



Urbanization effects on morphological traits of *Eriphia gonagra* (Decapoda, Eriphiidae) in tropical intertidal reefs of the Northeastern Brazil

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Abstract. We investigated the effects of urbanization on the population characteristics of *Eriphia gonagra* found on sandstone reefs between tides. Sampling was carried out from September 2015 to August 2016 in two sandstone reefs with different degrees of urbanization. Environmental parameters were retrieved for both reefs and collected individuals were measured and sexed in the laboratory. Traits were modeled individually for females and males using a generalized linear mixed model (GLMM). Our results indicate that males are significantly smaller and less heavy in the urbanized reef, whereas females showed no evidence of urbanization effects. As *E. gonagra* is a top predator, the advance of urbanization in coastal areas has great potential to harm the ecosystem functioning of intertidal sandstone reefs.

Key words: urbanized areas; ecosystem functioning; human-induced impacts; crabs.

Resumo. Efeitos da urbanização nos traços morfológicos de *Eriphia gonagra* (Decapoda, Eriphiidae) em recifes tropicais da zona entremarés do Nordeste do Brasil. Nós investigamos os efeitos da urbanização nas características morfológicas de *Eriphia gonagra*, encontradas em recifes de arenito entre marés. As coletas foram realizadas entre setembro de 2015 e agosto de 2016 em dois recifes de arenito com diferentes graus de urbanização. Parâmetros ambientais foram coletadas e os indivíduos capturados foram medidos e sexados em laboratório. Os traços foram modelados para cada sexo usando modelos lineares generalizados misto (GLMM). Nossos resultados indicam que machos são significativamente menores e menos pesados no recife urbanizado, já as fêmeas não mostraram evidência de efeitos da urbanização. Uma vez que *E. gonagra* é um predador de topo, o avanço da urbanização em áreas costeiras tem grande potencial para prejudicar o funcionamento ecossistêmico de recifes de arenito entremarés.

Palavras-Chave: áreas urbanizadas; funcionamento ecossistêmico; impacto humano; caranguejos.

Introduction

Human impacts on ecosystems and species have always drawn the attention of ecologists and conservationists worldwide, especially with the great increase of urbanization and tourism in the last decades (Eigenbrod et al. 2011; Cumming et al.

2014). In tropical regions, studies have shown that urbanized areas close to aquatic ecosystems, such as sandy beaches, estuaries and intertidal sandstone reefs, have caused great impact on native fauna, promoting changes in the mechanisms of habitat selection by species and decreasing the density of

many taxa (Schlacher et al. 2007; Costa & Zalmon 2019). This, in part, results from changes in landscape caused by the construction of nearby buildings and roads, as well as the increase in the number of humans in these areas which boost the number of threats to species and ecosystems (Costa et al. 2020).

In most of these environments, significant research has been recently carried out (Ludwig & Iannuzzi 2006; Stelling-Wood et al. 2016; Heery et al. 2018). Nevertheless, most of these studies have either focused on how urbanized areas impact the presence and abundance of species or how diversity patterns are affected, with a scientific gap on how species' traits linked to growth and survival might be modified by human activities (Suciu et al. 2018). Overall, species traits are strictly related to species ecology and are usually used as predictors of ecosystem functioning (Violle et al. 2007). Therefore, the analysis of possible impacts on these features might be crucial for the effective management and conservation of species and ecosystems, particularly for those with limited knowledge.

For example, few works have been carried out about ecosystem' response to anthropogenic pressures in intertidal sandstone reefs (Portugal et al. 2016), even though these areas host great diversity of species and high productivity levels. The intertidal reefs are of great socioeconomic and ecological importance, providing shelter and feeding habitats for many groups of species, especially for macroinvertebrate organisms which are typically used as bioindicators of human impacts on marine ecosystems (Orfanidis et al. 2001; Ar Gall et al. 2016). Like the decapod *Eriphia gonagra* (Brachyura: Eriphiidae) in the northeastern Brazil, which is one of the most abundant crab species found in intertidal zones with an important role in the ecosystem due to its predatory role (Araújo et al. 2016). Recent studies have shown the species in the *Eriphia* genus may be highly sensitive to human-induced disturbances, with impacts leading to the complete exclusion of some species in urbanized beaches (Stevčić et al. 2018), which makes these species a great biological indicator of impacts caused by urbanization.

