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Research article

Assessing the conservation values and tourism threats in Barrientos Island, Antarctic Peninsula

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ABSTRACT

Antarctica has been witnessing continued growth of tourism, both in the overall visitation and in the diversity of itineraries and visitor activities. Expanding tourism presents unique business and educational opportunities, but it is also putting immense pressure on Antarctica's natural, and for the most parts, pristine environment. Understanding the effectiveness of different tourism management strategies and instruments, like the Visitor Site Guidelines adopted by the Antarctic Treaty, is fundamental to the sustainable management of Antarctic tourism. The purpose of this study was to assess the effectiveness of Visitor Site Guidelines and other tourism management actions in reducing impacts to the natural environment and for this, we used Barrientos Island as our case study as this is one of the most popular sites for tourism activities in the Antarctic Peninsula Region. First, we conducted a literature review and biological inventories to enable a thorough description of Barrientos Island's ecological values. The results show that Barrientos Island occupies the third highest biological richness among the top 15 most visited sites in the Antarctic Peninsula Region. We then assessed how tourism use on Barrientos Island affected biodiversity and the environment, and how Visitor Site Guidelines and other management measures helped alleviate these impacts. As intended, these instruments has been positive and valuable by providing operational guidance. However, they may lack significant information for tourism decision-making processes. To this end, we propose an alternative adaptive management approach that can more efficiently conserve biodiversity and environmental values while allowing the development of sustainable tourism activities in Antarctica.

1. Introduction

Antarctica is the most remote and wild nature destination on Earth and tourism to this last frontier has been significantly increasing and diversifying over the last decades (Bauer and Dowling, 2009; Lamers and Gelter, 2012; Powell et al., 2008). During the 2018–2019 season, 55,

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489 tourists visited Antarctica representing a 70% increase if compared with the 1989–1990 season (Bauer and Dowling, 2009; International Association of Antarctic Tour Operators, 2019a). This active and evolving industry is expanding through the introduction of new modalities and activities reinforcing the need for incorporating new statutory procedures and practices that contribute to its protection.

Commercial tourism in the Antarctic Treaty Area began in the late 50s and early 60s with a few overflights and cruises and grew significantly in the 90s and early 2000s (Bauer and Dowling, 2009). In 1966, Lars-Erik Lindblad began offering regular trips to the Antarctic. Hereafter, expedition cruises to the Antarctic Peninsula –the traditional cruise modality-became an annual feature offered by other Tour Operators (Liggett, McIntosh, Thompson, Gilbert and Storey, 2011a).

The first documented tourist flight to Antarctica was made by Lan-Chile in 1956 operating from Tierra de Fuego, and overflying the South Shetlands and the Peninsula. Tourist flights to Antarctica involving landings were slow to develop commercially because of high overhead costs and lack of infrastructure and amenities for passengers. They increased gradually during the 1980s and 1990s, and since 2003 have expanded more rapidly (Stonehouse and Snyder, 2010). A recent development is the flights that connect tourists with cruise ships at King George Island. This travel option –known either as the air/cruise or the fly/fly modality-is diversifying not only the mode of transport but length, depth, and intensity of trip itineraries and activities in Antarctica.

A major concern of the tourism increase is related to spatial concentration. Most of the tourism activities involving landings take place in the Western Antarctic Peninsula Region, resulting in high concentrations of visitors in determined routes and sites (Bender et al., 2016; Lynch et al., 2010). Bender et al. (2016) estimated that if the total area used by tourists at the 24 most popular landing sites in 2012/13 is aggregated, 76.6% of all landings occurred on no more than 200 ha of land, which at the same time concentrate the presence of high-value natural elements.

The Antarctic Treaty and its related agreements, collectively known as the Antarctic Treaty System (ATS), regulate the uses and management of the Antarctic resources. To accomplish the provisions of the Treaty, complementary management instruments have been developed and adopted. Examples of specific management instruments are the Antarctic Specially Protected Areas (ASPA) and the Antarctic Specially Managed Areas (ASMA). Decisions, Measures, Resolutions and Visitor Site Guidelines are examples of management instruments adopted by Parties that establish procedures and regulations for the treatment of general and specific matters at a global and site-specific level (Antarctic Treaty Secretariat, 2019). Complementary, to contribute to managing biodiversity, science, and tourism, the Systematic Conservation Planning is being developed for the Antarctic Peninsula proposing an integrative, evidence-based approach to site management, incorporating science and tourism activities (Scientific Committee on Antarctic Research, 2019).

Visitor Site Guidelines constitute the most important management instruments used to address tourism uses at a site-specific level. Lynch et al. (2010) have emphasized the importance of evaluating the extent to which these instruments, as separate from other management strategies, work as intended to shape the future of tourism in the Antarctic Peninsula. However, to our knowledge the effectiveness of Visitor Site Guidelines has not been comprehensively assessed, making it significant and timely to analyze their contribution to the conservation and management of visited sites.

The purpose of this paper is to improve understanding of whether Visitor Site Guidelines are being effective in addressing site-specific management needs and impacts regarding tourism uses at highly visited sites. We used Barrientos Island as our case study as one of the top 15 most visited sites of the Antarctic Peninsula Region which is representative of those tourist concentrations and has been part of tourism itineraries since the summer season 1989–1990 (International Association of Antarctic Tour Operators, 2017). The reasons for its popularity are 1) high biodiversity and a variety of outstanding geological features (Antarctic Peninsula Compendium, Naveen and Lynch, 2011), 2) exceptional location in the South Shetland Islands, being part of the most common navigation routes (Bender et al., 2016; Lynch et al., 2010), and 3) possibilities of safe landings during the entire summer season, allowing the development of multiple tourism activities during one single visit, an extraordinary condition compared to other sites in the Antarctic Peninsula.

The assessment we present is divided into the following objectives: 1. Fill information gaps on the ecological values of Barrientos Island that could influence decision-making processes. 2. Evaluate the effectiveness of management instruments (i.e., Visitor Site Guidelines, Resolutions) to address tourism uses and impacts on Barrientos Island.

Based on the information contained in the Visitor Site Guidelines, we conduct a preliminary biological richness assessment to rank and compare Barrientos Island's biodiversity with other highly visited sites in the Antarctic Peninsula. To fill any potential information gap, we systematize available information and include data from our biological inventories regarding flora, soil fauna (Collembola), birds and mammals. We also analyze tourism uses and the environmental impacts identified on the island. Finally, we evaluate the effectiveness of the management instruments adopted for Barrientos Island and the suitability of adopting additional management instruments. We discuss the importance of improving our knowledge about natural values, human pressures, and environmental impacts on all visited sites in Antarctica with the aim of effectively address their management needs.

2. Management instruments in Antarctica

To address the second objective of this article (i.e. evaluate the effectiveness of the management instruments applied on Barrientos Island), it is necessary to introduce the basic characteristics and performance of management instruments. Since 1959, the Antarctic Treaty has been expanded into the Antarctic Treaty System (ATS), including complementary management instruments. The legal text devoted to the protection and management of the Antarctic environment is the Protocol on Environmental Protection, also known as the Madrid Protocol, signed in 1991 and in force since 1998. Within its Annex V, this Protocol defines the System of Antarctic Protected Areas including Antarctic Specially Protected Areas (ASPA) and Antarctic Specially Managed Areas (ASMA), used for the environmental protection in Antarctica (Antarctic Treaty Secretariat, 1991b).

ASPA represents the highest level of land area protection within the Antarctic Treaty Area and are designated to protect outstanding environmental, scientific, historic, aesthetic or wilderness values, a combination of those values, or ongoing and future scientific research. Access to ASPA areas is possible only through specific permits that should be issued by proponent Parties, and in most cases, tourism is restricted. Specific regulations and rules should be contained in Management Plans such as in the case of ASMA which, however, constitute a much more flexible management option. ASMA's are designated to assist in the planning and coordination of activities within a specified area, improve cooperation between Parties, and minimizing environmental impacts. They allow the development of tourism activities.

The Antarctic Treaty Consultative Meetings (ATCM), held annually, constitute the main decision-making forum for Antarctica. *Measures, Decisions* and *Resolutions* are adopted at the ATCM by consensus, giving effect to the principles of the Antarctic Treaty and the Madrid Protocol and including the treatment of general and specific matters. *Measures* are mandatory instruments once they are approved by all Consultative Parties (e.g., Amendment of Annex of the Madrid Protocol). *Decisions* are taken to address internal organizational matters of the ATCM (e.g., Expert Meetings, Subsidiary Groups conformation) and *Resolutions* are hortatory and not legally binding instruments that could address general matters (e.g., general principles of Antarctic tourism) or specific and temporary issues (e.g., banning access to specific locations) to contribute to Antarctica conservation (Table S1, supplementary material).

