The occurrence and description of *Neocaridina denticulata sinensis* (Kemp, 1918) (Crustacea: Decapoda: Atyidae), a new introduction to the Hawaiian Islands[1]

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First found in the Hawaiian Islands in 1991 (Devick, 1991), the introduced freshwater shrimp *Neocaridina denticulata sinensis* (Kemp) is now widespread throughout O'ahu. Recently, we examined specimens collected from widely separated O'ahu localities that had previously been reported as *Caridina weberi* by Devick (1991). These specimens proved to be *N. d. sinensis*, a subspecies previously known only from the Chinese mainland and Taiwan. The discovery of this introduced shrimp species raises the total number of atyid species from Hawaiian Islands to five, with two species now found in freshwater habitats. Atyid shrimp native to Hawai'i are: *Atyoida bisulcata* Randall, *Antecaridina lauensis* (Edmondson), *Halocaridina rubra* Holthuis, and *Halocaridina palahemo* Kensley & Williams (Eldredge & Miller, 1997). Both species of *Halocaridina* are found in anchialine pool habitats, *A. lauensis* is marine, and *A. bisulcata* is the only native freshwater atyid shrimp in Hawai'i.

In this paper we redescribe *N. d. sinensis* from specimens collected in O'ahu, Hawai'i, provide ecological and distributional information, and discuss potential impacts on the culturally important endemic Hawaiian stream shrimp, *Atyoida bisulcata*. As there is a size overlap between the native *A. bisulcata* and *N. d. sinensis*, we provide detailed drawings of the latter species to enable the differentiation between the native and introduced freshwater atyid shrimp species. We also provide evidence that *N. d. sinensis* originated from aquarium releases into O'ahu streams.

Specimens are vouchered in Bishop Museum (BPBM) and Zoological Reference Collection, National University of Singapore (ZRC).

Neocaridina denticulata sinensis (Kemp) **New state record**
(Figs. 1–3)

Caridina denticulata sinensis Kemp, 1918: 287, fig.11(c,d). [type locality: Taihu Lake, near Shanghai, eastern China.]

Neocaridina denticulata sinensis: Kubo, 1938: 28, fig. 10(c,f), fig.11(c.); Cai, 1996: 132, figs.1–2. [See Cai, 1996 for full synonymy.]

Material examined. **O'AHU:** 1 male, cl. 3.8 mm, 4 females, cl.3.8–4.8 mm, ZRC; 1 male, 3.1 mm, 5 females, 4.0–4.8 mm, BPBM; Maunawili Stream, at Maunawili Road bridge, 24 m, 21 April 1998 (R.A. Englund). 5 males, cl. 3.7–4.4 mm, 5 females (4 ovigerous), cl. 4.3–5.0 mm, ZRC; 1 male, cl. 3.8 mm, 6 females (3 ovigerous), cl.4.7–6.2, BPBM; Nu'uanu Stream, Board of Water Supply pump house area, 240 m, 9 July 1998 (R.A. Englund & D.J. Preston). 1 male, cl. 3.5 mm, 2 females (1 ovigerous), cl. 4.6–4.9 mm, ZRC; 2 males, cl. 3.0–3.2mm, 3 females, cl. 3.7–4.8 mm, BPBM; Pet's Plus Petshop, 4 July 1998, Ward Avenue, Honolulu (R.A. Englund). 3 males, cl. 3.0–3.3 mm, 4 females (3 ovigerous), cl. 3.8–5.0 mm, ZRC, 11 males, cl.1.7–2.9 mm, 27 males (7 ovigerous), cl. 2.3–4.5 mm, BPBM, Waikele Stream at Waikele Springs, 1–7 m, 9 July 1998, (R.A. Englund & D.J. Preston). Numerous individuals, Mānoa Stream near Mānoa Elementary School, 55 m eleva-

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tion, 8 May 1998 (R.A. Englund & D.J. Preston). Numerous individuals, Hoʻomaluhia Reservoir and Kamoʻoaliʻi Stream (a Kaneʻohe Stream tributary), 1993, (M. Yamamoto & A. Tagawa, Hawaii Division of Aquatic Resources).

