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Landscape Visual Quality and Meiofauna Biodiversity on Sandy Beaches

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Abstract Sandy beaches are central economic assets, attracting more recreational users than other coastal ecosystems. However, urbanization and landscape modification can compromise both the functional integrity and the attractiveness of beach ecosystems. Our study aimed at investigating the relationship between sandy beach artificialization and the landscape perception by the users, and between sandy beach visual attractiveness and biodiversity. We conducted visual and biodiversity assessments of urbanized and semiurbanized sandy beaches in Brazil and Uruguay. We specifically examined meiofauna as an indicator of biodiversity. We hypothesized that urbanization of sandy beaches results in a higher number of landscape detractors that negatively affect user evaluation, and that lower-rated beach units support lower levels of biodiversity. We found that urbanized beach units were rated lower than semiurbanized units, indicating that visual quality was sensitive to human interventions. Our expectations regarding the relationship between landscape perception and biodiversity were only partially met; only few structural and functional descriptors of meiofauna assemblages differed among classes of visual quality. However, lower-rated beach units exhibited signs of lower environmental quality, indicated by higher oligochaete densities and significant differences in meiofauna structure. We conclude that managing sandy beaches needs to advance beyond assessment of aesthetic parameters to also include the structure and function of beach ecosystems. Use of such supporting tools for managing sandy beaches is particularly important in view of sea level rise and increasing coastal development.

Keywords Coastal management · Landscape perception · Beach quality · Artificial and natural landscapes · Meiofauna

Introduction

At a global scale, sandy beaches are the dominant coastal ecosystem (McLachlan and Brown 2006). They are central economic assets, attracting more tourists and recreational users than any other coastal ecosystem (Maguire et al. 2011; Schlacher and Thompson 2012). Sandy beaches harbor a rich and dense community of animals and plants (McLachlan and Brown 2006; Harris et al. 2014). Benthic invertebrates in particular, play multiple roles, such as nutrient regeneration, provision of food for fishes and seabirds, and trophic subsidies to terrestrial consumers (Hennig et al. 1983; Barrett et al. 2005; Gheskiere et al. 2005). However, despite their economic and ecological importance, sandy beaches are generally overlooked and hence disproportionally represented in coastal protected area networks. As a consequence, beaches are increasingly artificialized, which can deeply modify their visual quality, negatively affect the benthic community (e.g., Dugan et al. 2003; Gheskiere et al. 2005), and ultimately comprise both

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the ecosystem functional integrity (Dugan et al. 2008; Harris et al. 2014) and the attractiveness of the beach.

The landscape visual quality is a key aspect for environmental planners and decision makers, as it is directly linked with the public perception. People tend to judge on the basis of what they see more than on what they know; therefore, such judgments have major implications for the public acceptability of landscape plans (Bell 2001) with negative consequences for the ecological health of the beach ecosystem. Because sandy beaches are prime tourism assets, their infrastructure is frequently (planned to be) placed within the active shoreline, which is conducive to the recreational feeling of the beach visitor. Moreover, to meet the supposed expectations and acceptance of the beach visitors and in order to maximize their recreational experience, beaches are continuously modified with progressive human interventions (Defeo et al. 2009), such as mechanical cleaning (Dugan et al. 2003), beach armoring (Dugan et al. 2008), and wholesale change or destruction of the dunes for the development of tourism infrastructure and housing (Nordstrom 2000; Nordstrom et al. 2000). To sum it up, “managing sandy beaches” is almost a synonym of “artificialization by urbanization,” with the idea to increase the pleasant experience of the beach users. As visual attractiveness is the basis for beach management strategies, the beach ecosystem as such is neglected, which may have considerable consequences for the local biodiversity.

The aim of this study was to analyze the public perception of urbanized and semiurbanized sandy beaches, and to link the visual quality of the beaches with a biodiversity indicator. First, we evaluated the visual quality of urbanized and semiurbanized beaches along the Warm-Temperate Southwestern Atlantic province (sensu Spalding et al. 2007), which includes Brazil and Uruguay, and where sandy beaches are by far the dominant coastal landscape. We hypothesized a negative relation between the degree of urbanization and the attractiveness of the beach as seen by its visitors. Second, we assessed biodiversity in order to relate it to the visual quality of the beach. As a biodiversity indicator, we chose the meiofauna, as it is the most abundant and species-rich group of marine invertebrates, and reaches densities up to 10^6 individuals/m^2 in exposed sandy beaches (Giere 2009). Moreover, two aspects were crucial to select meiofauna as a biodiversity indicator: (1) It should be independent of the valuation by the users and not influence the aesthetic of the beach (as would be the case for, e.g., vegetation or birds), and (2) it should be an indicator of the environmental quality of the beach (e.g., Gheskiere et al. 2005; Alves et al. 2013; Zeppilli et al. 2015). Artificialized beaches or portions of these beaches exhibit lower diversity of some organisms than those who are not artificially modified [e.g., insects (González et al. 2014), large scavengers (Huijibers et al. 2013), ghost crabs (Noriega et al. 2012)]. Consequently, we hypothesized that the visually most attractive landscape units have more biodiversity. The results of the present study may be valuable for decision makers for the management of sandy beaches, because usually biodiversity is not included in management plans.

