Tundra degradation in the vicinity of the Polish Polar Station, Hornsund, Svalbard

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Studies performed in the summers of 1979 and 1980 in the surroundings of the Polish Polar Station at Hornsund, Svalbard, aimed at determining the impact of the presence of a research station on its immediate tundra surroundings. The sources of environmental degradation were singled out; the ways of expansion of various contaminants and the degree of their harmfulness to the environment were evaluated. This gave insight into the extent of tundra degradation in the vicinity of a polar research station. It was found that the heaviest impacts were caused by changes in the chemical composition of the soil, resulting from spills of petroleum-derived fuels, and by transport which damaged the surface of the tundra.

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In polar regions, human impact is particularly dangerous on account of the great sensitivity of the tundra ecosystem (Ives 1970; Bliss 1971; Dorogostaiskaya 1972; Wielgolaski 1972; Billings 1973; Bliss et al. 1973; Dunbar 1973; Dahl 1975; Doane 1977) to even slight disturbances, e.g. those caused by the presence of a small research station. So far, only a few papers reporting complex studies of the effect of the presence of polar research stations on the tundra ecosystem, have been published (Smith 1977). There is a predominance of papers describing the principles of handling problems like water-and-sewage management, heating management, sewage treatment technology and solid wastes management (Schindler et al. 1974). Some papers are concerned with the technical problems of fresh water supply or electric energy production (Pope 1967; Shafer 1967; Whitmer 1967; Barber 1968). The present studies are an attempt at a many-sided estimation of the effect of a polar research station on the environment. In assessing this effect, the balance of the material utilized at the Station and of the resulting waste has to be established, and the ways of expansion of various contaminants in the vicinity of the Station determined.

Methods

Studies were performed in the surroundings of the Polish Polar Station (at Isbjørnhamna, Hornsund) between June and September in 1979 and again in 1980. The Station comprises a dwelling house for 10 persons in the winter and 28 persons in the summer, a power station with two diesel engines (70 h.p. each), a storage shed, three tanks for fuel (25 m^3 each), a storage yard for fuel barrels and housing for motor boats in the bay (Fig. 1). The amount of material supplied to the Station and the resulting quantities of waste penetrating the soil, air and water in the surroundings of the Station were determined partly by a scheme prepared by Odum (1972) for farms.

The sources of contamination comprised: (1) petroleum-derived fuel spills; (2) sewage carried through a sewer ditch and penetrating into soil; (3) excrements (faeces and urine) collected in metal containers (0.48 m^3) and dumped in the bay; (4) solid wastes of which 83% were dumped into the sea, the rest burned.

To estimate the extent of contamination caused by the power station, the content of petroleum-derived substances in the soil was determined. The dustfall was measured and the amounts of noxious combustion gases reaching the atmosphere calculated using the data of Michałowska (1973) for fuel oil combustion products. The content of petroleum-derived substances in the soil was determined by semimicroextraction with n-hexance (Hermanowicz et al. 1976). These determinations were performed for 47 soil samples collected at depths of 0–5 cm, as well as 49 samples taken from other sites at depths of 2, 5, 10, 15, 20, 30, 40, and 50 cm (nine profiles). At the sites of nine profiles (at a depth of 10 cm) the water

