Studies of Soil Microorganisms Inuvik, Northwest Territories

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ABSTRACT. A study of soil microorganisms of the Inuvik area (68°21'N., 133°40'W.) was carried out during the summer of 1964. In almost all samples taken, psychrophilic, mesophilic, and especially thermophilic bacteria were found in greater numbers than in samples obtained from northern and southwestern Alaska. These studies also demonstrated that the soil microflora in this area was more varied physiologically and metabolically than in its Alaskan counterpart, and that the Canadian soils were warmer, had better drainage, and had certain chemical and physical properties that could account for the differences in bacterial numbers.

RÉSUMÉ. *Etudes sur les microorganismes du sol, Inuvik, T. du N.-O.* Au cours de l'été de 1964, on a mené une étude des microorganismes du sol dans la région d'Inuvik (68°21'N., 133°40'W.). Dans tous les échantillons recueillis les bactéries psychrophiles, mésophiles et surtout thermophiles ont été trouvées en plus grand nombre que dans des échantillons provenant du Nord et du sud-ouest de l'Alaska. Ces études ont aussi démontré que dans cette région, la microflore du sol était physiologiquement et métaboliquement plus variée que son équivalent alaskien, et que les sols canadiens étaient plus chauds et mieux drainés, et possédaient certaines propriétés chimiques et physiques qui pourraient expliquer ces différences dans les comptages de bactéries.

РЕЗЮМЕ. *Исследование почвенных микроорганизмов в районе города Инувик (Северо-Западные Территории).* Проведенное летом 1964 г. исследование микроорганизмов, обитающих в почве в районе города Инувик (68° 21'N; 133° 40'W), выявило наличие психофрильных, мезофильных и термофильных бактерий, причем в больших количествах, чем в пробах, взятых в северных и юго-западных районах Аляски. Было установлено, что почвенная микрофлора исследованного района характеризуется большим разнообразием физиологических и метаболических показателей, чем почвенная микрофлора Аляски. Кроме того, канадские почвы теплее, а также обладают определенными химическими и физическими свойствами, которые возможно обуславливают отмеченные различия в содержании бактерий.

INTRODUCTION

During the last two decades microbiological studies carried out at Point Barrow and other regions along the northern coast of Alaska have shown that polar habitats of North America have a significant and measurable microflora (Boyd 1958) but usually in numbers lower than found in temperate soils. Psychrophiles, mesophiles, and thermophiles capable of growth over the entire temperature spectrum (2°C. to 55°C.) are present; bacteria, moulds, actinomycetes, and myxobacteria are important members of the soil population. A wide variety of species and physiological types have been demonstrated (Boyd 1967; Boyd and Boyd 1962; Brockman and Boyd 1963; McBee and McBee 1956), and the physiology and metabolism of the soil microorganisms are of a lower rate than normally encountered in temperate latitudes (Boyd 1967; Douglas and Tedrow

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1959). This area is underlain with continuous permafrost, and microorganisms have been shown to be present even in vertical cuts drilled into this permanently frozen ground (Boyd and Boyd 1964). Some microbial species derived from temperate habitats will become established in the soil for various periods of time, while others, particularly coliform bacteria, die at a very rapid rate (Boyd and Boyd 1962a; Boyd *et al.* 1966).

South of the Arctic coastal plain of northern Alaska and in the Mackenzie Delta region of Canada are areas also underlain with continuous permafrost; these represent habitats quite different from Point Barrow in that vegetation of a higher order exists, and certain crops of temperate regions can be cultivated to maturity during the short growing season. Arctic and subarctic agriculture problems in Alaska have been discussed by Mick (1957), and the characteristics of permafrost soils in the Inuvik, Northwest Territories area have been described by Day and Rice (1964). Some preliminary microbiological work has been reported by Ivarson (1965) on cultivated and uncultivated soil at Inuvik and Reindeer Station (both are on the East Channel of the Mackenzie River), and more recently Fournelle (1967) has published on soil and aquatic bacteria of the Alaskan subarctic.

This paper is a result of studies which were made on various soils and lake and river sediments in the area of Inuvik during the summer of 1964, in an attempt to compare the number and, to a certain extent, the types of bacteria found there with those that are indigenous to northern Alaska.

MATERIALS AND METHODS

Five areas in the vicinity of Inuvik were selected for study; with one exception there was no evidence of these soils having been previously disturbed. In addition to the above sites, the experimental, agricultural plots cultivated by the Canada Department of Agriculture (based at Fort Simpson, Northwest Territories) and adjacent uncultivated areas which served as controls were sampled on a weekly basis. The soil sites shown in Fig. 1, represented Subarctic Brown Wooded soil with various types of vegetation and will be described in greater detail later on.

