PCAS 21 (2018/2019)

Supervised Project Report
(ANTA604)

An analysis of conservation and management tools for Antarctica's terrestrial ecosystems

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Word count: 5198

Abstract/executive summary

The value within the terrestrial ecosystems of Antarctica and the management and conservation implemented is a pressing topic as the intensifying human footprint makes consideration of this issue more urgent. Investigation of the Protected Areas system of the Antarctic Treaty demonstrates that microbial habitats are poorly protected. There is no other region on Earth that is dominated to a similar extent by microbial life. This presents an opportunity to develop and integrate new mechanisms of conservation and management of terrestrial biota on a continental scale.

This account examines the reliability of tools of the Antarctic Treaty System (ATS), including the Antarctic Specially Protected Areas (ASPAs), and the Antarctic Conservation Biogeographic Regions (ACBRs) and highlights possible threats to Antarctic terrestrial ecosystems. Analysis of the Secretariat of the Antarctic Treaty Database (ATS, 2019) showed that of the 73 ASPAs only 7 were created specifically for the management and protection of the terrestrial ecosystem, 27 ASPAs were created with terrestrial ecosystem values as a part of their management plans and 38 did not list terrestrial ecosystem values within their management plans at all.

The study demonstrates that there is scope to enhance the management and protection of Antarctic terrestrial ecosystems and these improvements must be considered urgently and implemented before ecosystem disturbance is irreversible.

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Introduction

Antarctica is a harsh continent; with a highest mean elevation at 2,500 meters ("Antarctic Environment - Antarctic Logistics & Expeditions", 2019), the coldest minimum temperature at -89.6℃ and is the most geographically isolated continent on Earth (Kennedy, 1995). The severe climate as well as its isolation explains many of the characteristics of the terrestrial biota of Antarctica. Communities of pre-adapted species can exploit the low energy environment (Kennedy, 1995).

Direct human pressure in Antarctica is increasing rapidly (Shaw et al., 2014) . Terrestrial ecosystems are vulnerable to human contamination and disturbance. For instance, wherever humans go they release non-native microorganisms into Antarctica's 'pristine' environment (Hughes et al., 2013). Antarctic microbiology could continue to contribute much to understanding of ecosystem function but for this to occur threats must be addressed and resolved. There have been several investigations on the theme of protection of Antarctic terrestrial ecosystems with special reference to the microbial life (Hughes et al., 2013, 2015; Shaw et al., 2016; Coetzee et al., 2017). Each study has raised interesting points regarding the conservation of the biota. This report adds to the theme.

The purpose of this report is to investigate the current protection for terrestrial ecosystems of Antarctica and to make assessments of whether the current frameworks put in place by the Antarctic Treaty System and the Antarctic Conservation Biogeographic Regions are adequate tools to ensure their conservation and management, at present and for future generations.

This report will:

i. Introduce the reader to the terrestrial ecosystems of Antarctica.
ii. Introduce the instruments that the Antarctic Treaty System has put into place to provide protection for the continent.
iii. Assess the successes and limitations of these instruments.

1. Terrestrial ecosystems of Antarctica

1.1. The extent and characteristics of ice-free areas

Antarctica has a limited area of ice-free ground (Kennedy, 1995). It makes up only 0.34% of the 14 000 000 km² continent (Hughes & Pertierra, 2016). This area is only 44,000 km² with about 10% comprised of the high latitude frigid deserts of the McMurdo Dry Valleys of Victoria Land and much of the remaining is inland nunataks and mountain ranges (Hughes et al., 2015). Biodiversity and human activity are concentrated in the ice-free areas of Antarctica and this causes significant issues (Shaw et al., 2014). Ice-free areas have an abundance of terrestrial life as well as forming essential breeding sites for seabirds and seals (Lee et al., 2017).

Ice-free areas of Antarctica range from exposed mountain tops, scree slopes, cliffs, ice-free valleys and coastal oases to off-shore islands. They range in size from less than 1 km^2 to thousands of km^2 and can be separated by a couple of meters or hundreds of kilometres (Lee et al., 2017). Many species have only ever been recorded within a single region or even within a single ice-free area such as the tardigrade *Mopsechiniscus franciscae* from Victoria Land. However, it is uncertain whether there is a lack of dispersal potential for these species or whether we have limited understanding of their distribution due to limited surveys. Geographic isolation and lack of connectivity has largely prevented dispersal of terrestrial Antarctic life as well as reducing interspecific competition (Lee et al., 2017).

1.2 The diversity and ecology of terrestrial life

Throughout the continent there are high levels of endemism within the biota (Hughes et al., 2015). Microorganisms include fungi, bacteria (including cyanobacteria otherwise known as blue-green algae), archaea and eukaryotic microalgae. Terrestrial plants are mainly very small and include mosses, liverworts and lichens. The terrestrial fauna is largely restricted to micro-invertebrates (Hughes & Pertierra, 2016) and is comprised of nematodes, rotifers, tardigrades, protozoa and microarthropods (mostly mites and collembola). There are only two species of flowering plants, the hairgrass *Deschampsia antarctica* and pearlwort, *Colobanthus quitensis* (Block, 1984; Smith, 1984). All these species have adaptations enabling them to survive the hostile conditions such as desiccation and freezing. They also can adjust life-cycles to exploit ephemeral growth conditions. Their traits are typically defined as A-selection, whereby an organism can adjust to constant unpredictable hostile environments (Kennedy, 1995).

Due to the harsh climate and very short summers, the rate of growth and reproduction in biota is extremely limited. For example, the climate plays a controlling role for bryophyte communities in which production rates vary between 5 and 100g m^{-2} y^{-1} in harsher microenvironments to 300-650 g m^{-2} y^{-1} at more favourable locations (Kennedy, 1995). There are fossils of species from previous glacial cycles which show endurance, such as lacustrine algae, which has survived at least one full cycle (Convoy et al, 2008). Due to the conditions, Antarctica supports biodiversity that is highly diversified and adapted to the circumstances. Food chains are restricted to microorganisms, invertebrates, micro-invertebrates, cryptogams, and plants and all possess specialised genes which enable them to survive and function in these polar environments (D’Amico et al., 2006; Sawstrom et al., 2008). Most visible biota is found in the coastal areas, particularly along the Antarctic Peninsula, the archipelagos off the west coast of the Peninsula and the ‘oases’ of East Antarctica (Hughes & Pertierra, 2016).

An example of an important Antarctic life form is lichen. Lichens are involved in various processes such as nutrient cycling and provide shelter and habitats for invertebrates such as tardigrades and mites (Ovstedal & Lewis-Smith, 2001). Due to their importance and role in the terrestrial ecosystem it is important to consider their rate of growth. Some have been measured to grow at the extremely low rate of 0.01 mm per year, but these growth rates vary between regions (Green et al., 2012). With such a slow growth rate, any damage to this species would take thousands of years to recover, which therefore impacts the rest of the terrestrial ecosystem which depend upon it such as tardigrades for habitat. Lichen growth have been regarded as a sensitive indicator of climate change (Sancho et al., 2007) so it is important that their growth rates are studied.

1.3. Introduction to human impact

Since the 1950s human activity within Antarctica has increased immensely due to scientific and geo-political interests, establishment of research stations and other infrastructure and expansion of tourism (Tin et al., 2014; Hughes et al., 2015). For logistical reasons, coastal locations are favoured for tourist visits and research activities and there is construction of stations and other logistical facilities of national Antarctic programmes. These human activities are primarily based on the ice-free ground of the continent. With less than 6,000 km² ice-free area within 5 km of the coast, this causes significant impact on the terrestrial ecosystem as these areas are being exploited by humans contributing to the disruption, destruction and pollution of their habitat (Hughes et al., 2015).

