How to correctly manage human impacts on Antarctica? Learned lessons from Barrientos Island

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1. INTRODUCTION

Barrientos is a small island in the South Shetland archipelago, Antarctica. It receives c. 5000 visitors per year, ranking among the top fifteen visited sites in the Antarctic Peninsula (International Association of Antarctica Tour Operators, 2013). In 2005, the Secretariat of the Antarctic Treaty established a list of site guidelines to manage the human presence there and to avoid disturbances on local flora and fauna. One of this proposals was the use of a new route, identified as the *Coastal Path* in this work, in substitution of the path traditionally used by visitors to cross the central part of the island (heretofore referred to as the *Central Path*). The reason for this change was to minimize the pressure over the extensive moss carpet area that is covering the central part of the island, which is very vulnerable to trampling. This new path runs in part along the course of a small stream, reducing the direct contact between visitors and mosses (Fig. 1).

Fig. 1. Representative images from the *Coastal Path* (left) and the *Central Path* (right).

In the 2011-12 campaign, a significant damage to important moss beds on the centre of the island was recorded in the vicinity of the *Coastal Path* as a result of repeated foot traffic (Ecuador & Spain, 2012). The Committee for Environmental Protection (CEP) recommended to restrict access to the central part of Barrientos Island by Parties and operators, other than for reasons of scientific research and monitoring related to the recovery of the site. The CEP also proposed to those Parties active in the area cooperate in designing and implementing appropriate surveys, and monitoring plans that will help inform decisions on future management actions (Secretariat of the Antarctic Treaty, 2012). This work showed the first progress on this monitoring effort. The main aim of the research is to determine what route is more adequate to concentrate visitors' displacements based on several physical and biological indicators.

2.1. PHYSICAL PARAMETERS

Methods

Trail width, soil penetration resistance, and secondary treads were recorded in each path. Trail width and soil penetration resistance were measured every 10 m. For the second parameter, 5 replicas per point were obtained using a manual precision penetrometer ST-308, both in the centre of the path (zone of maximum impact) and 50 cm to either side (used as control areas). For the secondary treads, the length and the occupied surface were scored. During the field work, most of the central path was covered by snow, impeding the collection of width and soil penetration resistance in many sections.

Results

1. The mean width of the coastal path was 1.68 ± 0.21 m. This data was not obtained for the *Central Path* due to the presence of snow covering much of the track. However, we developed a similar study in 2009 recording a width of 1.28 ± 0.07 m.

2. The variability of soil penetration resistance values in the *Coastal Path* is much higher than in the *Central Path* (Fig. 2). In both tracks, the central area is the most impacted, existing significant differences between the three considered strips (Kruskal-Wallis test, p-values 0.042 and 0.007, respectively).

3. Secondary treads were only detected in the *Coastal Path*. In total, 10 sections occupying 327 m and affecting an area of 385.3 m^2 were recorded.

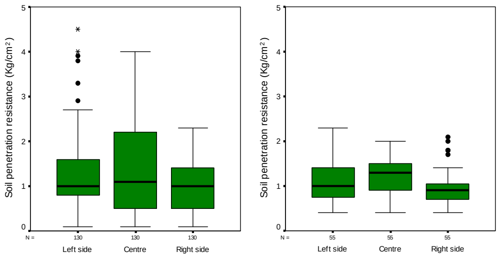

Fig. 2. Soil penetration resistance recorded in the *Coastal Path* (left) and the *Central Path* (right).

Discussion

The *Central Path* is wider than the *Coastal Path*, showing a more clearly marked track. For this reason, visitors do not leave the trail and secondary treads are not generated. It is also more affected by the ice formed along the Antarctic winter (Fig. 3), which remains more time covering some sections of this route. This ice partly protects the ground surface from the effects of trampling by visitors. The *Coastal Path* is usually waterlogged due to the presence of the stream and the melt water during Antarctic summer. This makes visitors leave the route to avoid these muddy areas, creating some secondary treads that are seriously affecting certain moss carpets.

Fig. 3. Certain sections of the *Central Path* remain protected from trampling by snow for much of the Antarctic summer.

2.2. SOIL SURVEY

Methods

Three representative sites were chosen in each path and three classes of parameters were analysed: physical-chemical, microbiological and biochemical.

Results

1. The *Coastal Path* shows higher values for enzymatic activity, soil respiration, C-biomass, nutrients, organic matter, and soil moisture (Table 1 & 2).

2. The 'assessed path' factor (*Coastal* vs *Central*) influences significantly (p-value < 0.05) on soil microbiological and biochemical properties (Table 2).

Discussion

There are significant differences between both paths regarding soil quality parameters. Samples from the *Coastal Path* have higher organic matter content, soil moisture, and a more active microbial community which produces a higher respiration. The soil quality is lower in the *Central Path*, where environmental conditions are less favourable for microorganisms.

Table 1. Physical and chemical parameters.

	pH	Electrical Conductivity (dS/m)	Phosphorous	Total Nitrogen	Carbonates	Total Carbon	C:N ratio	Organic Matter (%)	Soil Moisture (%)
Coastal Path (N = 18)	6.39 ± 0.03	22.13 ± 0.75	130.38 ± 5.28	0.244 ± 0.005	0.039 ± 0.001	1.957 ± 0.106	8.23 ± 0.58	3.365 ± 0.183	34.36 ± 5.11
Central Path (N = 18)	5.83 ± 0.06	21.47 ± 0.54	93.30 ± 4.28	0.125 ± 0.001	0.043 ± 0.003	0.630 ± 0.002	5.04 ± 0.02	1.084 ± 0.003	13.04 ± 0.55

Table 2. Microbiological and biochemical parameters. Results of the ANOVA test for the studied factor (assessed path) are also showed.