In this respect, the aim of the present study was to evaluate the effects of urbanization on morphological traits of *Eriphia gonagra* found in intertidal sandstone reefs from the northeastern Brazil. Our work focused on traits that are strongly related to the growth and reproductive success of

crabs, being linked to the mating success, competition mechanisms, as well as mortality and fecundity rates of species. Specifically, we statistically compared morphological traits of female and male individuals of *E. gonagra* from two areas with different degree of urbanization. We hypothesized that the population traits of individuals in the urbanized reef would differ from the ones in the non-urbanized as a response to urbanization.

Materials and Methods

Study area and sampling: Two intertidal sandstone reefs located in the city of Maceió in the northeastern Brazil were included in the present study (Figure 1a). Both areas have been previously studied and they show similar physical-chemical characteristics but differ in their degree of urbanization and pollution (Paulino et al. 2020). The first reef (Figure 1b) is located in the Ipioca beach (9°31'55"S; 35°35'27"W) and is included in the largest marine protected area (MPA) in the region – the Área de Proteção Ambiental Costa dos Corais (APACC). The APACC is one of the most important MPA of Brazil, hosting approximately 120 km of coastal and marine ecosystems in its extension (Retka et al. 2019). The other reef system (Figure 1c) is located in the Ponta Verde beach (9°39'53"S; 35°41'41"W), which began its urbanization process in the early 1980s, but had a significant increase in its development during the last two decades (Cavalcante 2015). Currently, the area is characterized by a high degree of urbanization with an extensive real estate expansion that increased the numbers of buildings, industries and inhabitants in the area (Rechenberg 2019). This has resulted in many human-induced impacts on the beach and reef ecosystems, such as the direct inputs of untreated sewage in the water (Marinho et al. 2012) and high pollution rate, mainly represented by the great number of coliforms found in water (Paulino et al. 2020).

Samples of *Eriphia gonagra* were monthly carried out from September 2015 to August 2016 during low tide (≤ 0.3 m) by two active collectors in daytime (Teixeira et al. 2017). To reduce sampling bias and standardize samples, in both localities, four sampling points were previously established along the reef extension with similar cover perimeter, and sampling procedure in each point lasted for a fixed time of 30 minutes. In field, specimens were identified based on their morphological features, and captured by hand, using tongs whenever necessary. Environmental parameters for each reef (salinity,

