Effects of human trampling on a rocky shore fauna on the Sao Paulo coast, southeastern Brazil

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(With 6 figures)

Abstract

Increased tourist activity in coastal regions demands management strategies to reduce impacts on rocky shores. The highly populated coastal areas in southeastern Brazil are an example of degradation caused by development of industry and tourism. Among different shore impacts, trampling has been intensively studied, and may represent a significant source of stress for intertidal fauna. A randomised blocks design was applied to experimentally study the effects of two different trampling intensities on richness, diversity, density and biomass of the rocky shore fauna of Obuseiro beach, Guarujá, southeastern Brazil. Blocks were distributed in two portions of the intertidal zone, dominated respectively by *Chthamalus bisinuatus* (Cirripedia) and *Isognomon bicolor* (Bivalvia). Blocks were trampled over three months, simulating the vacation period in Brazil and were monitored for the following nine months. Results indicate that *Chthamalus bisinuatus* is vulnerable to trampling impacts. Richness, diversity and turn-over index tended to be higher in trampled plots four months after trampling ceased. In general, results agree with previous trampling studies, suggesting that even low intensities of trampling may cause some impact on intertidal communities. Management strategies should include isolation of sensitive areas, construction of boardwalks, visitor education and monitoring programmes. In Brazil, additional data obtained from experimental studies are necessary in order to achieve a better understanding of trampling impacts on rocky shore communities.

Keywords: rocky shore, intertidal community, trampling, tourism impacts.

Impactos do pisoteio humano na fauna de um costão rochoso do litoral de São Paulo, no sudeste brasileiro

Resumo

O aumento da atividade turística em áreas costeiras nas últimas décadas faz necessária a adoção de estratégias de manejo para reduzir os impactos gerados às comunidades de costões rochosos. A região costeira do sudeste brasileiro possui bons exemplos de degradação causada pelo turismo e desenvolvimento industrial. Dentre os diferentes distúrbios causados pela visitação, o pisoteio têm sido estudado de forma intensa e pode representar uma fonte significativa de impactos para as comunidades da zona entre-marés. Neste projeto, foi aplicado um desenho de blocos randômicos para se avaliar experimentalmente os efeitos de duas intensidades de pisoteio na riqueza, diversidade, densidade, recobrimento e biomassa da fauna de um costão situado na praia do Obuseiro, no município do Guarujá, São Paulo, Brasil. Os blocos foram alocados em dois povoamentos diferentes, dominados respectivamente por *Chthamalus bisinuatus* (Cirripedia) e *Isognomon bicolor* (Bivalvia). O pisoteio foi aplicado durante três meses, simulando a temporada de férias no Brasil, e os blocos foram monitorados nos nove meses seguintes. Os resultados indicaram que *Chthamalus bisinuatus* é vulnerável aos impactos do pisoteio. Os índices de riqueza, diversidade e turnover apresentaram uma tendência ao aumento nas áreas pisoteadas quatro meses após o término do pisoteio. No geral, os resultados concordam com estudos anteriores e sugerem que mesmo baixas intensidades do distúrbio podem causar impacto às comunidades bentônicas. Estratégias de manejo devem envolver o isolamento de áreas sensíveis, a construção de passarelas, a educação dos visitantes e o monitoramento das comunidades impactadas. No Brasil, a realização de maior quantidade de estudos experimentais é necessária para a melhor compreensão dos impactos do pisoteio nas comunidades de costões rochosos.

Palavras-chave: costão rochoso, comunidades intertidais, pisoteio, impactos turísticos.

1. Introduction

Rocky shores are subject to increasing anthropogenic impacts originating from both the land and the sea. These habitats have been, and are currently, affected by pollution, over-collection of living resources, introduction of alien species, modification of coastal processes and global changes (Thompson et al., 2002).

Increased tourist activity may also represent a significant source of impact to rocky shore communities. The effects of human trampling on intertidal fauna have been intensively studied, especially in temperate zones (Povey and Keough, 1991; Brosnan and Crumrine, 1994; Fletcher and Frid, 1996; Keough and Quinn, 1998; Schiel and Taylor, 1999). Most studies have observed a reduction in abundance of some taxa, such as polychaetes (Brown and Taylor, 1999), bivalves (Beauchamp and Gowing, 1982) and barnacles (Brosnan and Crumrine, 1994) that may affect population dynamics and diversity of the entire community.

