

Salmincola markewitschi (Copepoda: Lernaeopodidae) Parasitic on Whitespotted Char, *Salvelinus leucomaenis*, in a Mountain Stream of Honshu Island, Central Japan

Kazuya Nagasawa^{1,2}

¹ Graduate School of Integrated Sciences for Life, Hiroshima University,
1-4-4 Kagamiyama, Higashi-Hiroshima, Hiroshima 739-8528, Japan
E-mail: ornatus@hiroshima-u.ac.jp

² Present address: Aquaparasitology Laboratory; 365-61 Kusanagi, Shizuoka 424-0886, Japan

(Received 13 August 2020; Accepted 14 October 2020)

Females of the lernaeopodid copepod *Salmincola markewitschi* Shedko and Shedko, 2002 were collected from the buccal cavity of whitespotted char, *Salvelinus leucomaenis* (Pallas, 1814), in a mountain stream of Nagano Prefecture, Honshu Island, the largest main island of Japan. The females are described as the first record of *S. markewitschi* from Honshu Island, because the species has so far been reported from the Russian Far East and the southern Kuril Islands east of Hokkaido Island, Japan. The copepod previously reported as *Salmincola californiensis* (Dana, 1852) from the same host species from the same stream and a nearby hatchery is herein regarded as *S. markewitschi*. As the species closely resembles *Salmincola carpio-nis* (Krøyer, 1837), it is desirable to re-identify the copepod specimens reported before as *S. carpio-nis* from Japanese salmonids, especially *Salvelinus* spp. Contraction of the formalin-fixed and preserved specimens, especially their second maxillae, of *S. markewitschi* is discussed. Information on the known hosts and distribution records of *S. markewitschi* is also compiled.

Key Words: Parasitic copepod, freshwater fish parasite, new locality record.

Introduction

Copepods of the lernaeopodid genus *Salmincola* C. B. Wilson, 1915 are parasites of freshwater fishes, mainly members of the family Salmonidae and related families, in the Northern Hemisphere (Kabata 1969, 1979). Currently, the genus contains 22 valid species (Walter and Boxshall 2018). Of these species, *Salmincola californiensis* (Dana, 1852) parasitizes mainly Pacific salmon (the genus *Oncorhynchus* Suckley, 1861) in the U.S.A. (e.g., Kabata 1969; Hoffman 1999; Ruiz *et al.* 2017), Canada (Kabata 1969, 1988), the Russian Far East [Gussev 1951, reported as *Salmincola falculata* (C. B. Wilson, 1908); Shedko *et al.* 2005b; Sokolov *et al.* 2012] and Japan (Hoshina and Suenaga 1954, reported as *Salmincola yamame* Hoshina and Suenaga, 1954; Kabata 1969; Hoshina and Nishimura 1976; Nagasawa and Urawa 2002; Nagasawa *et al.* 2018). The host species of *Oncorhynchus* reported from Far East Asia (Russia and Japan) are: pink salmon, *Oncorhynchus gorbuscha* (Walbaum, 1792) (Gussev 1951; Shedko *et al.* 2005b); coho salmon, *Oncorhynchus kisutch* (Walbaum, 1792) (Shedko 2005); sockeye salmon, *Oncorhynchus nerka* (Walbaum, 1792) (Gussev 1951); masu salmon, *Oncorhynchus masou masou* (Brevoort, 1856) (Gussev 1951, reported as *O. masu*; Hoshina and Nishimura 1976, reported as *O. masou*; Nagasawa and Urawa 2002, reported as *O. masou*; Shedko *et al.* 2005b, reported as *O. masou*; Sokolov *et al.* 2012); amago salmon, *Oncorhynchus masou ishikawae* Jordan and McGregor, 1925 (Hoshina and Suenaga 1954, reported as *O. masou*;

Nagasawa *et al.* 2018); rainbow trout, *Oncorhynchus mykiss* (Walbaum, 1792) (Shedko 2005); and chinook salmon, *Oncorhynchus tshawytscha* (Walbaum, 1792) (Shedko 2005).

Nonetheless, there are two reports of “*Salmincola californiensis*” from whitespotted char, *Salvelinus leucomaenis* (Pallas, 1814), from central Honshu Island, Japan (Nishimura and Hoshina 1977; Denda and Ogawa 2011). Nishimura and Hoshina (1977) collected “*S. californiensis*” from whitespotted char [reported as *Salvelinus leucomaenis pluvius* (Hilgendorf, 1876)] reared at a hatchery in Nagano Prefecture. The infected fish had been transported live from a nearby mountain stream, the Zako River, a tributary of the upper Nakatsu River, to the hatchery. Later, Denda and Ogawa (2011) actually collected “*S. californiensis*” from whitespotted char in the Zako River and adjacent streams. Although *S. californiensis* was rarely recorded from chars (the genus *Salvelinus* Richardson, 1836) (Gussev 1951; Kabata 1988; Hoffman 1999), this parasite almost exclusively infects *Oncorhynchus* spp. (Kabata 1969). Thus, the records of “*S. californiensis*” from whitespotted char in central Honshu Island are regarded as unusual.

