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Research article

Assessing environmental conditions of Antarctic footpaths to support management decisions

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ABSTRACT

Thousands of tourists visit certain Antarctic sites each year, generating a wide variety of environmental impacts. Scientific knowledge of human activities and their impacts can help in the effective design of management measures and impact mitigation. We present a case study from Barrientos Island in which a management measure was originally put in place with the goal of minimizing environmental impacts but resulted in new undesired impacts. Two alternative footpaths used by tourist groups were compared. Both affected extensive moss carpets that cover the middle part of the island and that are very vulnerable to trampling. The first path has been used by tourists and scientists since over a decade and is a marked route that is clearly visible. The second one was created more recently. Several physical and biological indicators were measured in order to assess the environmental conditions for both paths. Some physical variables related to human impact were lower for the first path (e.g. soil penetration resistance and secondary treads), while other biochemical and microbiological variables were higher for the second path (e.g. β-glucosidase and phosphatase activities, soil respiration). Moss communities located along the new path were also more diverse and sensitive to trampling. Soil biota (Collembola) was also more abundant and richer. These data indicate that the decision to adopt the second path did not lead to the reduction of environmental impacts as this path runs over a more vulnerable area with more outstanding biological features (e.g. microbiota activity, flora and soil fauna diversity). In addition, the adoption of a new route effectively doubles the human footprint on the island. We propose using only the original path that is less vulnerable to the impacts of trampling. Finally from this process, we identify several key issues that may be taken into account when carrying out impact assessment and environmental management decision-making in the Antarctic area.

1. Introduction

The primary international legislation concerning Antarctica is the Antarctic Treaty. It was signed in 1959, came into force in 1961, and applies to the area south of 60 °S latitude (Convey et al., 2012). It places pre-existing national territorial claims in the region in abeyance, and prohibits military activity, nuclear explosions and the disposal of radioactive waste material, whilst promoting international cooperation in scientific investigation in Antarctica and recommending measures for the preservation and conservation of

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living resources in Antarctica [Article IX, para 1 (f)]. Since 1959, the Antarctic Treaty has expanded into the Antarctic Treaty System, which includes other legal instruments designed specifically for the protection and management of Antarctic environment. The main legal text devoted to the conservation of the marine and terrestrial ecosystems in the Antarctic region is the Protocol on Environmental Protection to the Antarctic Treaty. This was signed in 1991 and entered into force in 1998. It assigns a degree of special conservation to the entire Antarctic Treaty area. It contains six annexes: (I) Environmental Impact Assessment; (II) Conservation of Antarctic Fauna and Flora; (III) Waste Disposal; (IV) Marine Pollution; (V) Protected Areas; and (VI) Liability. Environmental management and conservation should be a priority within the Antarctic Treaty area since the footprint of human activities is increasing (e.g. Tin et al., 2009; Chown et al., 2012; Convey et al., 2012 and Hughes et al., 2013). Today, there are over 100 research facilities in Antarctica. At least 4000 national operator staff (Council of Managers of National Antarctic Programs, 2012) and up to 34,000 tourists go to Antarctica each year (International Association of Antarctica Tour Operators, 2015). Biological communities on ice-free coastal areas are particularly exposed to potential human impacts, as their level of resilience is largely unclear (Turner et al., 2009). This context makes it essential to consider whether current conservation and protection of Antarctica's environmental values are effective. Monitoring studies are an important tool in achieving this objective.

Here we present a case study developed at an Antarctic site: Barrientos Island. This is a small island located at the north entrance to English Strait, between Robert and Greenwich Islands, in the South Shetland archipelago, Antarctica (62° 24′ S, 59° 47′ W, Fig. 1). It has many attractive features including geological formations (columnar basalt outcrops and 70 m steep cliffs), extensive moss carpets covering the center of the island (unusual in Antarctica), and numerous seabird and mammal breeding colonies. The island's outstanding biological and geological richness has resulted in its inclusion among the sites with high diversity in the third edition of the *Antarctic Peninsula Compendium* (Naveen and Lynch, 2011). It has also aroused the interest of Antarctic tour operators. The number of visitors exhibited a positive trend up until 2007–08 season, with a certain decline in recent years (Fig. 2), like most of the tourist sites in Antarctica. In 2014–15 Barrientos Island received 5262 visitors while a record high of 7240 visitors was recorded in the 2006–07 season. Barrientos Island is among the fifteen most visited sites in the Antarctic Peninsula (International Association of Antarctica Tour Operators, 2015). It is less than three nautical miles from Greenwich Island, where the Ecuadorian research station Pedro Vicente Maldonado is located (62° 27′ S, 59° 44′ W). This summer-only station was opened in 1990 and, for a number of years, has been welcoming scientists from different nations to conduct research on Barrientos Island. Since 2011, our research group has enjoyed the support of Maldonado station in our tourism monitoring activities on Barrientos Island.