Description

The abbreviation, cl. is used for carapace length (measured from the postorbital margin to the posterior margin of the carapace). Rostral formula citation and morphological terminology follow that by Chace & Bruce (1993).

Rostrum straight, reaching to end of 2nd segment of antennular peduncle in male; to end of 3rd segment in females, never beyond it. Rostral formula 1–3 (mode 2)+8–18 (11–14)/1–6(mode 2–4); inferior orbital angle of carapace fused with antennal spine; pterygostomial angle rectangular with tiny spine. Telson ending in median projection; 4 pair of dorsal spinules, 1 pair of dorsolateral spines near distal end, 4 pair of spines on distal margin, lateral pair longer than sublateral pair, subequal to intermediate pairs; preanal carina rounded, no spine. Scaphocerite 3.0 × as long as wide.

Eyes well developed. Antennular peduncle stout, 0.75–0.85 × as long as carapace; stylocerite distinctly reaching not beyond end of basal segment of peduncle. Scaphocerite 3.5 × as long as wide. Mouthparts as in Fig. 1, palp of first maxilliped broadly rounded. Third maxilliped reaching the end of second segment of antennular peduncle, ultimate segment as long as penultimate segment.

First pereiopod reaching to end of basal segment of antennular peduncle; chela 2.0–2.2 × as long as broad, fingers slightly longer or as long as palm; carpus short, as long as palm, 1.4 × in female, 1.7 × in male, as long as high; merus stout, as long as carpus, 2.5 × as long as wide. Second pereiopod slender, reaching slightly beyond end of second segment of antennular peduncle, chela 2.4–2.6 × as long as broad; fingers 1.3 × as long as palm; carpus 1.2 × longer than chela, 5.0 × as long as high; merus as long as chela. Third pereiopod reaching end of antennular peduncle, dactylus terminating in 2 claws, 5–8 accessory spines on flexor margin; propodus slightly curved inwards, 3.0 × as long as dactylus (terminal spine included), 8.0 × as long as broad, numerous spinules on posterior margin; merus stout. Fifth pereiopod reaching end of basal segment of antennular peduncle; dactylus stout, 35–56 denticulate spines on flexor margin in male, slender, 50–65 denticulate spines on flexor margin in female. Propodus stout, 9.0 × as long as broad, 3.4 × as long as dactylus in female, slender, 12 × as long as broad, 2.7 × as long as dactylus in male.

Endopod of the male first pleopod extending to 0.7 × exopod length, rounded, pear-shaped, 1.2 × as long as broad, numerous tiny spinules on dorsal surface. Appendix interna short, at base of swollen part. Appendix masculina of male second pleopod dilated, reaching to 0.6 × endopod length, inner and distal surface densely lined with long spinules; appendix interna at basal quarter of appendix masculina, extending to distal 1/3 of appendix masculina. Uropodal diaeresis with 9–13 spinules. Eggs 1.00–1.18 × 0.65–0.78 mm diam.

Kemp (1918) separated *Neocaridina denticulata sinensis* from the nominal subspecies mainly on the basis of the rostral formula: 14–22/3–8 (vs. 10–15/2–5), and the anterior carpus margin of the first pereiopod, which is deeply excavate as compared to slightly excavate. The difference in the rostral formula for the 2 subspecies is not significant (8–19/1–9 in *N. d. sinensis* vs. 10–20/0–7 in *N.d. denticulata*), but rostrum length is more helpful for separation (Kubo, 1938). The rostrum of *N. d. sinensis* does not reach beyond the end of antennular peduncle as compared to much beyond in *N. d. denticulata*

Color

Hung *et al*. (1993) reported the color for this subspecies as “Body color varying from black, brown, dark red, dark green, white to translucent, sometimes also covered with stripes”. The specimens from the Chinese mainland have the same color pattern as those from Taiwan. (Y. Cai, pers. observ.). On Oʻahu, the body color of wild *N. d. sinensis* collected in streams ranged from a nearly translucent light brown to dark brown, often with

a darker brown stripe running along the entire dorsal portion of the body. Purchased shrimp were lighter with little coloration, and almost translucent in coloration.