Particularly for tourism matters, the ATS provides several mechanisms for managing Antarctic site visitation, such as the Visitor Site Guidelines developed for visited sites (Bender et al., 2016). These are not legally binding documents, issued through Resolutions and developed by the Parties in conjunction with the International Association of Antarctic Tour Operators (IAATO). They provide specific guidance for all tourism activities, taking into account site-specific sensitivities, safety considerations and environmental values (International Association of Antarctic Tour Operators, 2019b).

3. Materials and methods

3.1. Site description

Barrientos Island (also known as Aitcho Island) is located in the North entrance to the English Strait, between Robert and Greenwich Islands, in the South Shetland archipelago in the Antarctic Peninsula Region (62° 24′ S, 59° 47' W). This is a small island, of about 1.5 km long and 0.5 km wide, with a maximum height of 70 m at the cliffs of the north coast and descending gently down to the south coast at sea level. Site description key facts are presented in Table S2, supplementary material.

For this area, the climate normal, obtained at the nearby Arturo Prat meteorological station, is consistent with the characteristics of a cold oceanic climate showing a mean annual temperature of −2.5 °C and total annual precipitation of 797.9 mm (Fig. S1, supplementary material).

The predominant rocks of the Island are volcanic and belong to the Coppermine Formation dating from the Cretaceous. The whole central part of the island is dominated by basaltic intrusions. Furthermore, two smaller patches of undifferentiated olivine-basalt lavas and lapilli stones are present on the island (Smellie et al., 1984). The north coast of the island presents several basaltic cliffs.

Barrientos Island is an almost completely ice-free island. In fact, permafrost was not found within the first 100 cm in any of the studied localities on the Island (Paula, 2015).Furthermore, unlike much of the ice-free grounds that are usually barren, most of the ground on Barrientos Island is extensively vegetated by bryophytes and lichens. This abundance of vegetation is linked to one of the main features of Barrientos Island, the dominance of ornithogenic or bird-formed soils, which result from the deposition of the fecal matter of different species of birds and represent the most extensive source of nutrient input for the Antarctic terrestrial ecosystem (Emslie et al., 2014). Soils' physical-chemical characteristics are presented in Table S3, supplementary material.

3.2. Methods

3.2.1. Preliminary biological richness assessment

To compare the biological features among the Antarctic visited sites, and to assess the specific importance of the biological heritage of Barrientos in the Antarctic context, we analyzed updated versions of the Visitor Site Guidelines as they constitute the principal tourism management instrument for those locations (Antarctic Treaty Secretariat, 2019). IAATO statistics for the 2016–2017 season were used to identify the top 15 most popular landing sites, in which we focus our analysis.

Our comparative matrix was divided into two main fauna groups: birds and mammals, and one group corresponding to vegetation. All bird species analyzed correspond to species with confirmed breeders while mammals' numbers include species with breeders and presence. All fauna species were screened through the IUCN Red List Database to determine their degree of vulnerability. The flora information corresponds to algae, bryophytes, angiosperms, and lichens reported for the different sites.

3.2.2. Biological inventory

3.2.2.1. Flora and vegetation. Under the term flora, we consider bryophytes, lichens, angiosperms, and algae. A total of 46 sampling sites were surveyed for bryophytes and lichens. The samples were scattered around the island to reflect as much as possible the ecological diversity of Barrientos Island. Fieldwork took place during two summer field campaigns (Table S4, supplementary material). Lichens were collected during only one short visit to the island. Specimens were stored in plastic freezer bags and kept at −20 °C until they could be conveniently dried and studied at the laboratory. Species identification was based mainly on Bednarek-Ochyra et al. (2000) and Ochyra et al. (2008) for bryophytes, and Øvstedal et al. (2001), Søchting et al. (2004) and Olech (2004) for lichens.

The cryptogamic communities were characterized following the classifications by Lewis Smith (1996), Ochyra et al. (2008), Carvalho et al. (2009), Newsham (2009), Longton (1979), Tejedo et al. (2016), and Pertierra et al. (2013). A complementary vegetation index map was developed. A sentinel image of March 10th, 2018 was processed using expectable bands 2, 4 and 8. The Normalized Difference Vegetation Index (NDVI), was used for the determination of vegetation presence (Ichii et al., 2001), establishing 4 ranges: no vegetation (0.004–0.2), scattered and not deep vegetation (0.3), continuous but not deep vegetation (0.4–0.5), continuous, dense, and deep vegetation (0.6–0.7).

3.2.2.2. Soil fauna (Collembola). Other fifty-six sites scattered all over the island were sampled during three field seasons to obtain the Collembola (Table S5, supplementary material). Site selection was made to reflect the ecological diversity of the island and included both bare soils, as well as ornitogenic soils, and areas occupied by different types of vegetation. A cylinder of 500 cm^3 was used to sample the top 8 cm of soil to capture this edaphic fauna. If present, superficial vegetation was included in the sample. The samples were packaged in 1-L plastic freezer bags, double-labeled, and stored at 4 °C until extraction in the laboratory.

Collembola were obtained by Tullgren extraction of the samples, carried out within 2–3 days after collection. Animals collected were preserved in 99% ethanol before being sorted under a dissecting microscope. Specimens were cleared in lactic acid over 1 week, although this lapse was prolonged slightly for those individuals with dark pigmentation. Collembola were mounted on slides using Hoyer's solution and identified to species level under a phase-contrast microscope. Bibliographical references used for Collembola species identification could be found at Enríquez et al. (2019).

3.2.2.3. Birds. Probabilities of birds' occupancy (presence and breeding) for Barrientos Island came from a multi-state occupancy model that accounts for the probability of detection, November sea-ice concentration, and the prior state of the site (Schrimpf et al., 2020). The model was built using data on the presence/absence of two states (presence and breeding) from visits between 1995 and 2017 by the researchers with the Antarctic Site Inventory -ASI- (Lynch et al., 2013) The probabilities presented are the average latent state (i.e. assumed true state) calculated by the model for both presence and breeding status, averaged across all years during which data were collected (Table S6, supplementary material).

The probability of presence indicates the chance that the species visits the island at some point during the breeding season, while the probability of breeding represents the chance that the species attempts to nest on the island. The population models for both species of penguin, gentoo and chinstrap penguins, correspond to the period 1982–2014 and were obtained through the Mapping Application for Penguin Populations and Projected Dynamics (Humphries et al., 2017). See Fig. S2, supplementary material.

3.2.2.4. Mammals. During five summer seasons (Table S7, supplementary material), an assessment of the mammal populations on the island was conducted through the establishment of four monitoring transects (1,000, 500, 1400 and 200 m) covering all the areas used for these animals (Southeast beach, Northeast beach, Western tip, and its small beach). The study method was direct observation along the shoreline between the edge of the sea and 100 m inland. We used a fixed-width transect, a variant of the linear transect, as the most appropriate technique to estimate the population abundance of Antarctic pinnipeds (Erickson et al., 2009).

The fixed-width transect assumes that all individuals present along the route will be eye contacted, that the presence of an individual will not affect the presence or absence of another individual, that the individuals will not move before being detected, and that no individual will be counted more than once (Martella et al., 2012; Rabinowitz, 2003). Transects were visited two times per season, and counting was carried out between 10:00 and 18:00 h. The number of individuals of each species was determined by the technique of daily sum catches, which consisted of the cumulative record of the number of individuals observed within a study period (Davis, 1987). Complementarily, the general health of pinniped populations of the island was evaluated through the results obtained in the specialized literature, specifically in Rengifo-Herrera et al. (2012, 2013, 2014).

3.2.3. Tourism and management instruments

3.2.3.1. Tourism uses. Trends in the visitation of Barrientos Island were obtained from IAATO reports to the Antarctic Treaty for the period 1989–1990 to 2016–2017. To characterize the trends for the most common tourism activities undertaken on the island, detailed reports from IAATO corresponding to the period 2003–3004 to 2016–2017 were analyzed (Fig. S4, supplementary material).

To describe tourism uses and patterns, 29 observations were made during three Antarctic summer seasons. A total of 17 observations were made *in situ* and 12 observations were done by telescope from the Ecuadorian Antarctic Station "Pedro Vicente Maldonado," located 3 nautical miles away from the island. These observations allowed the identification of visited areas, the description of activities undertaken, and the human pressures related to tourism uses.

