Management Plan

for Antarctic Specially Protected Area (ASPA) No. 119 DAVIS VALLEY AND FORLIDAS POND, DUFEK MASSIF, PENSACOLA MOUNTAINS (51° 05' W, 82° 29' S)

Introduction

Davis Valley and Forlidas Pond Antarctic Specially Protected Area (ASPA) is situated within the Dufek Massif, Pensacola Mountains at 51°4'53"W, 82°29'21"S. Approximate area: 55.8 km^2. The primary reason for the designation of the Area is that it contains some of the most southerly freshwater ponds with autotrophic microbial life known to exist in Antarctica, which represent unique examples of near-pristine freshwater ecosystems and their catchments. The geomorphology of the Area represents a unique scientific resource for the reconstruction of previous glacial and climatic events. As a consequence of its extreme remoteness and inaccessibility, the Area has experienced very little human activity and with the total number of visitors estimated to be less than 50 people. As a result, the Area has outstanding potential as a scientific reference site. Furthermore, the Area possesses outstanding wilderness and aesthetic values. The Area is one of the most southerly 'dry valley' systems in Antarctica and, as of April 2015, is the most southerly Antarctic Specially Protected Area (ASPA) in Antarctica. The Area was originally proposed by the United States of America and adopted through Recommendation XVI-9 (1991, SPA No. 23). It included Forlidas Pond (51°16'48"W, 82°27'28"S) and several ponds along the northern ice margin of the Davis Valley. The boundaries of the Area were extended to include the entire ice-free region centered on the Davis Valley through Measure 2 (2005).

Newly available imagery in 2013 allowed the boundaries of the Area to be adjusted in the current management plan to follow the margins of ice-free ground.

The Area lies within 'Environment O – West Antarctic Ice Sheet' and 'Environment R – Transantarctic Mountains', as defined in the Environmental Domains Analysis for Antarctica (Resolution 3(2008)), and is the only protected area designated within Environment R. Under the Antarctic Conservation Biogeographic Regions classification (Resolution 6(2012)) the Area lies within ACBR10 – Transantarctic Mountains, and is also the only protected area designated within this bioregion.

1. Description of values to be protected

Forlidas Pond (51°16'48" W, 82°27'28" S) and several ponds along the northern ice margin of the Davis Valley (51°05' W, 82°27'30" S), in the Dufek Massif, Pensacola Mountains, were originally designated as a Specially Protected Area through Recommendation XVI-9 (1991, SPA No. 23) after a proposal by the United States of America. The Area was designated on the grounds that it "contains some of the most southerly freshwater ponds known in Antarctica containing plant life" which "should be protected as examples of unique near-pristine freshwater ecosystems and their catchments". The original Area comprised two sections approximately 500 metres apart with a combined total area of around 6 km^2. It included Forlidas Pond and the meltwater ponds along the ice margin at the northern limit of the Davis Valley. The site has been rarely visited and until recently there has been little information available on the ecosystems within the Area.

This Management Plan reaffirms the original reason for designation of the Area, recognizing the ponds and their associated plant life as pristine examples of a southerly freshwater habitat. The values identified for special protection and the boundaries of the Area were expanded as described below following a field visit made in December 2003 (Hodgson and Convey 2004).

The Davis Valley and the adjacent ice-free valleys is one of the most southerly 'dry valley' systems in Antarctica and, as of March 2015, is the most southerly Antarctic Specially Protected Area in Antarctica. While occupying an area of only 53 km^2, which is less than 1% of the area of the McMurdo Dry Valleys, the Area nevertheless contains the largest ice-free valley system found south of 80°S in the 90°W-0°-90°E half of Antarctica. Moreover, it is the only area known in this part of Antarctica where the geomorphology preserves such a detailed record of past glacial history. Some ice-free areas around the Weddell Sea region have scattered erratics and sometimes moraines, but the assemblage of drift limits, moraines, and abundant quartz- bearing erratics in the Davis Valley and associated valleys is very unusual. The location of the Dufek Massif close to the junction between the western and the eastern Antarctic ice sheets also makes this site particularly valuable for the collection of data that can be used to constrain parameters such as the past thickness and dynamics of this sector of the Antarctic ice sheet. Such data are potentially extremely valuable for understanding the response of the Antarctic ice sheet to climate change. The Area therefore has exceptional and unique scientific value for the interpretation of past glacial events and climate in this part of Antarctica and it is important that this value is maintained.

The terrestrial ecology of the Area is impoverished but is also highly unusual, with lake and meltwater stream environments and their associated biota being rare this far south in Antarctica. As such, they provide unique opportunities for the scientific study of biological communities near the extreme limit of the occurrence of these environments. Vegetation appears to be limited to cyanobacterial mats and a very sparse occurrence of small crustose lichens. The cyanobacterial mat growth in the terrestrial locations is surprisingly extensive, and represents the best examples of this community type known this far south. The cyanobacterial community appears to survive in at least three distinct environments:

- in the permanent water bodies;
- in exposed terrestrial locations, particularly at the boundaries of sorted polygons; and
- in a series of former or seasonally dry pond beds on ice-free ground in the Davis Valley.

No arthropods or nematodes have thus far been detected in samples taken from within the Area, and the invertebrate fauna in the Area is unusually sparse. This characteristic distinguishes the Area from more northerly ice-free valley systems such as those at the Ablation Valley – Ganymede Heights (ASPA No. 147), Alexander Island, or at the McMurdo Dry Valleys (ASMA No. 2), where such communities are present.

Rotifers and tardigrades have been extracted from samples taken within the Area, with the greatest numbers occurring within the former pond beds in the Davis Valley, although their diversity and abundance is also extremely limited compared with more northerly Antarctic sites (Hodgson and Convey 2004). Further analyses of the samples obtained and identification of all taxa present are published (Hodgson *et al*. 2010; Fernandez-Carazo *et al*. 2011; Peeters *et al*. 2011, 2012)) and are an important contribution to the understanding of biogeographical relationships between the different regions of Antarctica.

The Area is extremely isolated and difficult to access, and as a result has been visited by only a small number of people. Reports indicate that small field parties visited the Area in December 1957, in the 1965-66 and 1973-74 austral summer seasons, in December 1978 and in December 2003. The total number of people having visited probably numbers less than 50, with visits generally limited to a period of a few weeks or days. No structures or installations have been built within the Area, and as far as is known all equipment brought into the Area has subsequently been removed. While Hodgson and Convey (2004) reported evidence of a very limited number of human footprints and several old soil pit excavations, the Area has been exposed to few opportunities for direct human impact. The Area is believed to be one of the most pristine ice-free valley systems in Antarctica, and is therefore considered to possess outstanding potential as a reference area for microbiological studies, and it is important that these values receive long-term protection.

