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MINI REVIEW

Infection characteristics of *Metagonimus* species (Digenea: Heterophyidae) metacercariae in fish from major rivers of Korea

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Abstract

This article analyzed the infection characteristics of metacercariae of *Metagonimus* spp. (MsMc) in fish from 9 major water systems in Korea. A total of 19,568 fish in 87 species were examined over a period of 10 years (2011–2020). MsMc were detected in fish from all 44 survey areas in 9 water systems. Most of the surveyed sites showed very low and low infection levels (66.7%), while 33.3% of the areas, such as Tamjin-gang and Seomjin-gang, revealed moderate and high infection levels. High endemicity depends on the abundance of susceptible fish species, especially sweet smelt (*Plecoglosus altivelis*). The susceptibility index (SI) with MsMc in index fish, *Zacco* spp., was very low and low levels in 62.0%, moderate in 28.0%, and high in 10.0% regions. The SI was highest in the following order: Yeongam-cheon (283.8), Hoeng-cheon (192.3), Togyo-jeosuji (131.2), Deokcheon-gang (119.1), and Joyang-gang (106.3). The recent infection status of MsMc in *P. altivelis* was analyzed by the survey localities. In addition, except for *P. altivelis*, 9 fish species were highly infected with MsMc in some survey areas, including *Zacco platypus*, *Z. koreanus*, *Z. temminckii*, *Opsariichthys uncirostris*, *Rhynchocypris oxycephalus*, *Carassius auratus*, *Acheilognathus rhombeus*, *Onchorhynchus masou,* and *Tribolodon hakonensis*. In Korea, 74 fish species (15 families) are collectively listed as second intermediate hosts of *Metagonimus* spp. This review provides several novel characteristics of MsMc infection and clarifies the fish species of second intermediate host of *Metagonimus* spp. in this country.

Keywords: *Metagonimus* spp., metacercaria, endemicity, susceptibility index, second intermediate fish host

Background and Purpose

Helminthiases had been prevalent nationwide in Korea until the 1970s. The soil-transmitted helminthiases, such as ascariasis, trichuriasis, and hookworm infections were the main public health problems to be addressed at that time. Their prevalence has been drastically decreased by systematic nationwide control programs [1]. These dieases are no longer a health problem today, while the food-borne helminthiases, including clonorchiasis and metagonimiasis, continues to persist in riverside areas of Korea. The oriental liver fluke, *Clonorchis sinensis*, has been considered the most important helminth, and clonorchiasis has been a major endemic disease to be controlled in a project of the Division of Vectors and Parasitic diseases of Korea Disease Control and Prevention Agency (Korea DCPA). Clonorchiasis eradication project has been successfully conducted by Korea DCPA. How-

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Conceptualization: Sohn WM
Data curation: Sohn WM
Formal analysis: Sohn WM
Investigation: Sohn WM
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Project administration: Sohn WM
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Software: Sohn WM
Supervision: Sohn WM
Validation: Sohn WM
Visualization: Sohn WM
Writing – original draft: Sohn WM
Writing – review & editing: Sohn WM

Conflict of interest
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ever, metagonimiasis caused by infection with *Metagonimus* spp., is more or less neglected, even though it is another health problems among food-borne helminthiases in Korea [2-7]. The long history of metagonimiasis is currently being confirmed through molecular researches emplying archaeological specimens from Joseon Dynasty mummies [8,9].

Fluke members in the genus *Metagonimus* Katsurada, 1912 (Digenea: Heterophyidae) included more than 7 nominal species; i.e., *M. yokogawai* Katsurada, 1912, *M. takahashii* Suzuki, 1930, *M. minutus* Katsuta, 1932, *M. katsuradai* Izumi, 1935, *M. otsurui* Saito and Shimizu, 1968, *M. miyatai* Saito et al., 1997, and *M. hakubensis* Shimazu, 1999 [10,11]. Recently, 2 species, *M. suifunensis* Shumenko et al., 2017 and *M. pusillus* Tatonova et al., 2018, were additionally reported in Russia [12,13]. Among these 9 *Metagonimus* species, 3 ones, i.e., *M. yokogawai*, *M. takahashii,* and *M. miyatai*, are distributed in this country. These flukes casue an important food-borne zoonotic disease in Korea [2,10,11]. Especially, infections by *M. yokogawai* are mainly prevalent in the riverside areas of eastern and southern coast of Korean peninsula [14-20]. Human cases by *M. takahashii* were first reported in inhabitants of Eumseong-gun (gun = county), Chungcheongbuk-do (do = Province), along the upper reaches of the Namhan-gang (gang means river) [21]. *M. miyatai* infection was endemic among peoples residing around lakes and along the rivers and/or streams in inland of Korea [22-24]. These *Metagonimus* species cause severe gastrointestinal troubles and chronic diarrhea when heavily infected [10,11].

Since metacercaria of *Metagonimus yokogawai* (MyMc) was first discovered in Korea from a crusian carp (*Carassius auratus*), many fish species have been reported as the second intermediate hosts of *Metagonimus* spp., which is the source of infection [25,26]. The sweet smelt, *Plecoglossus altivelis*, and the crusian carp, *C. auratus*, were reported to be intermediate hosts of MyMc and *M. takahashii* metacercariae (MtMc), respectively, from Miryang-gang in Gyeongsangnam-do [27,28]. Kang et al. [29] detected MyMc in sweet smelt from Jeju-do, and Choi et al. [30] found MyMc in the sea rundace, *Tribolodon hakonensis*, from Hyeongsan-gang in Gyeongsangbuk-do. Thereafter, many workers reported the infections of *Metagonimus* spp. metacercariae (MsMc) in variety of fish species from various survey regions [31-48]. Rim et al. [47] performed a study to clarify the host (fish) specificity of MsMc with morphologies of adults, which were recovered from hamsters experimentally infected with MsMc from sweet smelt, crusian carp, and chubs (*Zacco platypus, Z. temminckii*, and *Opsarichthys uncirostris amurensis*). In Korea, 3 species of fish, i.e., sweet smelt, sea rundace, and Japanese seabass (*Lateolabrax japonicus*) were clearly known as second intermediate hosts of *M. yokogawai* [15-18]. The crusian carp, common carp (*Cyprinus carpio*), sea rundace, and Japanese seabass were reported as second intermediate hosts of *M. takahashii* [15,18,19]. Many species of fish including the sea rundace and chubs were listed as second intermediate hosts of *M. miyatai* in Korea [15,18,20].

Infecton status of MsMc was frequently examined in sweet smelts from the specific regions in Korea [14-18,27,29,33-35,37,38,41,43,48]. A previous study surveyed the infection status of zoonotic trematode metacercariae (ZTM), including *Metagonimus* spp., in freshwater fish from Gangwon-do [49]. Sohn et al. [50] investigated the infection status of digenetic trematode metacercariae (DTM) in freshwater fish from the water systems of Hantan-gang and Imjin-gang located in relatively northern regions of Korea. The infection status with MsMc in fishes from Seomjin-gang and Tamjin-gang was also recorded [51].

The riverside areas of Seomjin-gang and Tamjin-gang has been known as the endemic areas of heterophyid flukes including *M. yokogawai* [52-56]. Sohn et al. [57,58] reported the infection status of ZTM in fish from Geum-gang and of DTM in fish from coastal lakes in Gangwon-do. Sohn and Na [59] described the infection status of DTM in freshwater fishes from 2 visiting sites, Junam-jeosuji (jeosuji means reservoir) and Woopo-neup (neup means swamp), of migratory birds in Gyeongsangnam-do. Recent study [60] investigated the infection status of ZTM in freshwater fishes from Soyang-cheon in Wanju-gun, Jeollabuk-do during 2 survey periods, the former (2013–2015) and the latter periods (2018–2019). Sohn et al. [61,62] intensively investigated the infection status of ZTM in fish from the irrigation canal of Togyo-jeosuji in Cheorwon-gun, Gangwon-do for 3 years (2018–2020), and from Deokcheon-gang in Sancheong-gun, Gyeongsangnam-do.

Individual studies on the metacercarial infections in fish hosts were continuously performed, but the prevalence and intensity of MsMc infections in fish intermediate hosts have not been systematically and extensively analyzed in Korea. This article reviewed the data from published and unpublished results obtained from studies on the detection of MsMc by survey localities and by fish species in our laboratory during the past 10 years (2011–2020). The status of MsMc infection was analyzed on a total of 19,568 fishes in 87 species from 9 main water systems in Korea, which included Hantan-gang and Imjin-gang, Han-gang, Geum-gang, Mangyeong-gang, Yeongsan-gang, Tamjin-gang, Seomjin-gang, Nakdong-gang, and streams in the east coastal areas.

Data collection and analysis

All collected fishes were kept on ice and transported to the laboratory of the Department of Parasitology and Tropical Medicine, Gyeongsang National University College of Medicine, Jinju, Korea. After identifying the species, each fish was finely ground in a mortar with pestle. The ground fish meat was mixed with artificial gastric juice, and incubated at 36°C for about 2 h. The digested material was filtered through a mesh (pore size 1×1 mm) and washed with 0.85% physiological saline until the supernatant became clear. The sediment

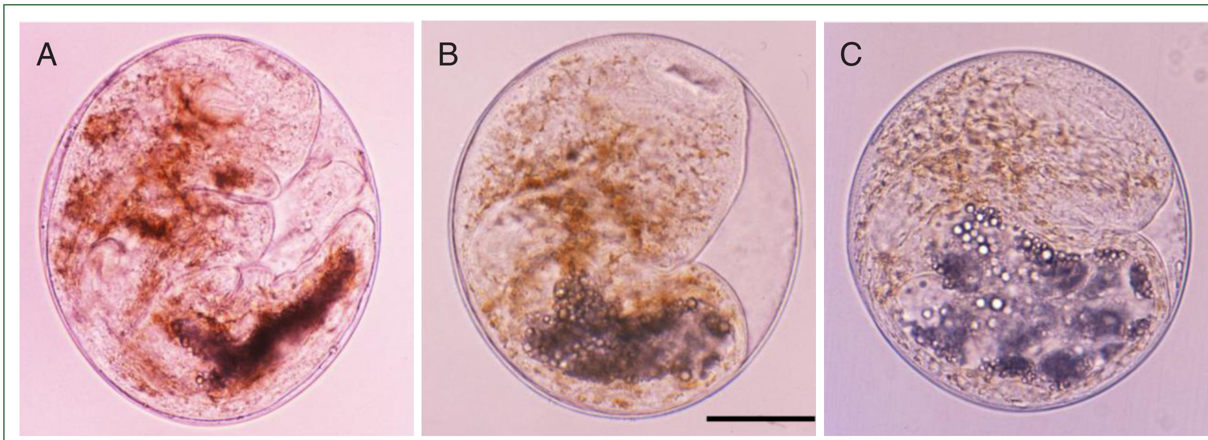

Fig. 1. Metacercariae of *Metagonimus* spp. in different fish hosts, *Plecoglossus altivelis* (A), *Carassius auratus* (B), and *Zacco platypus* (C) in Korea. The metacercariae are spherical or disc-shape and meaure 145–172 (160)×125–158 (140) µm. They had yellow brownish pigment granules, a ventral sucker deflectively located from median and a V-shaped excretory bladder. Scale bar = 50 µm.

