

## Morphological and functional peculiarities of saltmarsh plants and epilithic lichens in tidal conditions of Russian Arctic Seas

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### Abstract

Ecological plasticity in the tidal zone, specifically the effects of daily and seasonal dynamics of environmental factors on the dominant species of vascular plants and epilithic lichens has been studied. The investigations were conducted on the Pomorian coast of the White Sea (Republic of Karelia) during two growing seasons (2012-2013). The studies of the morphological and anatomical characteristics of dominant individuals in the plant and lichen cover types have been made along the model transect through different substrate types. Determination of plasticity of plants and lichens was made by the method of Cornelissen exploiting coefficient of variation (CV). The obtained data showed that the investigated groups of vascular plants and lichens on the tidal zone on all measured morphological and anatomical parameters have a high level of plasticity

**Key words:** tidal zone, coefficient of variation, vascular plants, lichens, pollen, anatomy, White Sea.

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### Introduction

Water is rather stable environment, and it's abiotic factors have relatively only minor fluctuations. Thus, aquatic organisms have smaller ecological plasticity in comparison with the terrestrial ones. However, in the tidal zone, where all the factors constantly vary in daily and seasonal dynamics, plants and animals inhabiting such habitats must cope with high instability of environmental conditions (Sergienko et al. 2012). This leads to an increased plasticity

of the species (the increase in the amplitude of the phenotypic variation) and, as a result, to strengthening their morphogenesis and speciation. Ecological plasticity underlies in the intraspecific polymorphism that has been investigated recently (Engels et al. 2011, Sheremetiev 2005, Sergienko 2008). However, the plant populations growing in the tidal zone of the Holarctic seas, their plasticity in particular, have not been studied. The purpose of this study is

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the investigation and evaluation of the variation of some morphological and functional characteristics of phototrophic organisms: vascular plants and lichens of the

coastal zone of the White Sea, evaluation of their adaptation to unstable environmental conditions in particular.

## Material and Methods

The study was conducted along the Pomorian coast of the White Sea, near the village Rast-Navolok (White Sea region, Republic of Karelia) during two consecutive growing seasons (2012-2013). The investigated area of the White Sea coast is located in sub-physiographic zone in the North of European part of Russia. White Sea, connecting with the Barents Sea, is the part of the Arctic ocean (Markovskaya *et al.* 2010) (*see* Fig. 1). The study area

was located in the tidal zone of the coastline of the White Sea - from the zero level (the littoral zone) to supralittoral (splash zone). The phototrophic organisms thriving in such high/latitude ecotypes of the coastal zone (vascular plants, lichens) cope with low temperature, seasonal variations of photoperiod, daily gradient of temperature and light conditions, flood, and salinity.



**Fig. 1.** Study area – Rastnavolok – Belomorsk district, Karelia Republic.

The distribution of vascular plants and epilithic lichens on the coast was assessed. Similarly, the study of morphological characteristics of dominant individuals in the plant and lichen cover types were evaluated along the model transect (length 260 m, width 10 m). The transect begun from the native coast, formed of stone boulders, height up to 2.5 m and followed up to the line of low-water's edge at low tide. Different length of time tiding in the full tide the three plots (PPs – see below), were found along the transect, the shapes of which coincide with the natural boundaries of plant communities.

PP 1 (3x6 m) was located in the distance of 5 m from the maximum low tide from the water's edge. The plot was typical by muddy and sand substrate. The height of the column of water from the substrate

to the maximum high tide reached 100-120 cm. TPC of vegetation was below 10%.

PP 2 (4x5 m) was located in the distance of 80 m from the water's edge. The plot was typical by muddy and sand substrate. The height of the column of water from the substrate was up to 80 cm. (TPC) vegetation ranged 30-40%.

PP 3 (4x5 m) was located in the distance of 140 m from the water's edge. The plot was typical by muddy and sand substrate. The height of the column of water from the substrate was up to 60 cm. (TPC) vegetation ranged 70-80%.

PP 4 (4x5 m) was located in the distance of 230 m from the water's edge. The height of the water column above the substrate during the complete flow was up to 40 cm. Total projective cover (TPC) of vegetation reached 50-60%.