2. The Antarctic Treaty System (ATS)

The Antarctic continent and the Southern Ocean south of 60°S are protected by the Antarctic Treaty System (ATS) (Terauds et al., 2012). The ATS is the agreed legislative framework (Hughes & Pertierra, 2016) and alongside this, the Protocol on Environmental Protection to the Antarctic Treaty (1998) is the instrument concerned with overall Antarctic protection and conservation. The Treaty embodies principles crucial to governing activities. It has the aim of ensuring peace, guaranteeing freedom for science research and for the free exchange of scientific results, to set aside arguments over sovereignty and to exchange information of activities within Antarctica. Inspection of other nations' activities was also given as a right (Jackson, 2011). Hughes and Pertierra (2016) counter argue that the Antarctic Treaty itself has little of substance to say about Antarctic conservation.

3. Antarctic Specially Protected Areas (ASPAs)

Specially Protected Areas and Sites of Special Interest were established in 1964, under the Agreed Measures for the Conservation of Native Fauna and Flora of Antarctica. Earlier classifications of protected areas were substituted by Annex V to the Environment Protocol, which was accepted in 1991 and implemented in 2002, providing the designation of Antarctic Specially Protected Areas (ASPA) and Antarctic Specially Managed Areas (ASMA) ("ATS - Area Protection and Management / Monuments", 2019). "An area of Antarctica may be designated an ASPA to protect outstanding environmental, scientific, historic, aesthetic or wilderness values, any combination of those values, or ongoing or planned scientific research. An area where activities are being conducted or may be conducted in the future may be designated as an ASMA, to assist in the planning and co-ordination of activities, avoid possible conflicts, improve co-operation between Parties or minimize environmental impacts" (ATS - Area Protection and Management / Monuments, 2019, p. 2). The Antarctic Treaty Consultative Meeting (ATCM) has implemented guidelines to support Parties in choosing sites for designation and in formulating management strategies ("ATS - Area Protection and Management / Monuments", 2019).

Currently there are 73 Antarctic Specially Protected Areas signifying value of cultural, physical or ecological significance (Shaw et al., 2014) but there is suggestion that more protection needs to occur within this framework (Hughes et al., 2013).

4. ASPAs that specify Antarctic terrestrial ecosystems

Antarctica's ice-free land is 44,000 km² (Hughes et al., 2015) and only approximately 745 km² of that area (1.69%) is protected by ASPAs (Shaw et al., 2014). Shaw et al. (2014) assessed the effectiveness of the ASPAs and overall protection of terrestrial biodiversity of the continent. Of the 73 ASPAs, 55 occur in ice-free areas and have recognised terrestrial biodiversity values and 18 ASPAs conserve other values. The 55 ASPAs that protect terrestrial habitats are in a combined area of less than 700km². Lichens are protected in 28 ASAPs, algae in 16, cyanobacteria in 7 and snow algae in 3. 8 ASPAs mention protection of 'microbial habitats' or 'microbial communities' or 'soil and lake microflora' but with little mention of specific bacteria, fungi or viruses which Hughes et al. (2015) believe indicates little understanding of their true value in these systems. The other 18 have been designated for conservation of historical sites or geological features (Shaw et al, 2014). It is important to note that Shaw et al. (2014) regard terrestrial ecosystem values in a different way to the values in the present report as they include avian and mammalian megafauna as a terrestrial value whereas in this study these animals are regarded as members of the marine ecosystems.

There are 4 locations and ASPAs (138, 119, 172, and 175) that share a rare characteristic of lacking all organisms except microorganisms. In contrast to this, where their presence is less obvious amongst macroscopic vegetation of mosses and lichens, their protection is almost absent from the system (Hughes et al., 2015). Hughes et al. (2015) state that in many cases microorganisms are protected mostly as an afterthought, as a secondary value within ASPA management plans.

In addition to the data supplied by Shaw et al. (2014) an updated list of data from the Secretariat of the Antarctic Treaty Database (ATS, 2019) was compiled to identify the values which were specified as reasons for establishing each ASPA. Each ASPA had its individual values recorded, its location and whether a component of the terrestrial ecosystem was identified within each management plan (see Appendix). This data is summarised in Tables 1 and 2.

There are only 7 ASPAs which were established solely to protect values of the Antarctic terrestrial ecosystem (Fig. 1, Table 1). More ASPAs (27) included the values of the terrestrial ecosystem, but these also included the value of something else, for example, historical values such as a historic hut or a breeding site of mammalian or avian fauna. It may be thought that many of these ASPAs protecting the terrestrial biota are circumstantially an afterthought to the birds and seals within the site. Even more (38) ASPAs do not list any value of the terrestrial ecosystem in their management plans. It is important to note that 38 of the current 73 ASPAs do not include terrestrial ecosystem values within their management plans. This means that they only are protected in about 52% of ASPAs.

Table 1: The total number of ASPAs which specify and do not specify terrestrial ecosystem values within their management plans.

Values	Number of ASPAs
Sites that only list terrestrial ecosystem values	7
Sites which list terrestrial ecosystem values together with other values	27
Sites which do not list terrestrial ecosystem values	38

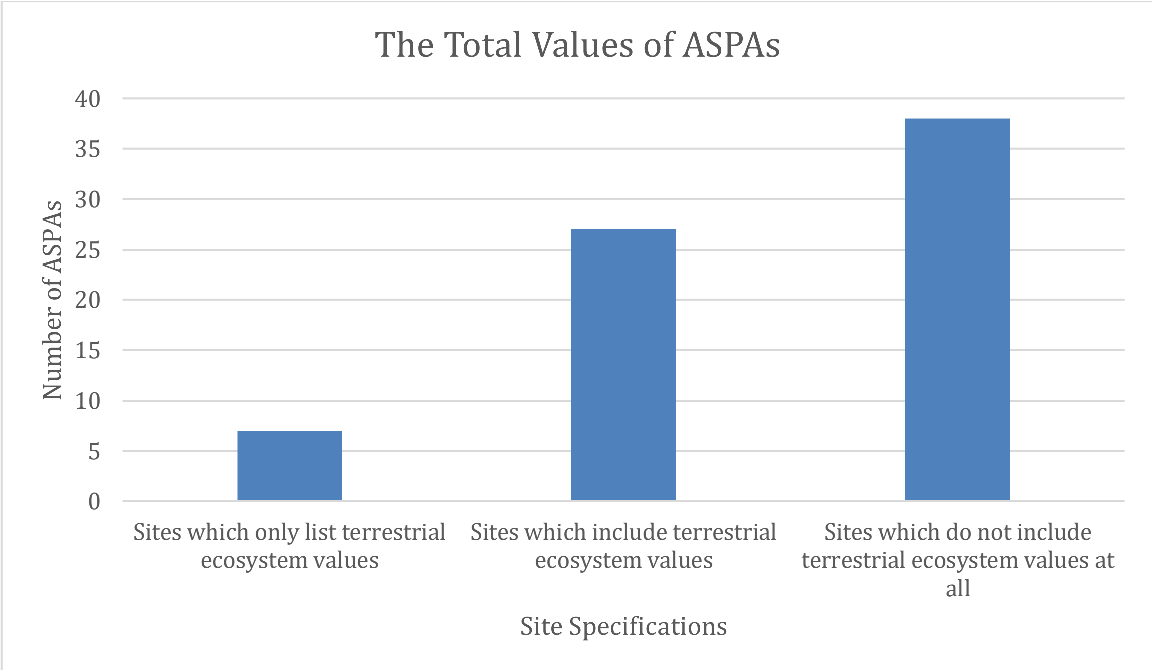

Figure 1: The values which each ASPA represents in total. Three categories have been selected to show if terrestrial ecosystem values have been specified within the ASPA, if they have been specified alongside other values or if they have not been specified at all. An increase is shown by the graph indicating that there is a significant number of ASPAs which do not express terrestrial ecosystems values at all.

The reasons for establishing ASPAs can be categorised into terrestrial ecosystem values, historic values and mammalian and avian megafauna (Fig. 2). These were all calculated in terms of how many times each value was specifically listed within the management plan of each ASPA. Each time a value such as a lichen or an invertebrate species was mentioned, it was noted (Table 2). These were then totalled and graphed. Avian and mammalian megafauna received the highest total times mentioned (xx???) within the 73 ASPAS with a significant decrease in numbers for mosses (22) , lichens (21), invertebrates (14) , historical values (15) and then algae listed to be protected and managed in 11 of the 73 APSAs.