All samples were collected from the surface layer (1 to 2 inches) using sterilized teaspoons and glass jars; microbial analysis in each case was initiated within a period of 2 hours. The depth of thaw was measured at the time of sampling using a metal rod probe; soil and air temperatures were taken at the same time. Dilutions of all samples were plated in triplicate using nutrient agar (Difco) and were incubated at 55°C. for 24 hours, at 20°C. to 22°C. for 5 days, and at 2°C. for 14 days prior to counting. Plates were also prepared with Sabouraud's dextrose agar (Difco), and Thornton's standardized medium (Allen 1951) and incubated at 20°C. to 22°C. for 5 days. The latter chemically defined medium was used for comparison with mesophilic bacteria counts made on nutrient agar.

An enrichment series for selecting 11 different physiological types of microorganisms was also inoculated with representative samples and will be described in detail later. Chemical analyses of air-dried soil samples were carried out routinely using a Hellige-Truog Combination Tester (Hellige, Inc., Garden City, N.Y.) within 2 months after collection.

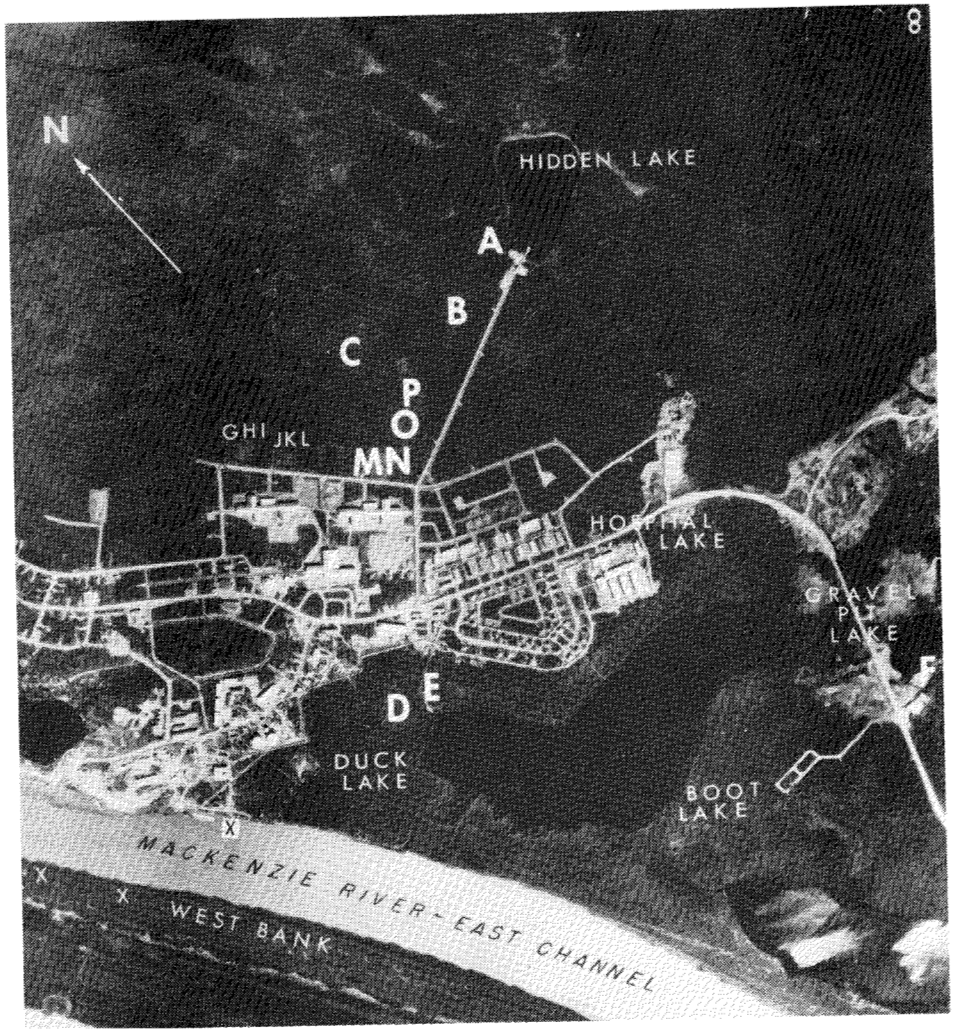

FIG. 1. Photo-map of soils sampled in the vicinity of Inuvik, Northwest Territories, Canada. Mentioned, but off map: Shell and Dolomite lakes (southeast of town); Twin Lake (west of town). Seaplane anchorage marked with black cross. Map reprinted from Royal Canadian Airforce photo VRR 2099/4, 408 (R), with the kind permission of Defence Photographic Interpretation Centre, R.C.A.F. Station, Rockcliffe.

