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Topographic and geomorphologic controls on the distribution of vegetation formations in Elephant Point (Livingston Island, Maritime Antarctica)

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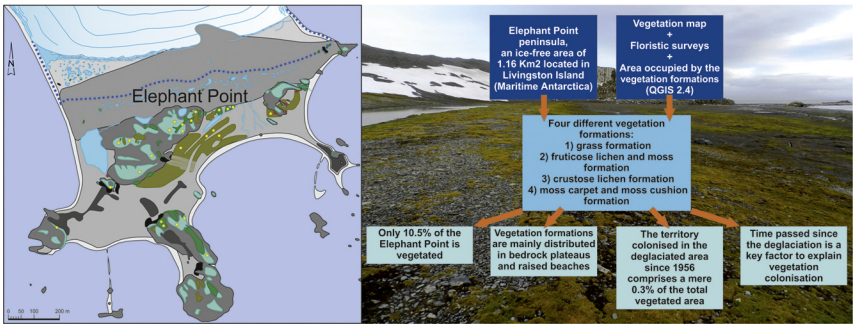
HIGHLIGHTS

- We identified four different vegetable formations in Elephant Point, Antarctica.
- These formations are mainly distributed in bedrock plateaus and raised beaches.
- Only 10.5% of the peninsular area is vegetated.
- These formations have barely colonised the areas deglaciated since 1956.
- Time passed since the deglaciation is a key factor to explain vegetable colonisation.

GRAPHICAL ABSTRACT



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ABSTRACT

This article focuses on the spatial distribution of vegetation formations in Elephant Point, an ice-free area of 1.16 km^2 located in Livingston Island (South Shetland Islands, Antarctica). Fieldwork carried out in January 2014 consisted of floristic surveys and designation of a vegetation map. We have examined these data in a GIS environment together with topographical and geomorphological features existing in the peninsula in order to infer the factors controlling vegetation distribution. This has allowed quantifying the total area covered by the four different vegetation formations distributed across the peninsula, proliferating mainly on bedrock plateaus and Holocene raised beaches. Grass formation is essentially composed of *Deschampsia antarctica*, distributed almost exclusively on raised beaches, and covering 4.1% of the ice-free surface. The remaining three formations are fundamentally composed of cryptogam species. The first of which is fruticose lichen and moss formation, present on high bedrock plateaus and principally formed by lichens such as *Usnea aurantiaco-atra*. The next is the crustose lichen formation, spreading on bedrock plateaus near the coast populated by bird colonies. In this case, ornitocoprophilous lichens such as *Caloplaca regalis*, *Xanthoria elegans* and *Haematomma erythromma* are predominant. Together, both formations have colonised 5.1% of the peninsula. The last variety, moss carpet and moss cushion formation, occupies 1.4% of the deglaciated surface, spreading primarily in flooded areas, stabilised talus slopes, and bedrock plateaus as well. Therefore, the total surface colonised by vegetation is 12.2 ha, which comprises 10.5% of the peninsula. Due to the retreat of the Rotch Dome glacier, 20.1 ha remain ice-free since 1956 (17.3% of the deglaciated area). Ever since, even though the Antarctic

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Peninsula has registered one of the most significant temperature rises on Earth, vegetation has only colonised 0.04 ha of this new space, which merely represents 0.3% of the vegetated area in Elephant Point.

1. Introduction

The Antarctic continent is almost completely covered by glacial ice. Ice-free areas account for a mere 0.4% of its area, and they generally correspond to small coastal stretches. Most of these deglaciated coastlines are located around the Antarctic Peninsula (AP) and adjacent islands, where the average annual temperatures are marginally below 0 °C. Most precisely, the ice-free coastlines of the AP encompass the areas exhibiting the highest biodiversity levels in Antarctica (Toro et al., 2007).

The progressive glacier retreat in the AP began after the Last Glacial Maximum (Ingólfsson et al., 1998; Ó Cofaigh et al., 2014), and continued during the Holocene (Bentley et al., 2009), as the climate variability occurred in the last millennia caused substantial changes in terrestrial ecosystems in these ice-free areas. This glacier retreat has increased in the AP's coastal environments during the last decades (Oliva and Ruiz-Fernández, 2015, 2016), as a response to the warming detected since the mid-20th century (Turner et al., 2005; Oliva et al., 2017). Besides, it has fostered the creation of new exposed terrestrial surfaces, and the expansion of those that already existed, and which generally provide habitat for many birds and diverse pinniped species.