I had the opportunity to examine specimens of the copepod collected from whitespotted char in the Zako River and identified them not as *S. californiensis* but as *Salmincola markewitschi* Shedko and Shedko, 2002. The latter species has so far been reported from the Russian Far East and the southern Kuril Islands east of Hokkaido Island, Japan (Shedko and Shedko 2002; Shedko *et al.* 2005a, b; Sokolov *et al.* 2012). Thus, the present collection represents the first record of *S. markewitschi* from Honshu Island, the largest

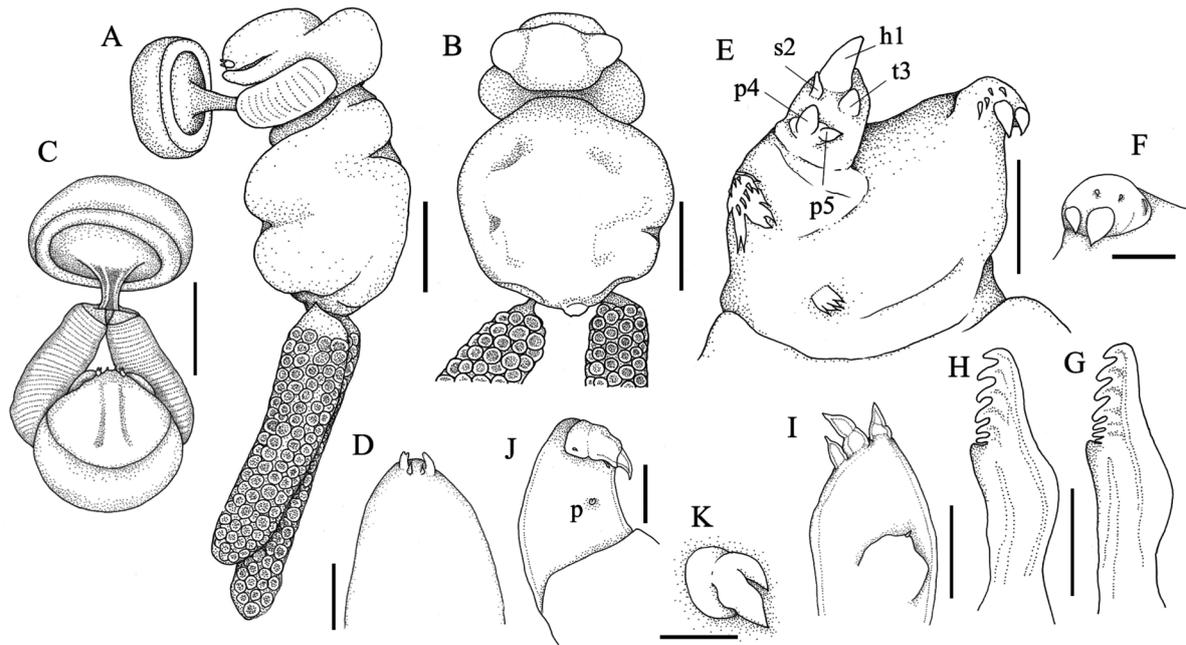


Fig. 1. *Salmincola markewitschi*, female, NSMT-Cr 28337, from whitespotted char, *Salvelinus leucomaenis*, from the Zako River, a tributary of the upper Nakatsu River, Nagano Prefecture, central Honshu Island, Japan. A, habitus, lateral view; B, habitus, dorsal view; C, cephalothorax, second maxillae and bulla, anterior view; D, first antenna, dorsal view; E, second antenna, anterolateral view; F, exopod of second antenna, lateral view; G, H, mandibles, lateral view; I, first maxilla, lateral view; J, maxilliped, dorsolateral view; K, maxilliped, palp, dorsolateral view. Abbreviations: h1, hook 1; p, palp; p4, process 4; p5, process 5; s2, spine 2; t3, tubercle 3. Scale bars: A–C, 1 mm; D, 20 μ m; E, 50 μ m; F–H, 20 μ m; I, 30 μ m; J, 100 μ m; K, 20 μ m.

main island of Japan. This paper describes *S. markewitschi* using the specimens collected and, as the previous reports of the species were all published in Russian, summarizes information on its known hosts and distribution records.

Materials and Methods

Two whitespotted char were collected using hook and line by a member of the Shiga Kogen Fisheries Cooperative Association on 17 July 2007 in the Zako River, a tributary of the upper Nakatsu River of the Shinano River system, near its junction with the Mansui River (at 1180 m altitude, 36°49'29"N, 138°32'46"E), Yamanouchi, Nagano Prefecture, central Honshu Island, Japan. The Zako River population of whitespotted char has been strictly conserved without the introduction of any fish from other locations (Nakamura and Iida 2009). Fish were fixed in 10% formalin immediately after capture. In February 2011, the fish were transferred into 70% ethanol, by the staff of the Nagano Prefectural Fisheries Experimental Station, and sent to the laboratory of Hiroshima University, Hiroshima Prefecture, where they were measured for standard length (SL, mm) and examined for the presence of parasitic copepods. When copepods were found, they were carefully removed and preserved in 70% ethanol after their attachment sites were recorded. Subsequently, at the Aquaparasitology Laboratory, Shizuoka Prefecture, the copepods were morphologically examined using an Olympus SZX10 stereo microscope and

an Olympus BX51 compound microscope. One specimen was soaked in lactophenol for 2–3 h, and dissected and observed using the hanging-drop method devised by Humes and Gooding (1964). All drawings were made with the aid of drawing tubes fitted on the stereo microscope (for the habitus, cephalothorax, and bulla) and the compound microscope (for the first and second antennae, mandible, first maxilla, and maxilliped). Morphological terminology follows Kabata (1979) and that for the armature of the endopod of the second antenna is based on Kabata (1969). Copepod voucher specimens have been deposited in the Crustacea collection of the National Museum of Nature and Science, Tsukuba, Ibaraki Prefecture (NSMT-Cr), and the remaining specimens are retained by the author at the Aquaparasitology Laboratory for a taxonomic study of *Salmincola* spp. from freshwater salmonids of Japan. Prevalence and intensity follow the definitions of Bush *et al.* (1997). The scientific and common names of fishes mentioned in this paper conform to FishBase (Froese and Pauly 2019), except for those of southern Asian Dolly Varden, *Salvelinus malma krascheninnikova* Taranetz, 1933, which are based on Nagasawa (2020). The scientific names of two subspecies of *O. masou* follow Nakabo (2013).