Habitat

In its native range, *N. d. sinensis* was reported from rivers, channels in agricultural fields, mountain streams, reservoirs, and ponds (Cai, 1996). On O‘ahu, this species has been collected in Nu‘uanu and Ho‘omaluhia Reservoirs and in natural and channelized stream habitats. *Neocaridina d. sinensis* was found only in areas of freshwater on O‘ahu and inhabited a wide range of stream habitats, from the clear, cool Waikele Spring complex found at Waikele Stream, to high water velocity riffles downstream of this spring area, and also in aquatic vegetation lining the stream channel. This species was also common in disturbed aquatic habitats such as the concrete channel raceways below Nu‘uanu Reservoir.

Discussion

No major differences were apparent between the Hawaiian, Chinese mainland, and Taiwan populations of *N. d. sinensis* except egg size. Eggs were slightly larger in Hawai‘i (1.00–1.18 × 0.65–0.78 mm) than in the Chinese mainland (0.85–1.05 × 0.55–0.65 mm) or Taiwan (1.08 × 0.57 mm) populations. *Neocaridina d. sinensis* is widely distributed in central and eastern China, Yunnan province of China, and Taiwan (Hung *et al*., 1993; Cai, 1996).

The occurrence of *N .d. sinensis* in Yunnan province in southwestern China may also be due to human introduction. Although it is now commonly found in most parts of Yunnan province, *N. d. sinensis* had not been recorded from this area until the 1980s. It is likely that *N. d. sinensis* was introduced when needle fish (*Neosalanx* sp.) from Taihu Lake in eastern China were introduced to the plateau lakes of Yunnan province (Y. Cai & Dai A.Y., unpubl.). Taihu Lake is the type locality of *N. d. sinensis*.

Neocaridina d. sinensis appears to be spreading rapidly throughout O‘ahu, and was found in high densities in five widely separated windward and leeward O‘ahu drainages. This species was not found during surveys conducted in Waikele Stream or its tributaries in 1993 or April 1997 (Englund, 1993, 1997), but was abundant in Waikele Stream in 1998. In O‘ahu streams, the introduced atyid shrimp was most abundant in high water velocity areas such as run and riffles but was also common in aquatic vegetation and stream side margins. In Waikele Stream *N. d. sinensis* were most common in areas of higher water velocities that averaged 33–52 cm/second but were also found in clear, cold spring areas with velocities as low as 10 cm/second (Englund & Filbert, in press).

Nu‘uanu and Ho‘omaluhia Reservoirs also contain large *N. d. sinensis* populations. Unlike the native freshwater atyid shrimp *Atyoida bisulcata*, *N. d. sinensis* does not have an obligate marine phase (Hung *et al*., 1993) and is restricted to freshwater. Thus, *N. d. sinensis* must have spread into separate watersheds by repeated human introductions. Small feeder aquarium shrimp were purchased at Pet’s Plus Petshop on Ward Avenue in Honolulu, and these specimens were identified as *N. d. sinensis*. This is strong evidence that *N. d. sinensis* was introduced to O‘ahu streams as an escaped or released aquarium species. According to the pet shop owner, these feeder shrimp are regularly purchased from O‘ahu breeders rearing these shrimp in their backyards in 200 liter drums.

It is possible that *N. d. sinensis* will compete for food and space with the native atyid shrimp *Atyoida bisulcata*, as they occupy similar habitats and have overlapping eleva-

tional distributions. In Waikele Stream, *N. d. sinensis* was found in high densities, and several hundred introduced shrimp were collected in each aquatic dip net sample. We did not observe any native atyid shrimp in O‘ahu streams where the introduced *N. d. sinensis* was found, despite these areas being suitable elevations and habitats for the native *A. bisulcata*. Native Hawaiian atyid shrimp are amphidromous (Meyers, 1949), and require access to the ocean to complete their life cycle, while the introduced *N. d. sinensis* reproduce only in freshwater (Hung *et al*., 1993). While this difference in reproductive biology could slow the island-wide spread of *N. d. sinensis*, it could also provide a competitive advantage to this introduced species in the numerous diverted streams found in the Hawaiian Islands.

