·Article·
Advances in Polar Science
doi: 10.3724/SP.J.1085.2013.00273
December 2013 Vol. 24 No. 4: 273-280

Spatial variability of soil nutrients in Punta Fort William, Greenwich Island, maritime Antarctic

Yii Siang Hii[1*], Siti Aisyah Alias[2], Monica Riofrío[3], Nadia Ordóñez[4] & Hernán Moreano[5]

[1] Institute of Oceanography and Environment, University Malaysia Terengganu, Kuala Terengganu 21030, Malaysia;
[2] Institute of Biological Science, University Malaya, Kuala Lumpur 50603, Malaysia;
[3] Instituto Antártico Ecuatoriano, Guayaquil 999165, Ecuador;
[4] Laboratorio de Biomedicina, FIMCM Escuela Superior Politécnica del Litora (ESPOL) Guayaquil, Guayaquil 999165, Ecuador;
[5] Instituto de Investigación Científica y Desarrollo Tecnológico, Universidad Estatal Península de Santa Elena, La Libertad, Ecuador

Received 16 June 2013; accepted 22 November 2013

Abstract This study aims to report baseline soil nutrients, specifically the organic carbon, nitrogen and phosphorus profile, in soil samples collected from Punta Fort William on Greenwich Island in maritime Antarctic. Samples were collected along two transect lines during the early summer of 2008. Ward's method of hierarchical agglomerative clustering was employed to group the sampling points based on their physico-chemical properties. In this context, the soil samples can be grouped into three major clusters: (1) Samples with intensive biological activities, (2) samples from the area recently exposed by glacial retreat and (3) samples from barren and dried areas. Nutrient contents in Punta Fort William are driven by the intensity of biological activities as well as melt water from the Quito glacier.

Keywords soil nutrients, Antarctic, nitrogen, phosphorus, South Shetland Islands

Citation: Hii Y S, Alias S A, Riofrío M, et al. Spatial variability of soil nutrients in Punta Fort William, Greenwich Island, maritime Antarctic . Adv Polar Sci, 2013, 24:273-280, doi: 10.3724/SP.J.1085.2013.00273

1 Introduction

The interaction between biotic and abiotic components, especially in nutrient dynamics, remains one of the most interesting research topics in Antarctic science. Nutrient availability and cycling are key for biodiversity in the Antarctic tundra. Nutrients, especially nitrogen (N), phosphorous (P) and carbon (C), play important roles in regulating biological activity in the Antarctic ecosystem. In fact, Jacobs et al.[1] reported the significant role of nutrients in Antarctica as early as 1979 in his letters to Nature. Although a number of studies have reported the level of nutrient availability in different regions in the Antarctic[2-5], the level of nutrients, specifically N and P, in the reports varies between areas studied. In addition, the rate of nutrient changes and cycling in the terrestrial environment are not well understood. To highlight these issues in a broader perspective, there is a need for extensive baseline data that covers both spatial and temporal aspects.

This study is focused at Punta Fort William at the northeastern tip of Greenwich Island, next to the well-known Discovery Bay and Guayaquil Cove. Greenwich Island is one of the southernmost islands of the South Shetland Islands in Antarctica. The island, situated at 62° south, has a low temperature most of the time and a relatively short summer from late December to March. Punta Fort William is a relatively small headland (~1.6 km^2) neighboring the Quito Glacier and has no snow cover during the summer. Parts of the headland are saturated with melt water from the Quito Glacier during the summer and this drives the vegetation growth and other biological activities in the area[6-8]. Considering the unique environment

* Corresponding author (email: hii@umt.edu.my)

of Punta Fort William, this study aims to provide some baseline data on the soil nutrients during early summer.

2 Materials and methods

2.1 Sampling

Soil samples were collected during the XII INAE Ecuadorian expedition (Institute of Antarctica). The expedition was conducted during early summer from 31 January 2008 to 17 February 2008. Twenty sampling points were established along two transects (Figure 1) on the Punta Fort William headland. Transect 1 was established along Culebra Brook, flowing from the Quito Glacier to Discovery Bay (Chile Bay). Transect 2 was established from Orion Point down to Escua Creek, crossing Transect 1. Transect 1 was generally wet and affected by the glacier melt water, while transect 2 was drier expect for the middle section. There were intensive bird activities towards the end of transect 2. The positions of the sampling points are listed in Table 1. Five soil samples were collected from the top 15 cm of each sampling point. Rocks and pebbles were excluded from the sample. The soil samples were then pooled, mixed thoroughly and sieved to 2 mm before being sealed in sample bags (Whirlpack). The samples were labeled and stored at 0℃ before being shipped to the laboratory. The soil samples were stored at −20℃ in the laboratory until further analysis.

The percentage cover of the mosses, lichens and higher plants was assessed every 100 meters along the transects using a 1 m quadrat. The percentage cover at each sampling point was recorded and a digital image was captured with a 8.0-megapixel digital camera (Canon, Ixus 860i) for reference. UTHSCSA Image tool software ver. 1.27[9] was used to measure the percentage cover. Activities of seabirds, penguins and seals in the area were observed but not quantitatively determined.

