

Epilithic lichens and their morphological adaptations to the conditions of the White and Barents Seas coast (Russian Arctic)

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Abstract

The main aim of our work was to investigate the biodiversity of coastal lichens, conditions of lichen cover formation, and study the structural and functional adaptations of *Lecanora intricata* (Ach.) Ach. and *L. polytropia* (Ehrh. ex Hoffm.) Rabenh. The investigation was carried out during 2008-2012 on cliffs both along the Murmansk (the Barents Sea) coast and the southern and western shores of the White Sea. For the evaluation of species composition, and ecotopic coenotical features of epilithic lichen growing on cliffs, the geobotanical methods have been used. In addition, the anatomical, morphological and biochemical studies of *Lecanora intricata* and *L. polytropia* have been made. 91 species have been included in the total list of lichens on the White Sea coast. On the Murmansk coast of the Barents Sea, 36 lichen species had revealed. On the coastal territory, the epilithic lichens inhabit the upper littoral and supralittoral zone. The lichen cover is formed by two interacting factors: the water factor (sea) and the terrestrial vegetation. Four lichen zones were distinguished in the all studying territories. They differed by the lichen species composition and effect of the sea. The first lichen's zone is the intrazonal structure in the complex coastal lichen cover. In *Lecanora polytropia* and *L. intricata*, structural and functional features of lichens for adaptation to unstable coastal conditions were identified. The crustose biormorphs were better adapted to temperature and degree of hydration of thalli. Formation of the smallest ascospores is reproductive strategy of epilithic lichens in extreme habitats. High content of usnic acid in the studied lichen thalli allows them to exist in the open areas exposed to solar radiation and provides the biotic regulation that affects the structure of lichen cover. Optimal ratio of algal to fungal components in the thalli of these species is necessary to maintain their life in extreme environments.

Key words: Epilithic lichens, morphological adaptations, physiological adaptations, usnic acid

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Introduction

The paper summarizes the results of the biodiversity investigations in epilithic lichens as well as their adaptive capacity to unstable conditions on the coasts of north seas of the Russian Arctic. The study of coastal lichens was a part of the complex investigations, concerning the structure and function of coastal ecosystems in different environmental conditions of northern seas.

Epilithic lichens are an essential component of the coastal ecosystems. They occupy various ecological niches which are unsuitable for colonization by higher plants. Lichens are highly adapted to insolation, duration of photoperiod, high winds speed, low temperature, periodic flooding, storm wave action, and other stress factors. It is widely known that, the morphotype of lichens' thallus, their ways of reproduction, and growth rate, reflect their adaptive capabilities to the above specified factors. The secondary metabo-

lites (lichen acids) synthesis is induced by extreme environmental conditions and are involved in these processes.

Detailed information about coastal epilithic lichens of northern tidal seas is lacking and quantitative ecological and physiological investigations of the coastal lichens are rare. Most of previous workers in Arctic Russia focused on basic checklist of lichens, noting their substrates, habitats, associated species and their frequency at investigated localities (Zhdanov et Dudoreva 2003, Urbanavichus et al. 2008, 2009, Sonina 2009).

Therefore, the main aim of our work was to investigate the biodiversity of coastal lichens, conditions of formation lichen cover and study the structural and functional adaptations of *Lecanora intricata* (Ach.) Ach. and *L. polytropa* (Ehrh. ex Hoffm.) Rabenh to different conditions of the northern tidal seas.

Material and Methods

The investigation was carried out during 2008-2012 on cliffs close to the Murmansk (the Barents Sea) coast, and on the southern and western shores of the White Sea (Fig. 1).

For the species composition, ecotopic coenotical features of epilithic lichen cliffs and geobotanical methods were used.

The environmental parameters and characteristics of lichen cover such as number of lichen species, projection area, of individual species, distance from water, radiation, slope of rock's surface, and condition of rock's surface were estimated on the plots with using the work frame 10 to 20 cm (Fadeeva et Sonina 2007). Sample plots were established on the line from the waters' edge to formed

terrestrial vegetation.