Results

Salmincola markewitschi Shedko and Shedko, 2002

[New Japanese name: Miyama-nagakubi-mushi]

(Fig. 1)

Salmincola markewitschi Shedko and Shedko, 2002: 147–152, figs 3–4 [original description; type locality: a river flowing into Bol'shoje Lake, Shumshu Island, northern Kuril Islands, Russia; Bol'shoje Lake, Shantar Islands, Russia; Severnyi Bay, Piltun Bay, Sakhalin Island, Russia; Samarga River, Edinka River, Primorye, Russia; Pioneer River (lower reaches of "Rausu-gawa" in Japanese), Kuibyshev Bay ("Rubetsu-wan" in Japanese), Iturup Island, southern Kuril Islands, Japan; a nameless creek 17 km away from the southwest of Yuzhno-Krilsk to Golovnino ("Furukamappu" and "Tomari" in Japanese), Petrova River (a river flowing at "Chikappunai" in Japanese), Kunashir Island, southern Kuril Islands, Japan]; Shedko 2005 (Raduga River, Azabach'e Lake, Neftebasovskoe Lake, Azabach'ya River, lower reaches of Kamchatka River, Kamchatka Peninsula, Russia); Shedko *et al.* 2005a (Yama River, Ola River, Taui River, Motyklei Bay, Magadan Region, Russia); Shedko *et al.* 2005b (Severnyi Bay, Tunaycha Lake, Uanga River, Monchigar Lake, Odoptu Bay, Maloe Chibisanskoe Lake, Uglegorka River, Val River, Nala River, Vavayskie Lakes, Pilvo River, Sakhalin Island, Russia; Kamchatka River, Kamchatka Peninsula, Russia; Yama River, Ola River, Taui River, Magadan Region, Russia; Shikotan Island, southern Kuril Islands, Japan); Sokolov *et al.* 2012 [Bol'shoy Goromai River, Tomi River, Bol'shaya Veni River, Aniva Bay, Muzma River, Langry River, Chingai River (mouth), Sakhalin Island, Russia].

Salmincola californiensis: Nishimura and Hoshina 1977: 67–70, fig. 1 (hatchery, Koakasawa, Nagano Prefecture, Japan); Denda and Ogawa 2011: 12 (Zako River and adjacent streams, Nagano Prefecture, Japan).

Material examined. Nine specimens: NSMT-Cr 28337, five specimens, intact, one vial; Aquaparasitology Laboratory, three specimens, intact, one vial; one specimen, dissected, one slide.

Description of adult female. Cephalothorax (Fig. 1A–C) oval with dorsal prominence, shorter than trunk, and separated from trunk by short constriction. Ratio of bulla diameter to cephalothorax length (including dorsal prominence) 0.72–1.13 (mean=0.90, $n=6$). Trunk (Fig. 1A, B) roughly ovoid with rounded lateral margins and genital process at posterior extremity; shallow transverse groove on ventral side, 2.0–2.5 (2.3) mm long ($n=6$) and 2.0–2.5 (2.2) mm wide ($n=6$). Total body length (excluding egg sacs) 2.6–3.6 (3.3) mm ($n=6$).

First antenna (Fig. 1D) short with at least two setae and two tubercles at apex. Second antenna (Fig. 1E, F) biramous with small spiny pad on sympod; exopod slightly bulbous, one-segmented with two papillae and three or four small

spines on tip; endopod two-segmented; basal segment with larger spiny pad on ventral surface; distal segment with apical armature consisting of powerful hook 1 arising from dorsal side, small spine 2 and tubercle 3 near base of spine 1, and conical process 4 and small process 5 slightly separated from spine 2 and tubercle 3. Mandible (Fig. 1G, H) short and unsegmented with six or seven teeth ($n=2$) on dentiferous margin; first four distal teeth larger than next one or two teeth; proximal tooth smallest. First maxilla (Fig. 1I) with three terminal papillae on endopod; ventral papilla shorter than other two; exopod represented by lateral swelling with small setule on tip. Second maxilla (Fig. 1A, B) short and thick, originating from lateral side of necklike part, where cephalothorax joins with trunk. Bulla (Fig. 1A, C) mushroom-shaped with long manubrium. Maxilliped (Fig. 1J, K) positioned in ventrolateral region of cephalothorax, tapering to its tip; corpus robust with palp of two outgrowths; subchela short with small seta near base, ending in hooked claw; barb present at base of claw.

Host. Whitespotted char, *Salvelinus leucomaenis* (Salmoniformes: Salmonidae).

Locality. Zako River, a tributary of the upper Nakatsu River of the Shinano River system, Yamanouchi, Nagano Prefecture, central Honshu Island, Japan.

Prevalence and intensity. The two fish examined (188 and 208 mm SL) were infected each by three and six copepods.

Attachment site. Buccal cavity. All copepods ($n=9$) were found in the buccal cavity of the fish. Six and three copepods were found attached to the bottom and roof of the buccal cavity, respectively.

