Features of the structural organization and biomorphology of dominant plant species of Holarctic seas' coasts along the tidal gradient

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Abstract

Investigations of the population and biomorphology of dominant species *Plantago maritima* L. (fam. *Plantaginaceae*) and *Triglochin maritima* L. (fam. *Juncaginaceae*) along the tidal gradient of the coasts of the White Sea are presented. The western coast of the White Sea has been chosen as a sample of Holarctic seas' coasts. These 2 euhalophyte species represent a group of the allochthonous elements that came from to the Arctic coasts the Middle Asia in the Pliocene-Pleistocene time. In our study, we evaluated structural and functional characteristics of populations of the two species along the tidal gradient. We found that vitality-ontogenetic structure of the populations and their biomorphological characteristics significantly differ depending on the tidal level and substrate structure. The different adaptive peculiarities of these species growing in these habitats were observed. Along the gradient from sea level to the native shore, the biomorphological indexes (number of shoots per plant, number of leaves per shoots, leaves parameters, length of the floriferous stem and spike, dry mass of aboveground shoots of plants) of the *Triglochin maritima* populations significantly decreased, while the same indexes of the *Plantago maritima* populations increased. The obtained results show the significant variability of all morphometric parameters of vegetative organs as well as generative features along the tidal gradient of these circumpolar plant species.

Key words: *Plantago maritima*, *Triglochin maritima*, population structure, tidal zone, adaptation, White Sea, Holarctic Seas

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Introduction

In connection with the prevention of the water area pollution, restoration of fish resources, the development of the ecological tourism, the tidal zone of the White Sea coasts is actively studied by biologists and ecologists recently (Naumov et Fedyakov 1993, Berger 2007, Zhitni 2007). The tidal zone refers to the azonal natural structure (Sergienko 2008) and is one of the most sensitive and vulnerable biological system. The balanced development of their structural and functional organization in the Holarctic biogeographic and Palaeoarctic regions attracts attention of researchers from different countries (Olsson 1974, Westhoff et Schouten 1979, Hadač 1989, Nordal et Stabbetorp 1990, Thannheiser 1998, Markovskaya et al. 2010, 2014).

The vascular plants play a significant role in the formation of vegetation cover of this zone and can be considered as the indicators for biological monitoring of negative human disturbance in this area (Jerling 1985, Vekhov 1992, Ralph et Short 2002). The study of the features of spatial distribution of populations, biomass accumulation and characteristics of biomorphology of the dominant species of tidal communities might be the basis for the development of biomonitoring at different levels for the assessment of the state of the coastal ecosystems to predict and minimize the risk of their violation. The western coast of the White Sea was selected as a standard area for the study of the structure of populations and biomorphological parameters of dominant species *Plantago maritima* L. (*Plantaginaceae*) and *Triglochin maritima* L. (*Juncaginaceae*) in the tidal zone of the Holarctic Seas.

Fig. 1. Location of study area (Kolezhma, Belomorsk district, Republic of Karelia).

Material and Methods

The field works were carried out on western coast of the White Sea, on the Lopskiy peninsula (64° 22' 81" N, 35° 93' 14" E), *see* Fig. 1. The study area has a continental climate with cool short summers and long winter period. The duration of a frost-free period is 120–130 days. The mean annual precipitation is 550–600 mm and the annual average temperature is from 0 to +1.3°C. The mean monthly temperature varies from -10.1 to -12.8°C in January to +13.9 to +14.7 °C in July (Nazarova 2005, 2015). The fragmentation of the coastline and the abundance of small rocky islands are important characteristics of the coast of the Lopskiy peninsula. Accumulative shore of the peninsula has the gravel-pebble and sandy ridge covered by alluvial-diluvial silts.

Plantago maritima is an obligate halophyte, hypoarctic Eurasian species, abundant on the coast of the White Sea. The species widely occurs in the areas of periodic inundation by salt water (Markovskaya et al. 2010, 2014). It is perennial herb, 10–60 cm tall, with a strong taproot. Branched caudex is from 2 up to 7 cm in length, covered by the dead leaves remains at the basis. Leaves are arranged in the rosette, succulent, lanceolate, and possessing the vaginal shape at the base (Fig. 2).