Sparse vegetation, essentially composed of moss and lichens, has progressively developed in the ice-free spaces of recent creation, forming an open tundra. There are numerous studies on various vegetation species present in these sites and their strategies for expanding and propagating (Lewis, 1995; Cuba et al., 2005; Zúñiga et al., 2009; Torres-Mellado et al., 2011; Vera, 2011; Casanova-Katny and Cavieres, 2012), their reproductive capacity (Vera et al., 2013), and other diverse biological and ecological aspects. However, few works focus on the characterisation, distribution and mapping of these vegetation communities, namely, those relying on a more geographical perspective (e.g. Vera, 2011; Victoria et al., 2013). Methodologies for vegetation mapping can vary greatly depending on the size and characteristics of the study area, as well as on the study objectives. When study areas are relatively small (such as the area in this research), the use of field work to generate the cartography is a common approach (e.g. Victoria et al., 2013), whereas in areas of greater extension the use of remote sensing imagery is widespread (Harvey and Hill, 2001; Kokaly et al., 2003). In this case it is necessary to identify the correlations of the different vegetation types with the discernible spectral characteristics of the remote sensing imagery (Xie et al., 2008).

In this sense, and from a geoecological perspective, scientists have recently proposed the creation of a protected site, designated as Antarctic Specially Protected Area (ASPA) in Elephant Point (Oliva et al., 2016), a small area deglaciated in the latest Holocene on the southeast flank of Livingston Island, in the South Shetland Islands archipelago (SSI). This area comprises a wide variety of landforms and processes characteristic to Maritime Antarctica (Oliva and Ruiz-Fernández, 2016), together with some of the best-preserved archaeological remains left by sealers in the AP (Oliva et al., 2016). Nevertheless, a detailed knowledge of the vegetation, its species and spatial distribution in this small peninsula, has not yet been analysed, and it is of capital importance for the categorisation and subsequent implementation of regulations associated with the designation of ASPA in Elephant Point.

Designed to overcome the current lack of knowledge of the natural system in Elephant Point, this work focuses on the distribution of vegetation and its interrelationships with the present and past geomorphological dynamics in the above-mentioned peninsula. Its development will provide solutions to several specific objectives:

1. Identifying, characterising and mapping the vegetation formations present in the peninsula, as well as measuring their spatial extension and their relation with other existing geomorphological units.
2. Discussing the factors explaining their characteristics and geographical distribution.
3. Evaluating the vegetation colonisation occurred since the recent deglaciation as a response to the warming registered during the second half of the 20th century in the AP (Turner et al., 2005).

2. Study area

The Elephant Point peninsula (62°40′53″S–62°41′34″S latitude, 60°52′21″W–60°50′48″W longitude) is situated in the southwest side of Livingston Island, which is the second largest Island in the SSI archipelago. This archipelago is located 120–130 km to the northwest of the AP, separated from it by the Bransfield Strait (Fig. 1). Like the rest of the SSI, Livingston Island is mainly covered by glaciers. From a topographic point of view the least significant areas of this island consist of glacial domes with smooth slopes, and their fronts generally reach the sea. Conversely, mountain glaciers have been formed on the peaks and in the more mountainous areas of the island.

The glacial retreat occurred during the Holocene has likewise generated ice-free areas that, on average, constitute 10% of the archipelago area (Serrano, 2003), showing important variations among islands: from ~57% in the volcanic Deception Island to ~10% of the surface in King George and Livingston (Serrano, 2008). The deglaciated areas present dissimilar dimensions: from the ~60 km^2 of Byers (Livingston), to areas with less than 1 km^2 on the sides of the islands. The Elephant Point peninsula is among the smaller extensions, displaying 1.16 km^2 of ice-free areas. Fig. 1C shows that approximately 17.3% of the above extension has formed between 1956 and 2010 due to the retreat of the Rotch Dome glacier (Oliva and Ruiz-Fernández, 2015, 2016), as indicated by the dotted line.

The climatic characteristics of the area are those of the northwest extremity of the AP and, by extension, of the SSI. In a station situated in the nearby Byers Peninsula, about 10 km away from Elephant Point, the average annual temperature at 70 m asl for the period 2002–2010 was −2.8 °C, while annual precipitation ranged between 500 and 800 mm (Bañón et al., 2013). The magnitude and length of low temperatures becomes the main limiting factor for vegetation development, comprising three months a year in which the average temperature is above 0 °C on average (Serrano, 2003, 2008; Newsham, 2010).

In Elephant Point the deglaciated area is mainly formed by basalt, and the following geomorphological units are distributed in the peninsula: proglacial area, moraine system, bedrock plateaus, raised beaches and present-day beach (Oliva and Ruiz-Fernández, 2016). Each of these units has particular implications with respect to vegetation distribution and wildlife. Periglacial landforms are diverse and abundant. Periglacial processes are very active, especially those connected with the presence of ice in the ground, and the seasonal variation of the active layer (frost shattering, cryoturbation, fast and slow mass movements, etc.). As happens in other recently deglaciated maritime environments in the SSI, permafrost conditions in Elephant Point are widely extended. The evolution of the annual snow cover also has important geomorphological effects, such as the existence of several active pronival ramparts in the area (Oliva and Ruiz-Fernández, 2016).

This peninsula boasts a large concentration of wildlife, mostly circumscribed to the area of marine influence, namely the present-day beach, the five levels of Holocene raised beaches and the surrounding

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