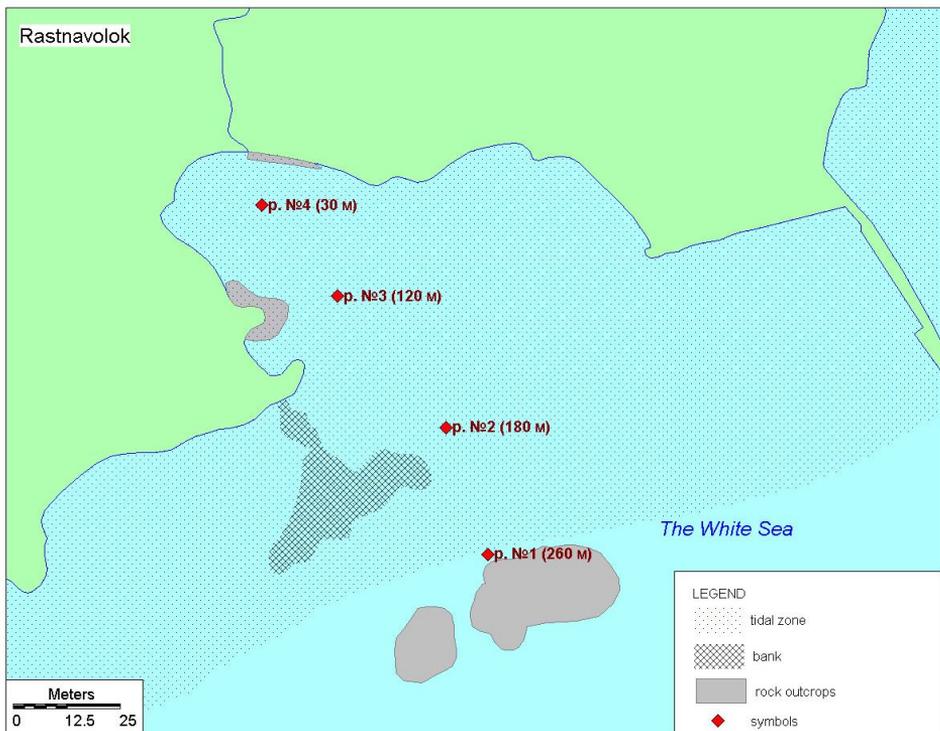


Fig. 2. Plots on the transect on the tidal zone on the shore of White Sea.

For plants, several morpho-physiological parameters were investigated: (1) plant height, (2) width and length of the lamina, (3) lamina area (S), (4) dry weight of leaf (m), (5) specific leaf area (SLA). Anatomic-morphological characteristics represented the following parameters: (6) the cell volume, (7) number of stomata, (8) size of stomata, (9) area of the stomatic cleft on the upper and lower sides of the lamina, (10) length and width of the cells of the upper and lower epidermis, (11) length and width of the cells of the palisade mesophyll, (12) number of chloroplasts in the spongy and the palisade mesophyll, (13) total number of chloroplasts, (14) cell volume corresponding to one chloroplast (KOH) the amount of cells corresponding to one chloroplast or cell volume of the chloroplast (*i.e.* the ratio of the volume of cells to the number of chloroplasts in its  $\text{mcm}^3$ ).

In this study, palynological parameter, *i.e.* determination of percentage of pollen violation in dominant vegetation species was estimated. 10 viable, well-developed and well-lighted plants in each plot were selected. 5 leaves from the middle part of the stem for fixation in 70% ethanol were taken from each plant. For palynological studies for each species 10 flowers from 1 plant was taken.

50 leaves were determined by their size

and measurement of anatomical structures (stomata cells of the epidermis and mesophyll) - 10 lamina from different individuals of each species from each PP. The plant material was dried in a thermostat at 60°C until constant weight, for determine of dry mass. Measurements of anatomical parameters were carried out using a light microscope with magnification of 100 x 100-fold replication for leaves from each plot. The number of chloroplasts was calculated as an indicator of stomatal apparatus according to the method of Mokrousov et Borzenkova (1978). For analysis of pollen grains, the acetocarmine method (Pausheva 1980, Dzyuba 2006) was used. Determination of plasticity (CV) of plants and lichens was done by the method of Cornelissen *et al.* (2003). The morpho-physiological, anatomical and palynological studies on the dominant higher vascular species of the salt marshes communities (*Glaux maritima*, *Tripolium pannonicum* subsp. *tripolium*, *Triglochin maritima*, *Plantago maritima*), were done at the selected transects. In *Glaux maritima* and *Tripolium pannonicum* subsp. *tripolium* the anatomical and morphological studies were performed. The variations of the halophytic species (Sonina 2012) (species of the genus *Verrucaria*) was used as characteristics of the lichen cover.

## Results

*Glaux maritima* L. – crynhalophyte, is common on the White Sea coast in salt marshes communities on the West coast. It is rare at other parts of the coast. The species has a disjunctive geographical range in the temperate zone of the Northern hemisphere. The results can be summarized as follows: (1) the number and the size of stomata on the upper side and the lower sides of the lamina, and (2) the cell volume increased with the distance from the shore to the water's edge on three plots.

The only two above-specified characteristics significantly differed in *Glaux maritima*. Other morphological, physiological and anatomical parameters considered in the analyzed plants did not showed significant changes along the transect.