The site possesses outstanding wilderness and aesthetic values. The dry and weathered brown valleys of the Area are surrounded by extensive ice-fields, the margins of which fringe the valleys with dry based glacial ice of a deep blue hue. This abrupt and dramatic blue-ice margin stands in stark contrast to the stony and barren ice-free landscape of the valleys, and aesthetically is extremely striking in appearance. One of the original explorers of this area in 1957 recalled “the excitement we felt at being the first people to view and enter this magnificently scenic, pristine area.” (Behrendt 1998: 354). Further examples of descriptions of the Area by visitors are: “[the blue ice] was towering over us ~ 150 feet – a large wave of blue. It was like being in a tidal wave that was held in suspension as we walked under it…” (Reynolds, field notes, 1978), and “I still cannot find adequate superlatives to describe the features, whether large or small, biologic or physical… [Of the] many settings that stretch the imagination…in my experience none match the northern side of the Dufek Massif, with Davis Valley as its crown jewel.” (Reynolds, pers. comm. 2000); “the most unusual [landscape] I have ever seen on any of the seven continents.” (Boyer, pers. comm. 2000); “Probably the single most remarkable environment I've been, either in Antarctica or elsewhere” (Convey, pers. comm. 2004). Burt (2004) described the region simply as “inspiringly awesome”.

The boundaries of the Area include the entire ice-free region centered on the Davis Valley, including the adjacent valleys and Forlidas Pond. In general, the margins of the surrounding ice sheets form the new boundary of the Area, providing special protection of the region as an integrated ice-free unit that closely approximates the valley catchments. The full catchments of the surrounding glaciers that flow into these valleys extend considerable distances from the ice-free area and do not possess many of the values related to the purpose of special protection, and are therefore excluded from the Area.

2. Aims and Objectives

Management at Davis Valley and Forlidas Pond aims to:

- avoid degradation of, or substantial risk to, the values of the Area by preventing unnecessary human disturbance and sampling in the Area;
- preserve the ecosystem as an area largely undisturbed by human activities;
- preserve the almost pristine ecosystem for its potential as a biological reference area;
- allow scientific research on the natural ecosystem and physical environment within the Area provided it is for compelling reasons which cannot be served elsewhere;
- minimize the possibility of introduction of alien plants, animals and microbes to the Area; and
- allow visits for management purposes in support of the aims of the Management Plan.

3. Management Activities

The following management activities shall be undertaken to protect the values of the Area:

- Markers, signs or other structures erected within the Area for scientific or management purposes shall be secured and maintained in good condition and removed when no longer necessary.
- National programs shall ensure the boundaries of the Area and the restrictions that apply within are marked on relevant maps and aeronautical charts;
- Visits shall be made as necessary to assess whether the Area continues to serve the purposes for which it was designated and to ensure management and maintenance measures are adequate.

4. Period of Designation

Designated for an indefinite period.

5. Maps

Map 1: Davis Valley and Forlidas Pond, ASPA No. 119, Dufek Massif, Pensacola Mountains: Location Map.

Map Specifications: Projection: Lambert Conformal Conic; Standard parallels: 1st 82°S; 2nd 83°S; Central Meridian: 51°W; Latitude of Origin: 81°S; Spheroid: WGS84.

Inset: the location of the Pensacola Mountains and Map 1 in Antarctica.

Map 2: Davis Valley and Forlidas Pond, ASPA No. 119: Topographic map and protected area boundary.

Map Specifications: Projection: Lambert Conformal Conic; Standard parallels: 1st 82°S; 2nd 83°S; Central Meridian: 51°W; Latitude of Origin: 81°S; Spheroid: WGS84; Vertical datum: WGS84. EGM96 MSL height differential –21 m. Contour interval 25 m. Topographic data generated by digital orthophoto and photogrammetric techniques from USGS aerial photography (TMA400, TMA908, TMA909 (1958) and TMA1498 (1964)) by the Mapping and Geographic Information Centre, British Antarctic Survey (Cziferszky *et al.* 2004). Accuracy estimates: horizontal: ±1 m; vertical: ±2 m, declining towards the south away from available ground control points. The surrounding ice fields and ice-free area beyond orthophoto coverage are mapped from WorldView 1 satellite imagery (05 Nov 2013) (© Digital Globe, courtesy NGA Commercial Imagery Program) with elevation data generated from a DEM produced by the Polar Geospatial Center (PGC) in 2014..

6. Description of the Area

6(i) Geographical coordinates, boundary markers and natural features General description

Davis Valley (51°05′W, 82°28′30″S) and Forlidas Pond (51°16′48″W, 82°27′28″S) are situated in the north- eastern Dufek Massif, Pensacola Mountains, part of the Transantarctic Mountain range (Map 1). The Dufek Massif is situated approximately mid-way between the Support Force Glacier and the Foundation Ice Stream, two of the major glaciers draining northwards from the Polar Plateau into the Ronne and Filchner Ice Shelves. Approximately 60 km to the southeast is the Forrestal Range (also part of the Pensacola Mountains), which is separated from the Dufek Massif by the Sallee Snowfield. The Ford Ice Piedmont separates the Dufek Massif from the Ronne and Filchner Ice Shelves, about 50 km to the northwest and 70 km to the northeast respectively.

The Davis Valley is approximately five kilometers wide and seven kilometers long, with its northern extent defined by the blue ice lobes that form part of the southern margin of the Ford Ice Piedmont (Map 2). It is bounded in the northeast by Wujek Ridge and Mount Pavlovskogo (1074 m) and southeast by Mount Beljakova (1240 m), flanked on the outer side by a glacier draining north from the Sallee Snowfield to the Ford Ice Piedmont. The western extent of the Davis Valley is defined by Clemons Spur, Angels Peak (964 m) and Forlidas Ridge. The Edge Glacier extends approximately 4 km into the Davis Valley from the Sallee Snowfield. The southern Davis Valley is dominated by Mount Beljakova (1240 m), on the northwestern margin of the Sallee Snowfield. Several smaller valleys exist in the west of the Area, adjacent to the prominent Preslik Spur and Forlidas Ridge. Almost 75% of the region enclosed by the large surrounding ice fields is ice-free, comprising 39 km^2 of ice-free ground in total, with the remainder of the area covered by the Edge Glacier, other permanent bodies of snow / ice and several small ponds.

Forlidas Pond is landlocked and occupies a small unnamed dry valley separated from the Davis Valley by a tributary ridge extending north from Forlidas Ridge. Other pro-glacial lakes and ponds occur within the Area at various locations along the blue ice margin of the Ford Ice Piedmont, at the terminus of the Edge Glacier, and along the ice margin west of Forlidas Ridge and Clemons Spur.

Boundary

The Area comprises all of the Davis Valley and the immediately adjacent ice-free valleys, including several of the valley glaciers within these catchments (Map 2). The boundary predominantly follows the margins of the surrounding ice fields of the Ford Ice Piedmont and Sallee Snowfield, which enclose the ice-free area that is considered to be of outstanding value. The northern boundary extends parallel to and 500 metres north from the southern margin of the Ford Ice Piedmont in the Davis Valley and in the adjacent valley containing Forlidas Pond, extending from 51°24′02″W, 82°26′23.4″S in the northwest to 50°52′10″W, 82°26′45.5″S in the northeast. This provides a buffer of protection around the freshwater bodies of value along the northern glacier margin. The eastern boundary follows the ice margin along Wujek Ridge from the Ford Ice Piedmont to Mount Pavlovskogo. The southeastern boundary extends from Mount Pavlovskogo across the Sallee Snowfield and the upper slopes of the

Edge Glacier, following areas of outcrop where they exist to Mount Beljakova. The southern and western boundaries of the Area follow the margins of the permanent ice, with the southernmost extent being at 51°17′00″W, 82°33′20″S. The boundary encompasses a total area of 55.8 km^2.