Remarks. The copepod specimens from whitespotted char from central Honshu Island are identical to the morphology of *S. markewitschi* described by Shedko and Shedko (2002). In particular, the species is characterized by three to five small spines on the tip of the exopod of the second antenna, two outgrowths of the palp on the corpus of the maxilliped, and the ratio of the bulla diameter to the cephalothorax length [0.74–1.17 (0.91)] (Shedko and Shedko 2002). The specimens examined in this study have three or four small spines on the exopod of the second antenna (Fig. 1E, F) and the maxilliped palp has two outgrowths (Fig. 1K). The specimens also show a similar ratio of the bulla diameter to the cephalothorax length [0.72–1.13 (0.90)]. Thus, there is no significant difference in the morphology of *S. markewitschi* and the specimens examined in this study.

The specimens resemble *S. carpionis* reported by Kabata (1969) but are differentiated by the following characters of *S. carpionis* (Kabata 1969; Shedko and Shedko 2002): no spination or minute specks on the tip of the exopod of the second antenna; a single outgrowth of the maxilliped palp; and a lower ratio of the bulla diameter to the cephalothorax length [0.34–0.80 (0.56)].

The general appearance of the specimens reported as "*Salmincola californiensis*" by Nishimura and Hoshina (1977) from whitespotted char from a hatchery near the Zako River is very similar to that of the specimens collected in the present study. Although the former specimens had

mandibles with 7 or 8 teeth (*vs.* 6 or 7 teeth in the present specimens), they were characterized by a mushroom-shaped bulla almost as long as the cephalothorax and the presence of two papillae and some small spines on the tip of the exopod of the second antenna. These morphological features correspond to those of *S. markewitschi* (Shedko and Shedko 2002), but not to those of *S. californiensis*, which has two papillae and a cluster of very strong and large spines on the tip of the exopod of the second antenna (Kabata 1969). The latter species also has a large palp on the corpus of the maxilliped (Hoshina and Suenaga 1954; Hoshina and Nishimura 1976), but the present specimens have no such large palp. Thus, it is reasonable to herein regard the specimens reported by Nishimura and Hoshina (1977) as *S. markewitschi*. Unfortunately, there is no information about deposition of their specimens, which may have been lost.

The copepod specimens examined in the present study had been preserved in 10% formalin for more than three years after collection and then were transferred into 70% ethanol. When the specimens were examined for identification, they were found slightly contracted. In particular, the second maxillae of the specimens were short and thick (Fig. 1A, B), which was most probably affected by the fixation and preservation in formalin. Like in the present study, Nishimura and Hoshina (1977) also showed short and thick second maxillae in the formalin-preserved specimens of "*Salmincola californiensis*" from whitespotted char. As illustrated by Kabata (1969: figs 53, 55, 57, 59, 61), the second maxillae of relaxed and contracted specimens of *S. californiensis* are extremely different in length (long *vs.* short) and shape (thin *vs.* thick), respectively. Kabata (1969) stated that the second maxilla has no value as a diagnostic feature in identification of *Salmincola* spp., but it is better to examine the appearance of relaxed specimens of *S. markewitschi* as well, because the members of the genus usually show considerable intraspecific variations in appearance and size (Kabata 1969) and we have poor knowledge of the morphology of the Japanese species of the genus.

Salmincola markewitschi was originally described using specimens from the buccal cavity of whitespotted char from Shumshu Island, one of the northern Kuril Islands, the Russian Far East (Shedko and Shedko 2002). The species has been reported from the Kamchatka Peninsula, Magadan Region, the Shantar Islands, Sakhalin Island, and Primorye, the Russian Far East, and also from the southern Kuril Islands, Japan (Fig. 2, for detailed collection localities, see the above synonym list; Shedko and Shedko 2002; Shedko 2005; Shedko *et al.* 2005a, b; Sokolov *et al.* 2012). These distribution records show that *S. markewitschi* is definitely a subarctic species. The present paper expands the southernmost distribution range of *S. markewitschi* from Shikotan Inland, the southern Kuril Islands, to the Zako River and adjacent streams, Nagano Prefecture, central Honshu Island (Nishimura and Hoshima 1977; Denda and Ogawa 2011; this paper).

Nagano Prefecture is located in the temperate region, and the collection sites are at altitudes of *ca.* 1230–1600 m (Denda and Ogawa 2011) and 1180 m (this paper) in a