In 2005, in response to the large number of visitors to the island, the Antarctic Treaty Consultative Meeting (ATCM) adopted a first list of visitor site guidelines to manage the human presence at this site in order to avoid disturbances to local flora and fauna. These guidelines were initially validated by the ATCM's Committee for Environmental Protection (CEP). The CEP was an advisory set up under the Protocol on Environmental Protection to the Antarctic Treaty to provide advice and formulate recommendations on environmental matters to the ATCM. One of these proposals was the adoption of a new footpath, identified as the *Lower Path* in this work, replacing the footpath traditionally used by visitors to cross the middle part of the island (hereafter referred to as the *Upper Path*). The reason for this change was to minimize the pressure over the extensive moss carpet area that is covering the middle part of the island, which is known to be very vulnerable to trampling (Pertierra et al., 2013). The new path runs partly along the course of a small snow melting stream, hypothetically reducing the area of direct contact between visitors and mosses. In theory, if visitors kept inside the track of the new path, the visual impact generated would be less than that produced by the old path, which is clearly visible from several points of the island.

During the 2011–12 austral summer season, significant damage to important moss beds on the middle part of the island was recorded in the vicinity of the *Lower Path* as a result of repeated foot traffic (Ecuador and Spain, 2012). Numerous footprints and secondary treads were observed alongside this path, with some new muddy areas created by trampling. This level of damage is an exception in Antarctica, and similar situations are only present marginally in the vicinity of research stations where human frequentation is high. This information was presented to the CEP, which recommended restricting access to the paths crossing Barrientos Island, allowing access only for scientific research and monitoring related to the recovery of the site (Antarctic Treaty Secretariat, 2012). The CEP also proposed to the Parties to undertake active work in the area, to design and implement appropriate surveys and monitoring plans that will help the CEP to inform decisions on future management actions.

This paper reports the first progress on this monitoring effort. The main aim of the research was to highlight the importance of scientific research in guiding decision-making processes, as part of an adaptive management model. In our case, this framework was applied to determine which route would be more effective in reducing the environmental impacts of visitors' foot traffic. The choice was based on results from a global assessment that included physical and biological indicators collected on Barrientos Island in 2013, with the exception of Collembola, which were sampled during 2012. Our experience shows the importance of looking at 'the whole ecosystem' when making decisions about environmental management in Antarctica. We have also identified a number of key issues that need to be taken into account in Antarctic environmental management. We hope our findings will help other research teams design appropriate strategies to improve the conservation of Antarctic terrestrial ecosystems.

2. Material and methods

2.1. Study paths

Both assessed paths begin in the primary landing area located in the south-eastern beach of Barrientos Island. They meet at a small pass that join with a third path (*Western Tip Path*) that runs to the western end of the island (Fig. 1). Although the start and end for both paths are coincident, they follow different routes most of the way. The route of the *Lower Path* runs at a lower altitude until it meets the *Upper Path*. This explains the terms selected for the routes. The *Lower Path* runs largely along the South beaches to avoid different sub-colonies of penguins, while the *Upper Path* crosses some penguin nesting areas. Moss carpets lie in the middle part of the island. The *Lower Path* runs through part of the mosses with the exception of a section that follows the course of a small stream. Part of the *Upper Path* runs along the outer edge of the moss carpets, close to a small rocky rise where moss carpets are absent. The length of both paths is quite similar (750 m for the *Lower Path* and 670 m for the *Upper Path*) and there are no steep slopes. Before the access restriction proposed by the CEP, the *Lower Path* was used more intensively than the *Upper Path*. During the 2011–12 tourist season, about 41% of tourism expeditions used the *Lower Path*, while 24% used the *Upper Path* (Ecuador and Spain, 2012) and 34% remained on the beach located close to the penguin colony at the