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Effects of recreational activities on Patagonian rocky shores

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A B S T R A C T

Recreational activities can be an important source of anthropogenic disturbance in intertidal benthic assemblages. On rocky shores, activities such as trampling, snorkeling and the handling of organisms may have a negative effect on benthic communities by modifying the abundance and distribution of key species. Here, we describe and quantify impacts due to recreational activities on benthic communities on a Patagonian rocky shore by investigating their resilience to two types of human disturbance: vehicle traffic and human trampling. To evaluate the effects of these activities, we carried out an observational study and assessed post-disturbance assemblage recovery. The rocky shores is most intensively visited during summer, and marked differences in the distribution and abundance of benthic species among disturbed and control plots were found after this season. The benthic community on the high intertidal was weakly impacted by disturbance generated due to vehicle traffic in summer (one vehicle on a single occasion, pulse disturbance); which did not affect the cover of dominant species. This suggests that the high intertidal community would be resistant to the passage of one vehicle on a single occasion. The effects of continuous trampling (press disturbance) were drastic and the community of the mid intertidal level did not recover before the next recreational season. Mid intertidal communities exposed to press disturbances require more than one tourist season of human inactivity to recover from anthropogenic effects, suggesting that resilience mechanisms in this community operate at broad timescales. Our findings highlight the need to establish and implement management actions that contemplate the nature of the disturbance and intertidal level to minimize habitat degradation due to human recreational activities.

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1. Introduction

Disturbance, both natural and anthropogenic, is one of the main structural factors in coastal communities (Bender et al., 1984; Underwood, 1989; Micheli et al., 2016). For example, the density and distribution of the species that form intertidal communities can be influenced by physical disturbances, such as waves, winds or ice (Underwood, 1998; Gaylord, 1999; Calcagno et al., 2012), as well as by human perturbations, such as recreation activities and tourism (Addessi, 1994; Crowe et al., 2000; Davenport and Davenport, 2006).

The tourism industry has grown exponentially in the last century and coastal cities have become favorite destinations (Miller, 1993; Dadon, 2002; Davenport and Davenport, 2006). Although tourism brings economic benefits, there are usually substantial environmental costs associated with its development (Dadon, 2002; Davenport and Davenport, 2006). Furthermore, the intense use of natural environments may lead to a deterioration of the original attractions. In coastal Atlantic Patagonia, one of the main tourist attractions is Península Valdés (42°30′ S; 64°00′ W), a Natural Reserve created in 1983 and recognized as a Natural World Heritage site by the UNESCO in 1999. Tourism is among the three main economic activities of Puerto Madryn, the closest city to Península Valdés (Secretaría de Turismo, 2015). Puerto Madryn, with ca. 100,000 permanent residents, receives ca. 250,000 tourists each year. Forty percent of visitors arrive in January and February during the austral summer (Secretaría de Turismo, 2015) and stay mostly in sandy city beaches. However, there has been an increase in the use of alternative coastal areas for recreation (<15 km from Puerto Madryn). The activities performed in these areas are not

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regulated nor supervised by the government, with potential consequences on the benthic ecosystem.

Among the activities performed on rocky shores, human trampling has been the focus of many studies in recent decades; its impact can be severe and even simple walking on a rocky shore may affect marine organisms (Povey and Keough, 1991; Milazzo et al., 2004; Huff, 2011; Araujo et al., 2012). Trampling may influence the benthic assemblage directly (*e.g.* by removing individuals) and indirectly (*e.g.* affecting biological interactions between species) (Brosnan and Crumrine, 1994; Brown and Taylor, 1999; Huff, 2011). Another activity that threatens coastal benthic communities and impacts their flora and fauna is the traffic of vehicles (Schlacher et al., 2007; Defeo et al., 2009 for sandy shores). Studies of vehicle impact on coastal biota are focused on sandy beaches and coastal dune ecosystems, where vehicle traffic is relatively common around the world (Stephenson, 1999; Schlacher et al., 2007; Kindermann and Gormally, 2010). On northern Patagonian shores, high amplitude tides permit road vehicles transit the mid and high rocky intertidal shores that have platforms with little slope and a relatively flat consolidated mudstone surface. Dozens of cars transit through the intertidal flats to access recreational fishing sites every year, concurrently excursions are offered by local tourism companies to these intertidal shores.