RESULTS

The first group of samples came from areas which had not been cultivated. There were 6 (A through F), and they are marked on the photo-map (Fig. 1). Descriptions of the plots and the increase in depth of the thawed layer as measured from late June until 14 August are given in Fig. 2. Of these uncultivated plots underlain with continuous permafrost, only plot B, the "disturbed" loam, thawed to more than 20 inches, showing a maximum of 36 inches. Drew *et al.* (1958) reported thaws of 50 inches for Arctic Brown soils and 18 inches for nearby tundra soils at Barrow.

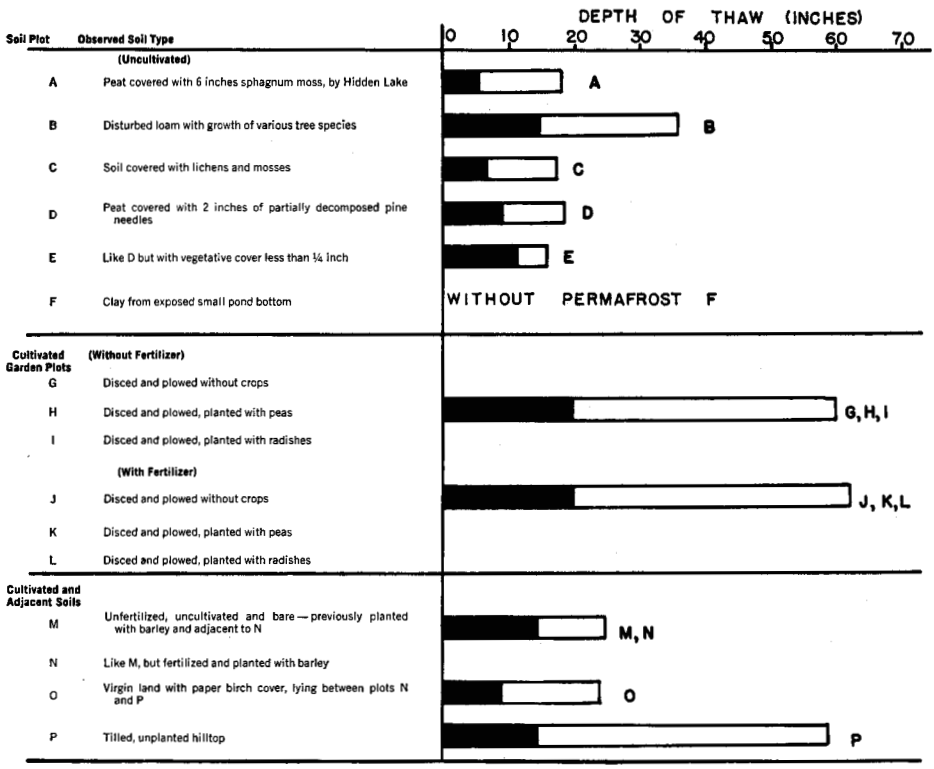

FIG. 2. Minimum and maximum thaw depths of soils measured between 20 June and 14 August. Minimum depths were measured between 20 and 28 June; maximum depths were measured on 14 August, except for plots G through L where maximum depth occurred 5 August.

The results presented in Table 1 represent minimal and maximal values observed throughout the study period. In order to obtain reliable readings for soil and air temperature, at least 2 separate observations were made a few moments apart, and the average of these values was recorded for that date. Microbial counts in each case were also the result of more than one sample. At a particular site, 2 or more soil samples were taken simultaneously. These samples were plated and averaged to give the microbial numbers reported. In every instance, the counts on Thornton's Agar (22°C.) were almost identical to those obtained on nutrient agar (22°C.), and for this reason were not reported.

At the start of our study period, soil temperatures were low (as low as 5.3°C.) but during July, some went up into the range for the optimum growth of mesophilic organisms (22°C. to 40°C.); these temperatures were much higher than normally encountered for a comparable time period at Barrow (Boyd 1958; Drew *et al.* 1958).

From our limited sampling, we were not able to establish any correlation between microbial count and temperature. The date of the highest soil temperature did not always occur on the date of the highest mesophilic or other microbial count. Where increase in numbers was observed, the increase was rarely more than one

TABLE 1. Microorganisms in uncultivated soils.

