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Spatial Heterogeneity of the Species Composition of a Clavarioid Fungi's Compex in the Eurasian Arctic

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Abstract—Using the example of a model group of macromycete (clavarioid fungi), a large-scale investigation into the mycological complex of the Eurasian Arctic is conducted. The species composition of clavarioid fungi's complex is revealed in all longitudinal sectors and latitudinal subzones, and a comparative analysis is carried out. It has been determined that, among groups of aphyllophoroid fungi, the clavarioid life form is the most adapted to the extremally psychrophilic conditions of the Arctic. It is shown that the near-oceanic sectors are the richest, whereas the continental sectors are much poorer. The distribution of the species composition of fungi conforms to the similar distribution of flowering plants, especially hemicryptophytes. The average annual quantity of atmospheric precipitation is the leading climatic factor. The differences make it possible to subdivide the Eurasian Arctic into four mycogeographical regions: Atlantic (European), Siberian, Chukotian (Beringian), and High Arctic.

Keywords: the Arctic, acclimatization, biogeography, diversity, expansion, clavarioid fungi, macroecology, structure, tundra, extremal ecotopes

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INTRODUCTION

One of the fundamental problems of modern ecology and biogeography is the study of the structure and functioning of global overorganismic coevolutionary systems, in particular, the system of climate–flora–mycobiota. The versatile investigation of this problem on a transcontinental scale is extremely important for the conservation of the biodiversity and forecasting of global changes of biota.

It is reasonable to begin revealing the basic principles of the functioning and coexistence of various groups of organisms with relatively simply arranged ecosystems of high latitude, followed in the future by an investigation into the revealed regularities using more complicated models. The above is also true for fungi, among which clavarioid fungi (*Basidiomycota, Aphyllophorales*) are a well-studied group (life form) in the Eurasian Arctic [1]. Because clavarioid fungi represent all three basic functional groups of fungi, being saprotrophes, parasites, and symbiontes (forming mycorrhiza and basidiolichens and, probably, being endophyte); they participate in the major processes of the life of the tundra biome.

In the early 21st century, clavarioid fungi were almost not known in the Arctic [2, 3]. However, due to a number of expeditions into the Eurasian Arctic [4–14], it was found that clavarioid fungi numerically prevail above other groups of aphyllophoroid fungi (poroid, corticioid, etc.) in the tundra complexes. In the High Arctic (Arctic deserts and the northern Arctic tundra), they are frequently the sole specimens of aphyllophoroid fungi, including the "sclerotioid" genus of *Typhula* and "basidiolichen" *Multiclavula* genus [7, 14, 15]. Thus, the studied life form of fungi is the most adapted aphyllophoroid to Arctic environmental conditions, which increases its importance in the course of investigating Arctic extremal psychrophilic mycobiots. This study is the first compilation of data from all districts of the Eurasian Arctic, not only for Russia, but for mycology around the world.

The purpose of this study was to reveal differences in the species composition and taxonomic structure of the tundra complex of clavarioid fungi in the spatial (latitudinal and longitudinal) gradient of the Arctic and whenever possible to analyze the dependence of the revealed heterogeneity of the spatial structure from the climatic and biotic factors.

DISTRICT, OBJECTS, AND METHODS OF STUDY

The investigations are carried out in all zonal and longitudinal districts of the Eurasian Arctic corresponding to the map of the Geobotanical division of the Arctic [16]. According to this map, the Arctic consists of five latitudinal subzones (A–E, from north to south). Subzone A is called "Polar Deserts." Subzone B is denoted as "Northern Arctic Tundra." Subzone C is called "Southern Arctic Tundra." Subzones D and E

Table 1. Sources of data concerning the specific composition of the clavarioid fungi in nine longitudinal sectors of the Eurasian Arctic

Designation	Sector	Source
FS	Fennoscandia, including the Barents Sea coast of the Finnmark province (Norway) and Murmansk area, as well as the Spitzbergen island	6, 12, 14, 18
KP	Kanin-Pechora, including the Kolguev Island	9
UR	Polar Ural–Novaya Zemlya	4, 7, 9, 13, 14, 15
YaG	Yamal-Gydan	5, 7, 9, 14
TM	Taimyr, including the Severnaya Zemlya islands	7, 8
AO	Anabar-Olenyek, including Kharaulakh	10
YaK	Yana-Kolyma, including the Novosibirsk islands	
ZCh	West Chukotian, including both West and Central Chukotian	11
VCh	East Chukotian, including both Beringian and South Chukotian	

are referred to as Northern and Southern Hypoarctic Tundra, correspondingly.

