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ECOSYSTEMS

Changes in plant communities and soil attributes in the "Cousteau's whale bone skeleton" tourist attraction area in Keller Peninsula after 48 years

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Abstract: Ice-free areas of Antarctica represent an important study region that helps us understand how human activity affects plant communities and soil properties. The goal of this study was to determine the changes in plant composition and soil properties around a whale bone skeleton (WB) near Ferraz Station, King George Island, Antarctica from 1972 to 2020 (48 years). The WB was assembled in 1972 by Jacques-Yves Cousteau and his team. It is located in a large moss field and visited by many tourists. We studied the plant composition and development based on historical and recent photographs and phytosociological studies from 1986 to 2020. The soil was sampled in February 2009 to determine general properties. The results showed that human activity surrounding the WB directly affected the plant community composition and soil properties. The *Syntrichia* cushions were positively affected by the calcium deposits from bone dissolution. The principal component analysis revealed that mineralization of the bones increased soil nutrient assembly. A strong phosphatization process was observed in the WB area, similar to that in ornithogenic soils. The WB on the marine terrace enhanced soil fertility and changed the plant community.

Key words: Anthropogenic impacts, human activity, ice-free areas, landscape modification.

INTRODUCTION

Human influence on Antarctic biota has been studied over the last few years, but few studies have dealt with long-term studies on vegetation succession following disturbance (Barnes et al. 2006, Convey 2007, Chwedorzewska 2009, Hughes & Convey 2010). Admiralty Bay on King George Island (South Shetland Islands) offers a unique opportunity to observe past anthropogenic effects that have persisted over the years and can be used as a proxy of the environmental effects of human intervention. Six different countries (Brazil, Poland, USA, Peru, Ecuador, and Italy) have scientific stations and refuges. Historically, intensive whaling and seal hunting took place at these places, leaving behind tools and thousands of whale remains, especially bones (Trathan & Reid 2009). On the Keller Peninsula many remnants of the whaling period are found, primarily as waste, scattered along the shore.

In this region, the main whaling activities occurred in the first half of the 20th century, when primarily humpbacks whales (*Megaptera novaeangliae*), fin whales (*Balaenoptera physalus*), blue whales (*Balaenoptera musculus*), and, to a lesser extent, sei whales (*Balaenoptera borealis*) were hunted (Kittel 2001). According

to historic data, from 1906–1909, a total of 3657 whales were officially captured in the South Shetland Islands (Rakusa-Suszczewski 1998). In 1972, when the Jacques-Yves Cousteau research team was performing studies during an expedition to Antarctica, they assembled an entire whale bone skeleton (WB) as a memorial to this unfortunate hunting period (Olmstead 2008).

This monument can be seen on the terrace in the vicinity of the Ferraz Station, allowing the long-term study of vegetation response. The whale comprises bones of different species, mainly blue and humpback whales (Kittel 2001). This monument is called the *Cousteau whale bones skeleton* and has been intensively visited by tourists and scientists working in this area, especially from the Brazilian Antarctic Ferraz Station. Therefore, there has been direct anthropic effects because of human interference on the moss carpet since 1984, when the Brazilian station was installed.

The plant communities in this region are restricted to mosses, lichens, and algae. Only two vascular plants (*Colobanthus quitensis* [Kunth] Bartl. and *Deschampsia antarctica* Desv.) occur ((Øvstedal & Lewis Smith 2001, Ochyra et al. 2008, Convey et al. 2014). Vegetated sites might be influenced by animal guano, as well as egg fragments and scattered bones (Pereira & Putzke 2013), which are extremely important to the nutrient cycling processes in terrestrial ecosystems of maritime Antarctica. In addition, the deposition of such materials can form soils with singular chemical and physical characteristics in a unique environment where the relationship between the soil and vegetation is strong (Schaefer et al. 2004, Francelino et al. 2011, Thomazini et al. 2016).

The WB acts as a physical barrier, reducing wind strength and promoting the accumulation of snow. This reduces wind erosion and creates hydromorphic spots during the summer caused by melting that are preferentially colonized by *Sanionia uncinata*. Additionally, bone fragments are also common around the WB because it has been subjected to weathering and dissolution over time, creating a micro-environment with a different chemical composition, especially chemicals related to organic contents and P–Ca forms in the soil (Schaefer et al. 2004, Pereira & Putzke 2013). With human interference, these processes can be altered over time, modifying the structure of the vegetal community and soil nutrient levels, which began with the construction of the WB. According to Tejedo et al. (2005), empirical evidence showed that even low human activity affects the soil at the surface layer. Hence, the objective of this study was to determine (i) plant composition and its dynamics and development from 1986 to 2020 and (ii) the dynamics of soil properties around the WB near the Ferraz Station, King George Island, South Shetlands Islands.