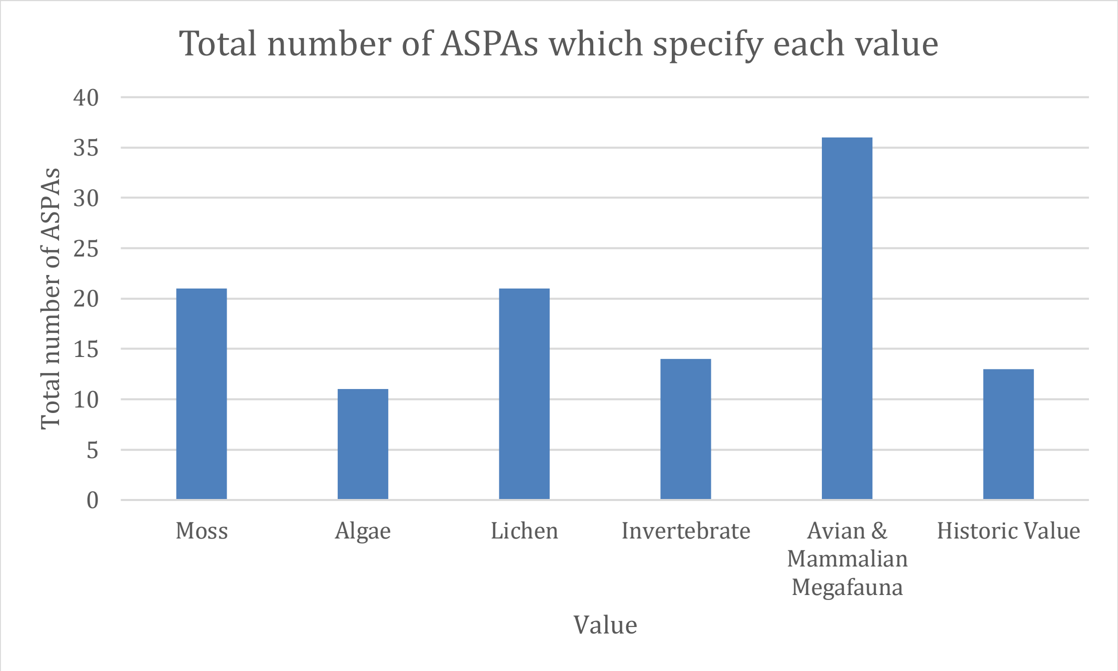

Figure 2: The number of ASPAs listing each value in its management plan. These values are broken up into broad categories of organisms of the terrestrial ecosystem, marine ecosystem values (avian and mammalian fauna) and historic values.

Table 2: The number of ASPAs listing each value within its management plan. Each value was recorded every time they were mentioned as a value to protect within each ASPA.

Value	**Number of ASPAs Including the Value**
Moss	21
Algae	11
Lichens	21
Invertebrates	14
Avian & Mammalian Megafauna	36
Historic Values	13

A comparison of ASPAs which include and do not include values of terrestrial ecosystems within their management plans is shown in Fig. 3. Note: the ASPA numbers that are coloured red are the ASPAs which contain a value being conserved within the terrestrial ecosystem (whether this value is algae, lichen, moss, cyanobacteria, liverworts, invertebrates etc.). There is a significant difference in ASPAs which specify the protection of a component of the terrestrial ecosystem compared to those that do not (Fig. 3, Table1).

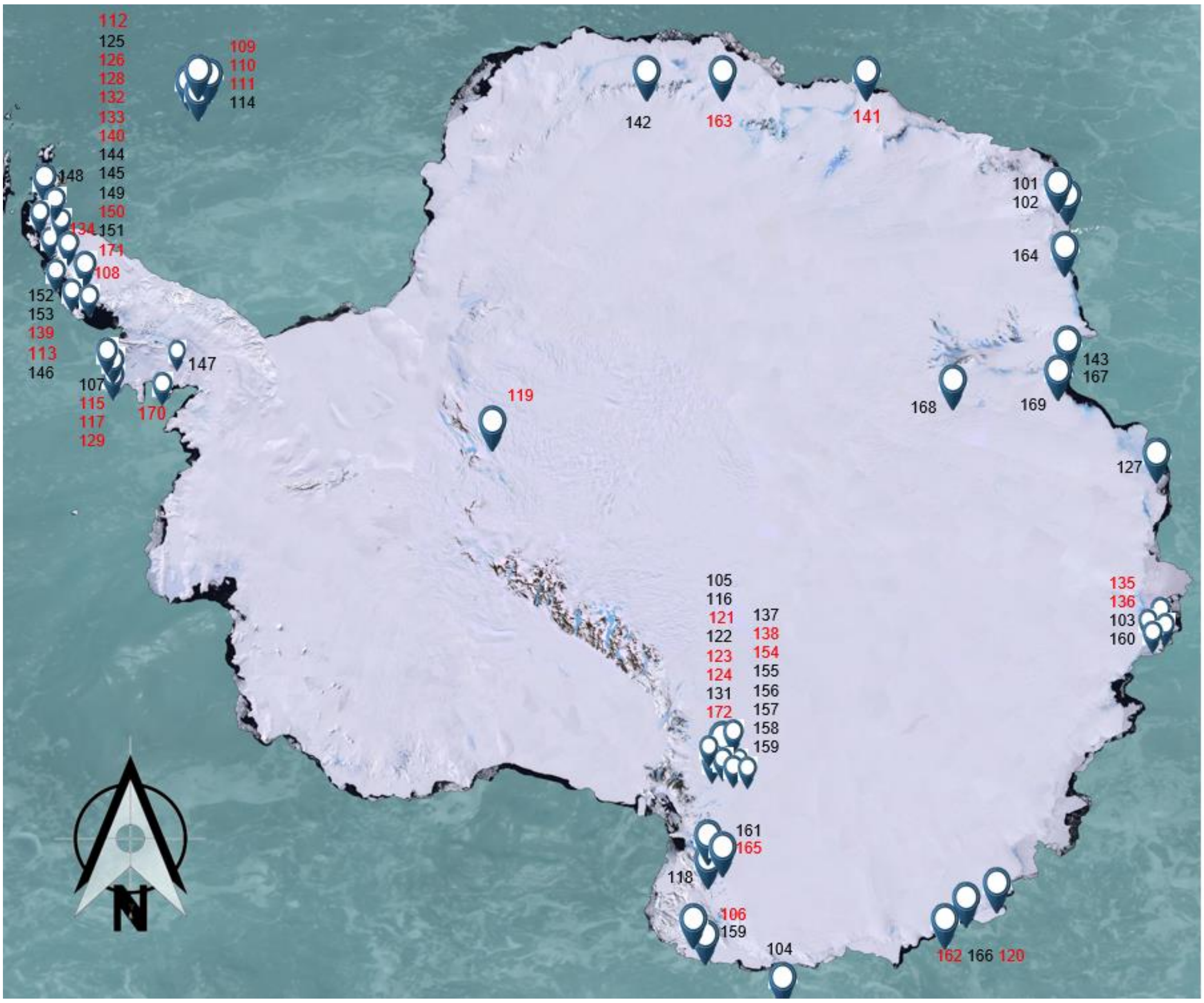

Figure 3: Map of Antarctic Specially Protected Areas with highlighted (red) ASPAs which include terrestrial ecosystem values within their management plans. Note: the pinpoints are not entirely accurate for the exact location of the ASPA.

In the Antarctic Peninsula region, of the current 31 ASPAs there are 19 that protect a value within the terrestrial ecosystem (61%). This is important to note as this area attracts the most tourism (Terauds & Lee, 2016) so measures here should be of the highest degree as this site is the most vulnerable to human disturbance.

