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Artisanal fishing of spiny lobsters with gillnets — A significant anthropic impact on tropical reef ecosystem

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HIGHLIGHTS

- Artisanal fishing using gillnets impact the shore reefs more than it is pictured.
- It impacts low-trophic level species such as important herbivores and detritivores.
- It impacts rare decapod populations that inhabit mainly coastal reefs.
- It impacts juveniles of lobster that use the shore reefs as nursery area.
- This activity results in serious ecological imbalance in the reef ecosystem.

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ABSTRACT

Artisanal fishing activity with gillnets to capture the spiny lobster is a common practice along the coastal reefs of Brazil. This research aims to understand the impact that this artisanal fishing practice is having on the coastal reef systems analysing its associated fauna (bycatch) and the stock of the target species *Panulirus echinatus*. The study compared an area which was subjected to intense gillnet fishing against one were the practice was absent. The analysis of target species using nocturnal visual census demonstrated a significantly higher number of *P. echinatus* at the site where gillnet use was virtually absent within three sampled habitats, fringe, cave and soft bottom. The analysis of bycatch species from artisanal fishermen's gillnet landings recorded 4 lobster species and 10 crab species. These decapod species play an important ecological role as detritivores, herbivorous and first consumers within the reef ecosystem as well as being natural prey items for several reef fishes. The study concludes that this non-discriminatory fishing technique impacts directly on populations of *P. echinatus, P. argus* and *P. laevicauda* as well as other lobster and crab species which in-turn indirectly affects the ecological role of the tropical coastal reefs of Brazil.

1. Introduction

Spiny lobsters from the family Palinuridae exhibit evolutionary habitat differentiation, with some species inhabiting the shallow coastal reefs throughout their entire benthic life cycle; while other species migrate to deep water during the

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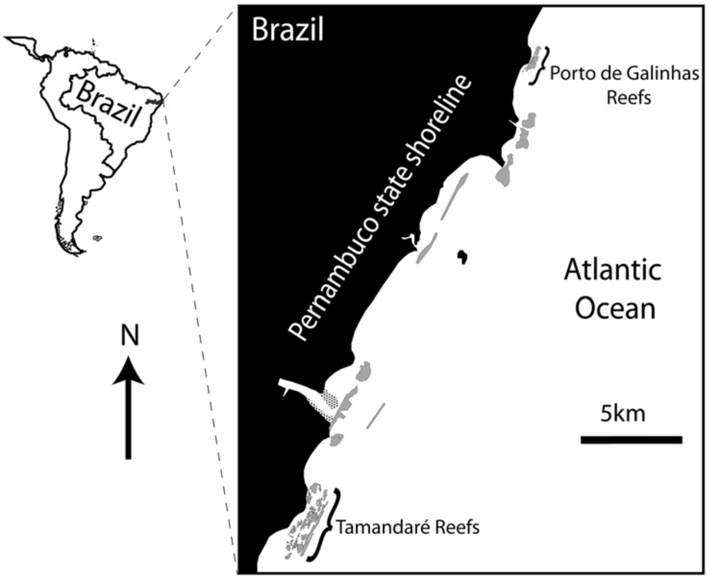

Fig. 1. The studied shore reef sites at Porto de Galinhas and Tamandaré, in Pernambuco state, Brazil.

juvenile/adult ontogeny (George, 2006). This life cycle pattern in Palinuridae has been observed worldwide; it has also been reported that only two or three species co-habit the same region (Holthuis, 1991). An example of this can be seen in Brazil where *Panulirus argus* (Latreille, 1804) and *Panulirus laevicauda* (Latreille, 1817) use the same shallow coastal reefs as nursery areas during the juvenile life phase. *Panulirus echinatus* Smith, 1869 also occupies the same habitats during its adult and juvenile life phases, and is considered one of the most abundant lobsters within the Brazilian tropical coastal reef habitats (Silva and Fonteles-Filho, 2011; Giraldes et al., 2012, 2015).

The spiny lobster fishery represents a significant economic resource in Brazil (Silva and Fonteles-Filho, 2011) and one of the most financially rewarding worldwide (Phillips, 2013). Over the last 20 years poor fishery management of spiny lobster stocks in the West Atlantic Ocean has led to a dramatic reduction in landings. Stock management tools such as minimum landing size and restricted periods of fishing are already in place for *P. argus* and *P. laevicauda* in Brazil, but have proved insufficient in protecting stock numbers. In addition, *P. echinatus* is still not subject to any fishery management legislation (Silva and Fonteles-Filho, 2011; Butler et al., 2013a,b).

Artisanal fishing techniques with gillnets (locally named *caççoeira*) for *P. echinatus* have been deployed in high densities along coastal reef areas in Brazil. The technique has already been banned for other species in deep water marks but it is still considered viable for the *P. echinatus* fishery. The argument for the continuation of the gillnet technique is based on the fact that the artisanal method uses non-mechanized sailboats (named locally as *jangada*) which in theory should present a low impact fishing effort and a much needed economic income for the local communities involved (Coelho et al., 1996; Rocha et al., 1997; Ferreira et al., 2003; Pinheiro et al., 2003; IBAMA, 2003, 2007; Silva and Corrêa, 2008; ICMBIO, 2013).

The *caçoeira* gillnets is a long trap attached directly onto the reef crests which are exposed during low tide. The nets stay attached to the reef fringe over a nightly tidal cycle, and collected the following morning. This unregulated harvesting activity may be having a direct influence on wild stocks and a significant impact on associated low-trophic level species, which are captured and discarded as bycatch (Hall, 1996; Lewison et al., 2004; Smith et al., 2011).

In order to analyse the impact of gillnet fishing over a coastal reef ecosystem we compared two coastal areas approximately 30 km apart. One site was fished intensely with gillnets while the practice was absent from the second survey site. The target species *P. echinatus* population was evaluated in both areas through nocturnal visual census and the bycatch species evaluated through in-situ landing counts from the local fishermen sailboats.