Triglochin maritima – obligate halophyte, plurizonal species. The species has a circumpolar range, it occurs all over on the White Sea coast in the salt marshes communities with high content of salt (Markovskaya et al. 2010, 2014). It is clonal perennial herbaceous rhizomatous plant with a rosette of succulent leaves and terminal racemose inflorescence.

Fig. 2. *Plantago maritima* L.

The measurements of structural and functional characteristics of populations of the studied species were done along the tidal gradient on the supralittoral and littoral zones on special plots (transects). The transects had a width of 10 m and varying length from the line with maximum storm sediments (supralittoral) up to the lower level of the maximum low tide (lower littoral). Within the transects, the three zones were distinguished, according to the type of substrate and vegetation. In each zone, the plant species composition and full geobotanical descriptions on the experimental plots (220) of 1 square meter were done using standard geobotanical method [1]. The plant populations were classified using classical population biology methods [2, 3]. The « polycormone» was chosen as the counting unit of the population. «Polycormone» – vegetative plant individual with numerous particulas (aboveground shoots forming by vegetative reproduction) (Markov 1990). The biometric measurements (height of the aboveground shoots, length of roots, length and width of the largest leaf, length of the floriferous stem, length of the inflorescence) were performed at 10 plants of generative individuals (at the identical ontogenetic stage) from each zone by ten replicates. Data processing was carried out mainly by the analysis of variance (ANOVA) with using MS «Excel».

Fig. 3. *Triglochin maritima* L.

Results

On study transects of the tidal zone, totally 20 species formed composition of the plant vegetation cover. Number of species per the sample plots (1 x 1 m) varied from 0 to 6. The dominant species in studied plant community were *P. maritima* (15%) and *T. maritima* (11%). Subdominant species were *Juncus gerardii* ssp. *atrofuscus* and *Tripolium vulgare*. Based on the characteristics of the habitat types and the results of our geobotanical descriptions, transects were divided into three zones (numbered from the highest level of flooding).

Zone I started from the lowest limit of zonal vegetation, which prevailed on the slightly overgrown coastal terraces with turf soils. The upper level of *zone I* is determined by a stripe of storm sediments. The main substrate of this zone was light sand and gravel (25% stones + gravel, sand formed 30%). Micro-relief was not expressed which resulted in poor drainage without stagnant waterlogged. There was a periodic waterlogging as a result of melting snow and rainfall, river floods and tides. According to the oceanographic classification of Vaillant (Vaillant 1891, as cited. Kafanov et al. 2004), the *zone I* covers the supralittoral splashing zone. The total projection area of vegetation cover composed of vascular plants ranged from 20 up to 40%. The average number of species per sample plots averaged from 1.5 to 3.5. The length of the *zone I* is 0-3 m from a stripe of storm sediments.

Zone II was situated in 3-6 m from a stripe of storm sediments. The substrate was represented by a turf-covered loam with gravel (10% gravel, 10% sand). The micro-relief was formed by small bumps of *Puccinellia maritima*. The drainage was rather weak. The waterlogged persisted during a part of vegetation season. Water retention occurred due to an organic horizon. According to the oceanographic classification of Vaillant (Vaillant 1891, as cited. Kafanov et al. 2004), the *zone II* occupied the middle littoral zone. The total projection area of vegetation cover formed by vascular plants ranged from 15 up to 30%, the average number of species per sample plots ranged from 1.0 to 3.0.

Zone III was located in 6-10 m from a stripe of storm sediments. The main substrate was represented by medium loam with silt on the surface of the spots (2% gravel, 20% sand). Microrelief was not expressed and the drainage was very weak. The habitats were typical by stagnant waterlogging during the growing season. According to the oceanographic classification of Vaillant (Vaillant 1891, as cited. Kafanov et al. 2004) the *zone III* occupies the lower littoral zone. The total projection area of vegetation cover of higher plants ranged from 10 to 20%. The average number of plant species in the accounting plots ranged between 1.0 and 1.5.