Methodology

Study Area

We analyzed urbanized and semiurbanized sandy beaches: two in Brazil (Central and Buraco in Balneário Camboriú) and two in Uruguay (Pocitos and Carrasco in Montevideo) (Fig. 1a). All sandy beaches were located within the urban area, but they exhibited different levels of urbanization and some were more accessible than others.

The city of Balneário Camboriú is located at the central northern coast of Santa Catarina state in south Brazil (Fig. 1a). The resident population is around 125,000 people, but it can reach more than one million during the summer periods (IBGE 2014). Buraco Beach is reflective and approximately 1 km long (Silveira et al. 2011). There is no urbanization, but just a remote hotel surrounded by the Atlantic rain forest, invisible for the beach users (Fig. 2a). By contrast, the Central Beach, separated from Buraco Beach by a rocky head, is dissipative and approximately 6 km long, with heavily urbanized and armored segments (Fig. 2b). The Uruguayan beaches are situated in Montevideo (Fig. 1a), the capital of Uruguay, which has a resident population of more than one million people. Carrasco, approximately 5 km north from the center of Montevideo, is an intermediate to dissipative beach. It is approximately 5 km long and only partially armored and urbanized (Fig. 2c; IMM 2011). By contrast, the Pocitos is an intermediate dissipative, approximately 1 km long, heavily urbanized, and armored beach (Fig. 2d).

Assessment of the Landscape Visual Quality

The assessment of landscape quality was carried out by direct and indirect methods (Loures et al. 2015 and references therein). In summary, direct landscape evaluation consists of the analysis and description of a set of landscape features, so that the combination results in a total value that allows for a comparison of the scenic landscape preferences of the public. The indirect methods include interviews, and incorporate the demand and value of specific environmental services to assess landscape quality. The visual evaluation procedure involved three sequential steps: 1. selection, 2. representation, and 3. valuation.

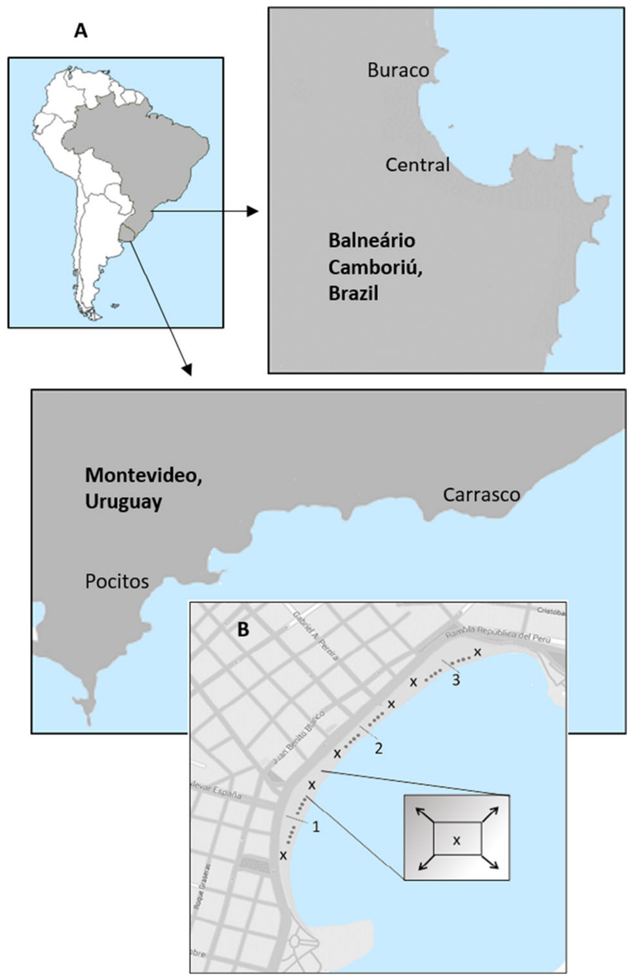

Fig. 1 The location of the studied sandy beaches in Brazil (*Buraco* and *Central*) and Uruguay (*Pocitos* and *Carrasco*), and a schematic representation of the landscape division, using Pocitos Beach as example, in units (*1*, *2*, and *3*) and two subunits within each unit (*left* and *right* side of the *dotted lines*). *Dots* represent meiofauna samples (four replicates in each subunit). Crosses indicate position where landscape pictures were taken. *Inlet* directions (*arrows*) in which pictures were taken. The same division and sampling/picture scheme was applied in all four beaches

In a first step, we selected three landscape units within each of the four studied beaches (= selection, Fig. 1b). The selection of these units aimed at better characterizing and evaluating the landscape variability of each beach. The units were defined based on their similarities of natural and/or anthropogenic elements, such as presence or absence of buildings, armoring, vegetation, and infrastructure. There were no fixed features as they varied among beaches. In a second step, we made a photographic survey during summer 2014 (= representation). Each of the three landscape units was divided into two subunits, and four pictures were taken in each subunit at four predetermined orientations, as seen by the user of the beach standing in the center of the unit: (1) facing the sea, (2) looking at the opposite side of the sea ("back side of the beach"), and (3) and (4) looking towards both sides along the lateral extension of the beach (left- and right-hand side) (Fig. 1b). Thus, eight photographs were taken in each landscape unit, resulting in a total of 24 photographs per beach.