Soil	Dry Weight (%)		Soil Temp. (°C.)		Air Temp. (°C.)		Number of Microorganisms per Gram of Dry Soil: Nutrient Agar 55°C.* (x 10^2)		Nutrient Agar 22°C. (x 10^4)		Nutrient Agar 2°C. (x 10^4)		Sabouraud's Dextrose Agar 22°C. (x 10^3)	
	L†	H†	L	H	L	H	L	H	L	H	L	H	L	H
(A)	10.0	20.6	7.8	15.8	7.6	23.5	0.0	59	67	210	9.0	270	7.8	52
(B)	32.5	70.6	5.8	12.9	7.7	27.7	80	6700	350	2600	31	1500	3.0	68
(C)	15.5	23.4	5.3	14.8	7.1	28.3	15	67	22	190	7.6	150	5.7	19
(D)	11.0	41.0	7.4	21.3	7.9	29.4	90	690	670	4100	170	870	24	90
(E)	25.9	33.5	7.1	17.8	7.3	25.5	17	700	1100	4200	78	1400	21	100
(F)	76.6	83.7	9.7	21.0	8.8	26.3	2.2	45	5.5	10	0.7	6.9	0.03	0.61

†L = low values and H = high values.
*Temperature of incubation.

log, except among psychrophilic microorganisms. Thus, profound seasonal increases in numbers were not demonstrated in all cases, although some of the counts approached those obtained for uncultivated soils in temperate regions (Waksman 1952). All samples also contained far higher numbers of thermophilic organisms than usually observed at Barrow (Boyd 1958; Boyd and Boyd 1964).

From the results presented in Table 2, it can be seen that all of the soils, with the exception of D and F were in the acid range. Phosphorus varied from very low to very high; calcium and potassium were found in medium to very high concentrations, and magnesium was present in concentrations ranging from low to high. Nitrate-nitrogen was very low except in soils A and B where it was high; ammonia-nitrogen was also high in plot A but varied from medium to very low in the others. Sulfate was very low except in plot F, where it was found in extremely high concentrations. Chloride was either undetectable or present in extremely low amounts.

TABLE 2. Chemical composition of uncultivated soil plots.*

Soil	pH	Parts per Million per Gram of Dry Soil: Phosphorus	Potassium	Calcium	Magnesium	Nitrate-nitrogen	Ammonia-nitrogen	Sulfate	Chloride
(A)	5.0	60	130	400	1000	30	50	0	0
(B)	6.5	30	80	5000	1000	30	25	25	25
(C)	4.6	15	250	1000	400	3	13	0	0
(D)	7.6	25	160	4000	2000	2	15	50	50
(E)	5.5	13	180	2000	1300	1	3	25	25
(F)	8.0	1000	3500	5000	2000	0	8	4600	0

*Samples were taken on 6 and 7 August.

Agriculture on a limited scale is carried out at Inuvik and, with the cooperation of the Canada Department of Agriculture, it was possible to sample soils from their experimental farm. In permafrost areas, it can take many years to modify land for farming. Preparation of the plots sampled by us started in 1957 with clearing and discing. Slumping (caving-in) occurred as ice-lenses melted, and repeated efforts (levelling, etc.) were needed to have even part of the land available for agriculture in 1964. Two suitable areas (each 140 x 150 feet) on a slope were fertilized on 17 June 1964, using a mixture composed of 80 pounds of 16-20-16 (N-P-K) fertilizer and 18 pounds of potassium sulfate.

Although a number of different crops were planted, it was decided to select study plots in only 2 locations. The first including plots G through L was divided into 2 sections of 3 plots each. Plots G, H, and I were not fertilized, whereas plots J, K, and L had the addition of the aforementioned fertilizer mixture. Plots G and J were disced, plowed, but not planted; plots H and K were planted with Alaska variety of peas; plots I and L were sown with Cherry Belle radishes. The second location was made up of plots M through P. Plot M was an unfertilized and unplanted control. Plot N, similar to plot M, was fertilized and planted on June 22 with barley that was up on July 15. Plot O, untilled virgin land, lay between plots N and P and had a floral cover dominated by paper birch, whereas plot P was located on a tilled, unplanted hill top. The results presented in Fig. 2 show that plowing and/or removal of surface insulating cover resulted in marked increase in the depth of thaw. The vegetable plots and plot P, the tilled, unplanted hill top, reached depths of 59 inches or greater, whereas plot O had a maximum thawed depth of but 24 inches. It appeared that the cover of barley was an effective insulator since plot N had a shallow thawed layer comparable to that of the virgin land. Plot M was also much more shallow, probably because it had been planted previously with barley and other crops as recently as 1962 and 1963.

