The Asian *Mesocyclops pehpeiensis* Hu, 1943 (Crustacea, Copepoda, Cyclopidae) in Southeast Mexico with comments on the distribution of the species

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ABSTRACT
The known distribution of *Mesocyclops pehpeiensis* Hu, 1943 includes South and Southeast Asia (India, Cambodge, Laos, Vietnam, Sri Lanka) and stretches eastwards to China and Japan. It has been recorded in the east coast of the United States as an introduced form. This species has not been found south of the United States or in tropical areas of the Americas. The analysis of samples collected in two ponds of the state of Chiapas, on the Pacific coast of Mexico, yielded the identification of male and female individuals of this species. The Mexican female individuals, like those found in the United States, tended to be slightly smaller than those of the type locality in China (1.2 mm vs 1.5 mm); the morphology of the Mexican specimens is identical in most characters to that described or depicted in previous works, including a recent redescription. Some of the morphologic and morphometric details of the caudal rami setae, the fourth leg endopod, and male and female antennules were found to differ among the different populations compared (Mexico, United States, China). This variability seems to be related to a speciation process in the group of Asian species of *Mesocyclops* to which

KEY WORDS
Crustacea,
Copepoda,
Cyclopidae,
faunistic,
zooplankton,
freshwater,
introduced species,
Mexico.

M. pehpeiensis belongs. This is the first report of this species in Mexico and it marks a new meridional limit of its distribution in the New World. This finding represents the fourth effective record of an introduced freshwater copepod species in Mexico and the second in the Mexican Pacific coast. It is speculated that the events by which this species invaded the Atlantic coast of the United States and now the tropical Pacific coast of Mexico are attributable to human agency and not inter-related.

RÉSUMÉ
L'espèce asiatique Mesocyclops pehpeiensis *Hu, 1943 (Crustacea, Copepoda, Cyclopidae) au sud-est du Mexique et commentaires sur sa distribution.*
La distribution connue de *Mesocyclops pehpeiensis* Hu, 1943 inclut l'Asie du Sud et du Sud-Est (Inde, Cambodge, Laos, Viêtnam, Sri Lanka) et s'étire vers l'est à la Chine et au Japon. Cette espèce a été trouvée sur la côte est des États-Unis suite à son introduction. Elle n'a pas été trouvée au sud des États-Unis ni dans les zones tropicales des Amériques. L'analyse d'échantillons récoltés dans deux mares de l'État du Chiapas (côte pacifique du Mexique) a permis l'identification d'individus mâles et femelles de cette espèce. Les individus femelles du Mexique, comme ceux des États-Unis, ont tendance à être légèrement plus petits que ceux de la localité type en Chine (1,2 mm *vs* 1,5 mm) ; les spécimens mexicains sont morphologiquement identiques pour la plupart des caractères à ceux décrits ou figurés dans les travaux précédents, incluant une redescription récente. Certains détails morphologiques et morphométriques des soies caudales, le quatrième endopode et les antennules mâles et femelles diffèrent entre les populations comparées (Mexique, États-Unis, Chine). Cette variabilité semble liée à un processus de spéciation dans le groupe des espèces asiatiques de *Mesocyclops* auquel appartient *M. pehpeiensis*. Ceci est la première mention de cette espèce au Mexique et marque une nouvelle limite méridionale pour sa distribution dans le Nouveau Monde. Cette découverte représente la quatrième mention effective d'un copépode d'eau douce introduit au Mexique et la seconde sur la côte pacifique mexicaine. L'hypothèse est proposée que les événements par lesquels cette espèce a envahi la côte atlantique des États-Unis et maintenant la côte pacifique tropicale du Mexique sont d'origine humaine et ne sont pas reliés.

MOTS CLÉS
Crustacea,
Copepoda,
Cyclopidae,
faunistique,
zooplancton,
eau douce,
espèce introduite,
Mexique.

INTRODUCTION

The freshwater cyclopoid copepod *Mesocyclops pehpeiensis* Hu, 1943 has a complex taxonomical history and its status and relationships with other congeners was under discussion for many years (Hołyńska *et al.* 2003). The recent redescription by Guo (2000) finally established a clear status and synonymies for this species.

