	0	0	0	0	3	0.21
	<i>Serranus flaviventris</i>	CAR	3	0.21	8	0.57	21	1.50
Syngnathidae	<i>Hippocampus</i> spp.	PLK	0	0	2	0.14	2	0.14
Tetraodontidae	<i>Sphoeroides greeleyi</i>	SIF	4	0.29	5	0.36	3	0.21
	<i>Sphoeroides</i> spp.	SIF	11	0.79	5	0.36	10	0.71



**Fig. 2.** Mean ( $\pm$ s.d.) fish abundance (a) and species richness (b) per recording sample for each of the different structures.

sampling was performed at the pier, with a total of 16 belt transects obtained around the 8 main supporting pillars. For the natural structure, a total of 16 horizontal transects was obtained along the mangrove roots.

#### Data analyses

One-way analysis of variance (ANOVA) was used to compare the abundance and species richness among the different structures. Data were normalized (Shapiro–Wilk normality test) and  $\log(x + 1)$  transformed. In addition, Tukey's honestly significant difference (HSD) test was used as a post hoc test to analyse differences among groups. Statistical analyses (ANOVA and Tukey's HSD) were performed using Statistica 10 (StatSoft, Tulsa, OK, USA). The ANOVA assumptions of normality and homogeneity were assessed by histograms and scatterplots of the residuals, respectively.

To test differences between fish trophic community and the different structures we used permutational multivariate analysis of variance (PERMANOVA). Data of fish trophic guilds were grouped according to the associated structure, log transformed ( $x + 1$ ) and reassembled in a Bray–Curtis similarity matrix. Unrestricted permutation of raw data was used as the best technique analysing one factor. A permutational analysis of multivariate dispersions (PERMIDISP) was also used to analyse whether the multivariate variations were homogeneous (Anderson *et al.* 2008; Anderson and Walsh 2013). These analyses were performed using Primer-e 6.0 PERMANOVA+1.0 software, ver. 6.1.14 (Anderson 2001).

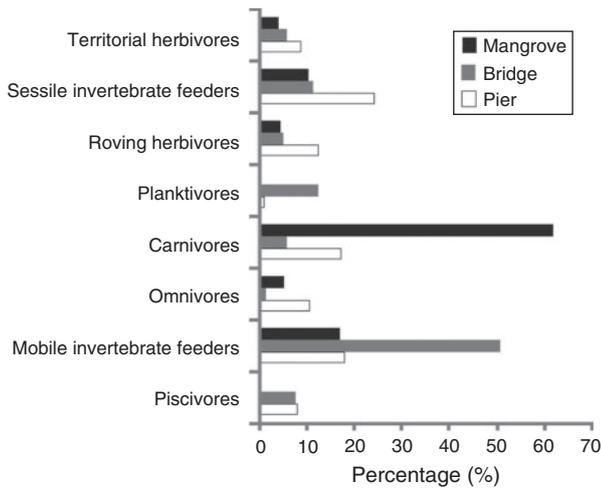
Redundancy analyses (RDA) were used to detect the linear correspondence between the dependent (i.e. trophic guilds) and the independent (i.e. benthos composition) data. The fish community trophic guilds data were transformed for the Hellinger scale according to Legendre and Gallagher (2001) and the benthos composition data were normalized using a logarithmic scale. For the RDA, variables were selected that better predict

the data distribution once an initial model was applied without any variables. Variables were then randomly inserted one by one until no contribution was observed in the model prediction for the subsequent variable. RDA was performed in R (R Development Core Team, Vienna, Austria) with significance set at one-sided  $P < 0.05$ .