The spatial structure of populations of *P. maritima* and *T. maritima* within the occupied area was characterized by a homogenous distribution of individuals. However, *P. maritima* aggregations of individuals were observed in the *zone I*. The age structure of populations of the studied species was characterized by rightward distribution of plant age with a predominance of mature generative individuals. Self-maintenance of the populations was carried out mainly by vegetative reproduction (forming of particulas).

The biomorphological parameters of *P. maritima* and *T. maritima* for each zone are represented in Table 1 and Table 2, correspondingly. Estimations of the biomorphological parameters of a population of plants growing in different unstable conditions of ecotopes showed that the morphological parameters of vegetative and generative shoots of *P. maritima* differed in the three zones (Table 1). The greatest differences in the total number of shoots in polycormone were observed. The highest number shoots in polycormone was found in the *zone II* (Fig. 4.). Compared to the *zone II* and *III*, the higher numerical values of most biomorphological parameters were found for plants from the *zone I* which was located under splashing conditions, and thus not exposed to the daily flooding. The plants from the *zone I* had two times greater height of the above ground shoots and the length of roots (Table 1).

In fact, the *P. maritima* plants from the *zone I* in comparison with plants from *zones II* and *III* were characterized by the highest values of leaves length, the largest size of the generative organs – the length of floriferous stem, and the inflorescence. In other words, decreased size of plants was observed closely to the minimum level of the low tide (the *zone III*).

The obtained data of the *T. maritima* population indicated, that the individuals growing in the *zone III*, had the largest total number of particulas in polycormone in comparison with *P. maritima* plants (Fig. 4). It should be particularly noted, that such biomorphological parameters, as the total number of shoots in polycormone and the number of vegetative and generative shoots in the *zone III* were two times higher than the same parameters for the *zones I* and *II* (Fig. 4). The plants *in zone III* had the greatest values of their height of aboveground shoots and length of roots (Table 2).

In addition, the biomass of aboveground shoots of *P. maritima* and *T. maritima* was determined for the selected zones of the transects (Fig. 5). According to obtained results, the total biomass of the aboveground shoots of plants *P. maritima* was greater in the *zone I* than in the *zones II* and *III* (Fig. 5). For *T. maritima* the highest values of biomass were found in the *zone III*.

An increase of different biometric and weight characteristics for *T. maritima* from the shoreline was found when compared to the same parameters from the lower level of the maximum low tide. An opposite trend was found for the parameters of *P. maritima*. They decreased along this gradient.

Parameters	CV,%	I zone	II zone	III zone
Number of vegetative shoots	56	10.4±4.7	28.8±11.4	27.4±12.9
Number of generative shoots	66	4.8±2.2	13.0±7.1	7.6±3.5
Number of leaves per shoots	32	6.8±1.4	4.3±0.9	3.9±0.7
Length of leaves, cm	57	24.9±4.2	9.8±2.4	8.6±2.0
Width of leaves, cm	88	0.7±0.8	0.3±0.09	0.3±0.09
Length of the floriferous stem, cm	58	26.7±5.1	13.9±9.2	9.4±2.2
Length of spike, cm	72	4.9±1.9	1.8±0.6	1.5±0,8
Height of aboveground vegetative shoots, cm	54	26.5±4.7	10.8±2.0	10.2±2.4
Height of generative shoots, cm	74	30.4±4.5	14.5±3.3	11.3±1.8
Length of roots, cm	84	38.7±4.3	28.5±10.2	26.2±11.6

Table 1. Biomorphological parameters of species *Plantago maritima* in different tidal zones.

Parameters	CV,%	I zone	II zone	III zone
Number of vegetative shoots	49	66.7±15.5	43.3±15.5	115±30.4
Number of generative shoots	67	10.7±2.0	4.3±2.8	15±8.8
Number of leaves per shoots	32	3.9±0.9	4.17±1.62	4.33±1.30
Length of leaves, cm	21	30.9±4.0	28.2±5.2	33.1±8.9
Width of leaves, cm	37	0.3±0.06	0.3±0,07	0.3±0.08
Length of the floriferous stem, cm	37	38.2±7.9	37.4±7.7	47.1±20.4
Length of the inflorescence, cm	48	20.1±5.3	18.9±6.6	24.0±13.9
Height of aboveground vegetative shoots, cm	21	30.0±4.5	29.6±5.0	33.1±8.8
Height of generative shoots, cm	36	37.0±9.0	33.6±5.2	45.3±21.7
Length of roots, cm	25	13.2±3.3	11.7±2.5	15.4±3.3

Table 2. Biomorphological parameters of species *Triglochin maritima* in different tidal zones.