2. Materials and methods

2.1. Study area

The site without gillnet activity was situated on the reefs at Porto de Galinhas (8°30′07″– 8°30′54″S and 35°00′08″–34°59′47″W) (Fig. 1). This is a popular tourist destination and is visited by a large number of tourists on a daily basis; and local fishermen ceased fishing activity in the area as the demands of the tourist industry proved to be more economically viable (Alcantara et al., 2004; Barradas et al., 2010, 2012). The traditional fishing boats the *jangada* were adapted to accommodate the tourist industry rendering them unsuitable for fishing (Fig. 3(A), (B)). According to the local fishermen's association that controls the local fishing activity, with Alcantara et al. (2004) and with personal observation, the sampled reef system

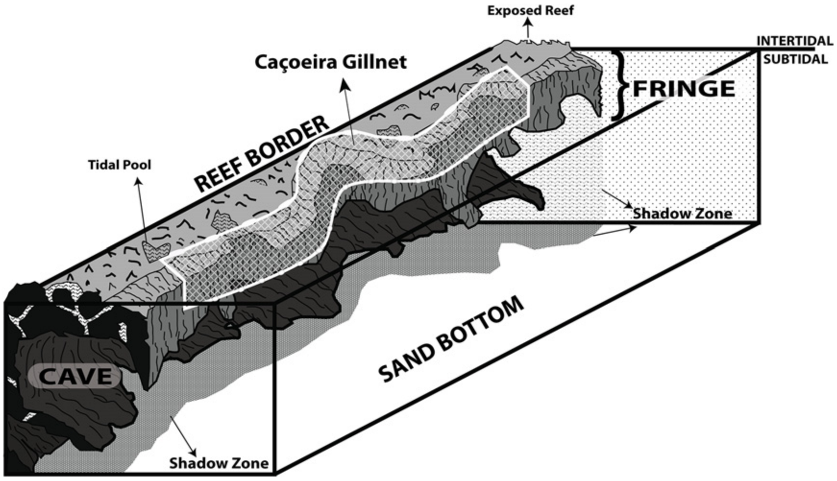

Fig. 2. Studied reefs border with: intertidal zone (exposed reef and the tide-pools); subtidal zone (fringe reef and gillnet caçoeira; cave and shadow zone; and soft bottom). Drawing Credits: Bruno W. Giraldes.

was virtually free from lobster fishing activity with gillnets and was only exposed to occasional collections by recreational divers.

In contrast, the reef at Tamandaré (08°44′23″–08°44′41″S and 35°07′29″–35°02′28′W) (Fig. 1) was subjected to intense fishing efforts from local fishermen using *caçoeira* gillnets (Fig. 2) to capture the brown spiny lobsters *P. echinatus* (Fig. 3(C), (E)). According to previous studies about 50 artisanal fishermen operate daily in Tamandaré most using the gillnet method for fishing spiny lobsters; the gillnet is normally 700–3500 m long with a mesh size of between 40 and 60 mm in diameter and boats fish a minimum of 7 and a maximum of 35 nets. A mark of the intensity of fishing at this reef is revealed by the official landings recorded during 2006 when 20.8 tons of lobsters landed in the Tamandaré region alone. (Ferreira et al., 2003; IBAMA, 2003; Alcantara et al., 2004; Silva and Corrêa, 2008; ICMBIO, 2013). Therefore, this sample site can be considered as a good representation of an anthropogenically impacted regions from artisanal fishing in Brazil.

The reef areas investigated during the research were both located on the north-eastern coast of Brazil, on the southern coast of Pernambuco state (Fig. 1). The research sites were located within the most prolific coral areas along the coastal reef between 8° and 9° S. These coastal reefs rarely exceed a depth of 10 m and are formed by sandstone profiles. The corals grow to the upper limit of the subtidal zone and expand laterally from the top, forming densely aggregated structures with a system of interconnected caves and grottos below the reef surface (Dominguez et al., 1990; Leão et al., 2003). The peculiarities of these reefs offer distinct habitat features for decapods like lobsters (Giraldes et al., 2012) (Fig. 2).

The Tamandaré reefs are located within a marine protected area "APA—Costa dos Corais". The management strategy in place to protect this area allows artisanal fishing methods by local fishermen and non-commercial diving activity (Ferreira et al., 2003; IBAMA, 2003; ICMBIO, 2013). Therefore, the reefs studied inside this marine area did not require a government access permit and no restrictions were imposed on research methodologies or logistics during the research.

3. Sampling methods

Impact over associated fauna—Bycatch

The associated fauna or bycatch was identified and quantified during the landings from the fishermen *caçoeira* gillnet. It was possible to record the number of species and individuals within the bycatch in-situ as the fishermen clear the *caçoeira* gillnets completely of catch at the time of landing. The bycatch study was performed only at Tamandaré as fishing with gillnet is not practised at Porto de Galinhas. All biological material was obtained only from local fishermen and analysis of bycatch species was performed after landing.

Gillnet landing assessments were carried out between November 2005 and June 2007 over a 19 month period with a total of 48 fishing boats surveyed (one gillnet per fishing boat). Species identification was in-situ during the emptying of gillnets. For decapod species identification were used pertinent taxonomic references (Williams, 1984; Holthuis, 1991; Melo, 1996, 1999). All taxa identifications were presented following the evolutionary sequence (De Grave et al., 2009) and species following the alphabetical sequence.

