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Short Communication

Two Asian fresh water shrimp species found in a thermally polluted stream system in North Rhine-Westphalia, Germany

Werner Klotz[1]*, Friedrich Wilhelm Miesen[2], Sebastian Hüllen[2] and Fabian Herder[2]

1 *Wiesenweg 1, 6063 Rum, Austria*
2 *Zoologisches Forschungsmuseum Alexander Koenig, Sektion Ichthyologie, Adenauerallee 160, D-53113 Bonn, Germany*

E-mail: wklotz@aon.at (WK), f.w.miesen@googlemail.com (FWM), sebastianhuellen@gmx.de (SH), Serkan Güse (SG), f.herder@zfmk.de (FH)

**Corresponding author*

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Abstract

The river Erft and its tributary Gillbach in western Germany are thermally polluted, and harbour exotic plant and animal species introduced by aquarium hobbyists. Here, we report for the first time the occurrence of two species of fresh water shrimp, *Neocaridina davidi* (Bouvier, 1904) and *Macrobrachium dayanum* (Henderson, 1893), from these heavily modified waters. We briefly discuss their taxonomy and provide characters for distinguishing the species. Due to its dependence on warm waters, it is unlikely that *M. dayanum* populations will persist permanently beyond the range of the thermal pollution. In contrast, *N. davidi* is able to tolerate much colder temperature regimes, and might disperse further into the Rhine drainage. Known parasites of *N. davidi* are however rather specific, and do most likely not pose a threat to native or other introduced crustacean species.

Key words: freshwater shrimp; *Neocaridina davidi; Macrobrachium dayanum*; Gillbach; Erft; neozoa

Introduction

Exotic animal species may cause severe changes to native species assemblages and their aquatic habitats (Cox 2004), with numerous documented cases from freshwater fish to molluscs to crustaceans (e.g., Carmichael et al. 1993; Gamradt and Kats 1996; Barbaresi and Gherardi 2000; Vitule et al. 2009; Gozlan et al. 2010). There are indications that the success of alien species invasions in freshwaters increases with habitat degradation (Kennard et al. 2005; Casatti et al. 2006), rendering modified or artificial habitats like channels or polluted rivers with limited or disturbed ecosystems especially prone to invasions. Permanent thermal pollution of temperate streams or rivers by warm waters originating from mining operations, power plants or other industries, may severely change animal communities and set the stage for the establishment of exotic species from warmer regions, as observed in natural warm springs in temperate habitats (Piazzini et al. 2010).

The Gillbach is a medium-sized stream of approx. 25 km length, located west of Cologne City in North Rhine-Westphalia (Germany). It drains to the Erft, a Rhine tributary. The natural headwaters of the Gillbach, as well as parts of the Erft, have been destroyed by coal surface mining; to date, the Gillbach's major source is coolant water from Niederaußem, Germany's second largest coal power plant. These discharges cause major thermal pollution, up to 25.5°C (F.W. Miesen pers. observation); the Erft itself permanently receives additional warm waters from mining operations, and power plants, like the power station at Frimmersdorf.

The unique set of influences results in a fluctuant abiotic environment as shown in Table 1, enabling exotic species to settle in areas with most suitable abiotic conditions. However, in some cases temperature remains a key factor for establishment of new populations.

The Gillbach has been used as a playground by aquarium hobbyists for decades, resulting in