MATERIALS AND METHODS

Study area

The study was conducted on Keller Peninsula, Admiralty Bay, King George Island, South Shetland Islands (Figure 1). The study area is approximately 500 ha, being 4 × 2 km in length and width, respectively (Francelino et al. 2011). According to historical data from the meteorological station located at the Brazilian Comandante Ferraz Antarctic Station (62°5'5.03"S, 58°23'31.92"W), mean air temperatures from 1986 to 2013 were 1.6 °C during summer (December–March) and −5.3 °C during winter (June–September) (INPE 2014). The mean annual precipitation is approximately 400 mm and the altitude vary from 0 to 340 m above sea level (Francelino et al. 2011). Basalt, andesites, and pyritized andesite rocks are the predominant geology of the peninsula. Leptosols

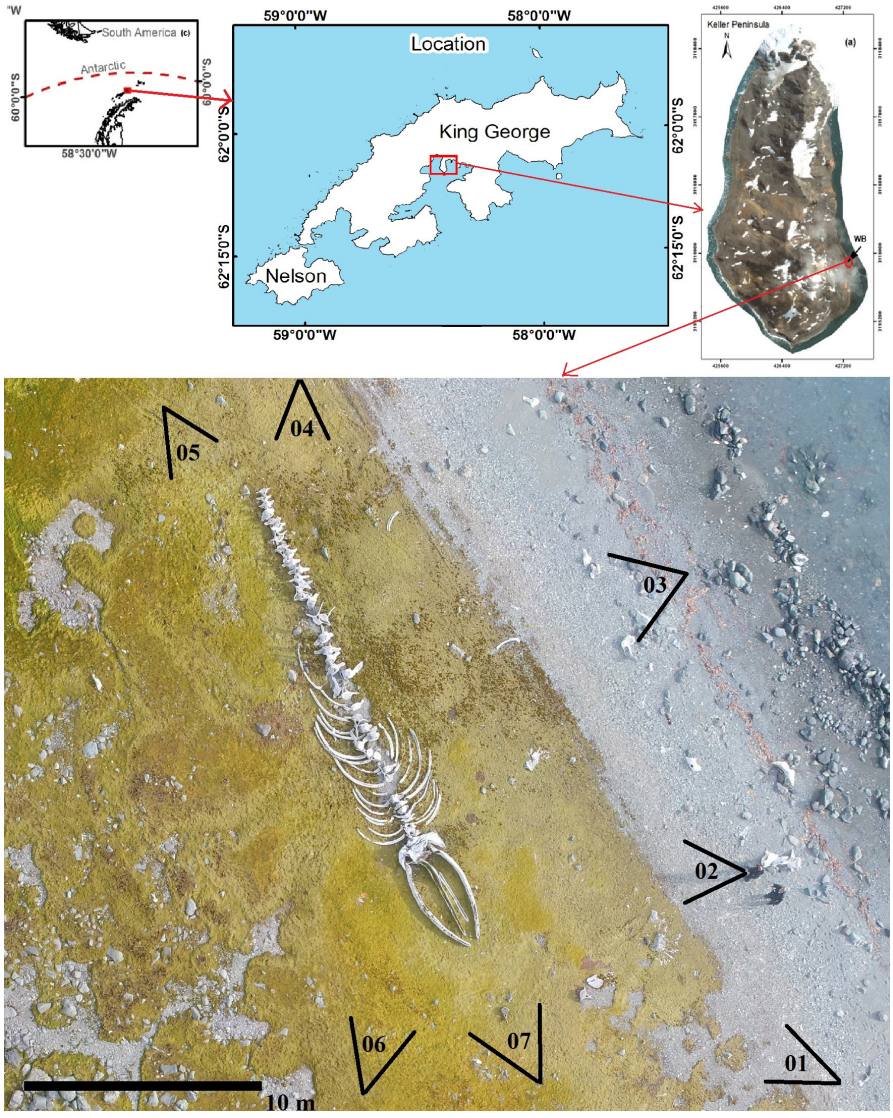

Figure 1. Schematic map with the location of the WB area and the distribution of each photographic position.

and Cryosols are the most representative soils (Francelino et al. 2011).

The WB was assembled in a large moss field near the Ferraz Station in December 1972 by Jacques-Yves Cousteau's team and has been visited by many tourists over the years. The WB is comprised of 43 vertebrae, 24 ribs, and a complete skull with mandibles, all in the correct anatomical position (Figures 2 and 3). The WB was presumably assembled using bones readily available from the vicinity (Kittel 2001). The bones were positioned in an NW–SE orientation on a marine terrace. The WB area is characterized by coarse sediment on a flat area with water accumulation. The plant community is a "moss carpet" community, covering approximately 360 × 50 m. There is no influence of guano because there are no bird or penguin colonies close to the area (Thomazini et al. 2016).

