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Long-term high Arctic ecosystem monitoring in Quttinirpaaq National Park, Ellesmere Island, Canada

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ABSTRACT: In 1990 a long-term monitoring program was established in Quttinirpaaq National Park on Ellesmere Island in the Canadian Arctic to study the effect of natural forces and human activity on the park's ecosystems. At that time nine transects were established, five in the Tanquary Fiord area and four in the Lake Hazen area. Data collected during the eleven-year monitoring period indicate that most of the ecosystems are fairly dynamic, displaying changes resulting primarily from natural processes. These processes generally have a stronger impact than human activities. The data collected in 2000 suggest that the air and soil temperatures have increased during the past three summers (1998–2000), resulting in deepening of the thaw layers on portions of most of the transects. Between 1990 and 2000 there was a significant change in the vegetation cover on three of the eight vegetated transects.

1 INTRODUCTION

A major problem with the use of parks in northern Canada is the extreme sensitivity of the land to repeated use and the possibility that damage may be irreparable (Kevan 1971). This problem has been examined by Churchill (1985a, b), who studied recreational impact and environmental degradation on trails in Auyuittuq National Park Reserve on Baffin Island. Welch and Churchill (1986) found that trails develop after 100–200 transits, depending on the terrain type. Cole (1989) has provided methods for monitoring the conditions of wilderness campsites in southern areas. The methods that he developed have been modified during this study for application to northern areas.

The impact of foot traffic (e.g., as a result of hiking) is one of the major human disturbances occurring on land surfaces in Quttinirpaaq National Park. When this type of traffic is dispersed and light it causes little or no permanent damage to the soil surface and does not initiate serious soil and vegetation degradation. In areas where this type of traffic is concentrated, however, such as near park centres and where it funnels through narrow corridors, such extensive use can be very damaging. On slopes and in exposed areas this could initiate water and wind erosion, while in materials with high ice content it could lead to thermal erosion of the ice-rich permafrost.

A long-term monitoring program was established in Quttinirpaaq National Park (then the Ellesmere Island National Park Reserve) in 1990 to study the effects of both foot traffic and natural changes on this sensitive Arctic environment (Tarnocai et al. 2001). It was also foreseen that this monitoring program would provide the park managers with an early warning system, before serious problems developed. In this paper, the data collected in 1990, 1994 and 2000 have been evaluated and changes in the ecosystems resulting from human impact and natural forces are discussed.

2 STUDY SITES AND METHODS

2.1 *Site selection*

The criteria for selecting the monitoring sites were:

1. Areas that will be affected by foot traffic, especially where topography causes the traffic to funnel through a narrow corridor.
2. Areas associated with sensitive soils. Sensitive soils are those that, because of texture, ice content or slope, are highly susceptible to erosion and thermal degradation.
3. Areas of wildlife habitat (e.g., sedge meadows) that are particularly sensitive to disturbance because of moisture levels, soil types, etc.
4. Areas where some disturbance has already occurred. These areas are needed in order to determine whether recovery is possible, whether conditions will remain static, or whether degradation will continue.

2.2 *Type of monitoring*

2.2.1 *Detailed monitoring (phase 1)*

In phase one of the long-term monitoring program, a methodology suitable for High Arctic environments was developed. Monitoring sites were established and detailed data were collected in 1990 on both the Lake Hazen and Tanquary Fiord transects (Fig. 1, Table 1) (Tarnocai et al. 1991).

Soil and vegetation data were recorded at set intervals from the zero point of each transect in 1990. Cross sections identifying vegetation, landforms, surface topography and soil parent materials were then prepared. Oblique photographs of every 2 m section were taken from a point approximately 3.5 m from the transect.

Thaw depth was determined by probing, soil moisture content was measured at a depth of 15 cm by using a TDR (Time Domain Reflectometer) (Topp 1987, Topp et al. 1984), and the natural state unconfined soil strength of the soil surface was determined by using a pocket penetrometer. A soil pit was dug at a representative site approximately 5–10 m from the transect, and the soil was described and sampled for chemical and physical analyses. Bulk density samples were also collected. Ice content samples were taken from the permafrost layer using a gasoline-driven Pico corer. Quantitative vegetation data were collected using the quadrat sampling method. Each quadrat (50 cm × 50 cm) was examined and photographed, all vascular plant species were identified and the percent cover of each plant species or group of species (i.e., mosses, lichens and cryptogamic crust), litter and bare ground were recorded.