Of particular conservation concern is the recovery time needed by benthic communities after anthropogenic disturbances. However, the resistance to disturbance through pre-existing compensatory processes may also be of importance by reducing or impeding change in the community (Connell and Ghedini, 2015). When an observable change in structure occurs, assemblage response is frequently related to the strength of the disturbance, its source and duration (Bender et al., 1984). Determining the resilience of a community, understood as the capacity of a system to return to a prior state after a disturbance is crucial for conservation efforts. Disturbances may be categorized in: short-term or pulse perturbations, and persistent or press disturbance (Bender et al., 1984). Mitigation of the effects of pulse disturbances could be relatively simple compared with chronic press disturbances (Bender et al., 1984; Underwood, 1992, 1994; Bravo et al., 2015). Furthermore, specific characteristics of the affected ecosystem, such as, the species involved, their life history and the amount of damage caused also determine the consequences of the disturbance (*i.e.* resistance and resilience of the community) (Underwood, 1998; Milazzo et al., 2004; Araujo et al., 2012; Connell and Ghedini, 2015).

In northern Patagonian rocky shores (41-55° S; 63-70° W), extreme desiccation is one of the most important ecological features (Bertness et al., 2006). Organisms are exposed to strong, dry winds, combined with low humidity and scarce rainfall (Bertness et al., 2006). In northern and central Patagonia, physical stress is the main structuring factor in the benthic intertidal communities, where biotic interactions, such as predation (Hidalgo et al., 2007) and herbivory (Bazterrica et al., 2007), have a secondary role. In general, the zonation pattern of intertidal Patagonian rocky shores is characterized by the presence of different species of algae in the lower areas (low intertidal), mainly dominated by the calcareous algae *Corallina officinalis* (Kelaher et al., 2007; Raffo et al., 2014). The middle level (mid intertidal) is dominated by two tiny mytilids species: *Brachidontes rodriguezii* and *B. purpuratus* (Silliman et al., 2011; Rechimont et al., 2013), which are arranged to form a dense matrix of organisms that can have several layers of individuals. Finally, the invasive barnacle *Balanus glandula* and the pulmonate limpet *Siphonaria lessoni* characterize the highest areas of the intertidal (high intertidal), where the percentage of bare rock is usually high (Schwindt, 2007; Raffo et al., 2014). Of these dominant species *C. officinalis*, *Brachidontes* spp. and *Balanus glandula* are considered to be engineer species. These species provide habitat, shelter and food for a number of associated organisms (Jones et al., 1994). The dominance of the engineers across the different levels of the intertidal ecosystem highlights the importance of facilitation as a dominant force under harsh environmental conditions (Silliman et al., 2011). Thus, the study of how these species are affected by and respond to disturbance provides information about what may happen to the rest of the community (Eckrich and Holmquist, 2000; Benedetti-Cecchi et al., 2001; Araujo et al., 2012).

Despite the marked growth of coastal recreational activities, there are very few studies that have evaluated their effect on intertidal benthic communities in Argentina (Dadon, 2002, 2005; Herrmann et al., 2009 in soft bottom communities). The purpose of this study was to describe and quantify impacts due to recreational activities on benthic communities in a Patagonian rocky shore by investigating their resilience to two types of disturbance: vehicle traffic (high intertidal) and trampling (mid intertidal). We are not aware of any studies on the direct effect of recreational activities on rocky shore benthic communities in Argentina. Furthermore, to our knowledge this is the first study where the impact of vehicles on a benthic assemblage is described and analyzed for any rocky shore. We hypothesized that the two activities would affect benthic species, decreasing their coverage and increasing the proportion of bare rock. Also, the magnitude of the impacts would be related to the intensity of the disturbance and the level in which they occurred.

2. Materials and methods

2.1. Study site

The study was performed at Punta Este (PE), an intertidal rocky shore located 10 km south of Puerto Madryn, Southwestern Atlantic coast. Punta Este is a wave-protected shore on the west coast of Golfo Nuevo (42°47′ S; 64°57′W). Westerly winds are predominant, persistent and intense all year round (Paruelo et al., 1998) with an annual mean speed of 15.4 km/h and reaching up to 114 km/h. The annual mean air temperature is 14.2 °C, with a minimum of −9.2 °C in winter (July) and a maximum of 37.2 °C in summer (January) (Laboratorio de Climatología, CENPAT-CONICET, data for 2014). At PE tides are semidiurnal with mean amplitude of ~4 m which exposes a sedimentary rock platform (consolidated limestone). Three intertidal levels can be distinguished (Rechimont, 2011): the high intertidal has a slope of 3.8° and high percentage of bare rock with the presence of the algae *Ulva prolifera* and small patches of the invasive barnacle *Balanus glandula* and the limpet *Siphonaria lessoni*. In the mid intertidal, the slope is 7.4° and a single-layered bed of *Brachidontes* spp. mussels characterized this level. The low intertidal has a slope of 20.2° and the calcareous alga *Corallina officinalis* is dominant, with the presence of other algal species such as *Codium* sp., *Ceramium* sp., *Dictyota dichotoma* and the invasive *Undaria pinnatifida* as well as the gastropods *Tegula patagonica* and *Trophon geversianus*. The rocky shore is commonly used by visitors due to its proximity to roads, easy access, clear waters and protection from the wind blowing from land to the sea, by an adjoining cliff.

