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The Asian cyclopoid copepod *Mesocyclops pehpeiensis* Hu, 1943 reported from the western basin of Lake Erie

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Abstract

The Asian cyclopoid copepod *Mesocyclops pehpeiensis* Hu, 1943 has been reported as an introduced species at several locations in the western hemisphere. In the United States, reports of this exotic species are restricted to localities in Louisiana, Mississippi, and Washington D.C. This report documents a new record of occurrence for *M. pehpeiensis* from the western basin of Lake Erie. The detection of *M. pehpeiensis* in Lake Erie constitutes the first record of this species from the Laurentian Great Lakes, and the northernmost record in the western hemisphere. The species was found in 2016, 2017 and 2018, including females with egg sacks, and can therefore be considered established in the area. The occurrence of *M. pehpeiensis* in Lake Erie suggests that this Asian copepod may be more widely distributed in North America than is currently understood.

Keywords

Copepoda; Laurentian Great Lakes; New species record; Biological monitoring; Non-indigenous species

Introduction

The Asian cyclopoid copepod *Mesocyclops pehpeiensis* Hu, 1943 was collected from the western basin of Lake Erie in 2016, 2017, and 2018. *M. pehpeiensis* is native to Central, South, Southeast, and East Asia, occupying a natural range extending from 50°N to 7°S (Suárez-Morales et al., 2005). *M. pehpeiensis* has been previously reported from Kazakhstan (Mirabdullayev et al., 1995; as the synonym *M. ruttneri* Kiefer, 1891), Uzbekistan (Mirabdullayev, 1996), India (Hoły ska et al., 2003), China (Hu, 1943; Guo, 2000), Japan (Kawabata and Defaye, 1994), and several other countries within this range. However,

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reports of the species from Malaysia (Lim and Fernando, 1985) and Sri Lanka (Dussart and Fernando, 1988) apparently refer to congeners other than *M. pehpeiensis* (Guo, 2000). In the western hemisphere, isolated occurrences of *M. pehpeiensis* have been reported from both the Neotropical and Nearctic regions. In the Neotropics, *M. pehpeiensis* has been reported only from the state of Chiapas, Mexico (Suárez-Morales et al., 2005), and Havana City province, Cuba (Menéndez Diaz et al., 2006). In the Nearctic, *M. pehpeiensis* has been reported only from Louisiana, Mississippi (Reid, 1993; Reid and Marten, 1995) and Washington D.C., United States (J.W. Reid, unpublished). This report extends the known distribution of *M. pehpeiensis* in North America well northward, to nearly 42°N. The Lake Erie occurrence of *M. pehpeiensis* is the first record of this Asian species from the Laurentian Great Lakes and represents the second detection of a new exotic cyclopoid copepod species in Lake Erie since 2014 (Connolly et al., 2017).

Methods

Samples were collected as part of the U.S. Environmental Protection Agency's (U.S. EPA) Great Lakes National Program Office (GLNPO) Great Lakes zooplankton genetic barcoding effort. Offshore samples were collected with a 0.5 m diameter, 63 µm-mesh plankton net towed vertically through the water column from 2 m above the lake bottom to the water surface. Offshore samples were collected at U.S. EPA GLNPO Biological Monitoring Program stations aboard the *R/V Lake Guardian*, following a standard operating procedure for field sampling (U.S. EPA, 2013). Nearshore samples were collected with a 15 cm-diameter, 53 µm-mesh miniature plankton net towed horizontally just below the water surface 5 to 10 times. Samples were preserved in 90% (or higher) non-denatured ethanol.

Preserved samples were drained of ethanol and transferred to deionized water for taxonomic sorting under an Olympus SZX7 dissecting microscope. Specimens of *M. pehpeiensis* were transferred to 75 mm × 25 mm glass slides in a drop of glycerin for dissection, and semi-permanent slide mounts were made using 22 mm round cover glasses and Permount™. Taxonomically important microcharacters were observed at higher magnifications, under an Olympus CX41 compound microscope. Photomicrographs were taken using an ACCU-SCOPE® Excelis HD microscope camera. All specimen measurements were taken using an Olympus CX41 compound microscope with a drawing tube and a GTCO CalComp DrawingBoard VI™.