This is a widespread tropical species known mainly from Asia (India, China, Sri Lanka, Indochina, China, Japan) (Dussart & Defaye 1985; Hołyńska 2000; Hołyńska *et al.* 2003). In the Americas, this species has been recorded only from the United States, many records of its synonym *M. ruttneri* Kiefer, 1981 are most probably referable to *M. pehpeiensis* (see Reid 1993; Hołyńska *et al.* 2003). This Asian species is consi-

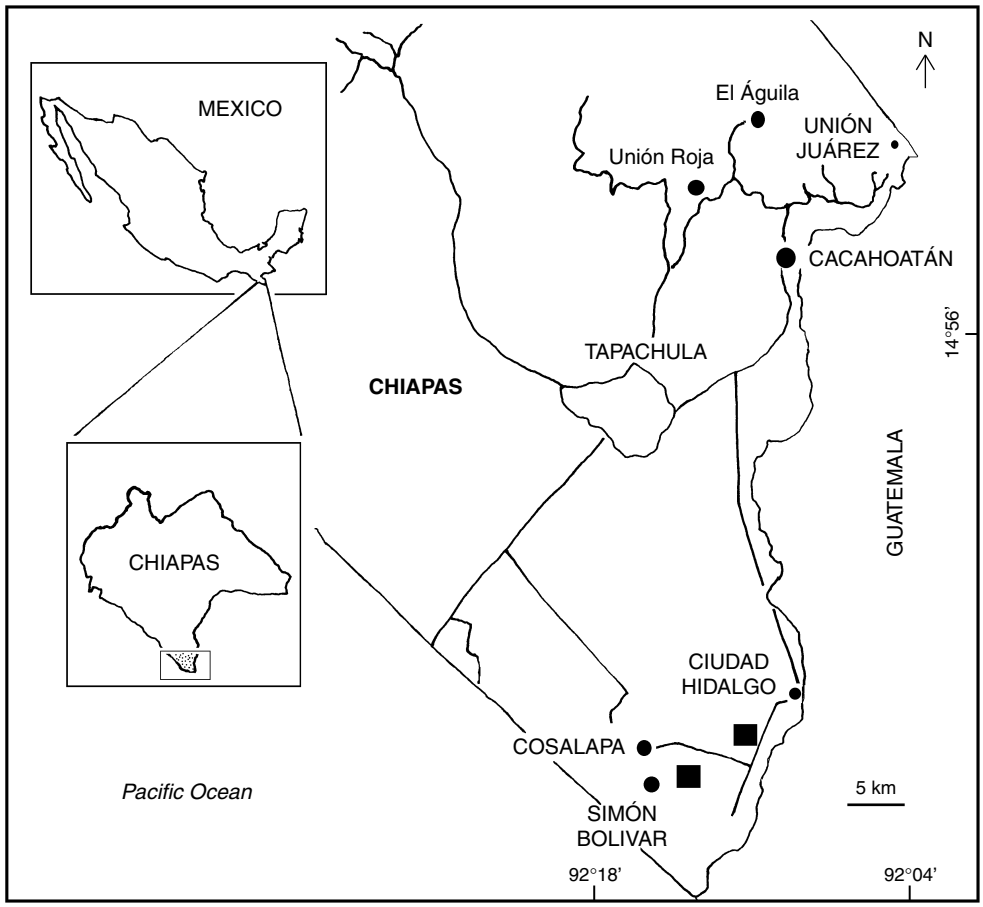

FIG. 1. — Map of area surveyed in the southern part of the state of Chiapas, Mexico, showing localities positive for *Mesocyclops pehpeiensis* Hu, 1943 (■).

dered to be an introduced form in the United States (Reid 1996; Hołyńska *et al*. 2003). Despite its occurrence in the United States and its wide distribution in tropical areas, this species has not been recorded in Mexico and Central or South America. Previous taxonomic accounts of species of *Mesocyclops* by Suárez-Morales & Reid (1998) and Suárez-Morales & Gutiérrez-Aguirre (2001) in Mexico did not include records of *M. pehpeiensis*.

From samples collected in different ponds in the coastal areas of the state of Chiapas, on the Pacific coast of Mexico, we report the occurrence of the Asian species *M. pehpeiensis* in this zone. The Mexican specimens were examined in full in order to make a reliable identification of this species which belongs to a group of Asian forms that have subtle morphological differences (Hołyńska 2000). Also, we provide complementary morphological data; a detailed comparison was made among the Chinese, the North American, and the Mexican populations in order to have additional data on the variability of this species.

MATERIAL AND METHODS

Zooplankton samples were collected in two small ponds located near the coast and outside the city of Tapachula, in Chiapas, Southeast Mexico. The

first pond is located in Simón Bolívar, near the city of Tapachula, Chiapas, Mexico (14°37'38"N, 92°16'08"W). The second site sampled is located on km 22 of highway to Ciudad Hidalgo, Cosalapa, Chiapas, Mexico (14°30'23"N, 92°16'12"W) (see Fig. 1). Samples were collected on August 29, 2003 and September 23, 2003, respectively, by Felipe Hernández. Zooplankton samples were collected with the aid of a scoop net with a mesh size of 0.05 mm. The specimens were sorted from the entire sample and identified using the descriptions and keys of Hołyńska (2000) and Hołyńska *et al*. (2003). Some individuals were processed for taxonomical examination which included dissection of the cephalic and thoracic appendages (Williamson & Reid 2001). The remaining specimens were preserved in 70% ethanol. Morphological observations were made under a standard microscope. Line illustrations were made using a camera lucida. Specimens were deposited in the collection of zooplankton of El Colegio de la Frontera Sur (ECO-CHZ) and in the collection of the Muséum national d'Histoire naturelle, Paris (MNHN).