In Table 1 the values of coefficient of variation (CV) for all studied parameters of plants are presented. According to data, the largest CV for *P. maritima* was observed in biomorphological parameters such as the width of the leaf (CV = 88), the height of generative shoot (CV = 74), as well as the length of the spike (CV = 72). The number of leaves on one single shoot did not varied that much (*c.f.* CV = 32). In the population of *T. maritima*, the highest CV was observed in the number of generative shoots (CV = 67). Contrastingly, both the leaf length, and the height of vegetative shoots had the smallest coefficient of variation, CV = 21, and 21, respectively (Table 1).

In the both populations of *P. maritima* and *T. maritima*, insignificant presence of young plants by seed reproduction was observed. The most of these plants were the particula individuals of generative ontogenetic period.

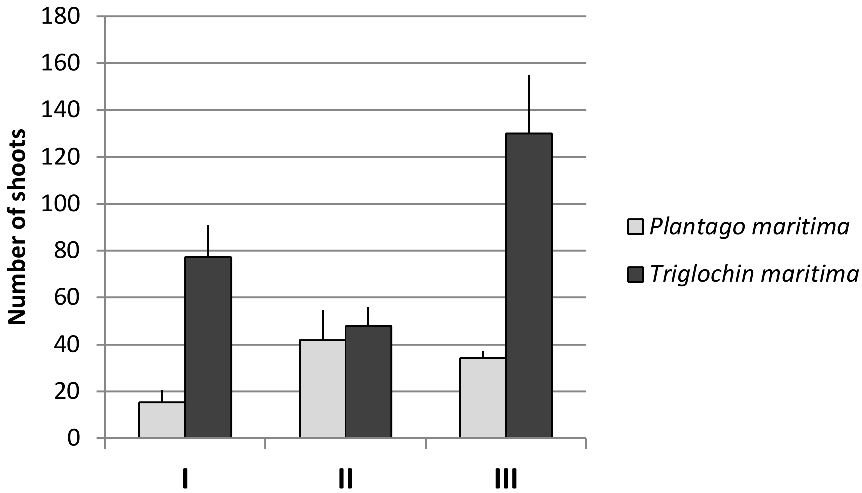

Fig. 4. Total number of shoots per plant of *Plantago maritima* and *Triglochin maritima* in different tidal zones.

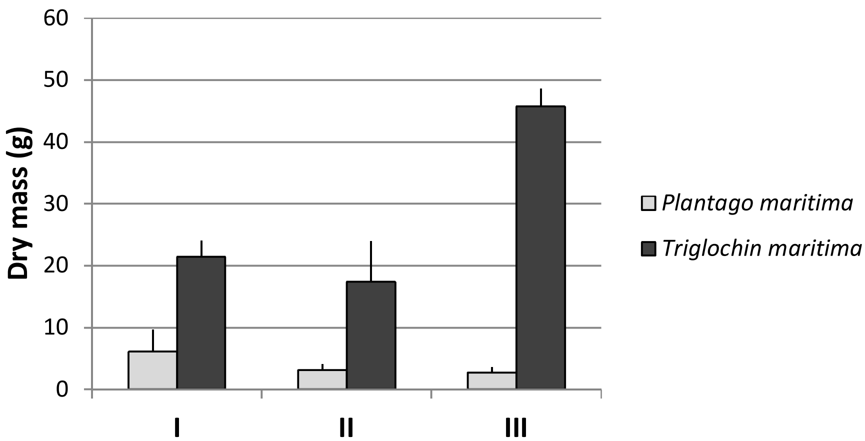

Fig. 5. Dry mass of aboveground shoots of plants *Plantago maritima* and *Triglochin maritima* in different tidal zones.

