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Ross Island recreational walking tracks: relationships between soil physiochemical properties and track usage

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ABSTRACT. The objective of this research was to determine the number of people using the Ross Island recreational walking tracks, and to examine the relationships between the number of users, track morphological characteristics, and soil physiochemical properties. Infrared track counters provided 2-years of data on five walking tracks on the island. Track width and track incision were measured and soil sampling in the vicinity of the track counter and an adjacent control site was undertaken. Between January 2009 and January 2011 5084 passes were recorded on the Scott Base to McMurdo Station walking track, 2842 on the Wind Vane Hill walking track, 3561 on the Round Observation Hill walking track, 10936 on the Up Observation Hill track, and 693 on the Crater Hill summit walking track. There were more users on all tracks in the 2010–2011 summer season than the 2009–2010 summer season. The highest frequency of visitors occurred on Sundays during the summer (November to January). There was no relationship between the number of passes on the track and the measured impact indicators. This indicates that higher usage of a formed track had little cumulative impact. Track width and incision were related to the slope of the terrain, with tracks traversing flatter areas generally wider ($R^2 = 0.85$) and less incised ($R^2 = 0.96$), than those traversing steeper hillsides. There were no significant differences between tracks and control samples in soil pH, soil EC, organic C, total N, and total P. However, soil bulk density was higher in the walking tracks than adjacent control areas ($p < 0.05$).

Introduction

Walking tracks are a fundamental part of recreation zones in wilderness areas, providing recreation opportunities, access, as well as resource protection by concentrating visitor flow (Hill and Pickering 2009), controlling erosion, and limiting damage to flora, fauna, and places of heritage and cultural importance. A walking 'track', as herein defined, is an area of continuous bare-ground which forms a pathway and which is formed by foot traffic. The term 'track', as used in this study, is analogous to the use of 'trail' in others. In environmentally sensitive areas, such as Antarctica, the balance between maintaining inherent ecological qualities and allowing the public to enjoy these qualities through recreational activity is delicate.

Science and tourism in Antarctica have seasonal visitation patterns with a sudden influx over the austral summer. The most popular sites, such as Deception Island and Half Moon Island adjacent to the Antarctic Peninsula, have up to 20,000 visitors over the summer season (IAATO 2011). In the Ross Sea region, although visitor numbers are fewer and the visitor season is shorter (between November and February) each year there are increasing visitor numbers. Scott's Terra Nova Hut at Cape Evans for example, is visited by approximately 1100 people annually (J. Newman, personal communication, 3 May 2012). About 70% of visitors to Cape Evans are United States Antarctic Programme (USAP) and New Zealand Antarctic Programme (NZAP) personnel, the remainder are ship-based tourists.

The study of impacts from recreational use of environmentally sensitive or protected areas is referred to as recreation ecology (Liddle 1997; Hammitt and Cole 1998; Leung and Marion 2000; Newsome and others 2002). Early recreation ecology research focussed on describing readily observable impacts of hiking and camping, particularly on soil and vegetation loss and change. Globally, common impacts from walking track use include:

Soil: compaction, loss of organic matter, loss of soil, reduction in moisture and microbial activity;
Vegetation: reduced height, loss of ground cover, loss of fragile species, increase in resistant species and introduction of non-native species, exposed roots;
Wildlife: habitat alteration, habitat loss, introduction of non-native species, modification of behaviour, reduced reproduction;
Track erosion (track deepening) resulting in rutted tracks, conduits for water and soil transport, thereby accelerating soil erosion;
Track widening: common when users spread laterally to avoid wet, muddy, or icy areas; and
Proliferation of unplanned or subsidiary walking tracks to access lookout points or take shortcuts.

Impacts are affected by season, rainfall, and topography, such as slope and aspect (Hill and Pickering 2009).

Few studies into the impacts of recreational walking tracks and camping on the terrestrial environment have been conducted in Antarctic and sub-Antarctic

environments. Scott and Kirkpatrick (1994) investigated the effects of human trampling on the sub-Antarctic vegetation on Macquarie Island; and Gremmen and others (2003) noted trampling impacts on plants on sub-Antarctic Marion Island. Impacts varied according to vegetation and soil types, but impacts in both studies included track widening and soil compaction. Ayres and others (2008) investigated the impacts to soil fauna (nematodes) in the Taylor Valley of the McMurdo Dry Valleys under low, intermediate, and high levels of human foot traffic. Ayres and others (2008) noted decreased abundances of the dominant nematode in heavily used walking tracks, compared with tracks experiencing lower levels of use. Trampling on vegetation-free soils in the South Shetland Islands in the Antarctic Peninsula led to increases in soil compaction and decreases in the abundance of soil arthropods (Tejedo and others 2005, 2009). Campbell and others (1998a) measured the rate at which tracks formed at three sites in the Ross Sea region by walking along a set route a set number of times, and observing changes in the nature of the surface. A clear walking track formed in as few as 20 passes on soft fine-textured materials and impacts were non-linear, with most impacts occurring in the initial stages of the trampling experiment (Campbell and others 1998a).

The Ross Sea region of Antarctica offers a range of outstanding natural features. The recreational walking tracks on the ice-free southern tip of Hut Point Peninsula, and the walking track to a lookout over Scott's Terra Nova Hut at Cape Evans, are popular with visitors to Ross Island. Personnel working in the vicinity of Scott Base and McMurdo Station are able to access the nearby walking tracks for recreation. Use is promoted by way of information booklets for users of the Round Observation Hill and Up Observation Hill walking tracks. The booklets provide information on the geology and the views on the track. The Ross Island walking tracks are visible in the landscape but, little is known about the effects of visitor use on soil physiochemical characteristics.

The objectives of this study were to determine the number of people using the Ross Island recreational walking tracks, and the relationship between the number of track users, track morphology, and soil physiochemical properties.

