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Fauna and shell morphology of limpets of the genus *Acroloxus* Beck (Gastropoda: Pulmonata: Acroloxidae), living in Lake Baikal (with notes on Transbaikalia limpets)

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ABSTRACT. Limpet fauna of the Holarctic genus *Acroloxus* Beck, 1837 was examined in Lake Baikal. Morphology of protoconch and teleoconch of three species (*A. baicalensis* Kozhov, 1936, *A. orientalis* Kruglov et Starobogatov, 1991 and possible new *Acroloxus* species) was studied with SEM. Additional shell characters were described for *A. baicalensis*, collected from its type locality. Distribution of representatives of the genus *Acroloxus* in Lake Baikal and its basin was discussed.

Introduction

Lake Baikal is arguably the most famous of the world's so-called ancient lakes and harbours highly diverse and endemic mollusc fauna. Molluscs are common members in Baikal biocoenoses. They play important roles in biological processes and often make up more than 60% of the biomass of macrozoobenthos of the stony littoral zone [Kozhov, 1931, 1947; Miklashevskaya, 1935; Gavrilov, 1950; Bekman, Den'gina, 1969; Kaplina, 1974]. The recent malacofauna of the Baikal water body consists of 180 species of which 83% are gastropods [Sitnikova *et al.*, 2004; Slugina, Starobogatov, 1999]. The family Acroloxidae Thiele, 1931 represents a sixth part of the total gastropod diversity of Lake Baikal and underwent a major radiation. The Baikal acroloxids amount to 48% of the world's Acroloxidae diversity.

Limpets in the open Lake Baikal number 25 species belonging to three endemic genera [Starobogatov, 1989; Sitnikova *et al.*, 1993; Shirokaya *et al.*, 2003; Shirokaya, 2007] which have radiated extensively since the Late Pliocene [Albrecht *et al.*, 2007]. In addition, the Holarctic genus *Acroloxus* Beck, 1837 is known to inhabit the shallow bays of Lake Baikal [Kozhov, 1936; Sitnikova *et al.*, 2004].

The first specimen of the Baikal *Acroloxus* was collected in Chivyrkuy Bay at the beginning of the last century [Kozhov, 1936]. The single specimen, lost at present, was described as an endemic subspecies of the common *A. lacustris* (Linnaeus, 1758) — *A. lacustris* var. *baicalensis* Kozhov, 1936. Subsequently, *A. baicalensis* Kozhov, 1936 was treated as an independent species [Kruglov, Starobogatov, 1991]. Its short original diagnosis was also enhanced with the data on shell shape and dimensions of the specimen from the Lower Yenisei River (Dudinka Settl. vicinity) [Ibid.] due to the unavailability of *Acroloxus* from Lake Baikal. Despite thorough sampling in shallow bays and gulfs of Lake Baikal, *A. baicalensis* limpets have not been found in the lake since its description. Only 70 years later, Shirokaya with co-authors [2009] published a short note on finding of several specimens of *Acroloxus* in Chirvyrkuy Bay which were identified as three independent species without detailed description of the shell morphology. Prozorova [2010] touched upon these species in the discussion on *Acroloxus orientalis* Kruglov et Starobogatov, 1991 distribution in the water bodies of the Russian Far East and Hokkaido Island (Japan). Below we present detailed characters of protoconch and teleoconch in the limpets identified as *A. baicalensis*, *A. orientalis* and *Acroloxus* sp. focusing on shell description of *A. baicalensis* collected in its type locality — Chivyrkuy Bay, Lake Baikal.

Material and methods

In 2008 we sampled *Acroloxus* limpets in Kotovo

Inlet (coordinates: 53°38’06.7”N, 108°58’10.7”E) of Chivyrkuy Bay, and in a channel, connecting the bay with Lake Arangatuy (53°37’40.4”N, 108°59’31.6”E). A total of 16 limpets was picked up from the aquatic plant *Elodea canadensis* Michaux, 1803 at the depth of 0-1.5 m.