The morphological (thallus morphotype, reproductive system), anatomical (thickness of the thallus, thickness of the algal layer) and biochemical (content of usnic acid) characteristics were studied in *Lecanora intricata* and *L. polytropa*. Analyses were done in the Laboratory of the Department of Botany and Plant Physiology of the PetrSU, and in the Bryological - Lichenological Laboratory, and in the Laboratory of Analytical Phytochemistry of the Komarov Botanical Institute RAS. Anatomical and morphological studies of the two species were carried out by binoculars MSP-2 and a microscope Mikmed-5. Images were taken with by a digital camera and a microscope

Shteimi (software Axio Vision). The measurement of thallus and algal layer thickness were made with an ocular micrometer. Evaluation of usnic acid content in the lichen samples was carried out on a chromatograph (Agilent 1200 USA), using the method of Feige et al. (1993) with few modifications.

Lecanora intricata and *L. polytropa* were selected for detail morphological, anatomical and biochemical investigations. Our earlier observations showed that these species differed morphologically. They

belong to the most widespread coastal epilithic lichens. They are typical inhabitants of acidic rocks, have a circumpolar distribution in the Northern hemisphere and are found everywhere on the coasts of the northern seas (Smith et al. 2009). All samples were collected on the cliffs and boulders in supralittoral zone (3–9 m from water line). These rock fragments are irrigated by a spray or surging during heavy storms, but usually they are not inundated with sea water.



Fig. 1. The White Sea coast with indication of the study areas denoted as territories in the text. The study areas are indicated by red points.

Results

Into the total list of lichens on the White Sea coast, 91 species were included. On the Murmask coast of the Barents Sea, 36 lichen species had revealed.

The study of coastal lichen flora allowed us to enrich the lists of species both for Murmansk and Karelia regions. Besides that, some species are noted for some biogeographical provinces for the first time.

For the first time for Karelia, two species - *Acarospora molibdina* (Wahlenb. in Ach.) A. Massal. and *Rhizocarpon leptolepis* Anzi. are noted. Ten species are noted for biogeographical province of Karelia keretina (Kk): *Acarospora fuscata* (Nyl.) Arnold, *Bellemerea cinereorufescens* (Ach.) Clauzade et Cl. Roux, *Catapyrenium cinereum* (Pers.) Körb., *Lecanora umbrina* (Ach.) A. Massal., *Lecidea plana* (J. Lahm.) Nyl., *Porpidia crustulata* (Ach.), *Rhizocarpon eupetraeum* (Nyl.) Arnold, *R. geminatum* Körb., *R. hochstetteri* (Körb.) Vain., *R. viridiatrum* (Wulfen) Körb. (Fadeeva et al. 2007). For the first time seventeen species are noted for Lapponia murmanica (Lm) (Urbanavichus et al. 2008): *Caloplaca marina* (Wedd.) Zahlbr., *Caloplaca saxicola* (Hoffm.) Nordin, *Candelariella arctica* (Körb.) R.Sant., *Clauzadea monticola* (Schaer.) Hafellner & Bellem., *Lecanora helicopsis* (Wahlend.) Ach., *Lecanora intricata* (Ach.) Ach., *Lecidea praenubila* (Nyl.), *Lobothallia melanaspis* (Ach.) Hafellner, *Orphniospora moriopsis* (A. Massal.) D. Hawksw., *Protoparmelia nephaea* (Sommerf.) R. Sant., *Rhizocarpon eupetraeoides* (Nyl.) Blomb & Forssell., *Rhizocarpon geminatum* Körb., *Rhizocarpon leptolepis* Anzi, *Rinodina balanina* (Wahlenb.) Vain., *Rinodina milvina* (Wahlenb.) Th. Fr., *Spilonema revertens* Nyl., *Verrucaria ceuthocarpa* Wahlenb.