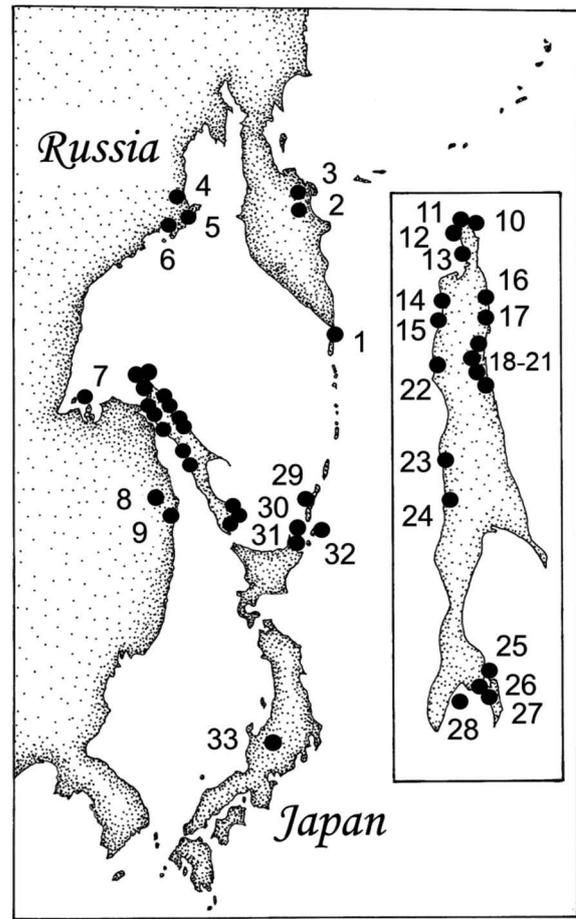


Fig. 2. Collection localities of *Salmincola markewitschi* in the Russian Far East and Japan, East Asia (Inset map: Sakhalin Island). Localities 1–28 and 29–33 are in the Russian Far East (Shedko and Shedko 2002; Shedko 2005; Shedko *et al.* 2005a, b; Sokolov *et al.* 2012) and Japan (Shedko and Shedko 2002; Shedko *et al.* 2005b; this paper), respectively. 1, a river flowing into Bol'shoie Lake, Shumshu Island, northern Kuril Islands (type locality); 2, Raduga River, Azabachè Lake, Neftebasovskoe Lake, Azabach'ya River, Kamchatka Peninsula; 3, lower reaches of Kamchatka River, Kamchatka Peninsula; 4, Yama River, Magadan Region; 5, Ola River, Magadan Region; 6, Taiui River and Motyklei Bay, Magadan Region; 7, Bol'shoie Lake, Shantar Islands; 8, Samarga River, Primorye; 9, Edinka River, Primorye; 10, Nala River, Sakhalin Island; 11, Severnyi Bay, Sakhalin Island; 12, Monchigar Lake, Sakhalin Island; 13, Muzma River, Sakhalin Island; 14, Langry River, Sakhalin Island; 15, Chingai River (mouth), Sakhalin Island; 16, Odoptu Bay, Sakhalin Island; 17, Piltun Bay, Sakhalin Island; 18, Bol'shoy Goromai River, Sakhalin Island; 19, Val River, Sakhalin Island; 20, Tomi River, Sakhalin Island; 21, Bol'shaya Veni River, Sakhalin Island; 22, Uanga River, Sakhalin Island; 23, Pilvo River, Sakhalin Island; 24, Uglegorka River, Sakhalin Island; 25, Tunaycha Lake, Sakhalin Island; 26, Maloe Chibisanskoe Lake, Sakhalin Island; 27, Vavayskie Lakes, Sakhalin Island; 28, Aniva Bay, Sakhalin Island; 29, Pioneer River (lower reaches of "Rausu-gawa" in Japanese), Kuibyshev Bay ("Rubetsu-wan" in Japanese), Iturup Island, southern Kuril Islands; 30, Petrova River (a river flowing at "Chikappunai" in Japanese), Kunashir Island, southern Kuril Islands; 31, a nameless creek 17 km away from the southwest of Yuzhno-Krilsk to Golovnino ("Furukamappu" and "Tomari" in Japanese), Kunashir Island, southern Kuril Islands; 32, Shikotan Island, southern Kuril Islands; 33, hatchery at Koakasawa, Zako River and adjacent streams, Nagano Prefecture, Honshu Island.

deep-mountain area and covered with much snow during the winter. Thus, these subarctic-like climatic conditions at high altitudes enable both the subarctic fish host (whitespotted char) and its ectoparasite (*S. markewitschi*) to survive and maintain their populations in the temperate region.

Several species of *Salmincola*, e.g., *Salmincola salmoneus* (Linnaeus, 1758) (Friend 1942; Kusterle *et al.* 2012, 2013) and *Salmincola edwardsii* (Olsson, 1869) (Black *et al.* 1983; Shedko and Shedko 2002), are known to be euryhaline parasites: these species infect their hosts in fresh waters but can survive during the host's ocean migration and return to fresh waters with the hosts. *Salmincola markewitschi* is also found on whitespotted char in coastal bays of the Russian Far East and the southern Kuril Islands, Japan (Shedko and Shedko 2002; Shedko *et al.* 2005a, b, see the above synonym list for the names and locations of the bays), suggesting that this parasite is also euryhaline. Sea-migrating whitespotted char have been reported from coastal marine waters of Hokkaido and northern Honshu islands (Arai *et al.* 2005; Morita *et al.* 2013). In particular, Hokkaido Island is close to Sakhalin Island and the southern Kuril Islands. Thus, *S. markewitschi* is likely to be found on such whitespotted char in the coastal sea of Hokkaido Island. Moreover, since whitespotted char widely occurs in fresh waters of Hokkaido Island (Fausch *et al.* 1994; Takegawa *et al.* 2017) and mountain streams of Honshu Island (Takegawa *et al.* 2017), it is necessary to examine whitespotted char from inland waters of these islands for the presence of *S. markewitschi* for clarifying the geographical distribution of the species in Japan (see also the Discussion section below).

The known hosts of *Salmincola markewitschi* are: whitespotted char, *Salvelinus leucomaenis* (type host), in the Russian Far East (Shedko and Shedko 2002; Shedko 2005; Shedko *et al.* 2005a, b; Sokolov *et al.* 2012) and Japan (Nishimura and Hoshina 1977; Shedko and Shedko 2002; Denda and Ogawa 2011; this paper); southern Asian Dolly Varden, *Salvelinus malma krascheninnikova*, on Sakhalin Island, the Russian Far East [reported as *Salvelinus curilus* (Pallas, 1814), Shedko *et al.* 2005b]; and Japanese huchen, *Parahucho perryi* (Brevoort, 1856), on Sakhalin Island, the Russian Far East (Shedko *et al.* 2005b). Of these hosts, whitespotted char is most commonly infected by *Salmincola markewitschi*, with its prevalence and intensity ranging from 38–62% and being up to 29 copepods, respectively, on Sakhalin Island (Shedko *et al.* 2005b). Infection of the two other salmonids by *S. markewitschi* is very rare (Shedko *et al.* 2005b).