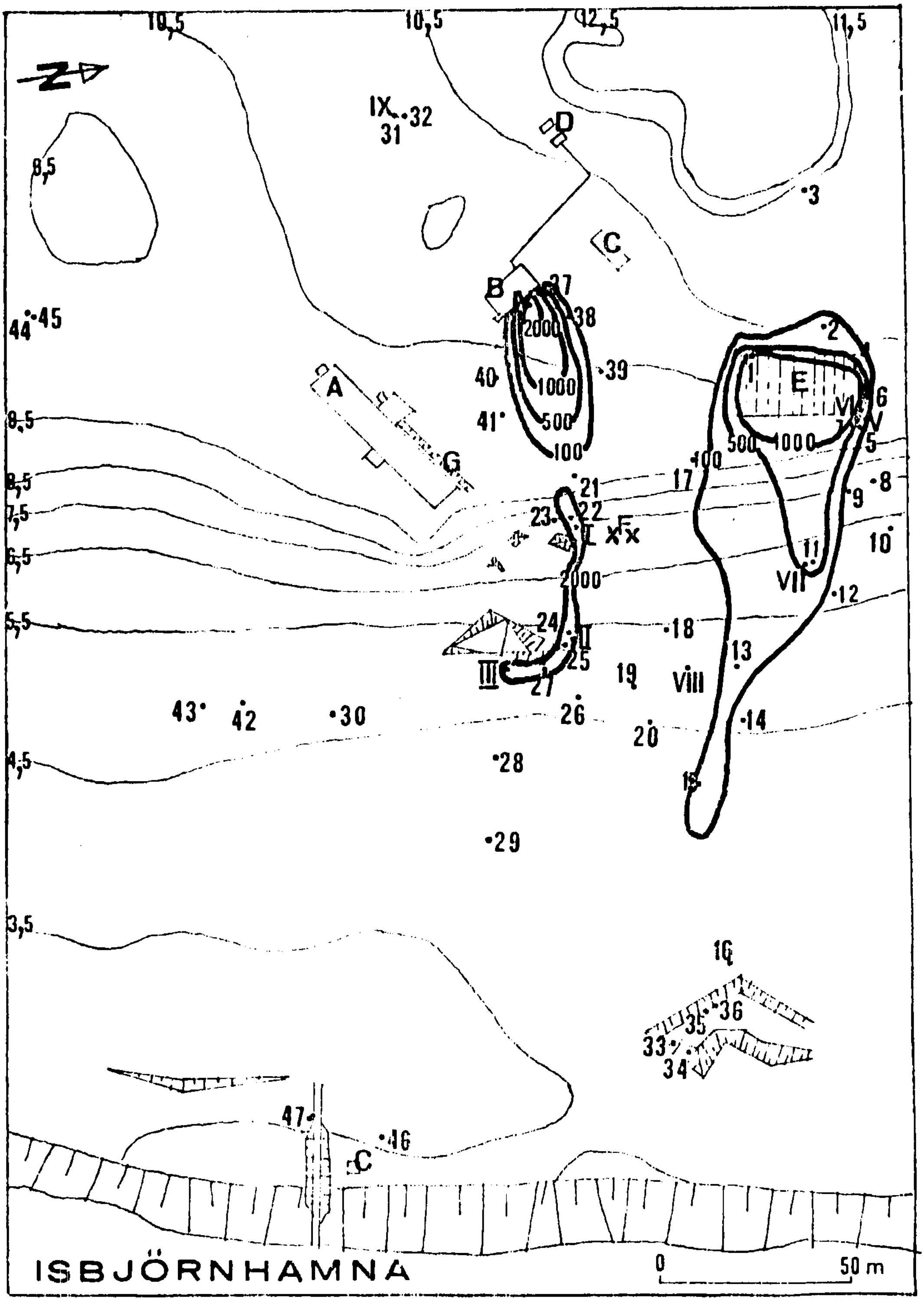

Fig. 1. Distribution of fuel content in soil in the vicinity of the Polish Polar Station (at 5 cm depth): 1–47 – sites of soil sample collection; I–IX – profiles of soil sample collection; ~ – contour lines; ○ – isolines for 100, 500, 1000, and 2000 mg of petroleum-derived fuel/100 g soil D.M.; A – dwelling house; B – power station; C – storage shed; D – fuel tanks; E – storage yard for fuel barrels; F – solid waste burning site; G – sewer ditch.

infiltration rate was measured using a Burger's cylinder (Instruction for designing of a hydrographic map of Poland, 1964). The dustfall was determined at six sites by exposing glass traps situated 2–3 m over the ground; the degree of dustiness was estimated with a Zeiss 'konimeter' (Juda & Chróściel 1974).

To gain insight into the effect on the environment of sewage from the Station, its volume per 24 h was measured ten times, and the chemical composition of this sewage and of surface water near the Station was estimated. The analyses comprised determinations of pH, conductance of electrolytes, total hardness, chloride, sulphate, phosphate, surface-active substances (Hermanowicz et al. 1975; Markowicz & Pulina 1979) and nitrate nitrogen (Golterman 1978). In samples of surface water, the conductance of electrolytes was measured with a battery-type N571 Mera Elwro conductometer, and total ion concentration was calculated. Nitrate nitrogen and phosphate were assayed using a Zeiss 10 spectrocolorimeter.

