New fossils of Neogene pricklebacks (Actinopterygii: Stichaeidae) from East Asia

Новые находки неогеновых стихеевых (Actinopterygii: Stichaeidae) из Восточной Азии

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Two new findings of fossil pricklebacks (Pisces: Stichaeidae) from the Miocene deposits of Honshu Island (Japan) and Kamchatka Peninsula (Russia) are described. Both specimens are incomplete and cannot be identified below either family or subfamily level. Nevertheless, these findings suggest wide distribution of stichaeids in the North-Western Pacific during the Miocene. The specimen from the deep-sea Bessho Formation of Honshu represents the first fossil record of pricklebacks of the subfamily Lumpeninae.

Описаны две новые находки ископаемых стихеевых рыб (Pisces: Stichaeidae) из отложений миоцена острова Хонсю (Япония) и полуострова Камчатка (Россия). Оба изученных образца очень фрагментарны, и не могут быть определены ниже уровня семейства или подсемейства. Однако эти находки показывают, что семейство стихеевых рыб было широко распространено в середине миоцена в северо-западной части Тихого океана. Экземпляр из глубоководной формации Бесшо острова Хонсю является первым обнаружением подсемейства Lumpeninae в ископаемом состоянии.

Key words: fossil pricklebacks, Miocene, Russia, Japan, Actinopterygii, Stichaeidae, new finds

Ключевые слова: ископаемые стихеевые, миоцен, Россия, Япония, Actinopterygii, Stichaeidae, новые находки

INTRODUCTION

Recent pricklebacks, family Stichaeidae, are widely distributed in the coastal marine waters of the Northern Hemisphere. They are common members of littoral and near shore fish communities (Makushok, 1958), though some species occur at depths more than 200 m. Most stichaeids inhabit the North Pacific, and only few species occur in the Northern Atlantic and in the Arctic (Andriashev, 1954; Makushok, 1958; Lindberg & Krasjukova, 1975). Pricklebacks are usually small elongated fishes, characterized by long-based dorsal fin, which consists of only or, less often, mostly of spines. Together with other morphologically similar families, pricklebacks belong to the suborder Zoarcoidei assigned to either Perciformes (Nelson, 2006) or Cottiformes (Imamura & Yabe, 2002; Wiley & Johnson, 2010).

Based on a detailed morphological analysis of the Stichaeidae and closely related families, Makushok (1958) divided pricklebacks into the eight subfamilies and proposed a hypothesis on their interrelationships. Mecklenburg & Sheiko (2004) reviewed later advances in the pricklebacks

taxonomy (i.e. Makushok, 1961a, 1961b, 1973; Shiogaki, 1984; Stoddard, 1985; Miki, 1985; Yatsu, 1985, 1986; Miki et al., 1987; Follett & Powell, 1988; Follett & Anderson, 1990; Anderson, 1994; Kimura & Jiang 1995; Posner & Lavenberg, 1999) and listed six stichaeid subfamilies diagnosed by morphological characters. The results of recent phylogenetic studies based on molecuar data (Kartavtsev et al., 2009; Radchenko et al., 2009, 2010, 2012; Turanov et al., 2012; Kwun & Kim, 2013) do not support previous classifications of pricklebacks based on morphology including osteology.

The greater taxonomic diversity of recent pricklebacks in the Northern Pacific suggests that they had originated from this region. This assumption is consistent with the known pricklebacks fossil findings, which are unique to North-Western Pacific. Until recently, fossil stichaeids were found in the two localities in East Asia: Honshu Island (Japan) and Sakhalin Island (Russia) (Fig. 1). *Stichaeus matsubarai* Niino (subfamily Stichaeinae) was described from the Miocene deposits near Azuma, Gunma Prefecture, Japan (Niino, 1951; Yabumoto & Uyeno, 1994). Five species of fossil pricklebacks were found in the Middle Miocene (Serravalian) Agnevo Formation of western Sakhalin, Russia: *Ernogrammus litoralis* Gretchina, 1980, *Stichaeus brachigrammus* Nazarkin, 1998, and *Stichaeopsis sakhalinensis* Nazarkin, 1998 (Stichaeinae); *Ascoldia agnevica* Gretchina, 1980 (Opistocentrinae); and *Nivchia makushoki* Nazarkin, 1998 (Xiphisterinae) (Gretchina, 1980; Nazarkin, 1998). All mentioned Miocene pricklebacks are members of recent subfamilies. Most of fossil species belong to the recent genera, with only one genus, *Nivchia,* presently extinct.

