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Functional Diversity of a Parasie Assemblages of the Chinese Sleeper *Perccottus glenii* Dybowskii, 1877 (Actinopterygii: Odontobutidae) and Habitat Structure of the Host

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Abstract—Analysis of the functional diversity of the parasite assemblage of Chinese sleeper individuals, based on classification of parasites by the paths of fish infestation, was conducted. It was ascertained that individuals of the Chinese sleeper obtain mainly ecologically reduced variants of parasite assemblages in the acquired part of the habitat.

INTRODUCTION

The Chinese sleeper (*Perccottus glenii* Dybowski, 1877) is a widespread fish species of Eastern Europe, Western Siberia, southern regions of Central and Eastern Siberia, and the Far East. Its habitat is divided in the spatiotemporal dimension into native and acquired parts (Reshetnikov, 2009). The chorologic peculiarities of the Chinese sleeper influence the taxonomy diversity of parasite assemblages formed in its populations (Sokolov, Zhukov, 2016).

We discerned the following aspects of diversity of parasite assemblages: species, taxonomic, and functional. The species aspect depends on the number of species and leveling of the indexes of their abundance (Megarran, 1992). In the case of this approach, differences or similarities of species that do not match the biological nature of diversity are ignored (Pielou, 1966). Because of this, the species aspect of diversity fundamentally differs from other aspects in which degrees of similarity and differences of species are taken into account. These aspects of diversity can be split into two groups, which take into account the closeness of species by their origin (genetic and taxonomic (phylogenetic) diversity) (Warwick, Clarke, 1995; Sokolov, Zhukov, 2014) and adaptations to the environment (functional and morphological) (Petchey, Gaston, 2006; Devictor *et al.*, 2010). To describe functional diversity, combinations of signs, which reflect morphological and physiological traits of organisms, peculiarities of the life cycle, colonization, and so on, are often used (Bernhardt-Romermann *et al.*, 2008).

The objective of this work is to ascertain regularities of change in the functional diversity of parasite assemblages of the Chinese sleeper specimens under conditions of large-scale habitat expansion of the host.

MATERIALS AND METHODS

We examined 634 parasite assemblages that formed in specimens of the Chinese sleeper from 22 water bodies including native and obtained parts of the habitat of this host (Table 1). The geographical location of these water bodies, as well as the specific composition of parasites, factors of infestation of the Chinese sleeper, and dimensional characteristics of the fish analyzed have been given previously (Sokolov, Frolov, 2012; Sokolov, 2013; Sokolov, Moshu, 2013; Sokolov *et al.,* 2013, 2014; Sokolov, Protasova, 2014; Sokolov *et al.,* 2014; Sokolov, Novozhilov, 2015). According to the unified principle decomposition of the structure and diversity of parasite assemblages (Sokolov, 2004; Sokolov, Zhukov, 2014, 2016), the groups of parasites in the host individuals investigated belong to the α-level hierarchy of the assemblages.

Analysis of the functional diversity is based on the classification of parasites by the path of infestation of the Chinese sleeper, which are the following: group I includes species colonizing cutaneous coverings, the epithelium of gills, and the mouth cavity; group II includes species with percutaneous invasion; group III includes species with alimentary invasion. Group I includes ectoparasitic protists, monogeneans, crustaceans (except adult females of *Lernaea elegans* Leigh-Sharpe, 1925), ticks, glochidia, and leeches; group II includes metacercariae, adult females of *L. elegans*, and myxozoans; group III includes nematodes, acan-

Table 1. Data concerning samples of fish studied.

Water body		n, specimens
name	location	
"Lake-1"	Primorye	30
"Lake-2"	The same	30
"Lake-3"	"	30
Sladkoe Lake	Sakhalin	47
Berdinskiy Pond	Novosibirsk oblast	30
Glushitsa Podstepnaya Lake	Voronezh oblast	37
"Pond-1"	Kaliningrad oblast	32
Sazanka Lake	Saratov oblast	37
"Raslovka"	The same	51
"Gornoslinkino-2"	Tyumen oblast	23
"Rechport"	The same	32
Krugloe Lake	Samara oblast	34
Dead arm of the Dragishte River near the village of Bulboaka	Republic of Moldova	21
"Neverovo sand-pit"	Moscow oblast	30
Ilev fish farm	Nizhny Novgorod oblast	39
Zhiloe Lake	Novosibirsk oblast	28
Protochnoe Lake	Perm krai	20
Motovilikhinskiy Pond	The same	33
"Pond-1"	"	19
"Maloe Konevo"	Arkhangelsk oblast	17
Roadside ditch	Novosibirsk oblast	30
"Yushala"	Sverdlovsk oblast	17

thocephalans, cestodes, adult trematodes, microsporidia, diplomonads, and coccidia.

