Seasonality in an Arctic fjord ecosystem: Hornsund, Spitsbergen

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Based on two complete years of marine ecological surveys (1981–82 and 1984–85) carried out in the Hornsund fjord on southern Spitsbergen (77°N), the seasonal variation of physical and biological processes is presented. Physical parameters reflect the strong seasonality of sun radiation, while water salinity and temperature fluctuate within a narrow range. Concentrations of nutrients and suspended matter depend on meltwater discharge from glaciers and snow cover thickness. The breeding period of most marine invertebrate species is strongly related to the phytoplankton bloom which peaks in May. Ringed seal and polar bear occurrences are directly related to sea ice conditions. Both species are most numerous in Hornsund during March–April. Sea birds which nest in huge colonies along the Hornsund coasts arrive in April–May and leave by August–September except for Fulmars and Brünnich's Guillemots which were observed year-round.

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Plans to start oil drilling on the Arctic shelf have promoted growing interest in the marine ecology of these remote areas. Numerous expeditions were conducted in the seventies and eighties as a part of various marine ecological programmes (see records in *Research on Svalbard* 1982–87 and *Greenland Newsletter* 1983–87). So far research has been carried out from spring to autumn, the seasons of easiest access. Reports on year-round ecological observations are scarce. Extensive studies done in the central Arctic Basin (Melinkov & Kulikov 1980), subarctic areas of Alaska and Canada (McGinitie 1955; Grainger 1959; Feder & Matheke 1980), Greenland (Thorson 1936; Anderson 1981) and the White and Barents Seas (Kuznetsov 1964; Khlebovitsh 1974; Prygunkova 1974) gave data mainly on pelagic biocenoses.

At the Norwegian Arctic Station in Ny-Ålesund (79°N) and the Soviet Meteorological Laboratory in Grønfjorden (78°N), both on Spitsbergen, only water temperature, tidal and ice data are available for the full year. South Spitsbergen National Park, where the Polish Polar Station has been operating since 1957 is an area of potential oil drilling activity (Bergsager 1984). We summarize the results of marine ecological surveys carried out in this region by Polish expeditions since 1977 and include the results of two year-round programmes conducted in 1981–82 and 1984–85 (Swerpel & Węsławski 1987).

Material and methods

The present study includes air temperature measurements, snow cover thickness, calving activity of the Hansbreen glacier, sea water temperature and salinity. Standard meteorological data were obtained from unpublished reports by P. Adamski from the Institute of Meteorology and Water Management in Gdynia. Calving activity of the glacier was assessed by frequencies of micro-quakes recorded with the seismograph of the Polish Polar Station (J. Dąbrowski unpublished). We measured water temperature and salinity with reversible thermometers and titration, respectively.

Primary production was measured by Eilertsen et al. (unpublished) on samples collected by us between February and July 1985. The method described by Strickland & Parsons (1972) was used. Silicate and orthophosphate were analysed using methods recommended by the same authors. Three analyses were carried out of each sample and three samples per month, collected from one sampling site in 1984–85, were averaged to give the mean values. Chlorophyll *a* was measured (Strickland & Parsons 1972) in samples collected in 1984–85. Phytoplankton was sampled in 1984–85; water samples of 10 l volume were filtered through a 20 μm mesh net and preserved in 4% buffered formaldehyde solution. Phytoplankton cells were identified and counted in the whole sample (J. Wiktor unpublished).

Suspended particulate matter was measured using 1 l water samples filtered through 0.45 μm Millipore filters. The filter was then dried at 80°C for 48 hours and weighed with 0.5 mg accuracy. The data are from 1984–85.

Zooplankton (mesozooplankton) biomass was calculated from samples collected with a WP-2 net of 200 μm mesh size during 1984–85. Formaldehyde solution weights of zooplankton were obtained after gently filtering the samples through a 100 μm mesh net and subsequent external drying on Whatman paper. Data from 0–10 m surface layer are presented. Monthly mean values were obtained from 2–6 samples a month from the central part of the fjord. Larval forms appearance and life cycles of *Copepoda* are described on the basis of plankton samples collected in 1981–82 (Kwasniewski 1985). The life cycles of higher crustaceans were described on the basis of samples collected in 1977, 1979, 1980, 1981–82 and 1984–85. Incubation was assumed to begin at the time when the first females with eggs were observed, whereas the end of incubation was taken to be the time of the hatching of the first juveniles (Węsławski 1987 and unpublished material).