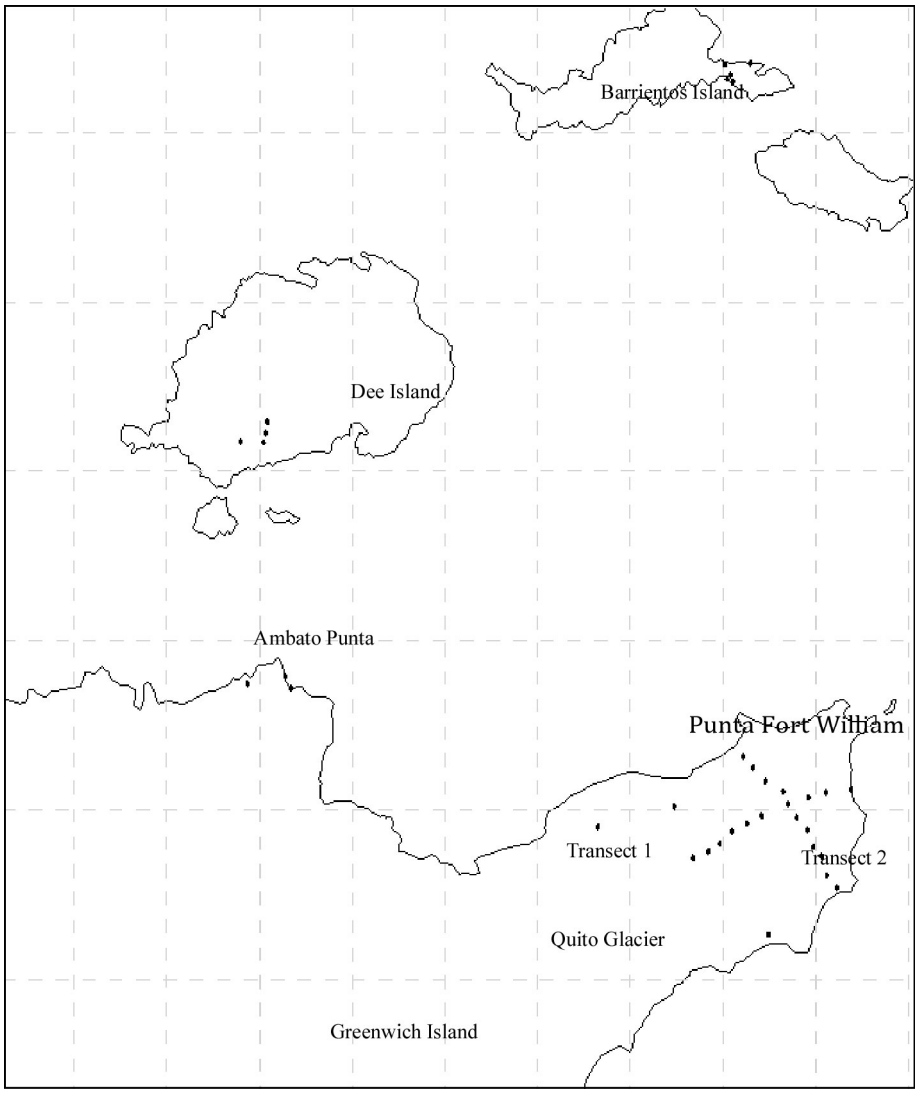

Figure 1 Study area and location of sampling points. Sampling points are indicated by black solid cycles. The dotted lines indicate the two transect lines.

Table 1 Locations and descriptions of the sampling points established in this study