Two approaches to description of functional diversity were used. The first one is connected with determination of the total length of branches of a dendrogram of the population built on the basis of a matrix of measures of differences of ecological properties of species (Petchey, Gaston, 2006). To build a matrix of similarity/difference by ecological properties, which are categorial variables, the Gower metrics was used (Gower, 1971). The second approach is implementation of multivariate scaling of parasitic populations on the basis of the matrix of similarity that takes into account ecological differences between species (Webb *et al.*, 2008). Calculations were conducted using Statistica 7.0 software, as well as

R program shell and the *vegan* (Oksanen *et al.*, 2007), *picante* (Kembel *et al.*, 2010), and *cluster* (Maechler *et al.*, 2015) libraries. The influence of different variables on the diversity indices was assessed using the general linear model.

Out of all types of calculations of this work, homotypical parasite assemblages were excluded, for their functional diversity is equal to zero. The number of

parasitic species in populations was normalize to a diapason 0−1, where 1 is the maximal quantity of the parasite among all tested specimens of fish. Species of protista, the numbers of which cannot be indicated by the quantity of individuals within the limits of the method used (*Trichodina* spp. etc.), were assessed by the variables 0 (absence of a species) and 10 (its presence). The percentage distribution of ecological groups by clusters was assessed according to normalized indices of numbers. For evaluation of evenness of ecological groups, Pielow's evenness index was used (Megarran, 1992).

RESULTS

The correlation of functional diversity of parasite assemblages of individuals of the Chinese sleeper with the specific diversity of assemblages themselves and the gender of the host is confirmed by the Linear model (Table 2). The functional diversity of the assemblages studied has a positive correlation with the number of species comprising them. The functional diversity of parasite assemblages in females of the Chinese sleeper is higher than in males (Fig. 1). The link of the covered aspect of diversity with the structure of

Table 2. The total linear model of influence of the structure of a host's areal, its gender, and specific abundance of parasites on the functional diversity of parasite assemblages of individuals of the Chinese sleeper ($R^2 = 0.36$, $F = 51.59$, $p = 0$)

Predictor	Sum of squares	Degree of freedom	Mean sum of squares	F-statistics	p-level
Coefficient	110.13	1	110.13	134.96	0
Size of the host	1	1	1	1.22	0.27
Species number of parasites	90.38	1	90.38	110.76	0
Structure of the habitat	0.05	1	0.05	0.06	0.81
Gender of the host	4.22	1	4.22	5.18	0.02
Structure of a habitat × host gender	0.03	1	0.03	0.04	0.85
Error	358.24	439	0.82	—	—

"×" is the interaction of variables, "−" means the value is not stipulated by the format of the analysis, R^2 is the coefficient of determination, F is Fisher's ratio, and p is the significance level.

the host's habitat (division into native and obtained parts) is not confirmed by this model (Table 2).

Differences between parasite assemblages of fish inhabiting native and obtained parts of the areal by their functional diversity are identified by the method of multidimensional scaling. In the area of multidirectional dimensions, parasite assemblages have formed seven clusters (Fig. 2). In cluster 4, assemblages formed in hosts inhabiting the native part of a geographic range (75% of the number of assemblages in the cluster) prevail, in all remaining clusters, assemblages formed in hosts inhabiting the obtained part of the habitat prevail. In clusters 2 and 6, however, representation of parasite assemblages connected with fish inhabiting native water bodies remains comparatively high (26.4 and 33.3%, respectively). Clusters 1, 3, and 5 are represented by parasite assemblages by more than 90%, and cluster 7 is completely (100%) represented by parasite assemblages from the obtained part of the host's habitat. Only cluster 4 includes assemblages consisting of species of three ecological groups. Assemblages of other clusters contain species of two (clusters 2, 3, 5, and 6) or one (clusters 1 and 7) ecological groups (Fig. 3).