Modifications to the plant communities

Plant composition and development were based on historical and recent photographs and phytosociological works. Phytosociological studies were conducted in three Antarctic

campaigns: 1997/1998, 2003/2004, 2013/2014. Mosses were identified using Ochyra et al. (2008).

Photographs from 1972 to 2020 were used and also interpreted pictures published in articles, books, and on the Internet, to enhance the interpretation of the modifications to the plant communities over the last 48 years. Drone Phantom 4 was used to take aerial photographs of the area and the Agisoft program was used to make a detailed map of the area. The following photographs, noting their respective position, were used for the complete analysis of the WB (Figure 1):

- Figueiredo (2006), Reuters (2014), Tanida (2008), Olmstead (2008) and Zalasiewicz (2011): taken from the frontal-right position (called position 01); this area was considered the better position to take o good photo with the skeleton being the most common on the internet;

- Tavares (2009): taken from frontal position to the right (position 02);

- Capozoli (1991): a lateral view (position 03);

- Mesquita (2013, photo taken in 2010 – right and left sides but taken from behind (positions 04 and 05);

- Kaehler (2010) and our Figure 11 (2011): from the frontal-right lateral position (position 06);

- Burchil (2011) from the exact frontal position (position 07).

All photos were compared with the originals taken by Cousteau's team in 1972, as well as our photos taken in the aforementioned expeditions since 1986. Aerial images taken in 2005, 2014 and 2020 helped to generate a schematic map to discuss what is happening to vegetation in area surrounding the better position to take a photograph by visitors in front of the whale skull (position 1). A sequence of photographs was taken at a height of 1 m (vertical position) in all areas surrounding the WB. The pictures were coupled to assess the plant composition and plant distribution by direct observation. A Cannon EOS 550D was used to take pictures with a resolution of 14 megapixels. Maps were drawn by assembling all photographs combined with the phytosociology. The phytosociology study was based on the method proposed by Braun-Blanquet (1932), by using 20 × 20 cm randomly placed quadrats to evaluate the dominant species.

Soil sampling and analysis

The soil was sampled in February 2009 to determine the general properties. Sixteen single soil samples were collected both inside and outside the WB area at 0–20 cm depth. The soil samples were air dried, ground, and sieved through a 2 mm sieve to remove the larger pieces of root material and stony fractions.

All soil samples were analyzed in the soil laboratory at the Universidade Federal de Viçosa, Minas Gerais, Brazil. The particle size distribution (sand, silt, and clay) was performed using the pipette method (Embrapa 1997). The pH was determined in a 1:5 soil: deionized water ratio. The potential acidity (H + Al) was extracted with 0.5 mol L^{-1} $Ca(OAc)_2$ buffered to pH 7.0, and quantified by titration with NaOH 0.0606 mol L^{-1}. Exchangeable Ca^{2+}, Mg^{2+}, and Al^{3+} were extracted with 1 mol L^{-1} KCl, and Na^{+} and K^{+} were extracted with Mehlich 1 (Embrapa 1997). The contents of elements in the extracts were determined by atomic absorption (Ca^{2+}, Mg^{2+}, and Al^{3+}), flame emission (Na^{+} and K^{+}), and photocolorimetry (P). Microelements (Fe^{2+}, Zn^{2+}, Mn^{2+}, and Cu^{2+}) were extracted with 0.05 mol L^{-1} HC1 + 0.025 mol L^{-1} H_2SO_4 and determined using inductively coupled spectroscopy. Total soil organic carbon was determined by wet oxidation with $K_2Cr_2O_7$ 0.167 mol L^{-1} in the presence of sulfuric acid with external heating (Yeomans & Bremner 1988).

Figure 2. Moss field (black contour) where the whale skeleton was disposed (arrow). The photo was taken in 2011.

Data analysis

Data on the general soil properties (n = 8) were interpreted in terms of general trends (mean and standard error). Principal component analysis (PCA) was performed to explore general trends and relationships with whale bone skeleton dissolution at the sampled zones. All soil data were analyzed using R software (R Development Core Team 2008).