Boundary markers have not been installed in the Area because of its remoteness, the limited opportunities for visits and the practical difficulties of maintenance. Moreover, the margins of the permanent ice fields are generally sharply defined and form a visually obvious boundary around most of the Area.

Meteorology

Several estimates of mean annual surface air temperature have been made in the Dufek Massif region from measurements taken in ice bores or crevasses at around 10 metres depth. A measurement of –24.96°C was obtained 32 km due north of Forlidas Pond on the Ford Ice Piedmont in December 1957 (Pit 12, Map 1) (Aughenbaugh *et al*. 1958). Another estimate of -9°C was made in December 1978 in the Enchanted Valley 26 km to the south (Map 1), measured in a crevasse at 8 metres depth (Boyer pers. comm. 2000).

Detailed meteorological data for the Area itself are limited to records collected over two weeks in 2003. Hodgson and Convey (2004) measured temperature and relative humidity over snow and rock surfaces at their sampling sites within the Area from 3-15 December 2003, with data recorded at 30-minute intervals, though sensors were not shielded with a Stevenson screen. Temperatures over snow ranged from a maximum of +12.8°C to a minimum of –14.5°C, with an average over the period of –0.56°C. Temperatures over rock ranged from a maximum of +16.0°C to a minimum of –8.6°C, with an average over the period of +0.93°C (data over rock were only recorded from 3-11 December 2003). Relative humidity recorded over snow ranged from a maximum of 80.4% to a minimum of 10.8%, with an average over the period of 42.6%. Over rock surfaces (from 3-11 December 2003), relative humidity ranged from a maximum of 80.9% to a minimum of 5.6%, with an average over the period of 38.7%.

Directly measured data on windspeeds and directions within the Area are not available, but models suggest near surface winds are predominantly from the west-north-west with mean winter velocities of c. 10 ms^{-1} (van Lipzig *et al.* 2004). While the older exposed ice-free areas above the glacial drift limit possess many features related to long-term wind erosion, there is some evidence to suggest that windspeeds within the locality are currently not especially high. For example, ice and snow surfaces were observed as largely free of wind- blown debris, and terrestrial cyanobacterial mats exist in-tact in exposed locations in the bottom of dry valleys (Hodgson and Convey 2004). No precipitation data are available, although the bare ice and rock surfaces and low average relative humidity recorded by Hodgson and Convey (2004) attest to a dry environment of low precipitation. This is consistent with a Type 2 dominated ablation area where sublimation-driven ablation occurs at the foot of the steep topographic barriers, with individual glacier valleys serving as gates for air drainage from the plateau to the Ronne-Filchner Ice Shelf. Strongest sublimation rates occur on these localized glaciers in the Transantarctic Mountains, where widespread blue ice areas are present (van den Broeke *et al*. 2006).

Geology, geomorphology and soils

The Dufek Massif is characterized by layered bands of cumulate rock belonging to the Dufek intrusion, thought to be one of the largest layered gabbro intrusions in the world (Behrendt *et al*. 1974; 1980; Ferris *et al.* 1998). This is exposed in the Davis Valley as the light- to medium-gray, medium-grained Aughenbaugh gabbro, which is the lowest exposed part of the Middle Jurassic Dufek intrusion (Ford *et al.* 1978).

The Davis Valley primarily consists of minimally weathered talus and glacial till of both local and exotic origin. In particular there appears to be an abundance of erratics of Dover Sandstone, one of several metasedimentary layers disrupted by the Dufek intrusion. An extensive glacial geomorphological record is evident. Features include overlapping valley-glacier moraines, ice sheet moraines, lake shoreline, lateral glacial channels, ice eroded surfaces, well-developed patterned ground and erratics. Boyer (1979) identified at least three major glacial and two major interglacial events, while Hodgson *et al*. (2012) maps geomorphological features derived from up to seven glacial stages. From oldest to youngest, these stages were: alpine glaciation of the escarpment edge; over-riding warm-based glaciation; glacier advance to an upper limit (760 m); two ice-sheet advances to closely parallel limits in the valleys; advance of the plateau outlet glacier (Edge Glacier) to merge with the ice sheet; and finally an advance and retreat of the main ice sheet margin. Attempts to provide age constraints for some of these glacial events have been carried out using paired cosmogenic ^{10}Be-^{26}Al exposure ages on erratic boulders, composed of Dover Sandstone. These suggest that some parts of the valley have been exposed for >1.0-1.8 Ma and experienced only a minor ice sheet advance at the Last Glacial Maximum, consistent with an emerging dataset from around the Weddell Sea rim that implies only rather modest ice thickening at this time.

Soils are not well-developed in the Area and generally lack a significant organic component. Parker *et al*. (1982) collected a soil that was light brown in color, resulting from gravel weathering predominantly to muscovite. The soil comprised sand (81%) with silt (14%) and clay (5%), a composition different from other sites in the Pensacola Mountains where the clay proportions of six samples ranges from 0.4% to 1.6%. The soil sample from the Davis Valley had a pH of 6.4 (Parker *et al*. 1982).

Lakes, ponds and streams

Forlidas Pond is a perennially frozen, shallow, round landlocked pond that was ~100 metres in diameter in 1957 (Behrendt 1998). In December 2003 the lake was measured by Hodgson and Convey (2004) as 90.3 metres in diameter from shoreline to shoreline on a transect azimuth of 306° (magnetic). At this time it was frozen almost completely to its base, with a thin layer of hypersaline slush at the lake bottom, and a freshwater meltwater moat that was partly ice free and partly covered by 10-15 cm of ice (Hodgson and Convey 2004).

Depth was measured at 1.83 m and the thickness of the ice between 1.63 and 1.83 metres. The conductivity and temperature in the brine layer was 142.02 mS cm^{-1} and -7.67°C respectively, compared with 2.22 mS cm^{-1} and 0.7°C in the freshwater moat (Hodgson *et al*. 2010). The salinity of the bottom-water in Forlidas Pond is thus around four times greater than seawater. This concentration of salts is the result of the pond being the remnant of a much larger lake, which evaporated from about 2200 years ago and can be identified by a series of lake terraces and a high shoreline 17.7 m above the present water level (Hodgson *et al.* 2012).

Hodgson and Convey (2004) also report a small remnant pro-glacial pond near the margin of the Ford Ice Piedmont, 900 metres north of Forlidas Pond. Two pro-glacial meltwater ponds also occur to the west of Forlidas Ridge and a series of similar pro-glacial meltwater ponds also occur along the blue-ice margin of the northern Davis Valley, located at 51° 05.5′ W, 82° 27.5′ S and 51° 07′ W, 82° 27.55′ S. The pro-glacial lake at the terminus of the Edge Glacier is the largest within the Area. This is permanently frozen to the bottom apart from at the eastern margins where seasonal meltwater has been observed.

Dry stream channels and water erosion features are evident within the ice-free area, although only the small glacial melt streams on the eastern margin of the Edge Glacier have thus far been reported as flowing in December (Hodgson and Convey 2004). The apparent lack of melt streams may be because all visits to date have been made in the month of December, possibly before streams become more active. The presence of lake moats, the positive temperatures recorded by Hodgson and Convey (2004), as well as the biological and the geomorphological evidence, as well observations of footprints into formerly moist ground (Convey pers. comm. 2015) suggest that it is probable that at least some streams become active later in the season from melting snow, although perhaps not on an annual basis.