Study area

Environmental setting and history

Ross Island is dominated by basaltic volcanoes (Mounts Erebus, Bird and Terror) with the foot-slopes near the coasts comprised of lava fields and scoria cones. The study investigated five walking tracks at two localities on Ross Island: four walking tracks around the Hut Point Peninsula (the Scott Base to McMurdo Station, Up Observation Hill, Round Observation Hill, and Crater Hill summit, walking tracks), and one walking track on Wind Vane Hill, Cape Evans (Fig. 1). Cape Evans is a small, triangular-shaped ice-free area in the southwest of Ross Island, 10 km southeast of Cape Royds and 22 km northwest of Hut Point.

The five walking tracks occurred on gently undulating to steep volcanic lava flows, and were formed on weakly weathered (and comparatively young) scoriaceous basalt dominated till and scoriaceous basalt bedrock. Soils at each locality are classed as Typic Haplorthels (United States Department of Agriculture 2010) and contained ice-cemented permafrost. Soils were generally coarsely textured, loose, and alkaline with very low organic matter contents (Campbell and Claridge 1987; Balks and others 2002; Aislabie and others 2004). The surface deposits and soils were unweathered (weathering stage 1 of Campbell and Claridge 1975), and salt stage 1 (Bockheim 1997), indicative of their comparatively young age. The mean annual air temperature at the study localities was approximately −16°C (Adlam and others 2010); however during the continuous daylight of the summer months, air temperatures were within the range of −7°C to +10°C, and surface soil temperatures can reach 20°C (Balks and others 2002). Ross Island soils have a subxerous moisture regime (wet for short periods during snow thaw) and are subject to moderate snowfalls (an average of seven snow fall events per month during summer (Campbell and others 1998b). Wind activity is a driver of surface processes but, in late spring and summer, liquid meltwater occurs which facilitates a range of weathering, leaching, erosion, and freeze-thaw processes.

Occupation of Hut Point Peninsula began in 1902 with the arrival of Scott's *Discovery* expedition (Headland 2009). The ice-free southern tip of the Hut Point Peninsula is occupied by New Zealand's Scott Base (1957) and the USA's McMurdo Station (1956). Permanent and continuous occupation of the area has occurred since the late 1950s (Kennicutt II and others 2010). Antarctica's largest station, McMurdo Station, has a winter population of about 200 and has a capacity for 1,100 people in summer (COMNAP 2012). Scott Base has a winter population of about 10, and can accommodate about 85 people in the summer (Waterhouse 2001).

Visitor attractions

Observation Hill is a topographic high between McMurdo Station and Scott Base (Figs. 1, 2a). The first ascents of Observation Hill occurred about 1902 by members of Scott's *Discovery* expedition. Scott's team's daily ascent of Observation Hill as they waited for their leader to return from the South Pole in 1912 would have initiated the development of the present day 'Up Observation Hill' walking track.

Cape Evans is the site of Scott's *Terra Nova* Hut (1911); the largest of the historic huts. The first ascent of Wind Vane Hill is likely to have occurred during Scott's first visit to Cape Evans around 1902 (Fig. 2c). Nowadays the Wind Vane Hill track is used by tourists visiting Scott's *Terra Nova* Hut, and staff of USAP and NZAP. The walk between Terra Nova hut and the Wind Vane Hill

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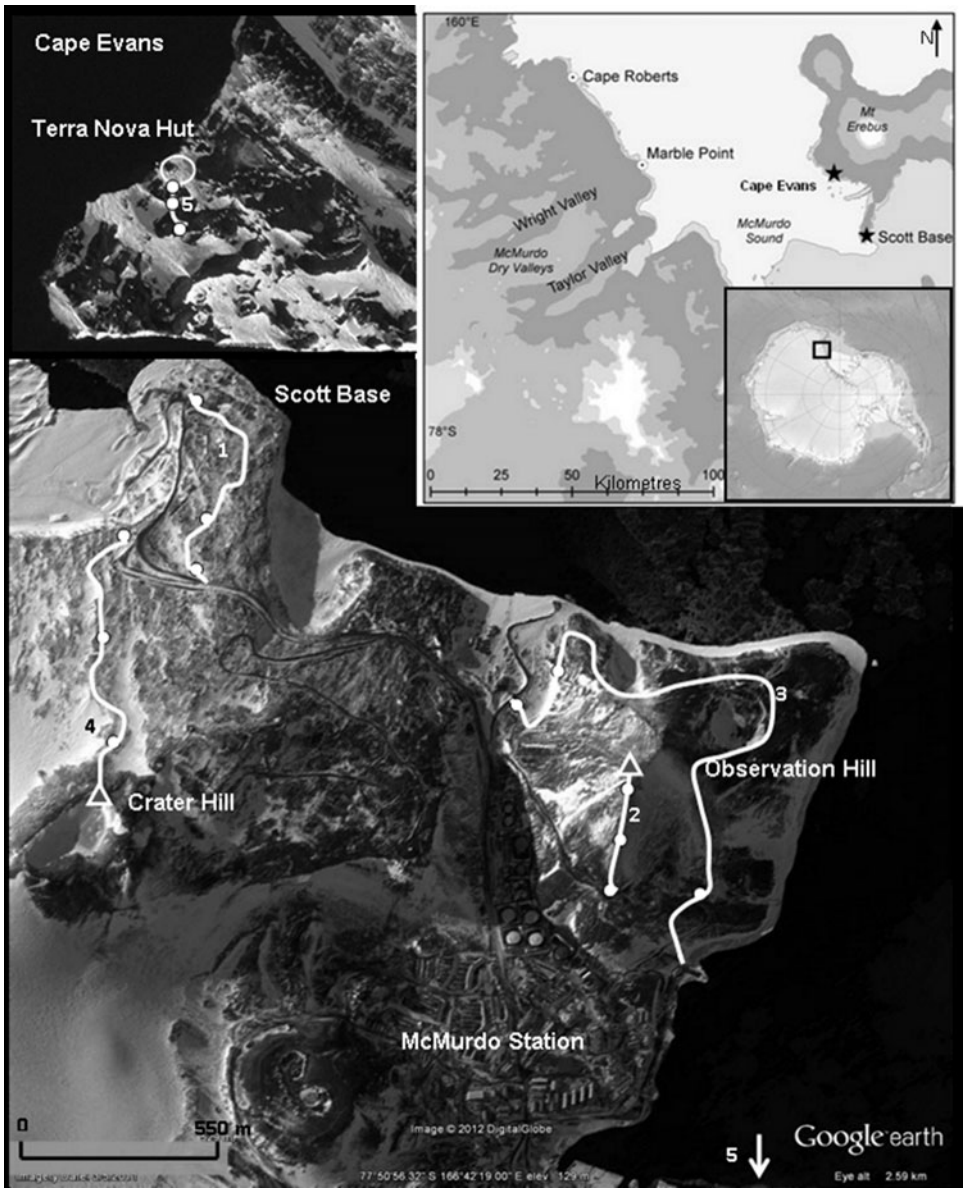