5. Antarctic Conservation Biogeographic Regions (ACBRs)

Long-term evolutionary isolation has influenced the development of spatially distinct biogeographic regions across Antarctica (Hughes et al., 2015). The Antarctic Conservation Biogeographic Regions (ACBRs) proposed in 2012 (Terauds et al., 2012) are an important tool for Antarctic science, conservation, management and policy. Identification of the ACBRs across Antarctica has provided policy makers and scientists with a more structured approach using which conservation planning and action can be developed within the governance procedures of the ATS (Hughes et al., 2015).

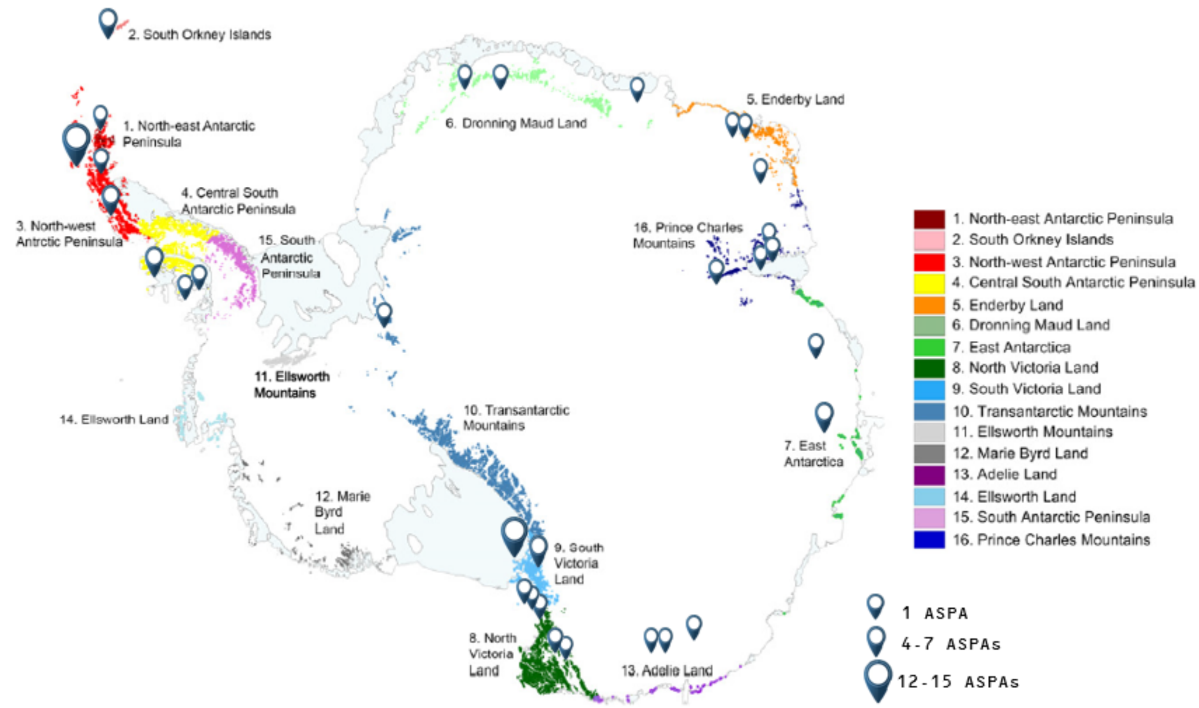

Figure 4: Sixteen Antarctic Conservation Biogeographic Regions (ACBRs) as recognised by Terauds & Lee, (2016) and with locations of Antarctic Specially Protected Areas (ASPAs) added to show their geographical distribution.

Table 3: Antarctic Conservation Biogeographic Regions (ACBRs) coverage of Antarctic Specially Protected Areas (ASPAs) (Taken from Terauds et al., 2012).

Conservation area ID	Name	Approximate area of ACBR (km^2)*	Number of ASPAs that overlap with ACBRs†	Number of overlapping ASPAs designated for ecological reasons†	Area of ACBR that overlap with ASPAs (km^2)†	% of ACBR covered by ASPAs
ACBR 1	North-east Antarctic Peninsula	1142	1	0	0.3	0.03
ACBR 2	South Orkney Islands	148	4	4	9	6.3
ACBR 3	North-west Antarctic Peninsula	5081	20	14	231	4.6
ACBR 4	Central south Antarctic Peninsula	4959	2	1	115	2.3
ACBR 5	Enderby Land	2152	1	1	5	0.2
ACBR 6	Dronning Maud Land	5500	2	1	11	0.2
ACBR 7	East Antarctica	1085	8	7	30	2.8
ACBR 8	North Victoria Land	9522	5	3	42	0.4
ACBR 9	South Victoria Land	10368	15	9	267	2.6
ACBR 10	Transantarctic Mountains	19347	1	1	57	0.3
ACBR 11	Ellsworth Mountains	2965	0	0	0	0
ACBR 12	Marie Byrd Land	1158	0	0	0	0
ACBR 13	Adelie Land	178	3	1	0.5	0.3
ACBR 14	Ellsworth Land	220	0	0	0	0
ACBR 15	South Antarctic Peninsula	2990	0	0	0	0

5.1 How much do they protect?

The ACBRs were first developed by Terauds et al. (2012) and have been under investigation as to how much they protect. The area of ice-free land in each region is variable and ranges from <1,000 km^2 in the Antarctic Peninsula domains, to nearly 20,000 km^2 in the Transantarctic Mountains (Terauds et al., 2012). Terauds et al. (2012) looked at the coverage of ASPAs in the ACBRs and found that the ACBR which had the greatest area covered by ASPAs is ACBR 2 (Table 3) with 6.3% coverage, four ACBRs have less than 10% coverage and the remaining ten have <1% ASPA coverage. They stated that the figures (Table 3) indicate that the management plans of these ASPAs and the provisions of reference for the designation of the ASPA in the ATS, indicate that many of them were not established to protect terrestrial biodiversity, but instead to protect other non-terrestrial species or historic features independent of biological considerations (Hughes & Convey, 2010).

Terauds & Lee (2016) states that four ACBRs have no area protection in the form of ASPAs and five had no area protection for the purposes of protecting biodiversity. South Victoria Land had the highest proportion of its area protected by ASPAs (4.3%) and ACBRs 11, 12, 14 and 15 having 0% of its area covered by ASPAs for purposes of protecting biodiversity (Terauds & Lee, 2016). Within those ASPAs which had 0% protected, ACBR 11 between 2014-2015 had 701 tourist landings which was the 5th highest overall for tourist landings within the ACBRs. This poses as a significant threat to the biodiversity due to human interference and activities. ACBR 3 has the highest number of tourist landings with 213,074 landings and only has 1.99% of its areas covered by ASPAs. Again, this region is highly utilised, creating a significant need to protect and conserve it. With 1.99% protected in the form of ASPAs for the highest tourist area, this poses serious considerations as to whether this region is being protected adequately (Table 4).

Shaw et al. (2014) proposed that the mean protected area of each Antarctic Conservation Biogeographic Region is 1.1% and no ACBR has more than 10% of its area designated as protected area. They then compared this to a global context in which Antarctica lies in the lowest quartile for total percentage protection of biodiversity (Shaw et al., 2014). Terauds and Lee (2016) then proposed a revised version of the ACBRs (Fig. 4) which covers all the ice-free areas of Antarctica and includes one extra bioregion.

Table 4: Summary statistics for updated Antarctic Conservation Biogeographic Regions (taken from Terauds & Lee, 2016). Comparing the total ACBR area (km²), percentage of ACBR covered by ASPAs (for biodiveristy), the number of stations or permanent infrastructure within the region and the number of tourist landings in the region (2014-2015). ACBR9 is highlighted as it has the highest % of ACBR covered by ASPAs (4.31%).