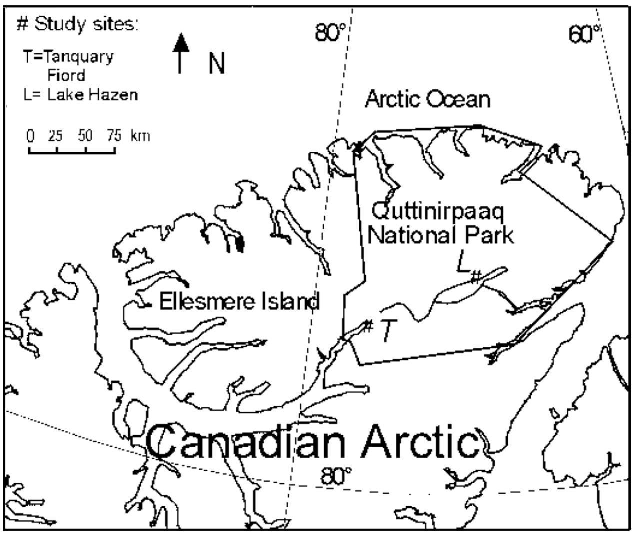

Figure 1. Study sites at Tanquary Fiord and Lake Hazen in Quttinirpaaq National Park on Ellesmere Island.

2.2.2 *Yearly monitoring (phase 2)*

In phase two, these sites are being monitored on a yearly basis by Parks Canada staff. This yearly monitoring is carried out in the middle of summer (July) every year, except for the years in which detailed monitoring is carried out. All data collected during monitoring (for all three phases) are recorded on Human Impact Monitoring Data Forms and photographs are taken along the transect.

2.2.3 *Detailed monitoring (phase 3)*

This detailed monitoring is carried out approximately every fifth year. In phase three, the second detailed monitoring was carried out in 1994 (fifth summer) and the third in 2000 (eleventh summer). These studies included detailed measurements and resampling of all those terrain, soil and vegetation parameters that were measured and sampled in 1990, when the transects were established in phase 1.

2.2.4 *Soil climate monitoring*

In 1994 a soil climate monitoring site was established at transect H-2 in the Lake Hazen area. At this site, air

Table 1. Descriptions of the study sites at Lake Hazen and Tanquary Fiord (for drainage and vegetation, see Table 5).

Study site	Lake Hazen				Tanquary Fiord	
Abbreviation	H-1	H-2	H-3	H-4	T-1A/B	T-2
Latitude	81°49′48″	81°49′12″	81°49′54″	81°49′36″	81°23′44″	81°23′56″
Longitude	71°17′54″	71°23′32″	71°26′25″	71°21′53″	76°48′00″	76°26′26″
Elevation	165 m	190 m	297 m	200 m	65 m	90 m
Landform	colluvial blanket	eolian veneer	alluvial veneer	ridged colluvial	fluvial terrace	inclined colluvial plain
Slope	5%	5%	5%	5%	7%	9%
Parent material	colluvial	eolian over colluvial	alluvial	colluvial	fluvial	colluvial
Patterned ground	ice-wedge polygons	hummocks	hummocks	hummocks	earth hummocks	frost cracks
Soil classification	Regosolic Turbic Cryosol	Regosolic Turbic Cryosol	Gleysolic Turbic Cryosol	Regosolic Turbic Cryosol	Regosolic Turbic Cryosol	Regosolic Turbic Cryosol

and soil temperatures at depths of 2.5, 10.0, 20.0, 35.0, 50.0 and 100.0 cm are monitored every six hours on the hour (12 and 6 a.m., 12 and 6 p.m.) throughout the year using a Richard Brancker Research Ltd. XL-800 eight-channel data logger. All data collected are entered into an Excel spreadsheet, which is used to calculate daily and monthly maximum, minimum and mean soil and air temperatures.