Impact on the target species population

To identify the impact of the gillnet fishing on the target species *P. echinatus*, an ecological population approach, was used, comparing the inter-site species population between a site exposed to fishing activity (Tamandaré) and a site where fishing activity is absent (Porto de Galinhas). In order to minimize any detrimental effects on the reef habitat, population surveys were performed using non-destructive Underwater Visual Census (UVC) methodology. Ecological data was obtained using a 20 m long Strip Transect Technique (STT). The sample area for transect deployment was restricted to the reef edge

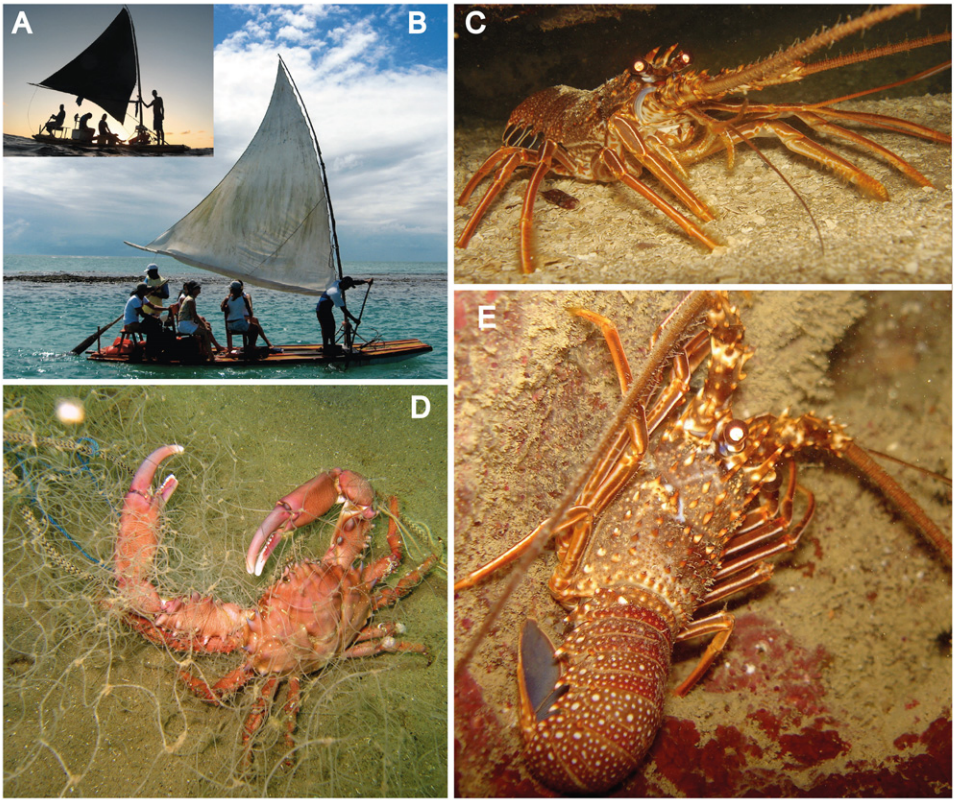

Fig. 3. Sailboat (*Jangada*) in Porto de Galinhas reefs transporting tourist (A, B); *Panulirus echinatus* Smith, 1869 in the studied reefs on soft bottom (C), and upside down inside the cave reef (E); *Damithrax hispidus* (Herbst, 1790) tangled in gillnet (D). Photographic Credits: (A–C, E) Bruno W. Giraldes; (D) Claudio L. S. Sampaio.

(where the gillnets are placed) with the width of transect being signified as the depth of the site (between the soft bottom and the water surface). All transects were deployed a day prior to sampling and fixed to the reef fringe at a similar location used for *caçoeira* gillnet deployments (Fig. 2). Twelve transects were surveyed at each site (12 in Tamandaré and 12 in Porto de Galinhas) at depths between 2 and 8 m: with 6 transects at depths of between 2 and 4 m; and 6 transects at depths of between 2 and 4 m. In November 2008 UVC surveys were undertaken using SCUBA diving during a low spring tide at night when *P. echinatus* (Fig. 3(C), (E)), are more likely to be active (Melo, 1999).

The sampled areas (reef edges) at each site were divided into three distinct reef habitats for the lobster (Fig. 2): (1) the reef fringe where lobsters accumulate at night to forage and also where the *caçoeira* are deployed; (2) reef caves and cavities that are used as refuge areas (Fig. 3(E)); and (3) the soft bottom that surrounds the reef outcrop where lobsters routinely forage (Fig. 3(C)). In order to ensure continuity throughout the survey the same diver carried out the dives; on the same monthly tidal and lunar cycles at Porto de Galinhas and Tamandaré in sequence. The number of individuals observed along each categorized sample transect were recorded in-situ using an underwater slate.

3.1. Data analysis

The decapod bycatch samples were quantified using: Abundance; Frequency of occurrence; and Dominance. The abundance of species is presented as total and average of specimens per gillnet (with standard deviation). The frequency of occurrence (percentage of occurrence per gillnet), species were categorized as, Rare ($Fa < 10\%$), Occasional ($10\% \leq Fa < 25\%$), Common ($25\% \leq Fa < 50\%$), Very Common ($50\% \leq Fa \leq 75\%$) or Constant ($75\% \leq Fa \leq 100\%$). The Dominance index (percentage at which each species was accounted for within the total of sampled specimens), species were considered, Dominant ($Da > 10\%$), Representative ($1\% \leq Da < 10\%$) or Inexpressive ($Da < 1\%$) (Odum and Barrett, 2007). Diversity indices and statistical analysis were performed using the PAST© statistical software package.

Abundance data of *P. echinatus* was obtained based on the number of individuals per transect (number of specimens at each 20 m of reef edge) within each schematic area: fringe; cave; and soft bottom. The abundance is presented as the total number of species observed at each area and the average (with standard deviation) based in the number of specimens per transect. To evaluate the differences between the populations inhabiting the two sample sites a Student T test was used with 95% of confidence and a significance level of 5% ($p < 0.05$). Analysis were performed using the PAST© statistical software package.

Table 1
Decapods captured using gillnet in the coastal reef, northeastern Brazil, with the target species and the data of the Bycatch species: Abundance, Frequency (CONST.—constant; VCOM.—very common; COM.—common; Ocas.—occasional; Rare), and dominance (DOMIN.—dominant; Repres.—representative; inexp.—inexpressive).