For species identification we used a measuring system suggested by Kruglov and Starobogatov [1991] for this gastropod family, as well as Starobogatov’s visual method of comparison of a shell with holotype templates using a MBS-1 stereo microscope (LOMO PLC) with camera lucida [Starobogatov, Tolstikova, 1986]. Protoconch characters were studied with scanning electron microscopy (PHILIPS 525 M). Preparation techniques were described in Shirokaya et al. [2003]. The shells were measured according to the scheme presented in Fig. 1.

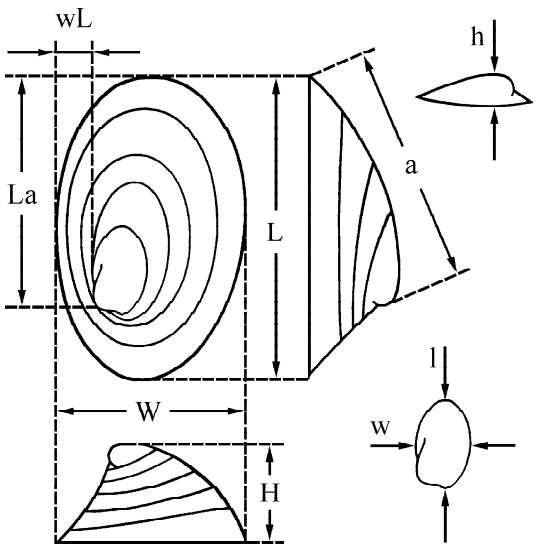

FIG. 1. Measurements of acroloxid shells (after Kruglov, Starobogatov [1991], modified). L — length of aperture; La — distance from apex to the frontal apertural edge (projected on longitudinal axis of aperture); W — width of aperture; wL — distance from apex to left apertural edge; a — chord of anterior (maximal) slope; H — height of teleoconch; l — length of protoconch; w — width of protoconch; h — height of protoconch.

РИС. 1. Схема промеров раковины акролоксид (по Круглову, Старобогатову [1991], с изменениями). L — длина устья; La — удаление вершины от переднего края устья (в проекции на плоскость устья); W — ширина устья; wL — удаление вершины от левого края устья; a — хорда переднего (максимального) склона; H — высота телеоконха; l — длина протоконха; w — ширина протоконха; h — высота протоконха.

Results and discussion

Most of limpets collected from Chivyrkuy Bay were identified as *Acroloxus baicalensis* and *A. orientalis*. Besides, a single shell had the morphological characters, which did not correspond to any known *Acroloxus* species. All limpets found in the channel of Lake Arangatuy were close to *A. orientalis*.

1. Shell morphology

Protoconch morphology of *A. baicalensis* and *A. orientalis*. Both species are characterized by a horn-shaped protoconch with a less strong reticular sculpture than that of littoral endemic acroloxids. The back slope of the protoconch has both radial and concentric ribs. On the front slope, a weakly expressed reticular sculpture is substituted by dots (Fig. 2: M, P). The initial plate of both *Acroloxus* species is drop-shaped (Fig. 2: H, I, S, T) or oval (Fig. 2: B, C, G, R). The rounded initial plate is typical of endemic Baikal species [Shirokaya *et al.*, 2003]. The initial plates of *A. baicalensis* and *A. orientalis* overlap each other in their dimensions: length and width in *A. baicalensis* are 0.2-0.24 mm and 0.13-0.16 mm, respectively, while in *A. orientalis* they are 0.21-0.27 mm and 0.15-0.19 mm. Interspecific differences in protoconch microsculpture have not been found between *A. baicalensis* and *A. orientalis*.

Protoconch morphology of *Acroloxus* sp. This species differs significantly from the two species mentioned above in its cap-shaped protoconch with a pitted microsculpture (Fig. 2: A, D, Q). The initial plate of *Acroloxus* sp. is drop-shaped (Fig. 2: A, Q). Interestingly, the protoconch bearing rows of pits is characteristic of the only abyssal Baikal limpet — *Pseudancylastrum frolikhae* Sitnikova et Starobogatov, 1993 [Shirokaya *et al.*, 2003].