The borders of the longitudinal sectors correspond to the same map with small changes [16]. In particular, Anabar-Olenyek and Kharaulakh floristic provinces are combined into one under the name "Anabar-Olenyek"; "Western Chukotian" combines both Western Chukotian and Central Chukotian; Beringian and Southern Chukotian provinces form "East Chukotian" (Table 1). It is possible to find data on the investigated points in nine sectors in the relevant publications (Table 1).

The combination of 5 zonal and 9 longitudinal sectors forms 45 zonal-sector districts of the Eurasian Arctic, 32 of which exist. In 1998–2012 the clavarioid fungi have been studied in all districts. The material includes 44 species (Table 2), which are submitted by 2917 samples (registration units), and is stored in the department of mycology of the herbarium of Institute of Plant and Animal Ecology, Ural Division of the Russian Academy of Science, Ekaterinburg (SVER).[1] The nomenclature corresponds to the tenth edition of the *Dictionary* of *Fungi*. [17]. The similarity between complexes was estimated using the index of Chekanovsky-Sorensen (*Kcs*). Some additional characteristics, like the index of cryophility (CrI), which reflects the part of "cryophilic species" (arctic–alpine and arctic–boreal) from the total number of species (in %), was used also. For an evaluation of the prevalence of arctic features in the complex, the part of *Typhula* genus from the total number of species was calculated. The "morphological index" (*Cl*/*Co*) was also calculated as the ratio between "life forms" presented by species with simple, unbrunched fruitbodies (*Cl*) and species with coral-brunched ones (*Co*), which make up the group of the clavarioid fungi. The mean diversity of species (ΔDS), which reflects the average number of species in a local-point of investigation, from species richness of zone-sectoral mycocomplex was calculated. Adventive species were excluded from the study.

The number of plant species is presented according to reports on different Arctic sectors [19, 20], the climatic indices are taken from the work *Climate of the Soviet Union* [21], and the index of continentality (K) is calculated as the difference between average annual temperatures in the coldest (January) and warmest (July) months. It should be noted that two zone-sectoral districts, A–KP (Franz Josef Land) and C–ZCH (Wrangel Island), have not been investigated enough; therefore, these districts are excluded from the study.

RESULTS AND DISCUSSION

The clavarioid fungi are widespread in the Arctic; they are found to the north of 80° of northerly latitude near the icy armors of Spitzbergen, Franz Josef Land, and the Severnaya Zemlya Islands [4, 8, 14]. Our investigations, which were carried out in all latitudinal subzones and longitudinal sectors of the Eurasian tundra, revealed 44 species of clavarioid fungi (Table 2), which makes up 6.6% of the species of the group known in the world [17]. There are no the specific species of clavarioid fungi endemic for tundra biome. The most southern subzone (the southern hypoarctic tundra, subzone E) includes all species which were found in the more northern subzones of the tundra (Table 3). All the species that were found in tundra were widespread in the taiga zone and/or in the relevant zones of mountains. Thus, the tundra complex of clavarioid fungi represents a depleted variant of taiga (to be exact, of the mining taiga mycocomplex) [1, 4, 7, 11]. Similar conclusions were received by an analysis of the distribution of myxomycetes [22], lichens [23] and poroid aphyllophoroid fungi [24].

[1] Based on the collected fruitbodies. We did not study species capable of existing in the Polar environments exclusively as dormant stages or mycorrhiza.