In a third step, the valuation was carried out (= valuation). First, 100 visitors per beach (i.e., a total of 400 persons) evaluated the photographs, providing scores from 1 (very low quality), 2 (low quality), 3 (medium quality), 4 (high quality), to 5 (very high quality). The persons were unaware of the objective of the study. The photographic evaluation took place on site. Second, the segregation of landscape elements was carried out using ArcGIS v9.3 (ESRI Redlands, CA). Each photograph was divided into a grid of 600 squares, and all landscape elements (e.g., infrastructure, sand, sky, vegetation) were counted and classified into 20 categories (online support information Table SI-A).

In order to relate the users' valuations to the landscape elements, separate multiple regression analyses were carried out for the urbanized (Central and Pocitos) and the semiurbanized beaches (Carrasco and Buraco), respectively. Linear models for the two types of sandy beaches (urbanized and semiurbanized) were built with the 20 landscape elements as the predictor variable and the evaluation scores by the 100 users as the dependent variable. Regression models that yielded the best fit with the smallest number of elements and most equitable distribution of residuals were selected. Statistical significance of regression models was tested by analysis of variance (ANOVA).

The significance of the differences among beaches in terms of landscape element richness and diversity (Shannon-Wiener H́), we performed a permutational analysis of variance (PERMANOVA, Anderson et al. 2008). In order to visualize similarity among beaches based on the structure of the landscape elements of the sandy beaches, similarity matrices were constructed based on Euclidian distances. The landscape elements were ordinated by nonmetric multidimensional scaling (nMDS; Clarke and Ainsworth 1993) and significance tests for differences among beaches were performed using the PERMANOVA permutation test. The degree of variability in landscape elements was assessed through permutational multivariate dispersion (PERMDISP; Anderson et al. 2008) for each of the four sandy beaches.

Assessment of Meiofauna Diversity

Four replicate meiofauna samples were taken in the retention zone (sensu Salvat 1964) in each of the six subunits per beach (Fig. 1), resulting in 24 samples per beach and a total of 96 samples. Samples were taken with a PVC corer of

Fig. 2 Photographic impressions of the studied beaches. **a** Buraco Beach, **b** Central Beach, **c** Carrasco Beach, **d** Pocitos

3.5 cm diameter × 5 cm height. Additionally, one sediment sample was taken with a corer of 5 cm diameter × 5 cm height for particle size analysis. Meiofauna samples were fixed in 10 % formalin in the field and processed according to Somerfield et al. (2005). In the laboratory, samples were sieved through a 63 µm mesh, and the fauna was extracted by flotation with Ludox TM (specific gravity 1.18). Whole samples were then evaporated with anhydrous glycerol and mounted on permanent slides. All invertebrates were identified to the lowest possible taxonomic level. Sediment grain size was determined by a sieving process (0,5 φ mesh size). Meiofauna univariate descriptors were the number of genera (richness; *S*), density (inds. 10 cm^{-2}; N), and Shannon-Wiener diversity index (log_2; *H*'). Functional descriptors were the nematode maturity index (MI; Bongers et al. 1991) and the index of trophic diversity (ITD; Heip et al. 1985). Differences among beaches in terms of meiofauna structural (richness, density, and diversity) and functional descriptors were tested with a permutational analysis of variance (PERMANOVA; Anderson et al. 2008). To visualize the similarity of the meiofauna composition among beaches, similarity matrices were constructed based on the Bray–Curtis similarity measure. Ordination was done by nMDS, and significance tests for differences among beaches were performed using PERMANOVA (Anderson et al. 2008).

Relationship Between Landscape Visual Quality and Biodiversity

To relate the visual quality of the landscape to biodiversity, we selected the two lowest-scored subunits (based on the average rating of the 4 pictures), the two intermediate subunits, and the two highest-scored subunits, along with the respective meiofauna samples. In order to test for faunal differences among the differently rated subunits, we classified the fauna samples in three visual quality classes (i.e., "high," "medium," and "low"). Then we performed an nMDS on the fourth root transformed faunal data based on the Bray–Curtis similarity index. The significance of differences in the meiofauna attributes among the different visual quality classes was tested with a permutation univariate analysis (PERMANOVA). A similarity percentage analysis (SIMPER) was applied to assess compositional similarity and to identify the main species contributing to dissimilarities among the different landscape visual quality classes (Clarke and Ainsworth 1993). Differences in meiofauna structural descriptors (richness, density, and diversity) and functional attributes (MI, ITD) among the visual classes were tested using the PERMANOVA permutation test based on Euclidean distances (Anderson et al. 2008). The relationships between meiofauna, sediment properties, and landscape elements of the selected units of sandy beaches were also explored using distance-based linear models (DISTLM, Anderson et al. 2008). Sediment predictors included grains size and, sorting, while landscape elements included 20 categories (support information Table SI-A). Selection of predictors was based on pairwise correlations between variables and the strength of their correlations with meiofauna structure in the marginal tests of a trial DistLM analysis that included all variables: where two or more variables were strongly correlated with each other ($r > 0.9$) only the one ranked highest in marginal tests of the initial DistLM analysis was retained. This process yielded 18 variables that were used in the final DistLM analyses (2 of sediments and 16 landscape elements). The influence of each variable was tested first in isolation (marginal tests) and then in a combined model in which variables were added sequentially using a step-wise selection procedure based on the adjusted r^2 criterion (Anderson et al. 2008).