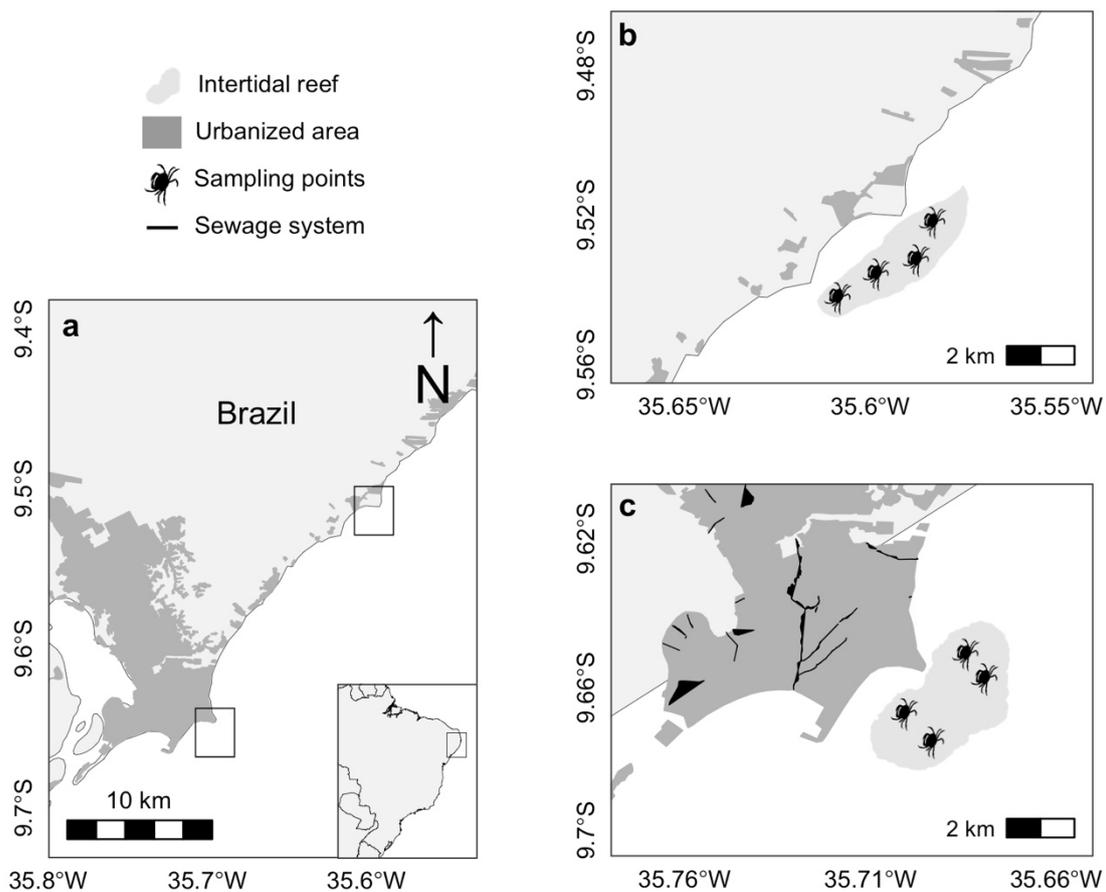


Figure 1. Map of studied area (a), showing the location of both studied reef systems in the northeastern Brazil. The Ipioca reef (b), which has lower degree of urbanization, and the highly urbanized Ponta Verde reef (c).

pluviosity, and air and water temperature) were retrieved from nearest stations of the National Institute of Meteorology (INMET). In laboratory, individuals were sexed, measured with a digital caliper (0.01 mm precision) and weighted with a digital balance (0.01 g precision). Analyzed traits were selected based on their well-known ecological importance for crab species (see Table I for details), focusing on growth performance and reproductive success of species. Thus, we measured the maximum carapace length (mm), carapace width (mm), and body wet weight (g) of all individuals, and the gonopod length for males (mm) and abdomen width for females (mm).

The presently reported study has been carried out in accordance with Brazilian regulations following the principles of the Basel Declaration and recommendations of the Chico Mendes Institute for Biodiversity Conservation committee under the normative #03/2014-SISBIO.

Data analysis: Environmental characterization of both reefs was carried out using principal components analysis (PCA), and variability in each environmental parameter was tested by the non-parametric test of Kruskal-Wallis. Before modeling the effect of environmental variables and urbanization on traits of *E. gonagra*, all statistical assumptions were previously analyzed and collinearity between variables was tested (Zuur et al. 2009). Since size sexual dimorphism has been reported for the species, traits were modelled individually for females and males using a generalized linear mixed model (GLMM) with “urbanization” as a fixed factor and the inclusion of measured environmental parameters as explanatory variables. The most parsimonious model for each trait was selected by the Akaike Information Criteria (AIC) from a set of produced models and the regression coefficient and confidence intervals of models were extracted in order to evaluate whether

Table I. Ecological meaning of measured morphological traits of *Eriphia gonagra*.

Trait	Ecological meaning	Reference
Carapace width	Related to individuals' mortality rate, recruitment, age, longevity, mating success, competition, molting and growth	Moyano & Gavio 2012; Tina 2020
Carapace length	Associated to the mortality rate, recruitment, age or longevity, competition of crab species	Ocaña et al. 2016; Vogt & Vogt 2019
Abdomen width	Related to females' fecundity, and morphological sexual maturity	Negreiros-Fransozo et al. 2003; Leme 2005
Gonopod length	Associated to males' mating success and morphological sexual maturity	Ribeiro et al. 2013; Pralon et al. 2019
Weight	Linked to fecundity rate, competition ability and growth of individuals	Araújo et al. 2012; de Macedo Costa et al. 2014; Ocaña et al. 2016

the effect caused by variables was either positive, negative or absent. Analysis were all carried out at a significance level of $p < 0.05$ in the software R statistics, using the packages 'lme4' and 'MuMIn' (Barton & Barton 2013).

Results

Both reefs had similar environmental conditions (Fig. 2a) with no significant variability in studied parameters between them (Kruskal-Wallis test, $p > 0.05$, Fig. 2). A total of 389 individuals of *E. gonagra* were collected during the sampling period. Out of those, 212 were collected in the Ponta Verde reef (urbanized) and 177 were found in the Ipioca reef (non-urbanized). The number of female and male individuals caught per location, as well as the range of measured traits is provided in Table II. For both reefs, less than 10 ovigerous females were caught, being 8 individuals found in the Ponta Verde reef and 9 specimens caught in the Ipioca reef.