Table 2. Distribution of the specific composition and dominant species of the clavarioid fungi on nine longitudinal sectors of the Eurasian Arctic (using the example of south hypoarctic tundra, subzone E)

Species	Arctic Sectors									Sum total
	FS	KP	UR	YaG	TM	AO	YaK	ZCh	VCh	
Clavaria argillacea	D	D	D	+	+	+	+	+	D	9
Clavaria falcata	D	D	D	+	+	+	+	+	+	9
Clavulina cinerea	+	+	+	+	+	+	+	+	+	9
Clavulina coralloides	+	+	+	+	+	+	+	+	+	9
Clavulinopsis helvola	+	+	+	+	+	+	+	+	+	9
Clavulinopsis luteoochracea	D	+	+	+	+	+	+	+	+	9
Multiclavula corynoides	D	D	D	D	D	D	D	D	D	9
Multiclavula vernalis	D	D	D	D	+	+	+	D	D	9
Pterula gracilis	+	+	+	+	+	+	+	+	+	9
Ramariopsis subarctica	D	D	D	+	+	+	+	+	+	9
Typhula capitata	+	+	+	+	+	+	+	+	+	9
Typhula caricina	D	D	D	D	D	D	D	D	D	9
Typhula chamaemori	D	+	D	+	+	+	+	+	+	9
Typhula crassipes	D	D	D	D	D	D	D	D	D	9
Typhula culmigena	D	D	D	D	D	D	D	D	D	9
Typhula erythropus	D	D	D	+	+	D	+	+	D	9
Typhula graminum	D	D	D	+	+	+	+	+	+	9
Typhula hyalina	D	D	D	D	D	D	D	D	D	9
Typhula lutescens	D	D	D	+	D	+	+	+	D	9
Typhula micans	+	+	+	+	D	+	+	D	+	9
Typhula setipes	D	D	D	D	D	+	+	+	D	9
Typhula spatulata	+	+	+	+	+	+	+	+	+	9
Typhula variabilis	D	+	D	+	D	+	+	+	+	9
Typhula uncialis	+	+	+	D	D	D	+	+	+	9
Typhula sclerotioides	+	+	+	+	+		+	+	+	7
Typhula phacorrhiza	+	+	+		+	+	+	+	+	8
Macrotyphula juncea	D	+	+					+	+	5
Typhula incarnata	D	+	D						+	4
Typhula ishikariensis	+	+	+						+	4
Typhula todei	+	+	+						+	4
Clavaria sphagnicola	D	D	D			+				4
Clavicorona taxophila	+		+							2
Clavulina rugosa	+									1
Clavulinopsis corniculata	+									1
Ramaria abietina	+									1
Typhula viticola	+									1
Typhula pertenius							+	+	+	3
Typhula erumpens								+	+	2
Macrotyphula fistulosa									+	1
Mucronella calva									+	1
Pistillaria petasitis									+	1
Typhula curvispora									+	1
Typhula spaeroidea									+	1
Typhula umbrina									+	1
Sum total	36	31	32	25	26	26	27	29	37	44

Note: Abbreviation of sectors is the as in the Table 1. D —dominant species. (+)—These species are present, but not dominant.

Table 3. Number of species and genera in 32 zone-sectoral complexes of the clavarioid fungi in the Eurasian Arctic

Subzone	Arctic Sector									Sum total
	FS	KP	UR	YaG	TM	AO	YaK	ZCh	VCh	
A	5/2	*	4/2	–	3/2	–	–	–	–	6/2
B	9/3	–	8/3	5/2	5/2	–	5/2	–	–	9/3
C	22/7	–	17/6	13/5	13/5	–	12/5	*	–	22/7
D	–	21/7	22/7	18/6	18/6	18/6	18/6	20/6	24/7	26/8
E	36/10	31/10	32/10	25/8	26/8	26/8	27/8	29/8	37/10	44/12

Note: The numerator is the number of species; the denominator is the number of genera. (–) This complex is absent. (*) Data are deficient.