Fig. 1. Map showing the location of the Ross Island recreational walking tracks. 1 = Scott Base to McMurdo Station walking track; 2 = Up Observation Hill walking track; 3 = Round Observation Hill walking track; 4 = Crater Hill summit walking track; 5 = Wind Vane Hill walking track, 22 km north at Cape Evans. White dots mark the approximate location of the sampling sites. Image modified from Google Earth.

lookout takes approximately 5 minutes (approximately 100 m in length).

Walking routes around Observation Hill (Fig. 2a,b), and the short-cut walking track between Scott Base and the road to McMurdo Station (Fig. 2d), are likely to have been first walked in the late 1950s during construction of Scott Base and McMurdo Station. An effort was made in the late 1990s-early 2000s to formalise the Scott Base to McMurdo Station walking track to keep people to one route. Large stones were cleared off the track and repositioned along the track margins to make a clearly defined walking track. Prior to that the whole area between Scott Base and the vehicle road to McMurdo Station was trampled, and multiple branches of informal tracks had formed. The route between Scott Base and the road to McMurdo Station takes approximately 10 minutes (approximately 1 km).

The Round Observation Hill walking track was opened officially on 27 December 2006. Prior to 2006 there were several informal tracks around Observation Hill. An identifiable track was cleared with flagged cairns installed at locations where additional markers were required (J. Heil, personal communication, 3 May 2012). The Up Observation Hill walk takes between

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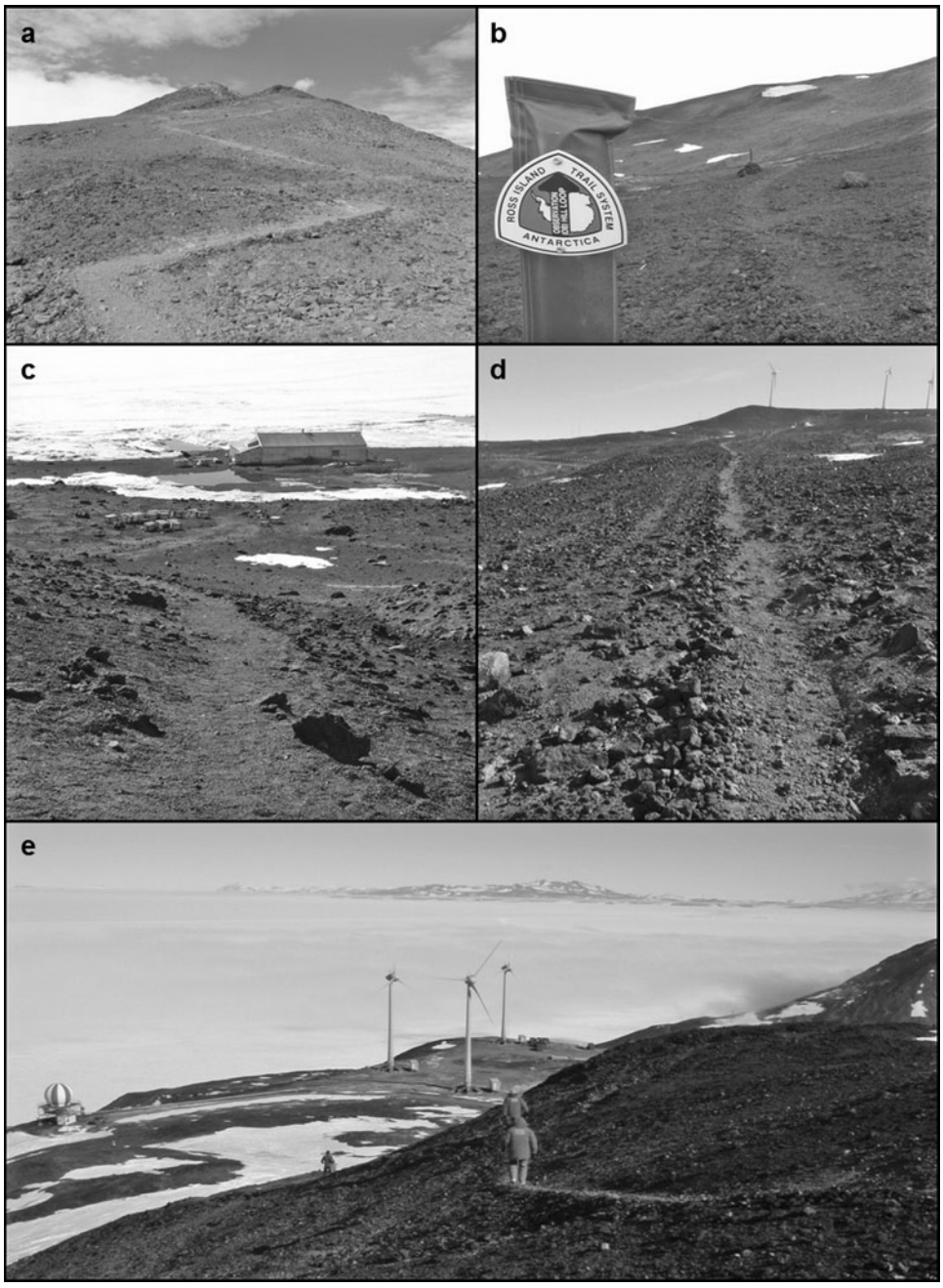

Fig. 2. Walking tracks in this study. (a) Up Observation Hill; (b) Round Observation Hill; (c) Wind Vane Hill, Cape Evans; (d) Scott Base to McMurdo Station road; (e) Crater Hill summit walking track.