3.2.3.2. Environmental impacts. Different environmental pressures were evaluated through specific studies developed on the island. Those included 1) the presence of non-indigenous species of flora (bryophytes and lichens) and soil fauna (Collembola), 2) the levels of chemical pollutants including heavy metals and hydrocarbons, and 3) the disturbance by visitors on soil and flora using compaction and denudation indicators. The presence of exotic flora was assessed during the visits to the island to collect samples of vegetation. The non-indigenous Collembola were obtained through the soil fauna study developed for the island. The concentration of heavy metals and hydrocarbons was studied as part of two more extensive studies developed in the Antarctic Peninsula by some of the authors of this paper. The methods and results are described in detail in Santamans et al. (2017) and Cabrerizo et al. (2016).

Soil compaction was assessed throughout the resistance to soil compression, which was obtained using a manual precision penetrometer ST-308 (Eurosite, Ancona, Italy). This instrument records the force (kg/cm^2) necessary to introduce a marker into the ground to a certain depth, allowing to obtain a fast measure of compaction. Sampling conditions and results are described in Tejedo et al. (2012). Soil denudation was assessed by using an appraisal of the extension of the impacted soil surface, both within the path and the affected external band (i.e., the zone of a direct influence of the path with slight alterations). These parameters were measured in the most critical trampled sections of the Upper and Lower paths. The formation of secondary trails was also recorded by estimating their extension and by measuring the same parameters of the soil erosion indicator. Visual records were complementarily taken for monitoring the evolution of trampled areas after the closure of the paths in 2012.

3.2.3.3. Management instruments. A summary of the tourism management measures taken for the island is presented. This includes a brief description of the general measures established in the Visitor Site Guidelines and the content of the Resolution 5 (Antarctic Treaty Secretariat, 2012) which was adopted for this site by the Committee for Environmental Protection (CEP, the ATS' panel of experts on environmental issues) in 2012 and put into effect since summer 2012–2013.

4. Results

4.1. Preliminary biological richness assessment

For consistent comparisons, the preliminary biological richness assessment we conducted was based solely on the information contained in the Visitor Site Guidelines. According to the information present in these instruments, Barrientos Island occupies third place in biological richness among the top 15 most popular visitor sites in the Antarctic Peninsula Region (Table 1). These results correspond with the interest of tour operators in visiting the island and, consequently, with the high number of tourists arriving at Barrientos Island each season. According

Table 1
Biological richness among 15 top most visited landed sites according to the information contained in Visitor Site Guidelines shows that three of them maintain an ASPA protection category. Visitor sites are ordered following total richness numbers as expressed in the Visitor Site Guidelines. Pop: order of popularity of the visited site corresponding to actual use. In parentheses are the numbers of species found by our studies for these three categories.

Most popular landed visitor sites (2016–2017)	Pop	Surface	Birds	Mammals	Flora	Total
Telefon Bay (ASPA 140, ASPA 4)	14	c. 1 Km2 (crater area)	0	2	22	24
Cuverville Island	1	2 Km x 2.5 Km island	9	3	7	19
Barrientos Island (Aitcho Island)	15	1.5 Km long island	6 (6)	3 (3)	8 (27)	17 (35)
Mikkelsen Harbor (D'Hainaut)	8	3 Km bay (comprises D'Hainaut)	4	4	6	14
Whalers Bay (ASPA 4)	4	2 km long (beach)	5	4	4	13
Petermann Island	13	1 Km long island	6	0	7	13
Half Moon Island	2	2 Km long island	7	2	3	12
Brown Bluff	6	1.5 Km long beach	6	2	3	11
Jougla Point	12	The rocky peninsula of Port Lockroy.	5	1	4	10
Goudier Island	5	Less than 0,5 Km (HSM 61)	4	2	3	9
Neko Harbor	3	500 m beach at Andvord Bay	3	1	3	7
Damoy Point/ Dorian Bay	11	Rocky isthmus off the west coast of Wiencke Island	3	2	0	5
Danco Island/ Errera Channel	7	1.60 Km long island	2	2	0	4
Brown station	9	No Visitor Site Guidelines available				
Wilhemina Bay	10	No Visitor Site Guidelines available				

to the IUCN Red List Data Base, all bird and mammals species in these sites belong to the 'Least Concern' category.

4.2. Biological inventory

4.2.1. Flora and vegetation

The floristic catalog (complete catalog and surveyed localities in Table S4, supplementary material) includes so far an alga, a vascular plant, 14 bryophytes, and 12 lichens. As in the whole of Antarctica, bryophytes and lichens are dominant, and prominence between them depends on environmental conditions. In Maritime Antarctica, ice-free areas can be heavily coated with bryophytes as is the case in Barrientos Island, where the area covered by mosses at the center of the island is quite remarkable.

The extension of this bryophyte carpet coincides with the area of highest NDVI values (Fig. 1), although there is an overlap with the area occupied by the alga *Prasiola crispa* that NDVI is unable to discriminate (Calviño-Cancela and Martín-Herrero, 2016). Lichens dominate rocky areas with considerable diversity and generally lesser biomass. These organisms have low reflectance values that are not properly detected by NDVI as several pigments common in lichens mask the chlorophyll (Calviño-Cancela and Martín-Herrero, 2016). In Fig. 1, rocky and sandy areas bare present low NDVI values. Finally, mixed communities of bryophytes and lichens and open bryophyte formations are frequent on gravel soils and well-drained slopes throughout the island (medium NDVI values in Fig. 1).

The green alga (Chlorophyta) *Prasiola crispa*, typical of areas under the influence of bird colonies is widespread on Barrientos Island (Tatur, 1989). Very scarce presence of *Deschampsia antarctica* has been detected at the western point, and *Colobanthus quitensis* –the other only native flowering plant in Antarctica– has not been reported, although both vascular plants are commonly found in other locations of Maritime Antarctica with ornithogenic soils (Michel et al., 2006; Simas et al., 2007).

A comprehensive terrestrial flora would need additional surveys at the northern and eastern cliffs, which may improve significantly the catalog of lichens and perhaps bryophytes too, but they are difficult to access. These lichen-dominated rocky areas occupy around 6% of the island. Terrestrial algae (apart from *P. crispa*) and snow algae are still to be reviewed.

The species assemblages in the Antarctic flora are not easily defined, as the restricted flora results in many species occurring in a range of habitats and few show a high degree of fidelity to particular communities (Longton, 1979). Besides, complex species associations frequently show an impoverished monospecific version under relatively stable conditions (Ochyra et al., 2008). Pure closed stands or two species co-dominated carpets cover several hundred square meters on Barrientos Island, at the center of the island. Based on our field data and literature, we have defined 8 bryolichenic communities (Table 2). These are (1) Monospecific community of *Sanionia uncinata*, (2) *Sanionia uncinata-Polytrichastrum alpinum* community, (3) *Bryum pseudotriquetrum-Cephaloziella varians* community, (4) Fellfield