On the coastal territories, the epilithic lichens inhabit the upper littoral and

supralittoral zone. With the increasing distance from a sea, the diversity of lichens gradually increase as well as density of lichen cover. Four lichen zones were distinguished in the all studied territories (see Fig.1). The first zone (a part of the upper littoral) is the tidal zone flooded by salt water twice a day. Only two species of lichens *Verrucaria maura* Wahlenb. and *Verrucaria ceuthocarpa* Wahlenb. can be observed in this zone. They form single-species groups with high projective cover (average 80%). The second zone is located above the intertidal zone (a part of supralittoral zone). The conditions in this zone are very severe for lichens; they can be washed out by storm surge. The diversity of lichens is increased up to 4-6 species. Lichens occupy small cracks, holes, chipping rocks. Their total cover does not exceed an average of 20%. The third zone is a part of the cliffs, which are located above the second zone and are irrigated by sea spray only during major storms. About 10 species of lichens live there. Lichen species from terrestrial ecosystems are present there. We consider this zone is an ecotone between plain and littoral area. The fourth zone is contiguous with terrestrial plant communities. The development of lichen cover (composition and structure) is affected by soil-plant complex. In this part, more stable coastal environment for lichens is formed. Genera of *Parmelia*, *Arctoparmelia*, *Umbilicaria*, *Flavocetraria* inhabit this area. The total projective cover of lichen species can reach up to 100%.

The study of adaptive capabilities of the coastal lichens *Lecanora polytropa* and *Lecanora intricata* to the conditions of northern seas showed differences in the morphological structures between the species from the shores of the Barents Sea and the White Sea.

Results of anatomical and biochemical investigations carried out on the samples

are presented only for the two species from the coast of the Barents Sea (Table 2). The anatomical analysis showed that the total thickness of the thallii *L. intricata*

was significantly higher than that of *L. polytropa*. The content of usnic acid was comparable for all samples.

Zone	Lichen species of White Sea	Lichen species of Barentz Sea
1 zone	<i>Verrucaria ceuthocarpa</i> , <i>Verrucaria maura</i>	<i>Verrucaria ceuthocarpa</i> , <i>Verrucaria maura</i>
$K_j=1$		
The first zone is the intrazonal structure in the complex coastal lichen covering		
2 zone	<i>Acarospora amphibola</i> , <i>A. molibdina</i> , <i>Caloplaca scopularis</i> , <i>Candelariella vitellina</i> , <i>Ephebe lanata</i> , <i>Xanthoria candelaria</i> , <i>Pseudephebe pubescens</i>	<i>Caloplaca marina</i> , <i>Caloplaca saxicola</i> , <i>Candelariella arctica</i> , <i>C. vitellina</i> , <i>Xanthoria candelaria</i> , <i>Xanthoria elegans</i>
$K_j=0.35$		
3 zone	<i>Bellemeria alpina</i> , <i>B. cinereorufescens</i> , <i>Candelariella vitellina</i> , <i>Catapyrenium cinereum</i> , <i>Immersaria cupreoatra</i> , <i>Lecanora dispersa</i> , <i>L. intricata</i> , <i>L. polytropa</i> , <i>L. lithophyla</i> , <i>Rhizocarpon eupetraeum</i>	<i>Lecidea lapicida</i> , <i>Lecidea praenubila</i> , <i>Lobothallia melanaspis</i> , <i>Melanelia hepatizon</i> , <i>Parmelia omphalodes</i> , <i>Orphniospora moriopsis</i> , <i>Physcia caesia</i> , <i>Rhizocarpon leptolepis</i>
$K_j=0.25$		
4 zone	<i>Arctoparmelia incurva</i> , <i>Flavocetraria nivalis</i> , <i>Umbilicaria deusta</i> , <i>U. torrefacta</i> , <i>Stereocaulon grande</i> , <i>Physcia caesia</i> , <i>P. subalbinea</i> , <i>Parmelia saxatilis</i> , <i>Peltigera canina</i> , <i>Cladonia spp.</i>	<i>Umbilicaria proboscidea</i> , <i>Umbilicaria arctica</i> , <i>Parmelia saxatilis</i> , <i>Parmelia omphalodes</i> , <i>Arctoparmelia centrifuga</i>
$K_j=0.14$		

Table 1. The comparative analysis of lichen cover. K_j - denotes Jackard’s coefficient.