RESULTS AND DISCUSSION

Substantial variation in plant species composition was an important feature of the WB area (Figures 1, 2, 3). By visualizing the photos taken in 2011 and 2020, it was possible to identify several unvegetated spots across the moss carpet where there were bare soil areas or ponds. Closer to the former G Base at south, the most distant point (~50 m), the vegetation was composed of a dominant cover mix of the flowering plants *Colobanthus quitensis* and *Deschampsia antarctica* associated to *Sanionia uncinata*. Downslope, patches of *Sanionia uncinata*/*Sanionia georgico-uncinata* associated with *Syntrichia* and *Bryum* spp. began to appear. Near the WB area, the dominant species was *Warnstorfia sarmentosa*, which

Figure 3. Original photo taken by the from Cousteau's team showing the complete mounted whale skeleton in 1972 on a deep snow bank (above) and a recent (2014) aspect of the whale bones.

covered the western side. In the northern part, *Bryum orbiculatifolium* was dominant, forming the largest area of this species on the peninsula, which was associated with *Warnstorfia sarmentosa,* as reported by Pereira et al. (2008) (Figure 4).

Comparing the original WB settlement (from 1972 and 1984), many changes could be observed because of wind erosion, human interference, and especially marine erosion. It is important to note that the Cousteau team did not recognize the moss field underneath the WB during assemblage because of the heavy snowpack on the ground at that time (as clearly shown by the original photo in Figure 3). Plant species surrounding the WB on the western side were mainly represented by *Warnstorfia* carpets, with only seven small cushions of *Syntrichia* at the southernmost part (Figure 5). On the northern side, where the WB acted as a wind barrier, two large communities with *Syntrichia* as dominant are found at the eastern side near whale tail.

The WB contributed to snow accumulation on the moss carpet because its structure reduced the dominant wind, creating a thick snowpack on the ground. Photos taken by Tanida (2008) and Palo Jr. (2008) showed the snowpack around the bones, whereas the carpet in the surrounding area is snow free. The snow contributed to a greater water supply and also reduced photosynthesis. It is expected that the moss carpet remained wetter around the WB, whereas waterlogged areas decreased with distance from the WB to the sea shore. In addition, greater Ca and P soil content because of the dissolution of bones was related to the occurrence of *Syntrichia* under the influence of waterflow. It was possible to observe large cushions of that species (Figures 4 and 7). MacKnight et al. (2013) reported that *Syntrichia ruralis* is associated with alkaline and calcium-rich soils.

Greater soil moisture in the moss fields made it more resistant to erosion and/or displacement by human trampling, which reduced fragmentation, and consequently, degradation. Hence, even with human access to the WB area, the wetter and central parts of the plant community dominated by *Warnstorfia* were completely preserved (Figure 11). Although several footprints on the moss carpet can be seen, it remains intact overall.

In the aerial imagens of 2005, 2014 and 2020, we observed substantial moss carpet