Results

Sandy Beach Visual Quality

The landscape units of the heavily urbanized beaches Central and Pocitos were rated, on average, with lower scores than the units of the semiurbanized beaches Carrasco and Buraco (Fig. 3). The poorest valuation was given to the urbanized Pocitos Beach, with two units evaluated as medium quality (score 3) and one as low quality (score 2; Fig. 3). The three units of the urbanized Central and the semiurbanized Carrasco Beach were valuated between high (score 4) and intermediate (score 3) quality. The highest scores were given to the semiurbanized Buraco Beach (high quality score 4; Fig. 3).

The landscape elements explained the visual quality scores given by the beach visitors to a high degree (Table 1). The best-fitting model for the urbanized beaches Central and Pocitos incorporated 17 independent variables

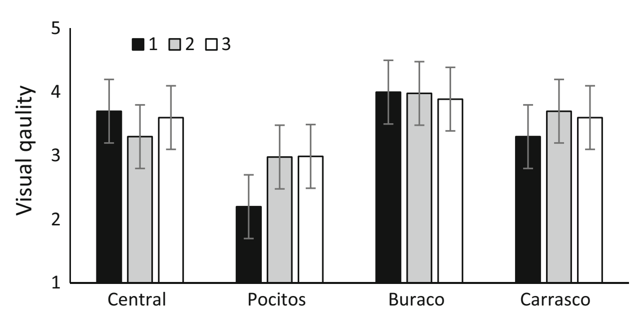

Fig. 3 Landscape visual quality (mean ± SE) of three units of two urbanized (*Central* and *Pocitos*) and two semiurbanized sandy beaches (*Buraco* and *Carrasco*)

Table 1 Results of multiple regression analyses and ANOVA tests assessing the relationship between landscape elements (predictor variable) and the visual quality of urbanized and semiurbanized sandy beaches

	Predictor variable	β	SE	F	P
Central and Pocitos (urbanized) $r^2 = 0.84$	Water	0.98	0.05	16.61	<0.0001
	Sand	1.98	0.07	26.54	<0.0001
	Pebbles	1.38	0.06	21.33	<0.0001
	Sky	2.01	0.09	20.22	<0.0001
	Buildings	1.52	0.09	16.61	<0.0001
	Beach infrastructure	0.66	0.02	29.03	<0.0001
	Urban infrastructure	0.18	0.01	12.17	<0.0001
	Boardwalk	0.79	0.05	13.97	<0.0001
	People	0.20	0.02	8.625	<0.0001
	Animals	−0.19	0.01	−29.75	<0.0001
	Wastes	0.51	0.02	17.85	<0.0001
	Boulders	0.60	0.02	25.37	<0.0001
	Breakwater	0.48	0.02	18.82	<0.0001
	Beach utensils	0.32	0.02	12.82	<0.0001
	Hills	1.09	0.04	27.09	<0.0001
	Urban arborisation	0.43	0.03	13.71	<0.0001
	Altered restingas[a]	0.68	0.03	19.09	<0.0001
Carrasco and Buraco (semiurbanized) $r^2 = 0.39$	Sky	0.72	0.03	22.52	<0.0001
	Building	−0.007	0.01	−0.42	0.67
	Beach infrastructure	0.11	0.01	9.51	<0.0001
	Sidewalk	−0.45	0.01	−25.09	<0.0001
	EH	−0.35	0.02	−11.74	<0.0001
	Boulder	−0.42	0.01	−22.43	<0.0001
	Beach utensils	0.29	0.02	10.18	<0.0001
	Hill	0.74	0.03	23.48	<0.0001
	Urban tree	0.65	0.02	26.74	<0.0001
	Modified Restingas[a]	−0.16	0.01	−13.98	<0.0001

[a] restingas = sand dune vegetation

β standardized coefficient; *SE* standard error

(landscape elements) and explained 84 % of the variability of the visual valuation. To the users of these two urbanized beaches, only the presence of animals negatively affected the visual quality. For the semiurbanized beaches Buraco and Carrasco, the best-fitting model included 10 independent variables and showed a lower correlation coefficient ($r = 62.87$) and coefficient of determination ($r^2 = 39.40$). The model indicated that buildings, boardwalks, the presence of people, boulders, and altered sand dune vegetation (restingas) negatively affected the visual quality of these beaches (Table 1).