The phenology of fish, birds, seals and polar bears was studied in 1977, 1979, 1980, 1981–82 and 1984–85.

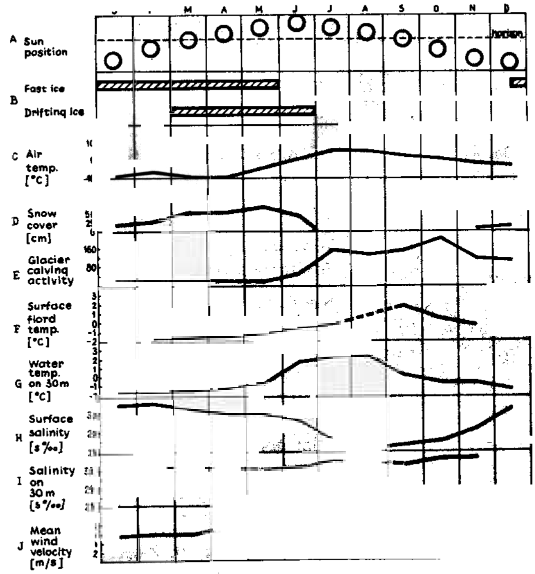

Fig. 1. Seasonal variation in some physical parameters at Hornsund.

Results

Seasonality of physical phenomena

The measured physical factors (Fig. 1) show either strong summer-winter variability or only slight changes during the course of the year. The sun stays above the horizon all day from 22 April to 15 August and stays beneath the horizon all day from 12 November to 13 February (Fig. 1a). The fast ice cover in the fjord varies from year to year and in the inner fjord usually occurs from mid-December till the end of May. The central and outer fjord parts are only occasionally covered with fast ice. Drifting pack ice occurs from April to late July and rarely in August. The pack ice is usually carried by the Sørkapp Current from Storfjorden (Fig. 1b).

Air temperature, snow cover thickness and calving activity of the Hansbreen glacier vary markedly from winter to summer (Fig. 1c, d, e). This is reflected in the discharge of fresh water and glacier ice (growlers, icebergs) to the fjord. Surface sea water temperature ranged between −1.88 and 3°C (Fig. 1f). Summer warming of the fjord water was delayed in near bottom waters for 1–2 months (Fig. 1g). It is noteworthy that in the innermost basins of Hornsund the temperature of near bottom waters was constant (−1.88°C) all year round. The surface salinity dropped rapidly during snow melting in June from about 32 to 25‰ and less (Fig. 1h). The salinity of near bottom waters varies slightly between 33 and 34‰ (Fig. 1i). Wind velocity varied little with seasons, the mean value being highest in April and lowest in June (Fig. 1j).

The observed rhythm of biological phenomena

The chlorophyll *a* concentration, the rate of primary production and the number of phytoplankton cells in surface waters indicate a high Arctic character of bloom in Hornsund. A single, well timed maximum in May and a subsequent marked decrease in the number of cells were observed. The decrease of silicate concentration during the bloom indicated that diatoms were predominant (Fig. 2a, d, e, g). Orthophosphate varied less and usually stayed well above the limit of detection (Fig. 2f). Total suspended matter in surface waters revealed a maximum in July and a minimum throughout the winter (Fig. 2b). The bulk of suspended matter consisted of clastic material introduced to the fjord with meltwater from tide water glaciers (Fig. 1g) as well as being transported by rivers, snow melting, etc.

Zooplankton biomass was at a maximum in August (Fig. 2c) and in lowest concentrations from January to April. The predominant species were: *Calanus finmarchicus, Pseudocalanus elongatus, Acartia clausi* and *Metridia longa*. The development of predominant copepods in plankton exhibited a one year life cycle (single breeding per year). The oceanic species *(Calanus finmarchicus)* released nauplii just in the time of phytoplankton bloom in May, while coastal species *(Pseudocalanus elongatus)* nauplii were released after the bloom in August, which was the time of yearly maximum zooplankton biomass. The former species spends the winter as older stages (copepodit 4 and adults) while *P. elongatus* winters as copepodit 3 and 4 stages (Fig. 2h, i). Pelagic larvae of *Polychaeta, Cirripedia* and *Bivalvia* were common in the summer and autumn zooplankton (Fig. 2j, 3a, b). The presence of *Bivalvia* veligers was very prolonged compared to other larvae.