2.3 *Data used*

Changes in thaw depth and soil moisture were determined by comparing the data for 1990 data with that for 2000. These two sets of data were used since both were collected in mid-July (July 8–10, 1990 and July 18–21, 2000 at Lake Hazen; July 13–16, 1990 and July 10–14, 2000 at Tanquary Fiord). The 1994 data was not used for this comparison since it was collected during the second part of June (June 29 – July 1 at Lake Hazen; June 23–25 at Tanquary Fiord).

3 RESULTS AND DISCUSSION

3.1 *Climate during the monitoring period*

Mean monthly air temperatures in June, July and August (Table 2) show no clear indication of warming, but mean summer soil temperatures (Table 3) show a trend to warmer temperatures at depths of 2.5, 5.0, 10.0 and 20.0 cm. Mean monthly minimum soil temperatures at depths of 2.5, 5.0 and 10.0 cm (Table 4) clearly show a warming of the soil in July. From 1994 to 2000 temperatures increased approximately 1°C at the 2.5 cm depth and approximately 1.5°C at depths of 5.0 cm and 10.0 cm. A further increase of soil temperature in the first centimeter of the soil will very quickly enhance all biological processes. No gradient of increasing temperatures from 1994 to 2000 can be identified; instead, between 1996 and 1998 a quite sharp threshold is obvious. Mean monthly minimum soil temperatures from 1994 to 1996 are low, and temperatures from 1998 to 2000 are higher.

3.2 *Depth of thaw and soil moisture*

Figures 2, 3 and 4 show the depth of thaw in 1990 compared to 2000 on the transects at the study sites in Tanquary Fiord and Lake Hazen. In general, the active layer is shallower in Tanquary Fiord than in Lake Hazen. In some cases there is little or no change in active layer depth during this period (H-1, T-1B), in other cases an increase in active layer depth is obvious (a portion of H-2, H-3, H-4, T-1A). On site T-2, however, the depth of thaw decreased from 1990 to 2000. Active layer

Table 2. Mean monthly air temperatures (June, July, August) on transect H-2 from 1994 to 2000.

	Temperatures (°C)						
Period	1994	1995	1996	1997	1998	1999	2000
June	n.d.	n.d.	1.9	n.d.	5.3	2.2	4.9
July	6.2	8.1	5.7	n.d	8.6	8.0	6.2
Aug.	4.0	4.1	0.7	−0.1	4.3	3.9	n.d.

(n.d. = not determined)

Table 3. Mean monthly summer soil temperatures (June, July, August) at various depths on transect H-2 in 1996, 1998 and 1999.

	Temperatures (°C)						
	cm:2.5	5.0	10.0	20.0	35.0	50.0	100.0
1996	2.2	1.6	1.1	−0.3	−1.9	−3.5	−6.2
1998	4.4	3.5	2.9	1.1	−1.0	−2.9	−5.9
1999	3.0	2.6	2.0	0.4	−1.6	−3.4	−6.3

Table 4. Mean monthly minimum soil temperature at 2.5, 5.0 and 10.0 cm depths on the mineral soil at transect H-2 from 1994 to 2000.

	2.5 cm depth		5 cm depth		10 cm depth	
Year	July	Aug	July	Aug	July	Aug
1994	2.3	−0.3	1.9	−0.1	1.8	0.0
1995	2.5	−0.2	2.0	−0.1	1.7	0.0
1996	1.7	−0.5	1.9	−0.3	1.7	−0.1
1997	n.d.	−2.1	n.d.	−1.7	n.d.	−0.9
1998	3.7	0.5	3.5	1.0	3.2	1.4
1999	3.0	−1.2	3.2	−0.3	3.2	0.0
2000	3.1	n.d.	3.5	n.d.	3.3	n.d.

(n.d. = not determined)

thicknesses on the trails sometimes show high variability since the effect of traffic is superimposed on the climatic influence.

Interestingly, the depth of the thaw layer on transect H-1, located near the shore of Lake Hazen, showed very little change or even some decrease. This was attributed to the lake effect of the ice cover on Lake Hazen, which resulted in a cooler microclimate. The deepening of the thaw layer that was noted on most transects would explain the development of large detachment slides in the Lake Hazen area.