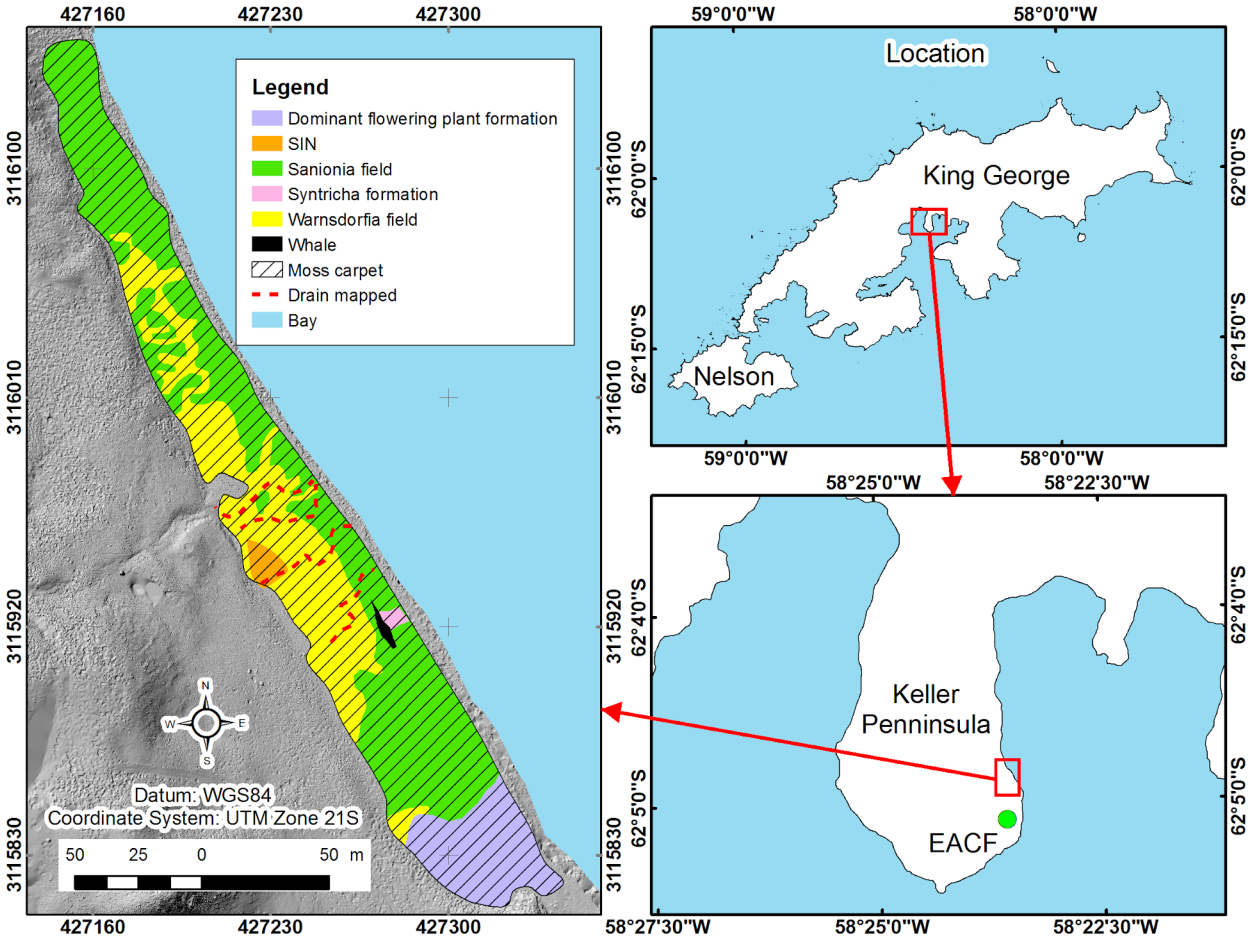

Figure 4. Schematic map showing the plant distribution in the studied area.

degraded by fragmentation in drier areas because of trampling and erosion, mostly near the Position 1, which was considered better to take photographs by the visitors. Calculating the progress of the impact, we observed an augmentation of 75% in the carpet loss from 2005 to 2014 and 152% in 2020, showing that the moss loss is faster in the last years (Figures 9 and 10).

Burchil (2011) showed two photographs taken in 1990 during her field trip with Cousteau´s second expedition to Antarctica. The frontal view (inverted horizontally) shows how visitors activity effected the moss carpet as people walked near the WB area. Additionally, Capozoli (2001) published a black and white photograph that showed a great area of footprints surrounding the WB.

In our photographs of 2011 of the Cousteau's WB distinct wheel marks are visible, disrupting the moss carpet on the left side and around the whale tail (Figures 6 and 8). The four-wheel motorcycle introduced by the Brazilian Navy accounted for this severe effect, which resulted in new recommendations by the Brazilian station commander to ban four-wheel drivers from crossing the moss field.

The most important losses were observed in the frontal position (southeast), one m away from the mandible. A large carpet segment (36 m^2) was fragmented and/or dried out, and is often blown away by the wind. Our older photos (before the 1990s) also showed that this part was the most affected area by visitors, with footprints occurring where people mostly took photos of the monument (called here Position 1). The degradation of the moss carpets was mainly associated with visitors. Pictures taken in 2005, 2014 and 2020 and overlapped, generated a schematic map that highlight these effects which continue nowadays and are affecting this area dramatically (Figure 10). Thus, this is the most important cause of moss disruption because this is a unique carpet in this area (Figures 9, 10). It is evident that the eastern position is more affected compared to the western area because of visitors interest (Figure 8, red line). Tejedo et al. (2005) considered that even low influence of human activity can affect soil at the surface layer, reducing infiltration capacity, and altering the ecosystem. Tejedo et al. (2009) considered that a "concentration" strategy based on the creation of properly signed paths is more appropriate in "sacrificial areas" and that strict control of areas visited by humans is necessary to prevent future disturbance because the unusually low diversity of Antarctic soil biota could be severely affected. Comparing the map produced by Pereira et al. (2008) with data from 2002/2003 (Francelino et al. 2004) with the image produced with the drone (2020), we could infer that the size of the moss carpet is now smaller than in the 1980s, and the relative proportions of exposed rock have increased.