Teleoconch morphology of *A. baicalensis* and *A. orientalis*. Baikal *A. baicalensis* and *A. orientalis* are characterized by a pronounced variability in their shell morphology which is similar to a pattern found in acroloxids from Lake Ohrid [Albrecht *et al.*, 2006]. There are several specimens with intermediate shell shapes (Fig. 2: C, F, G, J, N, O, R), which may be evidence of cross-breeding or extensive variation within a highly variable single species. Typical *A. orientalis* (Fig. 2: B, E, M) is characterized by a flattened shell (shell height (H) to aperture width (W) ratio ≤ 0.54), deep undertop concavity, evenly convex right slope and equally rounded front and back aperture edges. *Acroloxus baicalensis* (Fig. 2: H, I, K, L, P, S, T) has a higher shell (H/W ≥ 0.56) with a slight undertop concavity and a nearly straight right slope. The aperture is elongated oval with a broader anterior edge.

Morphology of the *A. baicalensis* shell in Fig. 2 (I, L, P, T) corresponds to the brief description given by Kozhov [1936, p. 184]. We describe this shell in detail to simplify the identification of this species in further investigations.

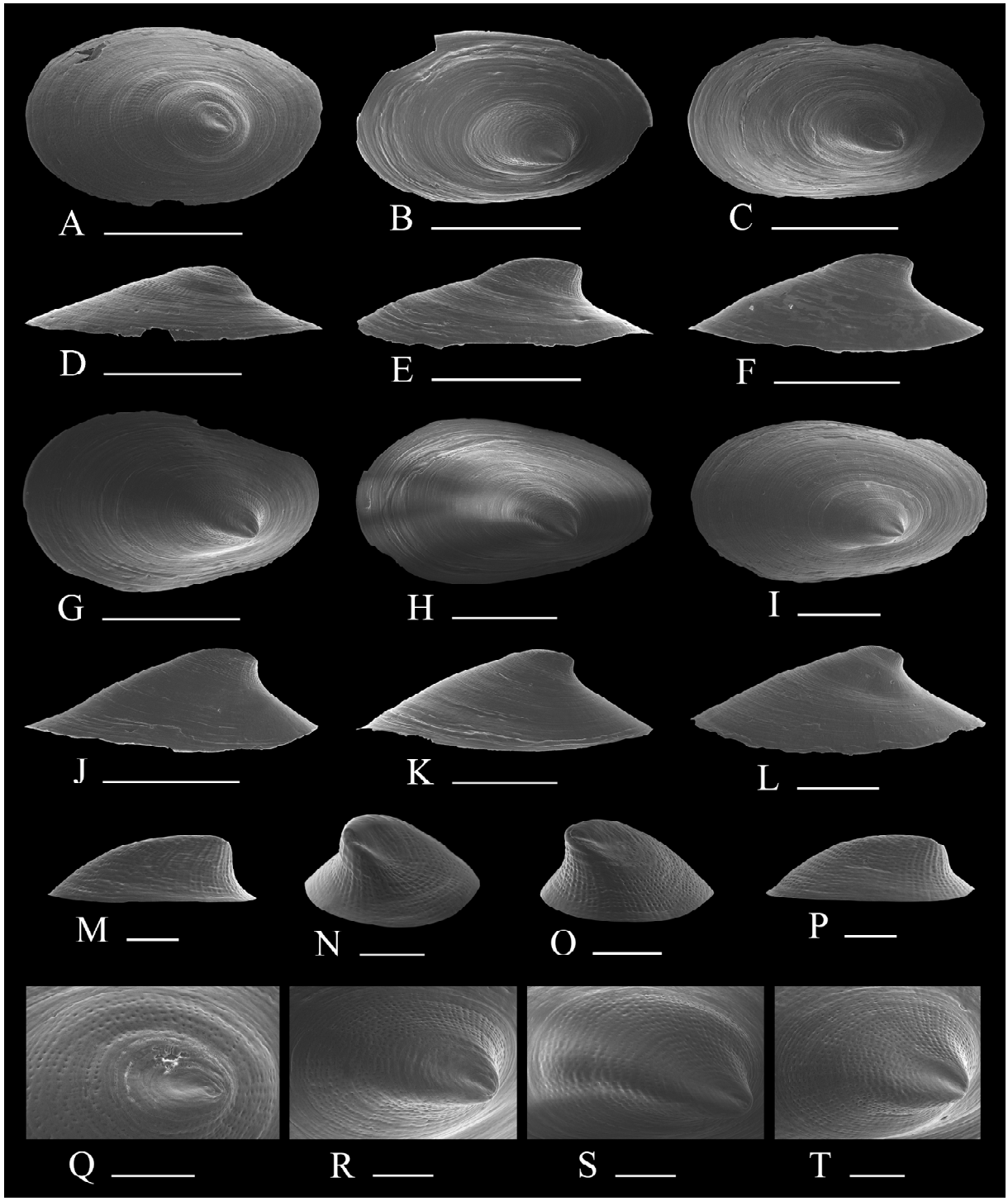

FIG. 2. Limpet shells of the genus *Acroloxus* from Chivyrkuy Bay, Lake Baikal. A, D, Q — *Acroloxus* sp. (the same specimen); B-C, E-F, M-N — *A. orientalis* (B, E, M — first specimen, C, F, N — second specimen); G, I-J, L, O-P, R, T — *A. baicalensis* (G, J, O, R — first specimen; H, K, S — second specimen; I, L, P, T — third specimen). A-L — teleoconch; M-T — protoconch; A-C, G-I, Q-T — top view; D-F, J-L, M, P — left view; N-O — rear view. Scale bars: A-L — 1 mm; M-T — 0.2 mm.

РИС. 2. Раковины чашечек рода *Acroloxus* из Чивыркуйского залива озера Байкал. A, D, Q — *Acroloxus* sp. (один экземпляр); B-C, E-F, M-N — *A. orientalis* (B, E, M — первый экземпляр, C, F, N — второй экземпляр); G, I-J, L, O-P, R, T — *A. baicalensis* (G, J, O, R — первый экземпляр; H, K, S — второй экземпляр; I, L, P, T — третий экземпляр). A-L — телеоконх; M-T — протоконх; A-C, G-I, Q-T — вид сверху; D-F, J-L, M, P — вид слева; N-O — вид сзади. Масштабные линейки: A-L — 1 мм; M-T — 0.2 мм.