	β-glucosidase activity (μmol reactive · g^{-1} soil · $hour^{-1}$)		Urease activity (μmol reactive · g^{-1} soil · $hour^{-1}$)		Dehydrogenase activity (μmol reactive · g^{-1} soil · $hour^{-1}$)		Phosphatase activity (μmol reactive · g^{-1} soil · $hour^{-1}$)		Soil Respiration (mg CO_2 · Kg^{-1})		C-Biomass (μg C · g^{-1})	
Coastal Path (N = 18)	122.07± 22.79		143.06 ± 23.40		0.029± 0.005		61.37± 8.01		46.12± 8.80		689.07± 166.37	
Central Path (N = 18)	28.66 ± 2.92		41.78 ± 5.08		0.009 ± 0.001		13.37 ± 1.93		8.96 ± 0.89		373.78± 62.01	
Factor	**F-ratio**	**p-value**	**F-ratio**	**p-value**	**F-ratio**	**p-value**	**F-ratio**	**p-value**	**F-ratio**	**p-value**	**F-ratio**	**p-value**
Assessed path (*Coastal* vs *Central*)	6.30	0.0274	8.49	0.0130	0.14	0.0291	9.53	0.0094	6.72	0.0236	21.09	0.0006

2.3. FLORA SURVEY

Methods

The non-vascular cryptogam communities presented along both paths were characterized following the classification by Smith (1996) and Ochyra *et al.* (2008). Several photographs were also taken to visually analyze the evolution of the damage on the moss carpet regarding the 2011-12 campaign.

Results

1. Five vegetal communities were identified (Table 3).

2. The *Central Path* is dominated by two communities, *Sanionia-Warnstorfia* association, and *Sanionia-Warnstorfia* mixed with *Polytrichastrum alpinum-Pohlia nutans* association (Fig. 4 & 5).

3. The *Coastal Path* shows a higher diversity, being the *Sanionia-Warnstorfia* association the more abundant vegetal community (Fig. 4 & 5).

4. Most of the damage observed in 2011-12 had barely recovered after one year despite having undergone a full freeze-thaw cycle. However, in some specific areas a slight improvement was observed at the surface probably due to the weight of snow (Fig. 6).

Discussion

According to Pertierra *et al.* (2013), moss communities presented in the vicinity of the *Coastal Path* are more vulnerable to human foot traffic than those associations localized in the *Central Path*. Even a single footstep over the continuous carpet of *Sanionia georgicouncinata* can produce a permanent impact, and this community is very common in the first track. The complete recovery of this vulnerable community may need a long period of time based on analyse of the photographs recorded to do the inter-annual comparison.

Table 3. Non-vascular cryptogam communities identified in the paths of Barrientos Island.

Community	Authority	Description
Prasiola crispa association	Smith (1996)	Assemblage of predominantly foliose green algae forming loose convoluted sheets, mainly on wet soils and commonly associated with biotically disturbed habitats
Sanionia-Warnstorfia association	Ochyra *et al.* (2008)	Assemblage of predominantly pleurocarpous mosses of shallow turf-like carpet and prostrate mat growth-forms on moist to wet soils
Bryum pseudotriquetrum-Sanionia association	Ochyra *et al.* (2008)	Assemblage of predominantly tall moss cushions and occasionally deep undulating carpet growth-forms on wet soil and rock and along melt-stream courses
Sanionia-Warnstorfia mixed with *Polytrichastrum alpinum-Pohlia nutans* association	Pertierra *et al.* (2013)	Corresponds to heterogeneous moss assemblages dominated by large hummocks of pleurocarpous mosses, irregularly patched with turfs and cushions of acrocarpous mosses, developed on seepages areas of raised beach terraces not permanently wetted
Polytrichum alpinum association / *Polytrichastrum alpinum-Pohlia nutans* association	Smith (1996) / Ochyra *et al.* (2008)	Assemblages of mosses with tall turf growth-form. On well drained soils and slopes

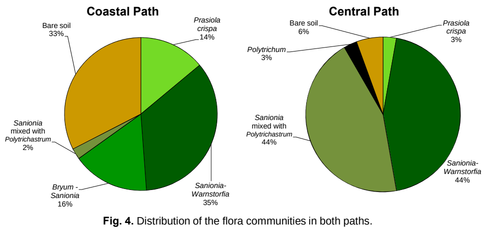

Fig. 4. Distribution of the flora communities in both paths.

Fig. 6. Evolution of trampling damage in one monitoring point of the *Coastal Path*. Pictures from 2011-12 (left) and 2012-13 (right).

Fig. 5. Vegetal coverage along the studied tracks. Flora communities are represented using the same colours used in Figure 4.

3. CONCLUSIONS

1. Based on these data, the creation of the second path (*Coastal Path*) was probably a wrong decision because: a) it runs over a more vulnerable area with more outstanding biological features, b) this route produces greater impacts than the initial, and c) the human footprint on Barrientos Island's trails has doubled by creating a new track.

2. Therefore, a proposal aimed to limit the damage caused by visitors ends up creating a bigger problem due to the adoption of a wrong management measure.

3. This study shows the necessity of apply an adequate environmental monitoring plan to previously assess the effectiveness and suitability of those management measures proposed for particularly Antarctic vulnerable sites.

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