

## Biometrical parameters, pigment content and functional characteristics of photosynthetic apparatus of *Bistorta vivipara* within the territory of West Spitsbergen

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### Abstract

In the present paper, the results of the research of biometric and functional parameters of photosynthetic apparatus of *Bistorta vivipara* from West Spitsbergen are presented and discussed. A high intraspecific variability of biometric parameters (linear dimensions and biomass) was found. The differences found in biomass suggest that biological productivity is associated with the functional activity of the plant individuals. A direct dependence of the biomass on the photosynthetic pigment content per unit dry mass of leaf has been revealed. A high variability of non-photochemical fluorescence quenching (NPQ), basic fluorescence yield ( $F_0$ ), maximal fluorescence yield ( $F_M$ ) and variable fluorescence yield ( $F_V$ ) have been shown contrastingly to relatively constant values of the maximum photochemical quantum yield of PS II ( $F_V/F_M$ ) and the coefficient of photochemical fluorescence quenching (qP). Close-to-theoretical-maximum  $F_V/F_M$  values indicated the absence of stress conditions and the presence of regulation systems in chloroplastic photosynthetic apparatus (PA) level functioning during varying microclimate parameters of the daily climate. The relatively constant qP indicated the same photosynthetic activity of the *B. vivipara* leaves, unaffected by the varying weather conditions. The NPQ data suggest that the non-photochemical quenching acts as a protective mechanism, sustaining the PA in an optimally active state and reducing probability of negative changes to PSII. The revealed high PA adaptability at the level of the plant structure and light-dependent reactions of photosynthesis makes it possible for *B. vivipara* to develop at a high functional level at various values of environmental factors, which provides for the successful growth of the species in the high Arctic region. The high PA flexibility suggests that *B. vivipara* is capable of active adaptation in the context of the forecast climate change.

**Key words:** Arctic, biomass, chlorophyll fluorescence, photosynthetic apparatus, photosynthetic pigments, *Polygonum viviparum*

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## Introduction

The study of the influence of environmental factors on plants and their adaptation to such exposure has been one of the most debated issues of plant ecology and physiology over an extended period of time. Recently this problem has acquired new significance due to the forecast climate change (IPCC 2007) and research into plant reactions to these changes. Against this background, the Arctic appears to be an interesting study area, because the high latitude zone is especially sensitive to climate changes (Bokhorst *et al.* 2010: cited by Barták 2012), whereas the plant community in high latitudes is characterized by a more distinct manifestation of the dependence of organisms' vital activity on climatic factors (Shmakova *et Markovskaya* 2010). The photosynthetic apparatus and its reaction to the exposure to various factors proves to be a reliable source of information on the state of the plant and its ability to adapt to the changing environmental conditions (Goltsev *et al.* 2014). In its turn, chlorophyll fluorescence is a reliable source of information on the state of the photosynthetic apparatus (Goltsev *et al.* 2014). Little is known from published sources about the chlorophyll fluorescence of plants growing on Spitsbergen (Barták 2012, Li *et al.* 2013).

One of the most widespread species on Spitsbergen is *Bistorta vivipara* (L.) S. F. Gray (= *Polygonum viviparum* L.) (*Polygonaceae*). *B. vivipara* is a circum-polar arctalpine species (Zajac *et Zajac* 2009), which is widely spread and grows from north-polar to temperate zones. It is a perennial geophyte with short roots and a straight non-ramose caulis (Pawłowski 1956, Webb *et Charter* 1964). *B. vivipara* is widely spread on Spitsbergen, adopting a wide range of natural and anthropogenic ecotopes.