Table 1. Summary on the fishes[a] examined for *Metagonimus* spp. metacercariae by the survey localities

Locality		No. fish spp. examined[a]	No. fish examined (No. infected fish (NIF))[b]
No. of water system	Administrative region		
① Hantan-gang	Cheorwon-gun, Gangwon	32	540 (130)
② Hantan-gang	Yeoncheon-gun, Gyeonggi	13	195 (63)
③ Togyo-jeosuji	Cheorwon-gun	19	568 (158)
④ Imjin-gang	Gyeonggi-do	15	283 (68)
⑤ Pyeongchang-gang	Pyeongchang-gun, Gangwon	15	228 (54)
⑥ Joyang-gang	Jeongseon-gun, Gangwon	15	196 (59)
⑦ Seom-gang	Hoengseong-gun, Gangwon	20	184 (28)
⑧ Seom-gang	Wonju-si, Gangwon	30	707 (148)
⑨ Dal-cheon	Goesan-gun, Chungbuk	12	99 (30)
⑩ Juja-cheon	Jinahn-gun, Jeonbuk	19	208 (80)
⑪ Chogang-cheon	Yeongdong-gun, Chungbuk	15	132 (6)
⑫ Geum-gang	Muju-gun, Jeonbuk	14	123 (11)
⑬ Geum-gang	Geumsan-gun, Chungnam	25	365 (60)
⑭ Yugu-cheon	Gongju-si, Chungnam	14	311 (59)
⑮ Ji-cheon	Cheongyang-gun, Chungnam	89	89 (33)
⑯ Nonsan-cheon	Nonsan-si, Chungnam	11	44 (0)
⑰ -1 Soyang-cheon	Wanju-gun, Jeonbuk	18	607 (128)
⑰ -2 Soyang-cheon	Wanju-gun	25	465 (109)
⑱ Hwangryong-gang	Jangseong-gun, Jeonnam	14	107 (15)
⑲ Jiseok-cheon	Naju-si, Jeonnam	14	140 (50)
⑳ Yeongam-cheon	Yeongam-gun, Jeonnam	8	45 (19)
㉑ -1 Tamjin-gang	Jangheung-gun, Jeonnam	21	712 (167)
㉑ -2 Tamjin-gang	Jangheung-gun	25	972 (233)
㉒ Tamjin-gang	Gangjin-gun, Jeonnam	17	517 (101)
㉓ Osu-cheon	Imsil-gun, Jeonbuk	15	341 (100)
㉔ -1 Seomjin-gang	Sunchang-gun, Jeonbuk	29	310 (66)
㉔ -2 Seomjin-gang	Sunchang-gun, Jeonbuk	32	676 (147)
㉕ Songdae-cheon	Namwon-si, Jeonbuk	25	420 (119)
㉖ -1 Seomjin-gang	Gokseong-gun, Jeonnam	15	289 (95)
㉖ -2 Seomjin-gang	Gokseong-gun, Jeonnam	22	631 (218)
㉗ Seomjin-gang	Gurye-gun, Jeonnam	28	356 (77)
㉘ Hwagye-cheon	Hadong-gun, Gyeongnam	15	202 (70)
㉙ Akyang-cheon	Hadong-gun	12	179 (65)
㉚ Namsan-cheon	Hadong-gun	14	328 (156)
㉛ Hoeng-cheon	Hadong-gun	13	318 (125)
㉜ Jugyo-cheon	Hadong-gun	23	196 (78)
㉝ Banbyeon-cheon	Yeongyang-gun, Gyeongbuk	12	161 (64)
㉞ Yongjeon-cheon	Cheongsong-gun, Gyeongbuk	20	804 (228)
㉟ -1 Wi-cheon	Gunwi-gun, Gyeongbuk	26	550 (204)
㉟ -2 Wi-cheon	Gunwi-gun, Gyeongbuk	33	723 (243)
㉟ -3 Wi-cheon	Gunwi-gun, Gyeongbuk	29	782 (227)
㊱ -1 Yang-cheon	Sancheong-gun, Gyeongnam	23	1,357 (322)
㊱ -2 Yang-cheon	Sancheong-gun, Gyeongnam	23	844 (241)
㊲ Deokcheon-gang	Sancheong-gun	19	871 (180)
㊳ Jisu-cheon[c]	Jinju-si, Gyeongnam	13	167 (74)
㊴ Namdae-cheon	Yangyang-gun, Gangwon	13	140 (38)
㊵ Osip-cheon	Samcheok-si, Gangwon	15	143 (15)
㊶ Whangpi-cheon	Uljin-gun, Gyeongbuk	13	239 (45)
㊷ Osip-cheon	Yeongdeok-gun, Gyeongbuk	17	283 (67)
㊸ Gigye-cheon	Gyeongju-si, Gyeongbuk	12	111 (41)
㊹ Taehwa-gang[d]	Ulsan Metropilitan City	17	310 (80)

[a]A total 19,568 (NIF: 5,194) fish in 87 species were examined.
[b]No. of index fish, *Zacco* spp., examined.
[c]fish from Haman-cheon in Haman-gun, Gyeongsangnam-do.
[d]fish from Cheokgwa-cheon in Ulju-gun, Ulsan Metropilitan City, Korea.

was carefully examined under a stereomicroscope. *Metagonimus* spp. metacercariae (MsMc: Fig. 1) were separately collected according to previously described method [26]. MsMc were counted to determine the infection rate (No. of fish with MsMc/No. of fish examined × 100) and intensity (No. of MsMc detected/No. of fish infected) by fish species. The endemicity was calculated by the formula, positive rate (No. of positive fish species/No. of fish spp. examined) of fish spp. × positive rate (No. of positive fish/No. of fish examined) in positive fish spp. (PFS) × mean No. of MsMc detected, and it was divided into 4 groups, i.e., very low (below 3.0), low (3.0–25.0), moderate (25.1–75.0), and high (over 75.1), by the endemic index. The susceptibility index (SI) of MsMc in index fish, *Zacco* spp., was calculated by the formula, prevalence/100 × mean metacercarial intensity per fish infected (PFI), and it was also divided into 4 groups, i.e., very low (below 5.0), low (5.01–30.0), moderate (30.1–100.0), and high (over 100.1), by survey regions.

Number of fish examined by the fish species and survey locality

The overall number of fishes examined by the survey localities is presented in Table 1 and each survey locality is marked in Fig. 2.

Water systems of Hantan-gang and Imjin-gang

A total of 540 fishes (32 species) were examined in ① Hantan-gang (Latitude: 38.23047; Longitude: 127.2179) in Cheorwon-gun, Gangwon-do (2012, 2013, 2019). In ② Hantan-gang (37.94375; 127.07142) in Yeoncheon-gun, Gyeonggi-do (2013), a total of 195 fish in 13 spp. were examined. A total of 568 fishes in 19 spp. were examined in ③ Togyo-jeosuji (38.27082; 127.28949), Cheorwon-gun, Gangwon-do (2018–2020). In ④ water systems of Imjin-gang (2013), a total of 283 fish in 15 spp. were examined. Fish species and the number of fish examined were designated by survey localities in Supplementary Table S1 in detail.

Water systems of Han-gang

A total of 228 fishes (15 spp.) were examined in ⑤ Pyeongchang-gang (37.32968; 128.37765) in Pyeongchang-gun, Gangwon-do (2013). In ⑥ Joyang-gang (37.44292; 128.66256) in Jeongseon-gun, Gangwon-do (2012), a total of 196 fish in 15 spp. were examined. A total of 184 fish in 20 species were examined in ⑦ Seom-gang (37.50058; 127.99337) in Hoengseong-gun, Gangwon-do (2011). In ⑧ Seom-gang (37.42690; 127.89634) in Wonju-si, Gangwon-do (2018–2020), a total of 707 fish in 30 spp. were examined. A total of 99 fish in 12 species were examined in ⑨ Dal-cheon in Goesan-gun, Chungcheongbuk-do (2011). Supplementary Table S2 shows the fish species and the number of fish examined according to the survey localities.

Water systems of Geum-gang

A total of 208 fish (19 spp.) were examined in ⑩ Juja-cheon (35.98023; 127.39388), the upper stream of Geum-gang, in Jinan-gun, Jeollabuk-do (2012). In ⑪ Chogang-cheon in Yeongdong-gun, Chungcheongbuk-do (2011), 132 fish in 15 spp. were examined. One hundred twenty-three fish (14 spp.) were examined in ⑫ Geum-gang (35.97529; 127.55662) in Muju-gun, Jeollabuk-do (2012). A total of 365 fish (25 spp.) were examined in ⑬ Geum-gang (36.11427; 127.58775) in Geumsan-gun, Chungcheongnam-do (2011, 2013, 2015). In

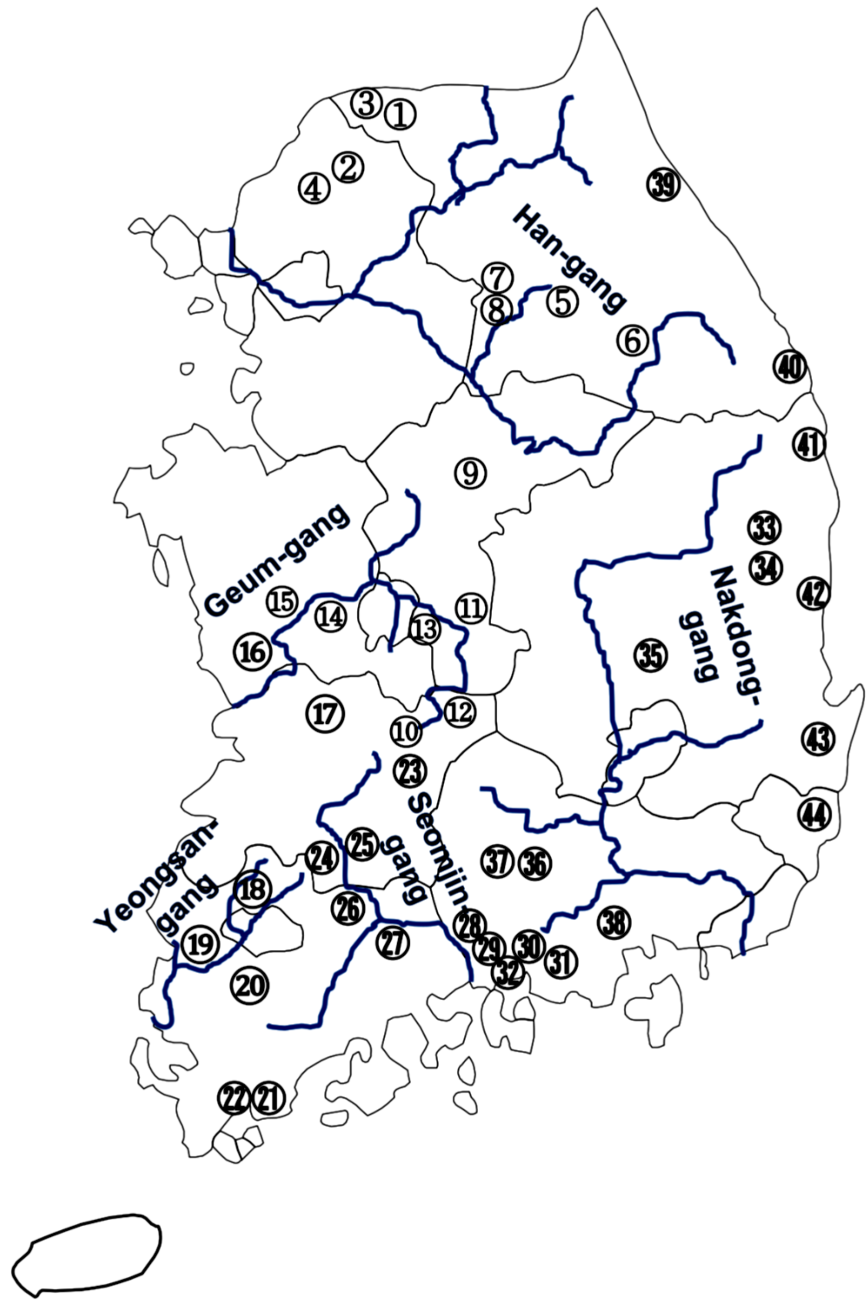

Fig. 2. A map showing 44 surveyed localities. Detailed information of each site (No., water system and administrative region) is shown in Table 1.

⑭ Yugu-cheon (36.53727; 126.94847) in Gongju-si, Chungcheongnam-do (2013, 2015), 311 fish (14 spp.) were examined. A total of 89 fish (13 spp.) were examined in ⑮ Ji-cheon (36.38958; 126.85174) in Cheongryang-gun, Chungcheongnam-do (2013). In ⑯ Nonsan-cheon (36.19906; 127.06790) in Nonsan-si, Chungcheongnam-do (2013), 44 fish (11 spp.) were examined. Fish species and the number of fish examined are shown by survey localities (Supplementary Table S3).