40–60 minutes return (approx. 1 km); and the Round Observation Hill loop walk 90–120 minutes return (approximately 4 km).

The Crater Hill summit route (Fig. 2e) had been walked for a number of decades however in the summer of 2007–2008 the route was formalised using marker flags from Scott Base to the summit of Crater Hill (J. Newman, personal communication, 3 May 2012). The Crater Hill track is regularly walked by NZAP participants and takes 60–90 minutes return (approx. 4 km).

Materials and methods

Infrared track counters

Infrared track counters (TRAFx, Canmore, Canada) were deployed to monitor visitor use over a two year period between the summers of 2008–2009 and 2009–2010. The monitor registers a pass-by event (that is a walker passing regardless of direction of travel) when the scope detects the warm moving object, the visitor count is recorded on the memory unit. Each pass-by event was date and time stamped accurate to a minute.

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Table 1. Location of Ross Island track counters and general characteristics of the track counter site

Track counter	GPS location	Elev (m)	Slope	Aspect	Dates of record
Hut Point Peninsula					
1. Scott Base-McMurdo	77°50'50.6"S, 166°44'52.0"E	77	3°	N	6.1.2009 – 31.1.2011
2. Up Observation Hill	77 51 04.5"S, 166°41'24.6"E	161	20°	SW	6.1.2009 – 31.1.2011
3. Round Observation Hill	77°51'07.7"S, 166°42'19.0"E	72	2°	NNE	7.1.2009 – 31.1.2011
4. Crater Hill Summit	77°50'38.7"S, 166°45'14.3"E	144	10°	NE	12.1.2009 - 15.1.2010
Cape Evans					
5. Wind Vane Hill	77°38'13.1"S, 166°25'09.3"E	15	15°	E	9.1.2009 – 31.1.2011

Track counters were installed in the first week of January 2009 at five walking tracks on Ross Island (Table 1). Track counters were hidden amongst mounds of rock material to prevent interference by track users. Care was taken to minimise counting errors by positioning the counters in areas out of direct sun strike, heavy snow accumulation, and at locations on the tracks where users were forced to walk in single-file. Counters were placed 1–3 m back from the track (well within the maximum detection distance of 6 m). A 1.5-second delay between counts was configured to attempt to ensure a single user could not be counted more than once. We therefore consider our results as best estimates of minimum counts. Data from the track counters were uploaded directly in the field onto a laptop via the TRAFx G3 Dock (TRAFx, Canmore, Canada), then imported into Microsoft Excel using the add-on TRAFx Reporter v7.1.

Track counters were calibrated by a series of tests and via direct observation in the field on two separate occasions in December 2009 and January 2010. Direct observations were recorded over an hour on a weekend day at each of the track counter locations (except at the Wind Vane Hill track due to inaccessibility) to check the accuracy of the automated visitor count. The calibration exercise was repeated approximately 6 weeks later. Visitor counts matched with direct observations on both occasions. In this paper we report the track counter data as the number of passes on the track that is the number of counts, as our focus is the impacts which are a function of the number of passes along a track, and irrespective of the actual number of users.

Track survey

Impact indicators

A survey was undertaken at three representative locations along each track. At each location the extent and severity of selected impact indicators were assessed. Evidence of track incision and track widening were measured and recorded in year one and year two to assess cumulative impacts from track use. Track incision was measured as the current incision below the original surface (that is the mean distance measured along a perpendicular transect of the walking track, including incision measurements of the middle and sides of the track). As the study area is free of macro-vegetation track width was defined as the area visibly affected by trampling (track incision), and with a visible colour difference between the track and surrounding undisturbed material.

Track width, incision, and slope, were measured at three sites on each of the five walking tracks. One site was situated at the lower, less steep, and often less confined part of the track. One site was situated in a typical area in the central part of the track (near the infra-red track counter), and the third site was situated at the upper, usually steeper, and better confined part of the track. At each of the representative sites on each track, five replicates were measured: one was taken from a central point, and then measurements were taken at one metre and five metres from the central point in each direction. This gives a total of 75 measurements per year (five replicates at three representative sites, on five different walking tracks). In year two of the study the original representative sites were relocated using GPS and measurements were repeated.

Soil sampling

In 2009–2010 soil samples (about 500 g) were collected at depths of 0 to 2 cm and 2 to 5 cm at each of the walking tracks, and at adjacent, relatively undisturbed control areas. Soil sampling took place at the track counter, 1 m down-track of the counter, and 3 m down-track of the counter, thus giving a total of 30 track and 30 adjacent paired control samples. Where the substrate was not too rocky, soil bulk density measurements were undertaken using the sand replacement technique (Burke and others 1986) at the track counter and nearby control (two replicates at each). Soil samples (air-dried and sieved to <2 mm) were analysed for water content, pH, electrical conductivity (EC), and total phosphorus using standard methods (Blakemore and others 1987). Total organic carbon and nitrogen were determined in a LECO FP 2000 analyser at 1050°C (LECO, St Joseph's, Michigan).