Different species of non-crustose algae were also vulnerable to trampling, showing reduction in values of abundance, cover and biomass (Povey and Keough, 1991; Fletcher and Frid, 1996; Keough and Quinn, 1998; Schiel and Taylor, 1999). Some groups, such as limpets and crustose algae, indirectly benefited from trampling, usually occupying empty areas created after the displacement of conspicuous species (Keough and Quinn, 1998).

Few studies have been developed on barnacle and bivalve assemblages, even though organisms in these groups are considered vulnerable to trampling, since they are small, sessile and easily squashed (Povey and Keough, 1991). Previous research has mostly focused on large conspicuous organisms, even though smaller cryptic animals also deserve attention due to their great abundance, high productivity and importance as food for higher trophic levels (Brown and Taylor, 1999).

The presence of beaches and other natural resources on practically the whole Brazilian coast attracts large number of tourists, especially at vacation periods and close to major cities, such as Sao Paulo. Guaruja municipality, for instance, has a population close to 230,000 people and receives more than 150,000 tourists during the summer season (IBGE, 2002).

The highly populated coastal areas in Brazil are an example of degradation caused by development of industry and tourism with several environmental impacts on coastal communities. However, the effects of human trampling on Brazilian rocky shores have not been previously examined. Therefore, this study aimed to investigate the effects of trampling on communities associated to *Chthamalus bisinuatus* Pilsbry (Cirripedia) and *Isognomon bicolor* (Adams) (Bivalvia) from a rocky shore in southeastern Brazil.

2. Material and Methods

2.1. Study site

The study was conducted at Obuseiro beach in the city of Guarujá (24° 02' 19.0" S and 46° 17' 16.2" W), located on the central coast of São Paulo state, in southeastern Brazil. Obuseiro beach is situated within the limits of a military area ("1º Batalhão de Artilharia Anti-Aérea do Forte dos Andradas", Brazilian Army), and the access to the beach is granted only to some local fishermen.

The study site consists of a gently sloping large granite rock, dominated by *Chthamalus bisinuatus* on the upper-shore and *Isognomon bicolor* on the mid-shore.

2.2. Experimental design

Ten randomised blocks were equally distributed in two portions of the intertidal zone, dominated respectively by *Chthamalus bisinuatus* and *Isognomon bicolor*. Both species were selected for this study since they are conspicuous, perennial and widely distributed on rocky shores in southeastern Brazil. *I. bicolor* is an exotic species that has been recorded on Brazilian rocky shores for the last ten years, especially in the zone originally occupied by the mussel *Perna perna* (Linnaeus) that has been over-exploited as a food resource in many areas (Martins, 2000).

Blocks were trampled in a single day over three months, simulating the summer vacation period in Brazil, and were monitored for the following nine months. Data collection was always performed before trampling, so data from the first month relates to community conditions before trampling impacts.

Each block consisted of three experimental units (EU), 4,900 cm^2 each, separated by a 20 cm stripe. In each block, different trampling intensities were applied in the EUs, as follows: treatment 0 (no trampling, control units); treatment 1 (50 steps per month); treatment 2 (250 steps per month). Since the steps were applied randomly in a 4,900 cm^2 area and foot size was 200 cm^2, it can be considered that on average each portion of EUs was trampled two times in treatment 1 and ten times in treatment 2. Trampling was performed by a 56 kg person using rubber-soled shoes.

An area of 900 cm^2 within the EU was selected for data collection. The position of this area and the treatment applied in each EU was randomly determined. The remaining portion of the EU in the *I. bicolor* assemblage blocks was used to perform total removals of individuals present in 100 cm^2, every 3 months during one year.

These samples were washed in a 0.5 mm mesh (GRANUTEST) in order to select macrofaunal organisms only. All organisms were counted after identification to species level, with the exception of Ophiuroidea, Turbellaria, Nemertea and Polychaeta which were identified to higher taxonomic levels.