Species	Abundance	Frequency	Dominance
Infraorder ACHELATA			
Family Palinuridae			
Palinurellus gundlachi von Martens, 1878	5 (0.1 ± 0.4)	Rare	Inexp.
Panulirus argus (Latreille, 1804)	14 (0.3 ± 1.4)	Rare	Repres.
Panulirus echinatus Smith, 1869	*Target species*		
Panulirus laevicauda (Latreille, 1817)	27 (0.6 ± 1.4)	COM.	Repres.
Family Scyllaridae			
Subfamily Ibacinae			
Parribacus antarcticus (Lund, 1793)	121 (2.5 ± 4.3)	VCOM.	DOMIN.
Infraorder BRACHYURA			
Family Dromiidae			
Subfamily Dromiinae			
Dromia erythropus (G. Edwards, 1771)	18 (0.4 ± 0.7)	COM.	Repres.
Family Carpiliidae			
Carpilius corallinus (Herbst, 1783)	1 (0.02 ± 0.1)	Rare	Inexp.
Family Menippidae			
Menippe nodifrons (Stimpson, 1859)	50 (1.1 ± 1.9)	COM.	Repres.
Family Epialtidae			
Subfamily Pisinae			
Chorinus heros (Herbst, 1790)	1 (0.02 ± 0.1)	Rare	Inexp.
Family Majidae			
Subfamily Mithracinae			
Microphrys antillensis (Rathbun, 1920)	1 (0.02 ± 0.1)	Rare	Inexp.
Mithraculus forceps (A. Milne Edwards, 1875)	18 (0.4 ± 0.8)	COM.	Repres.
Damithrax braziliensis (Rathbun, 1892)	50 (1.1 ± 1.9)	COM.	Repres.
Damithrax hemphilli (Rathbun, 1892)	1 (0.02 ± 0.1)	Rare	Inexp.
Damithrax hispidus (Herbst, 1790)	820 (17.1 ± 5.8)	CONST.	DOMIN.
Family Plagusiidae			
Subfamily Plagusiinae			
Plagusia depressa (J.C. Frabicius, 1775)	10 (0.2 ± 0.5)	Ocas.	Inexp.

4. Results

Impact on associated fauna—Bycatch

The bycatch samples from the *caçoeira* gillnet included a total of 1136 specimens with an average of 23.7 ±17.3 specimens per boat landing. A total of 14 decapod species (Table 1) were captured, plus the target species *P. echinatus,* which was recorded in 100% of gillnets retrieved.

The most significant bycatch species (Fig. 4) (Table 1) was the large herbivorous crab *Damithrax hispidus* (Fig. 3(D)) and the number of landings for this crab in some cases exceeded the target lobster *P. echinatus*; it does not have any economic trade value and fishermen only utilized the chelipeds from larger individuals for personal use (fishermen's comments), while the rest of body was discarded on the beach, along with smaller individuals. The second most dominant species was *Parribacus antarcticus* (Fig. 4) (Table 1), in the majority of landings these were small specimens (apparently juveniles) much smaller than the 20 cm size described for larger specimens; the species commands a good trade value in local markets and is also used as subsistence food.

The following species were all representative in dominance (Fig. 4) (Table 1). *Damithrax brasiliensis, Dromia erythropus, Mithraculus forceps* and *Menippe nodifrons* having no commercial value were discarded. *Panulirus laevicauda* and *Panulirus argus* landings were all considered as juveniles and under the permitted catch size (all fishermen were aware that it was undersized) and thereby prohibited for trade but used as subsistence food by the fishermen (fishermen comments).

The other six bycatch species were inexpressive in dominance, (Fig. 4) (Table 1). *Microphrys antillensis, Damithrax hemphilli* and *Chorinus heros* have no commercial value and are discarded as bycatch while *Plagusia depressa* is traded in local markets. *Palinurellus gundlachi* was landed as large adults and is a highly sought after local gastronomic delicacy likewise *Carpilius corallinus* the largest crab that is also hugely in demand as zootherapy or traded locally as material for handicrafts (Table 1).

Impact on the target species population

Inter-site comparisons showed *P. echinatus* to be in significantly higher abundances at Porto de Galinhas when compared to Tamandaré within all of the three characterized reef areas: fringe, cave and soft bottom (Fig. 5). A total of 384 specimens of *P. echinatus* were observed during this study. Porto de Galinhas had a total of 269 specimens recorded at an average of 22.4 ± 12.9 ind/20 m (specimens per 20 m transect along the reef edge), significantly higher ($p = 0.0073$) than Tamandaré were only 115 specimens were recorded with an average of 9.6 ± 6.9 ind/20 m.

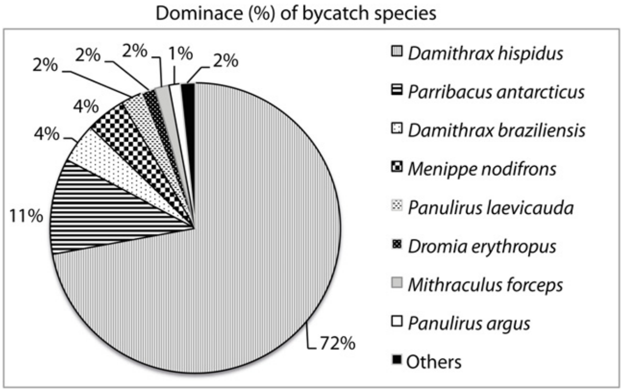

Fig. 4. Dominance (%) of bycatch decapods caught in artisanal fishing with caçoeira gillnet in Tamandaré/PE.

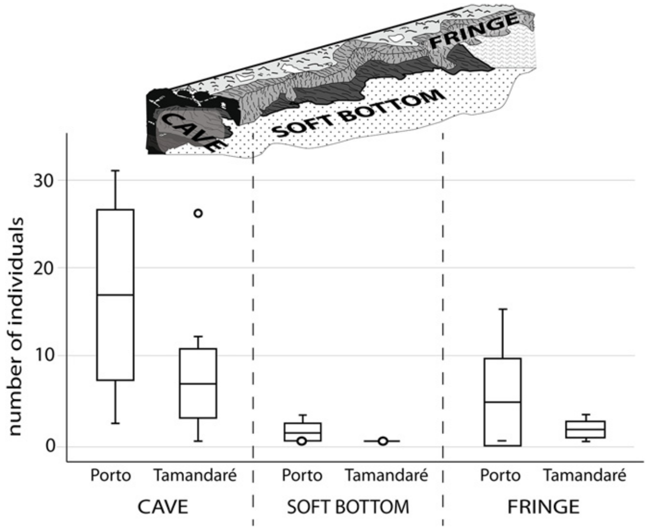

Fig. 5. Abundances Box Plot of *Panulirus echinatus*. Comparing the studied habitats in the reef structure (Cave, Soft Bottom and Fringe) between the two sample sites Porto de Galinhas (Porto) and Tamandaré.