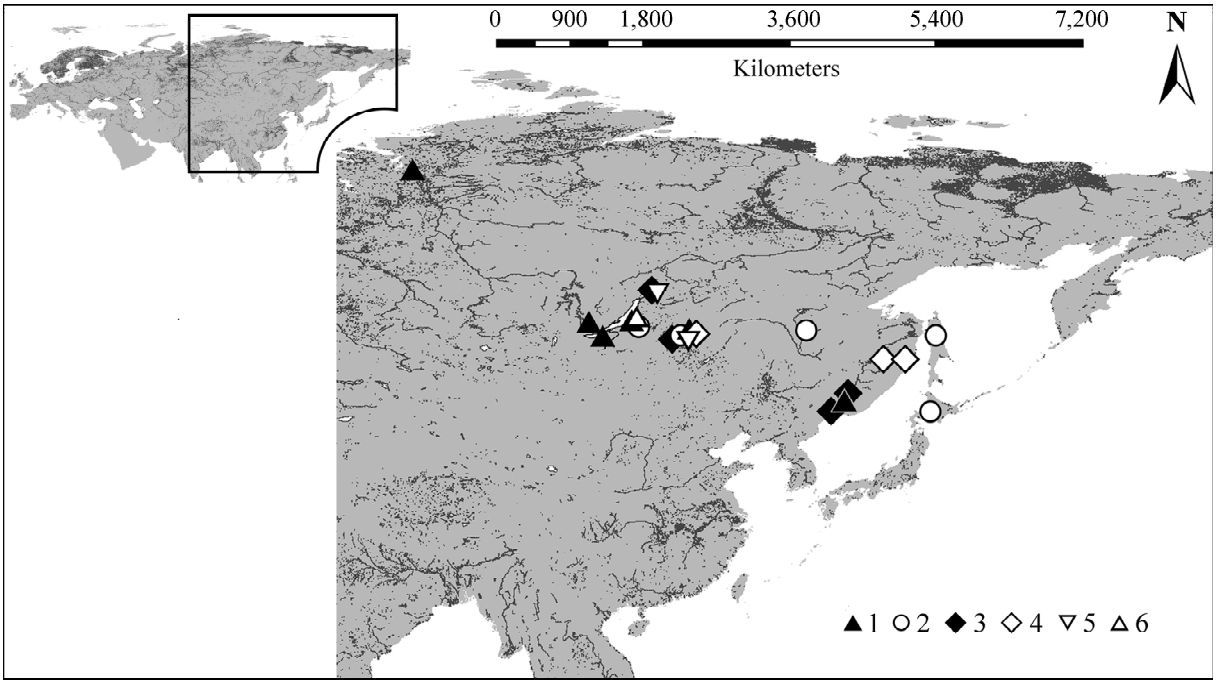

FIG. 3. Distribution areas of six *Acroloxus* species found in the Lake Baikal basin. 1 — *Acroloxus baicalensis*; 2 — *A. orientalis*; 3 — *A. hassanicus*; 4 — *A. victori*; 5 — *A. arachleicus*; 6 — *Acroloxus* sp.

РИС. 3. Ареалы шести видов акролоксид, обнаруженных в бассейне озера Байкал. 1 — *Acroloxus baicalensis*; 2 — *A. orientalis*; 3 — *A. hassanicus*; 4 — *A. victori*; 5 — *A. arachleicus*; 6 — *Acroloxus* sp.

Shell characters of *A. baicalensis* (Fig. 2: I, L, P, T). L=3.58 mm, W=1.97 mm, H=1.35 mm, a=2.71 mm, La=2.60 mm, wL=0.44 mm, l=0.80 mm, w=0.56 mm, h=0.26 mm. The shell is relatively high (H/W=0.69), and aperture is elongated oval (W/L=0.55) with a broader anterior edge. Front and left slopes of the shell are slightly convex, whereas posterior and right slopes are almost straight. The apex does not reach the left aperture edge (wL/W=0.22). The distance between the apex and anterior aperture edge is 0.73 of aperture length.

Teleoconch morphology of *Acroloxus* sp. The shell is very flat, flatter than that of *A. orientalis* (H/W=0.42), and wide (W/L=0.60) with equally rounded front and back aperture edges (Fig. 2: A, D). The shell apex is close to the aperture centre (wL/W=0.42), apex distance from frontal aperture edge is 0.70 of its length. Undertop concavity is absent. Front and back slopes of the shell are straight. Side slopes are slightly convex. In shell shape *Acroloxus* sp. is similar to *A. orientalis* and differs from that by lower teleoconch, straight front slope and flattened shell top, located close to the aperture centre.

It is impossible to formally describe this species as new for science in this paper due to the inadequate material.

Some differences were also revealed in shell morphology between Baikal and Far East *A. orientalis* specimens. Baikal specimens have a shell apex located beside the left aperture edge (wL) with the distance of 0.25-0.30 of its width; apex distance from the frontal aperture edge (La) is 0.69-0.73 of its length (L). The shell apex of the Far East *A. orientalis* specimens is close to the centre (wL/W= 0.4-0.45, La/L=0.58-0.61) [Kruglov, Starobogatov, 1991]. In addition, the shell apex of *A. baicalensis* from Chivyrkuy Bay is closer to the frontal aperture edge (La/L=0.71-0.72) than in specimen from the Yenisei River (La/L=0.79) [Ibid.].

