

POLISH POLAR RESEARCH	12	3	419-434	1991
-----------------------	----	---	---------	------

Krzysztof W. OPALIŃSKI

Institute of Ecology  
 Polish Academy of Sciences  
 Dziekanów Leśny  
 05-092 Łomianki, POLAND

## Primary production and organic matter destruction in Spitsbergen tundra

**ABSTRACT:** In the Fugleberget catchment area (Spitsbergen, Hornsund Fjord region) the growing season lasted 95 days, with growth beginning under the snow. In this time shoots of moss *Calliergon stramineum* reached a mean length of 19 mm and mean biomass of 0.593 mg dry weight. Annual primary production of moss communities amounts to 220–270 g dry weight per square meter per year.

In the first year of destruction the dead plant material lost 30–45% of its initial value, after 10 years only ca 25% of the initial amount of organic matter was left.

**Key words:** Arctic, Spitsbergen, tundra, production, destruction.

### Intriduction

The tundra ecosystem is characterized by low productivity caused by the limited energy input at high latitudes (Billings 1973). Slow decomposition and mineralization in this “conservative nutrient system” (Tieszen 1978a) slow the cycling of nutrients in the tundra. In tundra ecosystem the majority of primary production (99%) enters the decomposition chain (Bliss *et al.* 1973), whereas herbivores, especially invertebrates, play no important role in the energy flow and matter cycling (Svensson and Rosswall 1980, Remmert 1966, 1980). According to Bliss (1975) “tundra is largely a detritus system in which solar radiation — plant — decomposers — organic matter is the main pathway”.

The poverty of vegetation and its low productivity at high latitudes (High Arctic) is caused by several features, the most important of which are: shortage of nutrients (Kalff and Welch 1974, Shaver and Billings 1977, Oechel and Sveinbjornsson 1978, Tieszen 1978a), low humidity (Szerszeń 1965, Billings 1973, Bliss 1975, Webber 1978), low temperatures and a short growing period (Bliss 1975, Shaver and Billings 1977, Tieszen 1978a,b, Webber 1978, Priddle 1979).

Experimental fertilization of tundra communities points to the shortage of nutrients as a main cause of tundra poverty. Such fertilization brings about a 2 to 30-fold increase of plant production (Rüppell 1968, Bliss 1975). In the case of natural enrichment of the tundra by faeces produced by breeding colonies of sea birds an increase in plant production is also observed (cf. Belopolskij 1957, Remmert 1968). Eurola and Hakala (1977) have called this phenomenon the "ornithocoprophilous influence". As a result of this nutrient influx from the bird colonies, a special type of soil — so called ornithogenic soil — can be formed (Syroečkovskij 1959).

The aim of the present paper is to describe the organic matter cycling in an Arctic tundra ecosystem supplied with nutrients from a breeding colony of sea birds. Attention was especially focussed on measurements of primary production and the rate of destruction of moss communities that were a predominant feature of this ecosystem.

## Study area

The study site was a small fragment of High Arctic tundra situated in south-western part of Spitsbergen near the Hornsund Fiord (77°00'N 15°33'E). The site is situated on the southern slopes of Fugleberget (569 m a.s.l.) and Arieammen (511 m) stretching across the first sea terrace down to the sea shore (Isbjornhamna, Hornsund). Its area was about 1.36 km<sup>2</sup>. The site was a quasi-closed system consisting the catchment area of the Fuglebekken River.

According to French (1974) this tundra is of the "cold oceanic" type. Average summer temperature is 2°C, average winter temperature — 8°C, with total precipitation below 350 mm per year, the majority as snow (Baranowski 1975). The substratum consists of initial (premature) Arctic soils — lithosols (Plichta 1977). The soil microflora is not very active (Zabawski and Żurawska 1975). The vegetation cover varies from 50 to 100% and stretches from the sea shore to the height of ca 250 m on Fugleberget and 350 m on Arieammen.

According to Eurola and Hakala (1977) the vegetation in this site is an ornithocoprophilous one of the *Chryso-splenium tetrandarum* — *Oxyria digyna* type. Within the Fugleberget catchment area these authors distinguished several characteristic plant communities. On well drained (dry) rocks in the region of bird colonies ("the bird cliffs talus slopes covered of boulders") there is a plant community in which lichens play an important role — the *Xanthoria elegans* — *Umbilicaria* type. On moist shelves ("bird cliffs ledges") there is a community with preponderance of vascular plants — *Saxifraga cernua* type. The Fugleberget and Arieammen slopes are dominated by the community of "moist bird cliffs meadow" with vegetation of *Chryso-splenium tetrandarum* — *Plagiamnium* type. In this community, at least two thirds of the total cover constitute mosses, mainly *Splanchnum vasculosum* and *Calliergon stramineum* (cf. Kuc 1963). The

lowest part of the Fugleberget catchment area (“maritime lowland”) is covered by dense vegetation of mosses forming “frische Moosheiden” of *Cassiope tetragone* type (Eurola 1968). *Calliargon stramineum* is here a dominant species.

Information on the species composition of vascular plants, mosses and lichens of the Fugleberget catchment area and of the vicinity of Hornsund is given by Środoń (1958), Kuc (1963) and Nowak (1965).