SYSTEMATICS

Order CYCLOPOIDA Burmeister, 1934
Family CYCLOPIDAE G. O. Sars, 1913
Subfamily CYCLOPINAE G. O. Sars, 1913

Mesocyclops pehpeiensis Hu, 1943

MATERIAL EXAMINED. — Pond in Simón Bolívar, Chiapas, Mexico, 29.VIII.2003, 20 adult ♂♂, ethanol-preserved, 2 adult ♂♂, ethanol-preserved (ECO-CHZ-001667); same locality and date, 23 adult ♂♂ (ECO-CHZ-001672); same locality and date, 5 adult ♂♂, ethanol-preserved (MNHN-Cp 2181). — Additional material from highway to Ciudad Hidalgo, km 22, Cosalapa, Chiapas, Mexico, 23.IX.2003, 11 adult ♀♀, ethanol-preserved; same locality and date, 3 adult ♂♂, ethanol-preserved (collection of author).

MORPHOLOGY AND COMPARISONS

This species has been redescribed recently by Guo (2000); we based our morphological comparison on Guo's detailed work and on the redescription of *M. ruttneri* by Reid (1993). Some of the most important characters used for the identification of species of *Mesocyclops* (see Hołyńska *et al*. 2003) were considered to prepare the illustrations of the Mexican specimens of *M. pehpeiensis* (Figs 2-4). We present here the variant details detected on the body or appendages.

The morphology of the female and male specimens from Mexico agrees in general with the descriptions of Kiefer (1981), Reid (1993), Guo (2000), and Hołyńska *et al*. (2003). The size of this species seems to be variable in the different populations on areas (see Table 1), even in geographically restricted zones. The Chinese populations of females, however, have a tendency to be larger (1.2-1.7 mm) than the American ones (1.1-1.2 mm) (see Table 1). The body length of the males collected in Mexico (0.73-0.84 mm, average = 0.78 mm) falls within the range stated in Guo's (2000) redescription.

The morphology of the female antennule in the Mexican specimens is identical to that of *M. pehpeiensis*. The antennule of this species has rows of spinules on segments 1, 4 and 7-13; this feature is

TABLE 1. — Comparison of morphologic and morphometric characters in different populations of *Mesocyclops pehpeiensis* Hu, 1943. Characters based on Guo (2000): **CR**, caudal rami; **L4EN3**, third endopodal segment of fourth swimming leg; **TL**, total length to the distal end of CR. Setal nomenclature follows Guo (2000): **Sd**, dorsal seta; **Se**, outermost terminal seta; **Si**, innermost seta; **Sme**, outer medial seta; **Smi**, inner medial seta. **A**, antennular segment; **L**, length; **W**, width.

	Body length (mm)	L/W CR	L/W L4EN3	Si/Sme	Smi/TL	Sme/Smi	Si/Se	CR/Sd	A17/A16
China (Hu 1943)	1.5-1.7	3.5-4.0	3.6-4.0	0.66	0.50	0.66	–	–	–
China (Guo 2000)	1.2-1.5	3.5-4.0	2.6-2.9	0.65	0.47	0.64	3.6	1.38	0.68
USA (Reid 1993)	1.1	2.81	2.6	0.73	0.44	0.51	3.3	1.05	0.68
Mexico (present study)	1.1-1.2	3.5	3.3	0.63	0.46	0.71	3.1	1.28	0.79