On the reef fringe, *P. echinatus* sampled at Porto de Galinhas presented an average of 4.5 $\pm$ 5.1 ind/20 m, significantly higher ($p = 0.0241$) than Tamandaré which presented an average of 1.3 $\pm$ 0.9 ind/20 m (Fig. 5). In the cave/grotto reef habitat, Porto de Galinhas's samples presented an average of 16.7 $\pm$ 9.6 ind/20 m, significantly higher ($p = 0.0176$) than Tamandaré which presented an average of 8.2 $\pm$ 6.7 ind/20 m (Fig. 5). On the soft bottom, close to the reef structure, samples at Porto de Galinhas presented an average of 1.16 $\pm$ 1.5 ind/20 m, also significantly higher ($p = 0.012$) than Tamandaré which presented an average of 0.1 $\pm$ 0.3 ind/20 m (Fig. 5).

5. Discussion

In this study the landings of 48 sailboats were analysed. In Tamandaré, 50 artisanal fishermen using mainly gillnets for fishing spiny lobsters operate on a daily basis. This equates to a considerable annual tonnage of landings (20.8 tons in 2006) of *P. echinatus* (Ferreira et al., 2003; Silva and Corrêa, 2008; ICMBIO, 2013). Therefore, the results presented in this study are a small representation of the total annual catch in Brazil but do however highlight the huge biomass of associated fauna being removed from the coastal biogenic reef environment every year.

This study revealed that Tamandaré reefs have significantly fewer *P. echinatus* within all three categorized benthic areas when compared to those at Porto de Galinhas. The low abundance of *P. echinatus* at Tamandaré can be reflected in the decreasing tonnages contained in the landing records (Ferreira et al., 2003; IBAMA, 2003; Alcantara et al., 2004; Silva and Corrêa, 2008; ICMBIO, 2013). The differences reflected at these two tropical reef areas over the target species strongly suggest that the intensity of fishing in Tamandaré is also a detrimental factor over bycatch lobsters and crabs. Since this is a non-species-specific form of fishing which captures a great amount of associated fauna; and this form of fishing has a substantial impact on the entire coastal reef environment of Brazil and also in several other countries around the world (Hall, 1996; Rocha et al., 1997; Lewison et al., 2004; Shester and Micheli, 2011; Smith et al., 2011). Regardless of how destructive tourism can be for a reef environment it should be noted that in this case, the anthropogenic disturbance caused as a result of the tourism trade at Porto de Galinhas (Barradas et al., 2010), is a strong driver in the reduction of gillnet use, benefiting the lobster population and the accompanying bycatch decapods.

It was previously reported by Melo (1999) and by Pinheiro et al. (2003) that *P. echinatus* exhibits a nocturnal habit and lives in predation safe areas such as deep cavities in rocks; displaying nocturnal foraging behaviour especially during reproductive periods. The UVC data at both sites in this study strongly highlights how *P. echinatus* uses cave and grotto structures in coastal reef areas as its main habitat even during night. The higher densities of *P. echinatus* on the reef fringe comparing with soft bottom demonstrate its preferential foraging area. This can explain the success of this fishing technique and why it is a favoured area by fishermen to anchor gillnets.

The largest component with 80% of recorded bycatch landings were crabs from the subfamily Mithracinae. Herbivorous Crabs at this subfamily are known as "algae-cleaning crews" in the aquaria industry for their algal control abilities (Rhyne et al., 2005). They are associated with algae beds and usually are captured in these areas (Melo and Veloso, 2005). Studies have shown that the removal of crabs belonging to this group in a reef ecosystem can result in significant algal growth, reaching a 75% increase in algae where these crabs are removed (Coen, 1988a,b; Wilber and Wilber, 1989; Stachowicz and Hay, 1999). Ceccarelli et al. (2011) highlighted that in coral reefs the relationship between algae and corals is largely controlled by herbivores and therefore, the removal of these keystone low-trophic level crabs increases the effects of ecological imbalance because algae is the principal competitor of coral species in the reef environment and the dominance of algae can instigate serious damaging impacts within the coral reef environment (McCook, 1999, 2001; McCook et al., 2001).

In Brazilian reefs, similar to other coral reefs in the world the reef fish are in an overexploitation scenario (Ferreira and Maida, 2006; Bender et al., 2013), resulting in a decrease of predators of large decapods and a subsequent increase in non-traded species most of which are invertebrates (Pinnegar et al., 2000). This damaging overexploitation of decapods with gillnets reported here could be accelerating the collapse of this ecosystem especially when the majority of bycatch species are at the base of trophic chain like the herbivorous crabs (discussed above). Another considerable problem is the removal of detritivores / omnivorous decapods in places with large deposits of organic material, such as anthropogenic impacted coastal areas (Barradas et al., 2012). This can result in organic material not being consumed, thereby increasing nutrification leading to an excess of ammonia, nitrite and acidification of the water (Rabalais, 2002; Costa et al., 2008). This decrease in water quality makes the water toxic to several fragile animals leading to death a situation which can be observed in aquarium systems (Spotte, 1993). It has also been well documented that several decapods are responsible for removing parasites of fishes (McCammon et al., 2010) cleaning corals, removing sediment (Stewart et al., 2006) eating dead tissues of benthic organisms (Gleibs et al., 1995), and ensuring coral health (Abele and Patton, 1976). Therefore removing these environmental "cleaners" can lead to a dominance of undesirable organisms like pathogenic animals (Pinnegar et al., 2000). Another concern as a result of the intense removal of decapods involves the trophic relation of the reefs fish the natural predators of reef decapods (Randall and Bishop, 1967). Many of these fish species already find themselves in a state of overexploitation and almost 50% within the studied ecosystem are mobile invertebrate feeders (Chaves et al., 2013). Therefore the constant indiscriminate removal of primary and secondary consumers in the trophic chain by fishermen has the potential to cause large scale ecological imbalance in the coastal reef system and may be currently affecting trophic relationships which are not yet fully understood (Pinnegar et al., 2000; Smith et al., 2011; Mcconkey and O'Farrill, 2015). This ecological imbalance forced by the continuous gillnet uses can result in an irreversible change in the coastal reef ecosystem based in the ecological cascade theory (Pinnegar et al., 2000; Shears and Babcock, 2003; Smith et al., 2011), and the extinction cascade (Säterberg et al., 2013). Neubauer et al. (2013) states that any recovery of an overexploited marine population will be slow and ecosystems can collapse in periods of prolonged intense overexploitation.