	Station	Longitude	Latitude	Description
Transect 1: Greenwich Island	GiT1_0	62°26′55.6″S	59°43′34.3″W	Seaside
	GiT1_105	62°26′56.3″S	59°43′44.3″W	Barren, Lake side
	GiT1_205	62°26′50.8″S	59°43′50.8″W	Thick mosses
	GiT1_500	62°27′01.3″S	59°44′09.1″W	Thick mosses
	GiT1-600	62°27′07.2″S	59°44′25.3″W	Soil saturated with water
	GiT1-700	62°27′08.8″S	59°44′29.7″W	Soil saturated with water
	GiT1_800	62°27′10.1″S	59°44′35.6″W	Moist and covered by mosses
	GiT1_910	62°27′02.9″S	59°44′14.8″W	Barren land
	GiT1_972.5	62°27′04.5″S	59°44′20.6″W	Close to Quito glacier
Transect 2: Greenwich Island	GiT4_0	62°26′48.7″S	59°44′16.2″W	Sandy barren land
	GiT4_100	62°26′51.0″S	59°44′12.4″W	Sandy barren land
	GiT4_200	62°27′16.4″S	59°43′39.8″W	Sandy barren land
	GiT4_300	62°26′53.9″S	59°44′07.7″W	Barren, lake side
	GiT4_400	62°26′56.1″S	59°44′00.7″W	Near to ice
	GiT4_500	62°26′58.7″S	59°43′58.9″W	Soil saturated with water
	GiT4_600	62°27′01.6″S	59°43′55.4″W	Near to ice, hill slope
	GiT4_700	62°27′04.2″S	59°43′51.2″W	Hill, intensive bird nests
	GiT4_800	62°27′07.8″S	59°43′48.9″W	Rocky barren land
	GiT4_900	62°27′09.8″S	59°43′45.6″W	Hill, intensive bird nests
	GiT4_1000	62°27′13.9″S	59°43′43.8″W	Seaside
Punta Ambato	AMP_1	62°26′34.0″S	59°47′11.8″W	Rocky
	AMP-3	62°26′31.6″S	59°47′14.0″W	Rocky
	AMP-6	62°26′33.0″S	59°47′28.8″W	Thick mosses
Dee Island	DIT2-0	62°25′37.6″S	59°47′21.1″W	Rocky
	DIT2-140	62°25′39.9″S	59°47′21.7″W	Rocky
	DIT2-190	62°25′42.0″S	59°47′22.5″W	Rocky
Greenwich Island	GI-1	62°26′59.3″S	59°44′43.1″W	Close to glacier
	GI-4	62°27′03.6″S	59°45′12.6″W	*C. quitensis* found
	GI-8	62°27′26.4″S	59°44′06.5″W	Sandy barren land

2.2 General soil properties

Soil temperature was measured in-situ with a 5" thermometer probe (Hanna, Rhode Island, USA, HI45-01). Soil pH was determined based on a 1:1 soil:distilled water suspension. Soil moisture was determined in the laboratory using a moisture balance (Mettler Toledo, Ohio, USA, HB43-S) calibrated with a moisture balance reference substrate (Mettler Toledo, SmartCal). The particle size of the sieved (<2 mm) soil samples was determined based on the laser diffraction method as recommended by Malvern Master Sizer.

2.3 Total Organic Carbon

Total organic carbon (TOC) was analyzed based on the method in Simas et al.[10]. The soil sample was mixed and sieved to <500 μm to obtain a homogeneous sample. The TOC was determined using a solid sample module (SSM) incorporated into a TOC machine (Shimadzu TC5000). A standard curve was established between the area and organic carbon obtained from the TOC-SSM 5000A. Sodium bicarbonate and potassium hydrogen phthalate were used as inorganic carbon (IC) and total carbon (TC) standards, respectively. Strong correlations of $y = 0.490\ 7x$; $r^2 = 1$ and $y = 0.461\ 9x$; $r^2 = 1$ were obtained for TC and IC, respectively. Each sample was conducted in triplicate. TOC was obtained by the net difference between TC and IC.

2.4 Nitrogen fractions in soil

Soil nitrates (NO_3^-) and ammonium ions (NH_4^+) were determined according to the method of Maynard et al.[11] Briefly, 15 g of sieved (500 μm) sediment was extracted with 50 mL KCl (2 M) in an orbital shaker (250 rpm) for 1 h. The extracts were then centrifuged at 21 000×g for 15 min. The supernatant was poured into 60 mL Nalgene bottles for analysis. Ammonium-N was determined by the phenate method, while nitrate-N was determined by the

cadmium reduction and diazotization method.

Total N in soil was determined by the Kjeldahl method[12]. To measure total soil N, 1 g of sieved (500 μm) air-dried soil was weighed and added into a 50 mL Kjeldahl flask. Then 0.5 g of Hibbert's salt mixture (K_2SO_4:$FeSO_4$:$CuSO_4$; 10:1:5) was added. The soil was moistened with distilled water and 5 mL of concentrated 98% H_2SO_4 was then added. The mixture was digested for ~2 h. Upon cooling, 30 mL of distilled water was added. The digest was transferred and made up to 100 mL. Then 10 mL of the digest was pipetted into the distillation apparatus, and 10 mL of 40% NaOH was added and it was distilled and collected in 10 mL of boric acid-indicator solution. The distillate was titrated with 0.01 N H_2SO_4 until the color changed from green to purple. Each analysis was conducted in triplicate and a blank sample was used to correct the result. A recovery test was conducted on total N analysis of L-glutamic acid. A good recovery of 99.5% was obtained from the recovery test.