Water systems of Mangyeong-gang

A total of 607 fish in 18 spp. were examined in ⑰-1 Soyang-cheon (36.11427; 127.58775) in Wanju-gun, Jeollabuk-do (2012–2015). In same survey locality, ⑰-2 Soyang-cheon (2018, 2019), a total of 465 fish in 25 spp. were examined. Fish species and the number of fish examined are demonstrated in Supplementary Table S4.

Water systems of Yeongsan-gang

In ⑱ Hwangryong-gang (35.29296; 126.77087) in Jangseong-gun, Jeollanam-do (2011), 107 fish in 14 species were examined. A total of 140 fish in 14 species were examined in ⑲ Jiseok-cheon (35.04768; 126.80448) in Hwasun-gun, Jeollanam-do, (2011, 2013). In ⑳ Yeongam-cheon (35.04086; 126.65664) in Yeongam-gun, Jeollanam-do (2013), 45 fish (8 spp.) were examined. Fish species and the number of fish examined were shown by survey localities in Supplementary Table S5.

Water systems of Tamjin-gang

A total of 712 fish (21 spp.) were examined in ㉑-1 Tamjin-gang (34.42572; 126.54322) in Jangheung-gun, Jeollanam-do (2014–2016). In ㉑-2 Tamjin-gang, Jangheung-gun, Jeollanam-do (2017–2019), 972 fish in 25 spp. were examined. A total of 517 fish (17 spp.) were examined in ㉒ Tamjin-gang (34.38053; 126.48514) in Gangjin-gun, Jeollanam-do (2014, 2017). Fish species and the number of fish examined were designated in Supplementary Table S6 in detail.

Water systems of Seomjin-gang

In ㉓ Osu-cheon (35.52768; 127.32885) in Imsil-gun, Jeollabuk-do (2011–2013), 341 fish (15 spp.) were examined. A total of 310 fish in 29 spp. were examined in ㉔-1 Seomjin-gang (35.43854; 127.24047) in Sunchang-gun, Jeollabuk-do (2014, 2015). In ㉔-2 Seomjin-gang in Sunchang-gun, Jeollabuk-do (2018–2020), 676 fish (32 spp.) were examined. A total of 420 fish in 25 spp. were examined in ㉕ Songdae-cheon (35.91616; 127.15413) in Namwon-si, Jeollabuk-do (2012, 2013, 2020). Fish species and the number of fish examined were shown by survey localities (Supplementary Table S7).

In ㉖-1 Seomjin-gang (35.14903; 127.32589) in Gokseong-gun, Jeollanam-do (2015, 2016), 289 fish in 15 spp. were examined. A total of 631 fish in 22 spp. were examined in ㉖-2 Seomjin-gang in Gokseong-gun, Jeollanam-do (2018–2020). In ㉗ Seomjin-gang (35.14340; 127.31661) in Gurye-gun, Jeollanam-do (2014, 2020), 356 fish (28 spp.) were examined. Fish species and the number of fish examined are presented by survey localities (Supplementary Table S8).

A total of 202 fish in 15 spp. were examined in ㉘ Hwagye-cheon (35.02828; 127.81974) in Hadong-gun, Gyeongsangnam-do (2020). In ㉙ Akyang-cheon (35.16218; 127.71133) in Hadong-gun, Gyeongsangnam-do (2018), 179 fish in 12 spp. was examined. A total of 328 fish in 14 spp. were examined in ㉚ Namsan-cheon (35.09540; 127.79806) in Hadong-gun, Gyeongsangnam-do (2015, 2016, 2019). In ㉛ Hoeng-cheon (35.10716; 127.80779) in Hadong-gun, Gyeongsangnam-do (2014, 2016, 2019), 318 fish in 13 spp. were examined. A total of 196 fish in 23 spp. were examined in ㉜ Jugyo-cheon (35.02828; 127.81974) in Hadong-gun, Gyeongsangnam-do (2011, 2018). Fish species and the number of fish examined were shown by survey localities in Supplementary Table S9.

Water systems of Nakdong-gang

A total of 161 fish (12 spp.) were examined in ㉝ Banbyun-cheon (36.59338; 129.06975) in Yeongyang-gun, Gyeongsangbuk-do (2015). In ㉞ Yongjeon-cheon (36.40716; 129.36594) in Cheongsong-gun, Gyeongsangbuk-do (2019, 2020), 804 fish in 20 spp. was examined. Fish species and the number of fish examined are shown by survey localities in Supplementary Table S10.

We examined 550 fish in 26 spp. in Wi-cheon (㉟-1, 36.18863; 128.64873) in Gunwi-gun, Gyeongsangbuk-do (2011, 2013, 2014). In Wi-cheon (2015–2017), 723 fish in 33 spp. were examined (㉟-2). A total of 782 fish in 28 spp. were examined in Wi-cheon (㉟-3) in 2018–2020. Fish species and the number of fish examined by survey period are presented in Supplementary Table S11.

A total of 1,357 fish (23 spp.) were examined in Yang-cheon (㊱-1, 35.36021; 128.05820) in Sancheong-gun, Gyeongsangnam-do (2011–2014). In Yang-cheon (㊱-2, 2015–2017), 844 fish in 23 spp. were examined. A total of 871 fish 19 spp. were examined in ㊲ Deokcheon-gang (35.24643; 127.89224) in Sancheong-gun, Gyeongsangnam-do (2018–2020). In ㊳ Jisu-cheon (35.33582; 128.32520) and Haman-cheon (35.20562; 128.44302) in Jinju-si and Haman-gun, Gyeongsangnam-do (2015), 167 fish in 13 spp. were examined. Fish species and the number of fish examined by survey localities are shown in Supplementary Tables S12 and S13.

Water systems of east coastal areas

A total of 140 fish (13 spp.) were examined in ㊴ Namdae-cheon (38.07302; 128.59303) in Yangyang-gun, Gangwon-do (2015). In ㊵ Osip-cheon (37.42217; 129.11746) in Samcheok-si, Gangwon-do (2015), 143 fish in 15 spp. were examined. A total of 140 fish (13 spp.) were examined in ㊶ Wangpi-cheon (36.96583; 129.39499) in Uljin-gun, Gyeongsangbuk-do (2015). In ㊷ Osipcheon (36.40716; 129.36594) in Yeongdeok-gun, Gyeongsangbuk-do (2015, 2018), 283 fish in 17 spp. were examined. A total of 111 fish in 12 spp. were examined in ㊸ Gigye-cheon (36.03105; 129.24680) in Gyeongju-si, Gyeongsangbuk-do (2015). In ㊹ Cheokgwa-cheon (35.59894; 129.27461) and Taehwa-gang (35.58515; 129.22520) in Ulsan Metropilitan City (2015), 310 fish (17 spp.) were examined. Fish species and the number of fish examined by survey localities are shown in Supplementary Table S14.

Infection status of MsMc by fish species and survey regions

Hantan-gang and Imjin-gang

The prevalence of MsMc was 55.3%, 33.9%, 74.1%, and 57.4% in positive fish species (PFS) from ① Hantan-gang (Cheorwon), ② Hantan-gang (Yeoncheon), ③ Togyo-jeosuji, and ④ Imjin-gang (Table 2). The infection intensities were 35.1, 8.6, 62.0, and 9.6 per fish infected (PFI), respectively. Supplementary Table S1 shows the infection status by the fish species and survey locality.

In the early 1990s, 3.4% egg-positive rate (prevalence) of *Metagonimus* spp. from 465 fe-

Table 2. Overall infection status of *Metagonimus* spp. metacercariae (MsMc) in fish by water systems in Korea

Locality surveyed	No. fish examined[a]	No. (%) fish infected	No. MsMc detected	
			Range	Average
Hantan-gang and Imjin-gang				
① Hantan-gang (Cheorwon)	512	283 (55.3)	1–486	35.1
② Hantan-gang (Yeoncheon)	177	60 (33.9)	1–85	8.6
③ Togyo-jeosuji	544	403 (74.1)	1–1,020	62.0
④ Imjin-gang	197	113 (57.4)	1–250	9.6
Han-gang				
⑤ Pyeongchang-gang	198	132 (66.7)	1–145	10.0
⑥ Joyang-gang	172	122 (70.9)	1–403	60.1
⑦ Seom-gang (Hoengseong)	93	69 (74.2)	1–214	32.3
⑧ Seom-gang (Wonju)	673	298 (44.3)	1–374	27.4
⑨ Dal-cheon	62	39 (62.9)	1–329	79.4
Geum-gang				
⑩ Juja-cheon	156	68 (43.6)	1–25	4.2
⑪ Chogang-cheon	89	41 (46.1)	1–292	14.1
⑫ Geum-gang (Muju)	60	15 (25.0)	1–10	2.4
⑬ Geum-gang (Geumsan)	261	205 (78.5)	1–360	37.5
⑭ Yugu-cheon	260	56 (21.5)	1–14	2.9
⑮ Ji-cheon	65	46 (69.2)	1–332	32.7
⑯ Nonsan-cheon	15	6 (40.0)	1–13	4.2
Mangyeong-gang				
⑰ -1. Soyang-cheon	490	174 (35.5)	1–27	3.7
⑰ -2. Soyang-cheon	424	152 (35.9)	1–890	19.3
Yeongsan-gang				
⑱ Hwangryong-gang	49	27 (55.1)	1–26	5.9
⑲ Jiseok-cheon	127	71 (55.9)	1–25	5.3
⑳ Yeongam-cheon	30	27 (90.0)	1–1,520	202.7
Tamjin-gang				
㉑ -1. Tamjin-gang (Jangheung)	680	445 (65.4)	1–5,320	152.5
㉑ -2. Tamjin-gang (Jangheung)	940	422 (48.1)	1–5,280	63.1
㉒ Tamjin-gang (Gangjin)	491	326 (66.4)	1–4,280	121.1
Seomjin-gang				
㉓ Osu-cheon	299	90 (30.1)	1–32	3.7
㉔ -1. Seomjin-gang (Sunchang)	257	128 (49.8)	1–6,750	86.8
㉔ -2. Seomjin-gang (Sunchang)	635	294 (46.3)	1–130	7.1
㉕ Songdae-cheon	406	253 (62.3)	1–334	21.8
㉖ -1. Seomjin-gang (Gokseong)	286	207 (72.4)	1–4,380	43.1
㉖ -2. Seomjin-gang (Gokseong)	619	399 (64.5)	1–833	25.0
㉗ Seomjin-gang (Gurye)	320	213 (66.6)	1–16,830	281.5
㉘ Hwagye-cheon	194	141 (72.7)	1–17,750	800.5
㉙ Akyang-cheon	156	132 (84.6)	1–4,865	104.4
㉚ Namsan-cheon	323	185 (57.3)	1–2,860	61.8
㉛ Hoeng-cheon	318	197 (61.9)	1–5,860	127.7
㉜ Jugyo-cheon	174	128 (73.6)	1–85	9.6
Nakdong-gang				
㉝ Banbyeon-cheon	132	65 (49.2)	1–11	3.4
㉞ Yongjeon-cheon	730	306 (41.9)	1–200	14.5
㉟ -1. Wi-cheon	399	146 (36.6)	1–20	3.8
㉟ -2. Wi-cheon	566	226 (39.9)	1–50	3.9
㉟ -3. Wi-cheon	708	162 (22.9)	1–2,370	28.4
㊱ -1. Yang-cheon	1,282	305 (23.8)	1–197	7.1
㊱ -2. Yang-cheon	813	308 (37.9)	1–88	5.0

(Continued to the next page)

Table 2. Continued

Locality surveyed	No. fish examined[a]	No. (%) fish infected	No. MsMc detected	
			Range	Average
㊲ Deokcheon-gang	869	760 (87.5)	1–20,650	228.2
㊳ Jisu-cheon	123	71 (57.7)	1–49	6.4
Streams in east coastal areas				
㊴ Namdae-cheon	128	100 (78.1)	1–6,280	263.0
㊵ Osip-cheon (Samcheok)	111	63 (56.8)	1–638	41.8
㊶ Whangpi-cheon	226	193 (85.4)	1–6,199	307.0
㊷ Osip-cheon (Yeongdeok)	246	146 (59.3)	1–597	33.6
㊸ Gigye-cheon	103	50 (48.5)	1–34	3.4
㊹ Taehwa-gang	255	98 (38.4)	1–1,920	110.2

[a]Total number of fish examined in positive fish species (PFS).

cal samples of residents in riverside areas of Hantan-gang in Cheorwon-gun, Gangwon-do was reported [45]. They also reported 33.3% prevalence of MsMc in 7 PFS from this region. Cho et al. [49] reported 64.9% and 95.6% prevalence of MsMc and 98.8 and 24.0 MsMc intensity of infection in fishes from Hwa-gang (upper reaches of Hantan-gang) and Hantan-gang in Cheorwon-gun. We detected MsMc in 312 (61.1%) out of 511 fishes (in 19 PFS) from the water systems of Hantan-gang, and in 113 (59.0%) out of 191 fish (in 8 PFS) from the water systems of Imjin-gang [50]. The intensities of infection with MsMc were 47.5 and 9.6 PFI in each survey regions. In case of index fish, *Zacco* spp., the prevalence of MsMc were 74.0% and 72.1%, and their infection intensities were 43.9 and 18.6 PFI. Therefore, susceptibility indices (SI) were 32.49 and 13.41 in 2 survey regions of Hantan-gang and Imjin-gang. These SI values were very similar with those (30.09 and 13.19) of this review.