Biology

Visible biota is dominated by cyanobacterial mats, found both in lakes and in patches on the surface of ice- free ground, and a very sparse occurrence of small crustose lichens. Neuburg *et al.* (1959) observed yellow and black lichens growing sparsely in sheltered places in the Davis Valley, while Hodgson and Convey (2004) observed several lichen forms growing deep within the crevices of boulders. These have been identified as *Lecidea cancrioformis* Dodge & Baker (Hodgson *et al.* 2010, and see Appendix 1: Table A1 for a list of taxa identified in the Area). The British Antarctic Survey Plant Database also reports *Blastenia succinea* Dodge & Baker and *Xanthoria elegans* (Link.) Th. Fr. in samples from elsewhere in the Dufek Massif, although these have not been independently verified. Previous anecdotal reports of the possible occurrence of mosses within the Area could not be substantiated by Hodgson and Convey (2004), and it is probable that the rich cyanobacterial mat growth was earlier mistaken for bryophytes by non-specialists. The cyanobacterial community is the most abundant biota and is present in at least three distinct environments:

(1) In the permanent water bodies; particularly in the moat of Forlidas Pond, at the bottom and littoral zones of the Davis Valley Ponds, and in the seasonally wetted perimeter of Edge Lake. These habitats are extensively covered by red-brown cyanobacterial mats. These are actively photosynthesizing, as evidenced by gas bubbles trapped against the lower ice surfaces, and bubbles incorporated into the ice. Because perennially ice covered lakes have elevated concentrations of dissolved O_2 gas, the microbial mats growing on the bottom can become buoyant and start to float off the bottom as 'lift-off' mats, or become incorporated into the base of the lake ice when it makes contact with the bed. In Forlidas Pond and the Davis Valley Ponds lift off mats frozen into the base of the lake ice eventually migrate up through the ice profile. In the Davis Valley, this appears to take place over several years with each summer marked by the development of a 2-3 cm melt-cavity formed by the upward progression of the clump thorough the lake ice due to preferential heating of its upper surface. These clumps eventually break out at the surface and are dispersed by wind onto the shoreline, or further afield. Cyanobacteria were also present in the hypersaline brine of Forlidas Pond as single cells and as small flakes. A strain corresponding to the morphology of *Leptolyngbya antarctica* was isolated from the saline slush of TM1 (Fernandez-Carazo *et al.* 2011).

(2) In exposed terrestrial locations, particularly at the edge of larger rocks and within the boundary crevices of frost sorted polygons. These are generally very foliose in form, mid brown in colour, and best developed at the edge of larger rocks with depths of at least 10-15 cm. Nearly all clumps were completely dry on discovery, although those near to melting snow were damp and some had lower thalli that were often deep green in colour. Particularly good examples of this growth form were found in the mid valley floor of Forlidas Valley and in Davis Valley (near a large snow gully where it meets the second major terrace above Edge Lake).

(3) In a series of dry pond beds in the Davis Valley, two of up to 50 m diameter, which have extensive areas of almost continuous cyanobacterial mat on the former pond floors. These pond beds and gullies occupy depressions and therefore may accumulate snow in winter, permitting the cyanobacteria to take advantage of the wet and protected environment within the snow patches.

The growth form also occurs in many of the adjacent small gullies between polygons or other cryoturbation features, which often have the appearance of temporary drainage features.

Analyses of the cyanobacterial molecular diversity from four samples collected in and around Forlidas Pond show a depleted diversity, with only 2 - 5 Operational Taxonomic Units (OTUs) per sample (Hodgson *et al.* 2010). This is likely a product of geographical isolation combined with multiple environmental stressors such as salinity and seasonal desiccation, and UV radiation. Some of the cyanobacteria, for example from the brine of Forlidas Pond, are related to sequences from other hypersaline Antarctic lakes, whilst others are found almost exclusively in glacial regions. The six cyanobacterial OTUs described from the Dufek Massif are all distributed in more than one location within the continent and are found outside Antarctica.

The invertebrate fauna within the area is equally impoverished, with both the diversity and abundance of organisms being extremely limited compared with lower latitude and coastal Antarctic sites. No nematodes or arthropods have been found, but there are three species of tardigrade present from two Classes: *Echiniscus* (cf) *pseudowendti* Dastych, 1984 (Heterotardigrada), *Acutuncus antarcticus* (Richters 1904) and *Diphascon sanae* Dastych, Ryan and Watkins, 1990 (Eutardigrada), and a few unidentified bdelloid rotifers (Hodgson *et al.* 2010). *Acutuncus antarcticus* is an Antarctic species that occurs in semi-permanent damp / wet habitats throughout the Antarctic continent and sub-Antarctic islands, but has not been reported from any of the close neighbour continents. *Echiniscus* (cf) *pseudowendti* and *Diphascon sanae* found in samples from Forlidas Pond are also endemic to the Antarctic, with restricted distributions.

The most productive sites for these organisms were not the aquatic environments of the permanent lakes, but the former pond beds in the Davis Valley, showing these areas to be biologically productive, which necessitates a source of liquid water. In December 2003 very little snow was evident on the valley floor, prompting Hodgson and Convey (2004) to reason that the source of moisture may be from a considerable increase in melt later in the season flowing off the local ice sheet in the upper valley, or from local ice-cored moraines. Although this process was not occurring during their visit, footprints and shallow soil survey pits remaining from one of the previous parties (i.e. 25-46 years old) indicated that some ground was moist or waterlogged at the time of the earlier visit. Seasonal inundation by liquid water would explain the extensiveness and integrity of this cyanobacterial community, and its apparent resilience to the potential ravages of polar winds, as well as the relative abundance of invertebrates extracted from samples taken from within these areas.

Viable yeast species have been recorded in the soil, along with the algae *Oscillatoria* sp., *Trebouxia* sp. and *Heterococcus* sp. (Parker *et al.* 1982). Chasmoendolithic microorganisms have been recorded in rocks in the Dufek Massif (Friedmann 1977), although Hodgson and Convey (2004) found no evidence of their presence within the Area and noted that rock types most favorable for the occurrence of endolithic organisms are not widespread.

Avifauna is sparse: in December 2003 a single snow petrel (*Pagadroma nivea*) was noted flying around one of the peaks above Davis Valley.

Human activities and impact

There have been few visits to the Area and human impacts are believed to be minimal (Table A2 Appendix 1). Because of its remoteness and the infrequency of visits, it is one of the few ice-free areas of Antarctica where the compiled record of past human activity at the site is almost complete. The almost pristine condition of the environment contributes to the extremely high value of the Area and is an important reason for its special protection.

The key characteristics of visits recorded to the Area are summarized in Table A2 (Appendix 1), which should be updated as required (see Section 7(x)). Past camps have generally been on the ice sheet outside of the Area. Previous parties removed all wastes from the Area, with the possible exception of small quantities of human wastes. In 2003 all wastes including all human wastes were removed, both from within the Area and from the party's adjacent campsite on the Ford Ice Piedmont (Map 2). Hodgson and Convey (2004) noted that in December 2003 the evidence of previous visits was limited to a number of footprints and several shallow soil excavations in the Davis Valley.

6(ii) Access to the Area

Access to the Area may be made only on foot. Access to the icefields surrounding the Area may be made by aircraft or via overland routes. Access to the Area should be made as close as practicable to the intended study site, in order to minimize the amount of the Area that needs to be crossed. Due to the surrounding terrain and crevasse patterns, the most practical access routes into the Area are from the Ford Ice Piedmont to the north of the Area.