Its high adaptation level attracts the attention of researchers, who note the following characteristic biological properties: intraspecific morphological variability and reproduction peculiarities. Molecular studies have demonstrated that the intraspecific variability of arctic and alpine plants, to which *B. vivipara* belongs, is the result of migration processes (Skrede *et al.* 2006) and is associated with the spatial isolation of populations. It was demonstrated for two arctic and alpine species (*Salix herbacea*, *S. reticulata*). Active fluorescence is typical of the species, and it is usually accompanied not by the formation of seeds, but the emergence of bulbils – vegetative reproduction organs (Klokk *et Rønning* 1987, Wookey *et al.* 1994). This phenomenon is called infloral homophasic rhizogenic viviparity, the presence of brood buds (bulbils), which appear along the entire length of the inflorescence, alternating with blooms (Batygina *et Vasilyeva* 2002). These brood buds (bulbils) form in the sinus of the floral bract. A high genetic diversity of alpestrine, subarctic (Law *et al.* 1983, Bauert 1993, 1996) and high-altitude populations of *B. vivipara* (Diggle *et al.* 1998, 2002) is noted, which is probably determined by the insignificant seed propagation, which is sufficient for the sustention of the observed genetic diversity (Diggle *et al.* 1998). The phenomenon of viviparity is considered to be linked with polyploidy (Batygina *et Vasilyeva* 2002), which is characteristic of various species growing in polar regions.

The research objective included biometrical studies, research functional peculiarities of photosynthetic apparatus of *B. vivipara* and the estimation of this species' ability to adapt to the changing environmental factors in the setting of the high Arctic region.

## Material and Methods

The study was conducted in the arctic tundra zone on West Spitsbergen from 2010 to 2013. For the study, plants were selected that were growing in natural and anthropogenically transformed ecotopes of upland territories and mountain tundra slopes in the vicinity of Barentsburg. The climatic peculiarities account for a short vegetation period (40–70 days), the dura-

tion of which is determined by the time of the melting of snow cover in local habitats. The biometric measurements and the determination of pigment content were performed in July 2010 – 2015. The estimation of the PA photochemical activity was made in the first half of July 2015 at different times of the day.

### *Biometric method*

The biometric method included the measurement of the biomass of various organs of blossoming plants of *B. vivipara*,

as well as the measurement of their linear dimensions. A total of 200 plants were studied.

### *Pigment content determination*

Samples of mature leaves were selected from plants in three biological replications and fixed with 96% ethanol. The chlorophyll content and total carotenoid content were determined by means of the spectrophotometric method (UV-1800, Shimadzu, Japan) by the optical density in the peak points of chlorophyll *a* and *b* and carote-

noid absorption. The chlorophyll *b* proportion in the light-harvesting complex (LHC) was calculated with the assumption that practically all Chl *b* is in the LHC and the Chl *a/b* ratio in it equals 1.2 (Lichtenthaler et Wellburn 1983, Maslova et Popova 1993).

### *Determination of chlorophyll fluorescence*

To measure the chlorophyll fluorescence the fluorimeter with a pulse-modulated light source (JUNIOR-PAM, Walz, Germany) was used. The measurements were taken on actively growing leaves (1–2 leaves in immature plants and 3–5 leaves in virginil plants). The chlorophyll fluorescence parameters were measured after 30-minute dark adaptation. The following chlorophyll fluorescence parameters were determined: basic fluorescence yield ( $F_0$ ), maximal fluorescence yield ( $F_M$ ) and variable fluorescence yield ( $F_V$ ) (the saturating

impulse PPFD being  $10\,000\ \mu\text{mol m}^{-2}\ \text{s}^{-1}$ ), the maximum photochemical quantum yield of PS II ( $F_V/F_M$ ). Induction curves were measured using the standard settings of the WinControl software to determine electron transport rate (ETR), the coefficients of photochemical (qP) and non-photochemical (NPQ) fluorescence quenching. The actinic light intensity was 190, 420 and  $820\ \mu\text{mol m}^{-2}\ \text{s}^{-1}$ . The rapid light curves (RLCs) were measured using 8 increasing light levels: 66, 90, 125, 190, 285, 420, 625 and  $820\ \mu\text{mol m}^{-2}\ \text{s}^{-1}$ .

## Results

In the study area, a high dimension and biomass variability of *B. vivipara* plants was observed. So, for example, the dry weight of a blossoming plant can vary within the range of 0.05 to 1.50 g, the plant height – from 50 to 250 mm, which is consistent with the data obtained for plants from the alpine zone: the plant height varies from 28 to 400 mm (Pawłowski 1956, Webb et Chater 1964, Villar 1990, Bauert 1993). It should be noted that, in the Arctic, the dry weight of *B. vivipara* varies 30 times and its linear dimensions – 5 times only. Regardless of the size, the biomass distribution in the organs was similar: the leaves accounted for about 20%, the rootstalk (rhizome) with roots – 55%, the dead plant parts – 18%, the flower-bearing stem with blooms – 8%.