Different variables were analysed, according to assemblage characteristics. Variables and their collection methods are presented as follows:

i) Cover of *C. bisinuatus*: cover estimates were monthly obtained through photographs taken from nine squares of 100 cm^2 for each EU. Photographs were scanned and *C. bisinuatus* cover percentage was measured in a central area of 25 cm^2, using the software ArcView GIS 3.2 (ESRI, 1999). Therefore, for each EU, *C. bisinuatus* cover was estimated from a total area of 225 cm^2 (nine squares of 25 cm^2).

ii) Cover of *I. bicolor*: cover estimates were obtained monthly through the division of the 900 cm^2 area in 225 small squares of 4 cm^2. Each square was classified from zero to two (zero representing none to 35% cover of *I. bicolor*, one representing 36 to 70% cover and 2 representing more than 70% cover of *I. bicolor*). The sum of these classes (that could vary from 0 to 450) was then transformed into a percentage value that indicated the cover percentage of *I. bicolor* in each EU.

iii) Richness of the community associated with *I. bicolor*: richness was calculated for each sample (100 cm^2), based on the number of taxons (mostly species) present in the sample.

iv) Diversity of the community associated with *I. bicolor*: Shannon-Wiener diversity index (H') was applied in its exponential form ($2^{H'}$ – Shannon apparent richness) which represents a good alternative to H' and allows direct comparisons to absolute values of richness.

v) Turnover index of the community associated with *I. bicolor*: this index represents the sum of community losses and gains over time (Giordano, 2001) and it is calculated with the following formula:

$$T = L/ S_{Tn} + G/ S_{Tn+1} \quad (1)$$

where:

L = number of taxons present in T_n and absent in T_{n+1} (lost taxons)
G = number of taxons absent in T_n and present in T_{n+1} (gained taxons)
S_{Tn} = number of taxons in T_n time
S_{Tn+1} = number of taxons in T_{n+1} time
As the sum of two fractions, the turnover index can vary from zero to two, where zero represents

Table 1. Invertebrate intertidal fauna from a rocky shore in Obuseiro beach, SP, Brazil. Common taxa occured in more than 40 samples, frequent taxa occurred in 20 to 39 samples, and rare taxa occurred in less than 20 samples (total: 60 samples).

Taxon	Class	Occurence
Polycladia	Turbellaria	Frequent
HOPLONEMERTEA	Enopla	Frequent
*Fissurella clenchi (*Farfante)	Gastropoda	Frequent
Collisella subrugosa (d'Orbigny)	Gastropoda	Common
Nodilittorina lineolata (d'Orbigny)	Gastropoda	Frequent
Stramonita haemastoma (Linnaeus)	Gastropoda	Rare
Onchidella indolens (Gould)	Gastropoda	Frequent
Perna perna	Bivalvia	Frequent
Brachidontes solisianus (d'Orbigny)	Bivalvia	Common
Isognomon bicolor	Bivalvia	Common
Lasea adansoni (Gmelin)	Bivalvia	Common
SYLLIDAE	Polychaeta	Common
NEREIDIDAE	Polychaeta	Common
CIRRATULIDAE	Polychaeta	Frequent
Tetraclita stalactifera (Lamarck)	Cirripedia	Rare
Chthamalus bisinuatus	Cirripedia	Rare
Pachygrapsus transversus (Gibbes)	Malacostraca	Common
ALPHEIDAE	Malacostraca	Rare
Elasmopus brasiliensis (Dana)	Amphipoda	Common
Elasmopus pectenicrus (Bate)	Amphipoda	Common
Hyale nigra (Haswell)	Amphipoda	Common
Apohyale media (Dana)	Amphipoda	Rare
Apohyale wakabarae (Serejo)	Amphipoda	Common
Parhyale hawaiensis (Dana)	Amphipoda	Frequent
Gammaropsis togoensis (Schellenberg)	Amphipoda	Rare
Clianella castroi (Loyola e Silva)	Isopoda	Common
OPHIUROIDEA	Ophiuroidea	Rare

the persistence of the same taxa in the community, while two represents the complete substitution of community taxa over time.