When the microbial counts of the cultivated plots are compared with those of the uncultivated soils (Tables 1 and 3) several observations can be made. It must be understood that soil sampling in the garden plots was done far enough from the root system to minimize disturbance of the plants. As might be expected, greater variation of all measurements (dry weight, temperatures, microbial numbers) was observed for the uncultivated soils than for the more homogeneous garden plots. Even so, certain generalizations are apparent.

Thermophilic microbes were more prevalent in garden soils than in uncultivated soils although the uncultivated "disturbed" soil B had the greatest number of thermophilic organisms observed. Thermophile isolates from all sources were members only of the genus *Bacillus*. With the exception of plot F (an exposed pond bottom) and plot O, uncultivated soils contained higher numbers of mesophilic microbes than their cultivated counterparts. Again excepting plots F and perhaps O, uncultivated soils contained more psychrophiles than garden plots. Omitting data for plot F, there was a suggestion that moulds may be more prevalent in uncultivated soils. No observable differences in microbial counts could be attributed to fertilization. It should be noted that plot O, the virgin land adjacent to plots N and P, regularly showed the lowest counts when compared with the barley-planted N, and the tilled, unplanted P.

TABLE 3. Microbial counts in garden plots and other cultivated and adjacent soils.*

	Soil	Dry Weight (%)		Soil Temp. (°C.)		Air Temp. (°C.)		Number of Microorganisms per Gram of Dry Soil							
								Nutrient Agar						Sabouraud's Dextrose Agar	
								55°C.		22°C.		2°C.		22°C.	
		L	H	L	H	L	H	L (x 10^2)	H	L (x 10^4)	H	L (x 10^4)	H	L (x 10^3)	H
Cultivated Garden Plots															
	(G)	65.1	73.9	7.9	20.3	7.4	24.0	46	1500	170	420	14	280	4.0	30
	(H)	66.5	71.8	—	—	—	—	460	730	81	250	9.5	56	4.5	20
	(I)	70.4	77.4	—	—	—	—	110	730	64	220	4.9	18	2.8	14
	(J)	63.8	79.8	10.7	21.7	7.2	23.1	34	670	150	590	5.0	310	3.2	29
	(K)	66.1	77.9	—	—	—	—	330	840	100	580	19	60	5.0	19
	(L)	71.3	82.5	—	—	—	—	140	810	100	260	6.0	34	9.0	40
Cultivated and Adjacent Soils															
	(M)	34.7	71.3	6.3	20.5	8.0	24.7	55	3000	180	410	32	380	1.6	11
	(N)	47.8	75.6	—	—	—	—	560	3900	180	620	40	160	1.7	67
	(O)	63.7	75.1	6.2	13.8	8.1	25.1	3.8	42	9.8	85	4.5	23	1.8	22
	(P)	43.5	74.6	7.9	18.3	8.8	26.1	48	1500	2.3	640	13	390	0.84	47

*Conditions are as given for Table 1.

All of these plots were tested for possible differences in chemical composition during the last 2 days of sampling. The garden plots were characterized by a pH in the acid range (Table 4) and high to very high concentrations of phosphorus, potassium, calcium, nitrate and ammonia-nitrogen. Magnesium was found in low to medium concentrations, and chloride was present in very low or undetectable amounts. Of all the soils in this series (G through P), only 3 contained high concentrations of sulfate on 5 and 6 August, and by those dates potassium was the only fertilizer element to be more prevalent in the fertilized soils than in the unfertilized counterparts.

TABLE 4. Chemical composition of cultivated and adjacent plots.*

		Parts per Million per Gram of Dry Soil							
Soil	pH	Phosphorus	Potassium	Calcium	Magnesium	Nitrate-nitrogen	Ammonium-nitrogen	Sulfate	Chloride
(G)	6.5	130	560	3000	250	25	25	25	25
(H)	5.8	80	280	4000	400	50	100	0	25
(I)	6.2	150	560	4000	450	25	50	1500	0
(J)	6.5	80	930	4000	600	60	75	0	0
(K)	6.5	150	1100	4000	700	25	75	0	0
(L)	6.3	60	1800	4000	700	25	50	0	0
(M)	8.0	50	500	4000	750	100	75	2000	25
(N)	6.8	75	840	4000	750	40	75	2000	0
(O)	5.2	35	1500	3000	400	1	30	0	0
(P)	6.4	75	610	4000	600	15	45	0	0

*Samples were taken on 5 and 6 August.