Present study shows that the endemicities with MsMc were 36.25 in ③ Togyo-jeosuji, 14.48 in ① Hantan-gang (Cheorwon), 2.90 in ④ Imjin-gang and 2.02 in ② Hantan-gang (Yeoncheon) respectively. SI of MsMc in the index fish, *Zacco* spp., were 131.24 in ③ Togyo-jeosuji, 30.09 in ① Hantan-gang (Cheorwon), 13.19 in ④ Imjin-gang and 3.87 in ② Hantan-gang (Yeoncheon) respectively. In a previous study, SI were 14.23 and 22.61 in *Zacco* spp. from Hwa-gang and Hantan-gang in Cheorwon-gun [49]. Although this survey region (water systems of Hantan-gang and Imjin-gang) is in the northern part of Korea, MsMc is widespread in the PFS and is highly endemic in index fish from Togyo-jeosuji.

Han-gang

The prevalence of MsMc was 66.7%, 70.9%, 74.2%, 44.3%, and 62.9% in PFS from ⑤ Pyeongchang-gang, ⑥ Joyang-gang, ⑦ Seom-gang (Hoengseong), ⑧ Seom-gang (Wonju), and ⑨ Dal-cheon (Table 2). The infection intensities were 10.0, 60.1, 32.3, 27.4, and 79.4 PFI respectively. Supplementary Table S2 shows the infection status by the fish species and survey locality.

Some epidemiological studies on metagonimiasis have been conducted in the Han-gang system [21,42,44,46]. The prevalence of metagonimiasis in 529 fecal samples of inhabitants in the riverside areas of Hongcheon-gang in Hongcheon-gun, Gangwon-do were 7.4% and the infection status with MsMc from 44 pale chubs, *Z. platypus*, were 68.2% MsMc positive in PFS with average infection intensity of 26 MsMc [42]. Chai et al. [21] surveyed the prevalence of metagonimiasis with 231 fecal samples of inhabitants along the upper reaches of Namhan-gang in Umseong-gun, Chungcheongbuk-do and Yeongwol-gun, Gangwon-do (22.5% egg positivity) and 97.6% of the infection status with MsMc from 5 fish species including 42 *Z. platypus*. Ahn [44] reported 7.8% prevalence of metagonimiasis from 1,067 inhabitants residing in the riverside areas of Gangwon-do. He also examined for infections of MsMc in fish from 6 rivers, i.e., Seom-gang, Jucheon-gang, Pyeongchang-gang, Hongcheon-gang, Dong-gang, and Osip-cheon, in Gangwon-do. MsMc prevalence in *Z. platypus* was 75.7% (Seom-gang: 112/148), 77.1% (Jucheon-gang: 37/48), 87.5% (Pyeongchang-gang: 28/32), 63.2% (Hongcheon-gang: 12/19), and 81.5% (Dong-gang: 22/27) respectively. MsMC intensities of infection in *Z. platypus* were 165 (Seom-gang: $n=25$), 56 (Jucheon-gang: $n=20$), 35 (Pyeongchang-gang: $n=12$), and 68 (Hongcheon-gang: $n=12$) respectively. Yu et al. [46] reported 20.9% egg-positive rate of metagonimiasis from 67 fecal samples of inhabitants along Dal-cheon in Cheongwon-gun, Chungcheongbuk-do. They also detected MsMc in 13 fish species from this region.

The endemicities with MsMc were 5.4 in ⑤ Pyeongchang-gang, 9.6 in ⑦ Seom-gang (Hoengseong), 8.8 in ⑧ Seom-gang (Wonju), and 29 in ⑨ Dal-cheon in this review. The endemicities with MsMc were not able to calculate so the fish species and number of fish examined were not variety and enough in previous studies [44,46]. However, SI in index fish were 30.63 in Pyeongchang-gang, 124.91 in Seom-gang [44], and 100.70 in Dal-cheon [46]. Meanwhile in our study, SI were 10.88 in *Zacco* spp. from Pyeongchang-gang, 23.80 from Seom-gang (Hoengseong), 45.98 from Seom-gang (Wonju), and 80.67 from Dal-cheon. These findings from SI in index fish suggest that the endemicity with MsMc is decreased to some extent in fish from the water systems of Han-gang in these days.

Geum-gang

The prevalence of MsMc was 43.6%, 46.1%, 25%, 78.5%, 21.5%, 69.2%, and 40.0% in PFS from ⑩ Juja-cheon, ⑪ Chogang-cheon, ⑫ Geum-gang (Muju), ⑬ Geum-gang (Geumsan), ⑭ Yugu-cheon, ⑮ Ji-cheon, and ⑯ Nonsan-cheon (Table 2). The infection intensities were 4.2, 14.1, 2.4, 37.5, 2.9, 32.7, and 4.2 PFI, respectively. The infection status by the fish species and survey localities are shown in Supplementary Table S3.

A previous study reported 21.0% prevalence from 790 inhabitants in the river basin of Geum-gang in Chungcheongnam-do. In addition, MsMc were detected in 275 fish (76.8%) among 358 fish examined in 18 PFS including 106 *Z. platypus* and 6 *Z. temminckii* [22]. However, this study did not provide the data on the infection intensity of MsMc since endemicity and SI could not be calculated [22]. Another study reported 5.5% prevalence of metagonimiasis from 1,081 inhabitants along the Geum-gang in Okcheon-gun, Chungcheongbuk-do [24]. Kim et al. [23] detected MsMc in 7 fish spp. from Daecheong-ho (lake) and upper reaches of Geum-gang. In index fish, *Zacco* spp., the prevalence with MsMc was 79.4% (85/107) and 100% (26/26) and infection intensities were 36.1 and 103.5 PFI in these 2 sites. Therefore, SI in index fish were to be 28.66 and 103.50 in each region. Sohn et al. [56] detected MsMc in 432 (51.7%) out of 835 fishes in PFS from 6 survey localities, where the infection intensity averaged 30 PFI. The findings in 6 survey localities were nearly equal to those of same localities in this review. SI in *Zacco* spp. was relatively low in water systems of Geum-gang except for that of 2 regions, Chogang-cheon (74.0) and

Geum-gang (Geumsan: 43.7) [56]. Conclusively, the endemicity of *Metagonimus* infections has been gradually decreased in humans and fish intermediate hosts in the riverside areas and water systems of Geum-gang.

Mangyeong-gang

The prevalence of MsMc was 35.5% (the former period) and 35.9% (the latter period) in PFS from ⑰ Soyang-cheon in Wanju-gun, Jeollabuk-do (Table 2). The infection intensities were 3.7 and 19.3 PFI each. The infection status by the fish species and survey localities are presented in Supplementary Table S4.

An epidemiological study was performed to investigate the infection status of DTM in fish from Mangyeong-gang in the early 1980s [39]. This study detected 43.2% MsMc in 164 fish in 26 spp. (81.3%), as well as 96.4% out of 28 *Z. platypus*. Their infection intensity was 25 PFI. A recent study observed the infection status of ZTM in freshwater fish from this survey region during 2 periods (2013–2015 and 2018–2019) [59]. Among 6 species of ZTM (*C. sinensis*, *Metagonimus* spp., *Centrocestus armatus*, *Echinostoma* spp., *Clinostomum complanatum,* and *Metorchis orientalis*) detected, the infection status of *Metagonimus* spp. is nearly equal to that of present study. The prevalence of MsMc is nearly equal between 2 periods (35.5% and 35.9%), but the infection intensity of latter period (19.3 PFI) is much higher than that of former period (3.5 PFI) in this review. And then SI in index fish was 2.72 in the former period and 25.97 in the latter period. The higher SI in the latter period is due to the high infection intensity with MsMc (90.4 PFI) from 25 (89.3%) *Z. koreanus*. A previous study showed that SI in index fish was 24.10 which is similar with that of the latter period in this study [39]. The MsMc endemicity might be low in fish from Mangyeong-gang.

Yeongsan-gang

The prevalence of MsMc was 55.1%, 55.9%, and 90.0% in PFS from ⑱ Hwangryong-gang, ⑲ Jiseok-cheon, and ⑳ Yeongam-cheon (Table 2). The infection intensities were 5.9, 5.3, and 202.7 PFI, respectively. The infection status by the fish species and survey locality is presented in Supplementary Table S5.

The infection status of MsMc has not been reported in Yeongsan-gang basin. This study showed that the prevalence and infection intensity of MsMc were very low and similar in fish from Hwangryong-gang and Jiseok-cheon. However, the prevalence (90.0%) and infection intensity (202.7 PFI) were much higher in fish from Yeongam-cheon. Especially, the index fish, 15 *Z. platypus* and 4 *Z. temminckii*, were all heavily infected with MsMc and the infection intensity was 283.8 PFI. The SI in index fish from Yeongam-cheon was 283.77, the highest among all 51 surveys.

Tamjin-gang

The prevalence of MsMc was 65.4%, 48.1%, and 66.4% in PFS from ㉑ Tamjin-gang (Jangheung: the former and the latter periods) and ㉒ Tamjin-gang (Gangjin) (Table 2). The infection intensities were 152.5, 63.1, and 121.1 PFI, respectively. The infection status by the fish species and survey localitis is presented in Supplementary Table S6.

The riverside areas of Tamjin-gang have been known as the endemic area of intestinal fluke including *Metagonimus* spp. and heterophyid flukes [2,14,20,51-54,63]. Chai et al. [14]

reported 26.4% prevalence of metagonimiasis from 606 residents in the riverside areas of Tamjin-gang. Seo et al. treated 14 residents of the Tamjin river basin with praziquantel and $MgSO_4$, and recovered an average of 21,130 (2,886–63,587) *Metagonimus* worms from the patients [63]. Lee et al. recovered an average of 871 (245–1,219) *Metagonimus* worms from 6 inhabitants of the same village 23 years later [20]. Metagonimiasis endemicity, in terms of worm burden and/or infection intensity, decreased significantly between the 2 survey periods in this area.

Chai et al. [14] detected 15,688 (144-49,956) MsMc PFI in 20 *P. altivelis*, from Tamjin-gang. A recent study surveyed the infection status of MsMc in fish from Tamjin-gang in Jeollanam-do [51]. The prevalence was 56.1% and 66.4% and the infection intensity were 147 and 121 MsMc PFI in fish from the middle reaches in Jangheung-gun and the lower reaches in Gangjin-gun, respectively. SI in the index fish, *Zacco* spp., was 38.28 and 32.90 in 2 regions. In case of sweet smelt, *P. altivelis*, the SI was 1,313.56 and 841.0 in 2 regions. In this study, the prevalence of MsMc was 65.4%, 48.1%, and 66.4% in PFS from Tamjin-gang (Jangheung: the former and the latter periods and Gangjin). The infection intensities were found to be 152.5, 63.1, and 121.1 MsMc PFI, respectively. SI was 30.0, 65.14, and 32.94 in index fish, *Zacco* spp., and that of sweet smelt, *P. altivelis*, was 1,257.75, 1,476.0, and 841.0, respectively. These collective data suggest that the endemicity of MsMc has been continuously maintained in fish from Tamjin-gang and much affected with the number of sweet smelt examined.