Results

In total, 29 adult females and two CV copepodids of *M. pehpeiensis* were collected from the western basin of Lake Erie. The two CV copepodids were collected from the U.S. EPA monitoring station ER60 (41.8920, -83.1962) at a depth of 6.6 m on April 3, 2016, and measured 0.80 mm and 0.91 mm in length (tip of rostrum to end of caudal ramus, excluding caudal setae). One adult female specimen was collected from the U.S. EPA monitoring station ER60 at a depth of 5 m on August 13, 2017, and measured 1.36 mm in length. One adult female specimen was collected from East Harbor (41.5500, -82.8073), a small embayment of Lake Erie at < 1 m depth on November 10, 2017, and measured 1.21 mm in length. No egg sacs were observed attached to adult female specimens collected in 2017.

Twenty-five adult female *M. pehpeiensis* specimens were collected from Old Woman Creek (41.3772, -82.5101), a small tributary of Lake Erie at <1 m depth on September 18, 2018. Specimens collected from Old Woman Creek measured from 1.16 mm to 1.40 mm and averaged 1.30 mm in length. Eighteen of the 25 specimens collected from Old Woman Creek were observed with egg sacs attached. Two adult female specimens were collected from East Harbor at < 1 m depth on September 20, 2018 and measured 1.41 mm and 1.54 mm in length; one of them had egg sacs attached.

Morphological Description

The morphology of the Lake Erie adult female *M. pehpeiensis* specimens can be described as follows. The body form in general is cyclopiform (Fig. 1) and resembles the Great Lakes natives *M. edax* and *M. americanus*. Antennule (A1) of 17 segments, spinules present on segments 1,4,5, and 7–13. Antennule segment 16 has a smooth hyaline membrane, segment 17 with a serrate hyaline membrane with a deep notch toward the distal end (Fig. 2). Antennal (A2) basiopod frontal surface has a nearly continuous longitudinal row of approximately 24 large spinules (Fig. 3a). Antennal basiopod caudal surface has a proximally placed oblique row of approximately 8 spinules, a longitudinal row of approximately 12 large spinules (Fig. 3b), an oblique row of approximately 14 tiny spinules along the medial margin, a subdistal transverse row of 5–7 tiny spinules just proximal to the insertion of the medial seta (Fig. 3c), and a row of 2–3 tiny spinules at the distalmost margin (Fig. 3d). Antennal endopodite 2 has 7 setae. Maxilla syncoxopodite with a small patch of tiny spinules. Maxilliped has 2 conspicuous dense patches of spinules, one medially placed and one distally placed. Swimming legs (P1–P4) have spine formula of third exopodite being 2,3,3,3. The full spine and setal formulae of swimming legs, following Sewell (1949), are described in Table 1. P1 basiopod lacks a medial spine. P1 (Fig. 4) –P3 medial margin of basiopod haired and coupler (intercoxal sclerite) unornamented. Coxa ornamentation positions, described following Einsle (1996), are as follows. P1 coxa ornamented with hairs at positions B and F. P2 and P3 coxa ornamented with spinules at positions A, B, and hairs at position F. P4 coxa ornamented with spinules at positions A, C, D, and E (Fig. 5). P4 basiopod medial margin is unhaired and P4 coupler has 2 long spiniform protrusions (Fig. 6). Leg 5 (P5) has subapical seta inserted near midpoint of distal segment, both apical and subapical setae extending beyond midpoint of genital double-somite. Genital double-somite has lateral arms of seminal receptacle relatively long, and transverse ducts forming V-shape near curved copulatory pore (Fig. 7). Anal somite is ornamented with spinules along the entirety of the distal margin. Caudal rami are approximately 3 times longer than wide, with the inner margins bare. Lateral caudal seta and lateral most terminal caudal seta (S4) has a short row of spinules at the insertion.