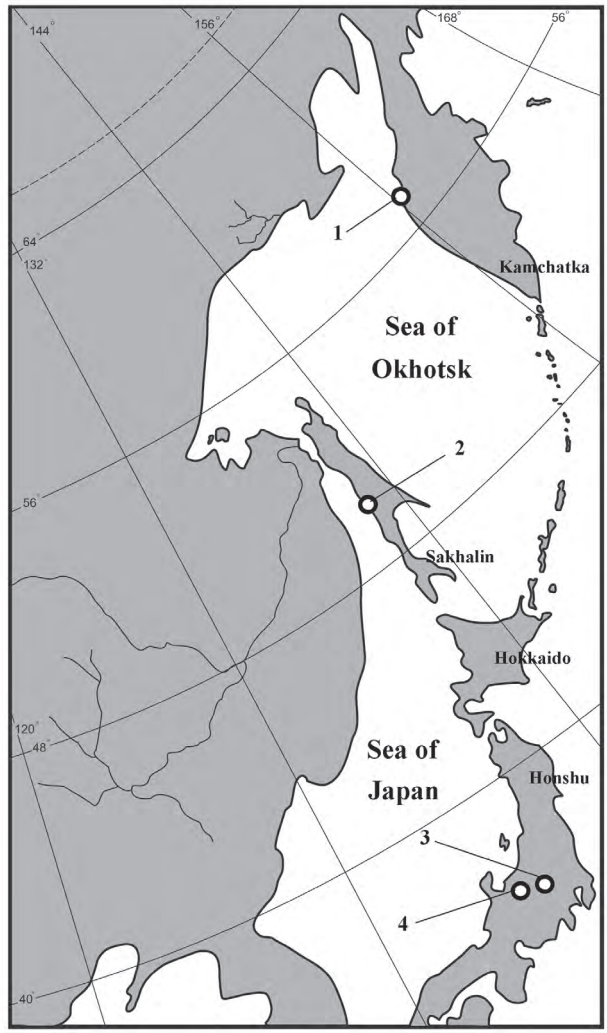

Fig. 1. Sketch map of the Sea of Japan and the Sea of Okhotsk showing localities of the Miocene pricklebacks: **1** – Kavran-Utcholok Bay; **2** – Agnevo; **3** – Azuma; **4** – Amikake.

Examination of fossil fish collections deposited in the National Museum of Nature and Science (NSMT, Tokyo, Japan) and Borisyak Paleontological Institute, Russian Academy of Sciences (PIN, Moscow, Russia) revealed two previously undescribed specimens of fossil pricklebacks from Hon-

shu Island (Japan) and Kamchatka Peninsula (Russia) (Fig. 1). Although both specimens are incomplete, they provide new important information on the distribution and diversity of Neogene stichaeids. The length of dorsal-fin spines in both specimens distinguishes them from the two closely related families also having the entirely spinous dorsal fin – gunnels (Pholidae) with a shorter dorsal-fin spines and wolffishes (Anarhichadidae) with much longer and slender dorsal-fin spines. In this paper, we describe these new findings and provide some remarks on geographical distribution of stichaeids in the Miocene.