Statistical analysis

Paired, two-tailed T-tests (Microsoft Excel v. 2007) were used to determine if there was a statistical difference between track width and incision values between years one and two of the investigation. Paired T-tests were also used to determine if soil physiochemical characteristics were statistically different between the walking track and adjacent control sites. The R^2 statistic was calculated to determine the relationship between track width, track

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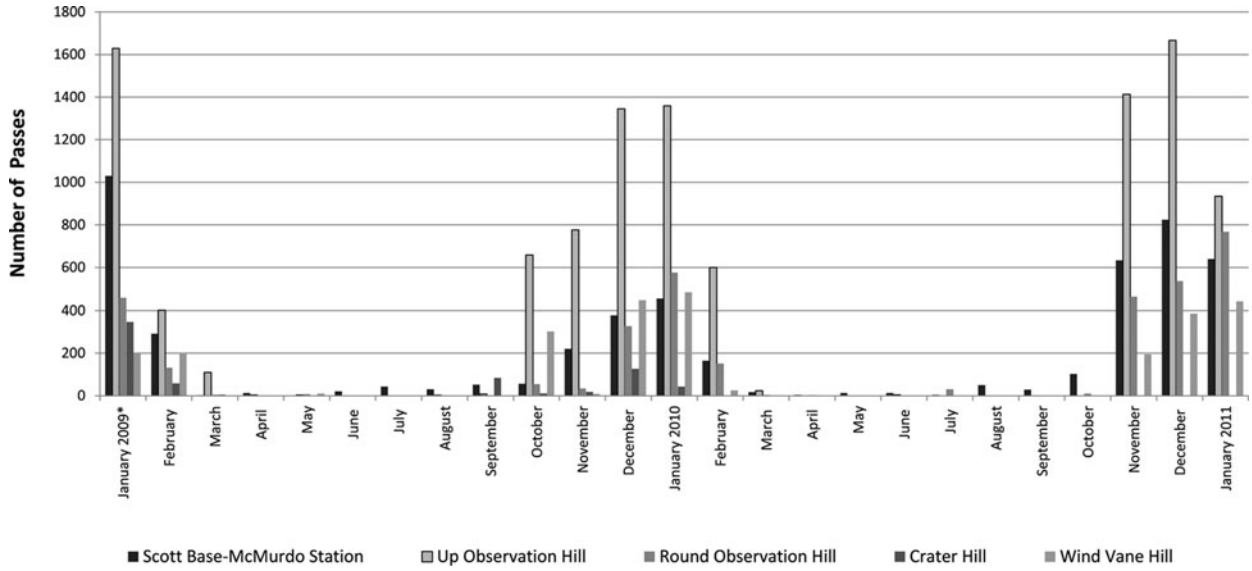

Fig. 3. Monthly counts at the five Ross Island walking tracks over the 2-year monitoring period, 6–12 January 2009 to 31 January 2011. *Incomplete data for January 2009 due to staggered installation of track counters.

incision, and track slope, and the relationship between track width, track incision, and the number of passes recorded on the individual walking tracks.

Results

Track use monitoring

Over the 2-year monitoring period (Table 1) the total number of passes recorded on the Scott Base to McMurdo Station walking track was 5084; 10936 on the Up Observation Hill track; 3561 on the Round Observation Hill track; 693 on the Crater Hill summit track; and 2842 counts on the Wind Vane Hill track (Table 2). The Crater Hill track was monitored for only 52 weeks.

Annual counts (given as Year 1: calendar year from 1 Feb 2009 to 31 Jan 2010, and Year 2: calendar year from 1 Feb 2010 to 31 Jan 2011) are shown in Table 2. At all tracks the peak months were consistently November, December, and January (Table 2; Fig. 3). In Year 1, track use in the summer months accounted for 67% of the total number of passes on the Scott Base to McMurdo Station track, 75% of the total counts on the Up Observation Hill track, 82% on the Round Observation Hill track, and 65% on the Wind Vane Hill Track. In Year 2 the proportion of total counts attributed to summer use increased at all tracks, to 84% at the Scott Base to McMurdo Station track, 86% at the Up Observation Hill track, 90% at the Round Observation Hill track, and 97% at the Wind Vane Hill track. The large increase in summer use at the Wind Vane Hill track can be attributed to the 2009 summer season extending into the month of February and beginning in October in 2009, and starting later in 2010. Use declined at all tracks between late February and March each year, and the Scott Base to McMurdo Station track was the only track regularly used over the winter (Fig. 3). Use began to rise again in October 2009 in Year 1, and early November 2010 in Year 2, again peaking in December and January of each year. There were differences in the level of weekday use, with the highest numbers of users recorded at the weekends and particularly on Sundays (Table 2). Other days when high levels of track use were recorded were Fridays and Saturdays.

There were eight occasions during the 2 year monitoring period where counts at the Wind Vane Hill track exceeded 100 passes. The highest of these occurred on 22 December 2009 (373 passes) which coincided with 122 tourist passengers visiting the area. Early summer visitor number peaks in November and early December corresponded to recreation trips run for NZAP and USAP personnel (Fig. 4). Visitor number peaks occurring in late December, January, and February corresponded to tourist ship visits (J. Newman, personal communication, 3 May 2012).

Track survey

Impact indicators

The Scott Base to McMurdo Station walking track was the widest of the five Ross Island tracks with a mean width of 1.23 m (average of Year 1 and Year 2), followed by the Round Observation Hill walking track at 1.21 m, and the Crater Hill walking track at 1.08 m wide (Table 3). The Wind Vane Hill (0.96 m) and Up Observation Hill (0.92 m) tracks were of a similar width. Track width increased in year two compared to year one at areas all three monitoring sites on the Crater Hill track ($p < 0.05$), and in the lower and less confined part of the Round Observation Hill track ($p < 0.05$) (Table 3).

Track incision ranged from 2 to 8 cm and there was little change in track incision over the monitoring period at all tracks except the Crater Hill walking track (Table 3). At the Crater Hill track counter site there was an increase ($p < 0.05$) in track incision from 5 cm below the original surface in year one to 8 cm below the original surface in

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Table 2. Track counter data showing the total number of passes between January 2009 and January 2011, total mean daily, peak daily, weekly and monthly counts, and mean daily counters during the summer months of November – January, on the five monitored Ross Island walking tracks.