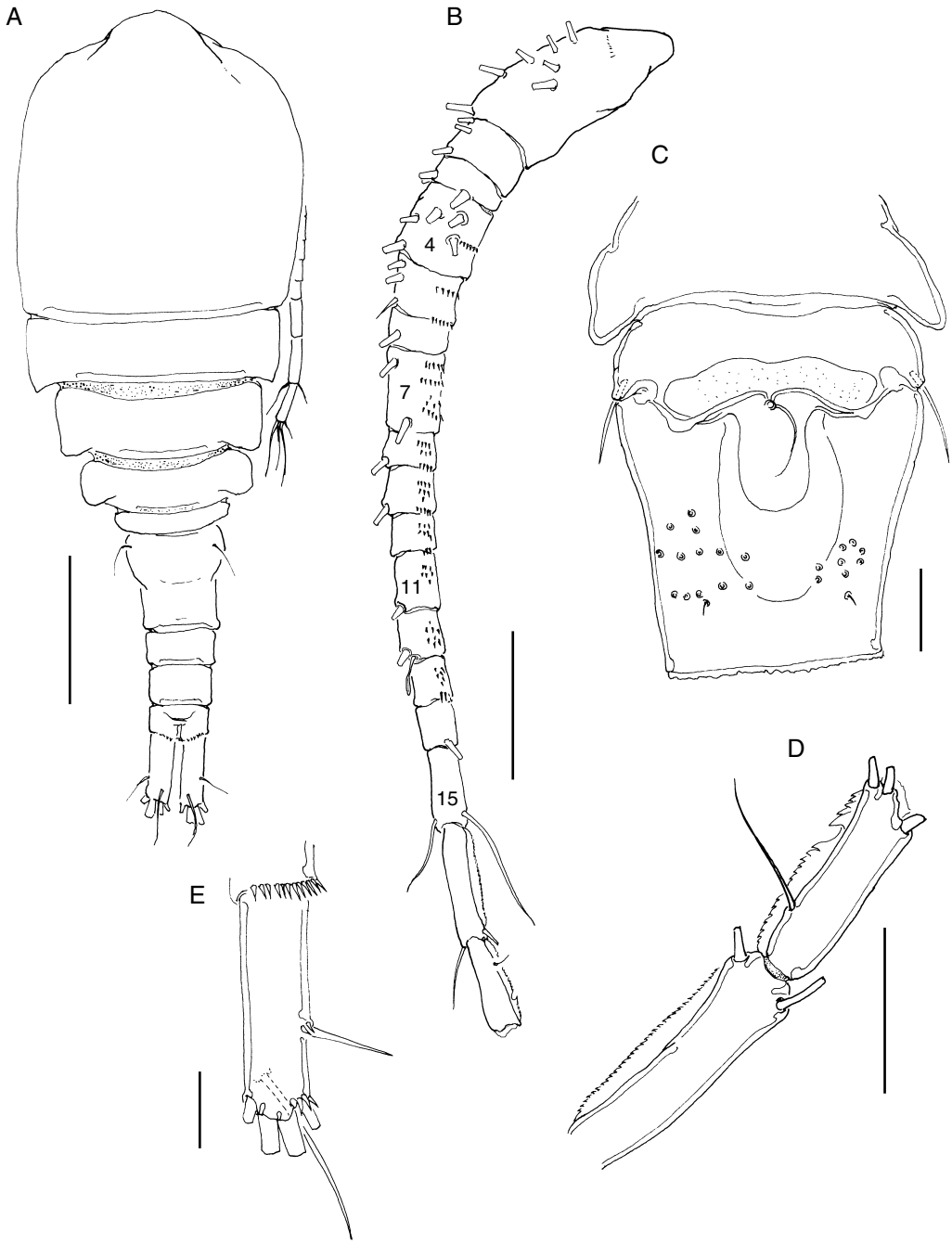

FIG. 2. — *Mesocyclops pehpeiensis* Hu, 1943, adult female from Chiapas, Mexico; **A**, habitus, dorsal view; **B**, antennule; **C**, fifth pedigerous and genital somite showing genital field, ventral view; **D**, terminal segments of antennule showing serrate lamella; **E**, right caudal ramus, ventral view. Scale bars: A, 250 µm; B, C, E, 100 µm; D, 50 µm.