2.2. Effects of vehicle traffic on the benthic community

Vehicle traffic was identified from observations as one of the human activities with high potential of harm to the benthic community. Damage caused by a vehicle on the compacted mudstone floor can be easily identified by the tracks left on it. These can last for several weeks and can be distinguished from that caused by multiple vehicles through direct observation of the tracks. We opportunistically delimited impacted plots soon after the passage of a vehicle driven by a visitor. During our previous visits to the site (January and February 2015) we had not observed vehicles nor tracks on this intertidal shore. To evaluate the potential effects of traffic from a single vehicle on the benthic community **v**ehicle impacted plots were delimited on the mentioned tracks (Fig. 1). Concurrently, control plots of the same dimensions were delimited on surrounding pristine habitat (Fig. 1). Plots (n = 7 per treatment) consisted of 24 × 10 cm lengths of tracks (impacted) or untouched substrate (control) established by semi-permanent marks within the high intertidal (Fig. 1). Plots were visited monthly and fresh tire tracks were not detected again throughout the study.

The plots were established at the end of the austral summer in March 2015 (Time I) and recovery of the assemblage was analyzed one month later in April (Time II), during winter in August (Time III) and before the start of the next summer season, in December (Time IV). During each sampling time, photographs of the marked plots were taken using a digital camera equipped with a fixed frame that standardized distance from the substrate. Photographs were analyzed using the free software Coral Point Count with Excel extensions (CPCe v4.1; Kohler and Gill, 2006). Equidistant points (n = 84) were placed over each image to estimate percentage cover of benthic organisms using a point-intercept method. All organisms were identified to the lowest possible taxonomic level.

Percentage covers of benthic taxa were analyzed using permutational analysis of variance (PERMANOVA) with the PERMANOVA extension in Primer v6.1.7 software (Anderson et al., 2008). Similarity matrices based on Bray-Curtis measure of were generated for the analyses, which used 9999 permutations of residuals under a reduced model (Anderson et al., 2008). PERMANOVA model had two factors: Treatment (Tr, fixed, 2 levels: impacted and control) and Time (Ti, fixed, 4 levels: I, II, III and IV). Pairwise comparisons were performed among all pair of levels for significant factors to identify differences. Non-metric multi-dimensional scaling (nMDS) was used to visualize multivariate patterns in benthic assemblages and a similarity percentage analysis (SIMPER) was performed to determine the taxa responsible for the differences between groups using PRIMER v6.1.7 software. Given that the number of species in