Two types of breeding seasonality were found among *Malacostraca* crustaceans in Hornsund. The first was represented by crustaceans with a life span of 2–4 years. They breed in the autumn, incubate eggs through the winter and hatch juveniles or larvae in the spring. Those are represented by *Mysis oculata* and most of the decapods and amphipods (Fig. 3c, d, e, f). The second type, crustaceans with a life span of 1–2 years, lay eggs in the late spring, incubate eggs through the short summer and release juveniles in the early autumn. Examples are the pelagic amphipod *Hyperia galba* (Fig. 3g) and the coastal *Ischyrocerus anguipes* (Fig. 3h). The timing of spawning and release of juveniles was pronounced and without year to year variation.

Little is known about the biology of fish from coastal Spitsbergen waters. One of the most common species, the sculpin *(Myoxocephalus scorpius)*, spawns in the autumn. Eggs were found on the bottom in November–December and larvae were observed in plankton in May–June (Fig. 4a).

The phenology of the predominant sea birds is more or less common to all speices in the area. Fulmars and Brünnich's Guillemots stayed the year round in Hornsund (Fig. 4d, e). Other species such as Eiders and Kittiwakes arrive in March–April and stay in the area until November

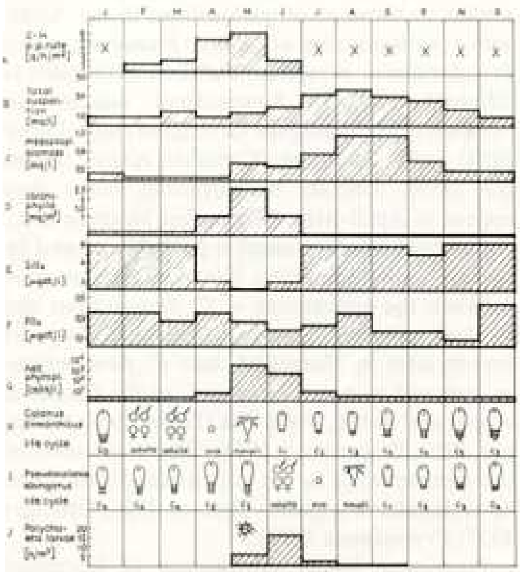

Fig. 2. Seasonal variation in some biological parameters at Hornsund. × – no data.

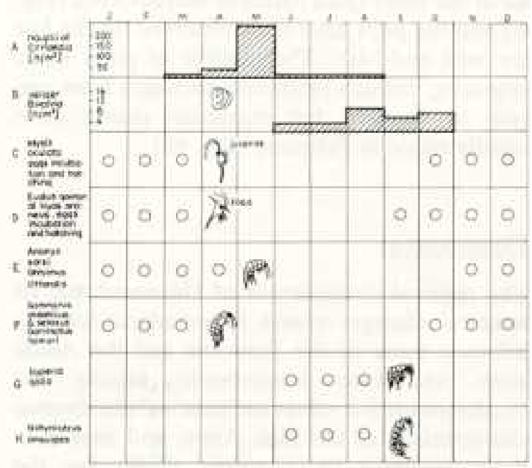

Fig. 3. Breeding patterns of prominent Hornsund invertebrates.

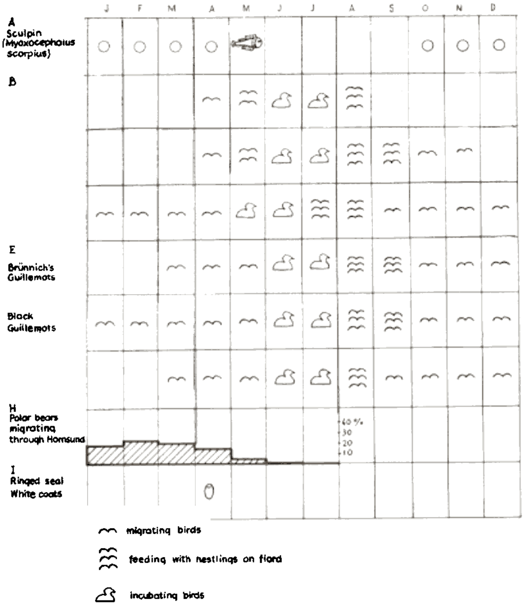

Fig. 4. Phenology of fish, birds and mammals at Hornsund.

(Fig. 4c, g). The colonies of Little Auk stay in the fjord for the shortest period, from March to August (Fig. 4b). The peak nesting season for most of the birds in Hornsund is in June. From May to July sea birds feed mainly off the coasts. In August, the first weeks after hatching, they concentrate in coastal areas and moult. Then Hornsund is densely inhabited by sea birds with their young.