Different degrees of plant cover and chemical properties of surface waters allow two zones to be distinguished: a western one — more fertile with richer vegetation, bordering, through the belt of cliffs, with fertile, rich in vegetation slopes of Ariekammen, and an eastern zone — with poorer vegetation, bordering with lateral moraine of Hansbreen glacier (see Fig. 1). The western part is richer because of the fertilizing effect of a breeding colony of Auks (*Plautus alle*) nesting on the slopes of Ariekammen at about 100 m a.s.l. The birds are present in the

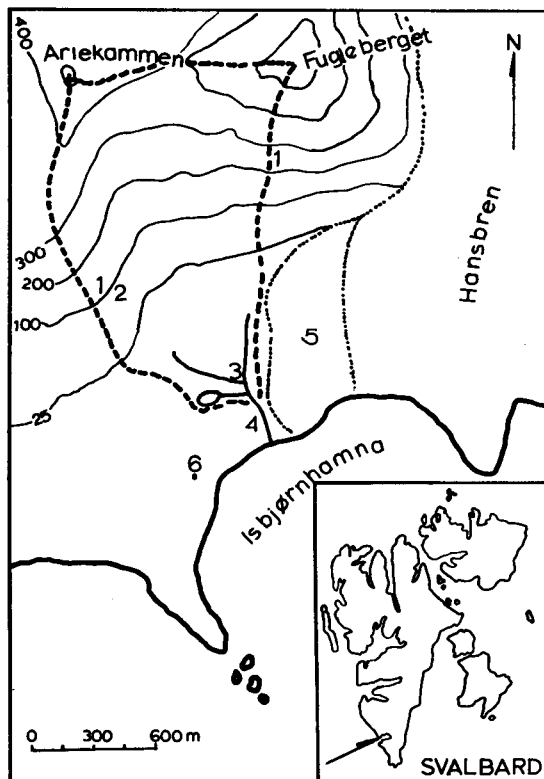


Fig. 1. The sketch of investigated area — Fugleberget catchment (Hornsund Fiord region, Spitsbergen). Dashed lines — the boundaries of investigated area, 1 — Little Auks colony, 2 — sites of primary production measurement “Colony I” and “Colony II”, 3 — site “Lowland”, 4 — Fuglebekken river, 5 — Hansbreen glacier moraine, 6 — Polish Polar Station Hornsund.  
Heights in meters

colony from the middle of May to the middle of August. The bird numbers are estimated as about 100 000 individuals (Stempniewicz, *pers. comm.*). Melt water passing through the bird colony is strongly enriched in nutrients, especially by nitrogen and phosphorous compounds (Krzyszowska, *unpubl.*).

The present investigations were carried out in three sites. Site "Colony I" was situated at a height of about 80 m a.s.l., on Arikammen slopes, on wet rocky rubble totally covered by moss, about 20 m below the bird colony. *Splachnum vasculosum* Hedw. was the dominant moss species. It is a nitrophilous species commonly occurring on moist, well fertilized sites. It did not occur in the lower parts of the tundra (*see also* Kuc 1963). The "Lowland" site was situated in the lower part of the catchment area, on the terrace I ca 15 m a.s.l., near the brook collection water from the whole catchment. The terrain was moist, slightly sloping southwards, totally covered by a moist moss meadow ("friche Moosheide"). *Calliergon stramineum* was the predominant species here. This species is commonly observed on low and moist shores (maritime lowlands); in the vicinity of Hornsund it is very common (Kuc 1963). The third site "Colony II" was considered only as a comparative area and was situated on a cliff ledge below the bird colony near "Colony I". It was an assemblage of vascular plants with alpine chickweed, *Cerastium alpinum* L. (*sensu lato*) as dominant species. This is a plant with a circumpolar range, typically missle and high Arctic, occurring in the vicinity of bird colonies, and commonly observed on the Fugleberget slopes (Polunin 1959, Eurola and Hakala 1977).

## Methods

Net primary production of the above ground parts of plants was measured using a method of "harvesting" (*cf.* Milner and Hughes 1968) at three sites: "Colony I", "Colony II" and "Lowland".

Three vegetation samples with a sampler of 9 cm diameter (63.6 cm<sup>2</sup>) were collected on each occasion. For each sample 20 measurements were made of the length and dry weight of newly grown (alive parts) of single shoots of moss and the total weight of living material in the whole sample was determined. Dry weight of plants was assessed after drying at 60°C for 48 hours. The length of individual shoots was measured with an accuracy of 1 mm, weight — with 0.001 mg. The ash content of moss was determined by burning the samples at a temperature of 450°C; C, H and N was determined by CHN Analyser (Carlo Erba).

Moss samples were collected on 20th May, 8th and 19th June, 13th July, 3rd and 22nd August, 1980, that is on 1, 20, 31, 55, 76 and 95 day of the growing season. The samples of vascular plants were collected once at the period of maximum biomass, *i.e.* on 3rd August.