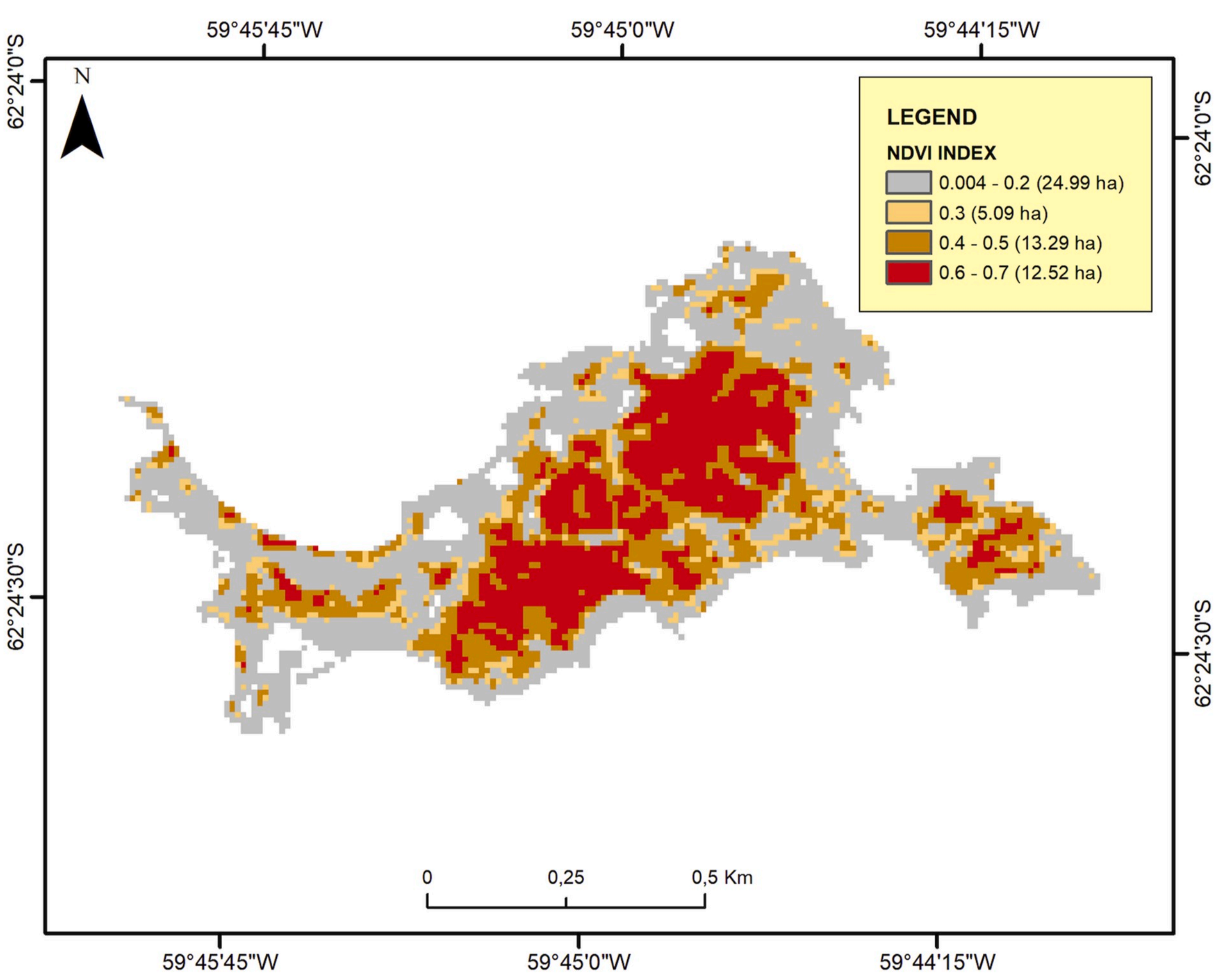

Fig. 1. Vegetation index map for Barrientos Island Highest NDVI values correspond to the extension of bryophyte carpet, with some overlapping with the area occupied by the alga Prasiola crispa. Medium values correspond to mixed communities of bryophytes and lichens and open bryophyte formations on gravel soils and well-drained slopes. Low values are for lichen-dominated rocky areas.

Table 2
Description and composition of the vegetation communities in Barrientos Island based on our studies.

Type of vegetation communities	
Sanionia uncinata-Polytrichastrum alpinum	**Description:** a heterogeneous assemblage of mosses (occasionally lichens), mostly dominated by hummocks of pleurocarpous species. Irregularly patched with turfs and cushions of acrocarpous mosses and lichens at seepage areas of raised beach terraces not always wet. Alongside the paths at the central zone and the Western tip on rocky, stony and gravelly substrates. *Sanionia uncinata* dominates on well-drained soils at more elevated areas, while *P. alpinum* is more abundant on lower and relatively dry soils. **Composition:** *Sanionia uncinata, Polytrichastrum alpinum, Bryum pseudotriquetrum, Ceratodon purpureus, Pohlia nutans, Ochrolechia frigida. Deschampsia antarctica* was found at the Western tip within this community. **Observations:** cited as assemblages of tall moss cushions (Lewis Smith, 1996; Ochyra et al., 2008), on Barrientos Island, it is mainly formed by short turfs and cushions. Described also by Pertierra et al. (2013) and Tejedo et al. (2016). Most frequent assemblage in this study. We consider it a transitional stage from the monospecific *Sanionia* formation to drier environmental conditions.
Sanionia uncinata	**Description:** monospecific communities occurring over a wide range of habitats, mainly on well-drained soils as well as exposed to drier conditions, on flat to steep substrates all along the island. It forms large carpets with 100% coverage of tall moss cushions and turfs. **Composition:** *Sanionia uncinata* **Observations:** *Sanionia uncinata* is the main species in terms of biomass and frequency, appearing in almost all communities present on Barrientos Island. This is the second most frequent type of vegetation of the Island. Described for the moss formations of King George Island (Carvalho et al., 2009).
Bryum pseudotriquetrum-Cephaloziella varians	**Description:** at the central part of the island, beside the Lower path, over gravelly and relatively dry soils. Constitutes the best example of a bryolichenic assemblage, formed mainly by short moss cushions. **Composition:** Dominated by *B. pseudotriquetrum* and the liverwort *C. varians.* Other species present: *Polytrichastrum alpinum*, *Sanionia uncinata, Hymenoloma grimmiaceum, Bacidia aff. stipata, Buellia latemarginata Ochrolechia frigida*, *Usnea antarctica,* and *Xanthoria candelaria*. **Observations:** a rare association according to Carvalho et al. (2009). Possibly this is both the richest in cryptogamic species and the most sensitive community to foot tracking of those described in this study.
Fellfield	**Description:** along the Upper path and at the Western tip, growing over gravelly steep and slightly elevated soils. Short cushions and turf growth-forms dominated by one or more species, depending on habitat features, with great variability in composition and subject to fluctuating environmental conditions. **Composition:** *Andreaea depressinervis*, *Cephaloziella varians*, *Ceratodon purpureus*, *Ditrichum hyalinum*, *Polytrichastrum alpinum, Sanionia uncinata, Polytrichum piliferum*, aff. *Huea coralligera Lecania brialmontii, Lecanora polytropa, Ochrolechia frigida, Placidium squamulosum, Rhizoplaca melanophthalma, Usnea antarctica* and *Xanthoria candelaria*. **Observations:** described by Ochyra et al. (2008) as the most diverse and disparate moss-dominated communities. Also related to the "short moss turf and cushion sub formation" defined by Longton (1979) including a continuum of communities dominated by *Andreaea* spp. and *Usnea* spp.
Sanionia georgicouncinata-Warnstorfia fontinaliopsis	**Description:** extensive turf-like carpets of pleurocarpous mosses over heavily flooded soils forming deep undulating carpets. **Composition:** *Warnstorfia fontinaliopsis* and a variable proportion of *Sanionia georgicouncinata*, **Observations:** restricted to the southern, lower part of the island. Longton's moss hummocks sub formation (Longton, 1979).
Bryum pseudotriquetum-Sanionia uncinata	**Description:** assemblages of tall moss cushions and occasionally deep undulating carpets on well-drained and stony soils close to melting streams **Composition:** *Sanionia uncinata* with a variable proportion of *Bryum pseudotriquetrum*. Lichens are usually absent except for the ubiquitous *Ochrolechia frigida* **Observations:** at the southern lower part of Barrientos Island but less extended than previous community
Sanionia georgicouncinata	**Description:** monospecific assemblage of tall moss cushions and turfs developing on running-water slopes alongside the Upper path at the central part of the island. It appears on soil with lower water content than those where *Sanionia georgicouncinata-Warnstorfia fontinaliopsis* community grows. **Composition:** *Sanionia georgicouncinata* **Observations:** similar situation described by Tejedo et al. (2016).
Crustaceous lichen	**Description:** saxicolous communities growing mostly on bare rocks

communities, (5) *Sanionia georgicouncinata-Warnstorfia* community, (6) *Bryum pseudotriquetrum-Sanionia uncinata* community, (7) *Sanionia georgicouncinata* community, and (8) Crustaceous lichen community.

4.2.2. Soil fauna (Collembola)

Ten species of Collembola were recorded (complete catalog in Table S5, supplementary material), all of them previously cited for Antarctica. The native species *Cryptopygus antarcticus* (Isotomidae) is the most abundant on the island. The remaining seven native species are: *Friesea bispinosa*, *F. antarctica*, *F. woyciechowskii*, *Tullbergia mixta*, *Archisotoma brucei, Cryptopygus badasa*, and *Folsomotoma octooculata*. Two non-native species –*Hypogastrura viatica* (Hypogastruridae) and *Mesaphorura macrochaeta* (Tullbergiidae) – were also identified, the first being much more common. The collembolan richness of Barrientos Island is significant considering that Deception Island, the site with the highest richness recorded in the Antarctic area, has 16 species, of which only nine are native (Enríquez et al., 2019).