2. Species diversity and distribution

In Lake Baikal, both *A. baicalensis* and *A. orientalis* were collected sympatrically in Chivyrkuy Bay. *Acroloxus orientalis* was described as a species from the Russian Southern Far East [Kruglov, Starobogatov, 1991]. Then, it was recognized in the Khilok River of the Baikal basin [Prozorova, Zasypkina, 2005] and in Northern Japan [Prozorova, 2010]. Thus, the range of *A. orientalis* covers the territory from Baikal to Sakhalin and Hokkaido islands, including northern tributaries of the Amur River (Fig. 3).

Originally known from Chivyrkuy Bay and the Lower Yenisei River [Starobogatov, Streletskaya, 1967], *A. baicalensis* likewise inhabits the Ivano-Arakhley lake-river system (Shirokaya River), small lakes near the south-east Baikal shore (Fig. 4), and probably the Angara River basin [Golyshkina, 1967; Sitnikova *et al.*, 2004; Prozorova *et al.*, 2009; original data]. Moreover, limpets morphologically resembling *A. baicalensis* occur with *A. likharevi*

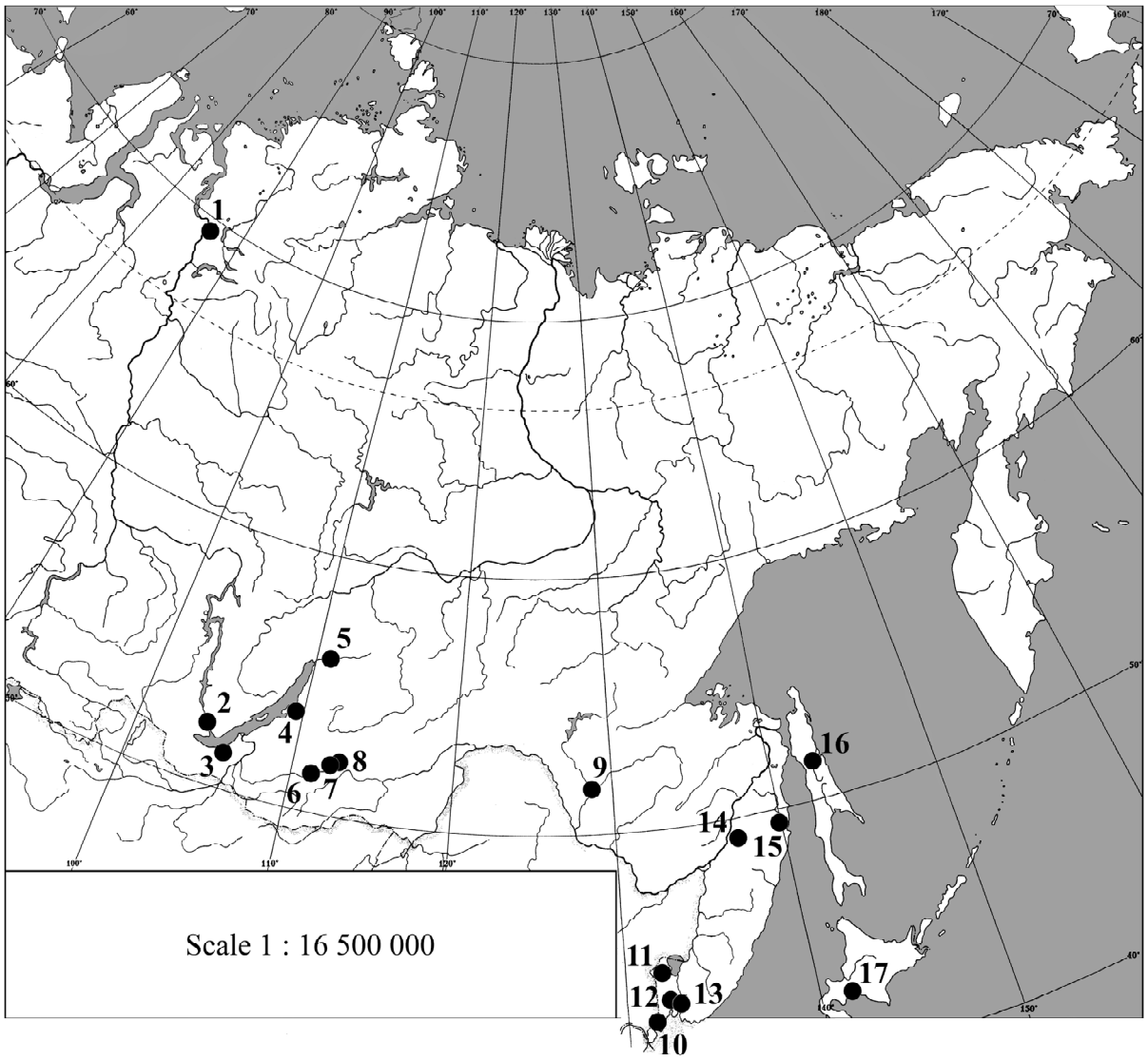

FIG. 4. Sites of sampling and discussed findings of *Acroloxus* limpets on the territory of East Siberia and the Russian Far East. Decoding of the localities is shown in Table 1.

РИС. 4. Места сбора и обсуждаемых находок чашечек рода *Acroloxus* на территории Восточной Сибири и Дальнего Востока России. Расшифровка местонахождений представлена в таблице 1.

