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The influence of abiotic factors on the growth of two vascular plant species (*Saxifraga oppositifolia* and *Salix polaris*) in the High Arctic

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ABSTRACT

The aim of this paper is to comprehensively evaluate the abiotic factors that influence changes in the annual growth rates of selected species of tundra plants (*Saxifraga oppositifolia* L. and *Salix polaris* Wahlenb.). The study was conducted in the area of the Fuglebergsletta coastal plain, in the vicinity of the Polish Polar Station (Wedel Jarlsberg Land, SW Spitsbergen). Relationships between the studied phenomenon and basic environmental factors and climate indicators were evaluated. The spatial variation of land surface temperatures (LST) was determined, as were the effects of the physical and chemical properties of soils and the spring melting of snow cover on growth rates.

It has been argued that the spatial and seasonal variability of annual growth is determined by the rate at which snow cover disappears and by soil moisture, which determines plants' access to water. Soil moisture depends on soil particle size distribution and weather; it is regulated by the supply of snowmelt water and rainfall as well as by the depth of the top layer of permafrost (thaw depth), which determines the level of groundwater during the growing season. The spatial characteristics of the process of the disappearance of seasonal snow cover are co-determined by the morphology of the substrate and the physical properties of the soil. An important but destructive role is played by thawing episodes, which are increasingly frequent in the winter season, 'rain-on-snow' events, and glaze ice. The values of correlation coefficients indicate a positive role for precipitation and negative influence of temperature. The higher the temperature (along with low precipitation), the lesser the extent of plant growth. The observed trend towards warming in polar areas does not inevitably lead to an increase in biomass production. An increase in temperature during the growing season does not necessarily promote plant growth, but rather indicates drought stress caused by the lowering of groundwater levels related to the increase in thaw depth.

1. Introduction

Recent large-scale warming observed in the Arctic has accelerated during recent decades and is occurring at a rate twice that of the global trend (AMAP, 2012). The climate in the Arctic is extremely varied, and inter-annual weather conditions and the dynamics of biological and biogeochemical processes in terrestrial ecosystems vary significantly (Przybylak, 2016; Raynolds et al., 2008; Wolf et al., 2008). Svalbard Archipelago is the warmest part of the northern polar zone (Przybylak et al., 2014). The number of days with a mean air temperature above 0 °C on western Spitsbergen has increased from 110 to 120 in the 1960s to 130–160 during the period 1971–2015 (Gjelten et al., 2016; Przybylak, 2016). Longer periods characterised by warm days intensify biological and biogeochemical processes and favour plant growth and soil development in deglaciated areas (Crawford, 2008; Migała et al., 2014; Myeneni et al., 1997; Rustad et al., 2001; Sala et al., 2000; Crawford, 2004).

The differentiation of local climatic conditions in the Arctic, which is mainly related to topography, vicinity of the ocean and glaciers, impact of snow and ice, and geology and hydrology, determines the

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development of vegetation (Owczarek et al., 2014). The tundra community is dominated by low, creeping dwarf shrubs and by various species of mosses, lichens, and vascular plants. Rønning (1996) distinguished four plant zones in the Svalbard Archipelago, depending on the dominant species. The northern coast of Hornsund is classified as the *Salix polaris* zone. Apart from dwarf shrubs from the syntaxon *Salicaceae*, this community mainly consists of *Saxifraga oppositifolia* L. and various species of mosses (Szymański et al., 2013, 2016a, 2016b; Wojtuń et al., 2013; Migała et al., 2014; Skrzypek et al., 2015). Although different plant species react differently to the same conditions, the response of those species with the broadest ecological amplitude can be used as a holistic indicator of habitat conditions (habitat quality).

S. oppositifolia and *S. polaris* are among the species with the greatest tolerance to unfavourable thermal conditions. In Spitsbergen, as in many places in the Arctic, these are the species with the broadest ecological amplitude. In various habitats, they either dominate or are in fact the only vascular plants present (Węgrzyn and Wietrzyk, 2015). This reflects their numerous adaptations to Arctic environments in which plants are exposed to stress factors that limit their growth and the production of biomass (Grime, 1979; Grime et al., 1986; Owczarek and Opała, 2016). Grime (1979) lists a number of stress factors that reduce biomass production: insufficient soil nutrient content, drought, anaerobic conditions under the ice-capped snow cover, low temperatures that result in slow metabolism and/or temperatures that drop below 0 °C during the growing period, a very short growing period, mechanical damage caused by frost heave, *abrasion* from wind-transported particles (sand, snowflakes), and animal grazing.

In the High Arctic, as in other regions of the earth, plant growth and vegetation development are strongly dependent on the physical and chemical properties of the soil. The physical properties of soil affect water availability in plants, root growth and development, the diffusion of soil solution, and soil thermal conditions (e.g. Brady and Weil, 2004; Jalota et al., 2010; Migała et al., 2014). Chemical properties of soil such as pH and the content and availability of nutrients and other elements are crucial for plant nutrition and productivity (e.g. Brady and Weil, 2004; Gordon et al., 2001; Madan et al., 2007; Ziółek and Melke, 2014). In addition, the quantity and quality of soil organic matter (SOM) play an important role in sorption and the accessibility of water and many elements that are important for plants (Brady and Weil, 2004; Stevenson, 1994). Soils in the High Arctic are characterised by the high level of diversity of their physical and chemical properties even within very small areas. This is related to the high level of diversity of other environmental components (soil-forming factors) on a small scale, including such factors as geology (i.e. various rocks and sediments), mezo- and microclimatic conditions, relief and morphogenetic processes (e.g. solifluction, deflation), hydrological conditions which are greatly affected by thaw depth and the thickness of the active layer of permafrost, tundra vegetation type, and the influence of seabirds (Migała et al., 2014; Paré and Bedard-Haughn, 2012; Sjögersten et al., 2006; Skrzypek et al., 2015; Szymański et al., 2013, 2016a, 2016b; Wolf et al., 2008; Zwolicki et al., 2013, 2016).