Many of the species on Barrientos Island can be considered as eurytopic, appearing in most of the eight analyzed substrate types. Median species richness for Collembola was higher in areas with plant and lichen cover (i.e. alga sheets, bryophyte carpets and mats, short moss turf and cushions, and tall moss cushions). By contrast, median species richness was usually low in samples taken from penguin colonies, the wallow area used by southern elephant seals, footpaths, and beaches.

4.2.3. Birds

The occupancy model was run for all sixteen bird species (complete catalog in Table S6, supplementary material) which breed in the region (Schrimpf et al., 2020). Twelve species representing 75% of the total number of bird species had above 0.60 probability of presence and four species have breeding probabilities greater than 0.75, corresponding to 25% of the total of bird species registered for the island (Table S6, supplementary material). Regarding the penguins' species populations, the ASI repeatedly documents the increase of gentoo penguins *(Pygoscelis papua)* in the Antarctic Peninsula and the southward expansion of the gentoo range.

Particularly in Barrientos Island, the annual rate of change is 1.05 ±

0.0. Chinstrap penguins *(Pygoscelis antarcticus)* on the contrary, are significantly declining throughout their range (Lynch et al., 2008). Even though MAPPPD models are still in an experimental phase for chinstrap and gentoo penguins (Humphries et al., 2017), they show the previously commented trends more clearly for gentoo penguins than for chinstraps due to insufficient data in the case of the latter (Fig. S2, supplementary material).

Finally, the situation of the giant petrel population in Barrientos Island remains unclear. In 2007, the Petrel population was estimated at a minimum of 232 individuals (Koester and Piedrahita, 2007) with an annual rate of population change of 1.04. Similar increases take place at other points in the Antarctic Peninsula (Lynch et al., 2008; Woehler, E., & Croxall, 1997). Despite this, the Antarctic Site Inventory (ASI) does not show a clear population trend yet, and the fisheries in the Southern Ocean still pose a threat to the species according to IUCN (Antarctic Treaty Secretariat, 2006,2007). According to Naveen et al. (2000) at the Antarctic Peninsula, this species suffered a significant decline during the 1990s, apparently unrelated to tourism activities. Recent inventories show the population is stabilizing throughout the Peninsula, with several sites showing population increases (Lynch et al., 2008).

4.2.4. Mammals

From six pinnipeds' species known in Antarctica (Bastida, R., & Rodríguez, 2003), three have been recorded in Barrientos Island (Tirira, 2010, 2017). These species (Table S7, supplementary material for complete scientific names) are the Antarctic fur seal *(Arctocephalus gazella)*, within the family Otariidae; the Weddell seal, *(Leptonychotes weddellii)* and the Southern elephant seal, *(Mirounga leonina)*, both within the family Phocidae. The aggregated results of the counting developed during five seasons (see Table S7, supplementary material) showed that the most abundant species was *M. leonina*, with 802 individuals (85%), followed by *A. gazella* with a total of 117 (12%) individuals and then *L. weddellii*, with 23 individuals (3%) (Table S7, supplementary material).

The differences among the years studied (Table S7, supplementary material) are explained because the observations were carried out during different months of the summer period. An analysis based on the month of record and the average number of individuals indicates that there was an inversely proportional relationship between the abundance of *M. leonina* and *A. gazella.* However, sightings of *L. weddellii* were not dependent on the month of observation (Fig. S3, supplementary material).

The presence of *M. leonina* was numerous in the western tip during January of all the years studied (82% of the total sightings of the species). Reproductive colonies were not confirmed, but important aggregations were identified in the columnar basaltic outcrop in the west. This area is considered the most important wallow area as more than 100 individuals were counted at this point at any one time. Most sightings of this species corresponded to solitary individuals, in most cases, females and young individuals conforming small groups. Adult males were rarely recorded but when it occurred, they were always surrounded by females.

Sightings of *A. gazella* constantly increased from the end of January through February and March. From the total sightings, 89% took place on the western tip of the island. More sightings of this species were of solitary individuals or small groups (up to three) that in no case were showing physical contact. Young males were the most commonly recorded, followed by adult females, young females and adult males. *Leptonychotes. weddellii* was the species with the lowest number of sightings. Just solitary males and female adults were recorded and only 70% of these sightings took place in the western tip of the island.

There are no registers of the leopard seal, *(Hydrurga leptonyx)* or crabeater seal, *(Lobodon carcinophaga)*. However, the incidental registration of individuals of these species is not ruled out since they have been observed while resting on fine stone or snow beaches in the neighboring Greenwich and Dee Islands (Aguayo and Aguayo, 1967; Tirira, 2010).

According to specialized literature, the general health of the pinniped populations in the island is good, at least if we consider the parasitic load and serological profiles, the only currently available information for them. Helminth parasites were present in feces of Southern elephant seals, but with a low prevalence (i.e. 2 positives by Anisakidae in 100 samples, and 1 positive by Metastrongyloidea in 50 samples (Rengifo-Herrera et al., 2014). Other studies analyzing the presence of antibodies due to parasites (*Toxoplasma gondii, Cryptosporidium,* and *Giardia* sp.) in Antarctic fur seals and Southern elephant seals from the island did not show positive results (Rengifo-Herrera et al., 2012, 2013).

4.3. Tourism and management instruments

4.3.1. Visited areas

1) **Southeast and Northeast beaches:** these black sand and cobble beaches constitute breeding areas for chinstrap *(Pygoscelis antarcticus*) and gentoo (*Pygoscelis papua*) penguins. On these beaches, it is common to find resting females and pups of elephant seals (*Mirounga leonina*) and sea lions (*Arctocephalus gazella*). Wildlife observation, walking, and photography are the primary tourism activities, which consist of tourists roaming free throughout the beaches, under naturalist guide's supervision (Fig. 2 tourist's roaming free area corresponds to dashed polygons on the right side).
2) **Upper and Lower paths:** used for at least 15 years, the Upper path (ca. 669 m long) connected to the western tip of the island through a skeletal floor, gravel and rocks. It presents little capacity for water retention and good drainage to the south by the slope of the ground. The presence of mosses and lichens in this zone is discontinuous, dominated by *Sanionia uncinata* and *Polytrichastrum alpinum.* This path is visually distinguishable in the sections that cross vegetated areas, but it also crosses bare areas where its trace is not visually striking (paths corresponds to red and green lines in Fig. 2).
   Used from 2005 to 2011, the Lower path (ca. 750 m long) connected to the west side of the island through a small snow-melting stream and ran across a soft soil in the interior zone of the slope, constantly saturated with water by melting of the snow uphill. The moss carpet in this path is formed by *Sanionia georgicouncinata* and *Warnstorfia fontinaliopsis.* This moss carpet could be more than 10 cm thick in many points, being very sensitive to human trampling.
3) **The western tip of the island:** visually attractive due to the presence of a melting lagoon that is separated from the sea through a narrow terrain. It is also characterized by the presence of a columnar basaltic outcrop in which a large number of elephant seals (*Mirounga leonina*) rest. A rocky ridge serves as a breeding area for giant petrels (*Macronectes giganteus*). Next to the melting lagoon is an important area of tundra with abundant mosses, namely *Sanionia uncinata*, *Bryum pseudotriquetrum* and *Polytrichastrum alpinum* and the presence of few patches of the autochthonous grass *Deschampsia antarctica.* A small sandy beach in the western tip holds an important number of resting pinnipeds. Tourism uses on this side of the island follow specific guidelines regarding viewing distances and group composition unless tourists are allowed to roam free over the area under guide's supervision (Fig. 2, tourists' roaming free area corresponds to dashed polygons on the left side).

4.3.2. Trends and activities

Tourism figures for Barrientos Island showed fluctuations throughout the last 27 years but with a general increasing trend (Fig. 3). According to IAATO reports, during the 1989–1990 season, a total of 271 tourists arrived at Barrientos Island while a total of 6969 tourists visited Barrientos Island during the season 2016–2017, corresponding to a 2300% increase for the analyzed period. As for the rest of the Antarctic Peninsula, the peak of visitation corresponds to late December to the first week of March, the same period in which wildlife is abundant because of the summer season.

In the case of Barrientos Island, the drop in visitation among seasons 2012–2013 and -2014-2015 is explained by the implementation of Resolution 5 (Antarctic Treaty Secretariat, 2012). All tourists' categories showed in Fig. 3, correspond to landed and non-landed tourists. No significant differences between landed and non-landed have been reported by IAATO for the analyzed period.