The documentation of the giant coral crab *Carpilius corallinus* during the study as bycatch deserves special attention. This crab inhabits coral reef regions and has an extremely limited distribution in Brazil (Melo, 1996). Recent research has shown that the species is in extremely low densities (Giraldes et al., 2012, 2015). This species is essentially traded for zootherapy and craftwork (fishermen's comments); it does not represent an important economic resource but it is not difficult to find this crab traded as souvenirs in local craft markets (Pers. Observ.) This species is in a threatened state along the coastal reefs of Brazil and if extinction is to be avoided management measures should be in place to control the exploitation of this species. The introduction of a ban in its trade for craftwork or as fishery resource in local markets would discourage is capture.

The most detrimental species-specific impact of the gillnet fishery was on *P. argus* and *P. laevicauda* population, the most important decapod resource in northeast coast of Brazil. This was a result of the nets being placed in their nursery habitats and that was evident among the landings of small juveniles from both species observed during this study. The disregard for fishery management and legislation shown by artisanal fishermen has put considerable pressure on lobster populations and this may be one of the factors contributing to the decreasing standing stocks at many of the 20–50 m deep offshore sites (Silva and Fonteles-Filho, 2011). These two lobsters present an ontogenetic migration for deeper habitat in their juvenile/adult phases (George, 2006; Silva and Fonteles-Filho, 2011) and the intense gillnet fishing in its nursery habitat stops the continuity of their life cycle, as the juvenile stage is being removed before migration to the adult habitual niche, compromising the whole population stock. This deleterious effect over a very important fishing resource strongly suggests that management measures should be in place to preserve the nursery habitat and their juvenile stages.

The population of *P. echinatus* is presenting all signs of a fishery in collapse, such as a dramatic stock declines over the last 20 years, low recruitment, smaller individuals within the catch and an increase in Catch Per Unit Effort (IBAMA, 2003;

Ferreira et al., 2003; Silva and Corrêa, 2008; Butler et al., 2013a; ICMBIO, 2013). We demonstrate in this study the substantial impact that the artisanal fishing using gillnet is having over *P. echinatus* populations and this is a matter of concern once this shallow coastal reef ecosystem is its only habitat through its entire lifecycle (Pinheiro et al., 2003; George, 2006; Butler et al., 2013a). The study concludes that this non-discriminatory fishing technique impacts directly on populations of *P. argus*, *P. laevicauda, P. echinatus* and other important bycatch species which in-turn indirectly affects the ecological role of the tropical coastal reefs of Brazil. If the lobster fishery is to avoid the fate of the much documented historical fishery collapses, like the North Atlantic cod and the Oyster (Walters and Maguire, 1996; Kirby, 2004), it is crucial that stringent management measures are introduced as soon as possible to prevent the current overexploitation scenario. Based on these previously documented stock collapses we suggest the immediate implementation of several small no take zones at the studied coastal reef ecosystem by the Brazilian authorities. It has been shown (Shears and Babcock, 2003) that if the environment is still not in collapse the no-take zones can revert the trophic cascade effect and slowly restore the reef ecosystem; and these zones could work as protected nurseries and brood stock sanctuaries in the studied coastal reef ecosystem. It is only with action like this that perhaps it will be possible to restore the reef fish and lobster stocks which benefit the environment and in turn increase the possibility of a self-sustaining resource for artisanal fishermen in Brazil.

We would also like to propose an increase in the monitoring of this decapod species using the nocturnal UVC technique to provide ecological information about these species population. This is of considerable importance as there is an absence of ecological information and this is the main reason why species like *P. argus* is still not considered as endangered by the IUCN (Butler et al., 2013b).