The effect of permafrost was either to produce thermal cracks (T-1A) or to raise the ground surface(H-3), presumably because of ground ice formation. This raising of the ground surface primarily affected the moisture regime of the site, as was found along a portion of transect H-3. Here, the increased ground ice formation was probably triggered by changes in hydrological conditions resulting from a shift in the stream. Both the aggregation of permafrost and the shift in the stream

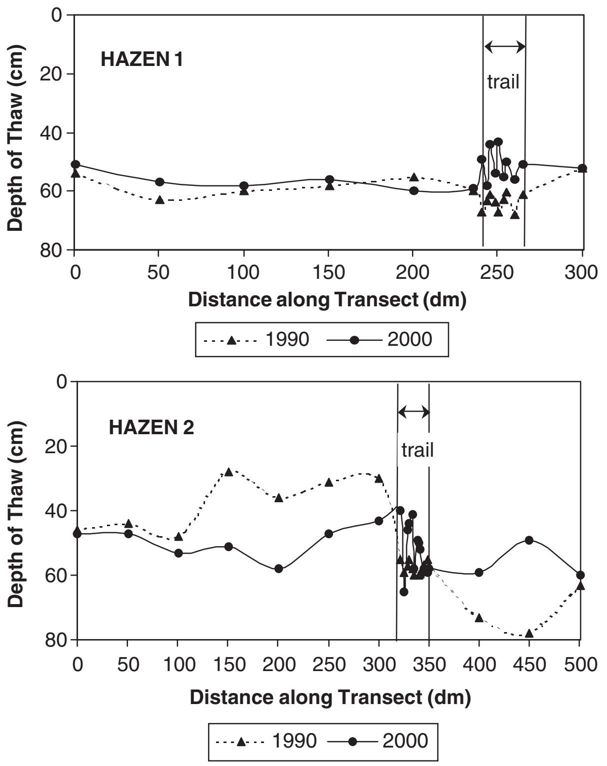

Figure 2. Depth of thaw along transects H-1 and H-2.

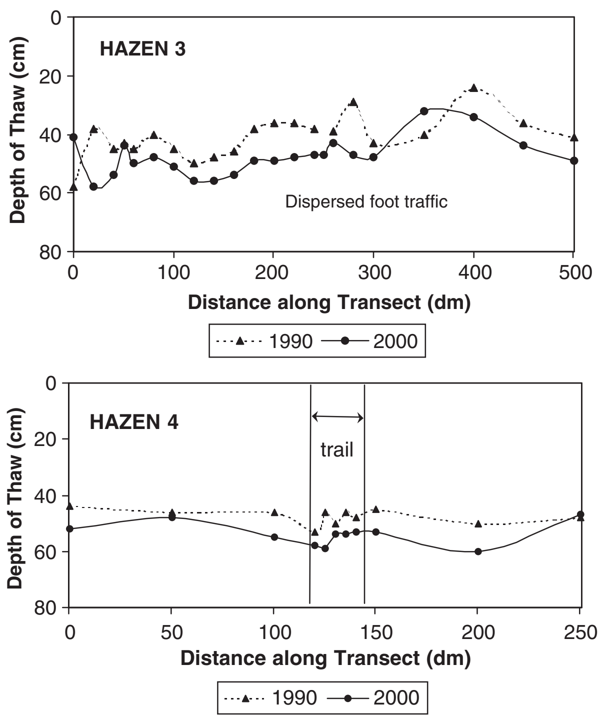

Figure 3. Depth of thaw along transects H-3 and H-4.