The Chinese experience in translocating *N. d. sinensis* into areas outside of its native range may indicate this species could adversely impact the native freshwater Hawaiian atyid shrimp, *A. bisulcata*. In China, *N. d. sinensis* is one of the most adaptable and hardy shrimp species, and the large eggs of this species ensure that the larvae undergo a rapid development period (Zhang & Sun, 1979). In contrast, migratory atyid shrimp undergo an extended larval development period (March *et al*., 1998). In areas where it has been introduced or is naturally found, *N. d. sinensis* occurs in large numbers, and it rarely occurs sympatrically with other atyid shrimp species (Y. Cai, pers. observ.). The introduction of *N. d. sinensis*, *Exopalaemon modestus* (Heller), and *Caridina aff. gracilipes* De Man, and exotic fish species into Dianchi Lake, China is believed to be responsible for the disappearance of an endemic atyid shrimp species, *Caridina dianchiensis* (Liang & Yan). *Caridina dianchiensis* is now found only in rivers and mountain streams lacking *N. d. sinensis* (Liang & Yan, 1985).

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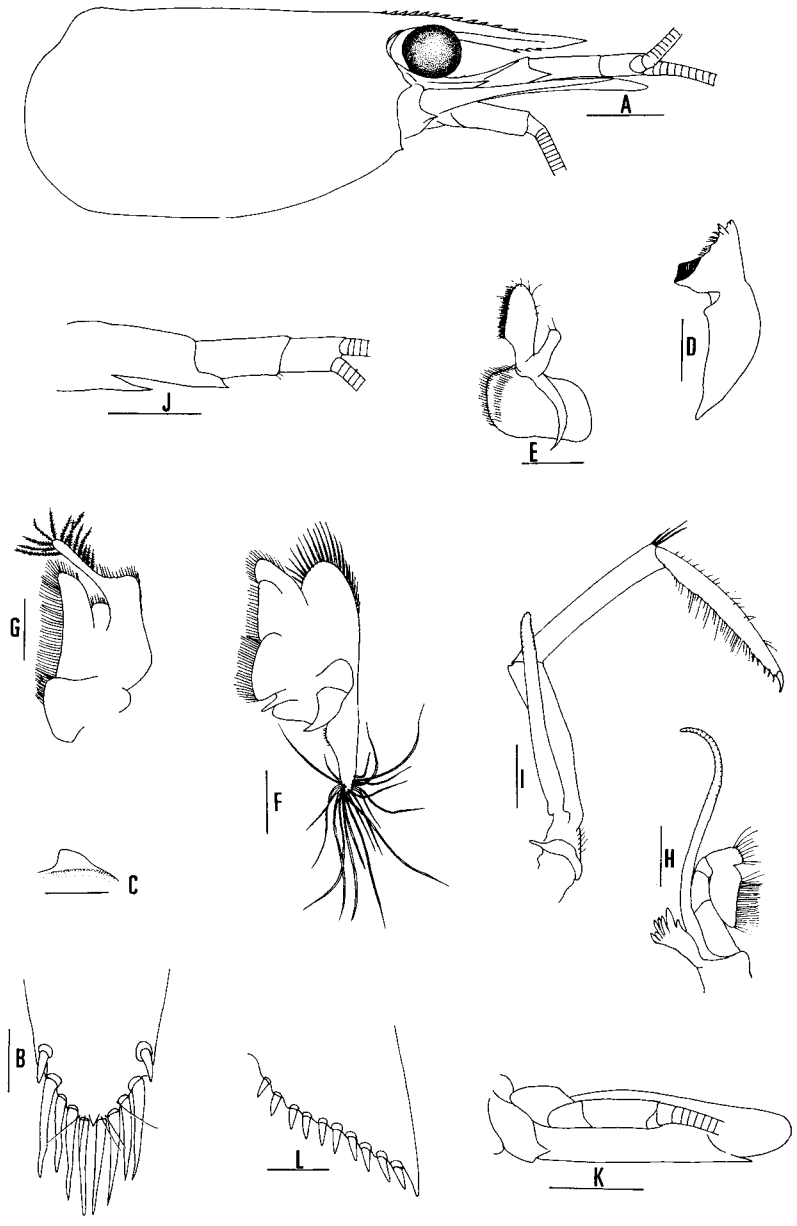
Fig. 1. *Neocaridina denticulata sinensis.* male, cl. 4.2 mm (ZRC. 1998.901) **A**. cephalothorax and its appendages; **B**. distal portion of telson, C. preanal carina, **D**. mandible, **E**. maxillula, **F**. maxilla, **G**. first maxilliped, **H**. second maxilliped, **I**. third maxilliped, **J**. antennular peduncle, **K**. scaphocerite, **L**. uropodal diaeresis. Scales: A, J, K = 1 mm; C, D, E, F, G, H, I = 0.5 mm; B, L = 0.2 mm.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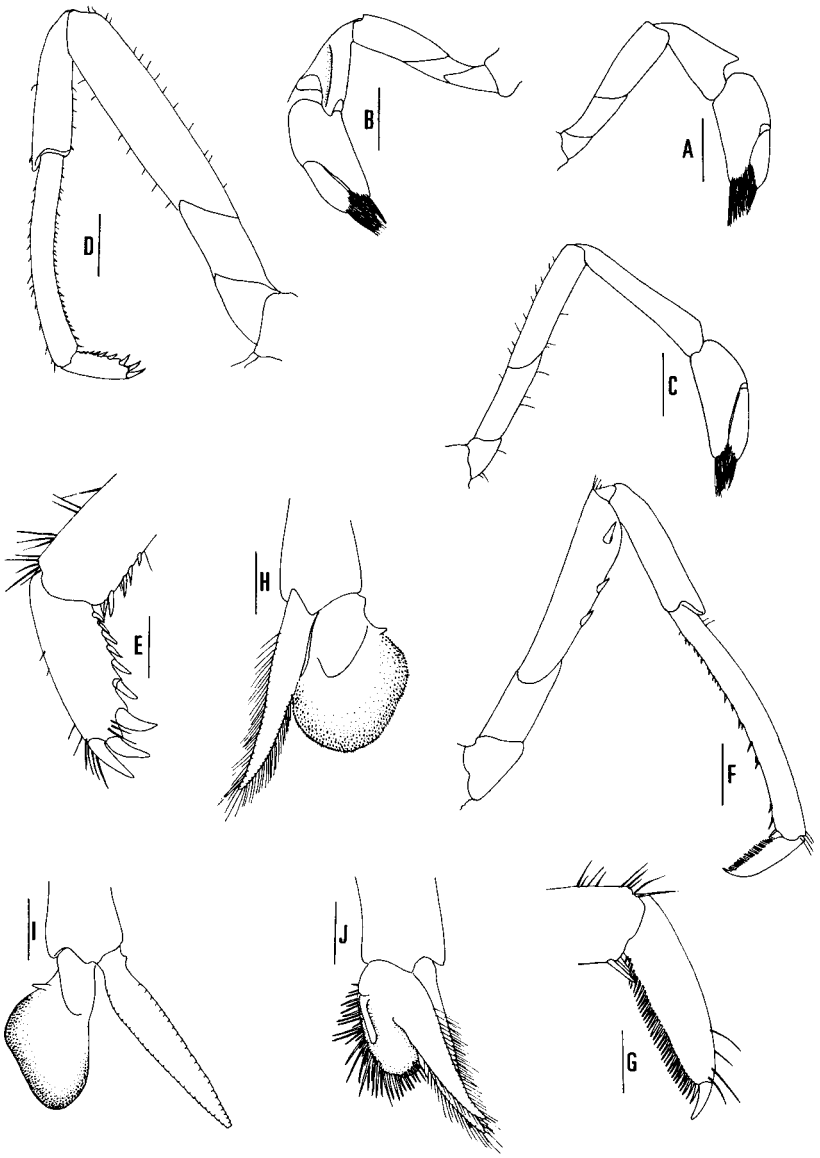