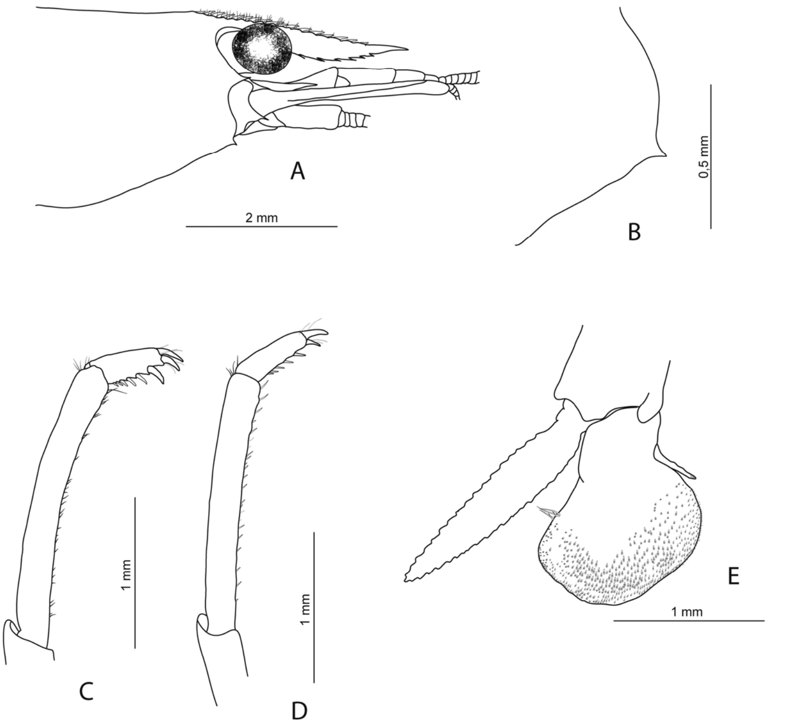

Figure 1. Morphological characteristics of *Neocaridina davidi* (Bouvier, 1904). A) anterior part of cephalothorax, B) pterygostomial angle, C) propodus and dactylus of third pereopod of male, D) propodus and dactylus of pereopod of female, E) endopod of first pleopod of male. Drawings by W. Klotz.

Table 1. Abiotic parameters of the upper Gillbach.

	Max	Min
O_2 content	8.01 mg/l	7.88 mg/l
O_2 saturation	105.5 %	103.3 %
Electrical conductivity	1625 µS/cm	1718 µS/cm
pH	8.46	8.41
Temp. 17.11.2012	18°C	11°C
Temp. 13.06.2013	28.9°C	28.7°C

the presence of stable populations of various aquarium fish species such as neotropical guppies (*Poecilia reticulata* Peters, 1859), a suckermouth catfish species (*Ancistrus* sp.), and cichlids [*Amatitlania nigrofasciata* (Günther, 1867), *Oreochromis* sp.]. Exotic fish and aquatic plant species occur also in the Erft, dominating its ecosystem along whole stretches (Friedrich 1973, Friedrich 2005). Here, we report the presence of proliferating exotic shrimp species, used as ornamental pets by aquarium hobbyists, in Gillbach and Erft. We investigated their morphology, present their taxonomic placement, discuss their likely origin, and highlight the potential of at least one of the two species for further downstream dispersal, which appears rather likely and might lead to its invasion into the temperate downstream habitats of the River Rhine drainage.

Methods

Specimens were obtained using dip-netting during field trips between 2011 to 2013, transferred alive to the lab, and finally permanently fixed in 80% ethanol. Morphometric measurements were taken using a stereomicroscope with an ocular micro-meter. Drawings were made from micro-photographs using Adobe Illustrator following Coleman (2003, 2006). Voucher specimens are stored in the collection of the Museum für Naturkunde, Berlin, Germany (ZMB), and the Oxford University Museum of Natural History (OUMNH). Comparative material was examined at the Muséum national d'Histoire naturelle, Paris (MNHN). For measurement of abiotic parameters (dissolved oxygen, electrical conductivity, pH-value and temperature), a Multi-Parameter Meter (HQ40d Portable Meter, HACH, Loveland, USA) was used at the sampling area.

Figure 2. Live colouration: A) *Neocaridina davidi*, female from the Gillbach; B) *N. davidi* var. Red Fire, ovigerous female from the Erft; C) *Macrobrachium dayanum*, adult male, aquarium population, D) *M. dayanum,* juvenile, aquarium population (all photos: W. Klotz).