	Scott-Base-McMurdo Station		Up Observation Hill		Round Observation Hill		[4]Crater Hill		Wind Vane Hill	
Infrared Track Counter	Total	Summer	Total	Summer	Total	Summer	Total	Summer	Total	Summer
[1]Total count over entire monitoring period	**5084**		**10936**		**3561**		**693**		**2842**	
[2]Year 1 annual count	1562	1053	4666	3480	1135	936	693	–	1452	941
[3]Year 1 summer count										
[2]Year 2 annual count	2492	2096	4641	4013	1966	1767	–	–	1052	1024
[3]Year 2 summer count										
Daily mean weekday	5.5	16.5	13.6	26.1	3.9	13.5	2.6	4.7	3.7	11.7
Daily mean weekend	9.8	28.6	16.7	31.4	6.7	22.1	5.2	4.4	4.9	17.6
Mean Monday	4.3	13.3	13.9	24.8	3.7	11.4	8.4	13.1	2.9	10.6
Mean Tuesday	6.4	19.2	17.7	32.6	3.5	10.5	2.0	3.0	8.4	24.2
Mean Wednesday	4.5	10.9	12.4	19.4	4.5	13.6	0.5	1.4	1.0	3.6
Mean Thursday	8.4	26.6	11.0	18.2	3.4	10.4	1.0	3.5	1.5	4.6
Mean Friday	4.0	12.5	12.9	18.4	4.6	14.6	0.9	2.6	4.6	16.0
Mean Saturday	6.7	20.9	15.3	38.7	6.7	20.1	1.5	5.4	3.8	13.5
Mean Sunday	12.9	36.3	18.2	52.8	6.7	22.3	8.9	3.4	6.1	21.7
Peak month	Jan 2009 (1030)		Dec 2010 (1666)		Jan 2011 (767)		Jan 2009 (347)		Jan 2010 (483)	
Peak week	13–19 Dec 2010 (236)		6–12 Dec 2010 (547)		22–28 Nov 2010 (180)		12–18 Jan 2009 (222)		21–27 Dec 2009 (373)	
Peak day	28 Nov 2010 (96)		27 Nov 2010 (138)		28 Nov 2010 (74)		22 Sept 2009 (83)		22 Dec 2009 (373)	

[1]Total count = total number of counts over the monitoring period, 6–12 Jan 2009 – 31 Jan 2011
[2]Year 1 annual count = calendar year, 1 Feb 2009 – 31 Jan 2010; Year 2 annual count = calendar year, 1 Feb 2010 – 31 Jan 2011
[3]Summer count = 1 Nov – 31 Jan each year
[4]Crater Hill track counter in operation 12 Jan 2009 – 15 Jan 2010

Table 3. Track width, slope, and incision measurements of Ross Island recreational walking tracks, repeated over two consecutive years (summers of 2008–2009 and 2009–2010). Bolded values have p-values < 0.05. *Width and incision measurements at the lower, upper, and track counter locations are means of five replicates.

		Year	Lower Track	Upper Track	Track Counter	Mean Std. Dev.	Overall Track Av.
SB to McM	Track	Y1	1.38	0.89	1.42	0.26	1.23
	Width* (m)	Y2	1.40	0.85	1.45	0.29	1.23
	Track	Y1	0.04	0.03	0.06	0.01	0.04
	Incision* (m)	Y2	0.04	0.04	0.06	0.01	0.04
	Track slope (°)		1–3	5–8	3	2.06	4
Up Observation Hill	Track	Y1	1.19	0.82	0.75	0.20	0.92
	Width* (m)	Y2	1.21	0.81	0.75	0.21	0.92
	Track	Y1	0.06	0.08	0.07	0.01	0.07
	Incision* (m)	Y2	0.07	0.08	0.07	0.01	0.07
	Track slope (°)		15–18	>35	20	10.20	25
Round Observation Hill	Track	Y1	1.45	1.20	0.94	0.22	1.19
	Width* (m)	Y2	1.50	1.22	0.95	0.23	1.22
	Track	Y1	0.03	0.03	0.04	0.01	0.04
	Incision* (m)	Y2	0.03	0.04	0.04	0.01	0.04
	Track slope (°)		1–3	1–3	2	0.78	2
Crater Hill	Track	Y1	1.45	0.64	1.02	0.34	1.04
	Width* (m)	Y2	1.55	0.63	1.15	0.39	1.11
	Track	Y1	0.02	0.07	0.05	0.02	0.05
	Incision* (m)	Y2	0.02	0.08	0.08	0.03	0.06
	Track slope (°)		2–5	20–25	10	8.47	12
Wind Vane Hill	Track	Y1	1.03	0.95	0.90	0.06	0.96
	Width* (m)	Y2	1.05	0.95	0.92	0.07	0.97
	Track	Y1	0.05	0.05	0.05	0.00	0.05
	Incision* (m)	Y2	0.05	0.05	0.05	0.01	0.05
	Track slope (°)		10–12	15–18	15	2.50	14