The barley-planted plot N and adjacent uncultivated plot M differed somewhat from the other plots in this locale. Plot M had a pH in the alkaline range, while both plots M and N had medium to high amounts of phosphorus and high sulfate concentrations. The remaining 2 plots (O and P) above the barley field were characterized by low pH, medium and high phosphorus, high potassium and calcium, medium magnesium, high ammonia, very low and medium nitrate, and low chloride and sulfate concentrations.

Direct observation suggested that the soil microflora and -fauna about Inuvik was more complex than in other regions of the North American Arctic and Subarctic which we have studied (Boyd 1958; Boyd and Boyd 1961; 1962; 1964; 1971; Brockman and Boyd 1963). Microscopic plants and animals, including bacteria, yeast and moulds, *Streptomyces* species, and protozoa (members of all the classes except *Sporozoa*), as well as rotifers and tartegrades, were observed microscopically. Higher members of the soil fauna were represented by a variety of bivalves, land snails, insects (spiders, ants, black flies, and mosquitoes at the surface), various rodents, birds, and a limited number of wolves and foxes. Humans undoubtably were associated directly and indirectly in the economy of the soil organisms in areas close to the town and in the garden plots.

TABLE 5. Physiological groups of microorganisms in soil and sediment.

Physiological Group	Soil Designation (G)	(O)	(A)	(B)	(C)	(D)	(E)	Mackenzie River Muds
Iron Oxidizers	0*	0	0	0	0	0	0	Bacteria
Acidophilic Sulfur Oxidizers	0	0	0	0	0	0	0	0
Photosynthetic Nitrogen-fixers	Blue-Green algae	0	0	0	0	0	0	0
Heterotrophic Nitrogen-fixers	*Azotobacter* Bacteria	*Azotobacter* Bacteria	*Azotobacter* Bacteria	*Azotobacter* Bacteria	*Azotobacter* Bacteria	*Azotobacter* Bacteria	*Azotobacter* Bacteria	*Spiral* bacteria
Ammonia Oxidizers	Bacteria	Bacteria	Bacteria	Bacteria	Bacteria	Bacteria	Bacteria	Bacteria
Photosynthetic Autotrophs	Green algae Blue-green algae	Green algae	0	Green algae	Green algae	Green algae	Green algae	Green algae
Photosynthetic Sulfur Bacteria	0	0	0	0	0	0	0	0
Photosynthetic Non-sulfur Bacteria	0	0	0	0	0	0	0	0
Methane Producers	0	0	0	0	0	0	0	0
Sulfate Reducers	Bacteria	Bacteria	0	Bacteria	Bacteria	Bacteria	Bacteria	Bacteria
Lactate Fermenters	Bacteria	Bacteria	Bacteria	Bacteria	Bacteria	Bacteria	Bacteria	Bacteria

*The designation "0" denotes no growth.

In an attempt to learn more about the physiological potentiality of the soil microflora and -fauna, an enrichment series was inoculated with samples of representative soil from a number of different habitats. A basal medium was made and varied in order to select out various physiological groups according to the protocol given by Boyd *et al.* (1966).

Results were obtained using liquid media and an original inoculum (20 mg. in each case) of mixed cultures (*i.e.*-soil), and only growth (under the defined nutritional conditions) or its lack could be observed. It is regrettable that we did not have the time or facilities to carry out complete taxonomic identification of the microbes in the physiological groups presented in Table 5. However, the data show that a wide variety of both autotrophic and heterotrophic microorganisms were present in soils of this region. In contrast to studies made at Point Barrow, all of the soils except A possessed green algae; only the cultivated soil G contained all of the photosynthetic types except photosynthetic sulfur and non-sulfur bacteria. Blue-green algae were observed only in the cultivated soils. No photosynthetic sulfur bacteria were detected; there was no evidence of H_2S except in one lake sediment (Hospital Lake) where large cells resembling members of the *Chromatium* genus were found (Boyd and Boyd 1967). No photosynthetic non-sulfur bacteria were present in any of the samples.

Among the heterotrophic (chemoorganotrophic) species, members of the genus *Azotobacter* (observed microscopically) were widespread as were other bacteria capable of growth in a nitrogen-free medium. Also found widely distributed were microorganisms capable of utilizing NH_3 as a primary nitrogen source (chemolithotrophs). The results given in Tables 2 and 5 show that some of the soils possessed relatively high amounts of nitrate, whereas others have little or none. This is indirect evidence for nitrification completely to nitrate-nitrogen. Since nitrite was not determined, the activity of members of the genus *Nitrosomonas* or nitrate-reducing species could not be ascertained. However, all of the soils studied had the potentiality to carry out autotrophic nitrification. Sulfate-reducers were also present in all but one sample. Bacteria capable of the anaerobic fermentation of sodium lactate were also widespread. Iron-oxidizing autotrophs were present in mud from the Mackenzie River but were not observed in any of the soil samples.