MATERIAL, LOCALITIES AND METHODS

NSM PV 22683, a single partial skeleton of the caudal region from the black shale (mudstones) of the Bessho Formation, Honshu, Japan, is represented by the molds on the matrix with most skeletal elements preserved as whitish mineralized bones. The Bessho mudstone formation is a part of the Neogene sequence of Fossa Magna. It showed typical flysch facies (Suzuki, 1982) and yielded fossil bivalves, indicating deep-sea hydrothermal activity (Takeuchi, 2004). The Bessho Formation is well known due to the reach assemblage of fossil organisms – plants, echinoderms, bivalves and cephalopods, elasmobranchs and deep-water teleosts, birds and sea mammals – discovered in its beds (Ohe & Koike, 1988; Matsuoka et al., 1998; Kawase & Koike, 2003, 2006; Kohno et al., 2007; Koike et al., 2008a, b; Takakuwa et al., 2009; Ishida et al., 2009). The age of the Bessho Formation is defined as Early-Middle Miocene, 13–16 mya (Takeuchi, 2004).

PIN 3181/1050, a mold of the caudal part of a fish skeleton on the thin-grained sandstone without any bones remaining, from the western coast of Kamchatka, Russia, was found in an outcrop of the Etolona Formation. This formation contains alternation of conglomerates, pebbles, sandstones and aleurolites, with layers of tuffaceous sandstones, lignite and shell-rocks. It had been deposited in the comparatively shallow-water conditions (Sinelnikova et al., 1985). The remains of plants, numerous bivalves and gastropods, echinoderms, worms and sea mammals are abundant in those beds. The rich assemblage of bivalves indicates a relatively warm littoral and sublittoral environment (Sinelnikova et al., 1985). The age of this formation is defined as Middle-Late Miocene (Gladenkov, 1978; Gladenkov et al., 1986).

Osteological features of recent stichaeids were studied based on X-ray photos of the following specimens from the main ichthyological collection of the Zoological Institute, Russian Academy of Sciences (ZIN; St Petersburg, Russia): *Alectrias gallinus* (Lindberg, 1938): ZIN 52834; *Ascoldia variegata* Pavlenko, 1910: ZIN 40310, 40361; *Bryozoichthys lysimus* (Jordan et Snyder, 1902): ZIN 44739; *Chirolophis snyderi* (Taranetz, 1938): ZIN 54503; *Dictyosoma burgeri* van der Hoeven, 1855: ZIN 55128; *Lumpenella longirostris* (Evermann et Goldsborough, 1907): ZIN 53762; *Opisthocentrus ocellatus* (Tilesius, 1811): ZIN 54194; *Stichaeus punctatus* (Fabricius, 1780): ZIN 54489, 54501, 54502; *Stichaeopsis nevelskoi* (Schmidt, 1904): ZIN 52837.

Measurements were made with calipers to the nearest 0.1 mm. Drawings were based on digital photos.

DESCRIPTION

Order **PERCIFORMES**

Family **STICHAEIDAE** Gill, 1864

Subfamily **LUMPENINAE** Jordan et Evermann, 1898

Gen. et sp. indet.
(Fig. 2)

Material. NSM PV 22683, part and counterpart of the caudal region; ca. 36°27'N 138°10'E, Sakaki Town, Amikake, Oami, Nagano Prefecture, Honshu, **Japan**; Bessho Formation, Early-Middle Miocene.