Results and discussion

Two species of Asian freshwater shrimps were identified in the samples collected at Gillbach and Erft in 2011–2013: The small and colorful *Neocaridina davidi* (Bouvier, 1904), and the considerably larger "Red Clawed Prawn" *Macrobrachium dayanum* (Henderson, 1893). Both species established proliferating populations. Especially *N. davidi* was present in considerable numbers at the time of sampling, in habitats characterized by submerged roots of trees at the upper Gillbach.

Neocaridina davidi is known as invasive species from other regions outside of Europe (Englund and Cai 1999; Nishino and Niwa 2004; Niwa 2010). However, its taxonomy is complex and partially in conflict, leading to some confusion in the respective literature. Below, we describe the morphology of both species, review their taxonomy, summarize the natural occurrence of both species as well as their reported introduction into other ecosystems, and comment on records of parasites as well as on their potential dispersal further into the Rhine drainage.

Neocaridina davidi (Bouvier, 1904)

Material examined

ZMB 28002: 4 males, 12 females, 1 juvenile, Gillbach near Rheidt/NRW; leg. F. Herder and F.W. Miesen 14.9.2011; OUMNH.ZC.2012-05-056: 5 specimens, Gillbach near Reidth/NRW; leg. W+M Klotz 13.5.2012; private collection of the first author 25-12: 8 females, 9 males, Gillbach near Reidth/NRW; leg. W+M Klotz 13.5.2012; private collection of the first author 26-12: 1 ovigerous female, Erft near Eppinghoven, NRW, Deutschland; coll. W+M Klotz 13.5.2012.

Morphology

A small freshwater shrimp species, body size up to 40 mm (average size of females 25 mm; average size of males 20 mm). Rostrum (Figure 1 A) slender, moderately long, not reaching beyond distal end of third antennal segment, unarmed near tip, dorsally with 9–22 teeth, 2–3 of them are placed on carapace behind posterior margin of orbital cavity (postorbital teeth), ventral with 1–9 teeth. Carapace without supraorbital tooth, with well-developed antennal tooth and a small tooth on pterygostomial angle (Figure 1 A, B). Pereopods without exopods; first two pereopods chelate, first pereopod shorter then second, both with dense brushes of setae near tip of fingers typical for atyid shrimp; third pair of pereopods with distinct sexual dimorphism, propodus of male (Figure 1 C) slightly curved, dactylus shorter, with stronger and more curved spines at posterior margin than in female (Figure 1 D). Endopod of first pleopod of male broad and pear-shaped, about 1.2 times as long as broad (Figure 1 E). Appendix masculina at second pleopod of male bean-shaped, with numerous strong spines, appendix interna reaching to about 80% of of appendix masculina. Egg size 0.55–0.58 × 0.85–1.00 mm.

Notes on taxonomy and identification

The first author examined type material of *Caridina davidi* (MNHN, Na 678, Na 679, Na 682), and found that these are conspecific with common aquarium populations and the population from Gillbach reported here. It is characterized by broad endopods of the first pair of pleopods (1.1–1.3 times as long as wide in adult males), a deeply excavated carpus of the first pair of chelipeds, a slight sexual dimorphism of the rostrum (most males show smaller and more apressed dorsal teeth on rostrum, compared to females), and the distinct sexual dimorphism at the third pereopods.

The taxonomy of *Neocaridina davidi* remains partially conflicting and unclear. In his revision of the genus *Neocaridina*, Cai (1996) transferred *C. davidi* to the genus *Neocaridina*, and considered it a subspecies of *N. denticulata* (*N. denticulata davidi*). The differences to the nominate form (carpus of first cheliped strongly excavated vs. slightly excavated in *N. d. denticulata*, third chelipeds with distinct sexual dimorphism vs. no noticeable sexual dimorphism in *N. d. denticulata*, rostrum not overreaching antennular peduncle in *N. denticulata davidi* vs. reaching beyond in *N. denticulata denticulata*) are however so distinct that species status appears justified, and *N. davidi* is regarded as distinct species here.