In addition to enumerating the microorganisms of cultivated and uncultivated soils, these studies were also extended to include bottom sediments from 8 lakes of the area and 2 different recently-exposed banks of the Mackenzie River near the west shore of the East Channel opposite the town (see Fig. 1). Large sterilized tin cans were dragged from behind a boat to collect material from the bottom. A report on the aquatic microorganisms of these bodies of water has already been published (Boyd and Boyd 1967).

The microbial contents of these sediments is presented in Table 6. Thermophilic bacteria were present in all of the samples and in numbers approximating the minimal numbers observed for uncultivated soils. Mesophilic bacteria and especially fungi were found in lower numbers than in almost all soils. Psychrophilic microbial numbers were similar to those observed for cultivated plots but less than those of uncultivated areas.

TABLE 6. Microorganisms in lake and river sediments.*

Location	Moisture (saturation)	Composition	Number of Microorganisms per Gram of Dry Sediment			
			Nutrient Agar			Sabouraud's Dextrose Agar
			55°C.	22°C.	2°C.	22°C.
	(%)		(x 10^2)	(x 10^4)	(x 10^4)	(x 10^3)
Dolomite Lake	61.4	Sand	3.6	430	75	0.50
Gravel Pit Lake	90.5	Black silt	9.7	45	1.1	0.11
Shell Lake	90.1	Black silt	130	12	1.3	0.10
Hospital Lake	88.7	Organic mud	110	13	0.88	0.00
Duck Lake	62.2	Silt	66	180	3.3	0.50
Twin Lake	63.0	Silt	74	35	30	0.29
Mackenzie River (opposite Boot Lake)	67.2	Silt	45	49	40	0.89
Mackenzie River (opposite seaplane anchorage)	66.2	Silt	66	20	31	0.22
Boot Lake	58.3	Silt	56	31	79	0.65
Hidden Lake	73.8	Sand-silt	33	48	56	0.89
Mackenzie River (exposed sediment)	68.9	Silt	78	110	200	0.97
Mackenzie River (exposed sediment)	68.9	Silt	60	44	43	0.20

*Conditions are as given for Table 1. Samples taken 1 August through 7 August.

There were also some major differences in chemical composition of these sediments when compared to the soils (Table 7). All of the samples, with 4 exceptions, had a pH well in the alkaline range; only one sediment had a pH below 6. However, the high pH could not be correlated with high ammonia-nitrogen. Phosphorus was usually present in low to very low concentrations, although the "lake" adjacent to the town's hospital was about medium in its level of this element, and 2 lakes had very high concentrations. Potassium and calcium were present in high to very high amounts; magnesium in 2 instances was medium to low, whereas in all other samples it was present in high to very high amounts. Sulfate was found in low to very low concentrations or was not detectable, except in the lake near the hospital which had a sulfide mud bottom, perhaps resulting from the anaerobic reduction of sulfate, for this lake's bottom as well as the others most likely had a low oxidation-reduction potential. This would also account for the absence of nitrate-nitrogen, since nitrification, whether it is carried out by autotrophic bacteria or heterotrophic fungi or bacteria, is an oxidative process requiring molecular oxygen. The rather large quantities of ammonia in all of the sediments was assumed to be

TABLE 7. Chemical composition of lake and river sediments.*

Area	Parts per Million per Gram of Dry Sediment								
	pH	Phosphorus	Potassium	Calcium	Magnesium	Nitrate-nitrogen	Ammonia-nitrogen	Sulfate	Chloride
Dolomite Lake	6.0	120	67	1600	200	0	480	0	0
Gravel Pit Lake	5.6	200	70	5000	400	0	450	50	0
Shell Lake	8.0	30	120	4000	1500	0	150	0	50
Hospital Lake	8.2	25	610	6000	900	0	130	0	0
Duck Lake	6.2	75	610	2000	2000	0	300	2000	50
Twin Lake	8.0	25	610	6000	1500	0	45	0	50
Mackenzie River (opposite Boot Lake)	8.1	15	940	6000	1500	0	50	0	0
Mackenzie River (opposite seaplane anchorage)	8.0	30	1100	6000	2000	0	10	0	0
Boot Lake	8.0	25	610	6000	2500	0	15	0	0
Hidden Lake	6.5	30	610	4000	130	0	700	250	0
Mackenzie River (exposed sediment)	8.1	60	840	5000	6000	0	450	0	0
Mackenzie River (exposed sediment)	8.2	30	280	6000	1500	0	30	0	300

*Samples were taken on 7 August.

the product of the anaerobic deamination of amino acids, accumulating as a result of the settling of organic matter during runoff and ice-free periods. As with the soils, chloride was present in either low or non-detectable amounts.