Moskvicheva, Kruglov et Starobogatov, 1991 in slow rivers in the Russian Southern Far East together. Thus, the distribution range of *A. baicalensis* probably bordered by the Yenisei River to the west and the Pacific Ocean shores to the east is generally concordant with that of *A. orientalis* (Fig. 3). Both species *A. orientalis* and *A. baicalensis* are ecologically similar and inhabit the macrophytic vegetation of slow rivers and large lakes. *Acroloxus baicalensis,* however, sometimes lives on hard substrate.

Given the new data, we assume that *A. baicalensis* and *A. orientalis* are closely related cryptic species with partly overlapping areas. Both species are possibly close to *Acroloxus* sp. that should be described formally. Further studies using appropriate genetic markers should specify the phylogenetic and phylogeographic status of the populations of *Acroloxus* spp. from Lake Baikal and its watershed.

It is important to note that in Transbaikalia two other limpet species have been recognized which were previously known from the Russian Southern Far East. These species are *A. hassanicus* Kruglov et Starobogatov, 1991 and *A. victori* Prozorova, 1996 originally described from the Tatar Strait shore [Prozorova, 1996]. The first species, previously recorded in the Kichera River, a tributary of Lake Baikal [Kruglov, Starobogatov, 1991], is found in

Table 1. Sites of sampling and discussed finds of *Acroloxus* limpets on the territory of East Siberia and the Russian Far East *. Locality numbers in the Table correspond to those in Fig. 4.