## Results and discussion

### Growing season

Using the definition given by Billings (1973) ("the growing season is the length of time during which plants are metabolically active above ground at site") the start of growing season in the Hornsund region in 1980 was 20th of May. On this day fresh green shoots 0.5 mm in length were observed on *Calliargon stramineum* under ca 1 m of snow, the temperature at daytime was around 0°C. This is the period of permanent day light, with the noon sun rising to 35° and at midnight to 8° above the horizon. Thus, insolation could penetrate the snow and warm up dark surfaces of moss below. It is commonly accepted that the beginning of growing season in High Arctic Zone (e.g. Barrow, Alaska) falls between 5th and 24th June (Tieszen 1978a), but usually the period with positive temperatures of air is considered as the vegetation season (cf. Bliss 1975, Webber 1978, Tieszen 1980a). However, Collins and Callaghan (1980) reported that mosses can be metabolically active under snow and the photosynthetic process in polar plants is adapted to low temperatures (Tieszen 1980b). The metabolic processes can occur even at air temperature below zero at a strong isolation.

Melt water started to leave the catchment area on 4th of June, 1980. On 20th of June sporophytes appeared on *C. stramineum*. Kuc (1963) reported that in the summer season of 1958 there were no sporangia on *C. stramineum* and *Splanchnum vasculosum* in the Hornsund region.

The maximum of plant biomass was observed in the first half of August (3 Aug.) which is in accordance with data for other tundra sites, e.g. Barrow, where the maximum plant production falls in the first days of August (Tieszen 1972, 1978a), i.e. after about 60 days of the growing season duration (Webber 1978).

The second part of September (22 Sept.) can be considered as the end of vegetation season, when the drying up of tundra occurs and both snowfall and negative temperatures begin, and the sun at noon is only about 20° over the horizon. In the period of studies (1980) the duration of growing season in the Fugleberget catchment area amounted thus 95 days. The length of growing season in other regions of High Arctic amounts to 71–81 days (Billings 1973, Tieszen 1978a, Webber 1978). In Arctic the duration of this season can vary  $\pm 20$  days but this variation only slightly affects the tundra productivity (Bliss 1975).

### Growth of the moss, *Calliargon stramineum*

In spring not all shoots of moss develop on old, last year's ones. As much as 44% of the 200 shoots examined of this moss species had no green buds on the top of last year's shoots. It is a phenomenon commonly observed in tundra mosses — Longton and Greene (1967) and Priddle (1979) have reported the lack of growth in 15–42% of moss individuals (*C. sarmentosum*, *Drepanocladus*

*seduncus*, *Polytrichum alpestre*). This phenomenon can reflect either dying of part of population or pausing in a given season which can be a sort of strategy of a given species to survive in an extremal habitat (cf. Callaghan and Collins 1976, Dunbar 1977).

Linear growth of individual shoots of *C. stramineum* during the summer was regular (Tab. 1). Mean annual growth in length amounted to 19.04 mm, and the mean daily growth rate was 0.20 mm. In the case of *Splanchnum vasculosum* the growth amounted to 15.99 mm and 0.17 mm, respectively. According to the literature data the annual growth of tundra mosses amount from 3 to 40 mm (Longton and Greene 1967, Collins 1976, Priddle 1979).

Table 1  
Linear growth\*, biomass\*, and chemical composition\*\* of *Calliergon stramineum* shoots during growing season in Fugleberget area, Spitsbergen. SE — standard error

Date	Shoot length (mm ± SE)	Shoot dry weight (mg ± SE)	Shoot chemical composition (in per cent of dry weight)					C:N Ratio
			N	C	H	Ash	O***	
May 20, 1980	0.50	0.052 ± 0.004	1.74	46.88	5.76	4.22	42.41	27
June 6, 1980	3.55 ± 0.10	0.139 ± 0.041	3.91	42.75	6.94	5.28	41.12	11
June 18, 1980	5.00 ± 0.19	0.181 ± 0.014	4.88	43.86	6.35	6.43	38.48	9
July 13, 1980	11.25 ± 0.45	0.426 ± 0.022	2.07	48.09	6.16	5.82	37.86	23
Aug. 3, 1980	13.55 ± 0.40	0.650 ± 0.040	1.87	48.53	6.76	5.19	37.65	26
Aug. 22, 1980	19.54 ± 0.53	0.595 ± 0.041	1.34	42.48	6.49	4.17	45.52	32

\* average of 20 measurements

\*\* average of 3 replications

\*\*\* as 100% — (N% + C% + H% + Ash)

The increase in biomass of an individual shoot of *Calliergon stramineum* is slow up to the middle of June, i.e. to the moment of sporangium formation. After this, an acceleration of moss growth occurs lasting to the beginning of August, when the maximum biomass is reached, followed by a slight (10% of the maximum value) decrease to the end of summer. The mean annual increment in the biomass of one shoot amounted to 0.543 mg dry weight, its daily rate being 0.0058 mg. In the case to *S. vasculosum* the corresponding values are 0.608 mg and 0.0064 mg. For comparison the annual increment of vascular plant — Alpine chickweed, *Cerastium alpinum*, amounted to 31.43 mg dry weight and by assuming that the growing season for this plant also lasted 95 days, its mean daily growth rate would have been 0.331 mg.