6(iii) Location of structures within and adjacent to the Area

No structures, installations or caches are known to exist within the Area.

6(iv) Location of other protected areas within close proximity of the Area

There are no other protected areas nearby, with the nearest being Ablation Valley – Ganymede Heights (ASPA No. 147), Alexander Island, which is approximately 1300 km to the north-west.

6(v) Special zones within the Area

None.

7. Permit conditions

7(i) General Permit conditions

Entry into the Area is prohibited except in accordance with a Permit issued by an appropriate national authority. Conditions for issuing a Permit to enter the Area are that:

- it is issued only for compelling scientific or educational reasons that cannot be served elsewhere, or for reasons essential to the management of the Area ;
- the actions permitted are in accordance with this Management Plan;
- The activities permitted will give due consideration via the environmental impact assessment process to the continued protection of the environmental, scientific and aesthetic and wilderness values of the Area, in particular its pristine value and its potential as a largely undisturbed biological reference site;
- The Permit shall be issued for a finite period.
- the Permit, or a copy, shall be carried when in the Area;

7(ii) Access to and movement within the Area

- Landing of aircraft is prohibited within the Area and overflight of the Area at less than 100 metres above ground level is prohibited.
- Vehicles are prohibited within the Area.
- Access into and movement within the Area shall be on foot.
- No special restrictions apply to the means of access, or air or land routes used, to move to and from the icefields surrounding the boundaries of the Area.
- Access into the Area should be at a practicable point close to sites of study in order to minimize the amount of the Area that needs to be traversed. The terrain and crevassing generally makes such access most practical from the Ford Ice Piedmont to the north of the Area.
- Pedestrian routes should avoid lakes, ponds, former pond beds, stream beds, areas of damp ground and areas of soft sediments or sedimentary features. Care should be exercised to avoid damage to any areas of cyanobacterial mat growth, in particular to the extensive areas found in relict pond beds in Davis Valley (see Map 2).
- Pedestrian traffic should be kept to the minimum necessary consistent with the objectives of any permitted activities and every reasonable effort should be made to minimize effects.

7(iii) Activities that may be conducted within the Area

- Scientific research that will not jeopardize the scientific, ecological or aesthetic and wilderness values of the Area, or its pristine value and potential as a reference site, and which cannot be served elsewhere;
- Essential management activities, including monitoring;
- Activities with educational aims that are undertaken for compelling reasons which cannot be served elsewhere. Activities may include documentary reporting (photographic, audio or written) or the production of educational resources or services. Educational activities shall not compromise the values for which the Area is protected, in particular its value as a near-pristine reference site. Educational aims do not include tourism.
- The appropriate authority should be notified of any activities / measures undertaken that were not included in the authorized Permit.

7(iv) Installation, modification or removal of structures

- No structures are to be erected within the Area except as specified in a Permit.
- Permanent structures are prohibited.
- All scientific equipment installed in the Area must be approved by Permit.
- Should equipment be intended to remain within the Area for a duration of more than one season it shall clearly be identified by country, name of the principal investigator and year of installation. All such items should be made of materials that pose minimal risk of contamination of the Area.
- Installation (including site selection), maintenance, modification or removal of structures shall be undertaken in a manner that minimizes disturbance to the physical, ecological, scientific or aesthetic and wilderness values of the Area;
- Removal of structures, equipment or markers for which the Permit has expired shall be a condition of the Permit. It shall be the responsibility of the authority which granted the Permit to ensure that this condition is included in the Permit, and, in the event that the Permit holder does not meet this obligation, it shall be that authority's responsibility to ensure removal.

7(v) Location of field camps

- Camping within the Area is prohibited.
- Suitable camp sites have been proven to the north and west of the Area on the Ford Ice Piedmont (Map 2), and also in the Enchanted Valley (Map 1).

7(vi) Restrictions on materials and organisms which may be brought into the Area

In addition to the requirements of the Protocol on Environmental Protection to the Antarctic Treaty, restrictions on materials and organisms which may be brought into the area are:

- Deliberate introduction of animals, plant material, micro-organisms and non-sterile soil into the Area is prohibited. Precautions shall be taken to prevent the accidental introduction of animals, plant material, micro-organisms and non-sterile soil from other biologically distinct regions (within or beyond the Antarctic Treaty area)
- Visitors shall ensure that sampling equipment and markers brought into the Area are clean. To the maximum extent practicable, footwear and other equipment used or brought into the area (including backpacks, carry-bags and tents) shall be thoroughly cleaned before entering the Area. Visitors should also consult and follow as appropriate recommendations contained in the Committee for Environmental Protection Non-native Species Manual (CEP 2011), and in the Environmental Code of Conduct for Terrestrial Scientific Field Research in Antarctica (SCAR 2009);
- To reduce the risk of microbial contamination, the exposed surfaces of footwear, sampling equipment and markers should be sterilized before use within the Area. Sterilization should be by an acceptable method, such as by washing in 70% ethanol solution in water.
- No pesticides shall be brought into the Area;
- Fuel, food, chemicals, and other materials shall not be stored in the Area, unless specifically authorized by permit and shall be stored and handled in a way that minimizes the risk of their accidental introduction into the environment;
- All materials introduced shall be present only for a finite period stated in the Permit and shall be removed at or before the conclusion of that stated period; and
- If release occurs which is likely to compromise the values of the Area, removal is encouraged only where the impact of removal is not likely to be greater than that of leaving the material *in situ*.

7(vii) Taking of, or harmful interference with, native flora or fauna

- Taking or harmful interference with native flora or fauna is prohibited, except in accordance with a permit issued under Article 3 of Annex II to the Protocol on Environmental Protection to the Antarctic Treaty. Where animal taking or harmful interference is involved, this should, as a minimum standard, be in accordance with the SCAR Code of Conduct for the Use of Animals for Scientific Purposes in Antarctica.

7(viii) Collection or removal of materials not brought into the Area by the Permit holder

- Material may be collected or removed from the Area only in accordance with a Permit and should be limited to the minimum necessary to meet scientific or management needs. Permits shall not be granted if there is a reasonable concern that the sampling proposed would take, remove or damage such quantities of soil, native flora or fauna that their distribution or abundance within the Area would be significantly affected.
- Material of human origin likely to compromise the values of the Area, which was not brought into the Area by the Permit Holder or otherwise authorized, may be removed from the Area unless the environmental impact of the removal is likely to be greater than leaving the material *in situ*: if this is the case the appropriate authority must be notified and approval obtained.

7(ix) Disposal of waste

All wastes, including water used for any human purpose and including all human wastes, shall be removed from the Area. Individuals or groups shall carry appropriate containers for human waste and gray water so that they may be safely transported and removed from the Area.