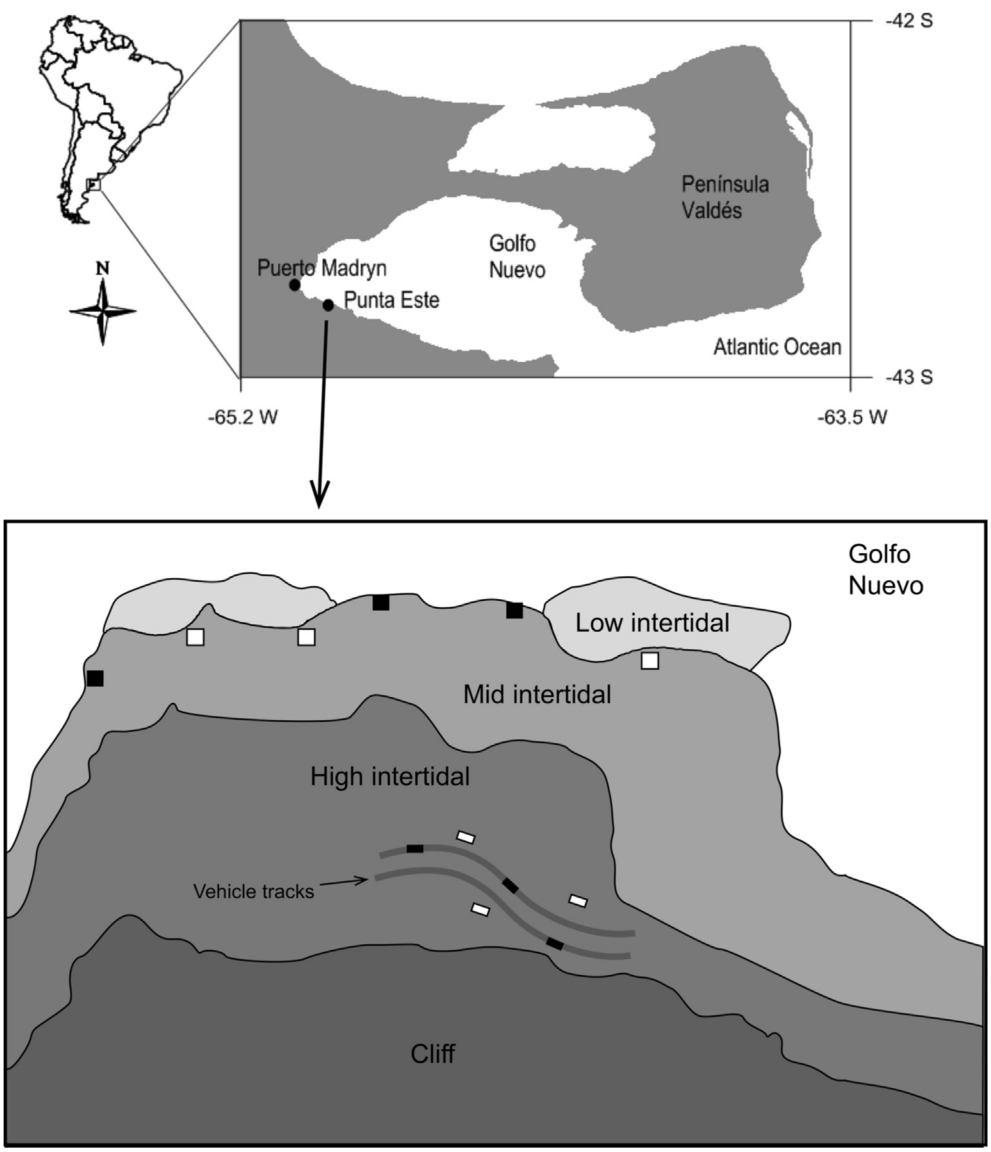

Fig. 1. Map of South America showing the location of Punta Este rocky shore and a schematic figure of the distribution of plots in the sampling area. Plots impacted by human trampling in the middle intertidal and by vehicle traffic in the high intertidal are shown in black. Control plots are shown in white.

the high intertidal is very low in the study site; we did not to include richness and diversity comparisons for this intertidal level. Univariate analyses were also done on the three major contributors to differences between groups. These analyses were done using a 2-factor PERMANOVA model (factors as above).

2.3. Effects of trampling on the benthic community

During field work, we registered that visitors walk on the north end of the intertidal flat platform to access a pebble beach, hence trampling was concentrated within the ~200 m stretch that separates the pebble beach and the primary access over the platform. In this area, people repeatedly used the same patches of rock to dive into the water. Thus, trampling in small patches (less than 1 m^2) in the mid intertidal was also considered as one of the human activities with high potential of harm to the benthic community in PE. Intense trampling takes place only in summer when water temperature reaches 19 °C and swimming is frequent, whilst throughout the rest of the year water temperature is low (9–12 °C). Sectors of the mid intertidal, normally covered by mussels, serve as diving platforms due to an ensuing vertical drop (approx. 2 m height, Fig. 1). Other sectors of the mid intertidal transition into low intertidal (dominated by coralline algae) in the form of a step which discourages use by visitors (Fig. 1). Repeated diving off the same sectors was observed and these were used as study plots. At the end of summer, intensely trampled patches (*i.e.* sectors used for diving) were readily recognized by the lack of mussel covering the substrate. Trampled plots (25 × 25 cm, n = 11) were established with semi-permanent marks. Control plots of the same dimensions (25 × 25 cm, n = 10) were interspread in the same area as the impacted plots in undisturbed patches (Fig. 1).

Recovery of delimited plots was followed through time as in the vehicle traffic section. No systematic attempt was made to evaluate the density of small mobile invertebrates associated with the *Brachidontes* spp. mussel bed since destructive methods would be necessary. Photographs were also analyzed using CPC software placing 100 equidistant points. Benthic assemblage data were analyzed using PERMANOVA, MDS and SIMPER as above. Additionally, the same PERMANOVA model was employed to determine significant differences in total richness and Shannon diversity index between trampled and non-trampled plots. Pair-wise comparisons were performed when differences occurred.