Table 4. Similarity of the specific composition of the clavarioid fungi in the Eurasian Arctic (using the example of the south hypoarctic tundra)

Arctic Sector	FS	KP	UR	YaG	TM	AO	YaK	ZCh	VCh
FS	36	**0.93**	**0.94**	0.82	0.84	0.84	0.83	0.80	0.76
KP		31	**0.98**	0.89	0.91	0.91	0.89	0.86	0.82
UR			32	0.88	0.90	0.90	0.88	0.85	0.80
YaG				25	**0.98**	**0.98**	**0.96**	0.92	0.81
TM					26	**0.98**	**0.96**	0.91	0.80
AO						26	**0.97**	0.91	0.80
YaK							27	0.91	0.84
ZCh								29	0.88
VCh									37

Two near-oceanic sectors such as East Chukotian (37 species) and Fennoscandia (36 species) are the richest, whereas in continental Siberian sectors this parameter decreased by one-third to 25 species in Yamal-Gydan. Only 28 species are mutual for near-oceanic sectors; thus, the similarity between them is only 0.76 (Table 4), which is relatively low in comparison with the results obtained for other groups of fungi [2, 22]. Certainly it is necessary to note that most species of tundra fungi are eurybionts and cosmopolites, and, as a whole, this ensures a high level of similarity between sectors (0.98–0.76). Fennoskandia is near Kanin-Pechora and Polar Ural sectors (0.93–0.94); to the east, from the Yamal-Gydan sector, a drastic decrease to 0.82 was marked. For East Chukotian, a maximal similarity with Western Chukotian (0.88) was noted. The high similarity is characteristic for Siberian sectors (0.98–0.96).

Ten species (23%) are met exclusively in two near-oceanic sectors (Table 2): in Fennoscandia (*Clavulina rugosa*, *Clavulinopsis corniculata*, *Ramaria abietina*, and *Typhula viticola*) and East Chukotian (*Macrotyphula fistulosa*, *Mucronella calva*, *Pistillaria petasitis*, *Typhula curvispora*, *T. spaeroidea*, and *T. umbrina*). *Clavicorona taxophila* was collected only in European sectors (FS–UR); *T. erumpens* was noted in Chukotian (ZCH–VCH), and it is possible to attribute here *T. pertenius*, which is revealed only in Chukotian sectors, reaching west up to the lower course of Kolyma river [11]. *Clavaria sphagnicola* species occurs in European sectors; is absent in the Yamal-Gydan's lowland and appears again in mountainous Taimyr. *Macrotyphula juncea*, *Typhula incarnate*, *Typhula ishikariensis*, and *T. todei* are collected in European and Chukotian sectors but absent in Siberian sectors. Thus, 18 species (41%) were collected exclusively in sectors in the zone of the softening action of the oceans. Species which were specific only for Siberian continental sectors were not revealed. Many of the species "specific" for Fennoskandia are also collected in the tundra districts of Greenland [25] and northern Iceland [18]. Unfortunately, a similar comparison between Chukotian sectors and the North American arctic complex cannot be made because of the absence of information concerning the latter. Thus, the near-oceanic sectors significantly differ from each other ($\chi^2 = 5.13$, $p = 0.01$) and from Siberian sectors ($\chi^2 = 2.59–3.73$, $p = 0.05$). Such a result suggests the presence of three large "mycological regions," European, Siberian, and Chukotian, in the Eurasian Arctic. In all the longitudinal sectors of the

Table 5. Description of the clavarioid fungi's complexes of the Eurasian Arctic longitudinal sectors

Statistical parameters	Arctic Sector								
	FS	KP	UR	YaG	TM	AO	YaK	ZCh	VCh
Number of species (S)	36	31	32	25	26	26	27	29	37
Number of genera (G)	10	10	10	8	8	8	8	8	10
S/G	3.6	3.1	3.2	3.1	3.2	3.2	3.3	3.6	3.7
CrI	20	22	22	24	24	25	26	22	16
Typh., %	51.4	51.6	53.1	56.0	57.7	57.7	59.2	62.0	62.3
Cl/Co	4.3	4.8	5.2	6.8	7.0	10.9	12.5	11.7	10.6

Note: The designations of parameters are in the text of the article.

Eurasian Arctic (or being absent in one of them), there are 26 species of fungi, making up only 59% of the total number of species revealed in the studied region (Table 2). Due to subsequent investigations, the percentage of such species will probably increase, but presumably it will be no more than two-thirds of the total resources of species (within the limits of the current volume of the group). Such a low number of species which are widespread in all the sectors demonstrates once again the doubtfulness of the thesis about the monotony and simplicity of the system of the Arctic's clavarioid mycocomplex [2, 22].