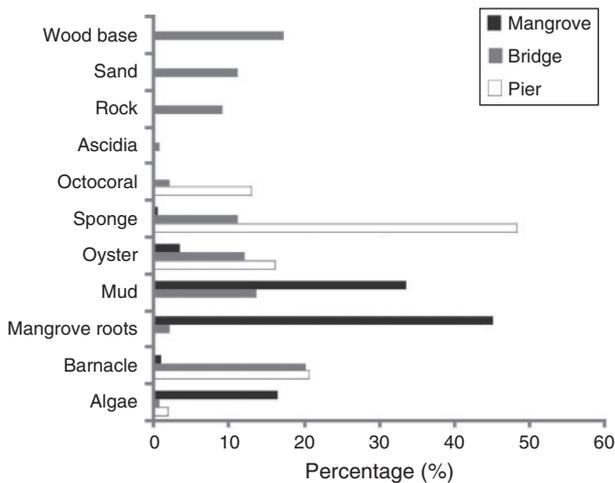
A multidimensional scale (MDS) biplot was also produced to compare the trophic structure of coral reefs and the natural and artificial structures in the estuary. Data were square root transformed and then reassembled in a Bray–Curtis similarity matrix using the relative abundance for each trophic guild. Relative abundance data were used to standardize the observed trophic guilds comparing coral reefs and estuarine sites to reduce any methodological bias. Primer-e 6.0 was used to conduct MDS analyses.

#### Results

In all, 1038 individuals from 56 fish species and 30 families were recorded through the remote analyses using digital cameras (Table 1). The mean ( $\pm$ s.d.) fish abundance was  $27.35 \pm 12.11$  individuals per recording sample for mangrove roots,  $61.69 \pm 46.11$  for the bridge and  $60.42 \pm 48.70$  for the pier (Fig. 2a). Significant differences in abundance were observed between the bridge and the mangrove roots (ANOVA;  $F = 4.13$ ;  $P < 0.05$ ) and between the pier and the mangrove roots (ANOVA;  $F = 8.41$ ;  $P < 0.05$ ). However, no significant difference in fish abundance was observed between the pier and the bridge (ANOVA;  $F = 6.97$ ;  $P = 0.69$ ). With regard to species richness,  $4.8 \pm 3.1$  species were recorded per sample for mangrove roots,  $10.8 \pm 3.7$  for the bridge and  $10.0 \pm 6.1$  for the pier (Fig. 2b). Significant differences were observed among species richness comparing the bridge and the mangrove roots (ANOVA;  $F = 8.01$ ;  $P < 0.05$ ) and comparing the pier and the mangrove roots (ANOVA;  $F = 7.25$ ;  $P < 0.05$ ), but no



**Fig. 3.** Fish trophic composition for each of the three estuarine habitats analysed.

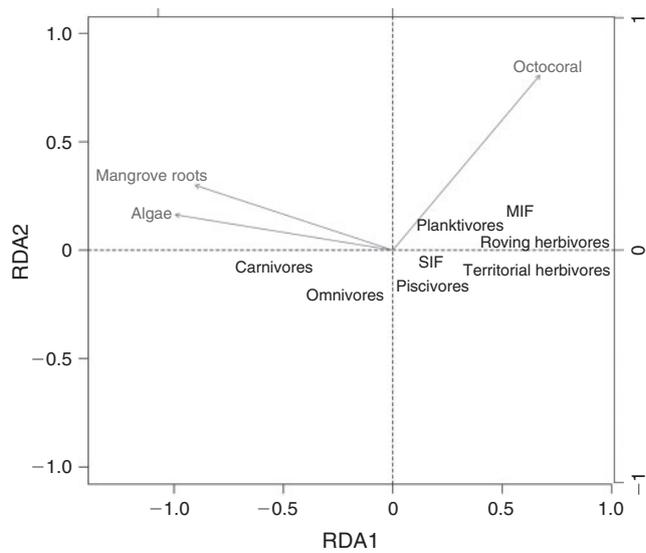


**Fig. 4.** Benthic community and substratum composition for each of the three estuarine habitats analysed.

significant difference was observed comparing species richness between the pier and the bridge (ANOVA;  $F = 6.10$ ;  $P = 0.28$ ).

Differences were also observed comparing the fish trophic communities associated with different structures (Fig. 3). The relative abundance of CAR was higher in the mangrove (60%), followed by MIF (14%). In contrast, MIF (53%) and PLK (18%) were the most representative trophic guilds in the bridge, whereas SIF (29%), MIF (19%) and ROVH (17%) were the most representative trophic guilds in the pier (Fig. 3). PERMANOVA analyses showed significant differences among fish trophic guilds comparing the different structures (PERMANOVA; pseudo  $F = 5.34$ ;  $P < 0.01$ ), and a non-significant PERMIDISP test ( $F = 0.83$ ,  $P_{perm} = 0.62$ ) revealed that multivariate variations are homogeneous, strengthening the PERMANOVA results.