Discussion

The obtained results on the populations of coastal dominant species *P. maritima* and *T. maritima* showed the significant changes in their structural parameters a-long a tidal gradient from the low supra-littoral up to low littoral zones. Among the investigated plants within the population of *P. maritima*, the largest differences were found for the plants grown in supralittoral zone, outside the area with the daily floods.

All biomorphological parameters and projection area of vegetation cover of this plant species were higher in the *zone I*, than in the lower zones. Thus, the plants *P. maritima*, grown in the tidal zone had the lower values of structural parameters. This is directly connected to the presence of the complex of perpetually (periodically) changing environmental factors: periodic tidal inundation (change of aggressive ground-air environment to the homogeneous aquatic surrounding), periodical variation in the temperature and light conditions, the availability of a mechanical wave and ice actions. The decrease in biomass and biomorphological parameters is, therefore, the response of the species *P. maritima* to the above-listed factors. In fact, the ratio of biomass of aboveground to underground plant organs changed noticeably. In the *zone I* (supralittoral), the ratio was 1.3, while it reached lower values in the *zone II* (0.4) and the *zone III* (0.75). This is indicative of the increased biomass of underground organs, which might be caused mainly due to the longer and stronger influence of the wave action at the water's edge during the low tide (Markov 1990).

Despite the fact that *P. maritima* is an obligate and widespread halophyte (Markov et et Botova 1982, Osmanova 2009) highly adapted to existence in the environment of the coastal communities, growth in such conditions is limited by constant non-specific influence of various environmental factors (Sergienko 1977, Markovskaya et al. 2010, 2014). Higher biological and generative productivity of *P. maritima* grown in splashing *zone I* (compared to the *zones II* and III) means that the plants spend more carbohydrates to adaptive response to the unstable conditions in the flooding zones. Moreover, the decreased biomass of generative shoots and the relative increase of biomass of underground shoots were found at low tide (*zone III*) due to the predominance of the vegetative reproduction. This fact may be indirect evidence that *P. maritima* plants have a well-defined capacity for responses to the changes of abiotic factors. Near the native coast (*zones II* and *I*), the density of plants and biomass increases. However, on the plots where they are combined into groups, sociability of the plants increases. All these features indicate the optimal habitat conditions (turf layer in soil, higher cover of codominant species compared to the *zones II and* III, lower duration under tidal water column) for growth of the plants.

The investigation of the populations of *P. maritima* and *T. maritima* on the tidal zone of the Holarctic seas (on the example of the Western coast of the White sea) revealed that these obligate halophytes, originating from Central Asia to the coast of the White sea and the Barents sea only in late Cenozoic time (Tolmachev et Yurtsev 1970, Chernov 1984, 2008) are well-adapted and widespread species in the new territories and in the evolutionary "new conditions" to their environment. The study supports the idea of Popov (1963, 1983), that “adaptive evolution is primarily somatic and thus affecting the vegetative organs”. The high level of variation in biometrical and population parameters of *P. maritima* and *T. maritima* suggests that adaptive capacity of the species happens on the Holarctic seas’ coasts in a wide range of areas with the flooding gradient.

Concluding remarks

The coastal meadows with a strong dominance of euarctic (high Arctic) species – euhalophytes (*Puccinellia angustata, Carex ursina, C. subspathacea, Dupontia fisheri*) (Chernov 1984, 2008) have been formed in conditions of the gradual cooling of the sea coasts, and establishment of iciness of the Polar basin in Pliocene–Pleistocene time. However, the gradual drying of the shelf, permanent movement of the coastline and the absence of competition in non-tussock areas of the coast allowed an introducion some allochthonous elements, which include the studied species. Because the Arctic flora is a relatively new formation (Tolmachev et Yurtsev 1970), and its formation relates to the age of the Pliocene-Pleistocene time and early Pleistocene, the time and ways of evolution of euhalophytes with a more "southern" parameters of the structures on the Arctic coast should be discussed and follow-up studies should focus such phenomenon.

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