The measurements of the photosynthetic pigment content showed that total chlorophyll (*Chl*) can vary within the range of 1.1 to 1.7 mg g<sup>-1</sup> of green weight, carotenoid content (*Car*) – from 0.2 to 0.4 mg g<sup>-1</sup> of green weight, the *Chl a/Chl b* ratio – from 1.7 to 4.5, *Chl/Car* – from 3.3 to 6.8. On average, *Chl* content totaled 1.35±0.05, *Car* content – 0.30 mg g<sup>-1</sup> of green weight; the *Chl a/Chl b* ratio – 3.0, *Chl/Car* – 4.5. The pigment content varies, but the variability of this parameter is less than that of the biometric parameters. Greater values of pigment content (1.73 mg g<sup>-1</sup> of green weight), and the *Chl a/Chl b* ratio (4.1–4.5 due to the quantity reduction of chlorophyll *b*) were observed in large individual in natural ecotopes and in plants within the territory of a colony of birds. The pigment content in this species on Spitsbergen was similar to that of *Bistorta vivipara* plants on Wrangel Island (Gerasimenko et al. 1989).

The study of photosynthesis photochemical reactions was conducted on plants only growing in natural tundra ecotopes. The work was begun with plants in a vege-

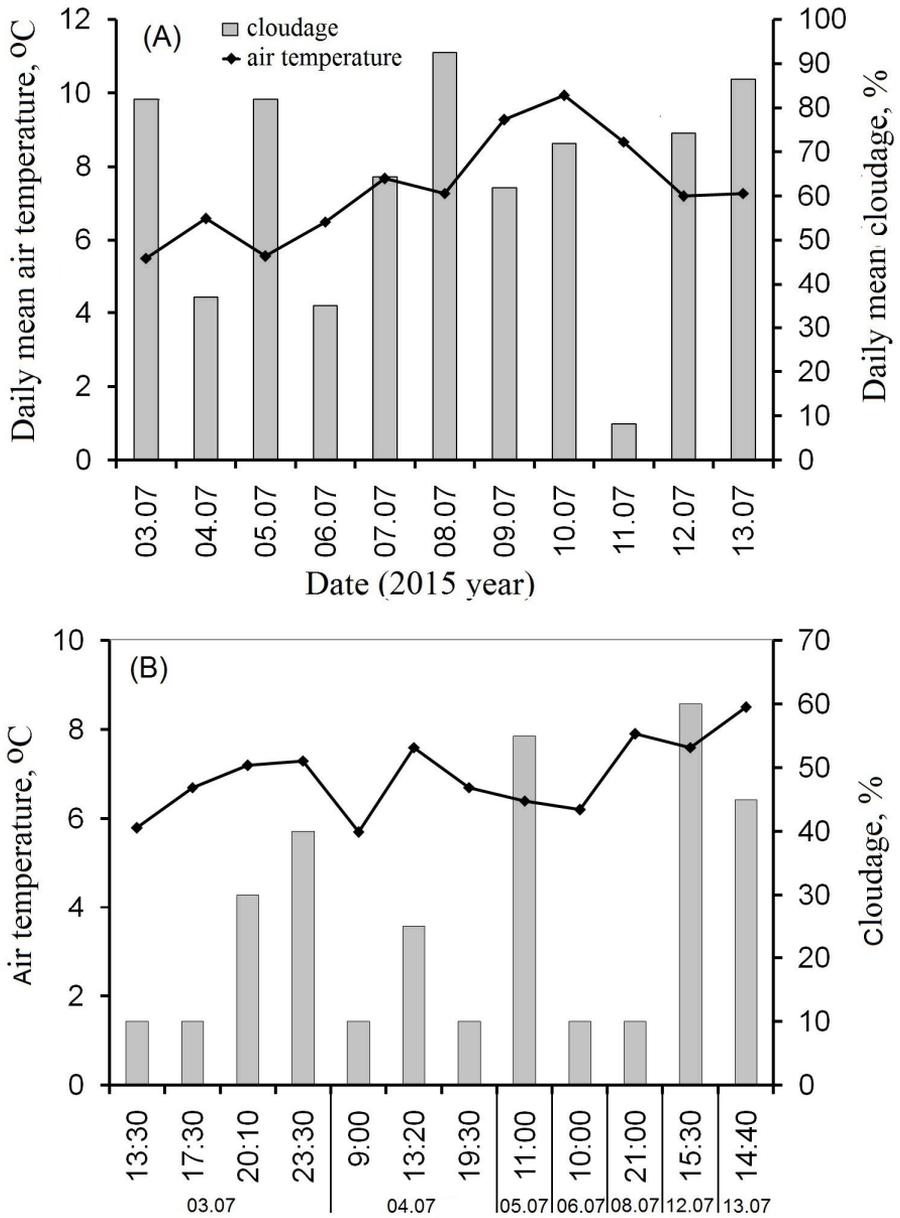
tative state, and a week later on the studied plants there emerged flower-bearing stem. The mass transition to blossoming was accompanied by a temperature rise.