All fitted models for females showed no significant relationship between variables and individuals' traits ($p > 0.05$), as well as no evidence of urbanization effects (Figure 3a). On the other hand, for males, the body weight, and carapace width and length, as well as the gonopod length were all positively related to salinity ($p < 0.05$, Figure 3b), and urbanization had a negative effect on all analyzed traits (Figure 2b), indicating that male individuals are significantly smaller and less heavy in the urbanized reef of Ponta Verde (Table II).

Discussion

The comprehension of how human activities may impact ecosystems and species is one of the key components of conservation science (Halpern et al. 2008). Hence, our study aimed to contribute to the current knowledge on impacts caused by anthropogenic pressure in natural environments by

analyzing possible effects of urbanization on the population traits of *E. gonagra* in tropical intertidal sandstone reefs. Overall, urbanization has been pointed out in many studies as one of the major factors affecting densities of crab populations across many habitats (Stelling-Wood et al. 2016; Costa et al. 2020). Our study adds new information to these results showing that not only the abundance of species may be affected, but their morphological traits related to species growth and reproductive success also respond negatively to human-induced impacts.

Species traits are strictly related to ecological characteristics of individuals, having a direct impact on survival rate, reproductive success, and predator-prey interactions (Toscano & Griffen 2014; da Silva et al. 2019). Therefore, traits response to urbanization is important to be understood, as changes in traits have high potential to affect not only the dynamics of populations, but also the functioning of ecosystems (Violle et al. 2007). For instance, in *E. gonagra*, observed changes found in traits of male individuals may indicate direct impacts on reproductive aspects of this species, as males from the urbanized reef were significantly smaller and less heavy than the ones found in the non-urbanized area. In crab species, the greater size of male individuals is considered one of the most effective reproductive strategies of species to ensure mating success by attracting females or gaining access to them through competition (Berglund et al. 1996; Jennions & Backwell 1996; Hartnoll 2006). Therefore, the smaller size of male individuals found in the urbanized reef may reflect different responses of species to urbanization impacts, such as a higher mortality rate of juveniles, earlier sexual maturity of individuals and lower investment in body growth (Schlachter et al. 2016; Costa & Zalmon 2019).