Eight out of 12 genera that were revealed in tundra (66%) are characteristic for all the longitudinal sectors (Table 3). However, four genera (one-third of the total number) are noted exclusively in the near-oceanic sectors. All these genera are widespread in the taiga. *Mucronella* and *Pistilaria* genera are found only in East Chukotian; *Clavicorona* and *Ramaria* genera are noted in Fennoscandian (and in the adjacent European sectors). If the three first of them go only at the most southern subzone of the tundra (subzone E), genus *Ramaria* reaches the southern Arctic tundra of Spitzbergen (subzone C). Thus, at a generic level, as well as at a specific one, it is possible to pick out three sectoral mycoregions. As a whole, the species/genus ratio (S/G) of the complex of the Eurasian Arctic clavarioid fungi is 3.7, which is three times lower than the similar ratio for the taiga mycocomplex [4, 7, 15].

In biogeography, the question about the affiliation of the Barents Sea coast of Fennoscandian with the tundra or taiga zone is widely discussed. Our data indicate that the north of Fennoscandian is characterized by tundra features, which is expressed by an increased role of arcto–alpine species [12].[2] Moreover, in this region there are fewer species of clavarioid fungi, and the index of cryophility is higher than in the tundra regions of East Chukotian, whereas the number of genera and specific saturation of genus are similar with analogous parameters revealed for the tundra regions of East Chukotian (Table 5). Thus, Fennoscandian is characterized by similar, or even by more expressed, tundra features than East Chukotian. On the other hand, the part of *Typhula* boreal genus, which is 51.4% in Fennoscandian (Table 5), increases to 57.7% in Taimyr and reaches a maximum in East Chukotian (62.3%). A similar tendency of augmentation in the east was noted also for the morphological index, which changed from 4.2 in Fennoscandian and peaked at 12.5 in the Yana-Kolyma sector. According to these parameters, Fennoscandian is characterized by weak tundra features. As a whole, the results that are peculiar to Fennoscandian also are characteristic for nearby European sectors, such as KP and UR, and similar indices with East Chukotian are observed in WCh. In the above parameters, the Siberian sectors (YaG–YaK) essentially differ from the near-oceanic Fennoscandian and East Chukotian sectors (Table 5), as well as from European and Chukotian sectors, as a whole. Twenty-one species numerically prevail in the collections from various sectors. Almost one-quarter of the dominating species is characteristic for all sectors (*Multiclavula corynoides*, *Typhula caricina*, *Typhula crassipes*, *Typhula culmigena*, and *Typhula hyaline*). Thirty-eight percent of dominating species, including *Clavaria falcata*, *C. sphagnicola*, *Clavulinopsis luteoochracea*, *Macrotyphula juncea*, *Ramariopsis subarctica*, *Typhula chamaemori*, *T. graminum*, and *T. incarnata*, are specific for European sectors (FS–UR); 9% of the prevailing species (including *Typhula micans* and *T. uncialis*) are specific for Siberian continental sectors. The specific dominating species for Chukotian sectors (VCh–ZCh) are not revealed. The *Clavaria argillacea* species prevail in both near-oceanic sectors (European and Chukotian). It is possible to add to this species *Typhula erythropus*, *T. lutescens*, *T. setipes*, which are also prevailing in the mountainous areas of Taimyr (TM), which is characterized by increased humidity when compared to the surrounding tundra plains of Yamal-Gydan and Yakutia. As a whole, more than half of the dominating species (57%) are specific for the humid sectors, whereas only one-tenth of them are specific for the continental sectors.

[2] It should be recalled that "arctic" species are absent among clavarioid fungi.