To better express the index descriptive value, a negative sign was attributed to the numeric value when the relative loss (L/S_{Tn}) surpassed the relative gain (G/S_{Tn+1}).

vi) Density of the macrofauna associated with *I. bicolor*: taxon density (number of individuals of the taxon/100 cm^2) was calculated for each collected sample.

2.3. Analyses

Considering the small numbers of replicates for each assemblage (n = 5), non-parametric tests were adopted in data analysis. Kruskal-Wallis and Mann-Whitney tests were used in order to identify significant differences between treatments.

Cover data from *C. bisinuatus* and *I. bicolor* followed repeated measures design and were analysed by a method proposed by Gurevitch and Chester Jr. (1986). The remaining variables were taken from independent samples collected every three months, and therefore could not be classified as repeated measures data.

Density values were analysed for each taxon separately, but only results that indicate some pattern are presented herein.

All data analysis was performed using STATISTICA 6.0 (StatSoft Inc., 2003), SPSS 12.0 (SPSS Inc., 2003) and MVSP 3.12a (KCS, 2000).

3. Results

Twenty-seven animal taxa were recorded in the studied assemblages (Table 1). Mean percentage cover of *C. bisinuatus* ranged from 15 to 50%. Trampling effects in *C. bisinuatus* cover were observed after the third month of trampling, especially for treatment 2 (Figure 1).

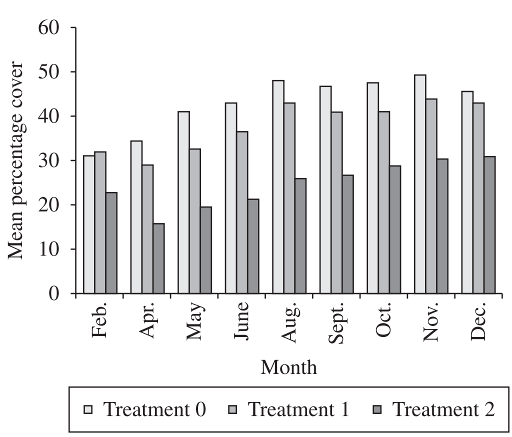

Figure 1. Mean cover percentage of *C. bisinuatus* over time at all trampling intensities observed at Obuseiro rocky shore, São Paulo, Brazil.

Recovery to original values of differences among treatments (Kruskal-Wallis test; february; p = 0.0493) was not observed even seven months after trampling ceased (Kruskal-Wallis test; November; p = 0.004). Repeated measures analysis also indicated that trampling promoted different patterns among treatments (Table 2), but the Tukey HSD test indicated significant differences only between treatments 0 and 2 (Tukey test; p = 0.0003).

Cover values of *I. bicolor* were usually high, ranging from 75 to 90% (Figure 2) and were not affected by trampling. However, mean values of percentages decreased with time in all treatments.

Mean richness values of the community associated to *I. bicolor* ranged from 13 to 18 taxa (Figure 3), while diversity values ranged from 4.5 to 5.8 (Figure 4). Both variables showed similar patterns four months after trampling ceased, with mean values for treatments 1 and 2 significantly higher when compared to original values (Table 3).

For all treatments, the turnover index values declined with time, changing from an initial pattern of gaining species (turnover positive values) to a pattern of losing species (turnover negative values). It is worth noting that while turnover values for treatment 0 were gradually reduced, treatments 1 and 2 values rose from May to August (Figure 5).

Density values varied widely among taxa, ranging from 0.2 to 413 indiviuals/100 cm^2. Highest values of

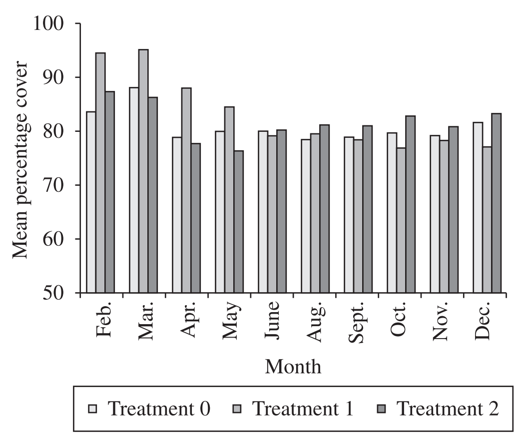

Figure 2. Mean cover percentage of *I. bicolor* over time at all trampling intensities observed at Obuseiro rocky shore, São Paulo, Brazil.