In the course of the study of chlorophyll fluorescence parameters it became available that in *B. vivipara* plants throughout the whole study period both low ( $F_0$  (19 – 53),  $F_M$  (88 – 204) and  $F_V$  (61 – 152)) and high ( $F_0$  (103 – 196),  $F_M$  (362 – 911); and  $F_V$  (279 – 696)) values of the PA photochemical activity parameters were observed. The changes in these values occurred from July 5 to July 6 and were associated with the changes in the daily weather conditions. On colder and cloudier days low values were registered, whereas on warmer and sunnier days we observed higher values of these basic chlorophyll fluorescence parameters (a four- or fivefold increase) (Fig. 1, 2).

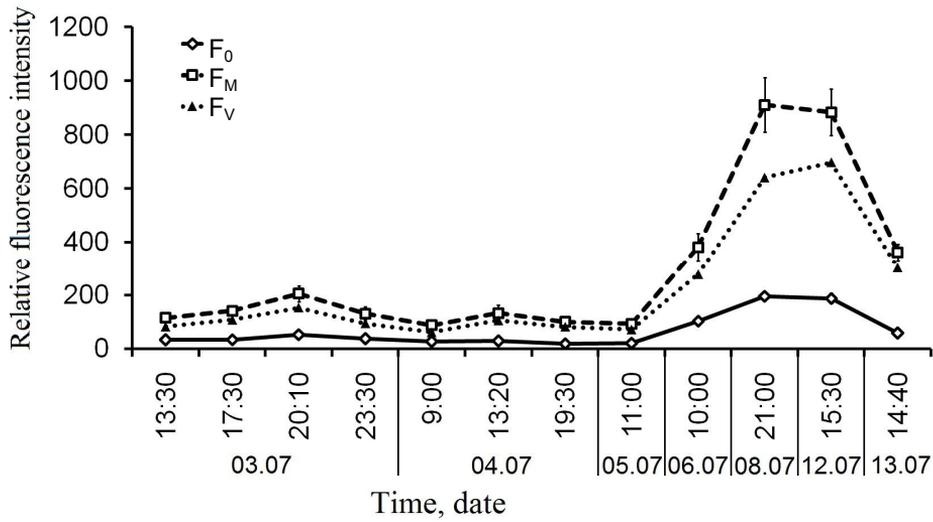
$F_V/F_M$  values varied in the studied plants in the range of 0.73 to 0.82 during the measurement period, which is consistent with the range of the optimal vital activity of the plants (Björkman et Demming 1987, Angelini et al. 2001: cited by Goltsev et al. 2014). Despite the changes in the weather conditions this range remained unchanged (Fig. 3).

Throughout the duration of the experiment, as the light and temperature conditions varied, constant values of  $qP$  were observed, it only varied within a relatively narrow range: 0.37 – 0.79 (on induction curves, at the PPFD of 820  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ) and 0.79 – 0.98 (the PPFD of 190  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ) with the coefficient of variability (CV) being 12.8% (Fig. 3).