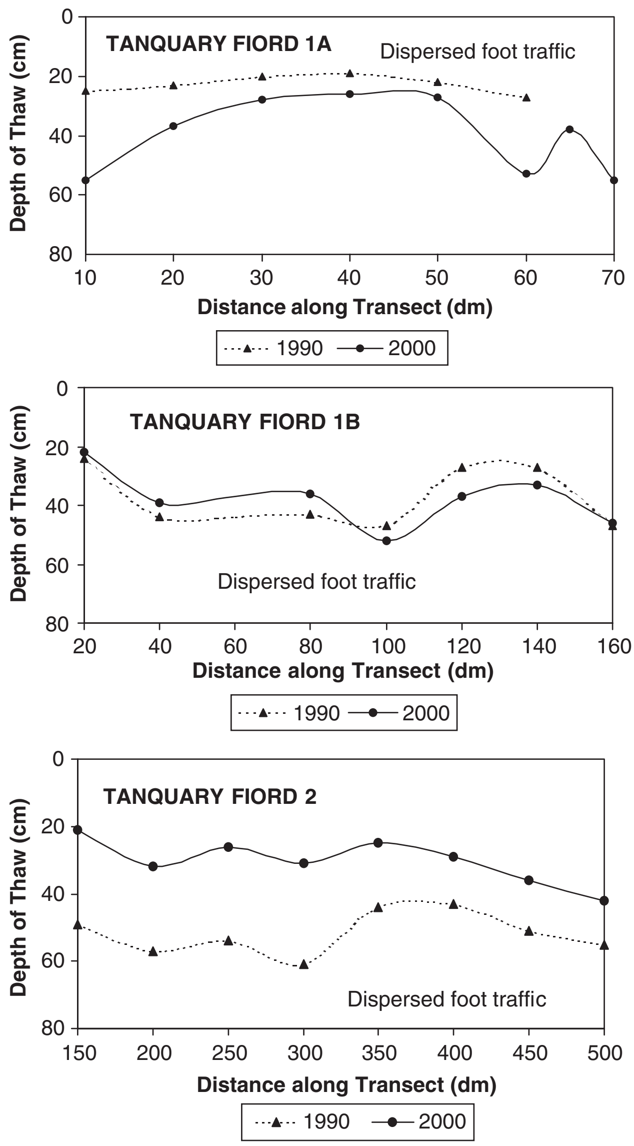

Figure 4. Depth of thaw along transects T-1A, T-1B and T-2.

caused changes in the vegetation cover and plant species composition at this site.

It can be predicted that biological processes in soils with different drainage and soil moisture status will react differently to climate change (Heal et al. 1998). The study sites on Ellesmere Island (Table 5) include all three soil moisture status (dry, moist, wet). The moisture status, which is determined by the measurement of soil moisture in percent volume (Table 5), corresponds well with the drainage conditions (well, imperfect, poor). Vegetation reflects the varying soil moisture conditions with Dryas dominating on dry sites, sedge and willow invading on moist sites additionally, and moss appearing on wet sites.

It was found that the change in thaw depth (Figure 2, 3 and 4) is controlled primarily by soil temperature and soil moisture (Table 5). The thaw depths on the two dry sites, H-1 and H-4, changed very little between 1990 and 2000, although in 2000 the thaw depth at site H-1 was slightly shallower at the end of the transect. However, the thaw depth on site H-2, which is also a dry site, increased along the 0–32 m portion of the transect and decreased along the remainder of the transect. The thaw depth increased on most parts of the transects on the moist sites (H-3a, T-1A and T-1B) and decreased on the

Table 5. Soil moisture, soil moisture status, drainage and vegetation on the study sites at Lake Hazen and Tanquary Fiord.

Study area	Lake Hazen*					Tanquary Fiord		
Study site	H-1	H-2	H-3a	H-3b	H-4	T-1A	T-1B	T-2
Soil moisture (vol. %)	15	13	24	44	18	28	29	61
Mean standard deviation	2.8	3.7	6.2	3.6	4.1	7.8	7.9	21.3
Soil moisture status**	dry	dry	moist	wet	dry	moist	moist	wet
Drainage	well	well to rapid	imperfect	poor	well	imperfect	imperfect	poor
Vegetation	Dryas sedge	Dryas	Dryas sedge willow	Dryas sedge willow moss	Dryas sedge	Dryas sedge willow	Dryas	sedge willow moss

* H-3a = 0–10 m; H-3b = 10–50 m.
** dry: <20 vol.% moist: 20–40 vol.% wet: >40 vol.%.

wet sites (T-2 and part of H-3b) in 2000. This decrease on the wet sites can be attributed to a combination of drying and the organic surface layer that occurs on the wet sites. Thus, the increase in temperature on wet sites between 1990 and 2000 has resulted in drying (greater evaporation) and this, in combination with the surface organic layer, which, when dry, acts as an insulator, has resulted in shallower thaw depths. On the dry and moist sites, however, the effect of higher temperatures may lead to an increase in thaw depth, although the effect may be minimal in the High Arctic.