An artificial barrier was created to protect the WB area, by setting aligned stones around

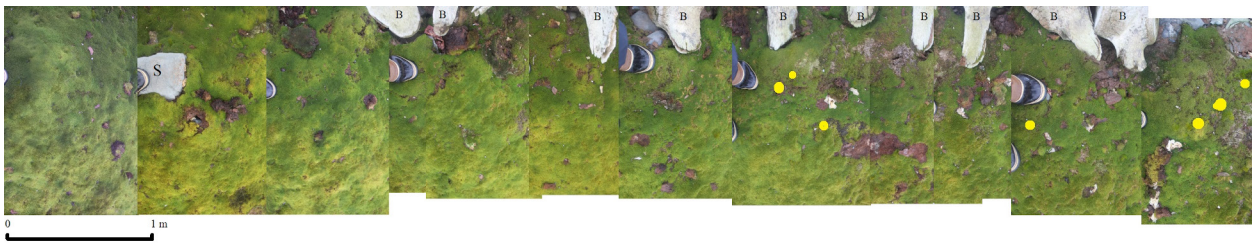

Figure 5. Photograph assembly showing the carpet at the western side (first sector) of the whale skeleton. Yellow dots are cushions of *Syntrichia* spp. B = vertebrae bones; S = stones.

the moss field mainly in the beach area (Alvarez et al. 2005). After this procedure, the entire WB area has been less affected over the years, contributing to its preservation, but the stones were 90% removed by the sea effect in 15 years. Nowadays some people do not follow the rules (explained in the Brazilian station to all visitors) and are still seen beside the bones trampling on the moss carpet like in the pictures showed by Thomas (2020).

Another problem is increasing marine erosion, which strongly affects the pathway to visit the monument, as already reported by Alvarez et al. (2005). The effects of this erosion to the moss carpet can be observed comparing aerial photographs from 1984 (taken from the Brazilian navy helicopter) and 2020 taken with drone. We can observe also that sea erosion has reduced the moss carpet by approximately 1/3 (Figure 7).

In 2011, a stormy summer with strong winds resulted in severe effects on the WB and the moss carpet. It caused the displacement of several vertebrae, already displaced from the original position in 2014. The physical degradation was also facilitated by progressive dissolution and weathering of the bones, making them more subject to displacement.

Another anthropogenic problem detected after 2012 was the fine sediment deposited on the *Deschampsia/Colobanthus* field near the former G-Base. A road opened has caused this disturbance and sediment deposition reduced 1/2 of its original extension (Figure 13).

The soil properties were highly influenced by the placement of the WB near Ferraz Station (Table I). Braun et al. (2012), while studying the human effects on the Fildes Peninsula-King George Island, showed that scientific and outdoor leisure activities undertaken by station personnel are more frequent than tourist activities and were likely to have a commensurate level of environmental effects. The area influenced by the WB exhibited a greater nutrient assembly compared to an adjacent area, which was outside of the influence of WB mineralization and dissolution. We observed P and Zn values that were two and three times higher, respectively, under WB influence. The sampled areas were clearly separated in the bi-plot diagram from the PCA (Figure 12). Two

Figure 6. Abundant erosive processes in the disrupted part of the moss field at the inner side of the whale skeleton.

Figure 7. Aerial photograph of the whale skeleton taken in 1984 with water ponds delimited to the right (above), and a comparison between photographs taken by drone in 2020 and 1984 (below).

principal components (PC1 and PC2) explained 40.30% and 14.5% of the variance in the total dataset, respectively. Principal component 2 (PC2) had three highly weighted variables: pH, Mn, and Mg. The other general soil properties were highly correlated with principal component 1 (PC1), wherein P, Zn, and clay were highly weighted, explaining 34.22% of the total variance in PC1. In the PC2, 41.09% of the total variance was explained by pH, Mn, and Mg.

Published results on the soils on the Keller Peninsula are consistent with our results, although the background for P at this marine terrace (Schaefer et al. 2004, Francelino et al. 2011) is very close to the mean value for bioavailable P in soils without the influence of the WB. This indicates that degradation of the WB is markedly increasing the amount of P in the soils under its influence; thus, partial weathering and dissolution of the bones account for greater P values, as well as increasing clay, organic matter, and Zn contents. All of these factors have been previously identified as covariates in areas with high P inputs, such as penguin rookeries (Simas et al. 2008, Francelino et al. 2011, Schaefer et al. 2017). This is caused by the higher formation of secondary P minerals in the clay and silt fractions, as well as Zn incorporation in the mineral structure of these secondary forms, as reported in previous studies (Schaefer et al. 2004).

These differences were markedly distinct after just 30 years of the WB being present on the marine terrace, highlighting the rapid chemical weathering and reactions following its interactions with the *Sanionia* moss carpet, a feature thus far undescribed for Antarctic environments. Hence, we postulate that this strong phosphatization process, which is rather similar to that of ornithogenic soils in the same region (Simas et al. 2008), can account for higher P values where a significant amount of WB are present, either naturally or artificially placed.

Figure 8. Photo taken in 2020 (drone) showing the trail of the quadbike (red lines) still evident and the openings in the moss carpet due to human trampling (red line). And detail (right) 2011 image, showing the motorcycle trail near the whale skeleton.