Discussion

Mesocyclops pehpeiensis superficially resembles the Great Lakes native copepods *M. edax* and *M. americanus* but several morphological characters separate the species. *M. pehpeiensis* can be easily distinguished from the common plankter *M. edax* by the lack of hairs on the inner margins of the caudal rami and the lack of a medial spine on the P1 basiopod. Discrimination between *M. pehpeiensis* and *M. americanus* is more difficult as

both species are members of the leuckarti group, similarly lacking the above-mentioned medial spine on the P1 basiopod. However, the long spiniform protrusions on the P4 coupler (Fig. 6) of *M. pehpeiensis* differs greatly from the small pointed or triangular protrusion on the P4 coupler of *M. americanus* and from the small rounded protrusions on the P4 coupler of *M. edax*. Additionally, the number of setae on the antennal endopodite 2 differ in each species: *M. edax* with 9 setae, *M. pehpeiensis* with 7 setae, and *M. americanus* with 6 setae.

M. pehpeiensis can occur in a variety of freshwater environments but may prefer eutrophic lentic water bodies (Holy et al., 2003). In its native Asian range, *M. pehpeiensis* females can reach 1.7 mm (Hu, 1943) and average 1.34 mm in length (Guo, 2000). Introduced populations in the Americas are reportedly smaller in size with females reaching 1.1 mm to 1.2 mm in length (Reid, 1993; Suárez-Morales et al., 2005). In the present study, *M. pehpeiensis* adult females from Lake Erie ranged from 1.16 mm to 1.54 mm and averaged 1.30 mm in length. The average lifespan reported for *M. pehpeiensis* was approximately 51 days, mating can occur multiple times, the average clutch size was approximately 90 eggs, and the time period between each clutch was approximately 1.5 days (Phong et al., 2008).

The ecological impacts of *M. pehpeiensis* on the zooplankton community of Lake Erie are at present uncertain (U.S. FWS, 2018). As are most cyclopoid copepods, larger individuals of this species are omnivores, consuming both zooplankton and phytoplankton in laboratory feeding experiments (Sarma et al. 2013). They are selective predators, *M. pehpeiensis* preferred the rotifers *Brachionus havanaensis*, *B. rubens* and the cladoceran *Moina macrocopa* (Sarma et al., 2013) in the laboratory. In mesocosm experiments, *M. pehpeiensis* exhibited selective feeding behavior, negatively impacting the cladoceran *Bosmina fatalis* while not affecting a similar species *B. longirostris* (Chang and Hanazato, 2005). The depression of cladoceran abundances in these experiments lead to a subsequent increase in rotifer abundances (Chang and Hanazato, 2005). Nagata et al. (2006) showed that *M. pehpeiensis* predation depressed abundances of the calanoid copepod *Eodiaptomus japonicus* and the cladocerans *Bosminopsis deitersi*, *Bosmina longirostris*, and *Ceriodaphnia megops* in mesocosm experiments. Hwang et al. (2009) found that *M. pehpeiensis* predation depressed populations of the cladocerans *Ceriodaphnia cornuta*, *Daphnia similoides*, *Moina macrocopa*, and *Scapholeberis kingii*. *M. pehpeiensis* may also prey on mosquito larvae. Dieng et al. (2002) showed that *M. pehpeiensis* was an effective predator on the first three larval instars of *Aedes albopictus*. Therefore, *M. pehpeiensis*, if it reaches high population levels, can be expected to affect populations of rotifers and cladocerans, and possibly calanoid copepods to some degree.