DISCUSSION

As in other high-latitude regions, soils of Inuvik will support the growth of a significant number of microorganisms which contribute to various aspects of soil fertility. Continuous permafrost is present, but in most cases thaw takes place during the summer to a greater depth than at Point Barrow, particularly in agricultural areas.

Thermophilic bacteria exist in far greater numbers in Inuvik soils than in Point Barrow soils. Although comparable thermophile counts have been found in central Alaska (Fournelle 1967), these soils were from a transitional area where tundra meets birch-spruce forests and were more closely related to the Subarctic Brown Wooded soils than the truly tundra soils to the north. Agriculture in a few cases appeared to increase these numbers. However, when Inuvik (68°21′N.) is compared to a region in Europe at about the same latitude (Tromsø, Norway: 69°40′N.), which also supports the growth of higher vegetation, the thermophilic flora of the Norwegian soils is in the same range as at Point Barrow; at Tromsø there is no permafrost, and soil temperatures are warmer. Agriculture in this area is accompanied by increased numbers of thermophilic bacteria, and fertilizers are not necessarily the source of these microorganisms (Boyd and Boyd 1971). At Inuvik, plowing which would increase the oxygen phase of the soil had little effect or was offset by other environmental factors, whereas in Norway it may have been responsible in part for the observed differences.

Thermophilic bacteria also exist in rather high numbers in the bottom deposits of lakes and rivers in the Inuvik area. Since our techniques did not allow us to enumerate anaerobic organisms and since river and lake bottoms could be expected to have a low oxidation-reduction potential, it is probable that many of these aerobic or facultatively anaerobic organisms entered the water via soil runoff and remained viable, in some cases without growth, under these environmental conditions.

Mesophilic and psychrophilic bacterial counts of uncultivated soils in some cases were in the range of 1 to 50 million per gram — the range normally found in temperate regions (Waksman 1952). However, contrary to results obtained in temperate regions and at Tromsø, cultivation did not increase the number of these organisms significantly in the Canadian soils (Boyd and Boyd 1971; Waksman 1952). It would be interesting to carry out year-round studies to determine if these results are consistent with population cycles occurring over long periods of time.

Psychrophilic microbes were in greater number in uncultivated soils than in the cultivated counterpart. Our counts of both mesophilic and psychrophilic bacteria compare favourably with those reported by Ivarson (1965) for the Inuvik area. Moulds, in greater number at Inuvik than at Point Barrow, appeared also to be in greater number in uncultivated than in cultivated soils. The slightly higher

numbers reported by Ivarson (1965) may be related to our higher temperature of incubation and not to any differences in media, for we observed no significant variation between Sabouraud's dextrose agar and rose bengal agar when we employed both media to enumerate moulds in Alaska (Boyd and Boyd 1961). Contrary to data obtained at Point Barrow, we were unable to observe consistent, seasonal increases in psychrophilic bacterial numbers at Inuvik. This finding may be the result of more limited sampling at Inuvik than at Point Barrow.

In almost all cases the pH of the soils at Inuvik was higher than encountered at Point Barrow, and the temperature was warmer for longer periods of time. There was no significant difference in chemical composition with the possible exception of higher nitrate-nitrogen which might account in part for the microflora differences. Drainage was good: there were no areas which were water-logged, and for this reason the oxidation-reduction potential was probably higher. All of the above factors tend to favour the growth of aerobic mesophilic bacteria and could account for the higher numbers of microbes encountered.

There was also a profound difference in vegetation, both natural and cultivated, which would result in a qualitative difference in the organic fraction (humus) and could affect the numbers and types of microorganisms which might be encountered. Nothing is known of microhabitats and their roles in the ecology of this area. This knowledge would be especially interesting as related to the large numbers of thermophilic bacteria that were encountered.

It would also be of some interest to know something of the soil-plant nutrient interactions of tundra plants indigenous to Point Barrow versus those more highly developed forms common to the Inuvik area and what effect they might have on the overall growth and metabolic activity of the soil microflora.

Further work in the far North will be necessary, of course, before the exact role played by microorganisms in soil fertility and plant growth can be fully ascertained and their role in the overall ecology of these regions be fully understood and appreciated.

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