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References

Abele, L., Patton, W., 1976. The size of coral heads and the community biology of associated decapod crustaceans. J. Biogeogr. 3, 35–47.
Alcantara, R., Ferreira, B.P., Travassos, P., 2004. A pesca artesanal e o turismo em Porto de Galinhas, Estado Pernambuco. In: Bol. Tec. do CEPENE 12. pp. 195–207.
Barradas, J.I., Amaral, F.D., Hernández, M.I., Flores-montes, M.J., Steiner, A.Q., 2012. Tourism impact on reef flats in Porto de Galinhas beach, Pernambuco, Brazil. Labomar. Arq. Ciências do MarArquivos Ciências do Mar 45, 81–88.
Barradas, J.I., Amaral, F.D., Hernández, M.I.M., Montes, M.D.J.F., Steiner, A.Q., 2010. Spatial distribution of benthic macroorganisms on reef flats at Porto de Galinhas Beach (northeastern Brazil), with special focus on corals and calcified hydroids. Biotemas 23, 61–67. http://dx.doi.org/10.5007/2175-7925.2010v23n2p61.
Bender, M.G., Floeter, S.R., Mayer, F.P., Vila-Nova, D.A., Longo, G.O., Hanazaki, N., Carvalho-Filho, A., Ferreira, C.E.L., 2013. Biological attributes and major threats as predictors of the vulnerability of species: a case study with Brazilian reef fishes. Oryx 47, 259–265. http://dx.doi.org/10.1017/S003060531100144X.
Butler, M., Cockcroft, A., MacDiarmid, A., 2013a. *Panulirus echinatus.* The IUCN red list of threatened species. Version 2014.3. [WWW Document]. URL: www.iucnredlist.org (accessed 12.1.14).
Butler, M., Cockcroft, A., MacDiarmid, A., Wahle, R., 2013b. *Panulirus argus*. The IUCN red list of threatened species. Version 2014.3 [WWW Document]. URL www.iucnredlist.org (accessed 12.1.14).
Ceccarelli, D.M., Jones, G.P., McCook, L.J., 2011. Interactions between herbivorous fish guilds and their influence on algal succession on a coastal coral reef. J. Exp. Mar. Biol. Ecol. 399, 60–67. http://dx.doi.org/10.1016/j.jembe.2011.01.019.
Chaves, L.T.C., Pereira, P.H.C., Feitosa, J.L.L., 2013. Coral reef fish association with macroalgal beds on a tropical reef system in North-eastern Brazil. Mar. Freshw. Res. 64, 1101–1111. http://dx.doi.org/10.1071/MF13054.
Coelho, P.A., Dias, A.F., Oliveira, G.M., Pontes, A.C.P., 1996. Estudo comparativo da pesca de lagostas com covos, redes-de-espera e mergulho no estado de Pernambuco. In: Bol. Técnico Cient. do CEPENE 4.
Coen, L.D., 1988a. Herbivory by Caribbean majid crabs: feeding ecology and plant susceptibility. J. Exp. Mar. Biol. Ecol. 122, 257–276. http://dx.doi.org/10.1016/0022-0981(88)90127-X.
Coen, L.D., 1988b. Herbivory by crabs and the control of algal epibionts on Caribbean host corals. Oecologia 75, 198–203. http://dx.doi.org/10.1007/BF00378597.
Costa, O.S., Nimmo, M., Attrill, M.J., 2008. Coastal nutrification in Brazil: A review of the role of nutrient excess on coral reef demise. J. South Amer. Earth Sci. 25, 257–270. http://dx.doi.org/10.1016/j.jsames.2007.10.002.
De Grave, S., Pentcheff, N.D., Ahyong, S.T., Chan, T., Crandall, K.A., Dworschak, P.C., Felder, D.L., Feldmann, R.M., Fransen, C.H.J.M., Goulding, L.Y.D., Lemaitre, R., Low, M.E.Y., Martin, J.W., Ng, P.K.L., Schweitzer, C.E., Tan, S.H., Tshudy, D., Wetzer, R., 2009. A classification of living and fossil genera of decapod crustacea. Raffles Bull. Zool. Suppl. Ser. 21, 1–109.
Dominguez, J.M.L., Bittencourt, A., Leão, Z., Azevedo, A., 1990. Geologia do quaternário costeiro do estado de pernambuco. Rev. Bras. Geociên. 20, 208–215.
Ferreira, B.P., Maida, M., 2006. Monitoramento dos Recifes de Coral do Brasil: situação e perspectivas. In: Biod., Série (Ed.), Monitoramento dos Recifes de Coral do Brasil. Ministério do Meio Ambiente—MMA, Brasília, DF.
Ferreira, B.P., Maida, M., Cava, F., Messias, L., 2003. Interações entre a pesca artesanal e o turismo em Tamandaré, APA Costa dos Corais. In: II Congr. sobre Planej. e Gestão das Zo. Costeiras dos Países Expressão Port. IX Congr. da Assoc. Bras. Estud. do Quaternário II Congr. do Quaternário dos Países Línguas Ibéricas 1–3.
George, R.W., 2006. Tethys sea fragmentation and speciation of panulirus spiny lobsters. Crustaceana 78, 1281–1309.
Giraldes, B.W., Coelho Filho, P.A., Coelho, P.A., 2012. Composition and spatial distribution of subtidal Decapoda on the "Reef Coast", northeastern Brazil, evaluated through a low-impact visual census technique. Crustacea. Org. Br 20, 187–201.
Giraldes, B.W., Coelho Filho, P.A., Smyth, D.M., 2015. Decapod assemblages in subtidal and intertidal zones—importance of scuba diving as a survey technique in tropical reefs, Brazil. Glob. Ecol. Conserv. 3, 163–175. http://dx.doi.org/10.1016/j.gecco.2014.11.011.
Gleibs, S., Mebs, D., Werding, B., 1995. Studies on the origin and distribution of palytoxin in a Caribbean coral reef. Toxicon 33, 1531–1537.
Hall, M.A., 1996. On bycatches. Rev. Fish Biol. Fish. 6, 319–352. http://dx.doi.org/10.1007/BF00122585.
Holthuis, L.B., 1991. FAO species catalogue. Marine lobsters of the world: An annotated and illustrated catalogue of species of interest to fisheries known to date. In: FAO Fish. Synopsis No. 125 13, p. 292.