Seomjin-gang

The prevalence of MsMc was 30.1%, 49.8%, 46.3%, 62.3%, 72.4%, 64.5%, 66.6%, 72.7%, 84.6%, 57.3%, 61.9%, and 73.6% in PFS from ㉓ Osu-cheon, ㉔ Seomjin-gang (Sunchang: the former and the latter periods), ㉕ Songdae-cheon, ㉖ Seomjin-gang (Gokseong: the former and the latter periods), ㉗ Seomjin-gang (Gurye), ㉘ Hwagye-cheon, ㉙ Akyang-cheon, ㉚ Namsan-cheon, ㉚ Hoeng-cheon, and ㉛ Jugyo-cheon, respectively (Table 2). The infection intensities were 3.7, 86.8, 7.1, 21.8, 43.1, 25.0, 281.5, 800.5, 104.4, 61.8, 127.7, and 9.6 PFI, respectively. The infection status by the fish species and survey locality is presented in Supplementary Tables S7-S9.

It has been known that the riverside area of Seomjin-gang, especially Hadong-gun in Gyeongsangnam-do, is an endemic area of metagonimiasis in Korea. Yeo and Seo [64] reported 47.5% prevalence in 221 inhabitants of Hadong-gun at the early 1970s. Hong and Seo [33] detected 3,851 MsMc PFI in 10 sweet smelt from Hwagae-myeon, Hadong-gun. Kim et al. [16] reported 29.1% prevalence in 1,163 inhabitants of Hadong-gun with 2,455 MsMc PFI in 14 sweet smelt from the survey region. Chai et al. [65] detected 584 MsMc PFI in 15 sea rundace, *T. hakonensis*, from Seomjin-gang in Hadong-gun. However, except for 1 study [51], no epidemiological study on the status of MsMc infection in Seomjin-gang fish has been conducted extensively and systematically. Sohn et al. [51] investigated the infection status of MsMc in fish from 3 tentative regions, the upper (Osu-cheon in Imsil and Seomjin-gang in Sunchang), middle (Songdae-cheon in Namwon and Seomjin-gang in Gokseong), and lower (Seomjin-gang in Gurye, Namsan-cheon and Hoeng-cheon in Hadong) reaches of Seomjin-gang over 5 years (2012–2016). In this review, I also analyzed the unpublished epidemiological data (2017–2020) on the infection status of MsMc in fish from Seomjin-gang together with previously published data [51].

The prevalence of MsMc was 36.3%, 49.8%, 64.5%, 43.1%, 78.8%, 58.9%, and 73.3% in PFS from Osu-cheon, Seomjin-gang (Sunchang), Songdae-cheon, Seomjin-gang (Gokseong), Seomjin-gang (Gurye), Namsan-cheon, and Hoeng-cheon [51] with infection intensities of 4.2, 86.8, 39.9, 43.1, 246.5, 67.5, and 173.6 PFI, respectively. The SI of MsMc from the upper, middle, and lower reaches of Seomjin-gang fish was 25.93, 29.04, and 114.51, repectively. The SI in index fish, *Zacco* spp., was 2.52, 18.90, 45.30, 18.35, 98.27, 75.39, and 244.44 in same regions [51]. The MsMc SI of the upper, middle, and lower reaches of Seomjin-gang *Zacco* spp. was 9.93, 32.37, and 134.95. In this study, the prevalence of MsMc was 47.9%, 66.9%, and 67.2%, and infection intensities were 24.9, 96.3, and 201.1 PFI, respectively. The SI of MsMc was 11.93, 64.42, and 135.14 in PFS from the upper, middle, and lower reaches of Seomjin-gang. The SI of MsMc were 17.08, 32.42, and 89.39 in *Zacco* spp. from the upper, middle, and lower reaches of Seomjin-gang in this study.

These results collectively demonstrated that the endemicity of MsMc is relatively low in fish from the upper (Imsil-gun, Sunchang-gun, and Namwon-si, Jeollabuk-do) and middle reaches (Gokseong-gun and Gurye-gun in Jeollanam-do) of Seomjin-gang compared with that in fish from the lower reaches of Seomjin-gang (Hadong-gun, Gyeongsangnam-do). The individual endemicity with MsMc is different to some extent by the survey regions, but it evidenced a tendency to gradually increase along with the lower level of reaches in Seomjin-gang.

Nakdong-gang

The prevalence of MsMc was 49.2%, 41.9%, 36.6%, 39.9%, 22.9%, 23.8%, 37.9%, 87.5%, and 57.7% in PFS from ㉝ Banbyeon-cheon, ㉞ Yongjeon-cheon, ㉟ Wi-cheon (in 3 times of survey), ㊱ Yang-cheon (in the former and the latter survey), ㊲ Deokcheon-gang, and Jisu-cheon (+Haman-cheon) (Table 2). The infection intensities were 3.4, 14.5, 3.8, 3.9, 28.4, 7.1, 5.0, 228.2, and 6.4 PFI, respectively. The infection status by the fish species and survey locality is shown in Supplementary Tables S10-S13.

It has been known that the riverside area of Nakdong-gang is an endemic area of clonorchiasis in Korea [1-7]. The high endemicity of *C. sinensis* metecercariae was also reported in fish from the water systems of Nakdong-gang [66]. However, to date, only a limited number of studies on the endemicity of MsMc have been conducted in this watershed, and no endemic areas of metagonimiasis have been reported in these regions. A previous study investigated the infections of DTM in freshwater fish from Geumho-gang in Gyeongsangbuk-do [32]. MsMc were detected in 234 (47.9%) out of 489 fish in 10 PFS. As a result of investigating the status of MsMc infection in sweet smelt and sea rundace in 3 regions of Osip-cheon, Hyeongsan-gang, and Yu-cheon in Gyeongsangbuk-do, the infection intensity of MsMc was found to be 4,333 (328–12,767) and 1,541 (408–2,652) PFI in 10 each of sweet smelt and sea rundace, respectively [34].

The endemicity of MsMc was relatively low in 8 survey regions of Nakdong-gang except for Deokcheon-gang in Sancheong-gun, Gyeongsangnam-do. The endemic status of MsMc in Deokcheon-gang was preiously reported [62]. In this study, the prevalence of MsMc was 43.0%, 31.9%, and 46.8% in PFS from the upper (Banbyeon-cheon and Yongjeon-cheon), middle (Wi-cheon), and lower (Yang-cheon, Deokcheon-gang, and Jisu-cheon+Haman-cheon) reaches. Their infection intensities were 12.6, 11.3, and 123.0 PFI, repectively. The SI of MsMc were 5.40, 3.61, and 57.56 in PFS. The SI in *Zacco* spp. was 13.22, 1.97, and 28.4 in the upper, middle, and lower reaches of Nakdong-gang.

Three streams Banbyeon-cheon, Yongjeon-cheon, and Wi-cheon that flow in Yeongyang-gun, Cheongsong-gun, and Gunwi-gun flow into the inland of Gyeongsangbuk-do, where the upper Nakdong-gang flows. The endemicity of MsMc were very low from these stream fish. Even for the index fish, *Zacco* spp., SI was very low in these 3 streams. The survey region of Gyeongho-gang, which is composed of branch streams, Yang-cheon and Deokcheon-gang (in Sancheong-gun), and of Nam-gang (Jisu-cheon and Haman-cheon) are the lower reaches of Nakdong-gang in Gyeongsangnam-do. The endemicity of MsMc were very low in all survey regions except for Deokcheon-gang. The SI of index fish was high only in Deokcheon-gang and very low in the other 3 regions [62]. Collectively, the endemicity of MsMc is relatively low in fish from the water systems of Nakdong-gang except for Deokcheon-gang, while these regions are known to be high endemic areas of clonorchiasis. Ecological environment is different between 2 fluke groups, *Metagonimus* spp. and *C. sinensis*. The first intermediate snail host of *Metagonimus* spp. (*Semisulcospira* spp.) mainly thrives clean, cold torrents and streams in the upper and middle reaches of rivers, whereas *Parafossarulus manchouricus*, the snail host of *C. sinensis* commonly inhabits stagnant water such as lake, pond, rice paddy, and irrigation ditchs.

Streams in east coastal areas

The prevalence of MsMc was 78.1%, 56.8%, 85.4%, 59.3%, 48.5%, and 38.4% in PFS from ㊴ Namdae-cheon, ㊵ Osip-cheon (Samcheok), ㊶ Whangpi-cheon, ㊶ Osip-cheon (Yeongdeok), ㊸ Gigye-cheon, and ㊹ Taehwa-gang (Table 2). The infection intensities were 263.0, 41.8, 307.0, 33.6, 3.4, and 110.2 PFI, respectively. The infection status by the fish species and survey locality is presented in Supplementary Table S14.

Many Korean workers have surveyed the epidemiological situation of metagonimiasis and the infection status of MsMc in fish hosts including sweet smelt in the east coastal areas of Korea [2,17-19]. Previous studies reported 13.3% prevalence among 1,172 inhabitants in Samcheok-si, Gangwon-do, and 6.6% prevalence from 2,357 inhabitants in the eastern coast of Gangwon-do [17,18]. Another study also found high endemicity of metagonimiasis among residents of Samcheok-si, Gangwon-do, in which 29.7% prevalence from 165 residents examined. Worm burden was over 22,000 in average from 11 candidate residents [19]. Since Choi et al. [30] first surveyed the infection with MsMc in sea rundace, *T. hakonensis*, from the lower reaches of Hyeongsan-gang in Gyeongsangbuk-do, Ahn [44] reported MsMc infections in *T. hakonensis* from Osip-cheon in Samcheok-si. Joo and his colleagues investigated the infections of DTM including MsMc in fish from the streams of Hyeongsan-gang and Taehwa-gang in Gyeongsangbuk-do and Ulsan Metropolitan City [67-70]. The infection status of MsMc has been frequently examined in *P. altivelis*, which is the most susceptible fish host in streams along the east coastal areas of Korea [17,18,37,38,41,43,44,48,49]. Recently, Sohn et al. [58] surveyed DTM in fish from 5 coastal lakes, i.e., Hwajinpo-ho, Songji-ho, Mae-ho, Hyang-ho, and Gyeongpo-ho in Gangwon-do. They detected MsMc in 52 (41.3%) of 126 *T. hakonensis* and their infection intensity was 14.6 PFI. It has been known that coastal lakes in Gangwon-do have an ecologically favorable environmental condition for brackish water fish. Therefore, this fish ecology is regarded as a good factor for studies on the heterophyid flukes including the species diversity of *Metagonimus* in Korea.

In this review, MsMc prevalence was relatively high in fish from Whangpi-cheon (85.4%) and Namdae-cheon (78.1%). The infection intensities were higher in fish from Whangpi-cheon (307 PFI), Namdae-cheon (263 PFI), and Taehwa-gang (110 PFI). The endemicity was also high in fish from Whangpi-cheon (180.06) and Namdae-cheon (174.37). High endemicity of MsMc was probably caused by the number of highly susceptible fish species, *P. altivelis*, *T. hakonensis*, and *Onchorhynchus masou* in these 2 regions. Interstingly, however, the high infection intensity was found to be caused by 20 Chinese minnow, *Rhynchocypris oxycephalus*, as well as 16 sweet smelt in Taehwa-gang. In rivers along the east coast of Korea, the SI of MsMc in the index fish *Zacco* spp. was relatively low, but that in Namdae-cheon fish showed moderate level (42.58).