2.5 Phosphorous fractions in soil

Soil P fractions were analyzed using the five-step sequential extraction described by Kuo[13]. The first P fraction is the extractable and loosely bound P extracted using 1 M NH_4Cl. The second fraction is the $Al(OH)_3$ surface bound fraction extracted using 0.5 M NH_4F. The third fraction is the $Fe(OH)_2$ surface bound fraction extracted using 0.1 M NaOH. The fourth fraction is occluded P extracted using 0.3 M $Na_3C_3H_6O_7$+1 M $NaHCO_3$+$Na_2S_2O_4$. The last fraction is the Ca-bound mineral P fraction extracted using 0.25 M H_2SO_4. Two organic P fractions, microbial P and labile organic P were analyzed following the procedures of Zhang and Kovar[14]. Total labile P was determined using 0.5 M $NaHCO_3$+$K_2S_2O_8$. Total labile P+$CHCl_3$ was determined using 2 mL $CHCl_3$+0.5 M $NaHCO_3$+$K_2S_2O_8$. Labile inorganic P was determined using 0.5 M $NaHCO_3$ only. Microbial P was determined by subtracting total labile P + $CHCl_3$ P with total labile P. Total labile organic P was obtained by subtracting labile inorganic P with total labile P. The extracts were filtered through a 0.2 mm membrane and P concentrations were determined colorimetrically at 882 nm based on the modified ascorbic acid procedure described by Rodriguez et al.[15]

3 Statistical analysis

One-way ANOVAs with post-hoc tests were conducted to verify the differences in nutrient contents at all sampling points. Tukey analysis was conducted to verify where the differences were in all the physico-chemical data including TOC, soil ammonia (NH_4^+-N), soil nitrate (NO_3^--N), total Kjeldahl N (TKN), extractable P, aluminum-bound P, iron-bound P, occluded P, calcium-bound P, microbial P, labile organic P, percentage of silt content and soil pH. Missing data were then removed and the variable was rescaled for comparability. The sum of squares by number of clusters extracted was plotted and used to determine the appropriate number of clusters. Ward's method of hierarchical agglomerative clustering was used to group the sampling points based on their physio-chemical properties. Pearson's correlation was conducted to determine the relationship among the parameters to the flora cover. All the statistical analyses were conducted by using R statistic version 2.15.1 GUI 1.52.

4 Results and discussion

Punta Fort William is low in terms of biotic coverage compared with other areas on King George Island and other islands within the maritime Antarctic[7,16-17]. The flora cover in the area, predominantly consisting of mosses and lichens, is low, ranging from 0.4% to 51%. A higher coverage of mosses and lichen was found in the areas with higher bird activities. The flora distribution is highly patchy and varies from point to point. Table 2 lists the general soil properties of the study area. The study area predominantly consisted of rocks and pebbles and sand, and finer particles are generally <5%. Santana and Dumont reported the presence of emerged pebble beach ridges in the study area[18]. There was no clay-size particle fraction found in the soil samples collected from the study area. The soil temperature measured during the fieldwork ranged from 1.9℃to 14.6℃, although the data may not represent the norm, it does reflect the high temperature fluctuation in the field. The moisture content of the soil, especially those samples collected after a drizzle or those closer to melting ice, rivers and lakes, should have higher moisture contents but owing to the coarse particles in the area, water retention is very minimal.

Tables 3 and 4 show the nutrient contents of the study area. In general, the level of nutrients in the soil is high compared with other reports in the continental Antarctic[19-22], but comparable to those reported in the maritime Antarctic[23]. The level of ammonia and extractable P is high compared with most reports from the Antarctic. Analysis of nitrite contents in the soil was attempted, but it was too low to contribute to the N contents of the soil. The soil C and N are locked in organic forms while the soil P is mainly in the inorganic Ca-bound fraction in the study area (Table 4). Phosphorus in this form (Ca-bound) is not directly available to organisms. The dominant Ca-bound fractions indicate minimal weathering of P bearing source rocks such as apatite and basalt. Similar trends have been reported in other extreme environments such as the Antarctic valleys[24] and hot deserts[25]. The average amount of extractable P in the study area was higher than those reported from cold deserts[24,26]. This is probably because of the geographical location of the study area. Extractable P, which is readily available to organisms, was low in the study area as in other maritime Antarctic areas. The average concentrations of extractable P in the soil of Punta Ambato, Dee Island and Greenwich Island, were 3.34, 17.96 and 19.94 $mg \cdot kg^{-1}$, respectively. The level of labile organic P and microbial associated P was much lower than the inorganic

fraction and the distribution showed a very patchy trend. On average, the levels of microbial-associated P and labile organic P were 5.91 mg·kg^{-1} and 13.6 mg·kg^{-1}, respectively in the study area.

Table 2 Basic characteristics of the soil samples in the study area. Particles >2 mm were disregarded