The most common seal in Hornsund is the ringed seal *(Phoca hispida)*. It breeds on the fast ice in the inner fjord basins in March–April (Fig. 4i) and the pups have been observed on the fast ice until mid-May. The number of polar bears migrating through Hornsund fluctuates from one year to another, but maximum counts were usually noted in February (Fig. 4h).

Discussion

The physical environment of Hornsund and its seasonal changes reveal intermediate features between those of the Subarctic and the Arctic zone. Sea water temperature, salinity and irradiance exhibit values and seasonal distribution characteristic of the high Arctic and similar to those reported by Grainger (1959) for the Canadian Arctic and by Anderson (1981) for Greenland. Sea ice conditions are not so severe as in other areas of the Arctic; they vary in successive years. Even in the coldest years the fjord is ice free for at least three months (Węsławski & Adamski 1987). Year to year climatic variation is notable. Climatic winter, defined as the period with a mean temperature below −2.5°C, may last from 140 to 210 days a year in Hornsund (Rodzik & Stepko 1985); the water temperature varies considerably from one year to another (Węsławski & Adamski 1987).

Nutrient and chlorophyll concentrations as well as primary production in Hornsund are similar to those in Northern Norwegian fjords and coastal waters of West Spitsbergen (Halldal & Halldal 1973; Eilertsen et al. 1981; Eilertsen, Taasen & Węsławski unpublished). The phytoplankton blooms in Hornsund are different from those reported from other Subarctic and Arctic localities. The definite single bloom in Hornsund with a maximum in May is early compared to the blooms in the central Arctic in August (Širšov 1982). West Greenland, the White Sea and the southern Barents Sea exhibit two or even three blooms a year (Khlebovitsh 1974; Anderson 1981). In a glacier fed fjord such as Hornsund the summer concentrations of suspended mineral matter in the brackish surface layer inhibit phytoplankton development after the spring bloom due to the light limitation.

The zooplankton communities in Hornsund are similar to those at other localities in the Arctic with a predominance of *Calanus finmarchicus* and *Pseudocalanus elongatus*, but their seasonality is different. *Calanus finmarchicus* nauplii are released in May along the Greenland coast (Digby 1954) and in July in the Canadian Arctic (Grainger 1959), contrary to Hornsund where they appear in April–May. The earlier hatching of *C. finmarchicus* in Hornsund is probably caused by the early phytoplankton bloom. The time span between the appearance of *C. finmarchicus* and *P. elongatus* nauplii is also different; *P. elongatus* breeds later in Hornsund than *C. finmarchicus* as opposed to near Greenland, in the Canadian Arctic and in the White Sea (Digby 1954; Grainger 1959; Prygunkova 1974). The seasonality of the occurrence of larvae in Hornsund is the same as in the above regions (Thorson 1936; Grainger 1959; Prygunkova 1974).

Prominent higher crustaceans in Hornsund were: *Gammarus oceanicus, G. setosus, Anonyx nugax, A. sarsi, Hyas araneus, Eualus gaimardi*, i.e. similar to other Arctic localities (Dunbar 1954; Golikov & Averincev 1977). The seasonality of their breeding is also similar to those observed elsewhere. At more southern latitudes, however, the timing is not so well defined and breeding periods are longer than for the Hornsund populations (Kuznetsov 1964).

Seasonality of breeding of sea birds observed in Hornsund is of Subarctic character, since the peak of the nesting season is in June–early July, while at High Arctic Siberian coasts the nesting is delayed until August (Belopolskij 1960).

The polar bear migration through Hornsund is related to ice and wind conditions because there is no denning in the study area. All individuals at Hornsund had drifted from Storfjorden and the Olgastretet region (east Svalbard), which is known as a breeding area for bears (Larsen 1985).

The seasonality of some of the phenomena presented here is quite regular, such as irradiation. Others, such as the breeding of birds and crustaceans, may vary within a narrow range. Sea and air temperature as well as snow and ice cover vary strongly from one year to another. More studies are necessary to resolve the question of how year to year climatic changes influence the seasonality and the intensity of primary production as well as the breeding success of key species in fjord waters.

The available data suggest that two periods are particularly important with regard to environmental stress such as oil spill. These are April–May with the phytoplankton bloom and surface zooplankton development and August with the most dense population of birds in the coastal area.

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