Table 2. Repeated-measures analysis for *C. bisinuatus* cover.

Total	df	MS	F	p
Treatment	2	30030.6	22,2970	0.000091
Error	12	8081.1	-	-
Total	14	-	-	-

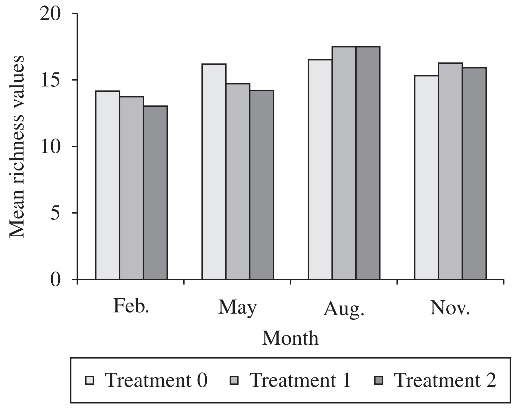

Figure 3. Mean values of richness of the community associated with *I. bicolor* over time at all trampling intensities observed at Obuseiro rocky shore, São Paulo, Brazil.

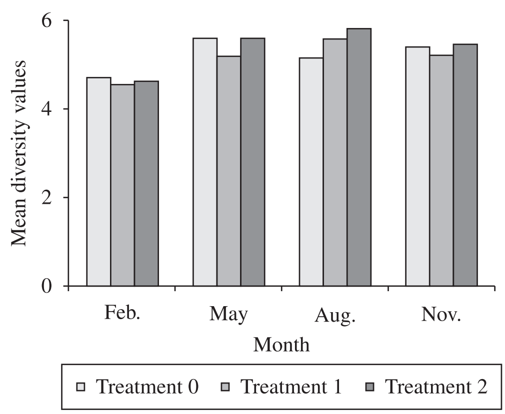

Figure 4. Mean values of diversity of the community associated with *I. bicolor* over time at all trampling intensities observed at Obuseiro rocky shore, São Paulo, Brazil.

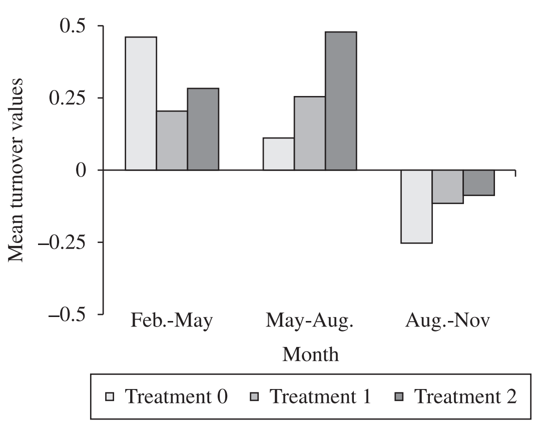

Figure 5. Mean turnover values of the community associated with *I. bicolor* over time at all trampling intensities observed at Obuseiro rocky shore, São Paulo, Brazil.

Table 3. Mann-whitney test results for richness and diversity values of the community associated with *I. bicolor* ($p < 0.05$)

	Mann-Whitney (p)		
Richness	**0**	**1**	**2**
Feb × May	0.2101	0.4034	0.4034
Feb × Aug	0.0947	0.0163	0.009
Feb × Nov	0.5309	0.0601	0.0601
Diversity	**0**	**1**	**2**
Feb × May	0.0163	0.1172	0.1172
Feb × Aug	0.1745	0.0283	0.0283
Feb × Nov	0.2506	0.1172	0.1745

density were presented by *I. bicolor*, indicating once again its dominance in the assemblage.