Benthic community and substratum composition also differed among the three different structures (Fig. 4). Mangrove



**Fig. 5.** Redundancy analyses (RDA) of fish trophic guild and benthic composition recorded in the three structures analysed. MIF, mobile invertebrate feeders; SIF, sessile invertebrate feeders.

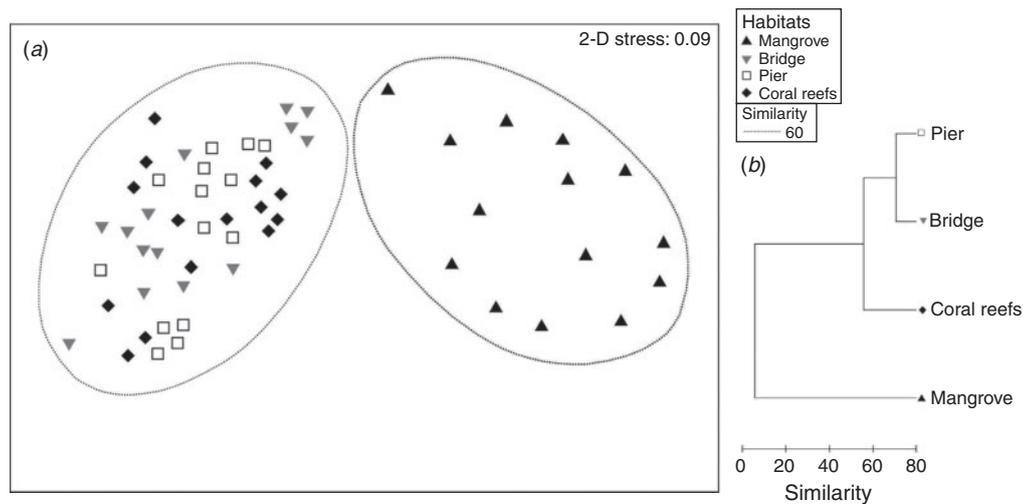
substratum composition was predominantly composed of mangrove roots (45%) and mud (33%). On the pier, sponges (50%), barnacles (22%) and octocorals (14%) dominated the benthic community. The benthic composition of the bridge habitat was the most diverse, with seven well-represented categories (up to 10% of the benthic community and substratum composition; Fig. 4).

A significant RDA was performed correlating fish community trophic guilds and the benthic composition (ANOVA RDA;  $F_{3,35} = 3.602$ ;  $P < 0.05$ ; Fig. 5). The RDA showed that the benthic composition explained 23.59% of the variation in the fish trophic guilds abundance (14.97% in the first RDA axis and 4.76% in the second RDA axis). There was a correlation of CAR species with the mangrove roots. In addition, TERH, SIF and ROVH were more associated with octocoral cover (Fig. 5).

Fish trophic structure on artificial habitats showed up to 60% similarity with the adjacent coral reef area according to MDS biplot samples (Fig. 6). In contrast, fish trophic guilds on the mangrove roots were extremely different from both artificial structures and coral reefs, with less than 20% similarity (Fig. 6).

### Discussion

The present study found differences in the trophic composition of fish communities between natural and artificial structures in a tropical estuary. Mangrove roots were predominantly inhabited by juvenile CAR (e.g. *Lutjanus* spp.). In contrast, SIF and ROVH were mostly associated with the artificial structures. Mangrove roots showed a less diverse benthic community, composed primarily of mud and algae. Benthos at the bridge and pier was more diverse and dominated by sponges, octocorals, barnacles and oysters. Therefore, the fish association is likely to be correlated with the benthic community on different structures. In addition, fish trophic structure on artificial habitats showed higher similarity with the adjacent coral reef area.



**Fig. 6.** (a) Multidimensional scaling biplot and (b) similarity analysis comparing the trophic structure of fish communities on natural coral reefs with the natural and artificial structures in the estuary.

The present study highlights that artificial structures (e.g. concrete blocks and piers) in estuaries could provide different resource availability for many species, which may alter the community structure of natural habitats.