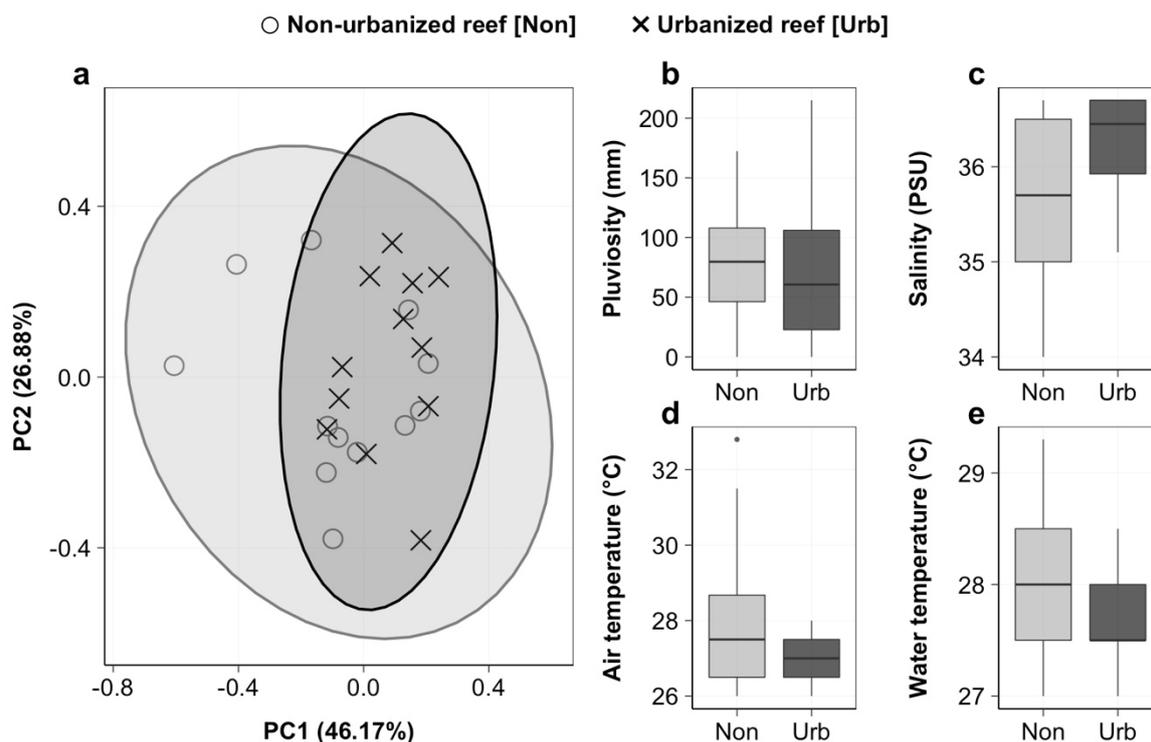


Figure 2. Environmental characterization of both studied reefs. Principal component analysis of samples in relation to environmental conditions (a), and variability in pluviosity (b), salinity (c), air (d) and water temperature (e) between the non-urbanized reef of Ipioca (Non) and the urbanized reef of Ponta Verde (Urb).

Table II. Number of females and males of *E. gonagra* collected during the study period with their respective range of measured traits: carapace width (CW); carapace length (CL), weight (W), females’ abdomen width (AW), and gonopod length (GL) of males.

Location	Sex	N	Traits				
			CW (mm)	CL (mm)	W (g)	AW (mm)	GL (mm)
Ipioca reef (non-urbanized)	Females	69	10.4–33.5	7.7–27.5	0.5–17.4	2.5–15.6	–
	Males	108	11.5–40.3	8.6–30.4	0.6–27.7	–	3.6–17.6
Ponta Verde reef (urbanized)	Females	87	12.8–40.6	9.4–29.9	0.8–24.1	2.9–14.9	–
	Males	125	12.2–38.5	9.4–28.5	0.6–23.9	–	3.0–13.2

The absent of urbanization effects on traits of females of *E. gonagra* may be surprising since males were highly impacted by this factor. However, the greater sensibility of male crabs to disturbance in relation to females has been previously reported for many brachyuran species (Dinuzzo et al. 2020). Although most threats are typically related to fishing pressures, due to the greater size and more active behavior of males (Sara 2010; Sara et al. 2019), there are many other stressors created by urbanization that can have a negative effect on those individuals (Schlacher et al. 2016). Indeed, studies have highlighted that beach cleaning, human presence and sediment pollution in urbanized ecosystems may act synergistically on different parts of the same population, causing diseases,

physiological stress and the reduction of crab species’ resilience (Schlacher et al. 2011; Suciú et al. 2017; Costa & Zalmon 2019). For example, different responses to human-induced impacts were also found between male and female individuals of the Atlantic ghost crab *Ocypode quadrata* (Gül & Griffen 2020). According to authors these different responses between sexes might be related to energy allocation strategies, as female tend to direct more energy to egg production instead of growth, while males may spend more energy for growing in size to increase chances of reproductive success, which would make male individuals more sensitive to impacts on traits related to growth and reproduction (Gül & Griffen 2020).