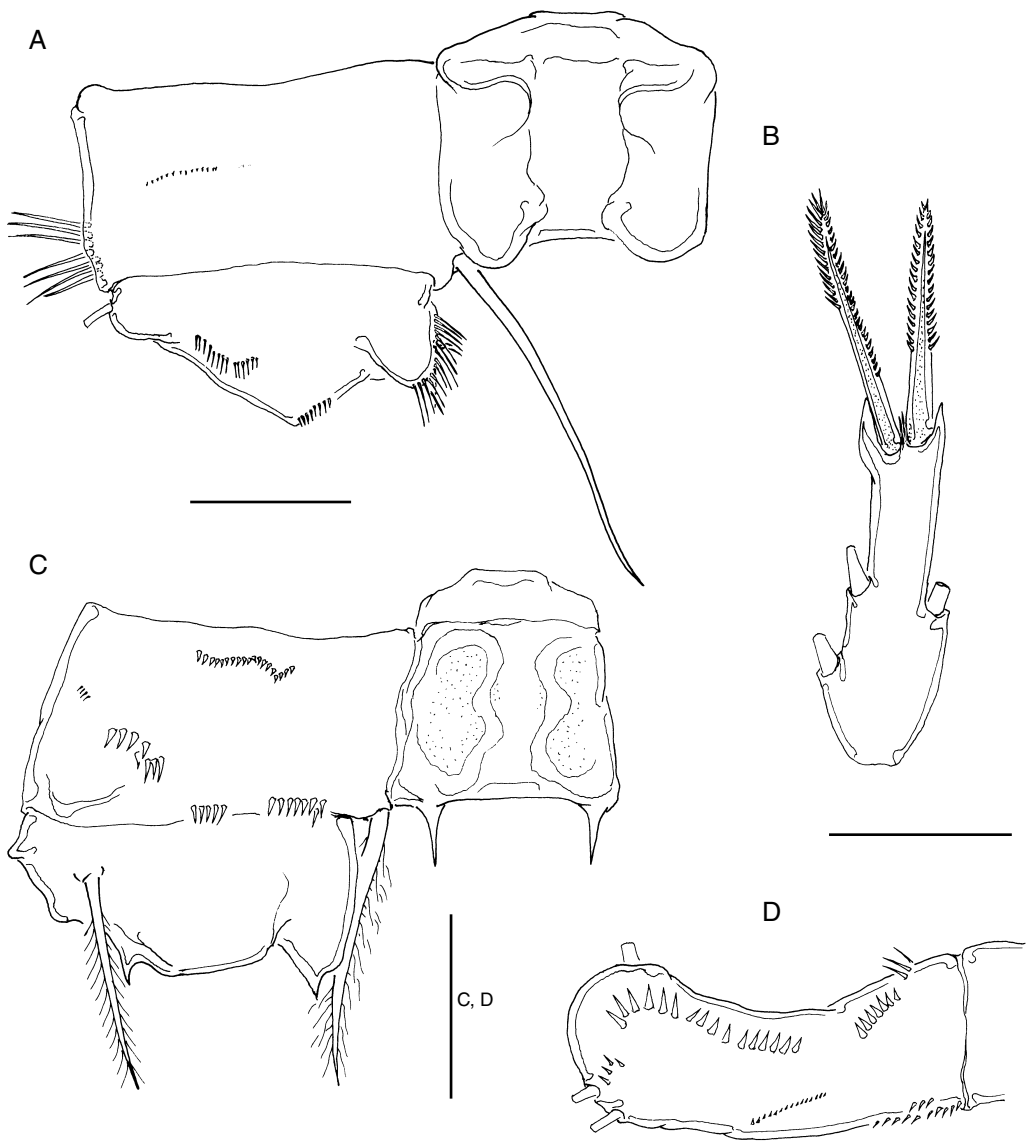

FIG. 3. — *Mesocyclops pehpeiensis* Hu, 1943, adult female from Chiapas, Mexico; **A**, coxa, coxal plate, and basipodite of first swimming leg showing ornamentation; **B**, third segment of endopodite of fourth swimming legs; **C**, coxa, coxal plate, and basipodite of fourth swimming leg; **D**, basipodite of antennae showing ornamentation, caudal view. Scale bars: 50 µm.

present in the Mexican specimens; however, the arrangement of the spinules in our material (Fig. 2B) seems to follow a clear transverse pattern along these segments whereas spinules seem to be scattered and even less dense in the North American (Reid 1993) and Japanese (Ueda *et al.* 1997) specimens. We found the usual pattern of one seta and one aesthetasc on antennular segment 12, as reported by Reid (1993). The structure of the antennular hyaline lamella is identical to that described by Kiefer (1981), Reid (1993), and Guo (2000). The antennular segment 17