Endemicity of MsMc in fish by survey areas

The endemicities of MsMc in fish from water systems of ② Hantan-gang (Yeoncheon) (2.02) and ④ Imjin-gang (2.90), which were very low, while those from ① Hantan-gang (Cheorwon) (14.48) and ③ Togyo-jeosuji (36.25) were low and moderate. In the water systems of Han-gang, endemicities were low in fish from ⑤ Pyeongchang-gang (5.44), ⑧ Seom-gang (Wonju) (8.80), and ⑦ Seom-gang (Hoengseong) (9.56). However, endemicities in fish from ⑨ Dal-cheon (29.01) and ⑥ Joyang-gang (31.15) was moderate. The endemicities of MsMc were very low in fish from ⑫ Geum-gang (Muju) (0.17), ⑭ Yugu-cheon (0.41), ⑯ Nonsan-cheon (0.45), and ⑩ Juja-cheon (0.68). However, endemicities in fish from ⑪ Chogang-cheon (3.89), ⑮ Ji-cheon (13.99), and ⑬ Geum-gang (Geumsan) (17.78) were low and moderate. The endemicity of MsMc showed very low and low levels in fish from ⑰ Mangyeong-gang (0.89 and 4.17). In the water systems of Yeongsan-gang, endemicities were very low in fish from ⑱ Hwangryong-gang (0.94) and ⑲ Jiseok-cheon (1.48), while that of ⑳ Yeongam-cheon was high (91.22). The endemicities of MsMc in fish from Tamjin-gang were moderate and high (㉑-2 (Jangheung) 25.44 and ㉒ (Gangjin) 65.54, and ㉑-1 (Jangheung) 85.25, respectively).

In the water systems of Seomjin-gang, endemicities were very low and low in fish from ㉓ Osu-cheon (0.52), ㉔-2 Seomjin-gang (Sunchang) (2.65), ㉜ Jugyo-cheon (4.97), ㉕ Songdae-cheon (9.19), and ㉖-2 Seomjin-gang (Gokseong) (13.76). However, moderate and high endemicities were found in fish from ㉔-1 Seomjin-gang (Sunchang) (26.91), ㉚ Namsancheon (27.83), ㉖-1 Seomjin-gang (Gokseong) (28.86), ㉙ Akyang-cheon (66.56), ㉛ Hoengcheon (79.17), ㉗ Seomjin-gang (Gurye) (143.34), and ㉘ Hwagye-cheon (508.40), respectively. The endemicity of MsMc in fish from the water systems of Nakdong-gang was relatively low except for that in ㊲ Deokcheon-gang (190.78). On the other hand, it was very low in fish from ㉟-1 Wi-cheon (0.59), ㉟-2 Wi-cheon (0.86), ㉝ Banbyun-cheon (0.97), ㊱-1 Yang-cheon (1.11), ㊳ Jisu-cheon and Haman-cheon (1.41), and ㊱-2 Yang-cheon (1.65). The low endemicity was observed in fish from ㉟-3 Wi-cheon (3.59) and ㉞ Yongjeon-cheon (3.65). In streams of the east coastal areas, endemicities in fish from ㊴ Namdae-cheon (174.37) and ㊶ Wangpi-cheon (180.06) were high, while those from ㊹ Cheokgwa-cheon and Taehwa-gang (22.19), ㊵ Osip-cheon (Samcheok) (12.63), ㊷ Osip-cheon (Yeongdeok) (11.70), and ㊸ Gigye-cheon (0.97) were relatively low (Table 3). Collectively, the endemicity of MsMc was high in fish from 8 (15.7%) regions, i.e., ⑳ Yeongam-cheon, ㉑-1 Tamjin-gang (Jang-

Table 3. Endemicity of *Metagonimus* species metacercariae (MsMc) in fish by survey area in Korea

Locality surveyed	Positive rate[a] of fish species	Positive rate[b] with MsMc in (+)ve fish sp.	Mean no.[c] of MsMc detected	Endemicity[d]
Hantan-gang and Imjin-gang				
①	24/32 (0.75)	283/512 (0.55)	35.1	14.48
②	9/13 (0.69)	60/177 (0.34)	8.6	2.02
③	15/19 (0.79)	403/544 (0.74)	62.0	36.25
④	8/15 (0.53)	113/197 (0.57)	9.6	2.90
Han-gang				
⑤	12/15 (0.80)	132/198 (0.68)	10.0	5.44
⑥	11/15 (0.73)	122/172 (0.71)	60.1	31.15
⑦	8/20 (0.40)	69/93 (0.74)	32.3	9.56
⑧	22/30 (0.73)	298/673 (0.44)	27.4	8.80
⑨	7/12 (0.58)	39/62 (0.63)	79.4	29.01
Geum-gang				
⑩	7/19 (0.37)	68/156 (0.44)	4.2	0.68
⑪	9/15 (0.60)	41/89 (0.46)	14.1	3.89
⑫	4/14 (0.29)	15/60 (0.25)	2.4	0.17
⑬	15/25 (0.60)	205/261 (0.79)	37.5	17.78
⑭	9/14 (0.64)	56/260 (0.22)	2.9	0.41
⑮	8/13 (0.62)	46/65 (0.69)	32.7	13.99
⑯	3/11 (0.27)	6/15 (0.40)	4.2	0.45
Mangyeong-gang				
⑰-1.	12/18 (0.67)	174/490 (0.36)	3.7	0.89
⑰-2.	15/25 (0.60)	152/424 (0.36)	19.3	4.17
Yeongsan-gang				
⑱	4/14 (0.29)	27/49 (0.55)	5.9	0.94
⑲	7/14 (0.50)	71/127 (0.56)	5.3	1.48
⑳	4/8 (0.50)	27/30 (0.90)	202.7	91.22
Tamjin-gang				
㉑-1.	18/21 (0.86)	445/680 (0.65)	152.5	85.25
㉑-2.	21/25 (0.84)	422/940 (0.48)	63.1	25.44
㉒	14/17 (0.82)	326/491 (0.66)	121.1	65.54
Seomjin-gang				
㉓	7/15 (0.47)	90/299 (0.30)	3.7	0.52
㉔-1.	18/29 (0.62)	128/257 (0.50)	86.8	26.91
㉔-2.	26/32 (0.81)	294/636 (0.46)	7.1	2.65
㉕	17/25 (0.68)	253/406 (0.62)	21.8	9.19
㉖-1.	14/15 (0.93)	207/288 (0.72)	43.1	28.86
㉖-2.	19/22 (0.86)	399/624 (0.64)	25.0	13.76
㉗	22/29 (0.76)	213/320 (0.67)	281.5	143.34
㉘	13/15 (0.87)	141/194 (0.73)	800.5	508.40
㉙	9/12 (0.75)	132/156 (0.85)	104.4	66.56
㉚	11/14 (0.79)	185/323 (0.57)	61.8	27.83
㉛	13/13 (1.0)	197/318 (0.62)	127.7	79.17
㉜	16/23 (0.70)	128/174 (0.74)	9.6	4.97
Nakdong-gang				
㉝	7/12 (0.58)	65/132 (0.49)	3.4	0.97
㉞	12/20 (0.60)	306/730 (0.42)	14.5	3.65
㉟-1.	11/26 (0.42)	146/399 (0.37)	3.8	0.59
㉟-2.	18/33 (0.55)	226/566 (0.40)	3.9	0.86
㉟-3.	16/29 (0.55)	162/708 (0.23)	28.4	3.59
㊱-1.	15/23 (0.65)	305/1,280 (0.24)	7.1	1.11
㊱-2.	20/23 (0.87)	308/813 (0.38)	5.0	1.65
㊲	18/19 (0.95)	760/869 (0.88)	228.2	190.78
㊳	5/13 (0.38)	71/123 (0.58)	6.4	1.41

(Continued to the next page)

Table 3. Continued

Locality surveyed	Positive rate[a] of fish species	Positive rate[b] with MsMc in (+)ve fish sp.	Mean no.[c] of MsMc detected	Endemicity[d]
Streams in east coastal areas				
㊴	11/13 (0.85)	100/128 (0.78)	263.0	174.37
㊵	8/15 (0.53)	63/111 (0.57)	41.8	12.63
㊶	9/13 (0.69)	193/226 (0.85)	307.0	180.06
㊷	10/17 (0.59)	146/246 (0.59)	33.6	11.70
㊸	7/12 (0.58)	50/103 (0.49)	3.4	0.97
㊹	9/17 (0.53)	98/255 (0.38)	110.2	22.19

[a]No. of positive fish species (PFS)/No. of fish spp. examined.
[b]No. of fish infected/No. of fish examined in PFS.
[d]Endemicity = $^a \times {}^b \times {}^c$.

Table 4. Distributions of endemicity with *Metagonimus* spp. metacercariae (MsMcs) in fish by the water systems in Korea

Locality (River) surveyed	No. of localities by the endemicity[a]				
	Very low	Low	Moderate	High	Total (%)
Hantan-gang and Imjin-gang	2	1	1	0	4 (7.8)
Han-gang	0	3	2	0	5 (9.8)
Geum-gang	4	3	0	0	7 (13.7)
Mangyeong-gang	1	1	0	0	2 (3.9)
Yeongsan-gang	2	0	0	1	3 (5.9)
Tamjin-gang	0	0	2	1	3 (5.9)
Seomjin-gang	2	3	4	3	12 (23.5)
Nakdong-gang	6	2	0	1	9 (17.6)
Streams in east coast	1	3	0	2	6 (11.8)
Total (%)	18 (35.3)	16 (31.4)	9 (17.6)	8 (15.7)	51 (100)

[a]Very low, below 3.0; Low, 3.01–25.0; Moderate, 25.01–75.0; High, over 75.01.

heung), ㉗ Seomjin-gang (Gurye), ㉘ Hwagye-cheon, ㉛ Hoeng-cheon, ㊲ Deokcheon-gang, ㊴ Namdae-cheon, and ㊶ Whangpi-cheon. The moderate levels were observed in fishes from 9 (17.6%) survey regions, i.e., ③ Togyo-jeosuji, ⑥ Joyang-gang, ⑨ Dal-cheon, ㉑-2 Tamjin-gang (Jangheung), ㉒ Tamjin-gang (Gangjin), ㉔-1 Seomjin-gang (Sunchang), ㉖-1 Seomjin-gang (Gokseong), ㉙ Akyang-cheon, and ㉚ Namsan-cheon. Fish from 16 (31.4%) locality showed low endemicity, which included ① Hantan-gang (Cheorwon), ⑤ Pyeongchang-gang, ⑦ Seom-gang (Hoengseong), ⑧ Seom-gang (Wonju), ⑪ Chogang-cheon, ⑬ Geum-gang (Geumsan), ⑮ Ji-cheon, ⑰-2 Soyang-cheon, ㉕ Songdae-cheon, ㉖-2 Seomjin-gang (Gokseong), ㉜ Jugyo-cheon, ㉞ Yongjeon-cheon, ㉟-3 Wi-cheon, ㊵ Osip-cheon (Samcheok), ㊷ Osip-cheon (Yeongdeok), and ㊹ Taehwa-gang and Cheokgwa-cheon, respectively. The endemicity of MsMc was very low in 18 (35.3%) region fish, i.e., ② Hantan-gang (Yeoncheon), ④ Imjin-gang, ⑩ Juja-cheon, ⑫ Geum-gang (Muju), ⑭ Yugu-cheon, ⑯ Nonsan-cheon, ⑰-1 Soyang-cheon, ⑱ Hwangryong-gang, ⑲ Jiseok-cheon, ㉓ Osu-cheon, ㉔-2 Seomjin-gang (Sunchang), ㉝ Banbyeon-cheon, ㉟-1 Wi-cheon, ㉟ -2 Wi-cheon, ㊱-1 Yang-cheon, ㊱-2 Yang-cheon, ㊳ Jisu-cheon, and ㊸ Gigye-cheon (Table 4).

Susceptibility of MsMc in the index fish, *Zacco* spp., by survey regions

Fig. 3. The index fish, *Zacco platypus* (A), *Z. temminckii* (B), and *Z. koreanus* (C). Male (top) and female (bottom), respectively. They are relatively susceptible to *Metagonimus* spp. metacercaria and widely distributed in Korean waters. Bar = 5 cm.

Three chub species, *Z. platypus*, *Z. temminckii,* and *Z. koreanus* (Fig. 3), which are widely distributed in the water systems in Korea, are appropriate to be the index fish to determine the endemicity of MsMc.