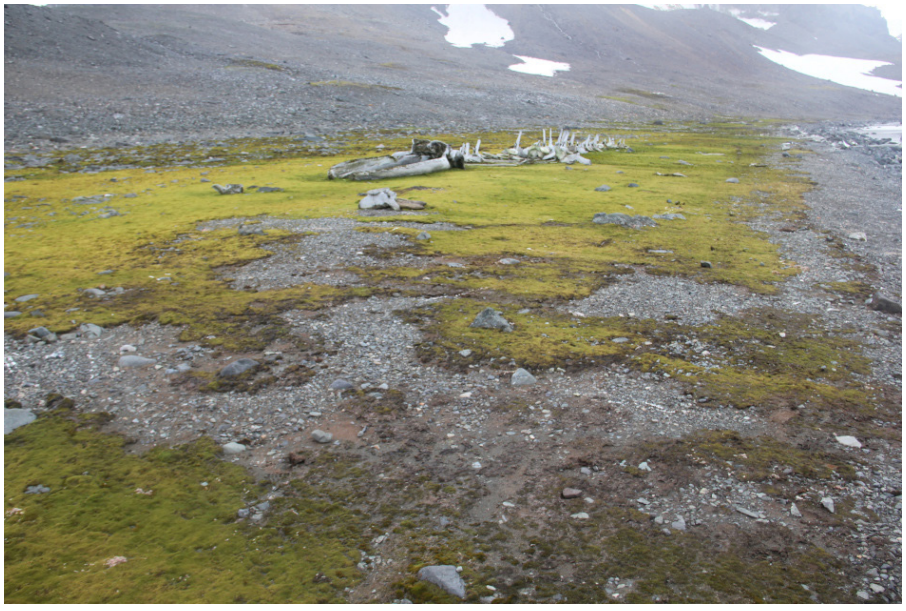

Figure 9. Moss field at the frontal-right part of the whale head (2011).

Figure 10. Detailed moss fragmentation in front of the whale skeleton from 2005 (red), 2014 (orange) and 2020 (yellow). A and B = two whale bones strategically positioned by visitors to take photographs.

Figure 11. Water pond still evident in 2011 (white line); unchanged since 1984, as seen in the aerial photo (Figure 7).

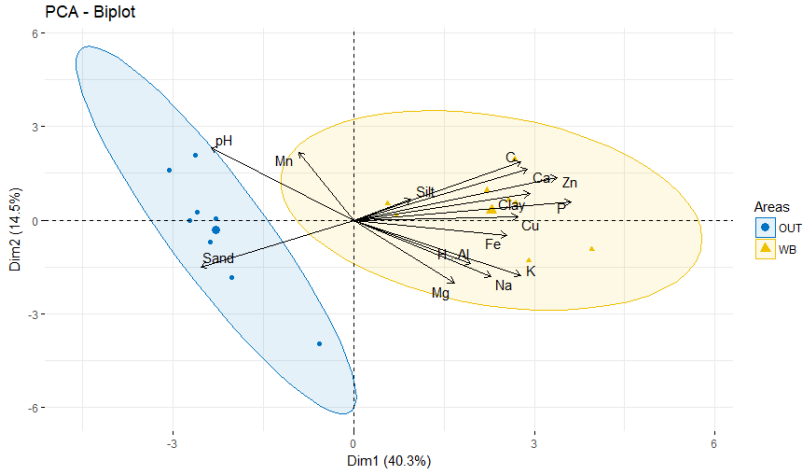

Figure 12. Bi-plot diagram from the PCA for all the studied soil attributes of the whale skeleton area (WB) and out of the influence of the WB area (OUT) on the Keller Peninsula.

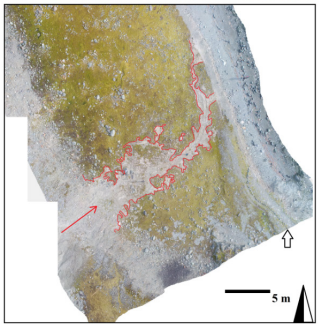

Figure 13. Recent impact over the moss carpet, with sediments deposition over the flowering plant formation from an inland photo (above) e taken by drone. Red setae = sediment flow.

Table I. Soil chemical attributes of in the whale skeleton area (WB area) and outside of the influence of whale bones (outside of the WB area) on the Keller Peninsula.