ACBR identifier	ACBR name	Total ACBR area (km^2)	Mean area of individual ice-free polygons (km^2)	Mean altitude (m)	Mean annual temperature (°C)	Number of ASPAs (for biodiversity)*	Areas of ASPA in ACBR (km^2) (for biodiversity)*	% of ACBR covered by ASPAs (for biodiversity)	Number of stations or permanent infrastructure	Number of tourist landings (2014–2015)
ACBR1	North-east Antarctic Peninsula	1215	3.33	412.6	−7.4	1 (0)	0.4 (0)	0.03 (0)	4	1503
ACBR2	South Orkney Islands	160	1.52	21.0	−3.2	3 (3)	4.8 (4.8)	3.03 (3.03)	2	1038
ACBR3	North-west Antarctic Peninsula	5183	1.00	572.2	−6.9	21 (17)	103.1 (100.5)	1.99 (1.94)	38	213074
ACBR4	Central South Antarctic Peninsula	4962	1.09	911.8	−11.6	2 (2)	77.4 (77.4)	1.56 (1.56)	1	6
ACBR5	Enderby Land	2188	2.21	549.9	−15.6	1 (1)	4.9 (4.9)	0.23 (0.23)	4	0
ACBR6	Dronning Maud Land	5523	5.31	1851.4	−23.9	2 (2)	9.1 (9.1)	0.17 (0.17)	9	81
ACBR7	East Antarctica	1109	3.46	114.9	−12.9	9 (8)	43.4 (27.9)	3.91 (2.51)	8	0
ACBR8	North Victoria Land	9431	2.18	1486.8	−21.8	6 (5)	4.4 (4.4)	0.05 (0.05)	5	669
ACBR9	South Victoria Land	10038	12.80	1109.6	−22.5	16 (11)	432.8 (431.2)	4.31 (4.29)	3	1296
ACBR10	Transantarctic Mountains	18480	5.53	1732.7	−25.5	1 (1)	42.6 (42.6)	0.23 (0.23)	1	0
ACBR11	Ellsworth Mountains	2859	5.44	1801.5	−24.9	0	0 (0)	0 (0)	0	701
ACBR12	Marie Byrd Land	1128	2.39	1054.8	−17.4	0	0 (0)	0 (0)	1	15
ACBR13	Adelie Land	178	1.7	222.5	−16.4	1 (1)	0.05 (0.05)	0.03 (0.03)	2	0
ACBR14	Ellsworth Land	217	1.26	479.2	−13.1	0	0 (0)	0 (0)	0	96
ACBR15	South Antarctic Peninsula	2875	1.55	1149.0	−18.1	0	0 (0)	0 (0)	0	0
ACBR16	Prince Charles Mountains	5992	9.20	937.4	−24.2	4 (3)	25.6 (5.0)	0.43 (0.08)	3	0

6. Is there adequate protection?

The protected areas are at risk of a range of pressures including global change drivers and localised pressures for example human disturbance to wildlife and the introduction of non-native species (Frenot et al., 2005; Coetzee et al., 2017). With rising tourism (Terauds et al., 2012), climate change and pollution from sources outside of the continent, Antarctic ecosystems are under increasing threat (Hughes & Pertierra, 2016).

While it is perceived that Antarctica is well conserved, in practice conservation for the terrestrial ecosystems is poorly served by the protected-area system (Shaw et al., 2014). Terauds et al. (2012) state that each biogeographic region should be managed as distinct areas of conservation significance and that they should be represented by at least one ASPA with biosecurity measures being significantly increased between regions.

6.1 Human impact on terrestrial ecosystems

All human actions, whether tourism or science, have intensified significantly over the last two decades and will continue to do so. There is a growing need to protect these communities with an accelerating frequency of human activity and rapidly changing climates (Shaw et al., 2014).

Most of the human presence occurs on the ice-free areas, with the scope and speed of human travel increasing as air networks are being developed and this increasing pressure of humans is leading to an increase in infrastructure, which inevitably will mostly be developed on ice-free ground (Terauds et al., 2012). Seven of the 73 ASPAs all of which are on the Antarctic Peninsula, are at high risk of non-indigenous species establishment in terms of microorganisms and plants (Shaw et al., 2014). The establishment of stations in Antarctica has increased over the years. There are many bases constructed for scientific purposes, whether they be only utilised for the summer period or year-round. The location of these bases follows a similar pattern to where the ASPAs are located. This may be due to several reasons such as the area is significantly more studied compared to areas that are less accessible to get to or due to the high levels of human activities, these ASPAs have been put into place to try and manage the area surrounding the stations (Fig. 5). There is one significant difference in that the number of bases in ACBR6: Drowning Maud Land, has only three ASPAs when there is a significant number of bases utilising that region. Seemingly that this area may not be receiving enough management and protection due to the amount of human activity being conducted in the region.

An example of the increase of infrastructure is the proposed construction of a paved runway near Davis research station by the Australian Antarctic Division ("New Davis runway", 2018). The proposal is that this runway will complement their summer-only ice runway enabling them access year-round to their bases. They state that it would improve their "ability to conduct year-round, world-class scientific research and respond to emergencies" ("New Davis runway", 2018, p. 2) but in doing so this is being constructed upon the terrestrial habitat thus impacting the native biota (Fig. 4). The runway will be 2,700 metres long, which is centred upon on the length necessary of sizable commercial aircraft. The Australian Government state they are loyal in practicing the correct environmental stewardship for the project and that it will be subjected to "extensive environmental and other government approval process" and will "meet the requirements of the *Antarctic Treaty (Environment Protection) Act 1980* and the *Environment Protection and Biodiversity Conservation Act 1999"* ("New Davis runway", 2018, p.3). However, this runway has conflicting opinions. According to an advisor for the Humane Society International on Antarctic policy, "a paved runway in Antarctica is not only a breach of these fundamental treaty obligations but also a distressing breach of faith with those of us in the Australian community who have supported past governments—of all persuasions—as good and honourable custodians of Antarctica" (Bergin, 2018, p. 11).

Figure 4: Site of the proposed new runway near Australia's Davis research station. ©Andrew Garner ("Building Antarctica's first paved runway", 2018).