Important factors that affect the distribution of plants on a small scale are the spatial distribution, thickness, retention time, and melting of snow cover (Eidesen et al., 2013). In open terrain with scarce vegetation, these features are largely controlled by snow transport (Pomeroy and Brun, 2001; Prokop et al., 2013). According to Körner (2003), snow cover protects plants from abrasion, extreme temperatures, and physiological drought in winter, whereas, in spring, melting snow increases the amount of water present in the soil. However, prolonged spring melting of thick snow cover significantly contributes to shortening the growing season. In places where snow cover melts late (at relatively high temperatures), an ice-capped layer is created; this layer is impermeable to air, resulting in anaerobic conditions which impair tissue metabolism in plants. Since Arctic plants start photosynthesis under snow cover (Moser et al., 2016), anaerobic conditions delay the initiation of this process.

The main aim of this study was to determine the influence of abiotic factors such as microclimatic/bioclimatic conditions, rate and duration of snow-cover thawing, and the physical and chemical properties of surface soil horizons on the growth of two common vascular plant species (*Saxifraga oppositifolia* L. and *Salix polaris* Wahlenb.) in the eastern part of the Fuglebergsletta coastal plain (SW Spitsbergen). In this way we intend to answer the following question: what are the key abiotic factors in the growth and biomass production processes and which of these factors determine local differences? We put forward the hypothesis that most plant growth occurs during the short period after snow cover has disappeared, and that access to water determines the growth process.

2. Study area

The research was carried out in Wedel Jarlsberg Land (SW Spitsbergen, Svalbard Archipelago) in the eastern part of the Fuglebergsletta coastal plain (Fig. 1). The plain is characterised by the occurrence of marine terraces uplifted during the Holocene (Birkenmajer, 1960; Lindner et al., 1991; Owczarek et al., 2014). On the north, the study area is surrounded by the Ariekammen (513 m a.s.l.) and Fugleberget (569 m a.s.l.) mountain massifs, both with talus cones (Owczarek, 2010; Owczarek et al., 2013). The eastern margin of the area is occupied by the ice-cored lateral moraine of the Hansbreen glacier (Błaszczyk et al., 2013). The bedrock of the study area mainly consists of Middle Proterozoic metamorphic schists and paragneiss (Czerny et al., 1993; Majka et al., 2010). The deposits of uplifted marine terraces contain boulders, stone, gravel, and sand. Locally, the marine deposits contain a larger amount of fine material, i.e. silt and clay fractions, and are characterised by a loamy texture. The active layer within the lower levels of the raised marine beaches reaches a maximum depth of 1.4 to 2.5 m, depending on the physical properties of the ground and weather conditions in each particular season (Dolnicki et al., 2013; Migała et al., 2004). The area is covered with a mosaic of soils and an independent (to some extent) mosaic of tundra vegetation. Haplic Cryosols, Reductaquic Cryosols, Turbic Cryosols, Hyperskeletic Cryosols, Leptic Regosols, and Lithic Leptosols are the most common soils in the study area (Szymański et al., 2013, 2015), exhibiting various thermal and moisture regimes during the growing season (Migała et al., 2014). The most important and widespread tundra plants in the study area (Szymański et al., 2013; Wojtuń et al., 2013; Migała et al., 2014; Owczarek and Opała, 2016) include a lichen-prostrate shrub community, dominated by *Cetrariella delisei* (Bory ex Schaer.) Kärnefelt & A. Thell, *Ochrolechia frigida* (Sw.) Lynge, *Salix polaris* Wahlenb., and *Saxifraga oppositifolia* L., which covers dry and well-drained terraces; a wet moss community with a predominance of the bryophytes *Sanionia uncinata* (Hedw.) Loeske, *Warnstorfia sarmentosa* (Wahlenb.) Tuomikoski & T. J. Kop., *Straminergon stramineum* (Dicks. ex Brid.) Hedenäs, and *Aulacomnium palustre* (Hedw.) Schwägr., which are restricted to areas with poor drainage; and an epilithic moss-lichen community, occurring on the dry sites of most rock outcrops, with great abundances of the moss *Racomitrium lanuginosum* (Hedw.) Brid., the lichens *Cetraria islandica* (L.) Ach. and *Cladonia mitis* Sandst., and the dwarf shrub *S. polaris*. Modern changes in tundra vegetation are strongly connected not only with climate changes but also with the presence of herbivores. The influence of recent dynamics on the size of reindeer (*Rangifer tarandus platyrhynchus*) populations, which were reintroduced or which have recovered naturally, has been clearly described (Øritsland, 1987; Elvebakk, 1997; van der Wal et al., 2001; Węgrzyn et al., 2013; Kapfer and Grytnes, 2017).

The area is drained by a small stream called Fuglebekken. Its flow rate varies from tens to hundreds of litres per second, depending on ablation of snow cover (Pulina et al., 1984). The catchment area is supplied only by precipitation; most of the outflow water (70–80%) is derived from the retention of winter snow. The main area supplying the