Fig. **2**. *Neocaridina denticulata sinensis.* male, cl. 4.2 mm (ZRC. 1998. 901) **A**, **B**. first pereiopod, **C**. second pereiopod, **D**. third pereiopod, **E**. dactylus of third pereiopod, **F**. fifth pereiopod, **G**. dactylus of fifth pereiopod, **H**, **I**. first pleopod, **J**. second pleopod. Scales: A, B, C, D, F, H, I, J = 0.5 mm; E, G = 0.2 mm.

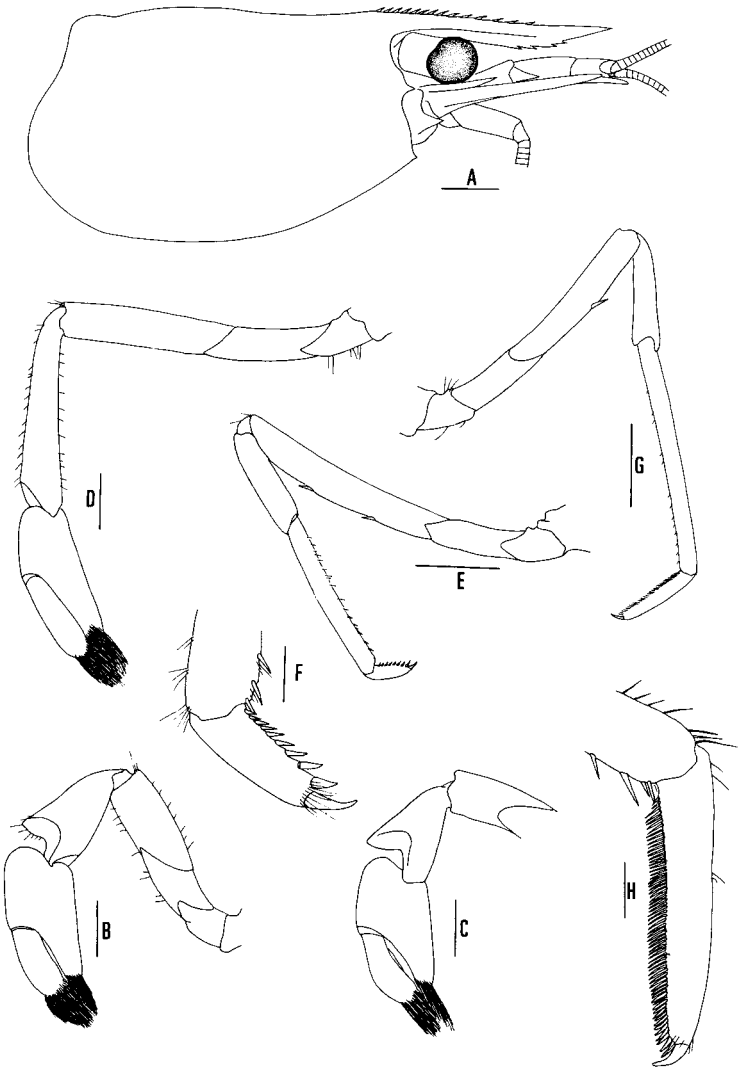

Fig. **3**. *Neocaridina denticulata sinensis.* female, cl. 5.4 mm (ZRC. 1998.901) **A**. cephalothorax and its appendages, **B**, **C**. first pereiopod (C. another female,from same lot, cl.5.7 mm), **D**. second pereiopod, **E**. third pereiopod, **F**. dactylus of third pereiopod, **G**. fifth pereiopod, **H**. dactylus of fifth pereiopod. Scales: A, E, G = 1 mm; B, C, D = 0.5 mm; F, H = 0.2 mm.