The observed decrease in biomass of *C. stramineum* at the end of summer probably resulted from withdrawal of some substances as well as P and N compounds to deeper parts of the plant (in the case of vascular plants — to roots — see Chapin 1978). Such storage facilitates a rapid initiation of plant development in spring, when favourable conditions appear and, according to Callaghan and Collins (1976), is an adaptation to the short growing season.

### Primary production of moss communities

During the first month of moss growth the biomass production was high, especially in the more fertile site "Colony I". After August 18, the production rate decreased and the production in both sites was similar (parallel course of the two curves in Fig. 2). In site "Colony II" the maximum living moss biomass amounted to  $281 \text{ g m}^{-2}$ , annual production was  $269 \text{ g m}^{-2} \text{ year}^{-1}$ . At site "Lowland" the maximum living biomass was  $229 \text{ g m}^{-2}$  and annual production —  $217 \text{ g m}^{-2} \text{ year}^{-1}$ . For comparison the biomass production of *Cerastium alpinum* at site "Colony II" was  $242 \text{ g m}^{-2} \text{ year}^{-1}$ . These values for primary production in the Fugleberget catchment area are much higher than values reported for the Arctic tundra, e.g. in Barrow or Devon Island (Bliss 1975, Bunnell, MacLean and Brown 1975), but considerably lower than listed for the tundra of subantarctic islands (Clarke, Greene S.W. and Greene D.M. 1971, Priddle 1979, Fenton 1980).

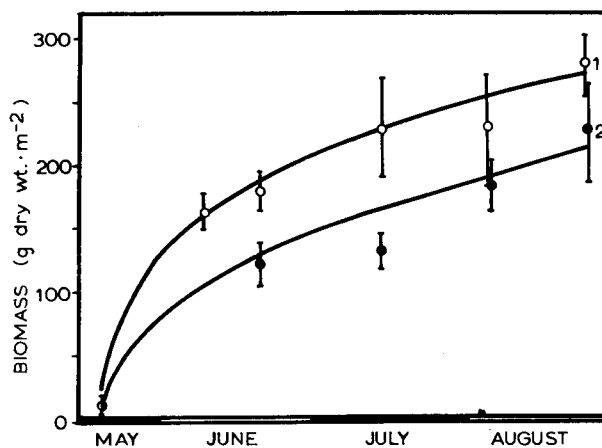


Fig. 2. Seasonal progression of mean standing crops of dry weight of mosses in Fugleberget catchment area. 1 — site "Colony I" (domination of moss *Splanchnum vasculosum*), 2 — site "Lowland" (domination of moss *Calliergon stramineum*)

### Destruction

In the moss meadows of the catchment area the moss carpet was about 10–15 cm deep with only the upper 16–19 mm of live moss shoots. The lower part of the moss layer consisted of dead shoots about 10 cm long. If it is assumed that year by year variations in climatic conditions only slightly affect plant growth (see Bliss 1975), one can assume that the annual increments of moss shoots are the same in subsequent years. From known values of such annual increments (*Calliergon stramineum* —  $16 \text{ mm year}^{-1}$ , *Splanchnum vasculosum* —  $19 \text{ mm}$

year<sup>-1</sup>) one can mark annual increments on a dead plant shoots and, by measuring weights of each section, assess the rate of destruction of moss.

In Tabs. 2 and 3 average biomasses of subsequent sections of moss shoots corresponding to annual increments of *C. stramineum* and *S. vasculosum* are given. Within the first year of decomposition 30% of the shoot vanishes, and within four years 55% of the original dry matter has been lost. In *S. vasculosum* from habitats protected against solifluction movement as many as 13 annual increments can be distinguished on dead shoots. During the first year of destruction, 45% of the biomass is lost, and after 3–4 years ca 70% of the original shoot vanished (Tab. 3, Fig. 3). During further 10 years no further significant loss

Table 2  
Dry weight losses and changes in chemical composition of dead shoots of *Calliigon stramineum* due to destruction in Fugleberget area, Spitsbergen. SE — standard error

Time of destruction (years)	Shoot dry weight (mg ± SE)	Chemical composition (per cent of dry weight)			C:N Ratio
		N	C	H	
0 (alive shoots)	0.595 ± 0.041	1.34	42.48	6.49	32
1	0.421 ± 0.019	1.77	45.39	6.74	26
2	0.355 ± 0.021	1.51	44.75	6.49	30
3	0.321 ± 0.024	1.34	44.52	6.14	33
4	0.272 ± 0.020	1.30	43.26	6.32	33

Dry weight — average of 20 measurements, chemical composition — average of 3 replications

Table 3  
Dry weight losses and changes in chemical composition of dead shoots of *Splanchnum vasculosum* due to destruction in Fugleberget area, Spitsbergen. SE — standard error

Time of destruction (years)	Shoot dry weight (mg ± SE)	Chemical composition (per cent of dry weight)			C:N Ratio
		N	C	H	
0 (alive shoots)	0.660 ± 0.022	3.36	41.97	6.38	12
1	0.363 ± 0.025	2.18	41.83	6.65	20
2	0.223 ± 0.013	2.08	49.53	7.18	24
3	0.194 ± 0.013	1.84	47.89	6.80	26
4	0.134 ± 0.008	1.48	45.66	7.04	31
5	0.133 ± 0.009	1.31	44.13	6.61	34
6	0.173 ± 0.008	1.30	42.14	6.43	32
7	0.175 ± 0.009	1.17	42.70	6.05	36
8	0.177 ± 0.015	1.17	43.52	5.91	37
9	0.175 ± 0.001	1.77	45.24	6.74	26
10	0.201 ± 0.013	2.04	45.77	6.65	22
11	0.143 ± 0.008	2.08	49.52	7.18	24
12	0.162 ± 0.015	1.84	47.89	6.80	26
13	0.156 ± 0.012	1.09	44.59	5.71	41

