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STATIONARY SUBSTRATES FACILITATE BIOINVASION IN PARANAGUÁ BAY IN SOUTHERN BRAZIL*

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ABSTRACT

Artificial substrates in and near ports and marinas commonly have many non-indigenous species and are the first stepping stone for the establishment of bioinvasors. Substrate movement influences fouling communities and so understanding of how species assemblages are related to specific substrate conditions is crucial as a management tool. Here we describe the species assemblage of the community after six months of development on granite plates in Paranaguá Bay. Species richness was similar in the two treatments, with 12 species on floating (constant depth) plates and 15 on stationary (variable depth) plates. However, species composition differed, with the community on floating plates being dominated by the native bivalve *Mytella charruana* (66.1 ± 5.5% cover) and that on stationary plates dominated by the barnacles *Fistulobalanus citerosum* (49.8 ± 3.5% cover) and the introduced *Amphibalanus reticulatus* (33.9 ± 3.7% cover). Other introduced species were *Garveia franciscana*, on one stationary plate, and *Megabalanus coccopoma* also on one stationary plate and not very abundant on half of the floating plates (< 2%). Thus, stationary plates were more susceptible to introduced species that may become very abundant, suggesting that this type of substrate should be a priority in management for bioinvasion control. We also hypothesize that the native bivalve *M. charruana* is the dominant competitor for space on floating substrates, thereby reducing the invasiveness of that type of substrate.

RESUMO

Substratos artificiais em regiões de portos e marinas geralmente abrigam muitas espécies introduzidas e sua colonização constitui o primeiro passo no estabelecimento de bioinvasores. O grau de movimentação do substrato influencia a comunidade incrustante e o conhecimento da assembléia de espécies associada a cada situação é crucial como ferramenta de manejo. Neste trabalho, reportamos a estrutura de comunidades de seis meses desenvolvidas em substratos de granito na baía de Paranaguá. Foram encontradas 12 espécies na condição flutuante (profundidade constante) e 15 na condição fixa (profundidade variável), mas o número médio de espécies por placa não foi diferente nos tratamentos. A comunidade das placas flutuantes foi dominada pelo bivalve nativo *Mytella charruana* (66.1 ± 5.5% de cobertura), enquanto as placas fixas foram dominadas pelos cirripédios *Fistulobalanus citerosum* (49.8 ± 3.5%) e *Amphibalanus reticulatus* (33.9 ± 3.7%), este último introduzido na região. Outras espécies introduzidas encontradas foram *Garveia franciscana,* em apenas uma placa fixa, e *Megabalanus coccopoma* também em uma placa fixa e em metade das placas flutuantes, mas sempre com baixa cobertura (< 2%). Em conclusão, placas fixas foram mais suscetíveis às espécies introduzidas, uma delas ocorrendo em alta abundância, o que sugere que este tipo de substrato deveria ser priorizado em ações de controle e manejo de bioinvasão. Também hipotetizamos que o bivalve nativo *M. charruana* é o competidor dominante por espaço na condição flutuante, reduzindo a susceptibilidade deste substrato à bioinvasão.

Descriptors: Bioinvasion, Artificial substrate, Estuary, Fouling, Exotic species.
Descritores: Bioinvasão, Substrato artificial, Estuário, Comunidade incrustante, Espécies exóticas.

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INTRODUCTION

In recent years urban structures in coastal waters have been considered relatively novel marine habitats, in that they support assemblages, both intertidal and subtidal, which are different in important ways from those on nearby natural surfaces (CONNELL; GLASBY, 1999; GABRIELE et al., 1999; GLASBY, 1999; CONNELL, 2001a; BACCHIOCCHI; AIROLDI, 2003; BULLERI; CHAPMAN, 2004). Encrusting communities on these artificial structures differ in diversity, species composition and abundance. More recently it has been shown that part of the difference may often be explained by the greater abundance of non-indigenous species (NIS) on artificial substrates. NIS transported by international ships must find adequate substrates on which to live where they are introduced and the urban structures associated with ports and marinas may frequently provide these substrates (BULLERI; ARIOLDI, 2005; GLASBY et al., 2007; TYRREL; BYERS, 2007).