3. Results

3.1. Effects of vehicle traffic on the benthic community

The benthic community of the high intertidal impacted by vehicle traffic was significantly different from the community of control plots and among sampling times (Table 1). Nevertheless, community composition of impacted plots did not differ from controls six months after the disturbance occurred (end of austral winter) (Table 2, Fig. 2A). SIMPER analysis showed minor differences in the abundance of some species between impacted and control plots; a greater abundance of the green algae *Ulva prolifera*, the mussel *Brachidontes* spp. and the gastropod *Siphonaria lessoni* were recorded in control plots (Table 3, Fig. 3A). Univariate analysis showed that *Brachidontes* spp. cover was higher in control than impacted plots but there was no significant differences in the percentage cover of bare rock or *U. prolifera* between treatments (Table 4).

Table 1
PERMANOVA results for the areas affected by vehicle traffic and human trampling ($d.f._{Treatment} = 1$, $d.f._{Time} = 3$, $d.f._{TrxTi} = 3$). Percentage covers were fourth-root transformed for vehicle traffic and square-root transformed for trampling. In bold $p < 0.01$.

Source	Vehicle traffic			Trampling		
	Pseudo-f	p	Perms	Pseudo-f	p	Perms
Treatment	10.099	**0.0011**	9961	965.28	**0.0001**	9940
Time	19.399	**0.0001**	9933	4.6883	**0.0018**	9965
Tr x Ti	1.1199	0.3741	9951	2.207	0.1022	9983

Table 2
Pairwise comparison results of PERMANOVA analysis between areas affected by vehicle traffic and human trampling and their controls in the four times considered (I: March, II: April, III: August and IV: December). In bold $p < 0.05$.

Time	Vehicle traffic			Trampling		
	t	p	Perms	t	p	Perms
I	2.4	**0.0310**	1253	15.4	**0.0001**	9739
II	2.7	**0.0028**	1251	15.6	**0.0001**	9716
III	0.8	0.5741	1251	13.7	**0.0001**	9752
IV	1.1	0.3040	789	18.5	**0.0001**	9598

Table 3
SIMPER routine results showing taxa with the greatest contributions to dissimilarity between control and impacted plots in areas affected by vehicle traffic and human trampling. Lists were truncated when cumulative percentage reached 90%.

Disturbance	Av. diss.	Taxa	Contrib. %	Cum. %
Vehicle traffic	22.15	*U. prolifera*	31.24	31.24
		Brachidontes spp.	28.22	59.46
		Bare Rock	18.55	78.01
		S. lessoni	16.55	94.56
Trampling	72.27	*Brachidontes* spp.	35.06	35.06
		Bare Rock	32.22	67.28
		Ralfsia sp.	21.08	88.36
		B. glandula	8.86	97.22

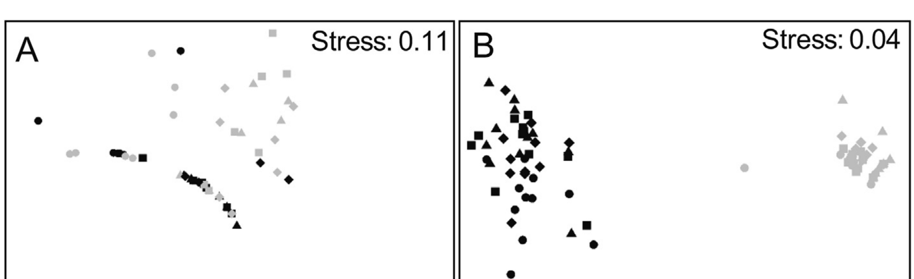

Fig. 2. Two-dimensional MDS ordination comparing benthic assemblages associated with impacted (black) and control (gray) plots in areas affected by vehicle traffic (A) and human trampling (B) for the different times (triangles: I (March), squares: II (April), circles: III (August) and diamonds: IV (December)).