Dry weight — average of 20 measurements, chemical composition — average of 3 replications



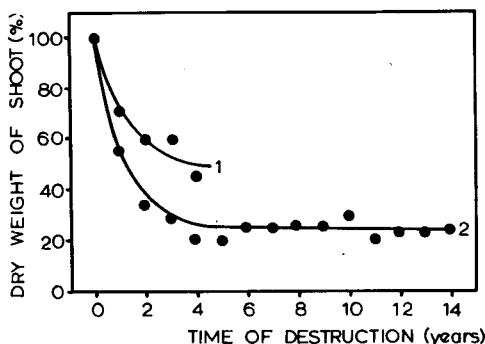


Fig. 3. Destruction rate of moss *Calliergon stramineum* (1) and *Splanchnum vasculosum* (2) in Fugleberget catchment area

of biomass was observed; after 13 years about 25% of primary (alive) moss shoots biomass remained. Some irregularities in changes of the biomass of dead shoots of mosses in years 4–6 and 10–11 (see Tab. 3) can result from variation in moss increments in previous growing seasons.

Average length of dead moss shoots in the study area amounted to about 10 cm which corresponded to 4–5 annual increments. The deeper parts of shoots had been apparently broken and damaged mechanically (but not chemically or biologically). Damaging and fragmentation of dead moss shoots was probably due to solifluction movements, periglacial processes and other phenomena connected with climate. Thus, destruction here is of a mechanical and not biological character.

#### Elementary composition of moss

In Table 1 the elementary composition (N, C, H, O and ash) of moss, *Calliergon stramineum*, during the growing season is presented. It was found that the nitrogen content in moss shoots increases from the start of summer (1.7% of dry matter) to the moment of appearance of sporangia (4.9%), followed by a decrease towards the end of growing season (1.3%). Corresponding with this is the course of changes in mineral substances (ash) in the moss shoots. In the beginning of the growing season the ash content was 4.2% increasing to its maximum at the appearance of sporangia (6.4%) and then falling to 4.2% at the end of summer season. Higher content of N and of mineral substances in moss shoots in the beginning of growing season as compared with values observed in autumn can provide evidence that some substances were withdrawn at the end of growing season to deeper, often dead parts of shoots (Callaghan and Collins 1976).

The analysis of elementary composition of dead shoots of moss, *C. stramineum* and *S. vasculosum* (Tables 2 and 3) shows a slow decrease of nitrogen

content. During the first year of destruction as much as 31% of initial value of nitrogen disappears from dead shoots of *C. stramineum* and 50% from shoots of *S. vasculosum*. Changes in nitrogen content in dead shoots are positively correlated ( $r = 0.9303$ ,  $n = 13$ ) with that of carbon content in shoots (see Tab. 3).

The constant decrease in nitrogen content in dead moss, positive correlation of changes in N and C contents (C:N ratio ranges from 22 to 37; see Tab. 3), all this excludes the microbial activity as a reason of vanishing the dead moss biomass. Transient increase in nitrogen content on about 10th year of destruction (Tab. 3) cannot be an evidence of increased microbial biomass in the material examined since it is accompanied by increase (and not decrease) in the carbon content.

There are few data on the rates of destruction and decomposition of organic matter produced in tundra. Bliss *et al.* (1973) reported that during the first year of exposure 15 to 19% of dry matter disappears, during the second year — 12 to 18% (litter bags method). In the case of mosses within one year of exposure only 1.3% of dry matter disappears (Baker 1972; experiments on Signy Island, Antarctic).

According to data reported by Rodin and Bazilevič (1965) average primary production in tundra amounts to less than  $100 \text{ g m}^{-2} \text{ year}^{-1}$  and is more than 10 times lower than that of meadows (1.120 g) and slightly lower than that of deserts (120 g). The results for primary production of moss and vascular plant communities in the Fugleberget catchment area are much higher than those given by Rodin and Bazilevič (1965) and by other authors for typical tundra regions (Tab. 4). The increased productivity of tundra in this catchment is a result of its fertilization by nutrients, mainly by N and P coming with drainage water from the breeding colony of Little Auk. Eurola and Hakala (1977) have pointed out

Table 4  
Aboveground annual net primary production (maximum values) of mosses and vascular plants communities in High Arctic (in  $\text{g dry wt m}^{-2} \text{ year}^{-1}$ )

Locality	Nonmanured sites	Manured sites	Author
<b>Mosses</b>			
Hornsund, Spitsbergen	—	269	Present paper
North East Land, Svalbard	150	1000	Eurola and Hakala 1977
Barrow, Alaska	160	—	Bunnell <i>et al.</i> 1975
Devon Island, Canadian Arctic	102	—	Bliss 1975
<b>Vascular plants</b>			
Hornsund, Spitsbergen	—	242	present paper
North East Land, Svalbard	35	120	Eurola and Hakala 1977
Barrow, Alaska	100	—	Tieszen 1972
Maria Pronchitscheva, Siberia	72	—	Matveeva <i>et al.</i> 1975
Adventdalen, Spitsbergen	—	422	Brzoska 1976

that primary production in the area under the influence of bird colonies at Spitsbergen is at least 7 times higher for mosses, and about 3 times higher for vascular plants when compared with places situated far from bird colonies. The values of primary production obtained in present study are within the limits reported for fragments of tundra fertilized by birds.