According to Shedko and Shedko (2002), *S. markewitschi* is specific to whitespotted char, whereas a morphologically similar species, *Salmincola carpionis* (Krøyer, 1837), to southern Asian Dolly Varden (reported as *Salvelinus malma*). As stated above, southern Asian Dolly Varden and Japanese huchen are also known to harbor *S. markewitschi*, but these salmonids are not important hosts (Shedko *et al.* 2005b). The host specificity of *S. markewitschi* and *S. carpionis* each to whitespotted char and southern Asian Dolly Varden has been supported by Sokolov *et al.* (2012). Kabata (1969; 2998) reported *S. carpionis* from "*Salvelinus leuco-*

maenis" from "South Sakhalin" but, based on an examination of the specimens at the Zoological Institute, St. Petersburg, Shedko *et al.* (2005b) stated that those specimens were actually collected on Shikotan Island, not from "*Salvelinus leucomaenis*"; but probably from southern Asian Dolly Varden (as *Salvelinus curilus*).

The attachment site of females of *S. markewitschi* on host fish is the buccal cavity (Shedko and Shedko 2002), where they are more abundant on the bottom of the mouth than the roof. A similar result was also obtained in the present study.

Japanese name. The species is a lernaeopodid copepod parasitic on Japanese char in deep mountain streams, and the new Japanese name refers to it: "miyama" and "nagaku-bi-mushi" mean deep mountains and a lernaeopodid, respectively.

Discussion

When Nagasawa *et al.* (1995) reported *Salmincola carpionis* for the first time from *Salvelinus* spp. and several other salmonids in Japan, their copepod specimens were identified based on the morphological characters of the species shown by Kabata (1969), and their identification has been followed in subsequent (Nagasawa *et al.* 1997, 1998; Wakabayashi 1997; Yamamoto and Nagasawa 1999, 2001; Watanabe and Ishii 2000) and recent papers (Nagasawa and Ishikawa 2017; Nagasawa and Sakaki 2019; Kawanobe 2020). However, Shedko and Shedko (2002) described *Salmincola markewitschi* as a new species from whitespotted char in the Russian Far East and the southern Kuril Islands east of Hokkaido Island, Japan, and morphologically differentiated *S. markewitschi* from *S. carpionis*. Therefore, now, it is important to identify specimens of *Salmincola* from Japanese *Salvelinus* spp. using Shedko and Shedko (2002) as well as Kabata (1969).

Copepods reported as *Salmincola carpionis* are known to occur in the following Japanese prefectures (from the north to the south): Hokkaido (Yamaguti 1939, reported as *S. faculata*; see Nagasawa *et al.* 1995; Nagasawa and Urawa 2002: appendix, footnote), Aomori (Nagasawa *et al.* 1995; Nagasawa and Sakaki 2019), Iwate (Kumagai 1985, reported as *Salmincola* sp.; Nagasawa *et al.* 1995), Fukushima (Watanabe and Ishii 2000), Tochigi (Nagasawa *et al.* 1997, 1998; Nagasawa and Ishikawa 2017), Toyama (Wakabayashi 1997), Nagano (Nagasawa *et al.* 1995; Kawanobe 2020), and Yamanashi (Yamamoto and Nagasawa 1999, 2001). Thus, it is highly desirable, using the two papers (Kabata 1969; Shedko and Shedko 2002), to re-identify the copepod specimens reported before as *Salmincola carpionis* from Japanese salmonids, especially from *Salvelinus* spp.

Acknowledgments

I thank the staff of the Shiga Kogen Fisheries Cooperative Association, Yamanouchi, and the Nagano Prefectural Fisheries Experimental Station, Akashina, for providing me

with the specimens of *S. markewitschi* reported herein. I am grateful to Marina B. Shedko and Sergey V. Shedko, Federal Scientific Center of the East Asia Terrestrial Biodiversity, Far Eastern Branch of Russian Academy of Sciences, Vladivostok, for help with literature and information on Russian collection localities. Thanks are also extended to two anonymous reviewers for constructive comments to improve the manuscript.