Changes in the tundra environment, resulting from mechanical damage by vehicles and humans to the surface of ground, were estimated by phytosociological records, granulometric analysis of ground, and measurements of the depth of permafrost.

Results and discussion

It was calculated that during one year about 1.5 t of solid wastes (D.M.) and 225 m^3 of sewage were produced at the Station. An exact material-and-energy balance of the material utilized at the Station and of the resulting waste will be published separately (Krzyszowska, in press). The degree of tundra degradation near the Station depends more on the quality of the waste than on its amount.

The mechanical and chemical effects entail the greatest risk for the environment. Travelling vehicles (a UAZ touring car, a tractor and a stripper-and-loader machine) and people (by trampling) damage the plant cover and cause changes in the granulometric composition of the ground. Phytosociological records were obtained on a path passed about 500 times by an ornithologist on his way from the Station to a colony of Little Auks *Alle alle* on the Ariekammen Mountain. They showed that mechanical destruction first affected lichens, subsequently mosses, and last vascular plants, in accordance with the findings of Greller et al. (1974). On transport roads and foot paths, the contents of sand and gravel increased twice in relation to the stone fraction. This was demonstrated by determination of the granulometric composition of ground samples which were collected both from the road leading from the Station to the Ariekammen Mountain, and from the ground beside the road. Destruction of plant cover and changes in the granulometric composition of the ground cause alterations in the thickness of the active layer. This thickness is 2–32 cm smaller on the roads than next to them, in contrast to wet terrains where thermokarst occurs (e.g. Bliss & Wein 1972; Haag & Bliss 1974; Bunnell et al. 1975; West 1976; Webber & Ives 1978). The more shallow location of frozen ground on roads than next to them can be explained by the fact that – particularly during the thaw period – roads are better drained, and a ground moisture content exceeding 50% hinders the process of thawing. Moreover, an increase in the fine-grained fraction of ground on roads as well as soil compactness reduces penetration of sun rays.

The chemical effects of the Station on the environment are caused by fuel oil spills on the ground and sewage carried to soil, as well as by solid and gaseous products of fuel oil combustion. The content of petroleum-derived fuel in samples of soil and plants is a measure of chemical contamination of the tundra by this product. Preliminary studies performed in 1979 pointed to big differences in surface contamination by petroleum-derived substances (Krzyszowska 1981). Factors accounting for the differences in contents of fuel oil in the ground comprise: configuration of the terrain, amount and quality of vegetation, kind of soil and depth of the ground-water level (Bliss 1970; Wein & Bliss 1973; Moore & Phillips 1975; Sextone & Atlas 1977). In summer 1980 the contents of petroleum-derived fuel in the ground were greatest at the storage yard for fuel barrels (4325 mg/100 g of soil D.M.), near the power station (2453.3 mg/100 g), on the escarpment along the run-off of fuel (2400–24237 mg/100 g), and at the base of the escarpment (2331 mg/100 g) (Fig. 1). The contamination by petroleum-derived fuel at these sites is comparable to that in the vicinity of gasoline filling stations in Warsaw (Daukszo et al. unpublished), reaching as far down as 40 cm. This is possible on account of the high permeability of the ground

Table 1. The content of petroleum-derived fuel in soil samples from profile II (location – Fig. 1).

No. of samples	Depth of sample collection (cm)	Moisture %	Lithological characterization of soil	Content of petroleum-derived fuel in soil (mg/100 g soil D.M.)
6	0–2	21.82	plant cover	17000.9
7	2–5	18.35	coarse sand, gravel	4224.9
8	5–10	11.77	coarse sand with metamorphic stone	290.3
9	10–25	17.89	clayey sand	157.4
10	25–40	14.48	coarse sand, gravel	169.6

($3 \cdot 10^{-4} - 3 \cdot 10^{-2}$ cm/s) (Table 1). The installation of fuel tanks in 1980 has reduced further contamination of the tundra, even though fuel biodegradation is attenuated by the persistence – on ground surface – of temperatures below 0°C throughout 8–9 months (McCown 1973; Doane 1977; Sextone & Atlas 1977; Westlake, Jobson & Cook 1978; Lissauer & Murphy 1978).