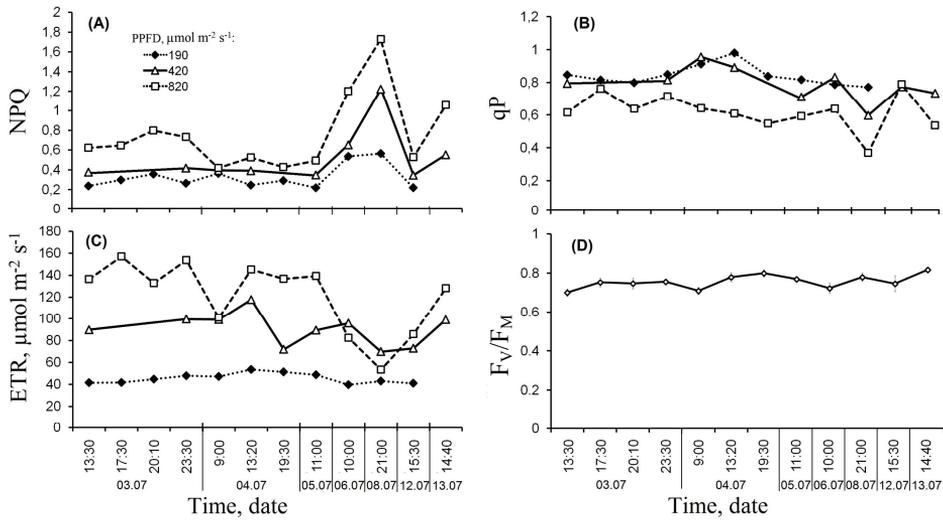
The NPQ values changed depending on the combination of light and temperature conditions: from 0.2 (on induction curves, at the PPFD of 190  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ) to 1.7 (the PPFD of 820  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ) with the coefficient of variability being 47.2% (see Fig. 3).



**Fig. 1.** Air temperature and cloudage: daily mean (A) and during the study period (B) (according to the data from Barentsburg meteorological station).



**Fig. 2.**  $F_0$ ,  $F_M$  and  $F_V$  values during the study period. *Note:* measurement time – local time in the study area is given (UTC+1). Each point is an average value of 4-11 measurements (leaves).



**Fig. 3.** NPQ, qP, ETR values at different PPFD and  $F_V/F_M$  values during the study period. *Note:* see Fig. 2.

The study of the *ETR* versus PAR showed that the electron transport rate at PPFD of up to  $420 \mu\text{mol photons m}^{-2} \text{s}^{-1}$  varies insignificantly in plants existing in different light and temperature conditions and at different times of the day. The coefficient of variability equals 10.0% and 16.9% at PPFD of 190 and  $420 \mu\text{mol m}^{-2} \text{s}^{-1}$  respectively. There are only variations in the *ETR* at high PAR (at PPFD of  $820 \mu\text{mol m}^{-2} \text{s}^{-1}$  they varied from 53 to  $180 \mu\text{mol m}^{-2} \text{s}^{-1}$ , which depended on the climatic conditions). So, for example, on July 3 (2 p.m.), July 6 (10 a.m.), July 8 (9 p.m.) and July 12 (3 p.m.) the maximum values of *ETR* did not exceed 100, whereas all the rest of the time during the

study these values came up to 128-157 (at PPFD of  $820 \mu\text{mol m}^{-2} \text{s}^{-1}$ ).