The detailed descriptions and drawings given by Englund and Cai (1999) left no doubt that *N. denticulata sinensis* reported from Hawaiian rivers and *N. davidi* reported here from Gillbach and Erft are conspecific. Liang (2004) considered *Caridina davidi* Bouvier, 1904 and accordingly also *N. denticula davidi*, together with *N. denticula sinensis* (Kemp, 1913), synonyms of *Neocaridina heteropoda* Liang, 2002 from Zhejiang province, China. As stated by Shih and Cai (2007), *C. davidi* Bouvier, 1904 has as the senior synonym clear priority over *N. heteropoda* Liang, 2002 (article 23 of the ICZN). The valid name for this species, frequently sold as an aquarium pet and proved by Gillbach and Erft in this study, is accordingly *N. davidi*. We tentatively assume that *N. heteroptera heteroptera* Liang, 2002 and *N. denticulata sinensis* (Kemp, 1913) are synonyms of *N. davidi*; however, clarification of this issue requires examination of the types of these two taxa, which is clearly beyond the scope of the present study.

N. davidi can be distinguished from *Atyaephyra desmarestii* (Millet, 1831), another superficially similar fresh water shrimp introduced into the Rhine drainage, by the following characters: a distinct tooth is present at the rounded pterygo-stomial carapace margin in *N. davidi* (Figure 1 B, A), vs. narrow carapax margin without distinct tooth in *A. desmarestii*; a supraorbital tooth present at the base of rostrum in *A. desmarestii*, lacking in *Neocaridina*; first and second pereopods with exopods in *A. desmarestii*, vs. exopods absent on all pereopods of *Neocaridina*; third and fourth pair of pereopods with distinct sexual dimorphism in *N. davidi* (Figure 1 C, D): propodit curved and dactylus short with strong curved claws in males, vs. pereopods without sexual dimorphism in *A. desmarestii*; endopodite of first pleopod broad and pear-shaped with basal appendix interna (Figure 1 E) in male *N. davidi*, vs. endopodite slender crescent-shaped with distal appendix interna in *A. desmarestii*.

Records at Gillbach and Erft

Neocaridina davidi was recorded at the following sites: Gillbach near Rheidt 25.09.2011, 13.05.2012, 51°00'06.65"N 6°40'12.33"E; Gillbach near Gill 13.05.2012, 51°01'33.7836"N 6°41'15. 6876"E; Gillbach near Niederaußem 25.09.2011. 51°00'00.40"N 6°39'59.23"E; Erft near Holzheim, 13.05.2012, 51°09'12.0492"N 6°40'48.2664" E.

Ecology, records from other areas, and parasites

Its attractive colour morphs (Red Fire Shrimp, Yellow Fire Shrimp, Sakura Shrimp), its tolerance of varying water qualities, and its brooding ecology with females carrying the eggs until the nearly fully developed larvae hatch, has rendered

N. davidi one of the most popular ornamental shrimp species (Karge and Klotz 2008). Unlike most of the other exotic species introduced to waters like Gillbach and Erft, *N. davidi* does however not originate from a tropical ecosystem: Its habitats are small to medium-sized streams in East and Central China. Temperatures in water bodies of this region vary between 6–8 °C in the winter and nearly 30°C in the summer (W. Klotz, pers. observations); Oh et al. (2004) reported ranges in water temperature from 4 °C in January to nearly 20°C in July in a natural habitat of *N. denticulata* in Korea. The red colour morph of *N. davidi* reportedly proliferated over several years in an artificial pond near Hannover, Germany, covered by a thick layer of ice in the winter (G. Voss, pers. com). Given this tolerance for comparatively low temperatures, we assume that *N. davidi* may spread from the artificially warmed waters of Gillbach and Erft downstream to colder habitats and finally into the river Rhine. Notably, *N. davidi* is invasive also in other regions, including Chinese waters, where it replaced other shrimp species; in these cases, artificial dispersal by fish stocking is the likely pathway of introduction (Englund and Cai 1999).