As a result of fuel oil combustion at the power station, the yearly production of waste gases is about 3 t; yearly dust emission amounts to about 0.5 t. The maximum reach of dustfall from fuel oil combustion can be estimated at 60 m westward of the power station (corresponding to 0.75–1.54 kg/100 m^2 × month), in agreement with the predominant direction of wind. Within the remaining area, the dustfall amounted to 0.01–0.28 kg/100 m^2 × month, corresponding to mean natural dustfall from sea water in the coastal zone, about 0.18 kg/100 m^2 × month (Manecki 1978).

Table 2. Chemical composition of fresh water and sewage in the vicinity of the Polish Polar Station (mean value ± SE; range)

	Water from pools above the outlet of sewer ditch	Water from pools beneath the outlet of sewer ditch	Sewage from the Station	Fresh water in the Fugleberget drainage basin	Polish standards for admissible level in sewage
pH	7.4 ± 0.1 6.4–7.8	7.6 ± 0.1 7.2–8.6	7.2 ± 0.5 5.4–9.1	7.2 ± 0.1 6.4–8.0	6.5–9.0
total hardness mval/dm³	1.19 ± 0.12 0.40–1.94	1.30 ± 0.18 0.70–2.70	— —	1.30 ± 0.08 0.38–1.98	
total concentration of ions mg/dm³	109.04 ± 20.63 32.83–347.0	92.12 ± 13.82 22.30–162.92	351.20 ± 114.02 57.00–1227.0	1.30 ± 0.08 0.38–1.98	<1000
chloride mg/dm³	8.28 ± 1.17 2.06–14.49	10.41 ± 2.06 4.19–26.08	45.76 ± 4.07 23.25–60.00	3.38 ± 0.42 0.57–13.13	<400
sulphate mg/dm³	5.73 ± 1.72 0.71–21.12	7.38 ± 1.41 0.71–14.80	54.61 ± 11.09 20.00–135.00	— —	<300
nitrate nitrogen mg/dm³	1.12 ± 0.21 0.08–2.50	0.56 ± 0.13 0.03–0.98	18.64 ± 5.94 0.05–52.00	1.61 ± 0.50 0.01–14.80	—
phosphate mg/dm³	0.02 ± 0.01 0.00–0.10	not detected	2.71 ± 0.83 0.06–9.20	0.10 ± 0.05 0.07–1.20	—
detergents mg/dm³			0.72 ± 0.19 0.05–2.00		<1
No. of samples	14	11	10	32	

Sewage from the Station is another factor which may possibly affect the environment. The chemical composition of this sewage remains within the range of Polish standards for sewage (Table 2). The composition of the water from small local pools situated either below or above the outlet of the sewer ditch is similar (Table 2). Thus, the sewage yearly discharged to the tundra in an amount of about 224.7 m^3 (42 l/head × 24 h) has not so far affected the environment in the vicinity of the Station. This may be due to the high permeability of the ground near the sewer ditch, resulting in penetration of sewage to the bay, or to sewage freezing in the permafrost. At the sites of frequent urination near the Station house, nitrophilic algae *Prasiola crispa* occur. These algae are also found at the sites fertilized by Little Auk excrements.

Summing up, it was found that the range and extent of anthropogenic mechanical and chemical effects on the tundra testify to differences in environmental degradation. The criteria used for estimation of the extent of degradation comprised: the degree of plant cover destruction, changes in the granulometric composition of the

Table 3. Criteria for estimation of the degree of environmental degradation in the vicinity of the Polish Polar Station, Hornsund.

Criterion	Strongly degraded area	Moderately degraded area	Non-degraded environment
Degree of damage to plant cover (%)	100	50	0–c. 3%
Content of petroleum-derived fuel in soil (at a 5 cm depth) (mg/100 g soil D.M.)	>100	<100	0
Dustfall from burned fuel (kg/100 m^2 × month)	>0.5	<0.5	0
Increase in the fine-particle fraction of soil (%)	>10	<10	0

ground, content of petroleum-derived substances in soil, and dustfall from fuel oil combustion (Table 3). The most degraded region (2.2 ha) includes the area between the Station buildings, the terrain beneath the outlet of the sewer ditch, and the roads going beyond the Station. The partly degraded region (1.3 ha) includes the area next to the meteorological station and to the accommodations for magnetism measurements. The surroundings of the Polar Station, remaining under direct human impact, occupy an area of 3.5 ha.

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