References

- Arai, T., Kotake, A., and Kitamura, T. 2005. Migration of anadromous white-spotted charr *Salvelinus leucomaenis*, as determined by otolith strontium: calcium ratios. *Fisheries Science* 71: 731–737.
- Black, G. A., Montgomery, W. L., and Whoriskey, F. G. 1983. Abundance and distribution of *Salmincola edwardsii* (Copepoda) on anadromous brook trout, *Salvelinus fontinalis* (Mitchill) in the Moisie River system, Quebec. *Journal of Fish Biology* 22: 567–575.
- Bush, A. O., Lafferty, K. D., Lotz, J. M., and Shostak, A. W. 1997. Parasitology meets ecology on its own terms: Margolis *et al.* revised. *Journal of Parasitology* 83: 575–583.
- Denda, I. and Ogawa, S. 2011. [Occurrence of *Salmincola californiensis* on wild Japanese char]. *Bulletin of the Nagano Prefectural Fisheries Experimental Station* 12: 12. [In Japanese]
- Fausch, K. D., Nakano, S., and Ishigaki, K. 1994. Distribution of two congeneric charrs in streams of Hokkaido Island, Japan: considering multiple factors across scales. *Oecologia* 100: 1–12.
- Friend, G. F. 1942. The life-history and ecology of the salmon gill-maggot *Salmincola salmonea* (L.) (Copepod crustacean). *Transactions of the Royal Society of Edinburgh* 60: 503–541.
- Froese, R. and Pauly, D. (Eds) 2019. FishBase. World Wide Web electronic publication, version (12/2019). Available at <http://www.fishbase.org> (30 July 2020).
- Gussev, A. V. 1951. [Parasitic Copepoda of some marine fishes]. *Parazitologicheskii Sbornik* 13: 394–463. [In Russian]
- Hoffman, G. L. 1999. *Parasites of North American Freshwater Fishes. Second Edition*. Cornell University Press, Ithaca, New York, 539 pp.
- Hoshina, T. and Nishimura, T. 1976. On a parasitic Copepoda, *Salmincola californiensis* found in [*sic*] a salmonid fish, Yamame, *Oncorhynchus masou*. *Fish Pathology* 11: 153–157.
- Hoshina, T. and Suenaga, G. 1954. On a new species of parasitic copepods from Yamame (salmonoid fish) of Japan. *Journal of the Tokyo University of Fisheries* 41: 75–78, pl. I.
- Humes, A. G. and Gooding, R. U. 1964. A method for studying the external anatomy of copepods. *Crustaceana* 6: 238–240.
- Kabata, Z. 1969. Revision of the genus *Salmincola* Wilson, 1915 (Copepoda: Lernaepodidae). *Journal of the Fisheries Research Board of Canada* 26: 2987–3041.
- Kabata, Z. 1979. *Parasitic Copepoda of British Fishes*. The Ray Society, London, 468 pp.
- Kabata, Z. 1988. Copepoda and Branchiura. Pp. 3–127. In: Margolis, L. and Kabata, Z. (Eds) *Guide to the Parasites of Fishes of Canada, Part II—Crustacea. Canadian Special Publication of Fisheries and Aquatic Sciences 101*. Department of Fisheries and Oceans, Ottawa.
- Kawanobe, M. 2020. Hatching of *Salmincola carpionis* and period of parasitic capacity of the larvae. *Bulletin of the Nagano Prefectural Fisheries Experimental Station* 19: 24–28. [In Japanese]
- Kumagai, A. 1985. [On *Salmincola* parasitic on trout]. *The Annual Report of the Iwate Prefectural Inland Fisheries Experimental Station for Fiscal 1984*: 85–93. [In Japanese]
- Kusterle, S., Kristoffersen, R., and Rikardsen, A. H. 2012. Population dynamics of *Salmincola salmoneus* on Atlantic salmon in a northern Norwegian river. *Diseases of Aquatic Organisms* 100: 59–70.
- Kusterle, S., Halttunen, E., Thorstad, E. B., Næsje, T. F., Jensen, J. L. A., Gallo-Bueno, A., Olague, E., and Rikardsen, A. H. 2013. The gill maggot *Salmincola salmoneus* as an indicator of repeat spawning in Atlantic salmon *Salmo salar*. *Journal of Fish Biology* 82: 1068–1073.
- Morita, K., Morita, S. H., Nagasawa, T., and Kuroki, M. 2013. Migratory patterns of anadromous white-spotted charr *Salvelinus leucomaenis* in eastern Hokkaido, Japan: the solution to a mystery? *Journal of Ichthyology* 53: 809–819.
- Nagasawa, K. 2020. *Salmincola edwardsii* (Copepoda: Lernaepodidae) parasitic on southern Asian Dolly Varden, *Salvelinus malma krascheninnikova*, from Hokkaido Island, Japan, with the southernmost distribution record of the copepod in Asia. *Species Diversity* 25: 197–203.
- Nagasawa, K. and Ishikawa, T. 2017. *Salmincola carpionis* (Copepoda: Lernaepodidae) parasitic on salmonids cultured at a fish farm in Tochigi Prefecture, Japan. *Bulletin of the Tochigi Prefectural Museum* 34: 1–4. [In Japanese with English abstract]
- Nagasawa, K. and Sakaki, M. 2019. Infection of *Salmincola carpionis* (Copepoda: Lernaepodidae) on whitespotted charr, *Salvelinus leucomaenis* (Salmonidae), reared in northern Honshu, Japan. *Nature of Kagoshima* 46: 113–115. [In Japanese with English abstract]
- Nagasawa, K. and Urawa, S. 2002. Infection of *Salmincola californiensis* (Copepoda: Lernaepodidae) on juvenile masu salmon (*Oncorhynchus masou*) from a stream in Hokkaido. *Bulletin of the National Salmon Resources Center* 5: 7–12.
- Nagasawa, K., Ikuta, K., and Kitamura, S. 1997. Distribution of *Salmincola carpionis* (Copepoda: Lernaepodidae) in the buccal cavity of salmonids. *Bulletin of the National Research Institute of Aquaculture* 26: 35–39.
- Nagasawa, K., Yamamoto, M., Sakurai, Y., and Kumagai, A. 1995. Rediscovery in Japan and host association of *Salmincola carpionis* (Copepoda: Lernaepodidae), a parasite of wild and reared freshwater salmonids. *Canadian Journal of Fisheries and Aquatic Sciences* 52 (supplement 1): 178–185.
- Nagasawa, K., Ikuta, K., Nakamura, H., Shikama, T., and Kitamura, S. 1998. Occurrence and effects of the parasitic copepod *Salmincola carpionis* on salmonids in the Nikko District, central Japan. *Journal of Marine System* 15: 269–272.
- Nagasawa, K., Kawanobe, M., Kumakawa, S., Matsuzawa, S., and Takehana, K. 2018. Rediscovery of the salmonid parasite *Salmincola californiensis* (Crustacea: Copepoda: Lernaepodidae) and identification of its host in the Ōtaki River, a tributary of the upper Kiso River, central Japan. *Bulletin of the Biogeographical Society of Japan* 72: 253–257. [In Japanese with English abstract]
- Nakabo, T. (Ed.) 2013. *Fishes of Japan with Pictorial Keys to the Species, Third Edition*. Tokai University Press, Hadano, 2428 pp. [In Japanese]
- Nakamura, T. and Iida, H. (Eds) 2009. *Conservation and Enhancement of Charr and Salmon in Japanese Mountain Streams*. Rural Culture Association Japan, Tokyo, 134 pp. [In Japanese]
- Nishimura, T. and Hoshina, T. 1977. On a parasitic Copepoda, *Salmincola californiensis* found in [*sic*] a salmonid fish, *Salvelinus leucomaenis pluvius*. *Journal of the Tokyo University of Fisheries* 63: 67–70. [In Japanese with English abstract]
- Ruiz, C. F., Rash, J. M., Besler, D. A., Roberts, J. R., Warren, M. B., Arias, C. R., and Bullard, S. A. 2017. Exotic “gill lice” species (Copepoda: Lernaepodidae: *Salmincola* spp.) infect rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*) in the southeastern United States. *Journal of Parasitology* 103: 377–