Station	Temperature/℃	pH	Moisture/%	Flora coverage/%	Sand/%	Silt/%
GiT1_0	13.6	6.19	5.70	bdl	92.6	7.4
GiT1_105	8.2	5.74	19.8	0.60	92.3	7.7
GiT1_205	10.4	5.77	6.80	51.2	84.8	15.2
GiT1_500	12.5	5.74	10.4	49.0	95.2	4.8
GiT1-600	8.9	5.66	17.2	0.60	97.9	2.1
GiT1-700	5.7	7.12	15.1	bdl	64.4	35.6
GiT1_800	14.6	6.14	9.70	18.2	78.0	22.0
GiT1_910	8.8	6.30	18.8	bdl	82.7	12.3
GiT1_972.5	6.2	6.55	19.2	bdl	93.7	6.3
GiT4_0	9.1	5.51	4.30	18.4	92.5	7.5
GiT4_100	6.2	5.71	5.30	bdl	97.5	2.5
GiT4_200	4.3	5.73	7.40	2.50	87.6	12.4
GiT4_300	7.3	6.66	22.2	2.40	92.2	7.8
GiT4_400	3.8	5.73	9.30	8.50	94.5	5.5
GiT4_500	7.3	5.47	4.40	33.0	99.9	0.1
GiT4_600	5.2	5.68	10.8	bdl	94.2	5.8
GiT4_700	4.1	5.66	15.1	11.5	88.8	11.2
GiT4_800	4.5	5.89	12.2	7.20	98.4	1.6
GiT4_900	5.0	6.10	10.1	27.5	85.0	15.0
GiT4_1000	5.3	6.19	5.70	bdl	93.9	6.1
AMP-1	6.2	5.75	-	57.0	90.8	9.2
AMP-3	5.0	5.41	-	-	96.4	3.6
AMP-6	4.1	5.20	23.0	45.0	83.7	16.3
DIT2-0	5.4	5.58	-	-	76.6	23.4
DIT2-140	9.3	5.72	10.3	bdl	93.0	7.0
DIT2-190	9.9	5.64	6.80	bdl	87.5	12.5
GI-1	1.9	5.51	14.3	-	70.6	29.4
GI-4	4.1	5.89	10.9	2	93.8	6.2
GI-8	9.5	5.73	13.4	bdl	93.7	6.3

Note: (-) indicates data not available, (bdl) indicates below detection limit.

Table 3 TOC, ammonia, nitrate and TK contents of the study area

Station	TOC/%	NH_4^+-N/(μg·g^{-1})	NO_3^--N/(μg·g^{-1})	TKN/%
GiT1_0	0.35±0.00	2.16±0.38	4.56±0.02×10^{-3}	0.029±0.001
GiT1_105	0.20±0.00	1.54±0.20	3.03±0.00×10^{-3}	0.030±0.003
GiT1_205	0.41±0.01	1.17±0.14	2.45±0.01×10^{-3}	0.014±0.000
GiT1_500	0.56±0.02	2.10±0.12	2.85±0.00×10^{-3}	0.025±0.001
GiT1-600	0.64±0.01	2.40±0.17	3.19±0.01×10^{-3}	0.021±0.001
GiT1-700	0.18±0.08	1.71±0.08	bdl	0.012±0.002
GiT1_800	0.42±0.09	1.80±0.17	2.38±0.01×10^{-3}	0.006±0.001
GiT1_910	0.11±0.00	1.31±0.09	bdl	0.046±0.001
GiT1_972.5	0.03±0.05	1.18±0.11	bdl	0.050±0.000
GiT4_0	1.00±0.11	2.34±0.11	5.42±0.03×10^{-3}	0.039±0.002
GiT4_100	0.54±0.02	2.57±0.04	2.06±0.01×10^{-3}	0.024±0.001

(To be continued on the next page)

(Continued)

GiT4_200	0.64±0.02	2.11±0.18	$3.33±0.03×10^{-3}$	0.006±0.001
GiT4_300	0.36±0.00	3.19±0.44	$3.04±0.02×10^{-3}$	0.034±0.002
GiT4_400	0.41±0.01	2.15±0.07	$3.05±0.04×10^{-3}$	0.017±0.002
GiT4_500	0.78±0.02	2.46±0.33	$3.28±0.01×10^{-3}$	0.048±0.001
GiT4_600	0.30±0.03	1.46±0.07	$2.66±0.04×10^{-3}$	0.015±0.001
GiT4_700	0.58±0.01	1.82±0.13	$4.10±0.02×10^{-3}$	0.027±0.001
GiT4_800	0.87±0.10	2.32±0.09	$5.02±0.05×10^{-3}$	-
GiT4_900	1.56±0.07	3.08±0.55	$5.54±0.02×10^{-3}$	0.054±0.001
GiT4_1000	0.74±0.02	1.61±0.28	$3.44±0.03×10^{-3}$	0.010±0.001
AMP-1	0.05±0.00	1.16±0.07	bdl	0.016±0.000
AMP-3	0.04±0.01	0.87±0.03	bdl	0.017±0.000
AMP-6	0.38±0.01	5.16±0.61	$0.34±0.00×10^{-3}$	0.033±0.001
DIT2-0	0.20±0.00	0.52±0.02	$0.18±0.00×10^{-3}$	0.014±0.001
DIT2-140	0.62±0.01	1.14±0.05	$0.21±0.00×10^{-3}$	0.019±0.000
DIT2-190	0.40±0.02	1.51±0.07	$0.19±0.00×10^{-3}$	0.014±0.001
GI-1	0.39±0.01	4.02±0.30	$0.28±0.00×10^{-3}$	0.023±0.002
GI-4	0.33±0.02	3.14±0.02	$0.21±0.00×10^{-3}$	0.017±0.001
GI-8	0.75±0.11	2.85±0.09	$0.19±0.00×10^{-3}$	0.007±0.000

Note: (-) indicates data not available while (bdl) indicates below detection limit. Values are mean±standard deviation on three replicates.