Some substrate characteristics may act as filters such that a different pool of the regionally available species can determine the species composition of encrusting communities at any location. Among such characteristics, texture (SKINNER; COUTINHO, 2005), orientation (GLASBY; CONNELL, 2001; MAUGAN, 2001; KNOTT et al., 2004) and substrate composition (RAIMONDI, 1988; GLASBY, 2000) all have important effects on recruitment and subsequently on the structure of the developing communities. Also the stability of the substrate, whether fixed or floating, is an important difference between natural and artificial hard substrates, when other variables such as substrate composition and texture are controlled (CONNELL, 2000; GLASBY; CONNELL, 2001; HOLLOWAY; CONNELL, 2002; COLE et al., 2005).

Both stationary and floating substrates are common in marinas and the role of floating pontoons as attractors of NIS is recognized. However, a clear increase in the ratio between NIS and native species richness toward moving substrates, in a gradient of fixed, moving and rotating settlement plates is not always found (GLASBY et al., 2007). On the other hand, movement seems to be an important factor for some species: the exotic invertebrates *Styela plicata* and *Bugula neritina* tended to be more abundant on floating pontoons than on rocky reefs in southeastern Australia (GLASBY; CONNELL, 2001).

In this study we describe an experiment comparing communities between both conditions (floating and stationary substrates) after six months in which substrate composition, orientation and size were controlled, at a marina in southern Brazil. We specifically tested whether the floating or stationary condition of the substrate influenced total species richness, NIS richness and cover.

MATERIALS AND METHODS

The experiment was carried out in a private marina, the Paranaguá Yatch Club, located on the Itiberê River, near its mouth in Paranaguá Bay. Although in the river, marina waters are tidal due to its nearness to Paranaguá Bay where salinities range from 12 to 34 ups (LANA et al., 2001). The marina is also very close to Paranaguá port, a major international port in southern Brazil (map and description in NEVES et al., 2007). At the marina, stationary substrates comprised the concrete columns that sustain the two main walkways for boat access. Floating substrates are of fiberglass with a wooden boardwalk.

In the experiment, substrate for settlement comprised rough cut (unpolished) granite plates (23 x 11.5 cm) in two treatments. Ten plates were attached with cable ties to the concrete columns (hereafter “stationary plates”), in a vertical position, 1m deep in low tide so they always remained underwater during the experiment. Another 10 plates were each attached to a brick and suspended vertically from the floating docks (hereafter “floating plates”) at 1m depth. The bricks provided increased weight to maintain the plate in position during strong tidal currents. All plates were placed in September 2007 and retrieved in March 2008, with no other manipulation during this interval.

Plates, when retrieved, were fixed in 4% formalin for later analysis. A grid with 50 cells was mounted on each plate and every other cell was analyzed. Species cover in each cell was visually estimated and ranked as follows: 0 = absent, 0.5 = present, very low abundance, 1 = up to 25% cover, 2 = 26 to 50% cover, 3 = 51 to 75% cover, 4 = 76 to 100% cover. Thus, total cover of the species is simply the sum of the ranked values of the 25 cells on the plate. Cover was compared between treatments by Student’s *t*-test, following the appropriate transformation if necessary.

RESULTS

Two plates were lost in each treatment, so sample sizes will be based on the eight plates that remained in each. Both treatments had similar numbers of taxa, with 15 on stationary plates and 12 on floating plates (species ± SE, stationary 9.5 ± 0.32; floating 8.5 ± 0.42, Table 1). Most of the species occurred on both treatments except *H. verrilli* and the tubiculous amphipods which were most frequent on stationary plates while *M. coccopoma* and anemone sp. 1 were mostly found on floating plates. *Garveia franciscana*, anemone sp. 2 and the Alcyonidae cnidarian only occurred on stationary plates.

Mytella charruana, A. improvisus and *Anemone* sp. 1 were more abundant on floating substrates while *F. citerosum, A. reticulatus* and *Membraniporidae* sp. were more abundant on stationary plates (all $P < 0.05$, Table 2). *M. charruana* dominated floating plates with more than 60% mean cover while space on stationary plates was dominated by *F. citerosum* and *A. reticulatus* which, together, covered more than 80% of the plates on average. While both substrates were dominated by native species, the NIS *A. reticulatus* contributed an important part of the cover on stationary plates. Another introduced species, *M. coccopoma* occupied less than 2% cover on average (only one floating plate was heavily colonized and the species reached 8% cover). Also introduced, *G. franciscana* was

Table 1. List and comparison of the taxa, and their invasive status, found in the two experimental treatments (maximum presence = 8) in Paranaguá Bay in southern Brazil.