No. example of species	No. 1 <i>L. intricata</i>	No. 2 <i>L. intricata</i>	No. 3 <i>L. polytropa</i>	No. 4 <i>L. polytropa</i>
Thickness of thallus (µm)	713.8±35.7	825.0±25.8	185.7±30.6	360.2±123.0
Thickness of algal layer (µm)	205.9±15.5	299.0±20.0	47.5±9.2	137.8±26.7
The value of usnic acid quantity (µg g ⁻¹)	6700±500	5700±500	8100±500	4000±500

Table 2. The anatomical characteristics and the content of usnic acid of the studying lichen thalli in the condition of the Barents Sea.

Discussion

In the formation of coastal lichen cover, the general regularities were determined: (1) The lichen cover is formed in condition when two main factors interact: the water factor (sea) and the terrestrial vegetation. (2) The sea influence, such as vulnerable tidal regime, strong storms is the main abiotic factor affecting lichen cover. (3) Further from the sea shore, the sea influence decreases and the lichen biodiversity as well as projective cover increases till 10 from 100%. (4) In this direction, the structure of lichen cover is complicated (Sonina 2009). These provisions have allow to distinguish four lichen zones. They differ in lichen species composition (Table 1). The first and the fourth zones differ from the other two greatly. The lichen covers in the first zone are the same for coasts of the Barents and the White seas. The data of comparative analyzes and the value of Jackard's coefficient of similarity confirmed this. There are two halophytic species in this zone. With the moving off from the sea shore, the lichen cover gets characteristic features of lichenoflora of specific climatic zone. The greatest differences in the coastal lichenoflora of the two seas are typical for the fourth zone. Therefore, according to our investigations, we can consider that the first zone is the intrazonal structure in the complex coastal lichen covering.

With the location further to the north, plant species can alter their morphotypes, the physiological and biochemical features (Markovskaya et al. 2010). The aspects of functional physiology of coastal lichens along the longitudinal gradient remain poorly studied.

For the coasts of the White Sea and the Barents Sea, *Lecanora polytropa* and *Lecanora intricata* are the common species for 3 and 4 zones. Such wide distribution of these species is connected with their ability to develop various morphological, physiological and bioche-

mical adaptations. They have crustose thalli, and are propagated by ascospores and/or conidiospores that can be fixed easily on the rocky substrate on the coasts. However, comparison of morphological features of these species in the coasts of the Barents and White seas showed the existence of morphotypes, associated with their responses to different climatic conditions (Markovskaya et al. 2010) (see Fig. 2).

Lecanora intricata forms thinner thallus and unimmersed apothecia on the White sea coast. Contrastingly, on the Barents Sea coast, the lichen's thallus is thick and the apothecia are immersed in thalli. These peculiarities confirm the polymorphism of this species.

On the coast of the White Sea, *Lecanora polytropa* has inconspicuous thallus with small dispersed areoles. In the condition of the Barents Sea, this species has developed thallus and submerged apothecia.

On the White Sea coast, this species spread more widely then alongs the Barents Sea coast. It spreads in the second, the third and the fourth zones. Whereas on the Barents Sea coast, it spreads in the third and the fourth zone only. According to our observations, these, species enhance its viability to the north.

Analysis of their anatomical structure showed that the total thickness of the thallii *L. intricata* was significantly higher then thickness of the thallii *L. polytropa*. This probably reflects the individual properties of the species, or testifies their different responses to the environment. However, the ratio of algal layer to the total thickness of the thallus was in all cases similar and was 1:3.

Usnic acid is an organic compound which is synthesized by fungal component in the presence algae in some lichen genera as: *Alectoria*, *Cladonia*, *Evernia*, *Lecanora*, *Ramalina* and *Usnea* (Culber-

son et Culberson 2001). The comparative analysis showed that even the morphological and anatomical parameters of the thalli differ considerably, the differences in the content of usnic acid are absent (Table 2). Chemical analysis showed that content of usnic acid in all specimens of both species was comparable. This means that regardless of the total amount of thalli, the both lichens contain similar quantity of usnic acid per unit of thallus area. This may indicate the protective function of the

substance in the body of lichen screening out UV-radiation and regulating water exchange and diffusion of CO₂ (Ravinskaya 1977, Culberson et Culberson 2001). *Lecanora polytropa* (see the sample 3 in the Table 2) had a minimum thickness of algal layer and the maximum quantity of usnic acid. It can be explained by the known fact that under certain conditions, usnic acid may inhibit the proliferation of algal cells in the lichen thallus (Ravinskaya 1977).