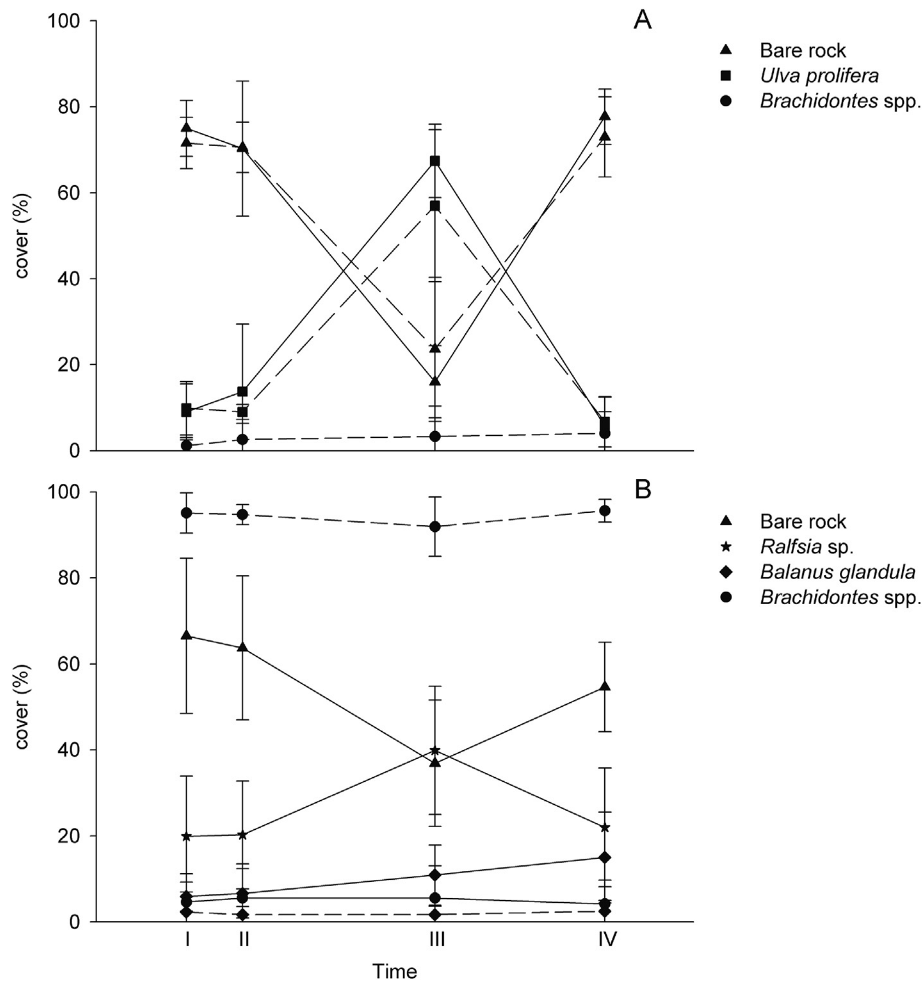

Fig. 3. Mean percentage cover of taxa within plots (control: dotted lines; impacted: solid lines) for patches affected by vehicle traffic (A) and human trampling (B) in the four times studied (I: March, II: April, III: August and IV: December). Only taxa with an average abundance greater than 1% were graphed.

Table 4
PERMANOVA results for the three major contributors to the differences between plots impacted by vehicle traffic and control plots (d.f.$_{Treatment}$ = 1, d.f.$_{Time}$ = 3, d.f.$_{TrxTi}$ = 3). In bold $p < 0.01$.

Source	*U. prolifera*			*Brachidontes* spp.			Bare rock		
	Pseudo-f	p	Perms	Pseudo-f	p	Perms	Pseudo-f	p	Perms
Treatment	1,89	0,1429	9943	10,77	**0,0004**	9942	0,35882	0,6859	9945
Time	23,305	**0,0001**	9938	1,4445	0,2129	9941	28,001	**0,0001**	9954
Tr x Ti	0,299	0,9537	9950	0,52554	0,758	9945	0,35075	0,9098	9942

3.2. Effects of trampling on the benthic community

In the mid intertidal, the benthic community impacted by trampling was significantly different from the community of control plots and among sampling times (Table 1). Differences between trampled and control plots persisted until the following summer (Table 2, Fig. 2B). The abundance of species was markedly different between controls and impacted plots. During the study, *Brachidontes* spp. was dominant in control plots whilst, bare rock, the crustose algae *Ralfsia* sp. and the invasive barnacle *Balanus glandula* characterized plots impacted by trampling (Table 3. Fig. 3B). In the control plots, mean cover of *Brachidontes* spp. was 95% whilst in trampled plots it never exceeded 5% with a concomitant increase in cover of macroalgae and barnacles and proportion of bare rock (Fig. 3B). Richness and diversity were significantly higher in the trampled plots than in the control plots throughout the four times considered (Tables 5 and 6). PERMANOVA did not detect interaction between factors nor differences through time within treatments for richness and diversity.

4. Discussion

The rocky intertidal zone of Punta Este experienced strong disturbance by human activities. People used the rocky shore for recreational purposes and performed various activities that affect the intertidal benthic community. We found differences in the benthic assemblage structure and composition between plots impacted by anthropogenic activities (*i.e.* traffic of vehicles and trampling) and control plots at the end of summer (crowded season). In the high intertidal, traffic of one vehicle produce an

Table 5
PERMANOVA results for total richness and Shannon diversity index in areas affected by human trampling (d.f.$_{Treatment}$ = 1, d.f.$_{Time}$ = 3, d.f.$_{TrxTi}$ = 3). In bold p < 0.01.