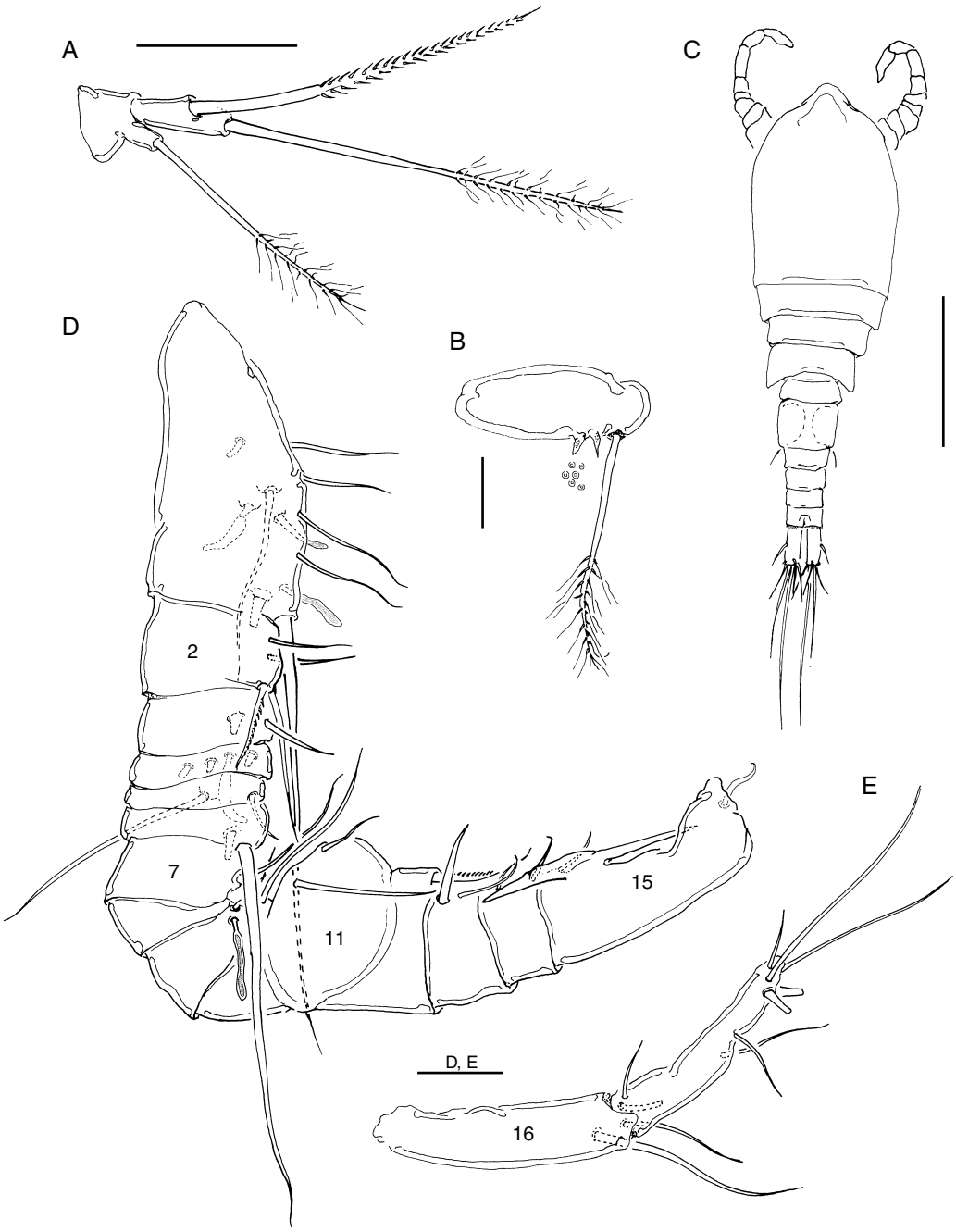

FIG. 4. — *Mesocyclops pehpeiensis* Hu, 1943; **A**, **B**, adult female from Chiapas, Mexico; **A**, fifth leg; **B**, sixth leg showing adjacent cuticular pores; **C**-**E**, adult male from same locality; **C**, habitus, dorsal view; **D**, segments 1-15 of geniculate antennule showing complete armament; **E**, segments 16-17 of geniculate antennule. Scale bars: A, 50 µm; B, D, E, 25 µm; C, 250 µm.

tends to be relatively shorter in the United States material (Reid 1993) and in the Chinese specimens (Guo 2000), than it is in the Mexican specimens and also in those depicted by Kiefer (1981) (see Table 1).

The Mexican specimens have clusters of cuticular pores on the ventral surface of the genital somite (Fig. 2C). This character was not mentioned in the redescription by Guo (2000); Reid (1993) and Kiefer (1981) depicted pores only on the lateral surface of the somite. These data suggest that the Asian specimens might lack the pores on the surface of the genital somite; however, it must be considered here that authors who are not alert to the existence and value of integumental structures might not mention or depict them. Hence, it will be necessary to examine representative specimens in order to determine if there are actual differences between the integumental ornamentation of the American and Asian specimens. Another consideration to be made here is that pits (*sensu* Baribwegure *et al*. 2001) and pores (as used by Reid 1993 and Kiefer 1981) are different morphological characters; the former are associated to a sensory structure, whereas the pore is a relatively simple hollow of the surface of the tegument. The pitting on the body might have future relevance in the genus in the light of recent studies of pore signature which have been used in the taxonomy of related genera such as *Thermocyclops* (Baribwegure & Dumont 1999). The morphology and structure of the seminal receptacle in the Mexican specimens agree with the different descriptions of this structure, including a characteristic curved pore-canal (Kiefer 1981; Guo 2000).

The furcal length/width ratio values (3.5-3.7) of the Mexican material (Fig. 2E) fall well within the range described for the Asian, but not for the North American material, which has the relatively shortest caudal rami (see Table 1). A comparison of the proportional length of the different caudal setae in different populations of *M. pehpeiensis* is presented in Table 1. Most of the values found in the Mexican specimens are within the ranges known for the species. It is noticeable that the Sme (outer medial seta) of our specimens is the longest reported in the species.

The structure and ornamentation of the antennae (Fig. 3D) and the coxa and basipodite of the swimming legs (Fig. 3A, C) are identical in most respects to the species pattern depicted in previous studies. We report here the presence of a cluster of five to six pores on the surface posterior to the sixth leg plate (see Fig. 4B). This character was previously unnoticed, its taxonomic value has not been explored.

We found slight differences in the proportion of the third endopodite of leg 4 (see Table 1) (Fig. 3B). The proportional length of the basal seta/terminal spine of the fifth leg of the Mexican specimens (see Fig. 4A) is the second shortest (0.56) after the Japanese specimens (see Ueda *et al*. 1997). Highest values were found in the North American (Reid 1993) (0.67) and Chinese (Guo 2000) (0.625) specimens.