7(x) Measures that are necessary to ensure that the aims and objectives of the Management Plan can continue to be met

Permits may be granted to enter the Area to:

- carry out monitoring and Area inspection activities , which may involve the collection of a small number of samples or data for analysis or review;
- carry out protective measures;

7(xi) Requirements for reports

- The principal permit holder for each visit to the Area shall submit a report to the appropriate national authority as soon as practicable, and no later than six months after the visit has been completed.
- Such reports should include, as appropriate, the information identified in the Visit Report form contained in Appendix 2 of the Guide to the Preparation of Management Plans for Antarctic Specially Protected Areas (Resolution 2 (2011)). If appropriate, the national authority should also forward a copy of the visit report to the Party that proposed the Management Plan, to assist in managing the Area and reviewing the Management Plan.
- Parties should, wherever possible, deposit originals or copies of such original reports in a publicly accessible archive to maintain a record of usage, to be used both in any review of the Management Plan and in organizing the scientific use of the Area.
- The appropriate authority should be notified of any activities / measures undertaken, anything removed, and / or of any materials released and not removed, that were not included in the authorized permit.

8. Supporting documentation

Aughenbaugh, N., Neuburg, H. and Walker P. 1958. Report 825-1-Part I, October 1958, USNC-IGY Antarctic Glaciological Data Field Work 1957 and 1958. Ohio State University Research Foundation. Source: World Data Center for Glaciology at Boulder, Colorado. (ftp://sidads.colorado.edu/pub/DATASETS/AGDC/antarctic_10m_temps/ells-filchner_57.txt).

Behrendt, J.C. 1998. *Innocents on the Ice; a memoir of Antarctic Exploration, 1957*. University Press of Colorado, Boulder.

Behrendt, J.C., Drewry, D.J., Jankowski, E., and Grim, M.S. 1980. Aeromagnetic and radio echo ice-sounding measurements show much greater area of the Dufek intrusion, Antarctica. *Science* **209***:* 1014-17.

Behrendt, J.C., Henderson, J.R., Meister, L. and Rambo, W.K. 1974. Geophysical investigations of the Pensacola Mountains and Adjacent Glacierized areas of Antarctica. *U.S. Geological Survey Professional Paper* 844*.*

Boyer, S.J. 1979. Glacial geologic observations in the Dufek Massif and Forrestal Range, 1978-79. *Antarctic Journal of the United States* **14**(5): 46-48.

Burt, R. 2004. Travel Report - Sledge Bravo 2003-2004. SAGES-10K & BIRESA: Field trip to the lakes and dry valleys in the Dufek Massif and the Shackleton Mountains. Unpublished BAS Internal Report Ref. R/2003/K1. British Antarctic Survey, Cambridge

Cziferszky, A., Fox, A., Hodgson, D. and Convey, P. 2004. Unpublished topographic base map for Davis Valley, Dufek Massif, Pensacola Mountains. Mapping and Geographic Information Centre, British Antarctic Survey, Cambridge.

England, A.W. and Nelson, W.H. 1977. Geophysical studies of the Dufek Instrusion, Pensacola Mountains, Antarctica, 1976-1977. *Antarctic Journal of the United States* **12**(5): 93-94. Fernandez-Carazo, R., Hodgson, D.A., Convey, P. & Wilmotte, A. 2011. Low cyanobacterial diversity in biotopes of the Transantarctic Mountains and Shackleton Range (80-82°S), Antarctica. *FEMS Microbiology Ecology* **77**: 503-17.

Ferris, J., Johnson, A. and Storey, B. 1998. Form and extent of the Dufek intrusion, Antarctica, from newly compiled aeromagnetic data. *Earth and Planetary Science Letters* **154**: 185-202.

Ford, A.B. 1976. Stratigraphy of the layered gabbroic Dufek intrusion, Antarctica. *Contributions to stratigraphy: Geological Survey Bulletin* 1405-D.

Ford, A.B. 1990. *The Dufek intrusion of Antarctica. Antarctic Research Series* **51**. American Geophysical Union, Washington D.C.: 15-32.

Ford, A.B., Schmidt, D.L. and Boyd, W.W. 1978. Geologic map of the Davis Valley quadrangle and part of the Cordiner Peaks quadrangle, Pensacola Mountains, Antarctica. *U.S Geological Survey Antarctic Geological Map A-10.*

Ford, A.B., Carlson, C., Czamanske, G.K., Nelson, W.H. and Nutt, C.J. 1977. Geological studies of the Dufek Instrusion, Pensacola Mountains, 1976-1977. *Antarctic Journal of the United States* **12**(5): 90-92.

Friedmann, E.I. 1977. Microorganisms in Antarctic desert rocks from dry valleys and Dufek Massif. *Antarctic Journal of the United States* **12**(5): 26-29.

Hodgson, D. and Convey, P. 2004. Scientific Report - Sledge Bravo 2003-2004. BAS Signals in Antarctica of Past Global Changes: Dufek Massif – Pensacola Mountains; Mount Gass – Shackleton Mountains. Unpublished BAS Internal Report Ref. R/2003/NT1. British Antarctic Survey, Cambridge.

Hodgson, D.A., Convey, P., Verleyen, E., Vyverman, W., McInnes, S.J., Sands, C.J., Fernández-Carazo, R., Wilmotte, A., DeWever, A., Peeters, K., Tavernier, I. and Willems, A. 2010. The limnology and biology of the Dufek Massif, Transantarctic Mountains 82° South. *Polar Science* **4**: 197-214.

Hodgson, D.A., Bentley, M.J., Schnabel, C., Cziferszky, A., Fretwell, P., Convey, P. and Xu, S. 2012. Glacial geomorphology and cosmogenic ^{10}Be and ^{26}Al exposure ages in the northern Dufek Massif, Weddell Sea embayment, Antarctica. *Antarctic Science* **24**(4): 377–94. doi:10.1017/S0954102012000016

Hodgson, D.A. & Bentley, M.J. 2013. Lake highstands in the Pensacola Mountains and Shackleton Range 4300-2250 cal. yr BP: Evidence of a warm climate anomaly in the interior of Antarctica. *The Holocene* **23**(3): 388-97. doi: 10.1177/0959683612460790

Neuburg, H., Theil, E., Walker, P.T., Behrendt, J.C and Aughenbaugh, N.B. 1959. The Filchner Ice Shelf. *Annals of the Association of American Geographers* **49**: 110-19.

Parker, B.C., Boyer, S., Allnutt, F.C.T., Seaburg, K.G., Wharton, R.A. and Simmons, G.M. 1982. Soils from the Pensacola Mountains, Antarctica: physical, chemical and biological characteristics. *Soil Biology and Biochemistry* **14**: 265-71.

Parker, B.C., Ford, A.B., Allnutt, T., Bishop, B. and Wendt, S. 1977. Baseline microbiological data for soils of the Dufek Massif. *Antarctic Journal of the United States* **12**(5): 24-26.

Peeters, K., Hodgson, D.A., Convey, P. & Willems, A. 2011. Culturable diversity of heterotrophic bacteria in Forlidas Pond (Pensacola Mountains) and Lundström Lake (Shackleton Range), Antarctica. *Microbial Ecology* **62**(2): 399-413.

Peeters, K., Verleyen, E., Hodgson, D.A., Convey, P., Ertz, D., Vyverman, W. & Willems, A. 2012. Heterotrophic bacterial diversity in terrestrial and aquatic microbial mat communities in Antarctica. *Polar Biology* **35**: 543-54.

Schmidt, D.L. and Ford, A.B. 1967. Pensacola Mountains geologic project. *Antarctic Journal of the United States* **2**(5): 179.