Source	Richness			Diversity		
	Pseudo-f	p	Perms	Pseudo-f	p	Perms
Treatment	105.66	**0.0001**	9923	173.96	**0.0001**	9941
Time	2.3005	0.0804	9951	1.2441	0.2661	9933
Tr x Ti	1.2449	0.2881	9948	1.1688	0.3196	9942

Table 6
Pairwise comparison results of PERMANOVA analysis of total richness and Shannon diversity index between areas affected by human trampling and controls in the four times considered (I: March, II: April, III: August and IV: December). In bold p < 0.01.

Time	Richness			Diversity		
	t	p	Perms	t	p	Perms
I	5.7	**0.0003**	35	6.0	**0.0001**	9601
II	4.4	**0.0005**	31	5.7	**0.0002**	9753
III	4.3	**0.0009**	37	7.9	**0.0001**	9720
IV	8.5	**0.0001**	17	8.0	**0.0001**	9441

immediate disturbance that lightly affect the community; with impacted plots displaying the natural assemblage registered in control plots in the following winter. This suggests that the high intertidal community would be resistant to the passage of one vehicle on a single occasion. In contrast, the effects of trampling on the benthic rocky shore were persistent and the community of the mid intertidal did not recover before the start of the next summer season. This may indicate that resilience mechanisms in this complex community operate at broader timescales than a year or that a tipping point was reached; as it was observed in other Patagonian rocky shores (Calcagno et al., 2012).

Recreational activities observed in Punta Este rocky shore can be classified as pulse disturbances since they are intense episodes concentrated in short periods of time (*i.e.* weekends of January and February) and then are removed (Bender et al., 1984). However, pulse disturbances can produce either a pulse or a press response in the assemblage (Glasby and Underwood, 1996; Bravo et al., 2015). In this sense, vehicle traffic would be causing a discrete pulse perturbation (*sensu* Glasby and Underwood, 1996) with the high intertidal benthic community being affected during summer and autumn, but becoming similar to controls soon after. Meanwhile, trampling would be producing a chronic and persistent press effect on the mid rocky shore community with consequences lasting longer than the time between disturbances (*i.e.* March–December). The marked differences in the intensity and the frequency of occurrence of both activities (*i.e.* trampling and vehicle traffic) would be contributing to the type of response of the communities. Concurrently, community composition would be determining mechanisms of recovery related to species identity and habitat. Hence, the nature of the disturbance along with the type of response from the benthic community must be considered in conservation and management decisions (Bender et al., 1984; Bravo et al., 2015).

Recovery depends not only on the cessation of the disturbance at the end of summer, but also on sufficient time for recruitment and growth of the species that have been affected (Schiel and Taylor, 1999). The impacted communities showed different recovery capabilities which can be explained by the nature of the disturbance and by the intertidal level in which they develop (mid *vs.* high) which have intrinsic characteristics. The community composition and dynamics in these two intertidal levels are different, and that likely plays an important role in their response, regardless of the disturbance type. For example, there is a marked seasonal cycle of algal coverage in the high intertidal that is absent in the mid intertidal (Raffo et al., 2014). In this sense, mussel recruitment and recovery in the mid intertidal appears to be slower than algal and barnacle recruitment in the high intertidal.

In Punta Este the effect of vehicle traffic in the high intertidal, where bare rock coverage is close to 75% and natural richness is low (3 species on average), was short-lived. Changes in the assemblage of impacted plots were noticeable only in the first two months. Vehicles cause no impact on the dominant species as *Ulva prolifera* and bare rock coverage were no different in controls and impacted plots throughout the study. Seasonal shifts in community composition of this dominant species could explain the observed patterns, showing a marked seasonality with the greatest abundance recorded in winter, as it was reported for nearby non-disturbed rocky shores (Raffo et al., 2014). Furthermore, the high resistance to physical and chemical changes of the opportunistic *Ulva* sp. would help the alga to persist in impacted plots (Castilla, 1996; Scardino et al., 2008; Luo and Liu, 2011). Thereby, impact of vehicle traffic must be operating on the less dominant species of the high intertidal such as *Brachidontes* spp., whose coverage was higher in control than impacted plots.

The apparent resistance to disturbance of the high intertidal community to vehicle traffic must be considered within the context that vehicle traffic in this study was reduced to a single vehicle on a single occasion. As previously mentioned, heavier traffic has been observed on other Patagonian rocky shores and merit further study. In addition, the impacts of vehicles are not circumscribed to the benthic assemblage as described for sandy shores (McGowan and Simons, 2006; Schlacher et al., 2013). Thus, the prevention of vehicle traffic will also contribute to the conservation of bird species, which are severely disturbed by motorized traffic (McGowan and Simons, 2006; Schlacher et al., 2013).