IBAMA, 2003. Boletim Estatístico da Pesca Marítima e Estuarina do Nordeste do Brasil—2002. Ministério do Meio Ambiente, IBAMA, CEPENE, Tamandaré.
IBAMA, 2007. Estatística da pesca 2007, Brasil, Grandes regiões e unidades da federação. Ministério do Meio Ambiente, Brasília-DF.
ICMBIO, 2013. Plano de manejo da APA Costa dos Corais. Instituto Chico Mendes de Conservação da Biodiversidade, Tamandaré-PE.
Kirby, M., 2004. Fishing down the coast: Historical expansion and collapse of oyster fisheries along continental margins. Proc. Natl. Acad. Sci. USA 101, 13096–13099. http://dx.doi.org/10.1073/pnas.0405150101.
Leão, Z.M.A.N., Kikuchi, R., Testa, V., 2003. Corals and coral reefs of Brazi. Cortés Jorge 1, 9–52.
Lewison, R.L., Crowder, L.B., Read, A.J., Freeman, S.A., 2004. Understanding impacts of fisheries bycatch on marine megafauna. Trends Ecol. Evol. 19, 598–604. http://dx.doi.org/10.1016/j.tree.2004.09.004.
McCammon, A., Sikkel, P.C., Nemeth, D., 2010. Effects of three Caribbean cleaner shrimps on ectoparasitic monogeneans in a semi-natural environment. Coral Reefs 29, 419–426. http://dx.doi.org/10.1007/s00338-009-0583-8.
Mcconkey, K.R., O'Farrill, G., 2015. Cryptic function loss in animal populations. Trends Ecol. Evol. 1–8.
McCook, L.J., 1999. Macroalgae, nutrients and phase shifts on coral reefs: scientific issues and management consequences for the Great Barrier Reef. Coral Reefs.
McCook, L., 2001. Competition between corals and algal turfs along a gradient of terrestrial influence in the nearshore central Great Barrier Reef. Coral Reefs.
McCook, L.J., Jompa, J., Diaz-Pulido, G., 2001. Competition between corals and algae on coral reefs: A review of evidence and mechanisms. Coral Reefs 19, 400–417. http://dx.doi.org/10.1007/s003380000129.
Melo, G.A.S., 1996. Manual de Identificação dos Brachyura (Caranguejos e Siris) do Litoral Brasileiro. Plêiade, Editora, Fundação de Amparo à Pesquisa do Estado de São Paulo.
Melo, G.A.S., 1999. Manual de identificação dos crustacea decápodo do litoral brasileiro: Anomura, thalassinidea, palinuridea e Astacidea. FAPESP. Ed. Plêiade, Museu de Zoologia. Universidade Estadual de São Paulo.
Melo, G.A.S., Veloso, V.G., 2005. The Brachyura (Crustacea, Decapoda) of the coast of the State of Paraíba Brazil, collected by Project Algas. Rev. Bras. Zool. 22, 795–805. http://dx.doi.org/10.1590/S0101-81752005000300044.
Neubauer, P., Jensen, O.P., Hutchings, J.A., Baum, J.K., 2013. Resilience and recovery of overexploited marine populations. Science 340 (80), 347–349. http://dx.doi.org/10.1126/science.1230441.
Odum, E.P., Barrett, G.W., 2007. Fundamentos de Ecologia, 5a ed. Thomson Learning, São Paulo.
Phillips, B., 2013. Lobsters: Biology, Management, Aquaculture & Fisheries. John Wiley & Sons Ltd..
Pinheiro, A.P., Freire, F.A.M., Oliveira, J.E.L., 2003. Population biology of *Panulirus echinatus* Smith, 1869 (Decapoda: Palinuridae) from São Pedro and São Paulo. Nauplius 11, 27–35.
Pinnegar, J.K., Polunin, N.V.C., Francour, P., Badalamenti, F., Chemello, R., Harmelin-Vivien, M.-L., Hereu, B., Milazzo, M., Zabala, M., D'Anna, G., Pipitone, C., 2000. Trophic cascades in benthic marine ecosystems: lessons for fisheries and protected-area management. Environ. Conserv. 27, 179–200. http://dx.doi.org/10.1017/S0376892900000205.
Rabalais, N.N., 2002. Nitrogen in aquatic ecosystems. Ambio 31, 102–112. http://dx.doi.org/10.2307/4315222.
Randall, J.E., Bishop, B.P., 1967. Food habits of reef fishes of the west indies. Stud. Trop. Oceanogr. 5, 665–847.
Rhyne, A.L., Penha-Lopes, G., Lin, J., 2005. Growth, development, and survival of larval *Mithraculus sculptus* (Lamark) and *Mithraculus forceps* (A. Milne Edwards) (Decapoda: Brachyura: Majidae): Economically important marine ornamental crabs. Aquaculture 245, 183–191. http://dx.doi.org/10.1016/j.aquaculture.2004.11.016.
Rocha, C.A., Junior, W.F., Dantas, N.P., 1997. Crise de sustentabilidade na pesca da lagosta e do caranguejo no Nordeste do Brasil 1–9.
Säterberg, T., Sellman, S., Ebenman, B., 2013. High frequency of functional extinctions in ecological networks. Nature 499, 468–470. http://dx.doi.org/10.1038/nature12277.
Shears, N., Babcock, R., 2003. Continuing trophic cascade effects after 25 years of no-take marine reserve protection. Mar. Ecol. Prog. Ser.
Shester, G.G., Micheli, F., 2011. Conservation challenges for small-scale fisheries: Bycatch and habitat impacts of traps and gillnets. Biol. Cons. 144, 1673–1681. http://dx.doi.org/10.1016/j.biocon.2011.02.023.
Silva, Z.A., Corrêa, F., 2008. Biologia e Pesca da lagosta pintada (*Panulirus echinatus*). In. IBAMA/GCSL—Relatório de Reunião Ordinária do Subcomite Científico para gestão da Lagosta, 22 a 24 de julho, Tamandaré, p. 32.
Silva, A.C., Fonteles-Filho, A.A., 2011. Avaliação do Defeso Aplicado à Pesca da Lagosta no Nordeste do Brasil. Editora Expressão, Graáfica, Fortaleza.
Smith, A.D.M., Brown, C.J., Bulman, C.M., Mackinson, S., Marzloff, M., Shannon, L.J., 2011. Impacts of fishing low–trophic level species on marine ecosystems. Science 333 (80), 1147–1151.
Spotte, S., 1993. Marine Aquarium Keeping.
Stachowicz, J.J., Hay, M.E., 1999. Mutualism and coral persistence: The role of herbivore resistance to algal chemical defense. Ecology 80, 2085–2101. http://dx.doi.org/10.1890/0012-9658(1999)080[2085:MACPTR]2.0.CO2.
Stewart, H.L., Holbrook, S.J., Schmitt, R.J., Brooks, A.J., 2006. Symbiotic crabs maintain coral health by clearing sediments. Coral Reefs 25, 609–615. http://dx.doi.org/10.1007/s00338-006-0132-7.
Walters, C., Maguire, J.J., 1996. Lessons for stock assessment from the northern cod collapse. Rev. Fish Biol. Fish. 6, http://dx.doi.org/10.1007/BF00182340.
Wilber, D.H., Wilber, T.P., 1989. The effects of holding space and diet on the growth of the West Indian spider crab *Mithrax spinosissimus* (Lamarck). J. Exp. Mar. Biol. Ecol. 131, 215–222.
Williams, A.B., 1984. Shrimps, lobsters, and crabs of the Atlantic Coast of the Eastern United States, Maine to Florida. Estuaries 8, 77. http://dx.doi.org/10.2307/1352125.