Table 6. Dependence of the specific wealth of the clavarioid fungi of the Arctic on the bioclimatic parameters (using the example of the south hypoarctic tundra, subzone E)

Parameter	Arctic Sector								
	FS	KP	UR	YaG	TA	AO	YaK	ZCh	VCh
Number of the species of fungi	36	31	32	25	26	26	27	29	37
Average diversity of species	24	22	23	17	16	15	14	14	18
Number of the plant species	618	456	462	387	494	482	651	779	749
Average annual temperature, °C	0	−3.8	−5.9	−6.6	−13.3	−13.4	−12.9	−12.5	−4.1
Index of continentality, K	26	29	31	40	48	55	44	41	24
Atmospheric precipitates, mm/year	518	433	405	380	268	275	290	297	691

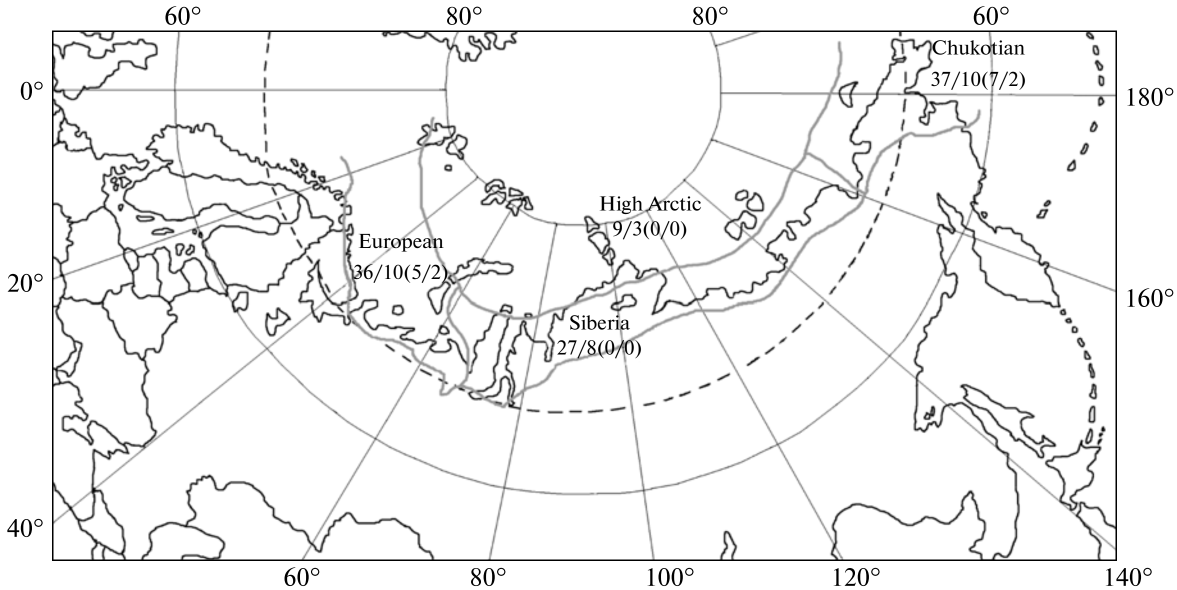
As has been shown above, the greatest species wealth of fungi was found in the near-oceanic sectors and nearby mountainous areas, in which there are much more atmospheric precipitates and the air humidity is higher than in the continental Siberian sectors and the maximum possible species wealth of flowering plants occurs (Table 6). Therefore, the maximal number of fungi species was collected in East Chukotian (37), which is characterized by one of the maximal levels of floristic wealth (749 species) and by maximal level of average annual atmospheric precipitates for the Eurasian Arctic (691 mm), whereas Yamal-Gydan sector is the poorest in number of fungal species (25) and the most floristically poor (387 species) with one of the minimal levels of atmospheric precipitates (380 mm).