For the period 2003–2004 to 2016–2017, IAATO reported 14 different types of tourism activities undertaken on the island. Those were small boat cruising, small boat landing, kayaking, extended walk, scuba diving, science support, remote underwater vehicle, skiing, snowboarding, filming, swimming, anchoring only, aircraft landing, and ship cruise. Among them, landings through zodiacs, extended walks, zodiac rides, and kayaking were the most frequently undertaken activities, representing 97% of the total (Fig. S4, supplementary material). During the monitoring periods, and according to the Visitor Site Guidelines, 100 passengers was the maximum number of visitors landed at the same time.

Extended walks were characterized by the use of two paths (Upper and Lower) connecting the east side to the western tip of the island. Over the southeast and northeast beaches, the observation of wildlife, particularly penguin observation is, to date, the most common activity. Kayaking and small boat cruising around the coast are complementary to terrestrial activities. Kayaking depends on weather and safety conditions, and it is always undertaken in small groups of tourists who paddle their kayaks along the east and west coasts of the island. For the period 2003–2004 to 2016–2017, activities as diving, operation of remote-controlled underwater vehicles, and support of scientific activities were reported by IAATO on just a few occasions.

Throughout the monitored periods of summer (from January to March), the most significant tourists' accumulations were observed on the western side of the island due to the presence of a permanent elephant seals' wallow area. This area constitutes the most representative aggregation of wildlife on the west side as the presence of other wildlife, particularly sea lions and Weddell seals, is scattered and consists of small groups or solitary individuals. To date, visits to the west side of the island take place only under good weather conditions due to the closure of the paths. No flagrant infractions of the visiting guidelines were observed in any case.

4.3.3. Environmental impacts

Two non-native Collembola species were recorded in our studies, suggesting that biosecurity practices need to be reinforced. An exhaustive review of these existing guidelines for biosecurity within the Antarctic Treaty Area can be consulted in Hughes et al. (2019). The first species, *Hypogastrura viatica*, is widely distributed in the Maritime Antarctic. Its presence could affect the native Collembola since this species seems to be able to outcompete *Cryptopygus antarcticus* on coastal sites on South Georgia (Convey et al., 1999). On Barrientos Island, *H. viatica* were recorded in five types of substrates from a total of eight, while *Mesaphorura macrochaeta* was present in only one. On the other

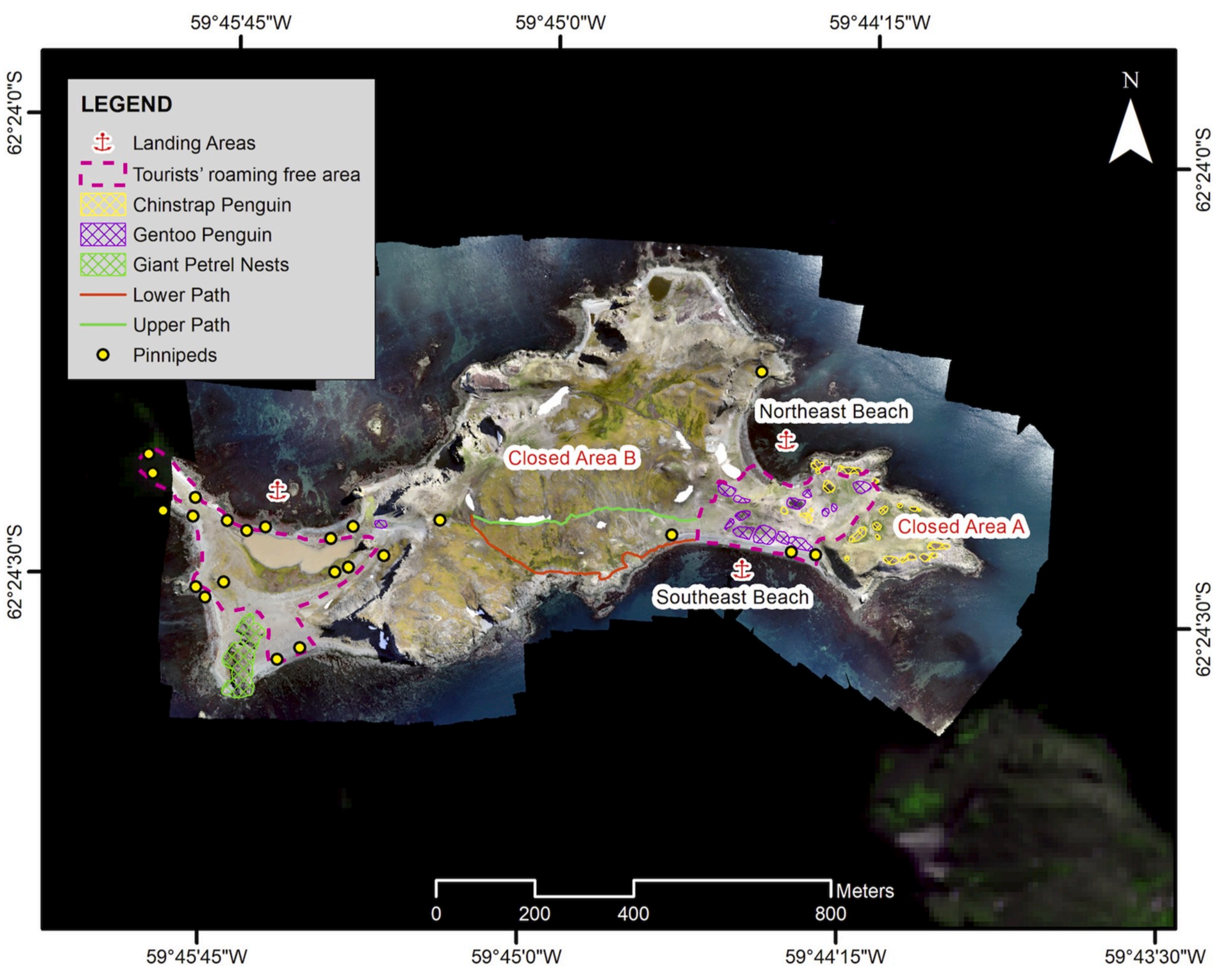

Fig. 2. Natural resources and tourism uses on Barrientos Island. Information layers correspond to field data collected during 2012–2013; 2016–2017 and 2017–2018 seasons. The image corresponds to an aerial 3D model generated in February 2019 by combining high-resolution aerial photographs. Continuous and deep vegetation areas could be appreciated especially in the central part of the island. The melting lagoon (western tip) is shown as a light brown color as a consequence of suspending materials in the water. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

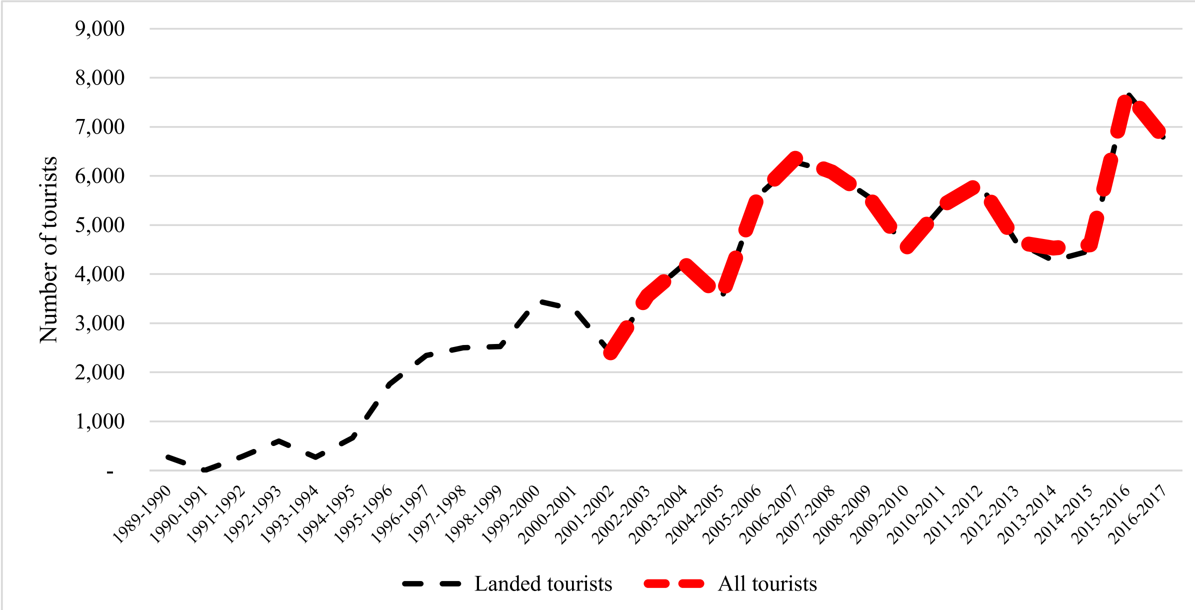

Fig. 3. Tourism statistics for Barrientos Island.

hand, no exotic flora species were found. Fortunately, this shows that the problem regarding non-native species is still very incipient on the island and is limited to Collembola, at least to our present knowledge.