The structure of the landscape elements was significantly different among beaches (Fig. 4a; Table 2). The number of landscape elements was higher at urbanized beaches. Accordingly, the heterogeneity of the landscape elements differed significantly (PERMDISP; $F = 12.76$; $P = 0.01$), and was higher in the urbanized beaches Central and Pocitos, intermediate in the semiurbanized Carrasco beach, and lower in the semiurbanized Buraco Beach, Fig. 4b).

Biodiversity

A total of nine higher meiobenthic taxa were recorded (online support information Table SI-B). Total meiofauna density ranged from 0 to 322 inds. 10 cm^{-2}. The numerically dominant copepods and nematodes accounted for more than 70 % of the total meiofauna (36.87 and 36.44 %, respectively). A total of 45 nematode genera belonging to 18 families was recorded (support information Table B). The numerically dominant nematode genera were *Microlaimus* (50.31 %), *Theristus* (12.87 %), and *Ascolaimus* (12.53 %).

The structure of the meiofauna communities differed significantly among the four sandy beaches (PERMANOVA, pseudo-$F = 19.8$, $P = 0.0001$); particularly at

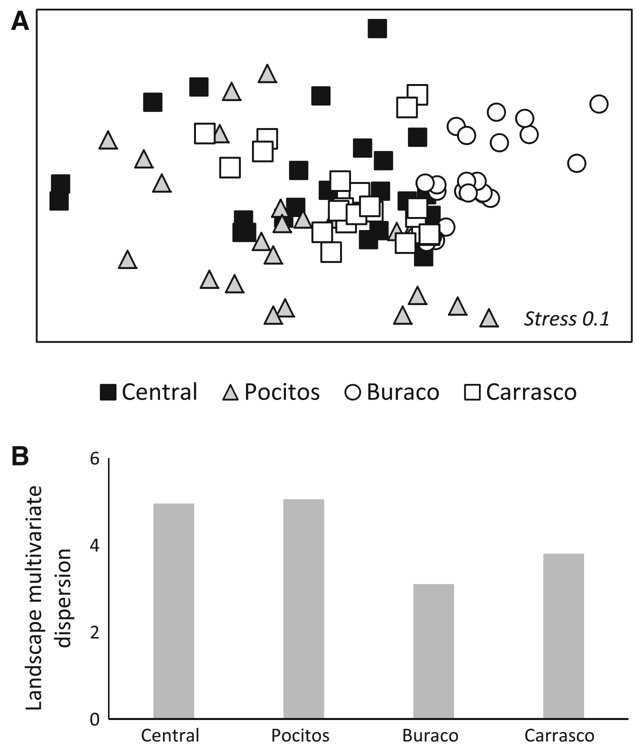

Fig. 4 **a** Nonmetric multidimensional scaling (nMDS) based on landscape element counts and **b** heterogeneity of the landscape elements (Stress 0.18) from urbanized (*Central* and *Pocitos*) and semiurbanized (*Buraco* and *Carrasco*) sandy beaches

Table 2 Results of the permutational analysis of variance (PERMANOVA) on landscape elements of urbanized (Central and Pocitos) and semiurbanized (Buraco and Carrasco) sandy beaches

PERMANOVA	df	SS	MS	Pseudo-*F*	*P*(MC)
Beach	3	508.29	169.43	8.1259	**0.001**
Residual	92	1918.2	20.851		
Total	95	2426.5			
		Pairwise comparisons			
		t			*P*(MC)
Central, Pocitos		1.89			**0.002**
Central, Buraco		2.90			**0.001**
Central, Carrasco		2.51			**0.001**
Pocitos, Buraco		4.01			**0.001**
Pocitos, Carrasco		1.99			**0.002**
Buraco, Carrasco		3.72			**0.001**

Values in bold indicate significant differences at $P < 0.05$. *df* degrees of freedom; *SS* sum of squares; *MS* mean squares; *P(MC) P*-value obtained with Monte Carlo permutation test

Buraco Beach, the meiofauna assemblages were more homogeneous compared to Pocitos, Carrasco, and Central (Fig. 5a). All univariate measures of meiofauna were significantly higher at Buraco Beach, followed by Central and Pocitos with intermediate levels, and finally Carrasco with the lowest values (Fig. 6).

Relating Landscape Visual Quality to Biodiversity

The meiofauna structure differed significantly among the different classes of landscape visual quality (MDS, Fig. 5b; PERMANOVA, Table 3). The pairwise comparisons revealed that the meiofauna assemblages of the units of low landscape visual quality differed significantly from the units of medium and high quality, whereas there was no difference between the units of medium and high quality (Table 3). The main factors responsible for the dissimilarities between the units of low landscape visual quality and medium/high quality units were the lower meiofauna density, together with higher densities of oligochaetes in the low-quality units (SIMPER, results not shown). Both the structural and functional descriptors of meiofauna assemblages did not differ among the different classes of visual landscape quality (all Pseudo-*F*-values < 1.02 and *P*(MC) >0.05; online support information Table SI-C). The only exception was the density of oligochaetes (Pseudo-$F = 3.82$, $P(MC) = 0.044$), which was significantly higher in units with low visual quality (Table SI-C).