Van den Broeke, M., van de Berg, W.J., van Meijgaard, E. and Reijmer, C. 2006. Identification of Antarctic ablation areas using a regional atmospheric climate model. *Journal of Geophysical Research* **111**: D18110. doi: 10.1029/2006JD007127

Van Lipzig, N.P.M., Turner, J., Colwell, S.R. and van Den Broeke, M.R. 2004. The near-surface wind field over the Antarctic continent. *International Journal of Climatology* **24**(15): 1973-82.

Appendix 1:

Table A1. Biological sampling program in the Davis and Forlidas Valleys: groups of taxa identified and the methods used (Hodgson et al., 2010).

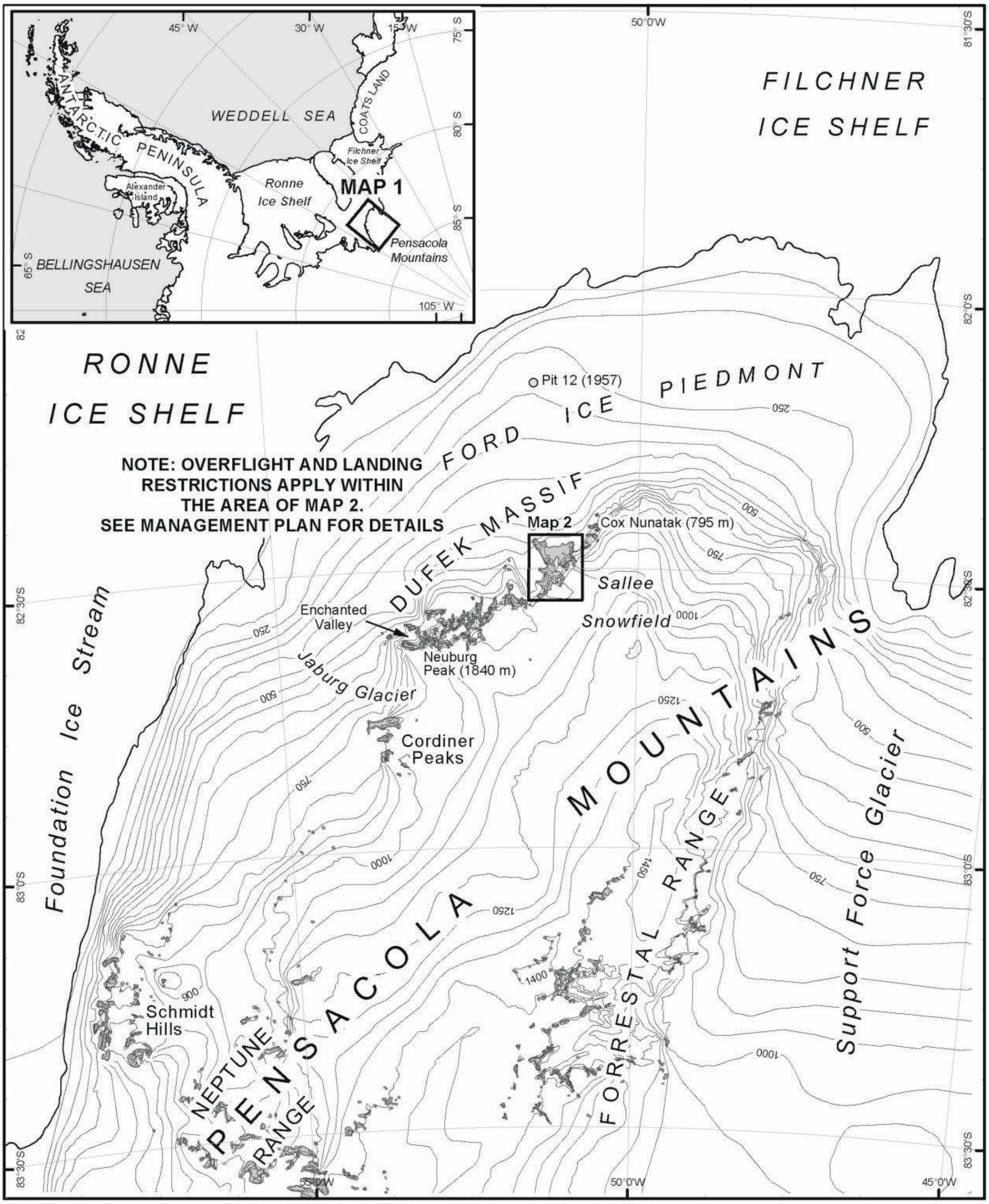
Description	Method	No. samples	No. taxa	Taxa
Bryophyta	Observational survey	0	0	n/a
Lichens	Observational survey	1	1	Lecidea cancriformis Dodge & Baker
Bacillariophyceae / Diatoms	Survey under light microscope	2	1	Pinnularia microstauron (Ehr.) Cl.††
Cyanobacteria	Clone library, DGGE + band sequencing, isolation of strains+ sequencing (microscopy)	3	6	Sample TM1: 16ST63, 16ST14 Sample TM2: 16ST63, 16ST14, 16ST44, 16ST49, 16ST80 Sample TM3: 16ST44, 16ST49, 16ST80, 16ST07
Chlorophyta / Green algae	DGGE + band sequencing	2	1	Urospora sp.
Rhizaria/ Cercozoa	DGGE + band sequencing	2	2	Heteromitidae, Paulinella sp.
Bacteria	DGGE + band sequencing	2	32	Cyanobacteria: Nostocales, Oscillatoriales, Chroococcales, Gloeobacteriales** Bacteroidetes: Sphingobacteriales, Flavobacteriales Firmicutes: Clostridiales Gammaproteobacteria: Pseudomonadales, Psychrobacter
Bacteria	Isolation of strains + sequencing	1	330 isolates	Firmicutes 33%, Bacteroidetes 23%, Alphaproteobacteria 25%, Actinobacteria 9%, Betaproteobacteria. 8%, Gammaproteobacteria 1.5%, Deinococci 0.3%
Arthropods	Tullenberg	50	0	n/a
Invertebrates	Baermann extractions	130	3	See Tardigrades (below)
Tardigrades	Light microscope (Molecular†)	14 20	3 1	Echiniscus (cf) pseudowendti Dastych, 1984 (Heterotardigrada), Acutuncus antarcticus (Richters, 1904) Diphascon sanae Dastych, Ryan and Watkins, 1990 (Eutardigrada)
Rotifers	Tullenberg and light microscope	130	present	Bdelloid rotifers
Soil bacteria and algae	Cultured (Parker et al., 1982)*	1	3	Cyanobacteria: Oscillatoria sp. Algae: Trebouxia sp., Heterocous sp. (viable yeasts present)
Avifauna	Observation	n/a	1	Snow petrel (Pagadroma nivea)

*previously published, ** tentative identification based on about 100 bases, †analyses carried out on morphologically congruent samples from the Shackleton Range, †† not considered as evidence of an extant community

Table A2. Known visits to the Davis Valley and adjacent ice-free valleys within and near the Area.