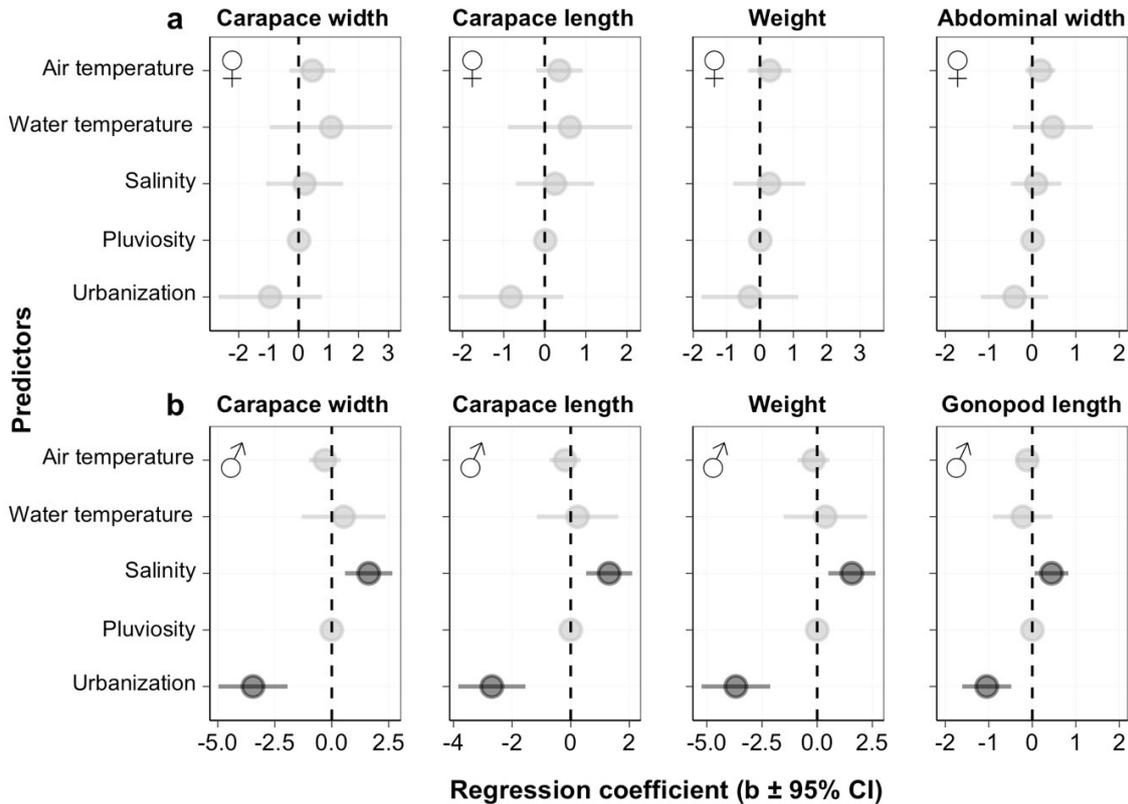


Figure 3. Coefficient estimates (95% confidence intervals), showing the direction and magnitude of effects of explanatory variables on traits of females (a) and male (b) individuals of *Eriphia gonagra* in intertidal sandstone reefs with different degrees of urbanization. Black lines and dots represent a significant effect of variables, and the position of dots represent the direction of the effect. Right-positioned dots represent a positive effect while left-positioned dots represent a negative effect. Gray lines and dots represent no effect.

In addition, urbanized areas have great potential to change ecosystem integrity of aquatic habitats by changing their abiotic parameters and water quality, which may have direct impacts on species (Pednekar et al. 2005; Ren et al. 2014). For instance, although a positive relationship between salinity and traits of male individuals of *E. gonagra* was found in our study, the magnitude of this relationship was not stronger than the urbanization effect, with males being smaller in the urbanized reef despite its high salinity profile. Salinity is one of the main factors affecting crabs' growth and survival, with species growing larger in higher salinity environments (Cadman & Weinstein 1988; Castejón et al. 2015). Moreover, higher salinity values are also related to greater rates of food consumption of crab species (Guerin & Stickle 1992), which also have direct impacts on their growth and total well-being of individuals. Nevertheless, as the urbanized reef suffers from direct sewage inputs that increases its pollution rates (Marinho et al. 2012) and nitrogen levels (Costanzo et al. 2001), changes in water quality, productivity

levels and prey availability are expected, which would explain why traits of male individuals in the urbanized reef responded negatively despite its higher salinity profile. Indeed, a previous study carried out in the same area showed significant changes in the diet of *E. gonagra* found in urbanized reefs in relation to other non-urbanized systems due to higher pollution levels (Santana 2018).

Eriphia gonagra responses to urbanization showed in the present study are concerning due to its predator role played in intertidal reef ecosystems (Araújo et al. 2016). This species has a considerable impact on lower trophic levels, and changes in its traits may affect ecosystems dynamics and resilience. Moreover, previous studies have also highlighted that species in the *Eriphia* genus might be very sensitive to human-induced impacts, which can cause, in some cases, the total exclusion of individuals in highly urbanized areas (Stevčić et al. 2018). Since urbanization of coastal areas are increasing, with many intertidal reefs suffering from greater modifications and disturbances, the management and planning of conservation actions

for these areas should take in consideration that urbanization has great potential to alter not only patterns of abundance and distribution of species, but also the whole ecosystem functioning.

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