The SI of MsMc in index fish, *Zacco* spp., from water systems of Hantan-gang and Imjin-gang was ① Hantan-gang (Cheorwon) (30.09), ② Hantan-gang (Yeoncheon) (3.87), ③ To-gyo-jeosuji (131.24), and ④ Imjin-gang (13.19), respectively. In the water systems of Han-gang (⑤–⑨), SI was found to be 10.88, 106.33, 23.80, 45.98, and 80.67, respectively. In Ge-um-gang water system, the SI showed very low level at 0.27 (⑫ Geum-gang in Muju), 1.82 (⑭ Yugu-cheon), and 3.26 (⑩ Juja-cheon). It was low at 5.38 (⑮ Ji-cheon) and moderate at 43.70 (⑬ Geum-gang in Geumsan) and 74.0 (⑪ Chogang-cheon), respectively. No chub fish was examined in ⑯ Nonsan-cheon. The SI was very low and low in fish from ⑰ Mangyeong-gang (2.72 and 25.97). The SI of Yeongsan-gang tributaries was low at 8.77 and 5.24 in ⑱ (Hwangryong-gang) and ⑲ (Jiseok-cheon), while it was high at 283.77 in ⑳ (Yeongam-cheon). The SI of Tamjin-gang tributaries ㉑-1 (Jangheung: 30.02), ㉒ (Gangjin: 32.93), and ㉑-2 (Jangheung: 65.18) were at a moderate levels.

The SI in Seomjin-gang was very low in ㉓ Osu-cheon (2.22), low in ㉔-2 Seomjin-gang (Sunchang) (8.22), ㉜ Jugyo-cheon (9.97), ㉖-1 Seomjin-gang (Gokseong) (18.36), ㉔-1 Seomjin-gang (Sunchang) (18.90), and ㉖-2 Seomjin-gang (Gokseong) (26.98); moderate in ㉕ Songdae-cheon (39.37), ㉘ Hwagye-cheon (43.37), ㉗ Seomjin-gang (Gurye) (65.18), ㉚ Namsan-cheon (72.88), and ㉙ Akyang-cheon (76.55); and high in ㉛ Hoeng-cheon (192.27). The SI of MsMc in index fish from Nakdong-gang was relatively low except for in ㊲ Deok-

Table 5. Susceptibility index of the index fish *Zacco* spp. to *Metagonimus* spp. metacercariae (MsMc) according to the surveyed areas

Surveyed areas	No. fish examined	No. (%) fish infected	Mean no. MsMc detected	Susceptibility index[a]
Hantan-gang and Imjin-gang				
①	130	123 (94.6)	31.8	30.09
②	63	28 (44.4)	8.7	3.87
③	158	155 (98.1)	133.8	131.24
④	68	49 (72.1)	18.3	13.19
Han-gang				
⑤	54	52 (96.3)	11.3	10.88
⑥	59	58 (98.3)	108.2	106.33
⑦	28	24 (85.7)	27.8	23.80
⑧	148	143 (96.6)	47.6	45.98
⑨	30	27 (90.0)	89.6	80.67
Geum-gang				
⑩	80	55 (68.8)	4.7	3.26
⑪	6	6 (100)	74.0	74.0
⑫	11	3 (27.3)	1.0	0.27
⑬	60	55 (91.7)	47.7	43.70
⑭	59	37 (62.7)	2.9	1.82
⑮	33	20 (60.6)	8.9	5.38
⑯	0	-	-	-
Mangyeong-gang				
⑰-1.	128	73 (57.0)	4.8	2.72
⑰-2.	109	91 (83.5)	31.1	25.97
Yeongsan-gang				
⑱	15	14 (93.3)	9.4	8.77
⑲	50	46 (92.0)	5.7	5.24
⑳	19	19 (100)	283.8	283.77
Tamjin-gang				
㉑-1.	167	147 (88.0)	34.1	30.02
㉑-2.	233	210 (90.1)	72.3	65.18
㉒	101	95 (94.1)	35.0	32.93
Seomjin-gang				
㉓	100	57 (57.0)	3.9	2.22
㉔-1.	66	56 (84.8)	22.3	18.90
㉔-2.	147	108 (73.5)	11.2	8.22
㉕	119	110 (92.4)	42.6	39.37
㉖-1.	95	84 (88.4)	20.8	18.36
㉖-2.	218	183 (83.9)	32.2	26.98
㉗	77	65 (84.4)	77.2	65.18
㉘	70	68 (97.1)	44.7	43.37
㉙	65	65 (100)	76.5	76.55
㉚	156	156 (100)	72.9	72.88
㉛	125	117 (93.6)	205.4	192.27
㉜	78	65 (83.3)	12.0	9.97
Nakdong-gang				
㉝	64	46 (71.9)	3.9	2.78
㉞	228	184 (80.7)	20.0	16.14
㉟-1.	204	116 (56.9)	4.2	2.37
㉟-2.	243	167 (68.7)	3.6	2.45
㉟-3.	227	83 (36.6)	2.9	1.05
㊱-1.	322	204 (63.4)	4.6	2.95
㊱-2.	241	156 (64.7)	3.8	2.47
㊲	180	180 (100)	119.1	119.07
㊳	74	40 (54.1)	5.8	3.12

(Continued to the next page)

Table 5. Continued

Surveyed areas	No. fish examined	No. (%) fish infected	Mean no. MsMc detected	Susceptibility index[a]
Streams in east coastal areas				
㊴	38	38 (100)	42.6	42.58
㊵	15	13 (86.7)	13.8	11.96
㊶	45	36 (80.0)	4.9	3.88
㊷	67	56 (83.6)	9.3	7.73
㊸	41	24 (58.5)	2.4	1.40
㊹	80	42 (52.5)	3.3	1.76

[a]Prevalence/100 × mean No. of MsMc detected.

Table 6. Distributions of susceptibility of *Metagonimus* spp. metacercariae (MsMcs) in index fish, *Zacco* spp., by the water systems in Korea

Locality (River) surveyed	No. of localities by the susceptibility[a] in index fish				
	Very low	Low	Moderate	High	Total (%)
Hantan-gang and Imjin-gang	1	1	1	1	4 (8.0)
Han-gang	0	2	2	1	5 (10.0)
Geum-gang	3	1	2	0	6 (12.0)
Mangyeong-gang	1	1	0	0	2 (4.0)
Yeongsan-gang	0	2	0	1	3 (6.0)
Tamjin-gang	0	0	3	0	3 (6.0)
Seomjin-gang	1	5	5	1	12 (24.0)
Nakdong-gang	7	1	0	1	9 (18.0)
Streams in east coast	3	2	1	0	6 (12.0)
Total (%)	16 (32.0)	15 (30.0)	14 (28.0)	5 (10.0)	50 (100)

[a]Very low, below 5.0; Low, 5.01–30.0; Moderate, 30.01–100.0; High, over 100.01.

cheon-gang (119.07). It was very low in *Zacco* spp. from ㉟-3 Wi-cheon (1.05), ㉟-1 Wi-cheon (2.37), ㉟-2 Wi-cheon (2.45), ㊱-2 Yang-cheon (2.47), ㉝ Banbyun-cheon (2.78), ㊱-1 Yang-cheon (2.95), and ㊳ Jisu-cheon and Haman-cheon (3.12), respectively. The low SI was shown in index fish from ㉞ Yongjeon-cheon (16.14). In streams of the east coastal areas, the SI in fish from ㊸ Gigye-cheon (1.40), ㊹ Cheokgwa-cheon and Taehwa-gang (1.76), and ㊶ Wangpi-cheon (3.88) was very low, while it was low and moderate in ㊷ Osip-cheon (Yeongdeok) (7.73), ㊵ Osip-cheon (Samcheok) (11.96), and ㊴ Namdae-cheon (42.58) (Table 5).

Collectively, the SI in index fish, *Zacco* spp., is fairly high in 5 (10.0%) survey regions, i.e., ③ Togyo-jeosuji, ⑥ Joyang-gang, ⑳ Yeongam-cheon, ㉛ Hoeng-cheon, and ㊲ Deokcheon-gang. The moderate SI levels were observed in fishes from 14 (28.0%) survey regions, i.e., ① Hantan-gang (Cheorwon), ⑧ Seom-gang (Wonju), ⑨ Dal-cheon, ⑪ Chogang-cheon, ⑬ Geum-gang (Geumsan), ㉑-1, and ㉑-2 Tamjin-gang (Jangheung), ㉒ Tamjin-gang (Gangjin), ㉕ Songdae-cheon, ㉗ Seomjin-gang (Gurye), ㉘ Hwagyae-cheon, ㉙ Akyang-cheon, ㉚ Namsan-cheon, and ㊴ Namdae-cheon. The low SI was shown in index fish from 15 (30.0%) regions, i.e., ④ Imjin-gang, ⑤ Pyeongchang-gang, ⑦ Seom-gang (Hoeng-seong), ⑮ Ji-cheon, ⑰-2 Soyang-cheon, ⑱ Hwangryong-gang, ⑲ Jiseok-cheon, ㉔-1 and -2 Seomjin-gang (Sunchang), ㉖-1 and ㉖-2 Seomjin-gang (Gokseong), ㉜ Jugyo-cheon, ㉞ Yongjeon-cheon, ㊵ Osip-cheon (Samcheok), and ㊷ Osip-cheon (Yeongdeok). The SI was very low in 16 (32.0%) regions, i.e., ② Hantan-gang (Yeoncheon), ⑩ Juja-cheon, ⑫ Geum-gang (Muju), ⑭ Yugu-cheon, ⑰-1 Soyang-cheon, ㉓ Osu-cheon, ㉝ Banbyeon-cheon, ㉟-1, ㉟-2 and ㉟-3 Wi-cheon, ㊱-1 and ㊱-2 Yang-cheon, ㊳ Jisu-cheon, ㊶ Whangpi-cheon, ㊸ Gigye-cheon, and ㊹ Taehwa-gang (+Cheokgwa-cheon), respectively (Table 6).

Infection status of MsMc in highly susceptible fish, *Plecoglossus altivelis*

The sweet smelt, *P. altivelis* (Fig. 4), has been known as the main infection source of human metagonimiasis in the endemic areas of Korea. This fish species has been popularly eaten in raw by the residents in the eastern and southern endemic areas. The epidemiological studies on the infections of MsMc in sweet smelt have been conducted by many workers in east and south coastal areas of Korean peninsula [14-18,27,29,33-35,37,38,41,43,48]. However, these studies have not been currently conducted in Korea. In this review, the recent infection status of MsMc was analyzed in 346 sweet smelt in 13 survey regions.

In Tamjin-gang, MsMc were detected 93 (98.9%) out of 94 sweet smelt in 2 survey regions, Jangheung-gun (53/54; 98.1%) and Gangjin-gun (40/40). Their infection intensity was 1,125 PFI (1,339 and 841 PFI, respectively). MsMc were found in 34 (75.6%) out of 45 sweet smelt from 5 survey regions (Sunchang, Gokseong, Gurye, Hwagye-cheon, and Akyang-cheon) in Seomjin-gang branches. Their overall infection intensity was 5,421 PFI (3,146, 826, 8,563, 6,830, and 4,215 PFI, respectively). In sweet smelt from Deokcheon-gang, an inland branch stream of Nakdong-gang, MsMc were detected in 40 (97.6%) out of 41 fish examined. The infection intensity averaged 3,570 PFI. MsMc were found 157 (94.6%) out of 166 sweet smelt from 5 survey regions, i.e., Namdae-cheon, Osip-cheon (Samcheok), Whangpi-cheon, Osip-cheon (Yeongdeok), and Taehwa-gang, in the east coastal areas. Their overall infection intensity was 558 MsMc PFI (1,522, 18, 939, 63, and 331 PFI, respectively). The infection status of MsMc in the most susceptible fish host, *P. altivelis*, by the survey localities was presented in Table 7.

Infection status of MsMc in some susceptible fish species

Except for the highly susceptible fish species, *P. altivelis*, MsMc were detected in 9 fish species, i.e., 3 *Zacco* spp., *O. uncirostris*, *Rhynchocypris oxycephalus*, *C. auratus*, *Acheilognathus rhombeus*, *O. masou*, and *T. hakonensis*. Infection status of MsMc by the fish species and by survey localities are summarized in Table 8.

Fish intermediate hosts of *Metagonimus* spp. in Korea

Fig. 4. Sweet smelt, *Plecoglossus altivelis*, the most susceptible and heavily infected fish with *Metagonimus* spp. metacercariae. The fish is common in rivers and streams on the east and south coasts of Korea. Bar = 5 cm.