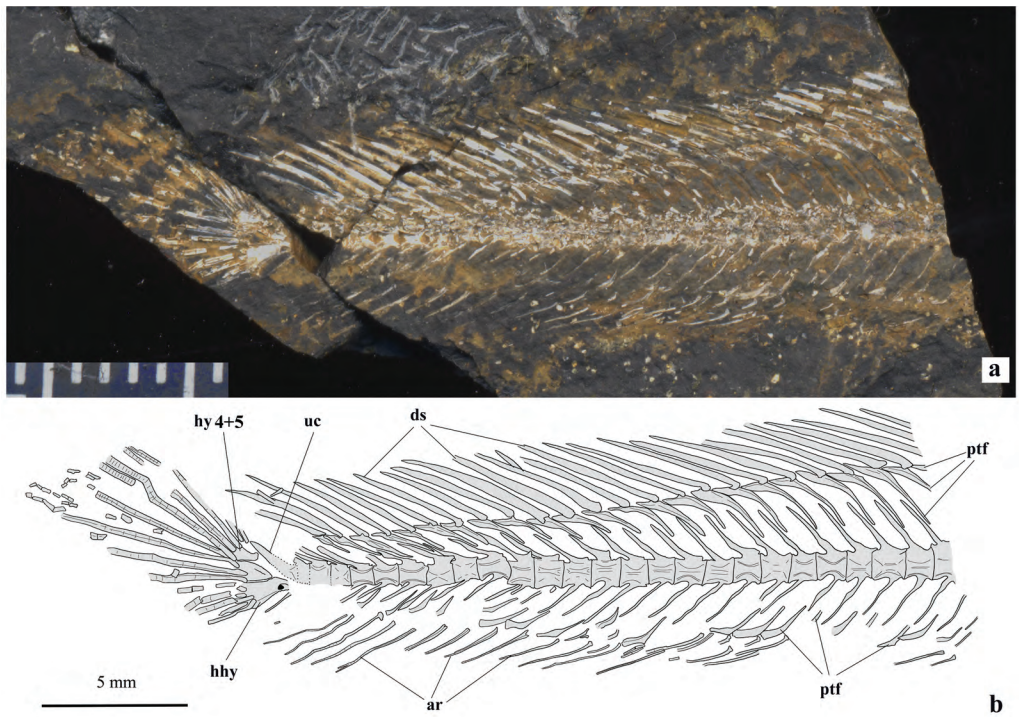

Fig. 2. Lumpeninae gen., sp. indet., specimen NSM PV 22683, photo **(a)** and outline drawing **(b)** based on part and counterpart: **ar**, anal rays; **ds**, dorsal fin spines; **hhy**, hypaxial hypural; **hy 4+5**, fused hypural 4+5; **ptf**, pterigiophores; **uc**, utostylar center.

Description. The fossil represents an incomplete caudal portion of the skeleton including posterior parts of the dorsal and anal fins, and a partially preserved caudal fin with its skeleton. Most of the elements are articulated in a natural position. The length of the fossil to the posterior edge of hypurals is 25.2 mm and the greatest body depth is 8.0 mm.

There are 26 preserved caudal vertebrae, including the urostylar one (the second preural centrum is completely lost). The vertebral centra are rectangular, longer than high, symmetrical. The neural and haemal spines are relatively long and slender, slightly curved backward. Tips of the neural spines located posterior to the dorsal-fin base are slightly expanded.

Twenty six spines and 24 pterygiophores are preserved in the dorsal fin. Generally, a single pterygiophore is placed in each interneural space, but the 1:1 ratio is not observed above the preural centra 10–12 as a result of fossilisation. Proximally, the pterygiophores are deeply placed in the interneural spaces, and overcome with neural spines on 1/3–1/2 of their length. The posteriormost dorsal pterygiophore is located between the neural spines of the preural centra 5 and 6. The dorsal spines are almost equal in their thickness and height, but the posteriormost one appears to be slightly shorter. The greatest spine height 1.8 times exceeds the caudal-peduncle depth measured between bases of the posteriormost dorsal- and anal-fin rays. The posterior dorsal pterygiophore supports only one spine.