Party	No. pers	Org	Purpose	Dates	Duration (days)	Locations visited	Camp	Transport
Aughenbaugh, Behrendt, Neuburg, Thiel, Walker	5	IGY (US)	Geology Geophysics	Dec 1957	?	FIP,DV,FP, FR	FIP west of FR	Sno-Cat traverse to FIP, then on foot
Ford, Schmidt, Nelson, Boyd, Rambo (?)	5	USGS	Geology	Dec 1965 – Jan 1966	?	?	Base camp in Neptune Range	Numerous helicopter landings in Dufek Massif
Ford & team	?	USGS	Geology	Summer 1973-74	?	?	?	?
Ford, Carlson, Czamanske, Nutt, England, Nelson	6	USGS	Geology	30 Nov – 30 Dec 1976 (expedition dates)	?	?	Base camp close to Walker Peak (southwest Dufek Massif)	Numerous helicopter landings in Dufek Massif. Motor toboggans and ski traverses used on ground.
Russian team led by Shuljatin, O. G. Accompanied by Ford (and Grue?) from the USA and Paech from Germany.	11	Soviet Antarctic Expedition (22)	Geology Geophysics	Summer 1976-77	49 (total expedition)	Dufek Massif and other locations in the Pensacola Mountains	Field camps on Provender Mountain, Read Mountain and Skidmor Mountain. Druznaja Station used as base camp.	Helicopter landings, snowmobile 'Buran', thence on foot
Russian team led by Kamenev, E. N.	6	Soviet Antarctic Expedition (23)	Geology Geophysics	06 Feb – 17 Feb 1978	11	Dufek Massif	Field camp in Schmidt Hills. Druznaja Station used as base camp.	Airplane, snowmobile 'Buran', thence on foot
Boyer, Reynolds	2	USGS	Geology	12 Dec 1978	2	FIP, DV	EV	Toboggan from EV to ice margin, thence on foot
Ford, Boyer, Reynolds Carl?	4	USGS	Geology	14 Dec 1978	4	FIP, DV, FR, AP	EV	Toboggan from EV to ice margin, thence on foot
Hodgson, Convey, Burt	3	BAS (UK)	Biology, Limnology, Glacial geo-morphology	3-15 Dec 2003	13	FIP, DV, FP, FR, AP	FIP 1.9km north of FP	Twin Otter to FIP, thence on foot.
TOTALS ~30					**~40??**	(numbers approximate owing to incomplete data)		

Key: FIP – Ford Ice Piedmont; DV – Davis Valley; FP – Forlidas Pond; FR– Forlidas Ridge; AP – Angels Peak; CS – Clemons Spur; PS – Preslik Spur; MB– Mt Beljakova; MP–Mt Pavlovskogo; EV–Enchanted Valley.



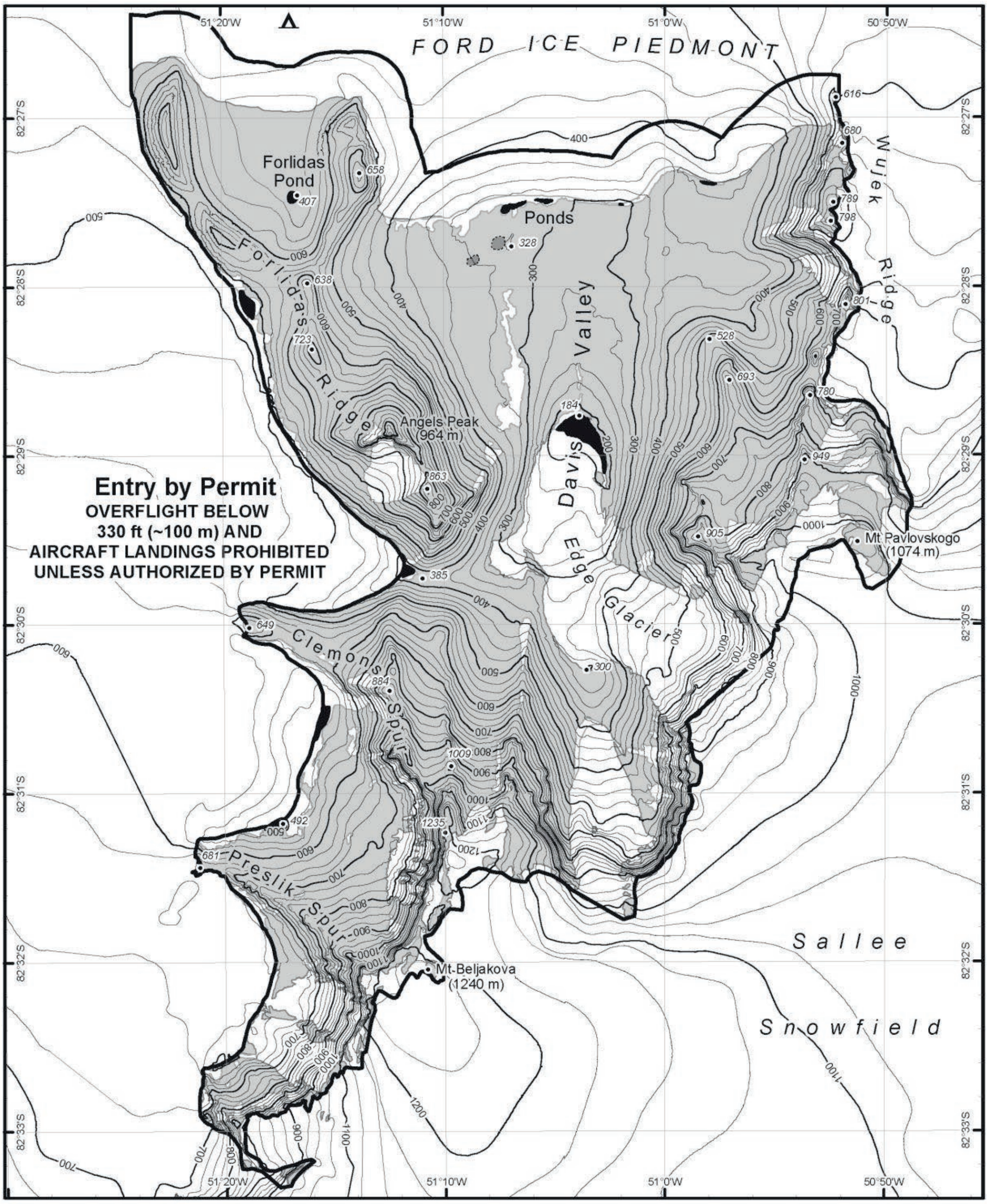
Map 1: ASPA No. 119 - Davis Valley and Forlidas Pond - Location Map

10 Feb 2015 (Map ID: 10068.0005.01)
United States Antarctic Program
Environmental Research & Assessment

0 10 20 Kilometers

Coastline — Contour (50 m) — Ice free ground — Permanent ice — Ice bore

Projection: Lambert Conformal Conic
Spheroid and horizontal datum: WGS84
Data sources: Coast & topography: SCAR ADD (v6, 2012).



Map 2: ASPA No. 119 - Davis Valley and Forlidas Pond - Topographic Map

13 Mar 2015 (Map ID: 10068.0006.01)
United States Antarctic Program
Environmental Research & Assessment

- Spot elevation
- Index contour (100 m)
- Contour (25 m)
- Ice free ground
- Permanent ice
- ASPA boundary
- Lake
- Relict pond bed
- Proven campsite

0 1 2 Kilometers

Projection: Lambert Conformal Conic
Spheroid and horizontal datum: WGS84
Data sources: Topographic data supplied by the MAGIC, BAS.
Derived from USGS aerial photography (1956, 1964), satellite imagery (2002) and field observations (Hodgson and Convey).
Updated by ERA using WorldView imagery and DEM provided by PGC.