However, the heterogeneous conditions along a transect caused some changes in the coefficient of variation. Morpho-physiological parameters changed along the transect and had values of coefficient of variation (CV) in the range: leaf surface

area values 537-424 mm<sup>2</sup> (CV 15-37%), length (1.0 to 1.1 cm) and the width of the sheet (0.43-0.52 cm) CV (5-30%), SLA (11.0-14.0 mm<sup>2</sup>.mg<sup>-1</sup>, CV range of 8-31%), dry matter content (214-245 mg.g<sup>-1</sup>, CV 12-26%).

In the morpho-anatomical parameters, the following range of values was found: volume of cells (to 12.0-17.0 thousand mcm<sup>3</sup>, CV 52-56%), the amount of cells corresponding to one chloroplast KOH (460-490 mcm<sup>3</sup>, CV 54-59%), the number

of chloroplasts, especially in the cells of the spongy parenchyma (28-36 units in the cell, CV 25-36%). The variation of the above-specified characteristics generally did not exceed 20-22%. The most variable parameters were found in the plants growing in the middle plots along the the transect, where the coverage of vegetation reached 70%, the abundance of *Glaux maritima* growing in the shaded spots provided by a taller species, was up to 30%.



**Fig. 3.** *Glaux maritima* on sand substrate on transect on the tidal zone on the shore of White Sea.

*Tripolium pannonicum* (Jacq.) Dobroc. subsp. *tripolium* (L.) Greuter - euhalophyte, boreal Eurasian species, is commonly spread on the coast of the Holarctic (Markovskaya et al. 2010). The plant height and the area of the lamina were found significantly reduced as the species moves from the native coast to the water's edge. The thickness of the lamina reached

almost 20% at the water's edge. In the plants growing near water's edge, the morpho-physiological and morpho-anatomical parameters of plant (number of stomata on both upper and lower epidermis) increased as well.

However, the heterogeneous conditions along the transect caused changes of the coefficient of variation of particular charac-

teristics. The highest CV values were found for the leaves area: the area values was about 460-1980 mm<sup>2</sup> (CV 39-56%). The CV showed somewhat lower values for the length (7-15 cm) and the width of the sheet (0.6 to 1.3 cm): CV was 26-35 and CV 26-33%, respectively. Mean values and CV reached 8-14 mm<sup>2</sup>.mg<sup>-1</sup>, and 29-30% for SLA and 150-160 mg.g<sup>-1</sup>, and 26-41% for dry mass respectively.

The highest values of CV were obtained on the volume of cells (20-23 thousand mcm<sup>3</sup>, CV 42-46%) and KOH (380-470 mcm<sup>3</sup>, CV 38-59%). All characteristics of the stomatal apparatus of

*Tripolium pannonicum* had lower CV values than in *Glaux maritima*. It was found for number of stomata per unit area: the values ranged 45-90 pieces/mm<sup>2</sup> (CV 25-36%), the area of the stomatic cleft were found within a range of 33-38 mcm<sup>2</sup> (CV 25-35%), the area of stomata on the upper and lower side of the lamina was 700-890 mcm<sup>2</sup> (CV 22-40%), 910-1130 mcm<sup>2</sup> (CV 12-37%), respectively. The range of CV for the other parameters was not found too high, CV was found within a range from 10 to 20%. When comparing data from all three plots, large differences in the coefficient of variation was not found.



**Fig. 4.** *Tripolium pannonicum* subsp. *tripolium* on pebble-shingle substrate on transect on the tidal zone on the shore of White Sea.

*Triglochin maritima* L. - euhalophyte, plurizonal species, has a circumpolar area, occurs all over on the White Sea coast in the salt marshes communities with high content of salt (Markovskaya et al. 2010). The plants of *Triglochin maritima* growing at water's edge (PP3) the leaf area compared to other points on the transect have been decreased, while the other parameters

were not significantly changed during the flooding duration. The coefficient of variation of leaves area: the area values is about 990-1380 mm<sup>2</sup> (CV 22-50%), the length of leaves – 28-37 cm and the width of the lamina – 0.3-0.4 cm (CV 5-30%); on the SLA – 3.3-3.8 mm<sup>2</sup>.mg<sup>-1</sup> (CV 17-35%) and the dry matter content 240-260 mg.g<sup>-1</sup> (CV 18-39%).



**Fig. 5.** *Triglochin maritima* on sandy-boulder substrate on transect on the tidal zone on the shore of White Sea.

*Plantago maritima* L. is a euhalophyte, hypoaerobic Eurasian species, abundant on the coast of the White Sea. The species widely occurs in the area of periodic inundation by salt water (Markovskaya et al.