Table 4 Soil inorganic P, microbial associated P and labile organic P in the study area

	Extractable P /(mg·kg^{-1})	Al-Bound P /(mg·kg^{-1})	Fe-Bound P /(mg·kg^{-1})	Occluded P /(mg·kg^{-1})	Ca-Bound P /(mg·kg^{-1})	Microbial P /(mg·kg^{-1})	Labile organic P /(mg·kg^{-1})
GiT1_0	26.44±7.51	45.69±1.94	106.09±1.08	1.96±0.80	8.63±4.75	13.63±2.35	22.45±1.21
GiT1_105	0.73±0.00	114.72±8.57	105.93±13.27	11.00±5.50	285.53±2.33	1.20±0.58	10.2±0.35
GiT1_205	1.01±1.16	134.62±1.65	215.32±2.25	19.56±9.26	293.80±6.92	bdl	12.26±0.53
GiT1_500	0.96±0.16	193.98±2.98	223.86±2.52	23.56±3.30	261.04±30.32	4.35±1.13	13.14±2.31
GiT1-600	1.25±0.18	261.55±4.99	322.06±6.96	16.1±10.19	283.48±4.86	10.81±0.21	14.84±1.20
GiT1-700	29.17±9.72	38.37±0.25	33.23±0.76	26.58±9.72	19.96±11.35	bdl	9.91±3.45
GiT1_800	87.16±62.26	84.28±0.78	113.29±2.24	36.26±1.56	11.62±10.17	0.38±0.13	7.25±3.47
GiT1_910	75.06±50.72	44.22±2.50	75.26±2.36	61.24±41.86	7.77±1.06	8.11±3.65	11.04±5.73
GiT1_972.5	0.85±0.00	33.52±1.57	34.94±7.68	33.81±3.40	320.90±9.38	bdl	bdl
GiT4_0	3.11±0.31	146.04±1.51	152.62±19.53	17.35±0.40	410.93±5.13	3.81±0.68	15.82±1.00
GiT4_100	14.64±0.00	100.27±1.34	106.83±2.60	2.77±0.48	3.20±1.76	bdl	19.76±0.49
GiT4_200	0.54±0.11	121.32±0.90	174.47±5.86	22.29±1.50	302.73±11.18	bdl	14.94±6.81
GiT4_300	33.95±13.58	54.81±1.00	103.23±1.32	0.88±0.57	6.99±4.28	0.7±0.02	15.44±4.82
GiT4_400	46.58±24.40	61.83±0.34	122.61±1.50	2.21±0.18	7.48±9.51	1.6±0.33	19.99±0.48
GiT4_500	1.38±0.00	122.54±0.21	204.15±3.65	17.2±2.67	310.78±1.73	bdl	11.75±0.07
GiT4_600	24.81±6.43	66.36±0.44	143.14±4.58	1.58±0.88	5.73±3.15	5.11±0.61	17.17±1.85
GiT4_700	1.13±0.06	167.46±2.23	241.65±0.37	14.48±3.37	275.55±4.66	1.57±0.23	11.23±0.49
GiT4_800	0.61±0.12	221.99±1.19	224.72±3.01	15.4±8.61	284.99±3.27	6.82±0.70	14.15±0.29
GiT4_900	0.68±0.12	241.26±3.61	217.96±9.81	4.17±0.66	267.82±3.28	6.35±0.70	18.55±0.41
GiT4_1000	26.26±7.50	28.35±0.47	89.72±0.94	30.51±10.28	3.75±1.55	bdl	25.93±0.46
AMP-1	1.96±0.16	54.72±3.69	82.15±12.90	15.65±1.71	330.21±6.86	16.72±3.29	14.7±0.15
AMP-3	3.56±0.12	49.79±1.83	65.98±9.15	9.67±0.29	343.49±7.22	3.06±0.68	11.09±0.31
AMP-6	4.49±0.21	101.07±3.36	118.1±3.52	17.82±2.37	330.20±4.29	3.67±1.50	5.8±1.35
DIT2-0	29.14±9.71	20.02±0.45	1.59±0.36	24.24±6.23	7.28±9.41	bdl	12.01±0.59
DIT2-140	0.97±0.19	102.47±2.12	118.82±8.44	9.61±4.20	237.39±9.13	bdl	14.57±0.90
DIT2-190	40.44±19.03	60.32±14.31	86.48±1.54	1.28±0.08	16.63±3.64	bdl	11.53±0.33
GI-1	4.65±0.09	127.46±0.38	138.23±0.84	14.76±0.30	363.41±7.37	bdl	2.27±0.84
GI-4	74.29±60.88	138.26±1.32	122.45±1.29	16.9±0.18	424.48±18.41	1.98±0.19	5.86±0.33
GI-8	3.38±0.10	134.67±3.72	114.4±2.56	15.15±0.23	389.38±12.65	8.31±0.52	18.75±0.19

Note: (bdl) indicates below detection limit. Values are mean±standard deviation on three replicates.