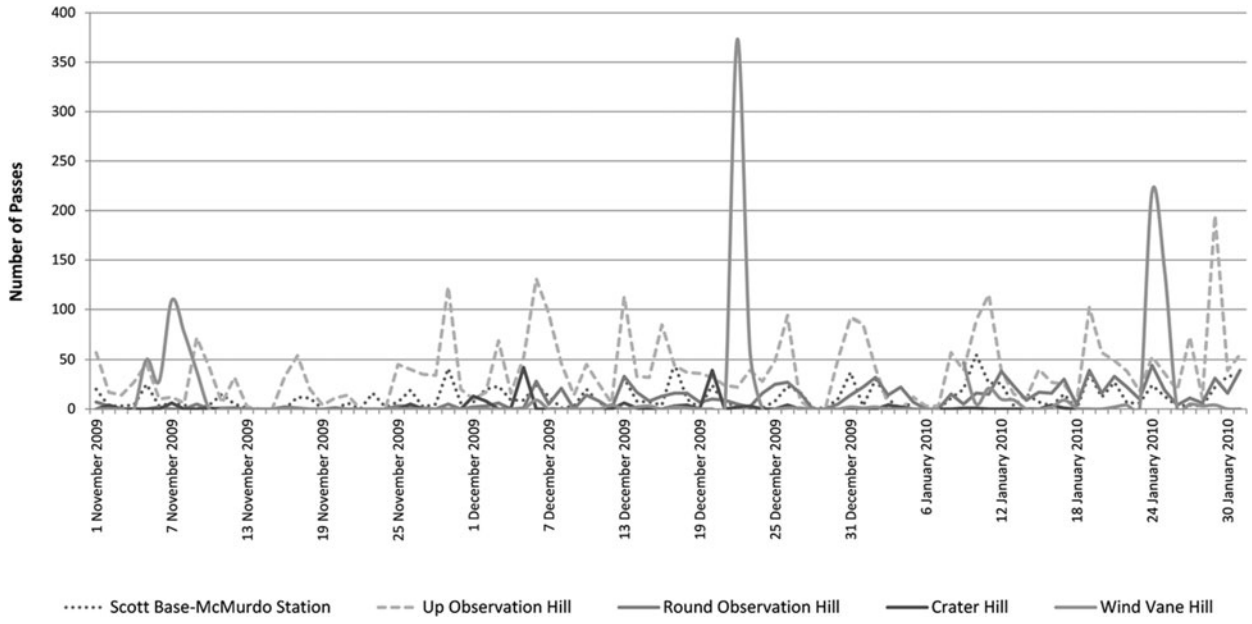

Fig. 4. Daily counts at the five Ross Island walking tracks during the 2009–2010 summer months, 1 November through to 31 January. *Wind Vane Hill peaks correspond to tourist ship visits on 22 December 2009 and 24 January 2010 (Table 2).

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year two. The mean slope (calculated as the mean of 15 measurement points along each track) of the Scott Base to McMurdo Station track was 4°, Up Observation Hill track, 25°, the Round Observation Hill track, 2°, Crater Hill summit track, 12°, and the Wind Vane Hill track, 14° (Table 3).

Soil sampling

Gravimetric water content was low to moderate and increased with depth from 1–7% at 0–2 cm to 2–12% at 2–5 cm depth (Table 4).

Soil samples were strongly alkaline (pH 8.4–9.7). The Scott Base to McMurdo Station, Round Observation Hill, and Crater Hill walking tracks were more alkaline than the Wind Vane Hill and Up Observation Hill walking tracks.

Electrical conductivity (EC) was variable and ranged between 0.04 $mScm^{-1}$ to 1.05 $mScm^{-1}$ (Table 4). EC was highest in the top 2 cm of all tracks and control samples and decreased with depth. EC was consistently higher in the top 2 cm of the control samples at four of the five walking tracks (ranging from 0.14 $mScm^{-1}$ to 1.05 $mScm^{-1}$); with the exception of the Up Observation Hill walking track, where salts were visible on the track but were not visible in the control.

The organic C content was low (0.02%–0.11%) in all tracks and controls. There was no change in organic C within the top 5 cm of soil. Total N was consistently very low (0–0.02%) in all samples and depths. C:N ratios were low and ranged between 3 and 19. Track and control samples had similar C:N ratios, however, the Up Observation Hill track samples had higher C:N ratios (mean C:N of 19) compared with the adjacent control samples (mean C:N of 7). Total P ranged from 510 $mgkg^{-1}$ to 1221 $mgkg^{-1}$ and was highest in the Scott Base to McMurdo Station track and control, and lowest in the Up Observation Hill track and control. There was no consistent change in total P with depth, or difference between track and control samples. Soil dry bulk density ranged from 1.01 gcm^{-3} to 1.74 gcm^{-3} (Table 4).

Paired T-tests showed no significant differences between the measured physiochemical properties of a track and adjacent control samples, except for bulk density. The walking tracks had a higher ($p < 0.05$) dry bulk density than the adjacent control sites, except at Crater Hill where bulk density was similar in the track (1.51 gcm^{-3}) and control (1.54 gcm^{-3}).

Discussion

There were more users on all tracks in the 2010–2011 season, compared with the 2009–2010 season. The increase around McMurdo Station probably resulted from increased promotion of the walking tracks and from onlookers taking interest in the Crater Hill wind turbines installation. At Cape Evans there were more tourist and national programme visits in the 2010–2011 season than in the 2009–2010 summer season (Table 2). Personnel working at the station (up to 1200 individuals over the summer months) were responsible for the majority of user counts at all tracks except the Wind Vane Hill walking track, where peaks corresponded to the arrival of tourist ships (that is 122 passengers on 22 December 2009 led to 373 counts on the Wind Vane Hill track). Winter increases in daily counts (for example on 9 July 2010 at the Round Observation Hill track) (Fig. 3) may represent a special event, such as a fun-run. Cruise-ship visitors visit Scott Base, McMurdo Station, and Discovery Hut. Some probably walked up Observation Hill, as part of their cruise itinerary. However, tourists are likely to have represented only a small proportion of the total user counts on the Observation Hill tracks. The Crater Hill summit track was likely to have very few cruise ship visitors due to their limited time ashore. All tracks showed a decrease in users over winter for obvious reasons. But access is available to all tracks (except Cape Evans) over the winter months. Track width and incision measurements showed tracks traversing flat or gently sloping surfaces, such as the Scott Base to McMurdo Station and Round Observation Hill tracks, tended to be wider ($R^2 = 0.85$), and have a smaller degree of track incision ($R^2 = 0.96$), compared with tracks on steeper slopes (Table 3). Past studies report that tracks with slopes of > 10 degrees are susceptible to erosion (Bratton and others 1979; Sun and Liddle 1993a, 1993b; Marion and Olive 2006) as foot slippage on steep slopes causes track deepening (Sun and Liddle 1993a). The Up Observation Hill walking track was the narrowest, and the level of track incision increased as the slope of the track increased from 15º in the lower reaches, to 20º at the mid-point (location of the track counter), and up to 35º in the upper reaches of the track (Table 3). Increased incision with increasing slope also occurred on the Crater Hill summit walking track ($p < 0.05$).

At the three long established walking tracks (Up Observation Hill, Scott Base to McMurdo Station, and Cape Evans Wind Vane Hill walking tracks) the lack of significant differences in the measured impact indicators between years one and two of the investigation imply that the walking tracks were in a steady state at the time of sampling. Data suggests that once tracks are well established, the current user intensities are not causing cumulative impacts in the measured parameters. However, the more recently flagged Round Observation Hill, and Crater Hill summit walking tracks showed increases in track width at the lower, less confined, and central reaches of the tracks in year two of the study compared to year one (Table 3).