The male antennule of the Mexican specimens has four setae on segment 2, differing from the armature presented for the same segment by Guo (2000). The fifth antennular segment was depicted by Guo (2000) as naked; in our specimens this segment has two setae. Segment 6 has two setae in our specimens and four in Guo's (2000) figure. Segments 7, 8, and 10-12, unarmed in Guo's redescription, bear setal elements in our specimens (Fig. 4D). The large aesthetasc on segment 9 is present in both cases. The Mexican specimens lack an aesthetasc on segment 13, depicted by Guo (2000). The large spiniform process on segment 15 was not mentioned or depicted in the redescription. The segments 16 and 17 are relatively longer in the Mexican specimens (Fig. 4E).

In her biogeographic analysis of the Australasian species of *Mesocyclops*, Hołyńska (2000) included this species in her group with Asian continental affinities, characterized by very closely related species that indicate an on-going speciation process. Overall, the morphological and morphometrical variability shown by the comparative analysis of the Asian and American populations of *M. pehpeiensis* could be related to the geographic isolation of both groups; although the isolation time is unknown, this will become an interesting topic for analysis in the future.

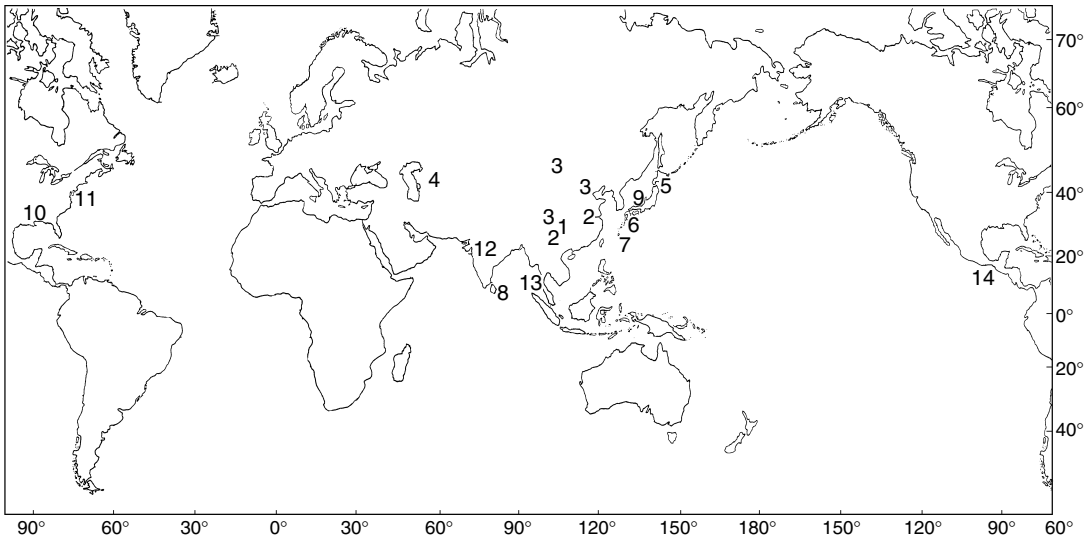

FIG. 5. — World distribution of *Mesocyclops pehpeiensis* Hu, 1943. Numbers represent records by different sources/authorities; **1**, Hu (1943) in Beipei, China, the type locality; **2**, Guo (2000) from Nanjing and Lake Caohai, China, both sites near the type locality; **3**, Tai & Chen (1979) from different areas of China and from Inner Mongolia; **4**, Mirabdullayev (1996) from Uzbekistan; **5**, Ishida (1999) from Hokkaido, northern Japan; **6**, Ueda *et al*. (1997) from Kyushu, Japan; **7**, Ueda & Ishida (1997) from Okinawa, Japan; **8**, Dussart & Fernando (1985b) from Sri Lanka; **9**, Kawabata & Defaye (1994) from Lake Kahoku, western coast of Japan; **10**, Reid (1993) from Louisiana and Mississippi, United States; **11**, Reid (1996) from the District of Columbia, United States; **12**, Hołyńska *et al*. (2003) from different areas including India; **13**, Dussart & Fernando (1985a) from Malaysia; **14**, present record in Chiapas, Mexico.

The morphometrical variation of some copepod appendages and structures can be related also to ecological factors (Riera 1985). Most of these allometric variations are clearly seasonal (Lescher-Moutué 1996), but in general, these processes are subtle and not well understood in copepods (Williamson & Reid 2001). Guo (2000) provided some data about the variability of *M. pehpeiensis* in different localities of China, but without further comments on it. As in other copepods, allometric variability might be present in this species; analysis of these factors could bring about interesting information on the biology of this species. This is particularly relevant when referred to an introduced species in which different sources of variability, i.e. geographical isolation and ecological constraints, are acting.