The anal fin is more damaged than the dorsal one. There are 20 anal-fin soft rays and approximately 22 pterygiophores preserved. Apparently, most of the pterigiophores and rays are displaced, and their real position had been changed. The greatest height of the anal fin rays is 1.3 times great-

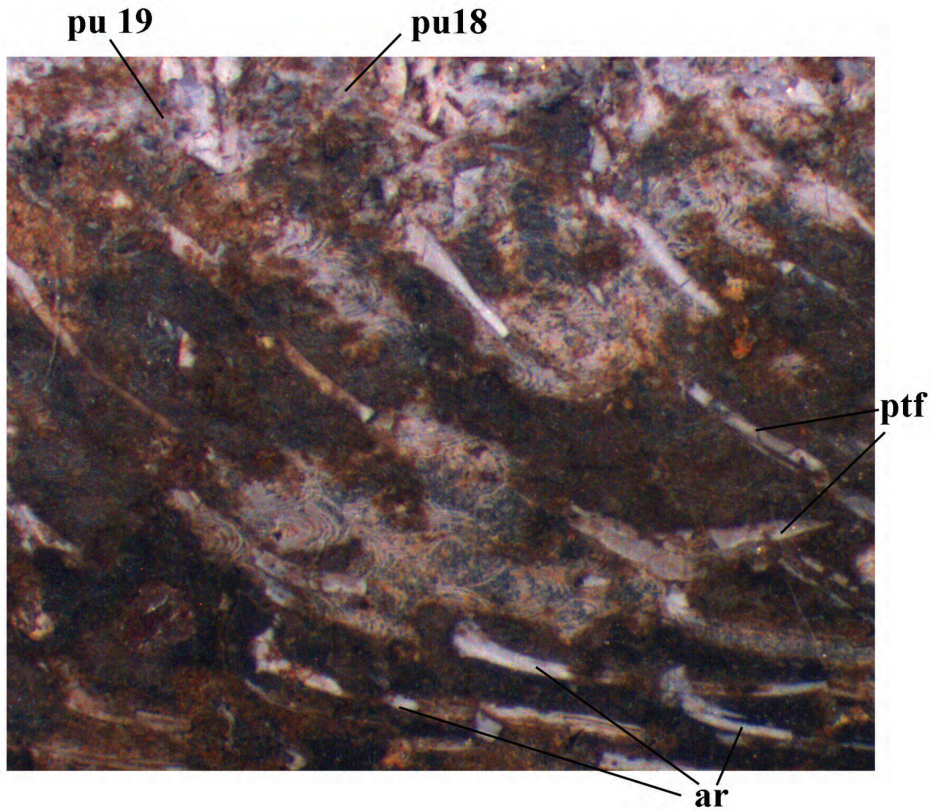

Fig. 3. Lumpeninae gen., sp. indet., specimen NSM PV 22683, fragment of scale cover of counterpart: **pu**, preural centrae and as in Fig. 2.

er than the caudal peduncle depth. All the anal-fin rays are segmented and, apparently, not branched.

The caudal fin with at least 12 branched principal rays. Bases of two dorsal procurrent rays are seen in the upper lobe. Distal part of the urostylar vertebra and a free hypaxial hypural plate, bearing the opening of the caudal vein, are discernible. The epaxial lobe was destroyed, but it can be assumed that there were two free epaxial hypurals – hypurals 3 and 4+5 – in its structure.

The entire body and the base of the anal fin are densely covered with elongated overlapped cycloid scales (Fig. 3).

Measurements (in mm): total length of the fossil 32.9; length of the fossil to the posterior edge of hypurals 25.2; length of 10 vertebrae (pu3–pu13) 8.0; greatest dorsal fin depth 5.4; greatest anal fin depth 4.0; caudal fin length 8.6; caudal peduncle depth (measured between bases of posteriormost rays of dorsal and anal fins) 3.0.

Comparative remarks. Incompleteness of this fossil does not allow its identification to the species or genus. Nevertheless, it possesses some key characters, usually used in the stichaeid taxonomy. The most important of them are the absence of the serial ray on the posteriormost dorsal pterygiophore, equal thickness of the dorsal spines, and the presence of dense scale cover on the body. Combination of these characters is unique for the fishes of the recent subfamily Lumpeninae (Makushok, 1958). Among pricklebacks, representatives of the subfamily Lumpeninae are the most deep-water dwellers (Makushok, 1958). Thus, it is not surprising that the species of this subfamily was a part of the deep-water fish commu-

nity of the Bessho Formation. The standard length of this fish, estimated by proportions in the recent *Lumpenella longirostris* Evermann et Goldsborough, was about 117 mm.