As part of two more extensive studies developed on the Antarctic Peninsula, our team analyzed the presence of contaminants (heavy metals and hydrocarbons). Regarding metals, only the high concentration of Cd and Zn, as well as the low abundance of Mo, are remarkable in penguin rockeries on Barrientos Island. Cd and Zn are biotransported by penguins from the sea (ingestion) to land (defecation), while Mo would be dependent on the parent rock contents (Santamans et al., 2017). Polycyclic aromatic hydrocarbons (PAHs), n-alkanes, biomarkers such as phytane (Ph) and pristane (Pr), and the aliphatic unresolved complex mixture (UCM), were also analyzed in soil and vegetation samples collected at Barrientos Island. Results are similar to the background values observed in other Antarctic zones, both near (e.g., Deception Island, Livingston Island, Penguin Island) and far (e.g., Western Antarctica), suggesting that anthropogenic activity has apparently not contributed to increasing the concentration of these substances in the intertidal soils and flora on the island (Cabrerizo et al., 2016). The main origin of these substances would be plant waxes and soil organic matter and marine algae decomposition, not visitors' presence or activities.

The disturbance by visitors on soil was initially assessed in 2009 using the soil penetration resistance as an indicator -a proxy for soil compaction-. This parameter was measured along the Upper path obtaining higher levels of compaction in the center of the path than in control areas (Mann-Whitney test, $P < 0.001$) which in many cases exceeded the upper limit of detection of the penetrometer. In February 2012, a segment of the path was reassessed. As the snow remained in many areas of the island that year and the path was little used, a recovery situation was demonstrated. Lower penetration resistance compared with 2009 was obtained, both in the center of the path and in the control areas (Mann-Whitney test, $P < 0.001$ in each case). In the most impacted segment, the penetration resistance decreased from an average of 5 kg/cm^2 to 1.43 kg/cm^2 (Tejedo et al., 2012). These data showed that the presence of visitors contributes to compacting the island's soils, but that the annual freeze-thaw cycle assists the recovery of the soil surface layer in a relatively short period of time. In this region, about 2–3 years without human presence would be enough to reach a significant recovery regarding soil compaction (Tejedo et al., 2012).

As mentioned before, the extended walks took place in the Upper and Lower paths of the island. In February 2012 we identified several occurrences of damage in the moss beds located on the Lower path and in its nearby areas. This damage, produced by trampling, caused the creation of several secondary paths as well as the removal of moss. During summer 2013, the width parameter of 10 sections of these secondary paths was assessed. Among the 64 monitored points, the width average was 1.25 m with a maximum of 4.9 m registered for one point corresponding to a bare area. The total extension of secondary paths was 327 m, affecting an area of 385.3 m^2. All these areas exhibited focused moss damage and erosion due to trampling activities related to tourism uses.

Four years later, during the 2016–2017 and 2017–2018 field seasons, fourteen points of the Lower path were reassessed. The average width values were 0.78 m and 0.88 m respectively. Although the trace of the trampled areas is still visible, it is remarkable that in many points of these paths, the borders are becoming indistinguishable. Two secondary paths, corresponding to the most visible and longest trampled areas, were also monitored during these two seasons. These paths showed a width average of 0.35 cm and 0.52 cm for the 2016–2017 season, and 0.61 cm and 0.67 cm width average for the 2017–2018 season. Although the entire area remains closed to human uses, soil stabilization is taking place. The slight increase in the width values of the monitored trails could be explained by the multiplication of drainage channels, probably favored by trampling and is being influenced by the fast-changing local weather conditions, and the natural effects of little melting streams which are exacerbating the formation of muddy and eroded areas.

The direct effects of tourism use on the condition of the natural values of the island present a direct relation with the presence and use of paths which have been helpful in concentrating trampling in less than 0.3% of the total surface of the island. Our data is insufficient to link the existence of other impacts (e.g., pollutants, presence non-native collembolan species) to tourism as those may be global and could have their origin in processes unrelated to tourism.

4.3.4. *Management instruments*

In 2005, the ATS approved the first Visitor Site Guidelines for Barrientos Island in response to the increasing number of tourists arriving each year. Since then, three amendments (2006, 2013, and 2018) have been introduced to this text. As do other Antarctic Site Guidelines, this Site Guidelines include a series of general management measures, such as the restriction of visits between 10:00 p.m. and 04:00 a.m., a maximum of two ships visiting the site per day with a maximum capacity of 200 passengers, landings of maximum 100 passengers at the same time, viewing distance limitations of 50 m for petrels and 5 m for penguins, organization of visitor groups of 20 people per guide, and the prohibition of access to restricted areas (Table S1, Supplementary material).

The 2005 Site Guidelines included the adoption of a new footpath, the Lower path, as an alternative to the traditional Upper path used by visitors to cross the island (Tejedo et al., 2016). Despite the description of specific preventive measures for the use of paths, such as the transit just through areas of stone and soil when mosses are free of snow, the adoption of the Lower path did not consider the high sensitivity of the vegetation communities present in this part of the island. Consequently, during the 2011–2012 season, trampling damage in the moss beds located on the Lower path and in its nearby areas was significant (Tejedo et al., 2016).

As a result, the ATS adopted Resolution 5 (Antarctic Treaty Secretariat, 2012), which recommended that Parties take appropriate steps within their own legal and administrative systems to restrict access to the central part of Barrientos Island, except for scientific research and monitoring related to the recovery of the site (Antarctic Treaty Secretariat, 2012). The updated versions of Barrientos Island's Visitor Site Guidelines removed all the sections corresponding to guided walks through and banned the use of both paths.

After Resolution 5 (Antarctic Treaty Secretariat, 2012) went into force, no visits have been recorded on any of these paths, and three monitoring and evaluation reports on the moss recovery have been presented to the ATS by Ecuador and Spain (Antarctic Treaty Secretariat, 2013,2016a;Antarctic Treaty Secretariat, 2018b). These reports stated that the Resolution has been positive as some soil stabilization process is taking place. However, the closure period is still insufficient to detect any conclusive recovery process of the vegetation trampled.

To date, the access limitation to the entire central part of the island continues. Consequently, activities are now highly concentrated over the nesting areas in the south and north beach on the east side of the island with some spatial measures being taken by tour operators to avoid potential disruptions of wildlife. Although the general management measures described above are still practiced, no additional comprehensive measures regarding the use of the closed paths have been put in place or adopted to date.

5. Discussion

The purpose of this paper was to analyze to what extent Visitor Site Guidelines have been effective in addressing site-specific management needs and impacts regarding tourism uses at highly visited sites. The information included in Visitor Site Guidelines has been conceived to inform tourism operations and tourists about the main features of the sites and specific precautions that must be taken. These general instruments are, in all cases, well complemented by interpretative activities and *in situ* guidance enriching the information and learning opportunities offered to tourists.

Despite their valuable use, it is clear that they neither constitute an exhaustive inventory of the environmental values present at a site nor provide information about time scale changes necessarily occurring, important for policy and decision-making processes. This emphasizes the validity of conducting specific studies and long term monitoring for filling information gaps and better-informing decision-making processes (Chwedorzewska and Korczak, 2010). Our field studies on Barrientos Island and further analysis allowed us to evaluate the quality of information contained in the Visitor Site Guidelines and the effectiveness of complementary management decisions taken for this site.

By comparing Visitor Site Guidelines for the Antarctic Peninsula Region, we found that Barrientos Island occupies the third place in biological richness of the top 15 most visited sites. Despite the remarkable biodiversity of Barrientos Island within the Maritime Antarctic, our literature review indicated that few specific studies had been developed for the island, and just one was related to tourism uses (Enríquez et al., 2019; Koester and Piedrahita, 2007; Paula, 2015; Tejedo et al., 2016; Tirira, 2010).

When conducting this analysis we found an important taxonomic disparity in the information available for different sites. For example, the information for fauna was always more detailed if compared with information regarding flora, which varies importantly from site to site and is very scattered and general. Although we were able to identify flora by species for some visited sites, differences in the information available in the Visitor Site Guidelines were substantial and did not allow us to present this category with more specific details, (e.g. increment or decrease). In the case of Barrientos Island (Table 1), our specific research demonstrated an important increase in the number of vegetation species when compared with the information contained in the site guidelines.