Trampling did not affect density values, that varied differently among taxa, but not among treatments. In general, three different patterns were observed: i) density reduction over time, presented by *I. bicolor*, *Brachidontes solisianus*, *Lasea adansoni* and *Hyale nigra*; ii) density increase over time, presented by *Collisella subrugosa*; and iii) constant values of density over time, presented by Syllidae polychaetes (Figure 6).

4. Discussion and Conclusions

Several studies indicated that invertebrate fauna associated with mussel communities may harbour from 32 to 99 species (Seed, 1996). However, in these studies all taxa were identified to species level, which may be responsible for the higher values found when compared to the *I. bicolor* community in this study (27 taxa). The structure of the bed may also interfere in these values, since mussel species usually form beds with several layers of individuals (Seed, 1996), increasing attachment and colonization surface for associated species while the *I. bicolor* bed is constituted by a single layer.

Trampling impacts on *C. bisinuatus* cover may be related to low resistance of individuals to direct effects of trampling. *Chthamalus* species were also affected by trampling on rocky shores in the United States, Australia and United Kingdom (Povey and Keough, 1991; Brosnan and Crumrine, 1994; Pinn and Rodgers, 2005), suggesting that morphological, physiological or reproductive aspects of the group may be responsible for its high vulnerability to trampling. Moreover, low cover values and indirect effects, such as limpets pasture could have also prevented *C. bisinuatus* recovery after trampling.

Resistance of *I. bicolor* to trampling may be explained by its high values of density and also by aspects, such as accommodation and lateral movement, that correspond to rapid colonization of small patches by adult individuals (Connell and Keough, 1985).

Increase in richness and diversity values after trampling have already been observed in previous studies