Fish abundance and species richness within estuaries have been found to be greater on artificial structures than on natural habitats (Folpp *et al.* 2013); this finding is supported by the results of the present study. Furthermore, artificial substrates may be colonized by a different benthic community, which differs from the local natural soft-substrate assemblage on or around mangrove roots. There was a higher abundance of sponges and octocorals on the bridge and pier; however, in the natural habitat (e.g. mangrove roots), their recorded abundance was extremely low. Alternatively, such artificial structures could also promote negative effects on growth rates of estuarine fish depending on the type of materials used during construction and light availability under artificial habitats. For example, Able *et al.* (1999) suggest that habitat quality under the platforms of large piers is poor for juvenile fish compared with nearby natural substrates and open-water habitats, with deleterious effects on species growth and survival. Hence, artificial structures may provide different benthic composition for associated species, which could have ecological consequences across spatiotemporal scales.

Carnivorous fish recorded in the present study were predominantly found associated with the mangrove roots. This group was mostly represented by individuals from the genus *Lutjanus* (*L. alexandrei* and *L. jocu*) during the juvenile life phase. The genus *Lutjanus* is well represented in mangrove areas, where they are observed sheltering and feeding (Nagelkerken 2000; Pimentel and Joyeux 2010; McMahon *et al.* 2011). Moreover, according to previous studies, the diets of the two most abundant species recorded herein comprises small crustaceans, primarily crabs (Monteiro *et al.* 2009; Pimentel and Joyeux 2010). Consequently, mangrove roots are a favourable habitat for juvenile lutjanidae because of the high availability of small crabs (Micheli 1993; Lee 1998; Amaral *et al.* 2014).

In contrast, MIF were the most representative trophic guild associated with the bridge (>50%). This group was composed of Haemulidae (*Haemulon* spp.) and *Bairdiella ronchus*. MIF feed primarily on small benthic invertebrates (e.g. crustaceans, molluscs and worms) associated with hard and nearby soft substrates (Ferreira *et al.* 2004; Pereira and Ferreira 2013; Pereira *et al.* 2015a). During benthic composition analyses, the bridge substratum was recognised as the most complex habitat, composed of sand, rock, mud and barnacle. This highly diverse benthic community and substratum composition supports large numbers of invertebrates and consequently MIF. Conversely, SIF (Pomacanthidae) and ROVH (Acanthuridae) were specifically found associated with the pier. The pier provides a high abundance of octocorals, sponges and barnacles, which explains the dominance of SIF. It is also important to point out that both the pier and the bridge have a larger vertical component compared with the natural mangrove habitat, which could influence the benthic composition and potentially increase fish diversity.

Fish trophic structure on artificial habitats showed higher similarity with the adjacent coral reef area. In addition, several reef fishes, such as *Pomacanthus paru*, *Acanthurus* spp., *Serranus flaviventris* and *Stegastes* spp., were recorded in the adult life phase in association with the bridge and pier. Because the estuary entrance is located extremely close (~2.0 km) to the adjacent coral reef area analysed (Pereira *et al.* 2014), it is likely that the artificial structures could be acting as an attractor for such species. Therefore, it is important to determine whether these species are migrants from the reefs or an established population at the estuarine artificial structures. Several studies have suggested that the rapid colonisation of artificial habitats could be correlated with individuals attracted to the newly deployed structure from nearby natural habitats (Bohnsack and Sutherland 1985; Matthews 1985; Hueckel *et al.* 1989; Folpp *et al.* 2011; Simon *et al.* 2011, 2013). In this context, it is known that competition for vital resources, such as food and habitat, is extremely high for some species on coral reefs

(Connell 1978; McCook *et al.* 2001; Connell *et al.* 2004) and consequently the availability of a habitat with similar benthic composition (e.g. sponges and octocorals) in the estuary could be a potential attractor for associated reef species. Accordingly, the high abundance of reef fish (adults and juveniles) on estuarine artificial structures is likely to be critical for resource competition in a nursery area where food is known to be in limited supply (for a description, see Le Pape and Bonhommeau 2015). Although we believe that some reef fish are indeed part of the estuarine–reef system, these migrants could increase resource competition for juvenile estuarine species and the capacity of the nursery habitats could be compromised. Further research using stable isotope, acoustic tagging or even larval dispersal analyses must be conducted to determine whether reef fish are migrants from the reefs or whether new settlers are colonising and establishing local populations in the estuary in association with artificial structures.