2010). The increasing of the number of indicators for *Plantago maritima* in different tidal conditions was noted. The increasing in the values of the number of indicators for *Plantago maritima* in differ-

ent tidal conditions was noted. The specific leaves area (SLA) and the accumulation of dry mass significantly increased in the plots at the water's edge. The plants of *Plantago maritima* had the following values of the means and CVs: for the

leaves area (650-1500 mm<sup>2</sup>, CV 54-81), the length (14-24 cm) and the width of the lamina (0.4 to 0.6 cm) (CV, accordingly 34-100% and 25-45%), SLA (9-12 mm<sup>2</sup>. mg<sup>-1</sup>, CV 34-97%), and dry matter content (170-210 mg.g<sup>-1</sup>, CV 22-31%).



**Fig. 6.** *Plantago maritima* on sandy-break stone substrate on transect on the tidal zone on the shore of White Sea.

The stage of formation of reproductive structures is one of the indicators of the functional state of the plant. Therefore, the structure of pollen grains in the three species -*Triglochin maritima* L., *Tripolium pannonicum* (Jacq.) Dobrocz. subsp. *tripolium* (L.) Greuter, *Glaux maritima* L. was investigated. The three species grow in the tidal zone which is typical by a high frequency of changes in abiotic factors of the environment. The changes happen from the native shore to the water's edge. That was why the structure of pollen grains was investigated. The value of the

coefficient of variation of normally developed pollen within transect at *Tripolium pannonicum* subsp. *tripolium* was found from 3.0 up to 5.0%. The value indicated a weak variation of this parameter and may be attributed to a long-term adaptation of this species to a wide range of conditions generated at the tidal zone.

The value of the CV of normally developed pollen within transect at *Glaux maritima* was 2.0 - 16.0%, indicating a moderate degree of variation. The CV value of normally developed pollen within transect at *Triglochin maritima* was found

from 6.0 to 48.0%. The highest CV values was recorded for *Triglochin maritima* grown in the central part of the transect (PP2) (CV 48.0%). This particular site was an open area with the most active tidal dynamics to which this species may respond.

The halophytic group of lichens of the genus *Verrucaria*, forming spots of different sizes depending on habitat conditions were found only in flooding areas on the stones. On all investigated plots along

transect, the projective lichen cover degree has the high values of CV, *i.e.* from 34 to 88%. At the sites along the transect where the highest CV values were found, the total average cover of lichen halophytes reached 30%. Contrastingly, at the water's edge, the CV value was found low (CV=34%). At the plots located closer to a native shore, the CV values increased to 83-88%, while the projective cover showed somewhat lower values (below 5%).

## Discussion

In this study, we compared CV values calculated for several morpho-physiological parameters in the investigated higher plant species. We considered the CV values as a measure of flexibility of the species at the site. The main conclusions can be summarized as follows: (1) high level of plasticity was found for *Plantago maritima*, while the lower CV values were in *Triglochin maritima* and *Tripolium pannonicum* subsp. *tripolium*, (2) the lowest level of plasticity had *Glaux maritima* (Crawford, 2011), (3) high CV values of morpho-physiological parameters were observed in all individuals of all species growing near water's edge. In morpho-anatomical parameters, the following two species (*Tripolium pannonicum* subsp. *tripolium* and *Glaux maritima*) were compared. It was found, that (4) *Tripolium pannonicum* subsp. *tripolium* had a larger number of indicators with a high level of variation compared with *Glaux maritima*. Therefore, we suppose that *Tripolium pannonicum* subsp. *tripolium* is more plastic than the plants of *Glaux maritima* in response to environmental perturbations.

Preliminary analysis of the development of reproductive structures showed that the investigated species of higher plants can be ranked according to high to low plasticity as follows: *Triglochin maritima*, *Glaux maritima* and *Tripolium*

*pannonicum* subsp. *tripolium*. For lichen of genus *Verrucaria*, a conclusion can be made that the pattern of its the distribution on the intertidal zone is associated with rising of salt water along the transect. Salt water is a essential condition for the existence of such halophytic genus like *Verrucaria*. At the water's edge at low tide on the rocks lichens have the greater projective cover in those micronches that are longer under the column of salt water. Near the native shore lichens can be found only in those micronches on the rocks, which at least are in the zone of influence of marine waters.

The highest CV values for projective cover of halophytic species of lichens were found near the native shore (CV 88%) in long-term low tide. The lowest CV value was found for the sites typical by long-term flooding and high water lifting. These sites were located near the water's edge (CV 34%). The differences in flood and water lifting dynamics led to the selection of the most stable to unsteady conditions of individuals of species of the genus *Verrucaria*.

The data presented in this study showed that the investigated groups of vascular plants and lichens morphological and anatomical parameters have a high level of plasticity (evaluated as CV variation) for the species forming vegetation cover of tidal zone. Only one species – *Glaux*

*maritima* had CV values as low that a conclusion of low morphological plasticity of the species can be done. The data presented in this study support the idea of a more detailed investigation in this field, at least as a continuation of recent study.

For future studies, enlargement of the scope is recommended as regards *e.g.* an inclusion of some new species and the extension of the indicators of vegetation structure and function.

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