Family **STICHAEIDAE** Gill, 1864

Gen. et sp. indet.
(Fig. 4)

Material. PIN 3181/1050, mold of caudal part of skeleton; coastal cliff 2 km north from the Kheysliveyem River mouth, Kavran-Utcholok Bay, western Kamchatka, **Russia**, ca. 57°24′N, 156°59′E; Etolona Formation, Middle-Late Miocene; coll. A.R. Geptner.

Description. The specimen contains seventeen caudal vertebrae (including the urostylar one) and associated pterygiophores and rays of the unpaired fins. The vertebrae are symmetrical, moderately elongated; the length of a vertebra exceeds its depth by a factor of 1.3. Preural vertebrae 2 and 3 are shorter, with their depth greater than the length. The neural and haemal spines are relatively elongate and slender.

Apparently, a single dorsal- or anal-fin pterygiophore is associated with each interneural or interhaemal space, but this arrangement was destroyed due to the fossilization. Thirteen spines and 12 pterygi-

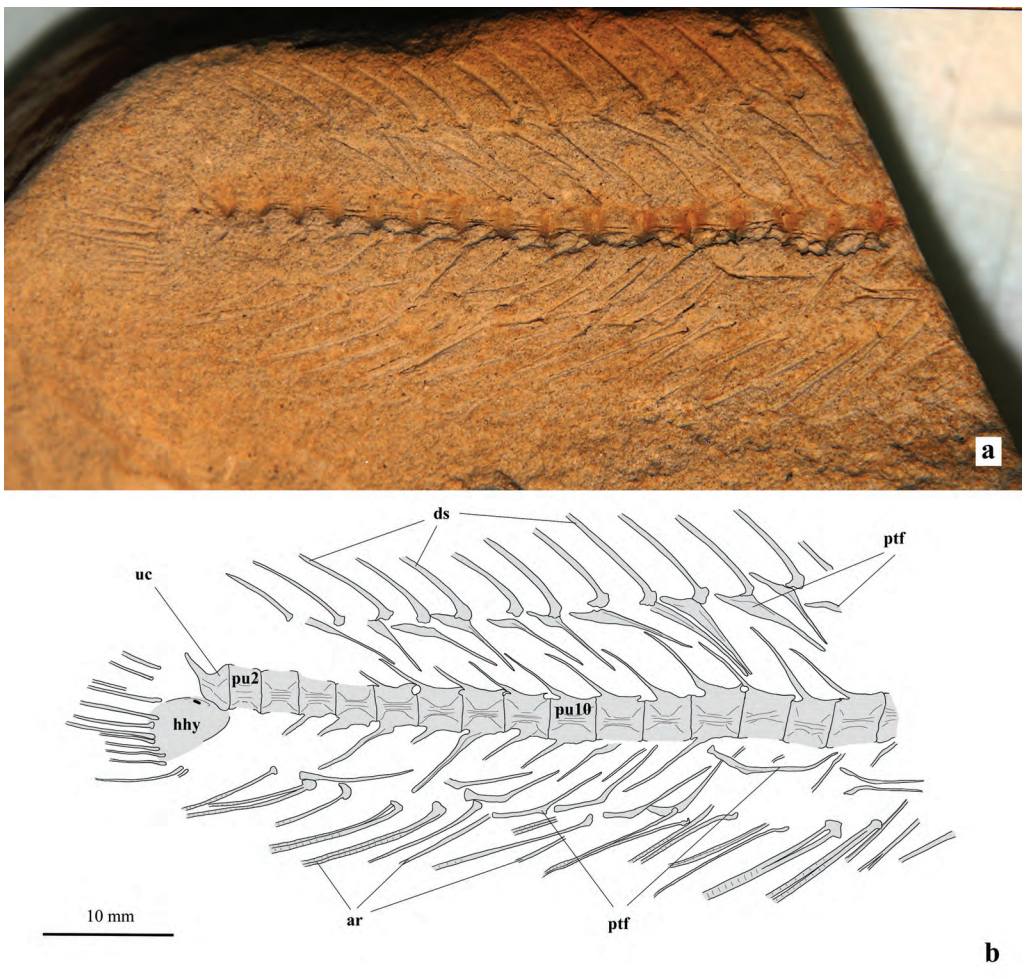

Fig. 4. Stichaeidae gen., sp. indet., specimen PIN 3181/1050, photo **(a)** and outline drawing **(b)**; abbreviations as in Fig. 2.

ophores are seen in the dorsal fin. The pterygiophores are comparatively long and deeply set in the interneural spaces–sometimes they almost reach the bases of the neural spines. Posterior pterygiophores of the dorsal and anal fins are inserted behind the 8th preural vertebrae. The posterior dorsal pterygiophore supports two spines. Dorsal-fin spines are stout, comparatively long; their greatest length is slightly shorter than the caudal-peduncle depth. There is no noticeable intergradation of thickness of the dorsal-fin spines in the posterior direction.

Only at least 8 anal-fin pterygiophores (slim, elongated and deeply set in the interhaemal spaces) and 17 segmented and, apparently, branched anal fin rays are preserved.

The caudal fin and its skeleton are severely destroyed. At least 11 principal rays (7 in the lower lobe) are preserved. Two procurrent rays are visible ventrally. The urostylar centrum is short. Hypurals of the upper lobe are not preserved. In the lower lobe there is a single hypural plate.

Measurements (in mm): total length of the fossil 71; length of the fossil to the posterior edge of hypurals 56.1; length of 10 vertebrae (pu3-pu13) 33.3; greatest dorsal fin depth 10.5; greatest anal fin depth 12.0; caudal peduncle depth (measured between bases of posteriormost rays of dorsal and anal fins) 11.7; greatest body depth 18.4.