Environmental variables such as temperature and salinity are also important factors affecting fish distribution in estuaries (Cyrus and Blaber 1992; Feyrer *et al.* 2011; França *et al.* 2012). Although they were not specifically analysed in the present study, they could be potentially important predictors for differences in fish communities within sites. It is worth mentioning that the analysed sites are very close and located in the same main segment of the estuary (mid-estuary region). Consequently, strong variations in the environmental parameters are unlikely between the different habitats. A recent study analysed temperature and salinity data in the study area (Silva-Falcão *et al.* 2013) and recorded small variations in these parameters comparing the samplings months of the present study (December–May). Temperature data varied less than 2°C along the estuary and low salinity stratification was observed in the mid-estuary region (Silva-Falcão *et al.* 2013).

In addition, the architectural structure and the material composition of artificial and natural habitats on the estuary differ. The bridge columns are large and made from concrete, the pier is made of thin timber and the mangrove roots are living mangrove. Therefore, it is possible that these different structures support different fish trophic guilds simply because different species prefer different physical habitat types (Jenkins and Wheatley 1998; Smokorowski and Pratt 2007). However, and more likely, different physical characteristics of the habitats could have promoted settlement and development of different benthic invertebrate communities, which, in turn, could have attracted and retained different trophic guilds that specialise on these particular food sources (Choat 1982; Pereira *et al.* 2015b). Indeed, this argument could also be demonstrating that fish communities among these three locations differ, and support our hypothesis that artificial habitats alter the community structure on tropical estuaries. That is, we argue that the different habitat types are the main reason for differences in the trophic structure of fish communities; however, other factors, both at the reef and estuary, such as habitat complexity (e.g. rugosity, availability of holes, shelter and crevices) and limitations in site replication may have affected our results to an unknown extent.

Estuaries are subject to severe human influence that has intensified over past centuries, resulting in depletion of important species and habitats (Lotze *et al.* 2006). The estuary analysed in the present study is a popular tourist destination

(Pereira *et al.* 2014), which, in addition to local pollution and habitat degradation, has increased anthropogenic pressure. Tourism development has been shown to affect reef and estuarine systems due to the construction of artificial structures, poor infrastructure, direct effects of snorkellers and scuba divers, as well as fish stocks, which have been overexploited to meet tourist demand (Gössling 2001). The real value of estuarine and coastal nurseries for fish has been discussed recently by Sheaves *et al.* (2015). The function of coastal nurseries for fish is much more extensive than previously thought, involving several additional, fundamentally important ecosystem processes (Sheaves *et al.* 2015). Only through this new and comprehensive understanding will researchers identify habitat mosaics and underlying connectivity and processes that are important to conserve and maintain the nursery production of these ecosystems (Sheaves *et al.* 2015). Consequently, there is an urgent need for a better understanding of fish association with estuarine structures and the ecological role of artificial structures on fish communities.

In conclusion, the present study has shown differences in the trophic composition of fish communities between natural and artificial habitats in a tropical estuary. In addition, the fish community on estuarine artificial structures resembles adjacent coral reefs. An ongoing debate exists regarding the use of artificial reefs and whether they act as fish producers or fish attractors on several marine ecosystems (Bohnsack 1989; Perkol-Finkel *et al.* 2006; Koeck *et al.* 2014). The answer is not black and white, and the spectrum of whether a reef (natural or artificial) acts as a fish producer or attractor remains inherently grey, affected by a large array of natural variables, including time of year (season and phase of the Moon), species in question and location. It has been argued that shipwrecks can change species distribution and modify the natural fish community (Simon *et al.* 2011). Moreover, Simon *et al.* (2013) state that the establishment of artificial structures near natural reefs should be avoided, because they offer a habitat that has a different physical composition than the natural reef. Thus, artificial habitats could be acting as an attractor for some species, which can migrate from natural to artificial structures. Results from the present study suggest that estuarine artificial structures support unique fish communities compared with natural mangrove habitats. The use of artificial structures near natural habitats should be carefully planned because they differ in benthic composition, and this may alter the community structure of natural habitats, attracting or dissipating species and changing trophic structures.

### Supplementary material

The supplementary video highlights different fish trophic guilds associated with each one of the estuarine natural or artificial habitats. This is available as an online video (see <https://youtu.be/sdhyme6SYOc>).

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