Ward's method of hierarchical agglomerative clustering was used to group the soil samples based on their physico-chemical parameters including TOC, soil ammonia (NH_4^+-N), soil nitrate (NO_3^--N), TKN, extractable P, aluminum-bound P, iron-bound P, occluded P, calcium-bound P, microbial P, labile organic P, percentage of silt content and soil pH. Based on the plot of the within group sum of squares by the number of cluster extracted, the soil samples from the Punta Fort William area can be grouped into three clusters. Figure 2 shows the hierarchical agglomerative clusters. The first cluster (AMP-6, GiT4_900, GiT4_0, GI-8, GiT1-600, GiT1_205, GiT1_500 and GiT4_700) is sampling points with higher flora cover and close to bird nesting. The second cluster (GiT1_900, GiT1_800 and GI-4) is sampling points located on newly exposed ground previously covered by the Quito Glacier. The third cluster (AMP-1, GiT1_105, AMP-3, GiT4_400, GiT4_600, GiT1_0, GiT4_300) is sampling points on raised ridges, which are mainly drier and on mainly barren ground with low biological activities. Nevertheless, there is no positive Pearson correlation between the percentage of flora cover and the nutrients analyzed in this study.

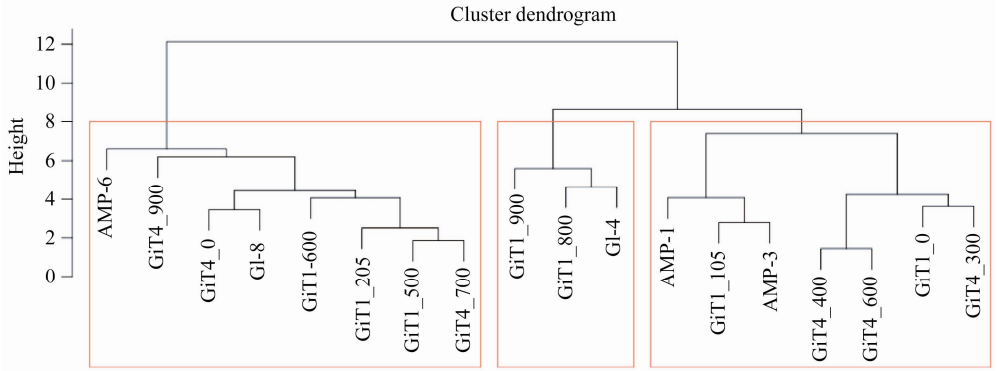

Figure 2 Hierarchical agglomerative clustering by Ward's method. The red borders on the dendrogram indicate the samples clusters.

Punta Fort William presents an interesting area where a small headland is packed with emerged pebble beach ridges. The melt water from the Quito Glacier has driven moss growth in the area. The nutrient content of the area is slightly higher than those reported from the continental Antarctic. Further research is needed to understand the nutrient cycles and dynamics in the maritime Antarctic as well as the biotic-abiotic interactions in the ecosystem[17]. Without a vast database of soil nutrients, future changes in the terrestrial environment are unlikely to be accurately predicted.

Acknowledgements The authors would like to thank the Malaysian Antarctic Research Program (MARP), Ministry of Higher Education (MoHE), Malaysia and Instituto Antartico Ecuatoriano (INAE) for sponsoring the study.