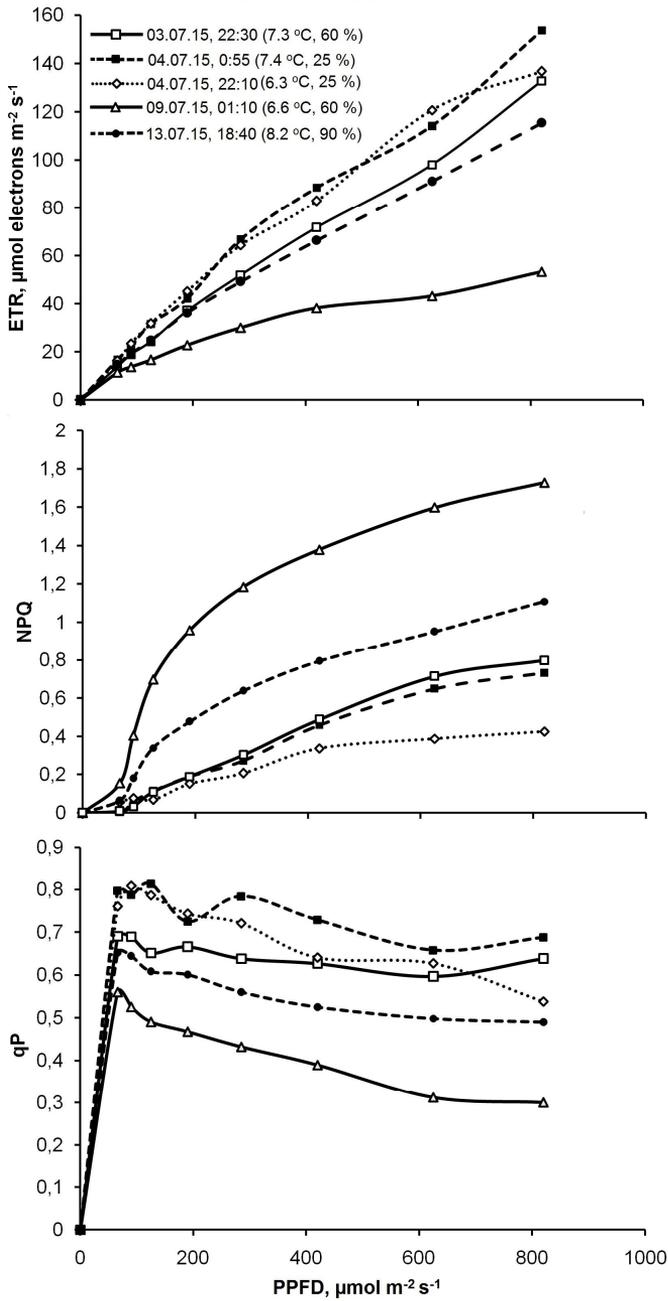
The form rapid light curves (RLCs) differ in plants existing in different light and temperature conditions and at different times of the day (Fig. 4). In polar plants exposed to low temperature combined with mostly cloudy (July 9 - 6.3°C, 60%) were observed low functional activity of the PA: the low values of *ETR* and *qP*, the high values of *NPQ*. Increase air temperature while maintaining mostly cloudy (July 3 and July 13) or decreasing clouds (increase PAR) (4 July), leads to activation of the work of FA: there are higher values of *ETR*, *qP* and lower values of *NPQ* (Fig 4).

## Discussion

Intraspecific variability of biometric parameters (linear dimensions and dry biomass) of *B. vivipara* plants was observed at West Spitsbergen. The revealed differences in the variability of growth and productivity parameters (sixfold) can be associated with the fact that low temperatures curb the growth of this species to a greater extent than its biomass accumulation (Gamalei 2004). The differences in biomass productivity must be associated with the functional activity of the plant, which was also confirmed by the measurement of pigment content in these plants. Our results demonstrated that the greater the biomass, the higher the photosynthetic pigment content. The study of the PA photochemical activity revealed several mechanisms included in the PA reaction to the changing weather conditions, which is characteristic of Arctic plants in circadian and seasonal dynamics.

In early July, considerable changes of several fluorescence parameters were observed (from July 5 to July 6). Above all,

these changes included a substantial increment of the  $F_0$  and  $F_M$  values, which can be associated with the regulation of the number of active reactive centers and the amount of active pigments in the light-harvesting complex (Marchand et al. 2006). However, did not lead to a decrease in PS II activity since only a slight variation of  $F_V/F_M$  was observed, indicating absence of stress conditions. Moreover, high and close-to-theoretical maximum  $F_V/F_M$  values indicate the presence of functioning regulation systems at the PA level in the unstable conditions of the daily climate. Such conclusion could be supported by the data of Lütz et al. (2012) who measured  $F_V/F_M$  circadian cycle in *Dryas octopetala* on Spitsbergen. It emerged that within 24 hours, the values of this parameter remained almost unchanged ranging within a narrow range of 0.7-0.8. Moreover, no inhibition of  $F_V/F_M$  midday depression was observed, like it was in other European lowland species (Lütz et al. 2012).



**Fig. 4.** The rapid light curves (RLCs) in plants existing in different light and temperature conditions and at different times of the day. *Note:* measurement time – local time in the study area is given (UTC+1). Each RLC is an average of 3 RLCs measurements. In brackets is air temperature and cloud cover during measurements.