Comparative remarks. Based on the morphological characters preserved on this mold, it is impossible to identify this fish below the family level. Presence of two spines on the postriormost dorsal-fin pterygiophore places this fossil outside of the subfamily Lumpeninae. On the other hand, this Miocene fish had a long caudal peduncle with 8 vertebrae posterior to dorsal fin (free caudal vertebrae of Makushok, 1958, p. 25), which exceeds the limits known for pricklebacks. Among recent stichaeids, only representatives of the subfamily Lumpeninae have a long caudal peduncle with 4–7 free caudal vertebrae (Makushok, 1958, Appendix 2, p. 120–121), a character state somewhat similar to the fossil specimen.

The size of the fossil, especially deep caudal peduncle, suggests a comparatively large fish. Examination of the comparative materials of extant pricklebacks shows that the relation of standard length (SL) to the caudal peduncle depth fluctuates from 13.3 in *Ascoldia variegata* to 38.9 in *Lumpenella longirostris*. Therefore, the fossil fish from Miocene of Kamchatka might have been 155 to 455 mm SL.

DISCUSSION

The remains of the Miocene stichaeids, described in this article, add new information on the Neogene stage of development of this family. Fossil representatives of three pricklebacks subfamilies have been known earlier: Stichaeinae, Xiphysterinae, Opistocentrinae (Niino, 1951; Gretchina, 1980; Nazarkin, 1998). The present study expands this list to the four subfamilies. Thus, four out of six extant prickleback subfamilies are confirmed from the Neogene fossils. It supports the assumption of an early origin of the family, and existence of its modern taxonomic structure from as early as the middle of the Miocene.

The locations of our findings mark the northern- and southernmost range of fossil stichaeids, expanding the known Neogene distribution of this family from Honshu to Kamchatka, approximately by 21 degree of latitude. The greatest diversity of the Miocene pricklebacks is found on the islands of Japan Sea basin. Apparently, this region played an important role in the speciation and evolution of this group of fishes.

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