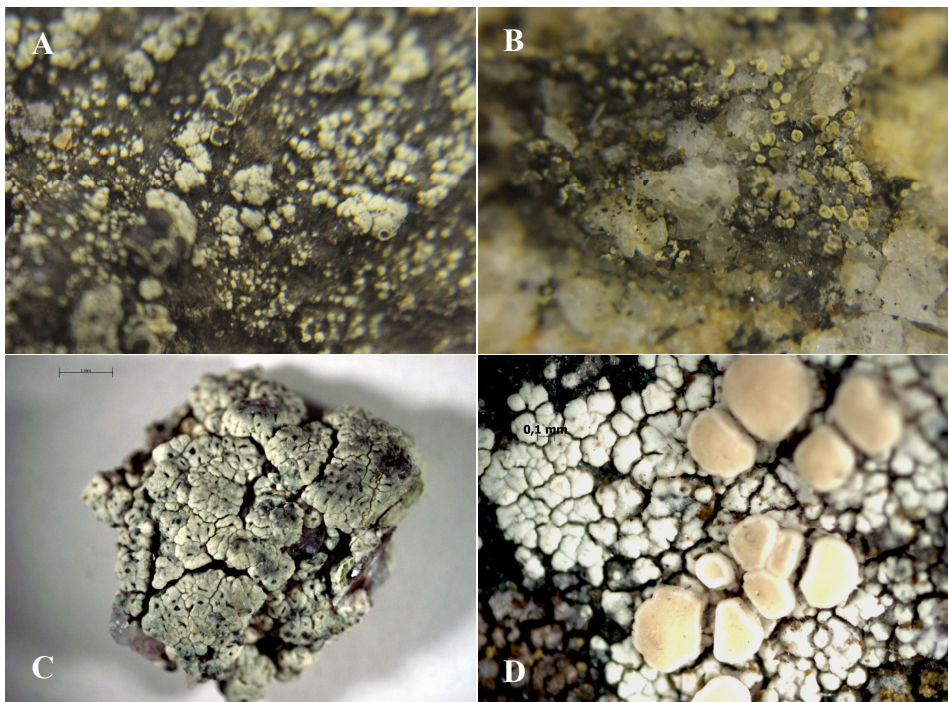


Fig. 2. Morphological adaptations on the examples of *Lecanora intricata* (Ach.) Ach. and *Lecanora polytropa* (Ehrh. ex Hoffm.) Rabenh in the conditions of the White Sea and the Barents Sea. A - *Lecanora intricata* (Ach.) Ach. (White Sea), B - *Lecanora polytropa* (Ehrh. ex Hoffm.) Rabenh (White Sea), C - *Lecanora intricata* (Ach.) Ach. (Barents Sea), D - *Lecanora polytropa* (Ehrh. ex Hoffm.) Rabenh (Barents Sea).

Conclusions

General rules of lichen's cover formation and structural and functional features of lichens, which allow them to be adapted for living in unstable coastal conditions of the Barents and the White seas can be summarized as follows.

The sea's influence, such as vulnerable tidal regime, strong storms is the main abiotic factor among others. The first lichen's zone is the intrazonal structure in the complex coastal lichen covering. The crustose, areolate and folded biomorphs are better adapted to temperature and degree of hydration of thalli in coastal conditions of the Northern seas. Reproductive strategy of the investigated coastal species is strategy of epilithic lichens of extreme habitats (Rogers 1990, Golubkova 2001). The high content of usnic acid in the studied lichen thalli allows them to exist in the open areas and provides the biotic regulation that defines the structure of lichen cover. The optimal ratio of algal and fungal components in the thalli of these species is necessary for maintain their life in extreme environments.

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