The  $F_V/F_M$  stability and functioning is supported by the absence of any qP variation, which is indicative of photochemical activity of the photosystem II, openness of PS II reaction centres in particular. The NPQ data suggest that the non-photochemical quenching acts as a protective mechanism, sustaining the PA in an optimally active state and/or reducing probability of negative changes to PSII thanks to overenergization of pigment protein complexes and PS II reaction centers in PA of plants in Arctic regions. For example, we observed an increase NPQ July 6 and July 8 (Fig. 3). These days were characterized by a relatively high daily mean air temperature and during the measurement period was clear weather (cloudage less than 10%). Typically, activation of NPQ mechanisms is associated both with the dissipation of energy in the form of heat, which does not lead to irreparable damage (Huner et al. 1993, Lutz 2010), and with the presence of a well-developed antioxidant defense system comprising a large pool of antioxidative enzymes and pigments, xanthophyll-cycle pigments in particular. Typically, Arctic plants maintain this antioxidative defense system at a constant high level during vegetation period (Lutz et al. 2012). The stability of photosynthetic processes in polar plants exposed to high illumination combined with low temperature can be accounted for by the high activity of the alternative oxidase (Streb et al. 2005).

Similarly high  $F_V/F_M$  data were obtained for Antarctic plants (*Deschampsia antarctica*, *Colobanthus quitensis*), growing at low temperatures and high illumination. In the field environment, high constant values of potential yield of photochemical processes in PS II ( $F_V/F_M$ ) are observed at a low temperature and high illumination not only on different days but in the circadian cycle (Casanova-Katny et al. 2010). The maintenance of high  $F_V/F_M$  ratio under high light is due to a high energy quenching capacity of these plants at their respective natural conditions (Bascañán-Godoy et al.

2010). These plants have optimal temperatures for photosynthetic processes – about 10°C. But even at a leaf temperature of 0°C, the photosynthesis rate still remains at the level of about 30% of its maximum (Perez-Torres et al. 2004, Xiong et al. 1999).

The similarity of the dependence between the ETR and PAR within the range of low light conditions shows that the plants are well adapted to low temperatures and illumination, which are mostly observed during the vegetation period at the time of the polar day in the course of a 24-hour day in the Arctic. From published sources it is known that many chlorophyll fluorescence parameters are highly dependent on the PAR dynamics. So, for example, in *Silene acaulis*, *Dryas octopetala*, *Salix Polar* the ETR reflected the PAR change and varied from 15 to 250  $\mu\text{mol m}^{-2} \text{s}^{-1}$  depending on the weather conditions (clear or overcast days), but never reached the zero value (even at night when the Sun was low above the horizon) (Barták et al. 2012). In the above-specified three species, photosynthetic apparatus worked in a similar way, despite the differences in the leaf morphology and anatomy, the growth form (lower values for *Dryas octopetala*). This reflects the consistency of photosynthetic processes with environmental factors and adaptation of the three species to Arctic summer ranges of light and temperature.

Our study showed that *B. vivipara* plants were well adapted to a wide range of ecotopes. The leading role in adaptation is played by the original intraspecific variability, which probably is the determining factor of their functional adaptation peculiarities. The PA adaptability at the level of the plant structure and light-dependent reactions enables this species to develop at a high functional level, which provides for the successful growth of the species in the high Arctic region. Previously it was shown that for this species at Spitsbergen, high total nitrogen content (3.3% abs. dry

weight) was indicative of its high functional activity (Markovskaya *et al.* 2014). The conditions on Spitsbergen facilitate *B. vivipara* development not only due to the more favourable environment for biological productivity, as compared to other Arctic regions in these latitudes, but also owing to the conditions for the sprouting of brood buds. The formed bulbils begin to grow under the conditions of increased humidity

(Batygina 1999), which is especially advantageous in Spitsbergen terrestrial ecosystems, where the dominating moss carpet creates most favourable environment for the growth and development of bulbils in *B. vivipara*. The high PA flexibility suggests that *Bistorta vivipara* is capable of active adaptive changes in the context of the predicted climate change in Arctic regions.

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