In the DISTLM model, 5 variables in isolation showed significant influence on meiofaunal community structure: −2 from the sediment properties, the mean grain size, and sorting; −3 landscape elements: sand beach infrastructure, sidewalk, and hill (marginal tests $P \leq 0.05$; Table 4). For step-wise selection based on R^2, 4 variables were significantly fitted in the full model. Variables associated to sediment explained 19.9 % of the total variance in the meiofauna data (grain size 12.1 % and sorting 7.8 %), while the landscape elements explained 14.2 % (sand beach infrastructure 7.6 % and sidewalk 6.6 %; Table 4).

Discussion

Our study aimed at investigating the effects of sandy beach artificialization on the landscape perception by the users, and if differences in the sandy beach visual attractiveness would also imply differences in biodiversity. We hypothesized that urbanization of sandy beaches increases the number of landscape detractors that negatively affect the valuation by the users. We found that visual quality was sensitive to human interventions, and landscape units of urbanized sandy beaches were rated lower than those of semiurbanized beaches. In addition, we hypothesized that lower-rated landscape units harbor lower meiofauna biodiversity. Our expectations regarding the relationship between landscape perception and biodiversity was only partially met as only few structural and functional

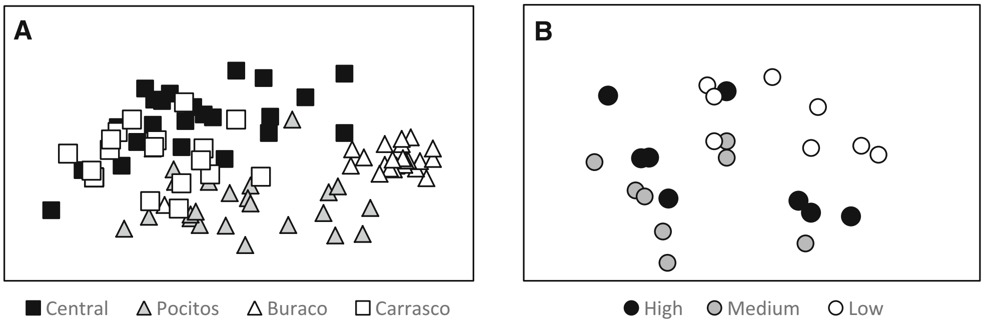

Fig. 5 Nonmetric multidimensional scaling (nMDS) based on log-transformed nematode abundances classified according to **a** the sandy beaches (*Central*, *Pocitos*, *Buraco*, and *Carrasco*), and classified into three groups (*high*, *medium*, and *low*) according to the landscape visual valuation by the beach users. nMDS stress: **a**- 0.18; **b**- 0.12

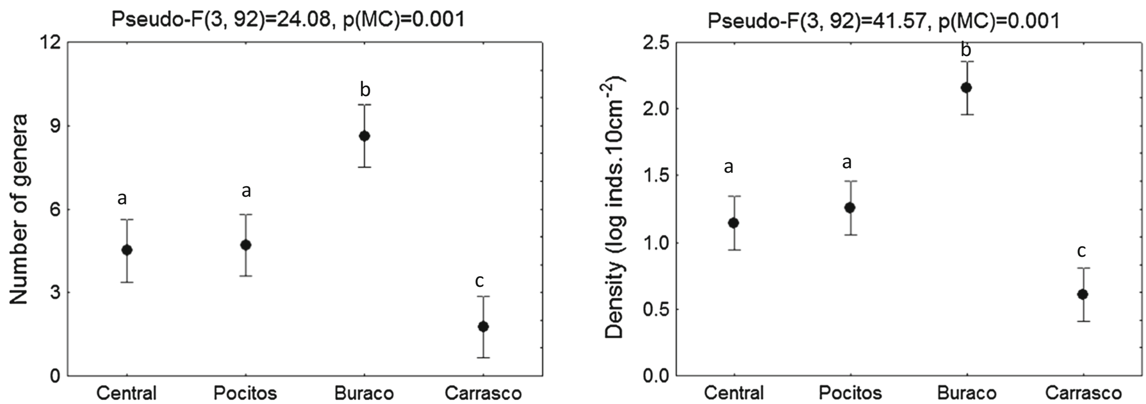

Fig. 6 Results of PERMAVONA tests and mean values (±95 % confidence intervals) of meiofauna descriptors in urbanized (*Central* and *Pocitos*) and semiurbanized (*Buraco* and *Carrasco*) sandy beaches. The different *letters* indicate significant differences ($P < 0.05$)

Table 3 Results of the PERMANOVA on meiofauna structure of three classes of landscape visual quality (low, medium, and high)

PERMANOVA	df	SS	MS	Pseudo-*F*	*P*(MC)
Classes of landscape visual quality	2	9628,8	4814,1	2,638	**0.004**
Residual	21	38315	1824,5		
Pairwise comparisons					
	Visual quality		*t*	*P*(MC)	
	Low versus medium		2.005	**0.009**	
	Low versus high		1.602	**0.03**	
	Medium versus high		1.21	0.21	

Values in bold indicate significant differences at $P < 0.05$. *df* degrees of freedom; *SS* sum of squares; *MS* mean squares; *P(MC) P*-value obtained with Monte Carlo permutation test

descriptors of meiofauna assemblages differed among classes of visual quality. There were no differences in meiofauna between medium and high visual quality units. However, lower-rated landscape units showed higher densities of oligochaetes and significant differences in the multivariate structure of the meiofauna. Besides, the results of linear models showed significant influence on meiofaunal community of some landscape elements indicative of urbanization, in addition to sediment characteristics.