Species	Status*	Floating	Stationary
Bivalvia			
Mytella charruana d'Orbigny, 1846	N	8	8
Cirripedia			
Fistulobalanus citerosum (Henry, 1973)	N	8	8
Amphibalanus reticulatus (Utinoni, 1967)	I	8	8
Amphibalanus improvisus (Darwin, 1854)	C	8	8
Megabalanus coccopoma (Darwin, 1854)	I	4	1
Bryozoa			
Hippoporina verrilli Maturo & Schopf, 1968	C	1	5
Membraniporidae	---	8	8
Cnidaria			
Garveia franciscana Torrey, 1902	I	0	1
Obelia spp.	---	7	8
Alcyonidae	---	0	3
Anemone sp 1	---	8	2
Anemone sp 2	---	0	7
Amphipoda[§]	---	3	7
Jassa sp	---		
Laticorophium sp	---		
Monocorophium sp	---		

* I – introduced, C = cryptogenic, N = native.

[§] The species could not be separated during plate analyses

Table 2. Cover of the abundant species compared between floating and stationary experimental substrates ($\alpha = 0.05$) in Paranaguá Bay, southern Brazil.

Species	Floating (% cover ± SE)	Stationary (% cover ± SE)	*t*- value	comparison
Mytella charruana	66.1 ± 5.5	12.8 ± 1.9	9.08	F > S
Fistulobalanus citerosum	22.7 ± 4.3	49.8 ± 2.3	5.50	F < S
Amphibalanus reticulatus	14.1 ± 3.1	33.9 ± 3.7	4.09	F < S
Amphibalanus improvisus	5.1 ± 0.7	2.9 ± 0.3	2.81	F > S
Megabalanus coccopoma	1.2 ± 1.0	0.2 ± 0.2	1.07	F = S
Membraniporidae bryozoan	5.6 ± 2.0	28.1 ± 6.8	3.17	F < S
Obelia sp.	8.5 ± 3.9	15.3 ± 5.3	1.03	F = S
Anemone sp. 1	2.9 ± 0.8	0.2 ± 0.1	3.24	F > S

DISCUSSION

As expected for artificial substrates, here three introduced and one cryptogenic species were all found on stationary plates but only *A. reticulatus* with an important contribution to cover. Floating plates neither had *G. franciscana* nor an important cover of any of the other NIS. Another important difference between 6-month-old communities formed on stationary or floating plates was which species dominated. Thus, stationary plates were dominated by two species of barnacles, one of them the introduced *A. reticulatus*, while floating plates were dominated by a native bivalve. These results contrast with patterns observed in southeastern Australia, where the number of NIS increased with increasing substrate movement (GLASBY et al., 2007). The difference may be due to the identity of NIS species in both regions, since there were no important non-native barnacle recruiters or space holders in Australia. Previous work at this site also found more introduced species on fiberglass floats than on stationary concrete columns (NEVES et al., 2007), however that study surveyed the intertidal zone of the concrete columns, and perhaps the severity of recurrent exposure during low tide restricted the pool of introduced species to only two barnacles.

The barnacle *A. reticulatus* is considered to be a recent introduction on the Brazilian coast. Since its first record in Pernambuco in 1990 (C. Farrapeira, personal commun.), it has spread southwards and was first found in Paraná during our first survey of the Paranaguá Yatch Club marina in 2004 (NEVES et al., 2007; NEVES; ROCHA, 2008). In that study, concrete columns, fiberglass floats and hulls of boats were sampled. *Amphibalanus reticulatus* abundance was similar in all three habitats, including the intertidal sample (NEVES et al., 2007). Furthermore, *A. reticulatus* can withstand eutrophic conditions (MAYER-PINTO; JUNQUEIRA, 2003) and is tolerant of environmental variation and therefore has invasive potential.