The influx of organic matter and nutrients to primary and poor soils in polar zones can bring about the formation of specific soils, rich in organic matter and nutrients, so called ornithogenic soils (Syroečkovskij 1959). In spite of influx of organic substances to Fugleberget catchment area occurrence of ornithogenic soils was not observed there. The soils found there are primary Arctic soils (Szerszeń 1965, Plichta 1977). The lack of well developed soils and permafrost hinder the development of microflora (Svensson and Roswall 1980) and therefore the decomposition and mineralization are slow. Losses of dead plant matter result rather from mechanical and not biological destruction of this material. At first such destruction depends on washing out of those fragments of leaves and shoots of dead plant which are destroyed, but even 3–5 years after dying the plants maintain their external structure. After this period partial tearing off and grinding of lower parts of dead shoots follows when they are partially stuck in permafrost. This is due to solifluction, thermoerosive and periglacial processes. Even whole surfaces of moss rod can be torn away from the substrate (Klementowski 1977). Mechanically destroyed and fragmented parts of plants are then carried out from the catchment area in melt waters. Dead parts of plants are being transported out of the catchment area — to the sea, since within the catchment area no considerable deposits of dead organic plant matter were observed in the form of peat or the like (K. Pełkala, *pers. comm.*) although in adjacent regions in Hornsund area, with different spatial and hydrological configuration, such deposits were observed (Klementowski 1977). Thus the organic matter and nutrients that reach the tundra from the bird colony, being assimilated later by plants in subsequent vegetation seasons, do not enter the cycling, nor are deposited in the habitat: they are removed beyond the ecosystem — to the sea. That is why one should speak here rather about the flow and not the cycling of matter (elements and nutrients). Of course, cycling of nutrients at a small scale takes place but the amount of them returning through the cycle is much lower than the amount of nutrients flowing through the ecosystem.

In the case of tundra in the Fugleberget catchment area the scheme of energy flow through the tundra ecosystem proposed by Bliss (1975) (solar energy — plants — decomposers — organic matter storage) would become much shorter: solar energy — plant matter — export from the system, with only small passage to dead plant material decomposers.

The unit within which the matter cycling really occurs is not the Fugleberget catchment area itself, but a system: catchment area — sea (the part of the sea where Little Auks forage). The element which triggers this rotation of matter and flow of energy are the birds that nest on slopes of Arieammen, and feed in inshore waters.

From the number of birds nesting in Ariekammen one can roughly estimate the order of magnitude in energy income to the catchment area in the form on Auks' faeces. This value would be ca  $0.2 \text{ cal cm}^{-2} \text{ day}^{-1}$ , which constitutes only one thousandth part of daily sum of solar energy radiation reaching tundra in the Hornsund region ( $161 \text{ cal cm}^{-2} \text{ day}^{-1}$ ; *after* Baranowski and Głowicki 1975).

It seems, however, that the decisive role in the influence of bird colony on the tundra is not the energy introduced to the tundra, but its carrier — matter, and especially nutrients. The impact of nutrients is, in turn, limited to stimulation of plant production not affecting in a perceivable manner the process of decomposition and mineralization. The latter seems to be dependent foremostly on climatic condition — the stream of energy reaching the biosphere in a given spot.