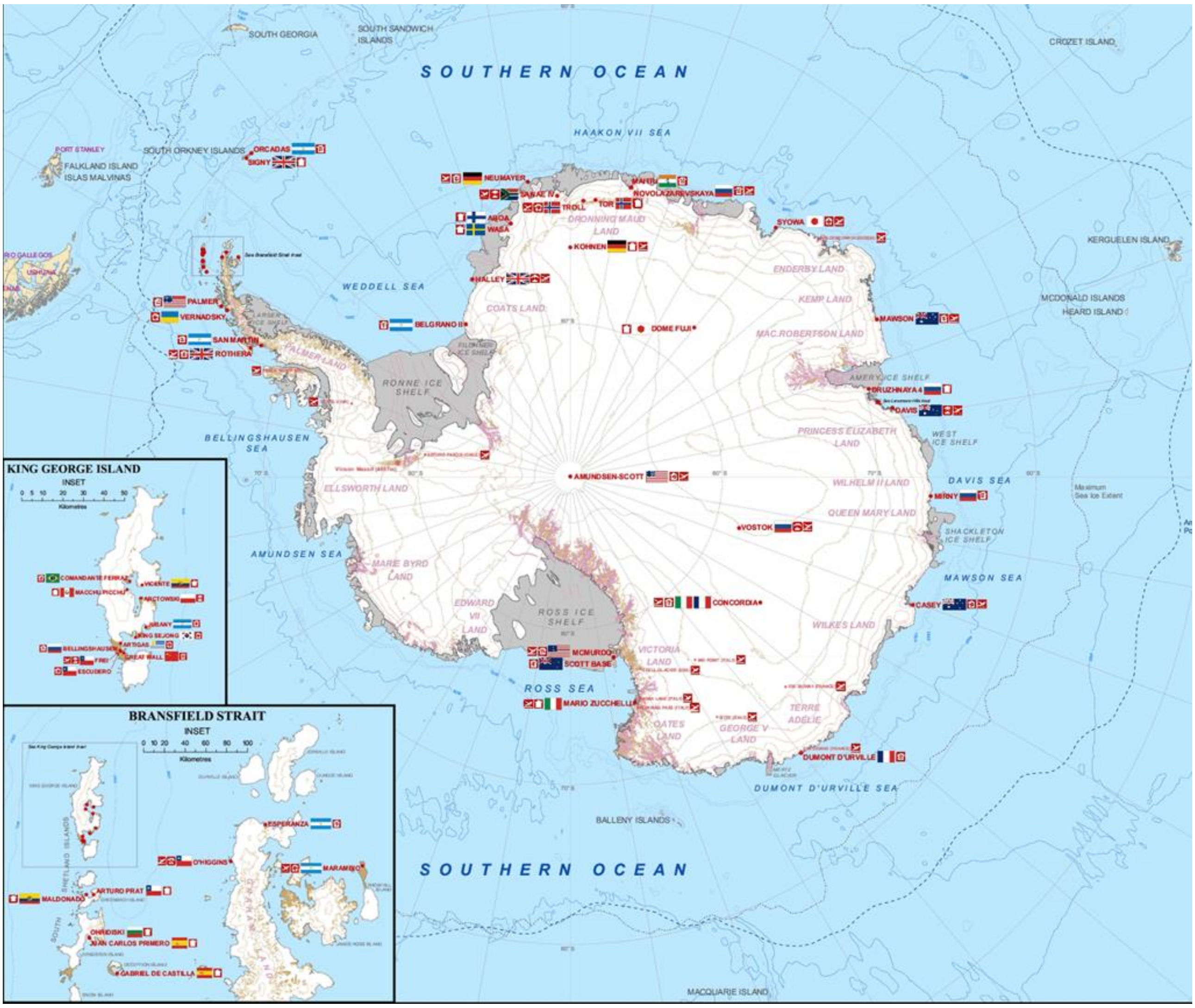

Figure 5: Locations of stations throughout Antarctica (COMNAP, 2014). It is interesting to note that the locations of the stations follow a similar pattern to the locations of the ASPAs. https://www.comnap.aq/Publications/Comnap%20Publications/COMNAP_Map_Edition4_A0_2009-03-26.pdf

Data from COMNAP (2017) is displayed in Table 6 (see Appendix). This showed that there were 64 stations based on ice-free land, 7 stations with an ice-sheet surface, 3 stations based upon an ice-shelf and 1 station with the surface of rock outcrop and scoria permafrost (Fig. 6). This indicates a significantly large percentage (84%) of bases being constructed on ice-free land thus implying direct threats and pressures on the terrestrial ecosystems which inhabit this land. 38 stations have recognised terrestrial biodiversity within their station region indicating that 50% of the stations are surrounded by values of the terrestrial ecosystem, which may suggest that the terrestrial biota living at half of the stations in Antarctica are under direct human pressure and would have been greatly perturbed by the construction of the stations and infrastructure. Of the total 76 stations there are 40 that operate year-round (53%). This poses a threat for the entire year to the terrestrial ecosystems as human disturbance would be constant, whether due to walking or use of heavy vehicles or other machinery.

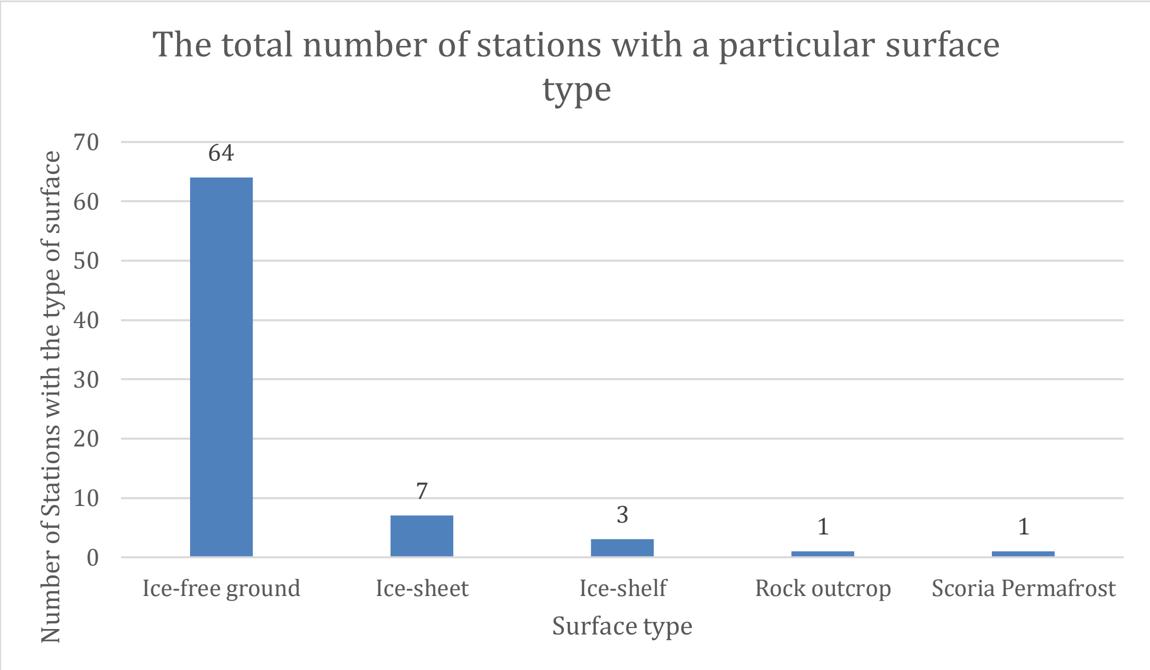

Figure 6: The total number of stations which have a specific surface type (ice-free ground, ice-sheet, ice-shelf, rock outcrop or scoria permafrost). This shows a significant difference in the number of stations that are constructed on ice-free ground compared to the other surface types. Data collated from COMNAP (2017).

6.2 Invasive species

Antarctica is one of the last regions on Earth to remain somewhat untouched by invasive non-native species, however the number is increasing and significantly threatening its native biodiversity (Hughes & Pertierra, 2016). The introduction of alien species has both been intentional and unintentional (Kennedy, 1995; Hughes et al., 2013). The legislation concerning non-native species introductions to the Antarctic Treaty area is confined within the Protocol on the Environmental protection to the Antarctic Treaty (Hughes & Pertierra, 2016). Eradicating these species may not be a practical option, due to the impact on native species and lack of effective eradication methodologies. Cost effective measures such as strict biosecurity has been put in place by the British Antarctic Survey (BAS) to prevent a midge, *Belgica antarctica*, for example being further distributed (Hughes et al., 2013). Due to the human presence around bases, there is an increasing presence of invertebrates which is creating an increasing problem, with eradication success mixed to date (Hughes & Pertierra, 2016). Terauds et al. (2012) state that terrestrial environments are not fully represented in the ASPA network and to avoid biotic homogenization in the regions biosecurity measures between the regions must be improved. Two ASPAs are already at risk of invasion by non-indigenous species due to poor safeguards (Shaw et al., 2014) and there need to be measures put into place to stop this.

7. Future of terrestrial ecosystems

Although it is evident that there are systems put in place to manage and conserve these terrestrial ecosystem values, many (Coetzee et al., 2017; Hughes et al., 2015; Shaw et al., 2016) would argue that there is more that could be done to protect them now and for future generations. Many things must be considered when approaching this question; conservation measures for the continent must consider the biological associations between terrestrial, nearshore, pelagic and sub-Antarctic ecosystems as well as considering the biologically different regions they are in to ensure the comprehensive protection of the regions' biodiversity and to maintain ecosystem functioning (Terauds et al., 2012). Biosecurity standards must be raised for terrestrial areas with microbiological value and additional investigations are required into the ability of the ASPA network to represent Antarctic terrestrial ecosystems (Terauds et al., 2012; Coetzee et al., 2017).

Shaw et al. (2014) state that protected areas are generally effective in reducing threats to biodiversity and their efficiency is enhanced when they are representative of the biodiversity of a region, but they demonstrate that Antarctic terrestrial ecology is not protected as it should be. Hughes et al. (2015) discuss similar attitudes stating that from examination of the Protected Areas System of the Antarctic Treaty they found that generally the microbial habitats are poorly protected as there is no other continent on Earth that is dominated to the same intensity by microbial life.