The mytilid bivalve domination of floating structures was also observed in southeastern Australia (CONNELL, 2000, 2001a; GLASBY; CONNELL, 2001; HOLLOWAY; CONNELL, 2002). The abundance of *Mytella charruana* on floating plates suggests that it is a dominant competitor for space in this habitat and thus it may limit invasion by *A. reticulatus.* On the stationary plates, however, *F. citerosum* might be a less efficient competitor, thereby allowing *A. reticulatus* to increase in abundance. This hypothesis remains to be tested with manipulative experiments.

The pool of species found on the plates comprises a quarter of the total number of species present in fouling communities in Paranaguá Bay, but includes 38% of the introduced species known to the region (Cangussu, unpublished data). This simplified assemblage might be explained in three ways. Firstly, by seasonality, since the experiment took place only during spring and summer. Second, by succession, in which very opportunistic and short-lived species were not analyzed due to the nature of the experiment. Thirdly, by the limited heterogeneity of the available substrate. Thus, the relatively large number of introduced species and the abundance of at least one of them are causes for concern.

The vertical orientation of plates in both treatments results in more similar communities (and therefore better comparisons) between artificial and natural substrates than horizontal substrates (KNOTT et al., 2004). Also, both treatments were always submerged and so avoided the swash that may explain differences between fixed pilings and floating pontoons (HOLLOWAY; CONNELL, 2002). Finally, since both treatments comprised the same material, texture and size of plates, differences in communities should only be attributed either to plate movement or to depth variation in the stationary treatment.

Tidal range in Paranaguá Bay is around 2 m and the effects of depth in fouling communities at this spatial scale have rarely been studied. Yet, larval zonation in barnacles can determine the vertical distribution of adults in a range of 3 m between minimal and maximal tide (GROSBERG, 1982). If larval depth stratification occurs in Paranaguá Bay for barnacles and other groups, then stationary plates exposed to a greater range of depths should result in greater species richness than floating plates, as observed here.

Another potential influence that differs between floating and stationary plates is the associated hydrodynamic conditions. Stationary plates were fixed, but randomly placed in relation to orientation on the columns with respect to tidal currents, while hanging plates could rotate and face different directions as well as move somewhat along with the current. Larval settlement on substrates can be dependent on flow (ABELSON; DENNY, 1997; JUDGE; CRAIG, 1997; ZILMAN et al., 2008) and post-settlement processes, such as survival and growth, also depend on water flow for filter feeders (OKAMURA, 1984, 1985; SANFORD, 1994). These subtle differences may influence the final species assemblages in the two treatments, and suggest avenues for research into how invasive species may take advantage of conditions that native species do not.

Alternatives to explain the differences between floating and stationary substrates were unable to account for community differences. Differential fish predation on pilings and on floating pontoons, for instance, in which fouling communities were not consistent with predation, was tested in southeastern

Australia (CONNELL, 2001b). The poor visibility of the water at our site suggests that fish predation is not important as a factor structuring communities here, either. Since stationary plates were on columns that reached the sea floor, benthic invertebrate predators might reach the plates and have a differential effect on treatments. Keough and Butler (1979) found that benthic predators had no discernible effect on pier piling communities while Cole et al. (2005) showed that epibiota cover decreased in the presence of grazing mollusks on floating pontoons. Thus the role of predation shaping the structure of sessile communities on artificial substrate is still not well understood, nor is its potential role in NIS control. Nor did substrate structure and material explain differences between floating and stationary substrates in southeastern Australia (CONNELL, 2001a; HOLLOWAY; CONNELL, 2002). These studies, therefore, strengthen our conclusions that the differences between treatments are real and due to differences in the qualities of substrates depending on whether they float or are fixed.

We demonstrate here that floating structures promote the development of communities that are different from those on stationary structures and that introduced species respond differently to these treatments. For example, the barnacle *Amphibalanus reticulatus* was 2.5 times more abundant on stationary plates attached to concrete columns than on floating plates. Thus, different types of artificial substrates may demand different management strategies in relation to NIS detection and control. Information provided by studies of this type will better inform managers who must make decisions about what type of structures should be given priority for cleaning or NIS population monitoring.

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