## References

- Baker J. H. 1972. The rate of production and decomposition of *Chrisodontium aciphyllum* (Hook F. et Wils). Broth. — Brit. Antarct. Surv. Bull., 27: 123–129
- Baranowski S. 1975. The climate of West Spitsbergen in the light of material obtained from Isfjord Radio and Hornsund. — Acta Univ. Wratislav., 251: 21–34.
- Baranowski S. and Głowicki B. 1975. Meteorological and hydrological investigations in the Hornsund region made in 1970. — Acta Univ. Wratislav., 251: 35–59.
- Belopol'skij L. O. 1957. Ekologija morskich kolonialnych ptic Barenovo morja. — Nauka, Moskva-Leningrad: 125 pp.
- Billings W. D. 1973. Arctic and Alpine vegetation: similarities, differences and susceptibility to disturbance. — Bioscience, 23: 679–704.
- Bliss L. C. 1975. Devon Island, Canada. In: T. Rosswall and O. W. Heal (eds.), Structure and function of tundra ecosystems. — Swedish natural Sciences Research Council, Stockholm; Ecol. Bull., 20: 17–60.
- Bliss L. C., Courtin G. M., Pattie D. L., Riewe R. R., Witfield D. W. A. and Widden P. 1973. Arctic tundra ecosystems. — Ann. Rev. Ecol. Syst., 4: 359–399.
- Brzoska W. 1976. Produktivität und Energiegehalte von Gefäßpflanzen in Adventdalen (Spitsbergen). — Oecologia, 22: 387–398.
- Bunnell P. L., MacLean S. F., Jr. and Brown J. 1975. Barrow, Alaska, USA. In: T. Rosswall and O. W. Heal (eds.). Structure and function of tundra ecosystems. — Swedish Natural Sciences Research Council; Ecol. Bull., 20: 73–124.
- Callaghan R. V. and Collins N. J. 1976. Strategies of growth and population dynamics of tundra plants. 1. Introduction. — Oikos., 27: 383–388.
- Chapin F. S. 1978. Phosphate uptake and nutrient utilisation by Barrow tundra vegetation. In: L. L. Tieszen (ed.), Vegetation and production ecology of an Alaskan Arctic tundra. — Springer Verlag, New York, Heidelberg, Berlin, 483–507.
- Clarke G. C. S., Greene S. W. and Greene D. M. 1971. Productivity of bryophytes in polar regions. Ann. Bot., 35: 99–108.
- Collins N. J. 1976. Growth and population dynamics of the moss *Polytrichum alpestre* in the maritime Arctic. Strategies of growth and population dynamics of tundra plants 2. — Oikos, 27: 389–401.
- Collins N. J. and Callaghan T. V. 1980. Predicted patterns of photosynthetic production in maritime Antarctic mosses. — Ann. Bot., 45: 601–620.
- Dunbar M. J. 1977. The evolution of polar ecosystems. In: G. Llano (ed.), Adaptations within

- Antarctic ecosystems. — Gulf Publishing Company Book Division Huston, Texas, 1063–1076.
- Eurola S. 1968. Ueber die Fjellethidervegetation in den Gebieten von Isfjorden und Hornsund in West Spitsbergen. — *Aquilo Ser. Bot.*, 7: 1–56.
- Eurola S. and Hakala U. K. 1977. The bird cliff vegetation of Svalbard. — *Aquilo Ser. Bot.*, 15: 1–18.
- Fenton J. H. C. 1980. The rate of peat accumulation in Antarctic moss banks. — *J. Ecol.*, 68: 211–228.
- French D. D. 1974. Classification of IBP Tundra Biome Sites based on climate and soil properties. *In*: A. J. Holding, O. W. Heal, S. F. MacLean Jr. and P. W. Flangan (eds.), *Soil organisms and decomposition in tundra*. — Tundra Biome Steering Committee, Stockholm, 3–25.
- Kalff J. and Welch J. E. 1974. Phytoplankton production in Char Lake, a natural polar lake and in Meretta Lake, a polluted polar lake, Cornvallis Island, Northwest Territories. — *J. Fish. Res. board Can.*, 31: 622–63.
- Klementowski J. 1977. Morfologia torfowisk SW Spitsbergenu. Polska Wyprawa na Spitsbergen w 1974 r. Materiały z Sympozjum Spitsberskiego. Wrocław, 11–12.04.1975. — Wydawnictwo Uniwersytetu Wrocławskiego, Wrocław, 59–64.
- Kuc M. 1963. Flora of mosses and their distribution on the north coast of Hornsund (SW Svalbard). — *Fragm. Flor. Geobot.*, 9: 291–366.
- Longton R. R. and Greene S. W. 1967. The growth and reproduction of *Polytrichum alpestre* Hoppe on South Georgia. — *Phil. trans. Roy. Soc., London. Ser. B*, 252: 295–322.
- Matveeva N. V., Darinkina O. M. and Chernov Y. I. 1975. Maria Pronchitseva Bay, USSR. *In*: T. Roswall and O. W. Heal (eds.), *Structure and function of tundra ecosystems*. — Swedish National Science Council, Stockholm, *Ecol. Bull.*, 20: 61–72.
- Milner C. and Hughes R. E. 1968. Methods for the measurement of the primary production of grassland. — Blackwell, Oxford, *Edinburgh IBP Handbook*, 6:
- Nowak J. 1965. The lichens from Hornsund (SW Spitsbergen) collected during the Polish Polar Expeditions in 1975 and 1958. — *Fragm. Flor. Geobot.*, 11: 171–190.
- Oechel W. C. and Sveinbjornsson B. 1978. Primary production processes in Arctic bryophytes at Barrow, Alaska. *In*: L. L. Tieszen (ed.), *Vegetation and production ecology of an Alaskan Arctic tundra*. — Springer Verlag, New York, Heidelberg, Berlin, 269–298.
- Plichta M. 1977. Systematics of soil of the Hornsund region. West Spitsbergen. — *Acta Univ. Nicolai Copernici, Geographia XIII*, 43: 175–180.
- Polunin N. 1959. Circumpolar Arctic flora. — Clarendon Press, Oxford: 514 pp.
- Priddle J. 1979. Morphology and adaptation of aquatic mosses in an Antarctic lake. — *J. Bryol.*, 10: 517–529.
- Remmert H. 1966. Zur Oekologie der Küstennahen Tundra Westspitsbergens. — *Z. Morph. Oekol. Tiere*, 58: 162–172.
- Remmert J. 1968. Ueber die Bedeutung vollreicher Meeresvogelkolonien und pflanzenfressenden Landtiere für Tundra Spitsbergens. — *Veröff Inst. Meeresforsch., Bremerhaven*, 11: 47–60.
- Remmert H. 1980. Arctic animal ecology. — Springer Verlag, Berlin, Heidelberg, New York, 250 pp.
- Rodin L. E. and Bazilevič N. J. 1965. Dinamika organiceskogo veščestva i bilogičeskij krugovorot v osnovnyh tipach rastitel'nosti. — *Nauka, Moskva-Leningrad*, 253 pp.
- Rueppel G. 1968. Ueber Oekologie und Tagesrhythmus von Bodenarthropoden eutropischer Tundragebiete Westspitsbergens. — *Pedobiologia*, 8: 150–157.
- Shaver G. R., Billings W. D. 1977. Effects of daylength and temperature on rood elongation in tundra graminoids. — *Oecologia*, 28: 57–65.
- Środoń A. 1958. Tymczasowe sprawozdanie z prac botanicznych na Spitsbergenie w lecie 1957 r. — *Przeł. Geofiz.*, 3: 185–186.
- Svensson B. H. and Rosswall T. 1980. Energy flow through the subarctic mire at Stordalen. *In*: M. Sonesson (ed.), *Ecology of a subarctic mire*. — Swedish Natural Science Research Council, Stockholm, *Ecol. Bull.*, 30: 283–301.