Cluster 4 combines 65.6% of parasite assemblsges that were formed in the Chinese sleeper in native habitats. Thus, within the boundaries of the native part of the host's habitat, high functional diversity is typical for parasite assemblages of individuals of the Chinese sleeper. The main number of parasite assemblages formed in introduced fish was represented in clusters 1, 2, 3, and 5 (15.1, 12.3, 29, and 23.7% respectively). These clusters are characterized by lesser functional diversity. All three ecological groups of parasites are represented only in 8.8% of assemblages connected
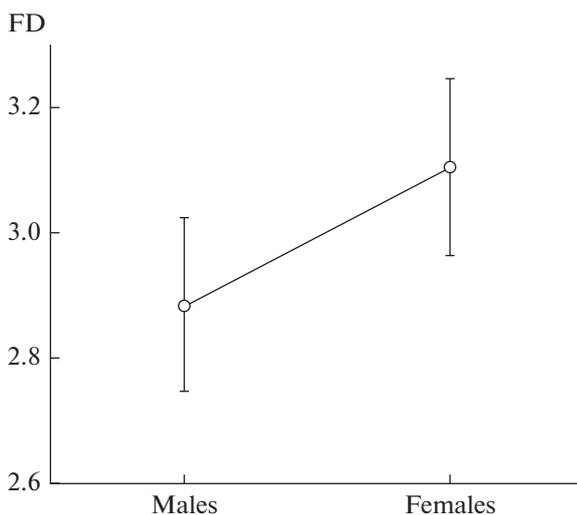

Fig. 1. Dependence of the functional diversity of parasite assemblages of specimens of the Chinese sleeper on the gender of the host. FD is the index of functional diversity (Petchey, Gaston, 2006).
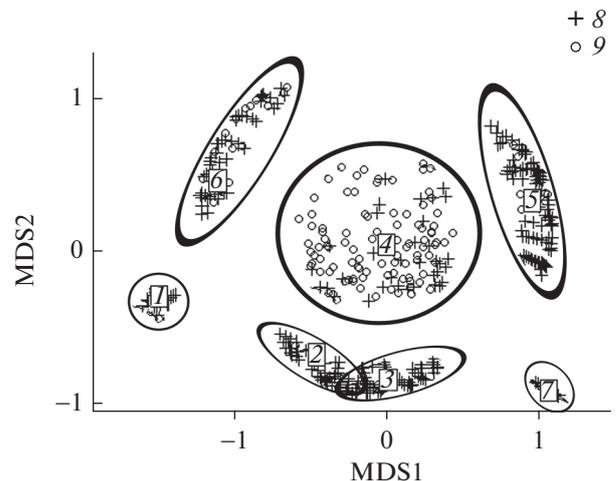

Fig. 2. Multidimensional scaling of parasite assemblages of specimens of the Chinese sleeper based on a matrix of ecological differences. 1−7, numbers of clusters; 8, parasite assemblages of introduced fish; 9, parasite assemblages of fish from native habitats, MDS1 and MDS2, axes of multidimensional scaling.
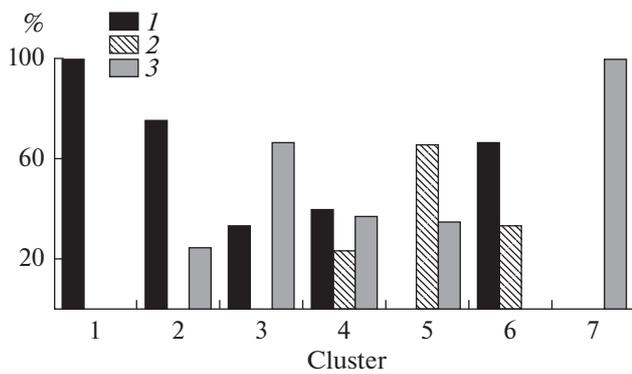
Fig. 3. Distribution of ecological groups of parasites by clusters in their averaged ratio (in % of numbers of specimens in parasite assemblages). 1–3, ecological groups I–III, respectively.

Fig. 4. Dependence of evenness (E) of the functional diversity of parasite assemblages of specimens of the Chinese sleeper on the structure of the habitat of the host and the cluster to which the assemblages belong. 1, native part of the habitat; 2, obtained part of habitat.

with individuals of the introduced Chinese sleeper. In case of the same functional structure, parasite assemblages in introduced fish are reliably different by evenness from those of individuals from native habitats only in clusters 4 (significance level is $p = 0.013$) and 5 ($p = 0.009$). In this case, assemblages formed in fish in the native part of the habitat are more evenness in cluster 4, but in cluster 5 the obtained part of the habitat prevails (Fig. 4).