- 389.
- Shedko, M. B. 2005. Fauna of the parasitic copepods of the genus *Salmincola* (Copepoda: Lernaepodidae) of the fishes from Kamchatka Peninsula. Pp. 128–149. In: Tokranov, A. M. (Ed.) *Conservation of Biodiversity of Kamchatka and Coastal Waters: Proceedings of the V Scientific Conference (Petropavlovsk-Kamchatsky, November 22–24, 2004)*. Kamchatpress Publishing House, Petropavlovsk-Kamchatsky. [In Russian with English abstract]
- Shedko, M. B. and Shedko, S. V. [Shed'ko, M. B. and Shed'ko, S. V. in English abstract] 2002. Parasitic copepods of the genus *Salmincola* (Lernaepodidae) from Far-Eastern charrs *Salvelinus* (Salmonidae) with a description of the new species *S. markewitschi* sp. n. *Zoologicheskii Zhurnal* 81: 141–153. [In Russian with English abstract]
- Shedko, M. B., Pospekhov, V. V., and Atrashkevitch, G. I. 2005a. New data on fauna of the freshwater parasitic copepods of the genus *Salmincola* (Copepoda: Lernaepodidae) of fishes from the northern coast of the Sea of Okhotsk. Pp. 421–434. In: Makarchenko, E. (Ed.) *Vladimir Ya. Levanidov's Biennial Memorial Meetings, 3*. Dalnauka, Vladivostok. [In Russian with English abstract]
- Shedko, M. B., Shedko, S. V., and Vinogradov, S. A. 2005b. Fauna of the freshwater parasitic copepods of the family Lernaepodidae (Crustacea: Copepoda) of fishes from Sakhalin Island. Pp. 52–63. In: Bogatov, V. V., Barkalov, V. Yu., Lelej, A. S., Makarchenko, E. A., and Storozhenko, S. Yu. (Eds) *Flora and Fauna of Sakhalin Island (Materials of International Sakhalin Island Project)*. Dalnauka, Vladivostok. [In Russian with English abstract]
- Sokolov, S. G., Shedko, M. B., Protasov, E. N., and Frolov, E. V. 2012. Parasites of the inland water fishes of Sakhalin Island. Pp. 179–216. In: Bogatov, V. V., Barkalov, V. Yu., Lelej, A. S., Makarchenko, E. A., and Storozhenko, S. Y. (Eds) *Flora and Fauna of North-West Pacific Islands (Materials of International Kuril Island and International Sakhalin Island Projects)*. Dalnauka, Vladivostok. [In Russian with English abstract]
- Takegawa, Y., Kawaguchi, Y., Mitsuhashi, H., and Taniguchi, Y. 2017. Implementing species distribution models to predict the impact of global warming on current and future potential habitats of whitespotted char (*Salvelinus leucomaenis*) for effective conservation planning in Japan. *Japanese journal of Conservation Ecology* 22: 121–134. [In Japanese with English abstract]
- Wakabayashi, S. 1997. Infection of whitespotted charr, *Salvelinus leucomaenis*, reared in Toyama Prefecture by *Salmincola carpionis* (Copepoda: Lernaepodidae). *Bulletin of the Toyama Prefectural Fisheries Research Institute* 9: 35–40. [In Japanese with English abstract]
- Walter, T. C. and Boxshall, G. 2018. World of Copepods database. *Salmincola* Wilson C. B., 1915. Accessed through: World Register of Marine Species at: <http://www.marinespecies.org/aphia.php?p=taxdetails&id=135610> (5 August 2020).
- Watanabe, H. and Ishii, T. 2000. [On the occurrence of *Salmincola*]. *The Annual Report of the Fukushima Prefectural Inland Fisheries Experimental Station for Fiscal 1998*: 41. [In Japanese]
- Yamaguti, S. 1939. Parasitic copepods from fishes of Japan. Part 6. Lernaepodidae, I. Volumen Jubliare pro Professore Sadao Yoshida 2: 529–578, pls 34–58.
- Yamamoto, A. and Nagasawa, K. 1999. [*Salmincola carpionis*, a parasitic copepod of cultured salmonids]. *Report of Yamanashi Prefectural Fisheries Technology Center* 26: 26–27. [In Japanese]
- Yamamoto, A. and Nagasawa, K. 2001. [*Salmincola carpionis*, a parasitic copepod of cultured salmonids–II. Experimental infection, infection period, number of spawning and speed of egg development]. *Report of Yamanashi Prefectural Fisheries Technology Center* 28: 14–17. [In Japanese]