Complementary, our field studies regarding the tourism-driven environmental impacts in Barrientos Island revealed three main concerns: 1) damage to soil and vegetation due to trampling, 2) potential wildlife disturbance, particularly during early stages of the season, and 3) the presence of two non-native collembolan soil species. Although the first two were already identified by the Visitor Site Guidelines as known or potential impacts, the last one was not referenced until now.

Consequently and considering this context three questions arise: 1) Are Visitor Site Guidelines enough to manage increasing tourism? And, 2) when is it appropriate to manage tourism impacts through Resolutions or Measures, and 3) how effective are they in practice?

While it is widely recognized that Visitor Site Guidelines and other additional measures taken by Operators, and highly encouraged by IAATO, had generally contributed to minimizing the impacts produced by tourism activities, the increasing numbers of tourists arriving in Antarctica and the consequences of activities diversification could prove problematic (Liggett et al., 2011a). Particularly for Barrientos Island, wildlife disturbance and the introduction of exotic species have been acceptably managed through the implementation of Visitor Site Guidelines and bio-invasions' control practices formulated by different Antarctic stakeholders (see Hughes et al., 2019; Hughes and Pertierra, 2016 for more details about these biosecurity measures and checklists).

Regarding the risk of introduction of exotic species into Barrientos Island, we recommend for the next revision of the Visitor Site Guidelines to include information about the currently established non-native species on the island and add Internet links to the existing biosecurity guidelines, for example, the 'Non-native Species Manual' published by the CEP (Antarctic Treaty Secretariat, 2016b) and the Codes of Conduct published by the SCAR (Scientific Committee on Antarctic Research, 2018).

Moreover, we suggest reinforcing the application of the biosecurity procedures for passengers and crew members developed by IAATO (International Association of Antarctic Tour Operators, 2005b; 2005a).

The risks of intra-regional species transfer must also be adequately considered within the mandatory Environmental Impact Assessments that are required for all Antarctic projects (Antarctic Treaty Secretariat, 1991a). These guidelines must be strictly complied with Barrientos Island both by scientists and tourists to avoid further non-native species introductions.

Regarding direct tourism impacts, it is important to recognize that the establishment of paths, due to the already perceived high sensitivity of the vegetation communities and potential tourism increase, particularly from non-IAATO vessels, has been a positive strategy in concentrating human pressures in a relatively small area of the island (ca. 2153 m^2 out of a total of 160,000 m^2 of vegetation carpet). However, the rationale regarding the location of the paths, particularly the Lower path, was based on insufficient information.

The Visitor Site Guidelines (2005) suggested the use of the Lower path as an alternative to reduce the visual impact of the footprint marked on the Upper path and because the Lower path, hypothetically, would reduce the contact area of visitors, bare soils, and mosses (Tejedo et al., 2016). This decision was not grounded on comprehensive knowledge on the high sensitivity to the trampling of the vegetation communities on Barrientos Island. Consequently, the use of the Lower path worsened the situation regarding erosion, vegetation damage and visual impact (Tejedo et al., 2016).

To amend this situation, Parties adopted Resolution 5 (Antarctic Treaty Secretariat, 2012) banning access to both paths of the island although trampled areas were reported for only the Lower path. Seven years after the closure, there is preliminary evidence of positive moss recovery on the Lower path, although the trend of any future ecological succession is still uncertain. In the case of the Upper path, no appreciable change has occurred, suggesting that the measure has neither influenced the reduction of the visual trace nor enabled the recovery of the scattered vegetation present on this path. Lastly, Resolution 5 (Antarctic Treaty Secretariat, 2012), triggered an increase in tourist congestion over the penguin beaches, whose effects are yet to be experientially determined.

In a general context, even though *Resolutions* could be a positive fast response action to evaluate and increase its effectiveness, it is essential to have both a solid knowledge of the environment and appropriate monitoring actions. Resolution 5 (Antarctic Treaty Secretariat, 2012) constitutes an emergency measure whose suitability and implementation should be subjected to monitoring or follow-up plans. Specific and detailed studies, like those we conducted for Barrientos Island, would assist in evaluating the effectiveness of management decisions and in designing comprehensive management frameworks that could benefit the achievement of conservation goals by also enhancing stakeholders' participation.

The management of natural protected areas, and particularly tourism management in protected areas, is generally part of an adaptive management approach (Leung et al., 2018). This structured, cyclical process has the objective to strengthen decision-making in the face of uncertainty through monitoring activities and continuous assessments of management decisions. ASMA areas are managed under this approach and could constitute a more flexible option for Barrientos Island. Moreover, this instrument could be enhanced and could encourage governance through the active participation of Parties and Tour Operators in monitoring activities and management decisions. This option could also be perfectly compatible with the scientific activities currently developed on the island, a site without permanent installations or long-term scientific projects, where research is present without constituting an appreciable pressure for the island.

Besides the current management instruments, an alternative management model for these sites could be to replicate the same scheme applied in the review processes of ASMA and ASPA Management Plans. This would include the establishment of specific working groups formed by Consultative Parties interested in the management and monitoring of visitor sites. These working groups, whose head may rotate annually, could issue 4 year-period monitoring reports that may include: 1) the status of the natural values and historical heritage of the site, 2) an analysis of tourism trends and dynamics, 3) a review of research results carried out for the area within the reporting period, 4) the results of monitoring once the most relevant pressures have been identified and relevant indicators have been applied and, 5) a set of management measure proposals to be evaluated by the Antarctic Treaty Parties for further adoption and implementation.

Given the success of the adaptive management approach in managing protected areas globally, this model adopts this approach as its core structure. The experience acquired through the study developed in Barrientos Island makes us very positive about the potential benefits of a model like the one we propose in this paper. This proposal is consistent with the efforts that SCAR and IAATO are deploying for developing the Systematic Conservation Plan (SCP) for the Antarctica Peninsula intended for optimal management of biodiversity, science, and tourism in the region.

6. Conclusions

Our results showed that Barrientos Island is a rich and representative site of the biological diversity of Antarctic visitor sites, particularly of those located on the Antarctic Peninsula. Our findings also revealed an important disparity in the ecological and biological information available, challenging the generation of finer resolution data consistent with the scale of which many visitor management decisions are made. Understanding the relationship between biological richness, site attractiveness, human pressures, and environmental impacts will allow managers, tour operators and the scientific community to develop a comprehensive vision of tourism management and allow the implementation of adaptive frameworks contributing to the conservation of Antarctica.

Under a predictable scenario of increasing tourism and the potential inclusion of non-IAATO operators to the region (Antarctic Treaty Secretariat, 2018a), it remains unclear to what extent voluntary instruments such Visitor Site Guidelines could continue being successful, or if specific instruments like Resolutions or Measures could be sufficient to address management needs comprehensively. As an alternative to address this latter concern, we propose the idea of developing site-specific follow-up plans focused on highly visited sites and based on an adaptive management approach. The purpose of these plans will be to fill information gaps through research and monitoring activities and thus contribute to the implementation of comprehensive management scenarios while encouraging the participation of different stakeholders.

Tourism management in Antarctica should be envisioned as an adaptive management process that needs to be based on the best scientific and technical information available. However, and as stated by different authors, without a comprehensive and strategic approach, all management actions and measures, from Visitor Site Guidelines to the establishment of ASMA and ASPA or even the adoption of new management instruments, could unintentionally trigger unexpected scenarios compromising both the sustainability of Antarctic tourism and the conservation of its unique ecosystems.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Daniela Cajiao: Conceptualization, Methodology, Investigation, Writing - original draft. **Belén Albertos:** Conceptualization, Methodology, Investigation, Writing - original draft. **Pablo Tejedo:** Conceptualization, Methodology, Investigation, Writing - original draft. **Laura Muñoz-Puelles:** Writing - review & editing. **Ricardo Garilleti:** Writing - review & editing. **Francisco Lara:** Writing - review & editing. **Leopoldo G. Sancho:** Writing - review & editing. **Diego G. Tirira:** Conceptualization, Methodology, Writing - review & editing. **Débora Simón-Baile:** Writing - original draft. **Günther K. Reck:** Writing - original draft. **Carlos Olave:** Resources. **Javier Benayas:** Conceptualization, Methodology, Writing - review & editing, Supervision.

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Appendix A. Supplementary data

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