Landscape visual quality and tourism are closely connected. This connection, however, is not straightforward and may at times be paradoxical. Several studies (e.g., Micallef et al. 1999; Unal and Williams 1999; Semeoshenkova and Williams 2011) have pointed out that high visual quality is the key characteristic sought by tourists. At the same time, transformations arising from tourism may progressively increase the number of detractor elements of the landscape, with putative negative

Table 4 Distance-based linear models (DISTLM) of meiofauna community variation in relation to sediment properties and landscape elements of sandy beaches

Marginal tests Variable	R^2	*SS*	Pseudo-*F*	*P*
Sediment grain size	0.12	9002.2	30.312	**0.004**
Sediment sorting	0.09	7332.7	24.075	**0.011**
Water	0.03	2534.1	0.77641	0.649
Sand	0.06	4435	13.958	0.181
Gravel	0.07	4068	12.736	0.243
Building	0.06	4430.5	13.943	0.17
Beach infrastructure	0.08	6110.4	19.703	**0.046**
Urban infrastructure	0.04	3364.7	10.429	0.392
Sidewalk	0.04	6060	19.052	**0.05**
Human element	0.08	5804.8	18.634	0.063
Animal element	0.06	4732.9	14.959	0.143
Residues	0.04	3172	0.98056	0.491
Jetty	0.09	1255.1	0.37782	0.969
Beach utensils	0.04	2971.4	0.91597	0.534
Hill	0.09	7124.6	2.332	**0.01**
Urban tree	0.05	3746.6	11.676	0.304
Modified restinga	0.06	4780.2	15.119	0.095

Sequential tests (step-wise)	Cumulative adjusted R^2	R^2	SS	Pseudo-*F*	*P*
Sediment grain size	0.1211	0.1211	9002.2	30.312	**0.005**
Sediment sorting	0.19847	0.07737	5751.8	20.271	**0.034**
Beach infrastructure	0.27211	0.07364	5474.4	20.234	**0.039**
Sidewalk	0.33662	0.06451	4796	18.478	**0.05**

Results showed marginal tests, individual variable relationships with meiofauna, and sequential test, including the significant explanatory variables to the model using step-wise selection based on the adjusted R^2 criterion. Significant contributions to the models ($P \leq 0.05$) are shown in bold

consequences for the tourism, and the sandy beach ecological system as well. We found that a high valuation of sandy beaches was associated with very low levels of artificialization (Fig. 7). As urbanization increases, the absence of basic infrastructure and services in more urbanized beaches had a strong and negative influence on the valuation of the landscape. The presence of basic infrastructure and services on beaches turned out to be a key factor in the valuation. Heavily urbanized beaches with permanent infrastructure and services (toilets, access, shade, lifeguards, small stores, restaurants) received a relatively high valuation of the landscape visual quality as long as sand and water were maintained clean (Fig. 7). Nevertheless, people tended to prefer natural beaches over artificialized ones.

Pocitos, a heavily urbanized sandy beach, received the lowest rating of all studied sites. The visual quality of a landscape is a combination of landscape characteristics and their influence on the beholder (Daniel 2001). Certain types of buildings and human modifications of coastal landscapes are known as detractor elements, impairing the local visual characteristics and quality (Duvat 2012; Rangel-Buitrago et al. 2012). In the case of Pocitos, particularly unit 1, the low visual quality was associated with a high level of artificiality and noticeable amounts of solid residues, such as plastic waste and other discarded materials.

The beaches Central and Carrasco, although mostly urbanized, have highly heterogeneous landscapes, and their valuation was different among units. The landscape units with a high degree of artificialization were lower rated. The two beaches clearly differed from the other two, especially Buraco, due to the high availability of infrastructure and services to users, which had a positive influence on their ratings. The services included, for example, environmental management and information, safety services, toilets, and small restaurants. Our results are similar to those reported by Cervantes et al. (2008): the comparison of urbanized beaches in Mexico and the United States revealed a positive relation between the evaluation and the availability of infrastructure and services.

Natural landscape elements dominate all units of Buraco Beach, the best evaluated beach in this study. Except from a small and discrete infrastructure provided by a hotel in unit 2, Buraco Beach has no urbanized landscape at all. Atlantic rain forest and clean sand and water dominate a homogeneous landscape. The combined results suggest that artificialization through urbanization increases the heterogeneity of sandy beach landscapes and the number of detractor elements of visual quality, which results in a lower evaluation by users.