It is essential to consider what pressures microbial communities encounter and whether enough security is given to this unique and valuable scientific resource (Hughes et al., 2015). Increasing temperatures may act as an environmental cues they adversely affect life cycles of the biota (Kennedy, 1995). This can create irreversible harm to many species and their conservation may become far too difficult (e.g. lichen).

General perception of microbial life anywhere in the world is low in comparison to other forms of life. This perception may be a reason why microorganisms generally are excluded from the concept of extinction (Hughes et al., 2015). Large, charismatic animals such as penguins and seals look 'cute' evoking an emotional attachment and inevitably biasing conservation efforts towards their protection. The more complex methods needed to identify microorganisms have had the effect of setting them aside or excluding them from general environmental biodiversity largely based on the visible characteristics of an organism. The absence of a visual link with microorganisms and the lack of understanding of their importance within an ecosystem by the public and in some cases policy makers, make the protection of microbial habitats in Antarctica difficult to advocate (Hughes et al., 2015). Because of their crucial role in ecosystem function, microbial protection should be at the forefront of policy-makers' awareness when discussing Antarctic conservation (Hughes et al., 2015).

When comparing biological conservation globally, 13% of terrestrial areas are protected compared to 1.5% (0.005% of the whole continent) being formally protected for the purposes of biological conservation in Antarctica (Shaw et al., 2014). This indicates the need for increasing the level of protection and management within Antarctica.

8. Conclusion

The terrestrial ecosystem of Antarctica has proven to be unique and worthy of conservation. It has been suggested (Hughes et al., 2013) that there should be a focus on protecting terrestrial microbial habitats and particularly those locations with potential for microbiological science. There has been criticism of the efficiency of the Antarctic Treaty System in protecting areas (Brooks et al., 2016). Others (Terauds et al., 2012; Shaw et al., 2014) have concluded that the present protected areas tool is insufficient and does not protect the complete diversity of Antarctica's terrestrial life and their habitats. As microbial diversity data is less complete than those for the larger fauna and flora, this creates substantial challenges for conservationists, scientists and policy makers (Cowan et al, 2010). The Antarctic Treaty database has only provided a way to designate areas of outstanding scientific interest as specially protected areas due to their importance for scientific research rather than for their conservation value (Coetzee et al., 2017).

We are quickly losing precious time if we intend to protect this unique resource, so Treaty parties should seriously consider both short and long-term conservation plans for Antarctic microbial ecosystems before their conservation and commercial worth are compromised once and for all (Hughes et al., 2018).

In conclusion:

- It is essential to consider the pressures that are placed upon the terrestrial ecosystems of Antarctica. Whether it be in the form of climate change, human activity or invasive species.
- Evidence suggests that there is not adequate protection currently put in place to manage and conserve the terrestrial ecosystem of Antarctica.
- A change in attitudes to the terrestrial ecosystem and its biota would be of benefit to its conservation.
- There must be an increase in understanding of the importance and role of terrestrial biota in the ecosystem, to ensure they are not just an afterthought.
- Policy makers must consider both long and short-term conservation plans.
- This issue must be addressed and taken seriously before the damage is irreversible.

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10. Appendix

Table 5: Each ASPA showing its location, an approximate area, the reasons in the management plans for designation as an ASPA and whether these include or do not include terrestrial ecosystem values. Note: Terrestrial Ecosystem Values highlighted.

ASPA	Location	Approx. Area km²	Reasons for ASPA	Terrestrial ecosystem only	Terrestrial ecosystem included	No terrestrial ecosystem
ASPA 101	67°26'S 60°50'E	0.26	• Emperor penguin breeding colony			X
ASPA 102	67°36'36.7"S 62°3 2'06.7"E	1.67	• Avian breeding colonies			X
ASPA 103	66°22'S; 66°22'S 110°28'E; 110°33'E	2.44	• Petrel colonies			X
ASPA 104	66°55'S 163°19´E	1.5	• Avian breeding colonies • Seal breeding colonies			X
ASPA 105	76°59'S 167°00'E	14.16	• Avian megafauna • Sea mammal breeding grounds			X
ASPA 106	72°19'S 170°16'E	0.53	• Vegetation supporting terrestrial fauna • Moss • Algae • lichens • Arthropods • Penguin breeding grounds • Aesthetic		X	
ASPA 107	67°52'S 68°42'W	4.67	• Emperor penguin colonies			X
ASPA 108	65°19' 64°09'W	0.17	• Moss turf • Peat	X		
ASPA 109	60°44'S 45°41'W	1.2	• Moss turf • Avian communities • Mites *Gamasellus racovitzai* and springtail *cryptopygus antarcticus*		X	
ASPA 110	60°39'10"S 45°36 '25"W	0.15	• Antarctic hair grass • Antarctic pearlwort • Mosses • Invertebrates-arthropods & enchytraeid worm • Bacteria, yeasts, fungi • soil	X		
ASPA 111	60°42'S 45°01'W	23.56	• Avian breeding colonies • Seal breeding colonies • Moss • peat • Snow algae		X	
ASPA 112	62°23'S 59°42'W	0.67	• Mosses • Algae • lichens • Avian breeding/resting communities • Seal communities		X	
ASPA 113	64°46'S 64°06'W	0.36 k	• Avian communities • Mosses		X	
ASPA 114			DEDESIGNATED			
ASPA 115	67°53'S 67°24'W	1.62	• Flowering plants • mosses		X	

			• lichens • Invertebrates • Avian breeding grounds • Geological value			
ASPA 116	77°13'S 166°29'E	0.34	• Mosses	X		
ASPA 117	67°46'S 68°54'W	1.12	• Breeding seabirds			X
ASPA 118			DEDESIGNATED			
ASPA 119	82°27'S 51°21'W	56.81	• Most southerly fresh water ponds with autotrophic microbial life • Cyanobacteria • lichens		X	
ASPA 120	66°40'S 140°02'E	0.37	• Avian and mammal breeding ground			X
ASPA 121	77°33'20"S 166°0 9'56"E	0.62	• Adele penguin colony • Algae • Heritage		X	
ASPA 122	77°49'S 166°39'E	0.73	• Electromagnetic			X
ASPA 123	77°20'S 161°E	418.14	• Lichens • Fungi • Algae • bacteria	X		
ASPA 124	77°30'30"S 169°2 1'30" E	72.21	• Avian & mammalian breeding megafauna • Moss • Algae • lichens • Historic values • Invertebrate and microbiological communities		X	
ASPA 125	62°12'S 58°58'W	2.34	• Unique fossils • Historic			X
ASPA 126	62°34'35"S 61°13' 07"W	90.56	• Lakes • Calcicolous and calcifuge plants • Cyanobacteria • Parochlus steineni (only native winged insect) • (Wingless midge) • Breeding avifauna • palaeontology		X	
ASPA 127	66°31'S 93°00'E	5.01	• Avian breeding site • Seal breeding site			X
ASPA 128	62°11'S 58°27'W	18.04	• Breeding Avian and mammalian fauna • Pearlwort • Algae • Mites • Nematodes • Lichens • Moss		X	
ASPA 129	67°34'S 68°06'W	0.04	• Biological research • Lichens • Soil • Breeding avian populations		X	
ASPA 130			DEDESIGNATED			
ASPA 131	77°37'S 163°03'E	1.51	• Water habitats			X
ASPA 132	62°15'S 58°39'W	2.17	• Protect environmental value & facilitate research		X	