- Syroečkovskij E. E. 1959. Rol' životnych v obrazovanii pervičnych počv v uslovijach poljarnoj oblasti Zemnogo Šara (na primere Arktiki). — Zool. žurn., 38: 1770–1775.
- Szerszeń L. 1965. Studia nad glebami strefy klimatu arktycznego na przykładzie południowo-zachodniego Spitsbergenu. — Zsz. Nauk. Wyż. Sz. Rol., Wrocław, Rolnictwo, 19: 39–79.
- Tieszen L. L. 1972. The seasonal course of aboveground productivity and chlorophyll distribution in a wet Arctic tundra at Barrow, Alaska. — Arct. Alp. Res., 4: 307–324.
- Tieszen L. L. 1978a. Summary. In: L. L. Tieszen (ed.) Vegetation and production ecology of an Alaskan Arctic tundra. — Springer Verlag, New York, Heidelberg, Berlin, 621–645.
- Tieszen L. L. 1978b. Photosynthesis in the Principal Barrow, Alaska species. A summary of field and laboratory responses. In: L. L. Tieszen (ed.), Vegetation and production ecology of an Alaskan Arctic tundra. — Springer Verlag, New York, Heidelberg, Berlin, 241–268.
- Webber P. J. 1978. Spatial and temporal variation of the vegetation and its production, Barrow, Alaska. In: L. L. Tieszen (ed.). Vegetation and production ecology of an Alaskan Arctic tundra. — Springer Verlag, New York, Heidelberg, Berlin, 37–112.
- Zabawski J. and Żurawka M. 1975. Mikroflora pierwotnych gleb rejonu Hornsundu i lodowca Werenskjøelda (Zachodni Spitsbergen). Polskie Wyprawy na Spitsbergen 1972 i 1973. Materiały Sympozjum Spitsberskiego, Wrocław, 29–30.03.1974. — Wydawnictwa Uniwersytetu Wrocławskiego. Wrocław, 101–108.

Received September 12, 1991

Revised and accepted October 2, 1991

## Streszczenie

Dla określenia dynamiki biomasy i produkcji zbiorowisk roślinnych ornitogennej tundry spitsbergeńskiej w rejonie Hornsundu (Spitsbergen Południowy) określono długość sezonu wegetacyjnego, wzrost liniowy i tempo wzrostu biomasy pojedynczych osobników mchów *Calliergon stramineum* i *Splanchnum vasculosum* oraz rośliny naczyniowej — rogownicy alpejskiej (*Cerastium alpinum*). Określono produkcję pierwotną zespołów roślinnych tundry i tempo destrukcji martwego materiału roślinnego.

W rejonie Hornsundu okres wegetacyjny w roku 1980 trwał 95 dni i rozpoczął się już pod pokrywą śnieżną. Tylko 56% osobników mchu *C. stramineum* wypuszcza wiosną młode pędy. Pędy te osiągają długość 19 mm i masę 0.563 mg masy suchej. Analogiczne dane dla mchu *S. vasculosum* wynoszą 16 mm i 0,609 mg. Produkcja pierwotna zespołów mchowych wynosi 220–270 g suchej masy na metr kwadratowy na rok, zespołów roślin kwiatowych — 240 g.

W ciągu pierwszego roku trwania destrukcji martwej materii roślinnej następuje ubytek 30–45% jej pierwotnej ilości, po 10 latach pozostaje jeszcze ok. 25% pierwotnej jej ilości.

Destrukcja materiału roślinnego w tundrze ma charakter raczej mechaniczny niż biologiczny. Świadczy o tym między innymi stosunek C:N w martwym materiale roślinnym wahający się od 1:12 do 1:41. Stosunek ten w żywych roślinach (w mchu) wynosi od 1:9 do 1:32.