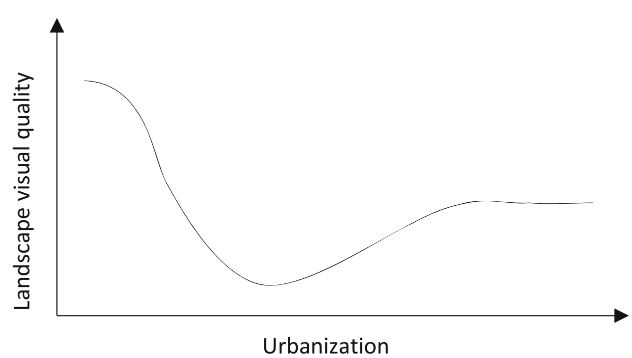

Fig. 7 Conceptual model of the relation between landscape visual quality and urbanization on sandy beaches

The meiofauna among the studied beaches differed significantly. The meiofauna from the reflective Buraco Beach exhibited higher richness, density, and diversity compared to the other, dissipative beaches. These results are in accordance with the few works relating meiofauna and beach morphodynamics (e.g., Rodriguez et al. 2003; Gheskiere et al. 2005), and stand in contrast to the general patterns of sandy beach macroinfauna, which is negatively affected by the coarser sediments of reflective sandy beaches (e.g., McLachlan and Jaramillo 1995; Alves and Pezzuto 2009).

The visual quality of the studied sandy beaches was not related to morphodynamics, as some units of Central Beach (dissipative) received the same score as Buraco Beach (reflective). The faunal data from landscape units with the same score were pooled in order to investigate the relationship between visual quality and biodiversity, and to avoid a potential methodological bias (i.e., to compare semiurbanized reflective beach with urbanized dissipative beach). We did not detect any changes in trophic structure of the nematodes among different classes visual quality. Food in sediments of oceanic sandy beaches is not abundant, and it is influenced by inputs from the land and the sea. This result probably occurred because most of the numerically dominant nematodes inhabiting sandy beaches are deposit feeders (e.g., Nicholas and Hodda 1999; Gheskiere et al. 2004), and probably display an opportunistic feeding behavior, changing their habits depending on the available food particle (Netto & Meneghel 2014). Differences in univariate descriptors of the meiofauna were minor, but still the results of linear models (DistLM) did show significant influence on meiofaunal community of some landscape elements indicative of urbanization, in addition to sediment characteristics. Sand beach infrastructure (which includes kiosks, lifeguards, and many other leisure services) and sidewalk explained (14.2 %) almost the same variability of meiofauna as grain size and sorting (19.9 %). Both sand beach infrastructure and side walk were conspicuous in low-rated units and absent in high-rated units. Moreover, our results revealed that units with different scores, particularly those rated as "low quality," were associated with a different meiofauna multivariate structure. The meiofauna assemblages of lower-rated landscape units were characterized by significantly higher oligochaete densities and lower total nematode densities. In these units, oligochaetes dominated over copepods as the second most abundant taxa. Meiobenthic oligochaetes are typical of sandy beach areas rich in decomposing organic material, such as the wrack zone (Giere and Pfannkuche 1982). Besides, Wang et al. (2011) showed that reduced meiofauna abundances occur in sandy beach sediments with organic enrichment.

It is particularly difficult to make comparisons between the present and other studies that relate visual quality of the landscape with biodiversity because most of them use vegetation or visually identifiable animals as an indicator of biodiversity (e.g., Williams and Cary 2002; Kurz and Baudains 2012; Qiu et al. 2013). Since these indicators of biodiversity change the landscape perception and valuation by the users, aesthetics and biodiversity are certainly related. Nevertheless, similar to other studies that linked sandy beach urbanization and biodiversity, particularly meiofauna (e.g., Moellmann and Corbisier 2003; Gheskiere et al. 2005), we found a negative relation between them. Yet, it should be borne in mind that it is the attractiveness of a beach which determines if people go to the beach, not the urbanization *per se*. Without the attractiveness of the beach and the people who perceive it, management does not make sense. Here we show that urbanized (i.e., with infrastructure) and semiurbanized (i.e., without infrastructure) sandy beaches may have both a good visual quality for the users and also good environmental quality (as indicated by the meiofauna structure and composition). However, we also clearly show that the urbanized beach units with low visual quality suffer from low environmental quality.

The use of supporting tools for the planning of resilient communities has gained particular importance for sandy beach ecosystems due to the increasing coastal squeeze resulting from population growth in coastal zones and sea level rise (Neumann et al. 2015). In the last decades, a myriad of beach certification schemes and other management tools have been used to fill the gap between conservation and recreation (e.g., Botero et al. 2013; Zielinski and Botero 2015). Although some of then use the analysis of visual quality of the sandy beaches, biodiversity estimations are generally not included, or if included, it refers only to some estimations of particular populations (Zielinski and Botero 2015). In some occasions, managing sandy beaches turns out to be almost a synonym of a gradual process of artificialization by urbanization, pressuring beaches by adding tourist amenity infrastructure (Duke et al. 2009). The complex relationship between the perception of a landscape and its biodiversity is crucial to the management and conservation of ecosystems and should be better understood. Managing sandy beaches needs to change from "mainly aesthetic" to "ecologically aesthetic" (sensu Gobster 1999), in which a cultural shift brings about the aesthetic appreciation of a landscape including the structure and function of the ecosystem.

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