On the territory including the obtained part of the habitat of the Chinese sleeper, water bodies of two fundamentally different categories were examined, namely, natural ones and those of the same status (lakes, dead channels, ponded riverbeds (Motovilikhinskiy and Berdskiy ponds) and their additional water bodies (Ilev fish farm, "Rechport")) and closed artificial ones (Roadside ditch, "Pond-1" in Kaliningrad oblast and Perm krai, "Neverovo sand-pit") (Table 1). Parasite assemblages of individuals of the Chinese sleeper from the artificial ponds mentioned are distributed only between the following two clusters : 1 ("Neverovo sand-pit" and "Pond-1" in Kaliningrad oblast) and 3 (Roadside ditch and "Pond-1" in Perm krai) (Fig. 3). Thus, the ecological structure of assemblages in these water bodies is more uniform compared to natural ponds located on the territory of the obtained part of the host's habitat and included in the spectrum of clusters 1–7. At the same time, parasite assemblages of fish from artificial ponds are not unique in the ecological structure, since clusters 1 and 3 include also assemblages of individuals of the Chinese sleeper from natural water bodies, for instance, "Gornoslinkino-2," Protochnoe Lake, and, partially, "Rechport" (cluster 3).

DISCUSSION

The basic problem of description of the functional diversity of parasite assemblages is in the choice of the functional (ecological) classification of parasites. In
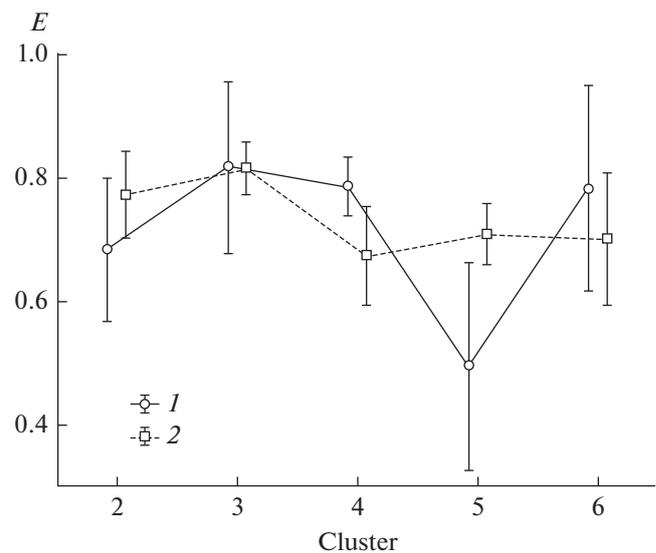
Pedersen's and Fenton's opinion (Pedersen, Fenton, 2007), functional organization of parasite assemblages (communities, according to the authors) adequately characterizes one of three criteria, namely, food resources of a parasite, localization in a host, and the mechanism of immune response induced by a parasite. However, consideration of most parasitic species from the position of the first and third of the mentioned criteria is not yet possible, since physiological information concerning them is absent or not sufficient. The difficulty of using the second criterion is connected with the possibility of registration of the same parasite (at the same stage of development) in different organs of a host. *Trichodina* spp., for instance, can be present on both the gills and fins of the same individual. The question of scaling of zones of parasite localization still remains to be answered, which is clearly illustrated by the example with parasites of fish eyes. Species with intraocular localization can be considered as members of the same guild or differentiated into parasites of the crystalline lens or other parts of the eye. This uncertainty contributes a substantial degree of subjectivity in the description of functional organization of the parasite assemblage. We have decided in favor of classification covering the strategy of colonization of a host. In addition, the classification contains partial information concerning localization of a parasite. Species of group I parasitize the skin, surface of gills, and oral cavity. Species of group II inhabit gill tissue and cutaneous covering, muscles, serous coat, and, rarely, organs of the digestive system (myxozoans of gall bladder). Species of group III are found mostly in the digestive tract and

adjacent organs (mesentery and liver), and, rarely, in the urinary system (*Phyllodistomum* spp.).

The dependence of the functional diversity of parasites on the gender of the host, which was recorded by us, probably reflects a positive interconnection of the gender factor with the specific abundance of parasites of the Chinese sleeper (Sokolov, Zhukov, 2014).

According to results of multidimensional scaling, ecologically reduced variants of parasite assemblages are most commonly formed in specimens of the Chinese sleeper in the obtained part of the habitat. In cases of full packaging with ecological groups, parasite assemblages of introduced fish have a less evenness functional structure than those of fish from the native part of the habitat (Fig. 4). In the obtained part of the habitat, individuals of the Chinese sleeper with zero functional diversity of parasite assemblages (consisting of one species) make up 36.5%, whereas in the native part they make up 5.9%. These peculiarities, together with the data obtained earlier (Sokolov, Zhukov, 2016), form the vector of impoverishment of diversity of parasite assemblages of the Chinese sleeper, which is directed away from the native to the obtained part of habitat of this host.

Parasite assemblages of introduced fish are most commonly devoid of species of group II which makes up 61.8% as against 29.1% (without group I) and 20.8% (without group III). Interestingly, in the native habitat of the Chinese sleeper, the portion of assemblages devoid of species of group II is also higher than those without parasites of group I or III (21% against 6.3 and 10.1%, respectively).