No.	Species	Sites	Authors
1	*A. baicalensis*	Yenisei River (Dudinka Settl. vicinity)	Kruglov, Starobogatov, 1991
2	*A.* cf. *baicalensis*	Angara River basin (small lakes)	Golyshkina, 1967
3	*A. baicalensis*	small lake near the Mishikha River (south-east Baikal shore)	Sitnikova *et al.*, 2004
4	*A. baicalensis*	Chivyrkuy Bay of Lake Baikal	Kozhov, 1936
4	*A. baicalensis, A. orientalis, Acroloxus sp.*	Chivyrkuy Bay of Lake Baikal and a channel, connecting the bay with Lake Arangatuy	Shirokaya et al., 2009; original data
5	*A. hassanicus, A. arachleicus*	Kichera River basin (unnamed lake), Buryatiya	Kruglov, Starobogatov, 1991
6	*A. orientalis*	Khilok River of the Baikal basin, Buryatiya	Prozorova, Zasypkina, 2005
6	*A. hassanicus*	Khilok River of the Baikal basin	original data
7	*A. baicalensis, A. arachleicus, A. victori*	Shirokaya River, Ivano-Arakhley lake-river system	original data, material collected by P.V. Matafonov
8	*A. arachleicus*	Lake Arakhley, Buryatiya	Kruglov, Starobogatov, 1991
9	*A. orientalis*	Lake Krugloye, basin of Zeya River, Amur R. tributary	Kruglov, Starobogatov, 1991
10	*A. hassanicus*	dead channel of Poima River, Bamburovo Settl. vicinity (Khasanskiy District, Primorskiy Krai)	Kruglov, Starobogatov, 1991
11	*A. hassanicus*	swamp near the Mel'gunovka River debouchment (Khorol'skiy District, Primorskiy Krai)	Kruglov, Starobogatov, 1991
12	*A. hassanicus*	Sirenevka River basin (small lake), Razdol'noye Settl. vicinity (Nadezhdinskiy District, Primorskiy Krai)	Prozorova, 1991
13	*A. baicalensis*	Artyomovka River, Shtykovo Settl. vicinity (Shkotovskiy District, Primorskiy Krai)	original data
14	*A. victori*	Moadi River near Arsenjevo Settl., Amur R. basin (Khabarovskiy Krai)	original data, material collected by V.V. Bogatov
15	*A. victori*	Chistovodnaya River near Vanino city, Sea of Japan drainage (Khabarovskiy Krai)	Prozorova, 1996
16	*A. orientalis*	a rivulet, connecting the Lake Kotika with Tym' River (Sakhalin Island)	Kruglov, Starobogatov, 1991
17	*A. orientalis*	Bibi River of the Abira R. system, Tomakomai city vicinity (Hokkaido Island, Japan)	Prozorova, 2010

* Six other species of the genus *Acroloxus* are known from the Russian Far East: *A. kolhymensis* Prozorova et Starobogatov, *A. regelae* Prozorova et Starobogatov, *A. likharevi*, *A. ussuriensis* Moskvicheva, Kruglov et Starobogatov, *A. zarjaensis* Kruglov et Starobogatov, *A. klucharevae* Kruglov et Starobogatov [Kruglov, Starobogatov, 1991; Prozorova, Starobogatov, 1998]. These species not found in Baikal basin are beyond the scope of this study.

the Khilok River as well (Fig. 4). Species *A. victori* is identified by L.A. Prozorova in the Shirokaya River of the Ivano-Arakhley lake-river system as well as in Amur River drainage (Moadi R., Arsenjevo Settl. vicinity) (Fig. 3, 4). Species *A. arachleicus* Kruglov et Starobogatov, 1991 was described as endemic of Lake Arakhley [Kruglov, Starobogatov, 1991]. We found, that it is the only limpet species inhabiting Arakhley. In the Shirokaya River, both *A. arachleicus* and *A. baicalensis* were collected sympatrically.

Thus, six species of the Holarctic genus *Acroloxus* have been recognized in Lake Baikal and Transbaikalia: *A. baicalensis, A. orientalis, A. arachleicus, A. hassanicus, A. victori* and *Acroloxus* sp., undescribed earlier. Species *A. victori* is new for the Baikal basin.

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Фауна и морфология раковины чашечек рода *Acroloxus* Beck (Gastropoda: Pulmonata: Acroloxidae), населяющих озеро Байкал (с замечаниями по акролоксидам Забайкалья)

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РЕЗЮМЕ. Исследована фауна чашечек голарктического рода *Acroloxus* Beck, 1837 в озере Байкал. С помощью сканирующего электронного микроскопа получены сведения о морфологии протоконха и телеоконха трех видов: *A. baicalensis* Kozhov, 1936, *A. orientalis* Kruglov et Starobogatov, 1991 и неописанного ранее *Acroloxus* sp. Для вида *A. baicalensis* приведены дополнительные конхологические признаки на основании изучения нового сбора из типового местонахождения. Обсуждается распространение видов рода *Acroloxus* в озере Байкал и его бассейне.

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