In the European tundra, the level of species wealth of the clavarioid fungi is determined, in many respects, by the wealth of the species composition of flowering plants [9]. The addition of Asian materials, as a whole, confirms this conclusion; however, direct extrapolation is impossible, since the number of species of flowering plants in Asia is noticeably higher (Table 6), but the species wealth of fungi does not reach the supposed high level ($r = 0.19$, $p > 0.05$). This is especially apparent for Western Chukotian, which has the highest index of wealth for flowering plants (779 species) but a low index of wealth for fungi (29 species). However, a separate examination of European and Asian Arctic regions reveals that the level of correlation between the species wealth of fungi and flowering plants is high both in the first ($r = 0.94$, $p < 0.01$) and second cases ($r = 0.76$, $p < 0.001$). As a whole, as is shown for Northern Eurasia, the role of the clavarioid life form rises when the role of hemicryptophytes increases ($r = 0.72$, $p < 0.01$) [4]. In regards to the climate, on the scale of all Arctic Eurasia, the species wealth of the clavarioid fungi depends on the level of continentality ($r = -0.93$, $p < 0.01$); the average annual temperature ($r = 0.86$, $p < 0.01$); and, especially, on the average annual level of atmospheric precipitates ($r = 0.94$, $p < 0.001$). The following fact indicates that the climatic factors are probably of no less importance than substrate ones. Therefore, in Western Chukotka, which is the richest floristic region, the number of fungi species is lower than the expected maximum, which is probably a result of the arid environments of the region (tundra-steppe), which are not favorable for the development of "hygrophilous" clavarioid fungi.

However, contrary to the sector species wealth, the average diversity of species (ΔDS) decreases unidirectionally to the east, from 24 species in Fennoscandian to 14 species in Western Chukotka (Table 6), which is similar to the character of change for the local floras of flowering plants [19]. This is probably connected with the history of mycocomplexe development, because the Fennoscandian mycocomplex is most certainly younger than that of Chukotka, which has existed continuously since remote geological ages in the territory of the Bering bridge in the place where Eurasia meets America and promotes an exchange between their biotes [11, 26, 27].

ATTEMPT AT A GEOGRAPHIC SUBDIVISION OF THE CLAVARIOID MYCOCOMPLEX OF THE EURASIAN ARCTIC

The results of this study show that the clavarioid fungi's complexes in various districts of the Eurasian Arctic differ greatly from each other. The near-oceanic longitudinal sectors differ from continental ones in all the analyzed parameters. The greatest differences are revealed between Fennoscandian and East Chukotian sectors. Kanin-Pechora and Polar Urals sectors are similar to the Fennoscandian sector; together they form the group of European (Atlantic) sectors. The jumplike depletion of the mycocomplex in the level of species and genera and the simultaneous essential alteration in the taxonomic structure occurs between the Polar Urals sector and the Yamal-Gydan sector, which is located to the east. Yamal-Gydan sector appears to be close to other continental, Siberian, complexes, such as Taimyr, Anabar-Olenyek, and Yana-Kolyma ones. To the east, the West Chukotian complex is close to the East Chukotian one. Thus, unlike phytogeographic division, according to which the Eurasian Arctic includes 12 longitudinal sectors, according to mycological data this region includes



Schematic subdivision of the Arctic complex of the clavarioid fungi of Eurasia into four mycogeographical districts. The numerator is the number of species; the denominator is the number of genera (the number of specific species/genera is in parentheses).

only 3 sectors (regions). Two of them (European (FS–UR) and Chukotian (WCh–ECh)) are near-oceanic, and one (Siberian sector (YaG–YaK)) is continental. A similar conclusion concerning the existence of a significant border between UR and YaG is revealed by an analysis of the distribution of the lichens of the Arctic, where UR and YaG are relegated to European and Siberian regions, correspondingly [23]. On the other hand, the distribution of mosses shows the affinity of YaG with UR, making it possible to consolidate these two regions into one (the European part + Western Siberia) [27].