References

1 Jacobs S S, Gordon A L, Amos A F. Effect of glacial ice melting on the Antarctic surface water. Nature, 1979, 277: 469-471.
2 Barett J E, Virgina R A, Lyons W B, et al. Biogeochemistry stoichiometry of Antarctic dry valley ecosystems. Journal of Geophysical Research, 2007, 12: G01010, doi: 10.1029/2005JG000141.
3 Ligeza S, Smal H. Accumulation of nutrients in soils affected by perennial colonies of piscivorous birds with reference to biogeochemical cycles of elements. Chemosphere, 2003, 52(3): 595-602, doi: 10.1016/S0045-6535(03)00241-8.
4 Magalhães C, Stevens M I, Cary S C, et al. At limits of life: multidisciplinary insights reveal environmental constraints on biotic diversity in continental Antarctica. PLoS ONE, 2012, 7(9): e44578, doi: 10.371/journal.pone.0044578.
5 Hopkins D W, Sparrow A D, Elberling B, et al. Carbon, nitrogen and temperature controls on microbial activity in soils from an Antarctic dry valley. Soil Biology and Biochemistry, 2006, 38(10): 3130–3140, doi: 10.1016/j.soilbio.2006.01.012.
6 Treiber de E B, Arcos F. Cianobacterias en sustratos terrestres de Punta Fort William, Isla Greenwich, Shetland del sur, Antártida. Acta Antartica Ecuatoriana, 1993, 3(1): 55-58.
7 Hii Y S, Alias S A, Hussin A, et al. Surface coverage and some soil chemicals properties at Punta Fort William, Greenwich Island, Antarctica. ASM Science Journal, 2009, 3(2): 143-152.
8 Ordoóñez N, Hii Y S, Alias S A, et al. Estudio preliminar de la cobertura superficial en la Isla Greenwich, Antártida. Revista Tecnologica ESPOL, 2008, 21(1) : 17-21.
9 Wilcox C D, Dove S B, Doss-McDavid W, et al. UTHSCSA ImageTool Ver. 1.27. San Antonio: University of Texas Health Science Center, 1997.
10 Simas F N B, Schaefer C E G R, Mendonça E S, et al. Organic carbon stocks in permafrost-affected soils from Admiralty Bay, Antarctica// Antarctica: A Keystone in a Changing World–Online Proceedings of the 10th International Symposium on Antarctic Earth Sciences, USGS Open-File Report 2007-1047, Short Research Paper 076, 2007.
11 Maynard D G, Kalra Y P, Crumbaugh J A. Nitrate and exchangeable ammonium nitrogen//Carter M R, Gregorich E G. Soil sampling and methods of analysis. 2nd edn. Ottawa: Canadian Society of Soil Science, 2007: 71-80.
12 Rutherford P M, McGill W B, Arocena J M, et al. Total nitrogen//Carter M R, Gregorich E G. Soil sampling and methods of analysis. 2nd edn. Ottawa: Canadian Society of Soil Science, 2007: 239-250.
13 Kuo S. Phosphorus//Sparks D L, Page A L, Helmke P A, et al. Methods of soil analysis. Part 3. Chemical Methods. Madison: American Society of Agronomy-Soil Science Society of America, 1996: 869-919.
14 Zhang H, Kovar J L. Phosphorus fractionation// Pierzynski G M. Methods of phosphorus analysis for soils, sediments, residuals, and waters. Southern Coop. Series Bull. #396. Raleigh: North Carolina State University, 2000: 50-59.
15 Rodriguez J B, Self J R, Soltanpour P N. Optimal conditions for phos-

phorus analysis by the ascorbic acid-molybdenum blue method. Soil Science Society of American Journal, 1994, 58: 866-870, doi: 10.2136/sssaj1994.03615995005800030034x.

16 Peat H J, Clarke A, Convey P. Diversity and biogeography of the Antarctic flora. Journal of Biogeography, 2007, 34: 132-146, doi: 10.1111/j.1365-2699.2006.01565.x.

17 Bölter M. Soil development and soil biology on King George Island, Maritime Antarctic. Polish Polar Research, 2011, 32(2): 105-116, doi: 10.2478/v10183-011-0002-z.

18 Santana E, Dumont J F. Granulometry of pebble beach ridges in Fort William Point, Greenwich Island, Antarcitic Peninsular; a possible result from Holocene climate fluctuations// Antarctica: A keystone in changing world-Online proceeding of the 10th ISAES. USGS Open File Report 2007-1047, Short Research Paper 027, 2007, doi:10.3133/of2007-1047.srp027.

19 Elberling B, Gregorich E G, Hopkins D W, et al. Distribution and dynamics of soil organic matter in an Antarctic dry valley. Soil Biology & Biochemistry, 2006, 38 (10): 3095-3106, doi: 10.1016/j.soilbio.2005.12.011.

20 Strauss S L, Christopher T R, Day T A. Trends in soil characteristics along a recently deglaciated foreland on Anvers Island, Antarctic Peninsula. Polar Biology, 2009, 32 (12): 1779-1788, doi: 10.1007/s00300-009-0677-3.

21 Barrett J E, Virginia R A, Hopkins D W, et al. Terrestrial ecosystem processes of Victoria Land, Antarctica. Soil Biology & Biochemistry, 2006, 38(10): 3019-3034, doi: 0.1016/j.soilbio.2006.04.041.

22 Engelen A, Convey P, Hodgson D A, et al. Soil properties of an Antarctic inland site: Implications for ecosystem development. Polar Biology, 2008, 31(12): 1453-1460, doi: 10.1007/s00300-008-0486-0.

23 Navas A, López-Martínez J, Casas J, et al. 2008. Soil characteristics on varying lithological substrates in the South Shetland Island, Maritime Antarctica. Geoderma, 2008, 144(1-2): 123-139, doi: 10.1016/j.geoderma.2007.10.011.

24 Blecker S W, Ippolitoa J A, Barrett J E, et al. Phosphorus fractions in soils of Taylor Valley, Antarctica. Soil Science Society of American Journal, 2006, 70 (3): 806-815, doi: 10.2136/sssaj2005.0333.

25 Lajtha K, Schlesinger W H. The biogeochemistry of phosphorous cycling and phosphorous availability along a desert soil chrono-sequence. Ecology, 1988, 69: 24-39.

26 Bate D B, Barrett J E, Poage M A, et al. Soil phosphorus cycling in an Antarctic polar desert. Geoderma, 2008, 144(1-2): 21-31, doi: 10.1016/j.geoderma.2007.10.007.