	Mean	SD	Median	Min	Max	Skew	Kurtosis	Error
	WB area							
pH	7.84	0.22	7.90	7.50	8.10	0.60	-0.21	-1.61
P (mg kg^{-1})	283.25	31.97	277.50	250.00	358.00	108.00	1.43	0.89
K (mg kg^{-1})	141.50	49.62	143.50	82.00	220.00	138.00	0.16	-1.68
Na (mg kg^{-1})	318.75	131.96	280.00	180.00	590.00	410.00	0.94	-0.49
Ca ($cmol_c$ kg^{-1})	4.97	0.74	4.95	4.00	6.30	2.30	0.38	-1.17
Mg ($cmol_c$ kg^{-1})	1.57	0.14	1.60	1.40	1.70	0.30	-0.18	-2.02
H+Al($cmol_c$ kg^{-1})	0.46	0.23	0.33	0.33	0.99	0.66	1.38	0.47
Sand (g kg^{-1})	41.75	3.01	42.50	38.00	45.00	7.00	-0.20	-1.93
Silt (g kg^{-1})	20.88	3.04	20.50	16.00	25.00	9.00	-0.14	-1.49
Clay (g kg^{-1})	29.25	2.43	29.00	25.00	33.00	8.00	-0.15	-1.05
C (dag kg^{-1})	0.46	0.11	0.45	0.34	0.65	0.31	0.43	-1.26
Zn ($cmol_c$ kg^{-1})	4.06	0.93	3.85	2.80	5.90	3.10	0.60	-0.65
Fe ($cmol_c$ kg^{-1})	307.91	111.01	269.40	204.20	565.00	360.80	1.41	0.71
Mn ($cmol_c$ kg^{-1})	77.21	27.93	75.30	44.90	136.50	91.60	0.90	-0.14
Cu ($cmol_c$ kg^{-1})	21.21	11.04	16.55	10.90	42.10	31.20	0.90	-0.99
	Out of WB area							
pH	8.12	0.44	8.30	7.4	8.60	-0.44	-1.62	0.15
P (mg kg^{-1})	136.00	15.18	138.00	110.0	158.00	-0.37	-1.14	5.37
K (mg kg^{-1})	94.50	34.22	84.50	62.0	150.00	0.72	-1.36	12.10
Na (mg kg^{-1})	200.75	101.77	197.00	70.0	420.00	0.94	0.07	35.98
Ca ($cmol_c$ kg^{-1})	3.71	0.62	3.75	2.9	4.60	0.00	-1.72	0.22
Mg ($cmol_c$ kg^{-1})	1.32	0.54	1.60	0.4	1.70	-0.91	-1.22	0.19
H+Al($cmol_c$ kg^{-1})	0.27	0.26	0.25	0.0	0.66	0.16	-1.86	0.09
Sand (g kg^{-1})	45.75	1.58	45.50	43.0	48.00	-0.21	-1.23	0.56
Silt (g kg^{-1})	19.88	2.23	20.00	16.0	23.00	-0.27	-1.21	0.79
Clay (g kg^{-1})	22.50	3.42	22.50	18.0	27.00	-0.11	-1.70	1.21
C (dag kg^{-1})	0.24	0.12	0.24	0.1	0.45	0.41	-1.27	0.04
Zn ($cmol_c$ kg^{-1})	1.34	0.17	1.35	1.1	1.60	0.11	-1.55	0.06
Fe ($cmol_c$ kg^{-1})	218.19	45.01	216.90	132.5	292.80	-0.26	-0.39	15.91
Mn ($cmol_c$ kg^{-1})	82.29	31.23	91.20	12.2	114.40	-1.23	0.34	11.04
Cu ($cmol_c$ kg^{-1})	9.68	1.43	9.55	7.2	11.90	-0.08	-1.02	0.51

Legend: pH: active acidity (H_2O); P: phosphorus; K: potassium; Na: sodium; Ca: calcium; Mg: magnesium; H+Al: potential acidity; C: total organic carbon.

CONCLUSIONS

The WB near the Ferraz Station represents a good place to assess the trends in plant community dynamics under human disturbance. First was the placement of the WB on one of the largest moss carpets of Antarctica. The second was the mineralization of bones enhancing soil nutrient status changing plant composition. Finally, there were direct human effects caused by tourist and scientist visitors over the years. Soils in the vicinity of the WB presented differences in chemical and physical properties, accounting for differences in plant community composition. Sea erosion is one of the most important impact over the plant community.

The time since the WB placement on the marine terrace was sufficient to enhance the soil nutrient profile, displaying phosphatization under the WB after just 30 years. Greater nutrient content in soils under the WB created micro-islands of higher biodiversity and more complex cryptogamic communities. The physical protection afforded by the WB against the wind was also a factor accounting for greater plant diversity and growth under the bones. With time, one can expect that the gradual dissolution of the WB will create a totally different plant community, with higher nutrient status. This study revealed that human activity can affect unique areas, and exhibited the importance of coordinated research/visits to minimize environmental effects.

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