DISTRIBUTION

The overall known latitudinal range of this species extends roughly from 50°N to 7°S, thus including mainly tropical areas of Asia (see Fig. 5). In North America the known range of this species was established between the 30 and 37°N (Reid 1993, 1996). This species was recorded from ricefields in Louisiana and Mississippi in the south-central United States (Reid 1993; Reid & Marten 1995). Later on, Reid (1996) found it in ponds of aquatic gardens in the area of Washington, D.C., attributing its presence to the importation of exotic plants. Most of the American records of *M. ruttneri* after the redescription by Reid (1993) are referable to *M. pehpeiensis* (see Guo 2000; Hołyńska *et al*. 2003). These records are only on the Atlantic and Gulf coasts of the United States; this is the first record of this species from the American Pacific coast.

There are no records of this species in Central or South America (see Reid 1990; Rocha & Botelho 1998). Hence, the southernmost limit of the known distributional range of this species in the Americas is expanded with this record, setting the known meridional limit of *M. pehpeiensis* in the Americas at 14°N latitude in Chiapas, Mexico

(see Fig. 5). Of course, it is expectable that this species could be present also in Guatemalan territory; however, it is more probable that its distribution would stretch northwards rather than southwards, considering the presence of other introduced species along the northern Pacific coast of Mexico (Gutiérrez-Aguirre *et al.* 2003).

This species has been considered to be an introduced form in the New World (Hołyńska *et al.* 2003), clearly more related to the Asian species (see Van de Velde 1984; Hołyńska 2000) than to the American forms. The morphological features shared by most Asian species of *Mesocyclops* (absence of spines next to exopodal insertion on the antennal basipod, inner basis of first leg naked, seminal receptacle with lateral arms forming concave [or even V-shaped] margin) (Van de Velde 1984; Hołyńska 2000) are clearly present in our specimens of *M. pehpeiensis*. This strengthens the idea that *M. pehpeiensis* is originally an Old World form.

Other introduced species have a disjunct distributional pattern and a successful invasion of both tropical and temperate zones in the New World (see Gutiérrez-Aguirre *et al.* 2003). Therefore, considering its morphology, origin, distribution, and the previous records (see Hołyńska *et al.* 2003), we speculate that rather than having a "cosmopolitan" distribution, *M. pehpeiensis* was introduced into Mexico by human agency. This introduction is probably a result of an isolated event which was independent from those that are supposedly related to introductions in the United States. This record, on the Mexican Pacific coast, suggests a relatively recent and independent dispersal process because: 1) this large, conspicuous species has not been recorded previously in other parts of Mexico; the southern and central areas of the country have been surveyed for several decades (Suárez-Morales *et al.* 1996; Suárez-Morales & Reid 1998), including a survey on *Mesocyclops* (see Suárez-Morales & Gutiérrez-Aguirre 2001); and 2) the coastal area of Chiapas is active for aquaculture and in the last decade shipments from the Far East, including Malaysia, have delivered seed specimens to support the culturing of the Malayan prawn (*Macrobrachium rosenbergii* de Man) (C. Tovilla pers. comm.). This is likely to be a probable way of introduction for *M. pehpeiensis* in this area; also, it suggests a relatively recent event. Ballast waters and aquacultural activities are widely known to favoring introduction of exotic copepod fauna (Reid & Pinto-Coelho 1994).

This is considered to be the fourth record of an introduced species of freshwater copepod in Mexico after the Asian *Mesocyclops thermocyclopoides* Harada, 1913 (Gutiérrez-Aguirre *et al.* 2003), *M. aspericornis* (Gutiérrez-Aguirre *et al.* 2002), and *Thermocyclops crassus* (Fischer, 1853) (Gutiérrez-Aguirre & Suárez-Morales 2000). Another introduced *Mesocyclops* in America is the Afro-Asian *Mesocyclops ogunnus* (Suárez-Morales *et al.* 1999), recorded from the Cayman Islands and Brazil.

Ecology

Mesocyclops pehpeiensis has been collected from a wide variety of tropical freshwater environments. They include ricefields and urban ponds (Reid 1993, 1996). The ponds in Chiapas, with abundant vegetation represents a good habitat for this species. According to Reid (1993), this species is more an epibenthic form dwelling in the littoral zones. In both surveyed ponds, this species coexists with at least two other species of *Mesocyclops*, *M. brasilianus* Kiefer, 1933 and *M. longisetus* s.s. (Thiébaud, 1912). Furthermore, Reid (1996) reported that in the ponds of Washington, D.C., *M. pehpeiensis* coexists with *Mesocyclops edax* and *M. americanus*. This would suggest that, despite the fact that these are omnivorous-carnivorous forms (Suárez-Morales *et al.* 2003), this introduced species is capable of successfully competing for part of the resources available in these systems. A relatively fast dispersion of this species is expected in this area.

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