In Hawaii, aquarium escapees established large populations in several streams and two lakes on the island of O´ahu; possible impacts on the native fresh water shrimp *Atyoida bisulcata* Randall, 1840 are under discussion (Englund and Cai 1999). Streams and rivers of Central Europe are naturally devoid of atyid shrimps; the only species of the family occurring in German streams, *Atyaephyra desmarestii*, was introduced from the western Mediterranean and widely dispersed throughout European waterways (Kinzelbach 1972; Rey et al. 2004). *N. davidi* feeds on detritus and biofilm, and could potentially compete with native aquatic insects, such as Ephemeroptera.

Freshwater shrimps of the genus *Neocaridina* are known to host worms of the families Branchiobdellidae and Scutariellidae. Already in the first description of the only European representative, *Scutariella didactyla* Mrazek 1907, the author presumed based on stomach content that the worm feeds as a parasite on body fluids of the host, in this case *A. desmarestii*. Our own investigations on *N. davidi* from the aquarium trade infected with scutariellids support this assumption. Infected shrimps show brown-bordered holes in their pleurobranchies, which disappear with the next molt after removal of the worms (Klotz 2010). Scutariellids living on *Neocaridina* are most likely *Scutariella japonica* (Matjasic, 1990); assuming that the worms depend on *Neocaridina* as host species; an impact on the likewise introduced, meanwhile established population of *A. desmarestii* in the Rhine system appears rather unlikely. No scutariellids could be observed on *N. davidi* collected from Gillbach and Erft. Thus we consider impacts on native aquatic animals comparable to that of the fungus-like oomycete *Aphanomyces astaci* Schikora, 1903, the causative agent of crayfish plague, which was repeatedly introduced to Europe with North American crayfish, rather unlikely (Diéguez-Uribeondo 2006).

Macrobrachium dayanum (Henderson, 1893)

Material examined

OUMNH.ZC.2012-05-057: 3 juveniles, Gillbach near Reidth, NRW, Germany; coll. F. Herder and S. Guese 2012; OUMNH.ZC.2013-05-042: one adult male cl. 12.4 mm, 3 ovigerous females cl. 10.4–12.4 mm, Gillbach at Niederaußem-Auenheim, Rhein-Erft Kreis (Germany), coll. F. W. Miesen 31.05.2013.

Morphology

A medium-sized palaemonid species with a body size between 7 and 9 cm. Rostrum straight or slightly curved, reaching to the distal end of scaphocerite or slightly beyond. Distinct sexual dimorphism, second pair of chelipeds stronger in adult males, fingers with longitudinal grooves covered by dense coat of fine hairs. Second pair of chelipeds less developed in females, fingers without dense hair coat. Diameter of eggs >1 mm. Subadults with red brownish stripes on chelipeds ("Ringelhandgarnele"/ "Red Clawed Prawn"), often with distinct red brownish longitudinal stripe on rostrum.

Macrobrachium dayanum differs from other European palaemonids, as well as from coastal species of the genera *Palaemon* and *Palaemonetes* and from the South European freshwater species *Palaemonetes antennarius* Edwards, 1837, in its strong second chelipeds. The armature of the carapace provides further characters: *M. dayanum,* a typical representative of the genus *Macrobrachium,* possess a strong tooth in the hepatic region of the carapace (behind and slightly below the antennal tooth). In contrast, the representatives of the genera *Palaemonetes* and *Palaemon* possess a tooth in the branchiostegal region (near to anterior margin of carapace, distinctly below antennal tooth) of carapace. This character even allows one to clearly distinguish juveniles from European palaemonids. *M. dayanum* differs from both atyid species occurring in North Rhine-Westphalia, namely *Atyaephyra desmarestii* and *Neocaridina davidi,* by its strong and slender chelipeds.