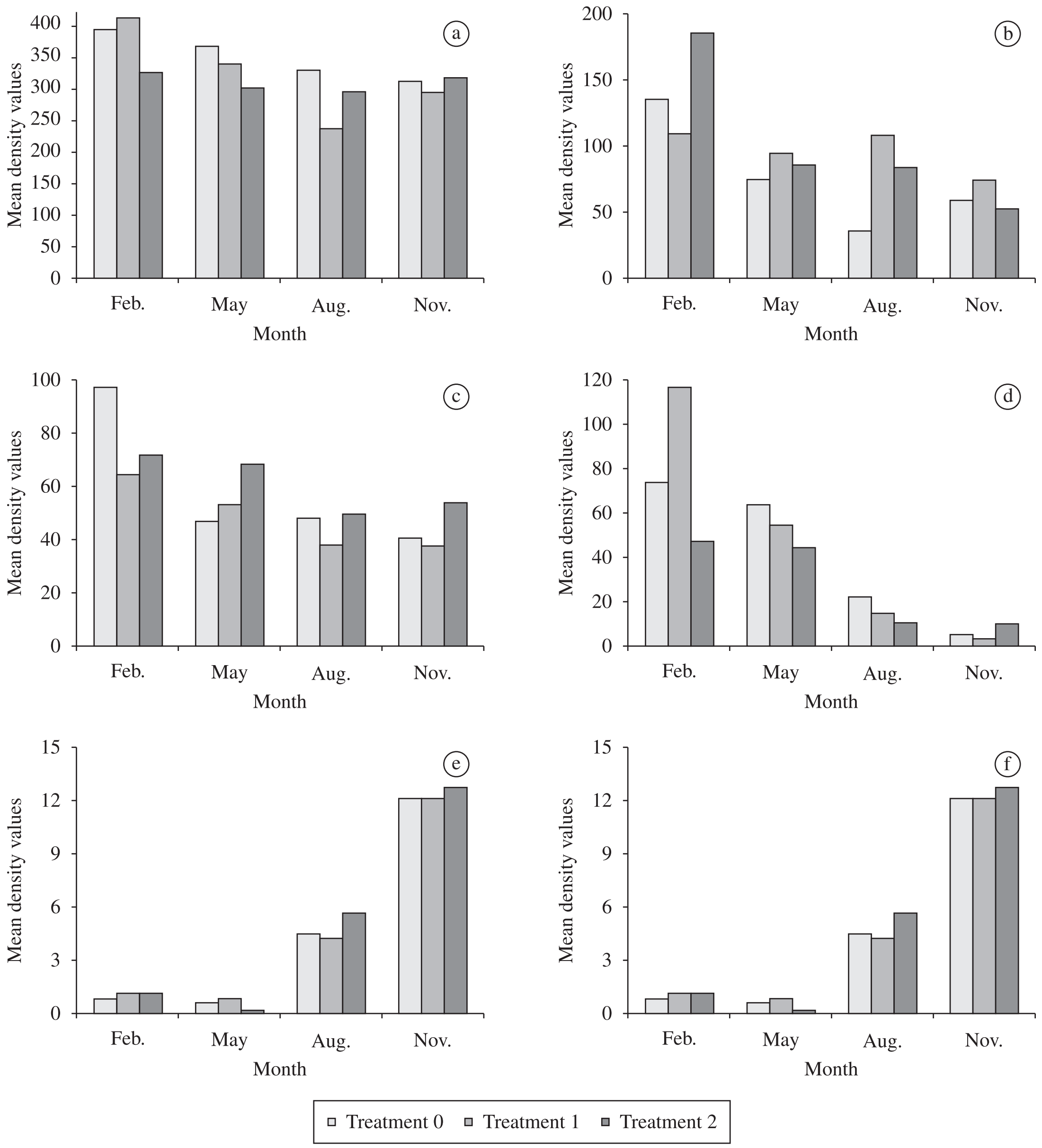

Figure 6. Mean density values (number of individuals/100 cm^2) over time of a) *I. bicolor*, b) *Brachidontes solisianus*, c) *Lasea adansoni*, d) *Hyale nigra*, e) *Collisella subrugosa* and f) Syllidae from Obuseiro rocky shore, São Paulo, Brazil.

especially for intermediate levels of trampling (Liddle, 1975; Beauchamp and Gowing, 1982).

This pattern follows the disturbance hypothesis proposed by Connell (1978), in which intermediate level perturbations may interfere in the competitive exclusion process, changing community structure and favouring the occurrence of new stages on patch succession. This process allows the colonization of species rare or absent from well-established communities, consequently enhancing richness and diversity values. The analysis of the turnover index corroborates this hypothesis, by indicating an increase in species gain tax for trampled plots until four months after trampling ceased.

It is well established that trampling may indirectly increase abundances of a range of common herbivores, as a result of cover reduction of dominant species (Povey and Keough, 1991; Keough and Quinn, 1998). In the present study, the decrease in *I. bicolor* cover percentage over time may be responsible for the increase in *C. subrugosa* densities, even though none of these processes were related to trampling impacts. During grazing, herbivores usually dislodge barnacle young recruits, reducing their survival rates and consequently affecting barnacle density values (Dayton, 1971; Safriel et al., 1994).

Recolonization of bare spaces in barnacle assemblages depended mainly on planktonical larvae recruitment, in contrast to mussels and algae species that present lateral movements or vegetative growth. This may amplify the impacts of herbivore grazing on barnacle populations.

In this study, although density increases of *C. subrugosa* were not related to trampling, higher levels of mollusk grazing may have been an important factor preventing recovery of *C. bisinuatus* populations after trampling.

Other patterns, such as those observed for *H. nigra*, *L. adansoni* and *B. solisianus* were probably related to the natural decrease of *I. bicolor* cover and density, since these species are strongly associated to the *I. bicolor* bed.

In general, results agree with previous trampling studies, suggesting that even low intensities of trampling may cause some impact on intertidal communities and recovery may take several years. In this study, effects of human trampling were mainly observed in *C. bisinuatus* population, that occur in the upper portion of the intertidal zone, remaining exposed to trampling during several hours. Moreover, *C. bisinuatus* recovery was not observed until the next vacation period (nine months after trampling ceased), which suggests that impacts from several years may be accumulative in heavily trampled rocky shores.

Management strategies should include isolation of sensitive areas, construction of boardwalks, visitor education and monitoring programmes. In Brazil, additional data obtained from experimental studies are necessary in order to achieve a better understanding of trampling impacts on rocky shore communities, especially in the highly populated southeastern Brazilian shores.

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