Trampling affects *Brachidontes* spp. mussels and reduces its cover from 95% in control plots to less than 5% in impacted ones. Mussels are subjected to foot pressure and people walking on them weakens the byssus attachment to the rocks, causing the direct dislodgment of organisms and also increasing their susceptibility to further disturbances (Beauchamp and Gowing, 1982; Brosnan and Crumrine, 1994; Smith and Murray, 2005; Van De Werfhorst and Pearse, 2007). Once a patch of bare rock has been created, natural forces (*e.g.* waves and winds) may cause more mussels to be torn out and the patches extended beyond the area that was originally trampled (Beauchamp and Gowing, 1982; Smith and Murray, 2005). Small patches created by the removal of a few individuals have been reported to recover quickly due to the encroachment of adjacent mussels (Paine and Levin, 1981; Sousa, 1984). Large gaps, however, need to be recolonized by new settlers and can take up to several decades to reach the full recovery of the mussel bed (Paine and Levin, 1981; Sousa, 1984; Calcagno et al., 2012). Furthermore, in Chile *Brachidontes* (*Perumytilus*) *purpuratus* does not settle directly on bare rock, instead it utilized conspecific matrices, filamentous algae and barnacle shells to successfully recruit (Castilla, 1999). Thus in Punta Este, recovery time of the tiny mussel bed could be determined by gap sizes, frequency of disturbance and the recruitment ecology of *Brachidontes* spp. mussels (Beauchamp and Gowing, 1982; Castilla, 1999; Smith and Murray, 2005).

After summer, the percentage of bare rock in the trampled area exceeded 65%. Bare rock generated by the loss of mussels becomes available for colonization by early successional organisms (Dayton, 1971; Brosnan and Crumrine, 1994). Crustose algae and barnacles do not require secondary space (*e.g.* algae, barnacles, or conspecifics) for larval settlement and can establish and colonize areas that have been affected by trampling (Dayton, 1971; Beauchamp and Gowing, 1982; Povey and Keough, 1991). In Punta Este, the brown algae *Ralfsia* sp. and the invasive barnacle *Balanus glandula* are able to recruit in trampled plots but their coverage does not exceeded 35% and become vulnerable to disturbance during the next season. Patterns of complete recovery can only be described through long term succession experiments, which are currently lacking in the literature for the studied area.

Mussels are well known ecosystem engineer species since they aggregate into beds that provide habitats for other organisms (Borthagaray and Carranza, 2007; Palomo et al., 2007; Buschbaum et al., 2009). In Patagonia, more than 40 invertebrate species live associated with *Brachidontes* spp. mussel beds to avoid desiccation stress (Silliman et al., 2011). Thus, damage to mussel beds would have important indirect effects on the associated assemblage. The apparent increased diversity and richness after disturbance observed in this study should be interpreted with care, keeping in mind that the photographic method used only considers percentage coverage of sessile species. Additionally, the frequency of disturbance (*i.e.* every summer) should not allow successional stages to progress to a stable state.

Areas such as Punta Este rocky shore along the Atlantic Patagonian coast are attractive recreational sites intensely visited every summer. This study shows that the development of various recreational activities has brought adverse changes in the intertidal assemblage. Trampling is significantly affecting a habitat-forming species that must be preserved in order to protect its associated fauna. Long-term studies are needed for determining the status of communities under the influence of human disturbance in other coastal recreational sites. However, this work highlights the importance of establishing and implementing effective management actions to achieve the desired conservation goals and mitigate the consequences of anthropogenic disturbances on rocky intertidal habitats. Regulating visitor numbers, implementing educational activities for visitors and the addition of informative signs have proven to be effective preventive measures (Hannak et al., 2011; Travaille et al., 2015; Williamson et al., 2017). These actions, together with prohibiting the entry of vehicles to the intertidal, should be implemented in the short term on Patagonian rocky shores.

As tourism and recreational activities continue to increase worldwide, changes in previously pristine benthic communities could be occurring on any given coast due to the presence of humans and the activities they perform. Future studies should focus on determining the carrying capacity of recreational sites in the Patagonian coast (*i.e.* the maximum number of people that should visit an area), evaluating the establishment of temporary exclusion zones or implementing a rotation in site use as potential palliatives to anthropogenic impacts.

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Conflict of interest

The authors declare that they have no conflict of interest.

Author contribution

MMM and GB conceived the ideas; MMM, GB and JPL performed field work; MMM and JPL analyzed the data; MMM, JPL, JC and GB wrote the manuscript. All authors have approved the final article.

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