Table 7. Infection status of *Metagonimus* spp. metacercariae (MsMc) of sweet smelt *Plecoglosus altivelis*, in the most susceptible fish host, by survey localities

Locality surveyed	No. fish examined	No. (%) fish infected	No. MsMc detected	
			Range	Average
Tamjin-gang				
㉑-1 (Jangheung)	40	39 (97.5)	1–5,320	1,290
㉑-2 (Jangheung)	14	14 (100)	80–5,280	1,476
㉒ (Gangjin)	40	40 (100)	26–4,280	841
Seomjin-gang				
㉔-1 (Sunchang)	3	3 (100)	282–6,750	3,146
㉖-1 (Gokseong)	2	2 (100)	1,370–4,380	2,875
㉖-2 (Gokseong)	16	5 (31.3)	1–16	7
㉗ (Gurye)	6	6 (100)	3,250–16,830	8,563
㉘ (Hwagye-cheon)	16	16 (100)	1,310–17,750	6,830
㉙ (Akyang-cheon)	2	2 (100)	3,565–4,865	4,215
Nakdong-gang				
㊲ (Deokcheon-gang)	41	40 (97.6)	3–20,650	3,570
Water systems in the eastern coastal regions				
㊴ (Namdae-cheon)	15	15 (100)	49–6,280	1,522
㊵ (Osip-cheon)	3	2 (66.7)	14–21	18
㊶ (Whangpi-cheon)	59	59 (100)	2–6,199	939
㊷ (Osip-cheon)	73	65 (89.0)	1–597	63
㊹ (Cheokgwa-cheon)	16	16 (100)	50–1,920	331

Table 8. Fish species highly infected with *Metagonimus* spp. metacercariae (MsMc) excluding sweet smelt

Fish species	Locality (no. fish positive/no. fish examined mean no. MsMc detected) surveyed
Zacco platypus	③ Togyo-jeosuji (137/139; 144), ⑨ Dal-cheon (15/15; 126), ⑪ Chogang-cheon (3/3; 102), ⑳ Yeongam-cheon (15/15; 104), ㊲ Deokcheon-gang (62/62; 106)
Zacco koreanus	⑰-2. Soyang-cheon (25/28; 90), ㉙ Akyang-cheon (40/40; 98), ㉚ Namsan-cheon (74/74; 104), ㊲ Hoeng-cheon (70/70; 273), ㊲ Deokcheon-gang (118/118; 126)
Zacco temminckii	⑥ Joyang-gang (38/39; 130), ⑳ Yeongam-cheon (4/4; 958), ㉑-2. Tamjin-gang (112/119; 113), ㉒ Tamjin-gang (25/26; 110), ㉚ Namsan-cheon (19/19; 97), ㉛ Hoeng-cheon (10/10; 157)
Opsariichthys uncirostris	⑧ Seom-gang (1/1; 260), ⑨ Dal-cheon (1/1; 380), ⑬ Geum-gang (8/8; 88), ㉖ -1 Seomjin-gang (2/2; 387), ㉗ Seomjin-gang (13/13; 144), ㉞ Yongjeon-cheon (3/3; 89)
Rhynchocypris oxycephalus	㉟-3. Wi-cheon (4/4; 747), ㊹ Cheokgwa-cheon (20/21; 266)
Carassius auratus	㉑-1. Tamjin-gang (51/75; 156)
Acheilognathus rhombeus	㉑-1. Tamjin-gang (5/5; 501), ㉗ Seomjin-gang (1/1; 185)
Onchorhynchus masou	㊴ Namdae-cheon (6/6; 200), ㊵ Osip-cheon (8/8; 253)
Tribolodon hakonensis	㊴ Namdae-cheon (2/2; 245), ㊶ Wangpi-cheon (16/16; 115)

Metacercaria of *Metagonimus* spp. was firstly described from crusian carp, *C. auratus* in 1917 [25]. Thereafter, many workers reported the fish intermediate hosts of *Metagonimus* spp. in Korea [22,23,26-28,30,32,39,40,47,65,71-74]. Sohn [26] collectively arranged the fish intermediate hosts of *Metagonimus* spp. and nominated 44 fish species in 6 families (Cyprinidae: 32 spp., Amblycipitidae: 1 sp., Bagridae: 2 spp., Centrarchidae: 1 sp., Cobitidae: 2 spp., Gobiidae: 1 sp., Lateolabracidae: 1 sp., Osphronemidae: 1 sp., Plecoglossidae: 1 sp., and Sinipercidae: 2 spp.). Recently, we added 30 fish species, which included *Acanthorhodeus macropterus*, *Acheilognathus koreensis*, *A. majusculus*, *A. signifer*, *A. somjinensis*, *Hemibarbus mylodon*, *Hemiculter leucisculus*, *Ladislabia taczanowskii*, *Microphysogobio ko-*

Table 9. The fish intermediate hosts of *Metagonimus* spp. in Korea

Family	Genus	Species[a]
Cyprinidae	*Abbottina*	*A. rivularis, A. springeri*
	Acanthorhodeus	*A. gracilis, A. macropterus*[b]
	Acheilognathus	*A. asmussi, A. koreensis*[b]*, A. lanceolate, A. majusculus*[b]*, A. rhombeus, A. signifer*[b]*, A. somjinensis*[b]*, A. yamatsutae*
	Aphyocypris	*A. chinensis*
	Carassius	*C. auratus*
	Coreoleuciscus	*C. splendidus*
	Cyprinus	*C. carpio*
	Gnathopogon	*G. strigatus*
	Gobiobotia	*G. brevibarba*
	Hemibarbus	*H. labeo, H. longirostris, H. mylodon*[b]
	Hemiculter	*H. eigenmanni, H. leucisculus*[b]
	Ladislabia	*L. taczanowskii*[b]
	Microphysogobio	*M. koreensis*[b]*, M. longidorsalis*[b]*, M. yaluensis*
	Opsariichthys	*O. uncirostris amurensis*
	Pseudogobio	*P. esocinus*
	Pseudopuntungia	*P. nigra, P. tenuicorpa*[b]
	Pseudorasbora	*P. parva*
	Puntungia	*P. herzi*
	Rhodeus	*R. ocellatus, R. pseudosericeus*[b]*, R. uyekii*
	Rhynchocypris	*R. oxycephalus*
	Sarcocheilichthys	*S. nigripinnis morii, S. variegatus wakiyae*
	Squalidus	*S. japonicus coreanus*[b]*, S. gracilis majimae,*
		S. chankaensis tsuchigae, S. multimaculatus[b]
	Tribolodon	*T. hakonensis*
	Zacco	*Z. platypus, Z. temminckii, Z. koreanus*[b]
Amblycipitidae	*Liobagrus*	*L. andersoni*[b]*, L. mediadiposalis, L. somjinensis*[b]
Bagridae	*Coreobagrus*	*C. brevicorpus*
	Pseudobagrus	*P. fulvidraco, P. koreanus*[b]
Channidae	*Channa*	*C. argus*[b]
Centrarchidae	*Lepomis*	*L. macrochirus*
	Micropterus	*M. salmoides*[b]
Cobitidae	*Cobitis*	*C. sinensis*[b]
	Iksookimia	*I. koreensis*
	Koreocobitis	*K. naktongensis*[b]
	Misgurnus	*M. anguillicaudatus*
Cottidae	*Cottus*	*C. hangiogensis*[b]
Gobiidae	*Acanthogobius*	*A. lactipes*[b]
	Gymnogobius	*G. urotaenia*[b]
	Rhinogobius	*R. brunneus*
	Tridentiger	*T. brevispinis*[b]
Lateolabracidae	*Lateolabrax*	*L. japonicus*
Mugilidae	*Mugil*	*M. cephalus*[b]
Odontobutidae	*Odontobutis*	*O. interrupta*[b]*, O. platycephala*[b]
Osphronemidae	*Macropodus*	*M. ocellatus*
Plecoglossidae	*Plecoglossus*	*P. altivels*
Salmonidae	*Oncorhynchus*	*O. masou masou*[b]
Sinipercidae	*Coreoperca*	*C. herzi*
	Siniperca	*S. scherzei*

[a]A total of 74 fish species (15 families) are listed as second intermediate hosts of *Metagonimus* spp. in Korea, of which 44 species were previously listed [26], and the remaining 30 spp. [b] were newly added [49-51, 57-62].

reensis, *M. longidorsalis*, *Pseudopuntungia tenuicorpa*, *Rhodeus pseudosericeus*, *Squalidus japonicus coreanus*, *S. multimaculatus, Zacco koreanus, Liobagrus andersoni, L. somjinensis, Pseudobagrus koreanus, Channa argus, Micropterus salmoides, Cobitis sinensis, Koreocobitis naktongensis, Cottus hangiogensis, Acanthogobius lactipes, Gymnogobius urotaenia, Tridentiger brevispinis, Mugil cephalus, Odontobutis interrupta, O. platycephala,* and *Oncorhynchus masou masou*, in the list of the second intermediate hosts [49-51,57-62]. Among them, 3 gobiid fish species, i.e., *A. lactipes, G. urotaenia*, and *T. brevispinis*, are mainly inhabit in brackish water. These fish species were reported as the second intermediate hosts of *M. otsurui* in Japan [75-77]. However, no MsMc were found in a total of 239 fish in 7 gobiid spp., i.e., *Acanthogobius flavimanus* ($n=76$), *A. lactipes* (42), *Tridentiger brevispinis* (44), *T. trigonocephalus* (11), *T. obscurus* (10), *Gymnogobius castaneus* (41), and *Favonigobius gymnauchen* (15), from 5 coastal lakes in Gangwon-do. MsMc were mainly detected in sea rundace, *T. hakonensis* [58]. As summarized in Table 9, 74 fish species in 15 families are currently designated as the second intermediate hosts of *Metagonimus* spp. in Korea.

Concluding remark

Metagonimiasis is one of the fish-borne trematodiasis, which is still endemic in Korea. This endemic disease causes a significant public health concern among residents in some major river basins. The infection status of MsMc in fish hosts is intimately associated with transmission of human disease. This article reviewed data from 10 years (2011–2020) of our research. The infection status of MsMc was analyzed for 19,568 fish of 87 species collected from 9 main water systems in Korea, such as Hantan-gang and Imjin-gang, Han-gang, Geum-gang, Mangyeong-gang, Yeongsan-gang, Tamjin-gang, Seomjin-gang, Nakdong-gang, and streams in the east coastal areas. This study clarifies some of the characteristics of MsMc infection in fish: The high endemicity was observed in fish from middle and low reaches of Seomjin-gang, Tamjin-gang (Jangheung-gun in Jeollanam-do), Deokcheon-gang (Sancheong-gun in Gyeongsangnam-do), Namdae-cheon (Yangyang-si in Gangwon-do), Whangpi-cheon (Uljin-gun in Gyeongsangbuk-do), and Yeongam-cheon (Yeongam-gun in Jeollanam-do). The high endemicity of MsMc depends on the number of susceptible fish species, especially sweet smelt, *P. altivelis*, and some other species. The infection status of MsMc in index fish, *Zacco* spp., might represent the overall infection patterns of the fish hosts. The susceptibility of *Zacco* spp. to MsMc was found to be very low and low in 62.0% of the areas, and moderate and high in 38.0% of the regions. This study also analyzed recent infection status of MsMc, which is the most susceptible fish host, *P. altivelis*. Except for the sweet smelt, 9 fish species, i.e., *Z. platypus*, *Z. koreanus*, *Z. temminckii*, *O. uncirostris*, *R. oxycephalus*, *C. auratus*, *A. rhombeus*, *O. masou*, and *T. hakonensis* showed the higher infections with MsMc in some survey regions. In Korea, 74 species in 15 families of fish have been collectively registered as second intermediate hosts of *Metagonimus* spp.

Nowadays, the endemicity of MsMc infections in fish hosts and the incidence of human metagonimiasis are gradually decreasing in this country. However, continuous monitoring of infection status of fish hosts is required to control and manage metagonimiasis affecting humans and reservoir hosts. In faunistic view point, studies on the species diversity of *Metagonimus* fluke including previously reported 3 spp. should be performed with ecologically different worm samples by the biological, morphological, and molecular approaches in Korea.

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