A difference exists not only between longitudinal sectors, but also between latitudinal subzones. Only 14% of the species of the clavarioid fungi are able to live in the whole latitudinal gradient of the Arctic (*Multiclavula corynoides*, *M. vernalis*, *Typhula crassipes*, *T. culmigena*, *T. lutescens*, and *T. variabilis*) from the Arctic deserts to the southern hypoarctic tundra (Table 3). Our investigations have shown that the most northern mycocomplexes (the Arctic deserts and the northern Arctic tundra) differ very much from the mycocomplexes of southern districts (the southern Arctic tundra and the northern and southern hypoarctic tundra) ($\chi^2 = 6.87–9.24$, $p = 0.001$) [1, 7, 8, 10, 14]. The species wealth of the "northern" zone-sectoral mycocomplexes varies in the limits of 3–9 species, whereas in the "southern" mycocomplexes these indices are noticeably higher: from 12 to 37 species (Table 3). As a whole, 9 and 44 species are noted in the northern and southern mycocomplexes, correspondingly. The similarity between two zonal mycocomplexes is low: 0.34. An essential difference also occurs in the level of genus, because there are only 3 genera of fungi in the northern mycocomplexes (the variation in zone-sectoral mycocomplexes is 2–3 genera), whereas in the southern mycocomplexes 12 genera are available (the variation is 5–10 genera) (Table 2). It is necessary to note that the mycocomplex of the High Arctic, despite its extreme poorness, is characterized by specific composition and proportions on the generic level. Therefore, two genera, *Typhula*, which includes 67% of all the species of the complex, and *Multiclavula*, which contains 22% of these (and plus 1 species (11%) of genus Clavaria), predominate here. No similar composition of species and genera, as well the proportions of them, occurs anywhere in the Arctic or in the other zonal complexes of the clavarioid fungi around the world. It is probably possible to consider a similar psychrophilic group respective mycogeographical etalon. Thus, the mycocomplexes of the Arctic deserts and the northern Arctic tundra, which are the most northern (the subzones A–B), differ greatly from the mycocomplexes located to the south, such as the southern Arctic tundra and northern and southern hypoarctic tundra (C–E), which has been also shown in studies on the separate sectors of the Arctic [1, 7, 8, 10, 14]. At the same time, the High Arctic, being barren and simple, differs completely from the Lower Arctic, which is wealthy and composite, and contains three longitudinal mycoregions (see above). Such a difference makes it possible to give the High Arctic the status of the fourth mycogeographical region of the Eurasian Arctic (figure). The revealed similarity in composition of species and genera, as well as in the taxonomic structure of the complexes of the clavarioid fungi of the Eurasian Arctic, indicates that this region is a depleted variant of boreal mycobiota and is not an independent mycogeographical area but only part of the arctic–boreal mycogeographical area [1]. An analysis of the distribution of lichens allows one to come to a similar conclusion [28].

CONCLUSIONS

Of all aphyllophoroid fungi, Clavarioid fungi adapt best to the extremal environments of the Arctic, allowing it to form specialized communities of fungi which are made up of the following two groups: psychrophilic symbiotic basidiolichens of the *Multiclavula* genus and sclerotioid of the *Typhula* genus, as well as parasitic specimens of the sclerotioid genus of *Typhula*, causing snow mold. The strategy of the formation of "sclerotioid" dormant stages and "basidiolichens" promotes the development of areas of bioclimatic pessimum of the High Arctic by clavarioid fungi, which prohibits the development of other groups of aphyllophoroid fungi.

The revealed complex is a depleted variant of the boreal (mining and boreal) analog, having a simplified composition of species; however, as a whole, it is impossible to denote the composition of species and taxonomic structure as monotonic and simple. The differences, which are commensurable with the more complicated forestry mycocomplexes, are characteristic for them.

Two near-oceanic sectors, East Chukotian (37 species) and Fennoscandian (36 species), are the richest, whereas in the sectors of continental Siberia this index decreases by one-third (to 25 species). A large difference in the composition of species between longitudinal ($Kcs = 0.76$) and latitudinal sectors ($Kcs = 0.34$) is determined. A quarter of the genera (25%) and species (23%) are characteristic only for one sector out of nine, and all of them are collected only in two near-oceanic sectors (Fennoscandian and East Chukotian). On the other hand, only 59% of the species and 66% of the genera are in all the sectors (or missing in one). The results are similar to the average values revealed for the taiga, which contradicts the opinion about "the simple and monotonous" mycocomplex of the tundra.

The wealth of the specific composition of the clavarioid life form in the Arctic correlates significantly to the wealth of the specific composition of flowering plants (especially hemicryptophytes) and the average annual quantity of atmospheric precipitates (as the integrated index of the level of continentality).

According to the similarity and difference in composition of species and genera, the assortment of specific species and genera, and the assortment of dominant species for separate sectors, the Eurasian Arctic may be subdivided into four mycogeographical regions. Two of these sectors (European and Chukotian) are the richest and have the maximal number of specific species and genera, whereas Siberia and the High Arctic are noticeably more depleted and do not contain a specific constituent.

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