Under the trampling intensities experienced on the tracks there were no significant differences in the soil physiochemical properties between track and control sites, except bulk density, which was consistently higher ($p < 0.05$) in the near surface soil on walking tracks than the adjacent control sites. Higher soil bulk density in walking tracks compared with adjacent control sites is likely to be a direct result of footfall causing

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Table 4. Soil physiochemical characteristics at track counter sites on the Ross Island walking tracks. *EC = electrical conductivity. Measurements are the mean of three samples (at the track counter, 1 m and 3m down track of the counter).

Walking Track	Water content (% dry wt)	Soil pH (H_2O)	Soil EC* ($mScm^{-1}$)	Organic C (%)	Total N (%)	C/N ratio	Total Kjeldhal P ($mgkg^{-1}$)	Bulk Density (gcm^{-3})
Scott Base-McMurdo (T)								
0–2 cm	3.3	9.7	0.18	0.05	0.01	7	1156	
Std. dev.	1.6	0.1	0.04	0.01	0.00	1	128	
2–5 cm	6.1	9.7	0.12	0.05	0.01	6	1117	1.32
Std. dev.	1.0	0.0	0.00	0.00	0.00	0	72	0.08
Scott Base-McMurdo (C)								
0–2 cm	2.4	9.4	0.77	0.10	0.02	6	1131	
Std. dev.	0.4	0.4	0.11	0.01	0.00	0	144	
2–5 cm	3.7	9.6	0.40	0.11	0.02	7	1221	1.01
Std. dev.	0.5	0.1	0.01	0.01	0.00	0	129	0.09
Up Ob Hill (T)								
0–2 cm	3.5	8.9	0.22	0.03	0.00	18	510	
Std. dev.	0.5	0.2	0.08	0.00	0.00	7	37	
2–5 cm	6.0	8.8	0.11	0.03	0.00	19	549	
Std. dev.	0.9	0.1	0.01	0.00	0.00	12	92	
Up Ob Hill (C)								
0–2 cm	6.7	8.5	0.04	0.08	0.01	7	703	
Std. dev.	0.7	0.1	0.01	0.00	0.00	0	96	
2–5 cm	6.6	8.4	0.03	0.05	0.01	9	681	
Std. dev.	0.7	0.0	0.00	0.00	0.00	0	114	
Round Ob Hill (T)								
0–2 cm	7.1	9.0	0.04	0.03	0.00	8	899	
Std. dev.	0.9	0.0	0.00	0.00	0.00	3	155	
2–5 cm	10.4	9.0	0.04	0.04	0.01	8	1068	1.74
Std. dev.	0.6	0.0	0.00	0.00	0.00	2	110	0.21
Round Ob Hill (C)								
0–2 cm	7.7	9.6	0.28	0.05	0.01	8	1047	
Std. dev.	0.1	0.0	0.00	0.01	0.00	1	100	
2–5 cm	11.7	9.3	0.10	0.05	0.01	9	1009	1.08
Std. dev.	1.3	0.0	0.01	0.00	0.00	0	47	0.09
Crater Hill (T)								
0–2 cm	1.0	9.4	0.16	–	–	–	–	
Std. dev.	0.0	0.0	0.01	–	–	–	–	
2–5 cm	3.0	9.5	0.09	–	–	–	–	1.51
Std. dev.	0.1	0.0	0.01	–	–	–	–	0.10
Crater Hill (C)								
0–2 cm	1.9	9.6	1.05	–	–	–	–	
Std. dev.	0.0	0.1	0.02	–	–	–	–	
2–5 cm	4.2	9.4	0.49	–	–	–	–	1.54
Std. dev.	0.1	0.1	0.03	–	–	–	–	0.08
Wind Vane Hill (T)								
0–2 cm	2.8	9.1	0.16	0.02	0.01	3	763	
Std. dev.	0.5	0.2	0.05	0.00	0.00	1	91	
2–5 cm	5.2	9.3	0.05	0.02	0.01	4	845	1.21
Std. dev.	0.3	0.0	0.00	0.00	0.00	1	225	0.11
Wind Vane Hill (C)								
0–2 cm	1.9	9.2	0.14	0.01	0.00	3	669	
Std. dev.	0.2	0.1	0.02	0.00	0.00	1	106	
2–5 cm	3.7	8.9	0.09	0.02	0.01	5	632	1.11
Std. dev.	0.3	0.3	0.04	0.01	0.00	3	164	0.10

compaction of the near surface soil. Differences in other soil physiochemical properties at sampling sites (such as soil pH, soil EC, and organic C) fall within the natural spatial variability that is common to soils in the Ross Sea region.

Conclusions

The objective of this research was to determine the number of people using the Ross Island recreational walking tracks, and to investigate the relationships between the

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number of users and track soil physiochemical and morphological characteristics.

The usage of the tracks is indicated previously. Annual data showed higher counts on all tracks in the 2010–2011 season, compared with the 2009–2010 season, and that the highest frequency of visitors occurred on Sundays in the summer months. The Scott Base to McMurdo Station track is used continuously throughout the year. Peak daily counts at the Wind Vane Hill track coincided with the arrival of tourist ships, whereas Scott Base and McMurdo Station personnel were responsible for the peaks in traffic at the other four walking tracks in the vicinity of the stations.

There was no relationship between the number of passes on the track and the measured impact indicators indicating that higher usage of a formed track had little cumulative impact. Track width and incision were related to the slope of the terrain, with tracks traversing flatter areas generally wider ($R^2 = 0.85$) and less incised ($R^2 = 0.96$) than those traversing steeper hillsides. Soil sampling of walking tracks and adjacent control material revealed no significant differences between the measured soil physiochemical properties, except soil bulk density. An increase in soil bulk density ($p < 0.05$) was observed in the walking tracks compared with adjacent control sites.

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