The means by which *M. pehpeiensis* may have arrived in Lake Erie is a matter of conjecture. *M. pehpeiensis* has successfully established populations beyond its natural range in Spain (Montoliu et al., 2015), Ukraine (Anufrieva et al., 2014; Anufrieva and Shadrin, 2016), Mexico (Suárez-Morales et al., 2005), Cuba (Menéndez Diaz et al., 2006), and the United States (Reid, 1993; Reid and Marten, 1995; Reid, unpublished). *M. pehpeiensis* was collected from multiple locations in the Lake Erie drainage from 2016 to 2018 and as a result should be considered established in Lake Erie. The species was reported by Kiefer (1981), under the synonym *Mesocyclops ruttneri*, from a greenhouse in Austria, suggesting that transport along with imported ornamental plants or agricultural practices may be

responsible for some introductions. Montoliu et al. (2015) reported *M. pehpeiensis* from Valencia, Spain, collected from a rice paddy in an area described as agriculturally active. Reid (1993) suggested that this exotic species may have been originally introduced to Louisiana and Mississippi along with imported ornamental aquatic plants, fish, or rice. Reid and Marten (1995) found *M. pehpeiensis* (then identified as “*M. ruttneri*”) in high densities in a pond-like canal, and remarked that the species appeared to be well-established in the area around New Orleans, Louisiana. Reid (unpublished) reported *M. pehpeiensis* (again as “*M. ruttneri*”) from the waters of aquatic gardens in Washington D.C., again suggesting that transport of the species may be associated with ornamental plants or agriculture. In the state of Chiapas, on the southern Pacific coast of Mexico, the introduction of *M. pehpeiensis* was believed to be related to aquaculture practices, specifically the importation of Malayan prawns (Suárez-Morales et al., 2005). Detections of *M. pehpeiensis* from the Crimean peninsula (Anufrieva et al., 2014) and eastern Ukraine (Anufrieva and Shadrin, 2016) probably represent natural range expansions rather than introductions related to human activity. The Lake Erie *M. pehpeiensis* population may be the result of an anthropogenic introduction. Given the circumstances surrounding other documented introductions of *M. pehpeiensis* beyond its natural range, it is more likely that the occurrence of this species in Lake Erie is related to the ornamental aquatic plant trade, aquaculture, or agricultural practices (particularly wet rice agriculture) rather than ballast water. Transport of copepod resting stages via migratory birds, as suggested by Reid and Reed (1994) and Suárez-Morales and Arroyo-Bustos (2012) from introduced populations of *M. pehpeiensis* in the southern United States, Mexico, or Cuba is another possible vector for the introduction into Lake Erie. Notably, Lake Erie and associated wetlands are part of the Mississippi Flyway for migratory waterfowl. The occurrence of *M. pehpeiensis* in Lake Erie, well north of the documented distribution of the species in the western hemisphere, suggest that *M. pehpeiensis* is more widely distributed in North America than is currently known. Researchers in North America should remain alert for occurrences of this exotic copepod.

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Figure 1:
Dorsal view of *Mesocyclops pehpeiensis* female specimen from Lake Erie.

Figure 2:
Mesocyclops pehpeiensis female: antennule (A1) segments 16 and 17 with hyaline membrane.

Figure 3:
Mesocyclops pehpeiensis female: (A) antenna (A2) basiopod frontal surface. (B) antenna basiopod caudal surface. (C) antenna basiopod caudal surface, showing subdistal row of tiny spinules. (D) antenna basiopod caudal surface, showing distal row of tiny spinules.

Figure 4:
Mesocyclops pehpeiensis female: Leg 1 (P1), coupler; note lack of ornamentation, and medial margin of basiopod with hairs.

Figure 5:
Mesocyclops pehpeiensis female: Leg 4 (P4) coxa ornamentation.

Figure 6:
Mesocyclops pehpeiensis female: Leg 4 coupler with long spiniform protrusions.

Figure 7:
Mesocyclops pehpeiensis female: genital double-somite showing genital field.

Table 1:

Swimming leg (P) spine and setal formula of Lake Erie *Mesocyclops pehpeiensis* specimens, following Sewell (1949).

	Coxa	Basis	Exopod	Endopod
P1	0-1	1-0	I-1; I-1; II, 1, 3	0-1; 0-2; 1,I, 4
P2	0-1	1-0	I-1; I-1; II, I, 4	0-1; 0-2; 1,I, 4
P3	0-1	1-0	I-1; I-1; II, I, 4	0-1; 0-2; 1,I, 4
P4	0-1	1-0	I-1; I-1; II, I, 4	0-1; 0-2; 1,II, 2