All three groups of parasites are ecologically heterogeneous, since they contain species specific for the Chinese sleeper and euryxenous species (Sokolov, Zhukov, 2016). By and large in the introduced fish that were examined in this study, four host-specific parasites were identified. Two of them belong to ecological group III (*Goussia obstinata* Sokolov et Moshu, 2014 and *Nippotaenia mogurndae* Yamaguti et Miyata, 1940) and the remaining two belong to groups II and I (*Henneguya alexeevi* Schulman, 1962 and *Gyrodactylus perccotti* Ergens et Yukhimenko, 1973, respectively).

In two natural water bodies (Zhiloe and Glushitsa Podstepnaya lakes), included in the obtained part of the habitat of the Chinese sleeper (from those recorded in this work), parasites specific for this host were not discovered (Sokolov *et al.,* 2013; Sokolov *et al.,* 2014). Parasite assemblages of fish from Glushitsa Podstepnaya Lake (all belong to cluster 5) are not more impoverished by the number of ecological groups forming it than assemblages of introduced Chinese sleepers from water bodies with species specific for them (Fig. 3). The mean value of the functional diversity index of parasite assemblages of specimens of the Chinese sleeper from Glushitsa Podstepnaya Lake (FD = 2.9) is comparable to that from water bodies with one (for instance, Protochnoe lake, FD = 2.8) or even two (for instance, Sazanka Lake, FD = 3)

species specific for this host. In Zhiloe Lake, parasite assemblages of specimens of the Chinese sleeper approaching 40% are characterized by zero functional diversity, and assemblages formed by more than one species are represented by two ecological groups (cluster 2) (Fig. 3). By representation of assemblages the functional diversity of which is different from zero and by the set of ecological groups in assemblages, Zhiloe Lake is comparable to the water bodies "Rechport" and "Gornoslinkino-2." Parasite assemblages formed in individuals of the Chinese sleeper from the latter two water bodies are mostly distributed between clusters 3 and 2 (Fig. 3). In these water bodies, two peculiar species of the host covered are found (Sokolov *et al.,* 2014). At the same time, the mean value of the FD index for parasite assemblages of specimens of the Chinese sleeper from Zhiloe Lake is significantly lower of those from "Rechport" and "Gornoslinkino-2" ponds (1.7 against 2.8−3 ($p = 0.01$)). In our opinion, the examples with Zhiloe and Glushitsa Podstepnaya lakes indicate that the presence/absence of peculiar species is not an unambiguous factor of enrichment/reduction of functional diversity of parasite assemblages formed in specimens of introduced Chinese sleeper.

Group III is more heterogeneous in the ecological respect than the other two, because it includes mono- and heteroxenous species apart from parasites specific to the Chinese sleeper and euryxenous parasites. The latter are differentiated to plankton- and benthos-dependent parasites. In the obtained part of the habitat of the Chinese sleeper, ecological group III is mainly represented in assemblages by monoxenous protists (coccidians and diplomonads) and plankton-dependent helminths (*N. mogurndae*, *Ophiotaenia europaea* Odening, 1963, *Spiroxys contortus* (Rudolphi, 1819) *et al.*). Benthos-dependent helminths (caryophyllids, acanthocephalans, a number of nematodes, and so forth) are rare. Two water bodies are exceptions, namely, the Dead arm of the Dragishte River near the village of Bulboaka and "Raslovka" (Sokolov, Moshu, 2013; Sokolov *et al.,* 2014). In the native part of the host's habitat, monoxenous protists of the ecological group examined in the composition of the parasite assemblages studied are rare and benthos-dependent helminths are found more often. Direct ways of infection of the Chinese sleeper by species of group III are difficult to decipher unambiguously due to the characteristic of this host of pantophagy with significant amount of predatoriness (Plyusnina, 2008; Koščo *et al.,* 2008), involvement of the paratenic section into circulation of heteroxenous helminths, and participation of a carrier in transition of monoxenous species (in particular, Oligochaeta (Steinhagen, Körting, 1990)). In connection with this, the observed mosaicism of infection of the Chinese sleeper by species of group III hardly has reliable interpretation. An additional difficulty is created by the dependence of the infection of fish by alimentary species of parasites on electivity of their diet and the

degree of suitability of a species as a host (Knudsen *et al.,* 1996; Cirtwill *et al.,* 2016) which, in cases with the introduced Chinese sleeper (with links to ponds and obtained species of parasites), cannot be assessed adequately at present.

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