			• Avian colonies • Seal colonies • Moss • Lichens • Antarctic grass			
ASPA 133	62°18'S 59°11'W	30.69	• Seabird breeding colonies • Moss carpets • Lichens • Fungi • 2 species of vascular plants • soil		X	
ASPA 134	64°10'S 61°01'W	59.3	• marine mammal breeding colonies • Avian breeding colonies • grasses		X	
ASPA 135	66°17'110°33'E	0.28	• moss • lichens • Vegetation	X		
ASPA 136	66°15'S 110°36'E	9.38	• primarily-undisturbed terrestrial ecosystem-flora • lichens • Adelie penguin breeding colonies		X	
ASPA 137	78°07'S 167°11'E	141.61	• Weddell seal populations			X
ASPA 138	77°35'S 161°05'E	0.78	• Cryptoendolithic microbial communities • Geological		X	
ASPA 139	64°48'S 63°47'W	0.6	• Vegetation-hair grass, pearlwort • Mosses • lichens • Soils • Seabird colonies		X	
ASPA 140	62°57'S	2.57	• Vegetation • Lichens • mosses	X		
ASPA 141	69°14'30"S 39°46' 00"E	4.88	• Moss • Lichens • Petrels		X	
ASPA 142	71°54'40"S 05°11' E	6.49	• Petrel breeding colonies			X
ASPA 143	68°37'50.2"S 78°0 7'55.2"E	20.46	• Special interest • Geographical • Palaeontology			X
ASPA 144	62°29'06"S; 62°28'30"S 59°41' 27"W;59°40'31" W	0.66	• Benthic fauna			X
ASPA 145	62°55'51"S; 62°57'33"S 60°37' 30"; 60°36'50"W	2.24	• Benthic fauna			X
ASPA 146	64°52'S 63°35'W	0.96	• Benthic habitat			X
ASPA 147	70°50'S 68°30'W	109.02	• Geology • Geomorphology • Glaciology			X
ASPA 148	63°25'S 57°01'W	0.35	• Fossil flora???			X
ASPA 149	62°27'30"S 60°47' 17"W	9.74	• Seabird colonies • Seal populations			X
ASPA 150	62°13'S 58°54'W	1.22	• Avian breeding grounds • Glaciology • Lichens • Moses • Vascular plants		X	

			• Elephant seal colonies			
ASPA 151	58.14 62.13	1.32	• Benthic Fish			X
ASPA 152	63° 23' S 62° 21' W	915.8	• Benthic fish			X
ASPA 153	64°10'S 62°50'W	609.54	• Fully marine • Benthic flora • Historic			X
ASPA 154	77°00'30"S 162°34'00"E	2.14	• Historic • Lichens • Mosses • Algae • invertebrates		X	
ASPA 155	77°38'S 166°24'E	0.06	• Historic			X
ASPA 156	77°25'29"S 167°28'30"E	14.41	• Historic			X
ASPA 157	77°33'10.7"S 166° 10'6.5"E	0.04	• Historic			X
ASPA 158	77°50'50"S 166°38'E	N/A	• Historic			X
ASPA 159	71°18'S 170°09'E	0.03	• Historic			X
ASPA 160	66°14'S 110°10'E	0.6	• Petrel breeding grounds			X
ASPA 161	74°45'S 164°10'E	29.46	• Area management-protection of direct human impact • Important littoral area for science investigation			X
ASPA 162	67°00'30"S 142°39'40"E	N/A	• Historic-primarily • Seal colonies • Avian colonies • Lichens		X	
ASPA 163	70°45'15"S 11°38'30"E	4.31	• Historic • Algae • Lichens • Moss • cyanobacteria		X	
ASPA 164	67°47'S;67°47'S 66°42'E; 66°53'E	10.23	• Seabird colonies			X
ASPA 165	74°20'S 165°08'E	5.5	• Algae • cyanobacteria • Scientific value		X	
ASPA 166	66°49'S 141°23'E	0.17	• Historic			X
ASPA 167	68°35'S 77°50'E	2.17	• Petrels breeding colony			X
ASPA 168	72°54'S 75°02'30" E	102.78	• Geomorphological features • Evolutionary history			X
ASPA 169	69°15'S 76°49' 59.9"E	17.15	• Emperor penguin breeding colonies			X
ASPA 170	69°45'S 75°15'W	179.55	• mosses • Lichens • NO predator arthropods or springtails-important scientific study (rare)	X		
ASPA 171	62° 14' 03" S 58° 46' 05" W	0.89	• Mosses • Lichens • Algae • Liverwort • Penguin colonies • Also has water-shed systems		X	
ASPA 172	77° 50' 13" S 161° 40' 14" E	436	• Unique physical properties • Unusual microbial ecology • Geochemistry		X	

			• lake			
ASPA 173	74° 37.1' S 164° 57.6' E	286	• Emperor penguin breeding grounds • Geoscientific value			X
ASPA 174	69° 25'S 76°6'E	21.13	• Geological features			X
ASPA 175	77° 31' 167° 06'	0.265	• Geothermal sites • Microbial communities		X	
TOTAL				**7**	**27**	**38**

Table 6: Complete list of Antarctic Stations, noting whether they run year-round, the type of surface they were constructed on and if the station is surrounded by terrestrial biodiversity. Totals calculated at bottom of table. (COMNAP, 2017). IFG indicates ice-free ground.

Station	**Year-round Y/N**	**Type of surface**	**Terrestrial biodiversity Yes or No**
Belgrano II	N	Ice-shelf	Y
Brown	N	IFG	N
Camara	Y	IFG	N
Carlini	Y	IFG	Y
Decepcion	N	IFG	N
Esperanza	Y	IFG	Y
Marambio	Y	IFG	Y
Matienzo	N	IFG	N
Melchoi	N	Ice-sheet, Moraine	N
Orcadas	Y	IFG	Y
Petrel	N	IFG	N
Primavera	N	IFG	Y
San Martin	Y	IFG	N
Casey	Y	IFG	Y
Davis	Y	IFG	N
Mawson	Y	IFG	N
Princess Elisabeth	N	IFG	N
Ferraz	Y	IFG	Y
St. Kliment Ohridski	N	IFG	N
Carvajal	N	IFG	Y
Dr. Guillermo Mann	N	IFG	Y
Frei	Y	IFG	Y
Gabriel Gonzalez Videla	N	IFG	N
O'Higgins	Y	IFG	N
Prat	Y	IFG	N
Professor Julio Escudero	Y	IFG	Y
Risopatron	N	IFG	Y
Yelcho	N	IFG	Y
Great Wall	Y	IFG	N
Kunlun	N	Ice-sheet	N
Taishan	Y	Ice-sheet	N
Zhongshan	N	IFG	N

Johann Gregor Mendel	N	IFG	Y
Pedro Vincente Maldonado	N	IFG	Y
Aboa	N	IFG	Y
Concordia	Y	Ice-sheet	N
Durmont d'Urville	Y	IFG	N
Dallmann	N	IFG	Y
Kohnen	N	Ice-sheet	N
Neumayer III	Y	Ice-shelf	N
Bharati	Y	IFG	N
Maitri	Y	IFG	N
Mario Zucchelli	N	IFG	Y
Syowa	Y	IFG	Y
Dirck Gerritsz Labroratory	N	IFG	Y
Scott	Y	Scoria permafrost	Y
Troll	Y	IFG	N
Machu Picchu	N	IFG	Y
Henryk Arctowski	Y	IFG	Y
Mountain Evening/ Vechernyana	N	IFG	Y
Jang Bago	Y	IFG	Y
King Sejong	Y	IFG	Y
Bellingshausen	Y	IFG	Y
Druzhynaya IV	N	IFG	N
Leningradskaya	N	IFG	N
Mirny	Y	IFG	Y
Molodezhnaya	N	IFG	Y
Novolazarevskaya	Y	IFG	Y
Oazis	Y	IFG	N
Progress	N	IFG	Y
Russkaya	Y	IFG	N
Vostok	N	Ice-sheet	N
Sanae IV	Y	Rock outcrop	Y
Gabriel de Castilla	Y	IFG	Y
International Field Camp Peninsula Byers	N	IFG	Y
Juan Carlos I	N	IFG	Y
Wasa	N	IFG	N
Vernadsky	N	IFG	Y
Halley VI	Y	Ice-shelf	N
Rothera	Y	IFG	N
Signy	N	IFG	Y
Amudsen-Scott Southpole	Y	Ice-sheet	N
McMurdo	Y	IFG	N
Palmer	Y	IFG	N
Artigas	Y	IFG	N
Ruperto Elichiribehety	N	IFG	N
TOTAL (76 stations)	**40 Year long stations**	**64 IFG**	**Yes = 38, No = 38**