Besides *M. dayanum*, *M.assamense assamense* (Tiwari, 1958) is infrequently present in the aquarium trade under the same common name (Karge and Klotz 2008). *M. assamense assamense* differs from *M. dayanum* by having a stouter carpus of the second cheliped in adult males (carpus of the major cheliped shorter than merus in *M. assamense assamense* vs. carpus as long as or longer than merus in *M. dayanum*), and in the shorter rostrum with few ventral teeth (1–5 vs. 3–7 (usually 5–7) in *M. dayanum*) (Tiwari 1955; Tiwari 1958). The specimens collected in the Gillbach show a long rostrum, distinctly curved upwards, with 5–6 ventral teeth; their second chelipeds and the ratio of rostrum length and carapace length agree with the characters provided by Tiwari (1955). Hence, we consider their determination as *M. dayanum* justified.

Records at Gillbach

Macrobrachium dayanum was recorded so far only at one site: Gillbach near Niederaußem, 51°00'00.40"N 6°39'59.23"E on 25.09.2011 and 31.05.2013.

General and ecology

The native habitat of *Macrobrachium dayanum* are hilly areas at the southern slopes of the eastern Himalaya, and stretches from north-eastern India to Myanmar. With longitudinal grooved claw fingers and the large eggs carried by females, the species belongs to the *Macrobrachium hendersoni* (De Man, 1906) complex. Its nine species or subspecies known so far are considered to show the most distinct adaptations to freshwater environments within the genus *Macrobrachium*. From the eggs of pregnant females hatch well-developed larvae, which instantly live benthically. This direct mode of development is considered an adaptation to streams with high currents and large distance to the coast (Jalihal et al. 1993), compared to the typical occurrence of planktonic larvae in the genus *Macrobrachium.*

Like most *Macrobrachium*, *M. dayanum* is omnivorous to carnivorous. Small invertebrates like oligochaetes, snails, or aquatic insects, are favoured, as well as small bottom-dwelling fish; the latter are caught using the second chelipeds (W. Klotz, pers. observation in the aquarium). This predatory trophic ecology will likely play a role in streams like the Gillbach, where *M. dayanum* co-exists with native and introduced fish and invertebrate species; *Macrobrachium* and *Neocaridina* are however likely affected by predation themselves, for example by the native omnivorous to predatory cyprinid fish *Squalius cephalus* (Linnaeus, 1758) (chub), or the European eel [*Anguilla anguilla* (Linnaeus, 1758)].

Unlike in *N. davidi*, *M. dayanum* requires at least subtropical water temperatures throughout the year. The animals largely stop activity at temperatures below about 15 °C, and die below 10 °C within a short time (W. Klotz, pers. observation). *Macrobrachium* are accordingly restricted to the warmer areas of the Gillbach, and cannot be expected to survive the European winter if accidentally dispersing to cooler areas or the Rhine itself.

Taken together, the occurrence of *M. dayanum* is most likely only of local effect to the widely artificial fauna of the Gillbach, whereas the introduction of *N. davidi* to Gillbach and Erft might lead to a successful downstream invasion, with unknown potential interferences with the local fauna. The risk of introducing parasites harmful for native crustaceans appears however low.

Conclusions

Due to its dependence on higher water temperature, we consider the Gillbach population of *Macrobrachium dayanum* rather unlikely to extend further downstream into the Rhine system. The Red Clawed Prawn population will likely disappear as soon as the source of the warm waters, namely the power plant, stops or substantially reduces discharging heated waters. Low temperatures are however unlikely a barrier or lethal to *Neocaridina davidi*, which is invasive also in other temperate regions. *N. davidi* might affect native aquatic invertebrates by competitive interactions; effects by scutariellid parasites potentially distributed by *N. davidi* appear unlikely due to the lack of other potential host species. No scutariellid worms or eggs could be observed on *N. davidi* collected from Gillbach and Erft. Taken together, the stocking of artificially warm waters with alien ornamental species is obviously harmless in some, but might be risky in other cases. The thermal gradient connected directly to native ecosystems might even be a prime setting for adaptation of exotic species.

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