3.3 *Vegetation*

Vegetation was examined during the detailed monitoring in 1990, 1994 and 2000 and was analyzed for the periods 1990–1994, 1994–2000 and 1990–2000. There was little change in plant cover over the eleven-year period of monitoring. In areas where deposition is active, however, the vegetation responded with a noticeable change in cover. At Lake Hazen the differences in vegetation cover between the various periods was not significant except at transect H-4, where a change in total cover of vascular plants, moss and lichen was noted in all periods studied. An analysis of the cover of different species or taxonomic groups on transect H-4 also showed a significant difference ($p = 0.05$) in cover of *Dryas integrifolia* and moss for 1990–2000. A trail is evident along this transect and, although it is possible that foot traffic accounts for the difference in cover, it is more likely the result of eolian deposition. At Tanquary Fiord significant difference in total cover of vascular plants, moss and lichen were noted along transect T1-B in 1990–1994 and 1990–2000 and along T-2 in 1994–2000 and 1990–2000. In addition, significant differences in total cover of *Carex* spp. were noted along transect total T-2 in 1990–1994 and 1990–2000. Trails are not evident at either location and, in fact, it appears that hikers are utilizing other areas. Therefore, the changes are likely due to either natural events or observer error. The change along transect T-2 is likely the result of changes in the vegetation due to natural processes.

3.4 *Source of disturbance*

The effect of wind was probably the most visible and was manifested in the form of eolian deposition on the vegetated surface and wind erosion (removal of materials). This effect was especially strong on sandy textured soils such as those associated with transect areas H-4 and T-4. On portions of these transects one to two centimeters of new material has been deposited on the vegetated surface since 1990, thus blanketing some of the vegetation. If human disturbance occurred in these areas, signs of it were quickly erased by the eolian process.

The effect of water shows clearly in transect areas H-3, T-2 and T-3. In transect areas H-3 and T-2 thin alluvial deposition occurred as a result of the action of streams or sheet flow of water, while in T-3 surface run-off eroded the surface soil materials. Very little human traffic affected these areas, probably because of their extreme wetness. Any signs of human traffic, such as that reported for transect T-3, would quickly be erased by this fluvial process (sheet erosion).

Measurable human impact occurred on two transects, T-1A, located near Kettle Lake in the Tanquary Fiord area and H-2 in the Lake Hazen area. These areas, which received the highest number of visitors, are situated in natural corridors. Considerable human impact was found in a 3–4 km radius around the Tanquary and Lake Hazen camps.

4 CONCLUSIONS

Ecosystems studied during the eleven-year monitoring period were found to be fairly dynamic, displaying changes resulting mainly from natural forces. The operation of these natural forces was shown primarily by the effects of eolian (wind), fluvial (water), permafrost and hydrological (water regime) processes. In addition, during the last monitoring year (2000) unexpectedly large changes in thaw depths were found, perhaps indicating warmer summer temperatures between 1994 and 2000. The data collected in 2000 suggest that, in addition to the impact of wind, water and human activities, the increase in soil temperature during recent summers has also had a noticeable effect on thaw depths. The deepening of the thaw layer on part of transect H-3 as well as on transects H-4 and T-1A was likely due to the higher air temperatures in 1998 and 1999. On the other hand, the decrease of the thaw depth on transect T-2 and the remainder of transect H-3 was likely due to drying of the ground (decreased soil moisture) and the insulating capacity of the surface organic layer. It is difficult to say whether this warming is just a period of warmer summers or whether it indicates the beginning of global warming, which has been predicted to lead to the greatest temperature increases in Arctic areas. It suggests, however, that a change may be occurring in the park's ecosystems, as evidenced by the observation of landslides, detachment slides and permafrost degradation.

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