Rapid Communication

Appearance of exotic shrimp *Palaemon sinensis* (Sollaud, 1911) and other freshwater shrimps before and after the 2018 extreme flood in western Japan

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Abstract

*Palaemon sinensis* is a landlocked shrimp imported to Japan from China for use as fishing bait. This species was first confirmed in the wild in Japan in 2005, mainly appearing in riverside pools and irrigation canals. The July 2018 flood in western Japan greatly altered streambeds, adjacent riparian, and aquatic zones. However, there is no information on the effects of extreme flood disturbances on populations of this species. In this study, we compared the occurrence of freshwater shrimp before and after the 2018 flood. The results showed that, in the post-flood survey in 2022, *P. sinensis* appeared in four out of 12 canals but not at the river sampling stations. At the river sampling stations, the amphidromous shrimp *Caridina leucosticta* was recorded before and after the flood. Other landlocked species, *Neocaridina* spp., which may show positive stereotaxis to submerged vegetation, appeared after flooding. The present study is the first follow-up survey of the exotic *P. sinensis* shrimp after the 2018 flood. This species showed relatively low resistance to flooding compared with other freshwater shrimp species. However, irrigation canals were found to be less susceptible to flooding disturbances than rivers as habitats for this species.

Key words: amphidromous, *Caridina leucosticta*, fishing bait, landlocked, *Neocaridina* spp.

Introduction

The flow regime is a major factor in the physical habitat of streams, which, in turn, is a major determinant of biotic composition (Bunn and Arthington 2002). Natural causes of change or modification of flow regimes include seasonal changes, droughts, and floods (Rytwinski et al. 2017). Heavy rainfall caused disaster-class flooding in July 2018 in western Japan (Izumi et al. 2019). This catastrophic flooding disturbance altered the sediments and debris found in the streambeds, adjacent riparian, and aquatic zones. This has resulted in the collapse of riverside pools in flood plains, mainly in short rivers, including the Seno and Kamo Rivers in Hiroshima Prefecture. Consequently, freshwater organisms, such as fish and shrimp, are affected.
Palaemon sinensis (Sollaud, 1911) is a freshwater landlocked palaemonid shrimp that is naturally distributed in China, Myanmar, Siberia, and Sakhalin (Shen 1939; Cai and Dai 1999; Cai and Ng 2002; Labay 2011). Many species of freshwater shrimp were imported into Japan, mainly from China, for use as live fishing bait from 1969 to 2016 (Niwa 2010; Saito et al. 2011; Saito 2017, 2018). Palaemon sinensis was not reported in the wild in Japan before 1990 (Liu et al. 1990) and was first discovered in a pond in Shizuoka Prefecture in 2005 (Oonuki et al. 2010). It has subsequently been reported in 28 out of the 47 prefectures (Imai and Oonuki 2014; Imai et al. 2021a, b, c; Uchida et al. 2023). Mitochondrial 16S rRNA sequence analysis suggested that haplotypes of P. sinensis did not differentiate independently in Japan but were introduced through Chinese imports (Ogasawara et al. 2021).

Surveys of freshwater shrimp in western Japan, specifically the Hiroshima and Okayama prefectures, from 2015 to 2017 revealed that P. sinensis inhabited lentic areas at six river sampling stations and five irrigation canals (Saito et al. 2016; Saito 2018).

However, there is no information on the effects of extreme flood disturbances on populations of this species. This study compares the distribution and habitat of freshwater shrimp in rivers and irrigation canals in Hiroshima and Okayama prefectures in 2022, when river improvements after flooding were completed and the riverbank was safely accessible, with previous data (Saito et al. 2016; Saito 2018). We discuss the differences in the ecological characteristics that affect the post-flood appearance of P. sinensis and other freshwater shrimp, such as other landlocked species Neocaridina spp. and Caridina leucosticta (Stimpson, 1860).

Materials and methods

Five rivers in Hiroshima Prefecture were tested with two sampling stations per river: R1–2, Ohota River (103 km in total length of main stream channel); R3–4, Seno River (22.5 km); R5–6, Kurose River (102.5 km); R7–8, Kamo River (19.5 km); and R9–10, Nuta River (47.8 km). Sampling was conducted in March 2022, referred to as the post-flood survey (Figure 1). For comparison, data for each station for March 2015 were obtained from Saito et al. (2016), referred to as the pre-flood survey. In addition, surveys were conducted at 12 sampling stations on irrigation canals that are connected to flow water from rivers: C1–6, 11, and 12 in the Kurashiki River system and C7–10 in the Sasagase River system. The survey was conducted in May–June 2022 (post-flood) and was compared with pre-flood survey data from May 2017 from Saito (2018).

Freshwater shrimp were sampled using a D-shaped hand net (opening, 35 × 30 cm; mesh size, 2.5 mm; handle length, 165 cm) from submerged vegetation and root masses in an approximate 1 m² area at each station along the riverbanks during the day. The shrimps were immediately preserved in 10% freshwater formalin and identified using a stereo-microscope (SMZ745T;
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Figure 1. Location of the sampling sites in rivers of Hiroshima Prefecture, and irrigation canals of Okayama Prefecture, western Japan. Sampling stations were located at Ohota (R1–2), Seno (R3–4), Kurose (R5–6), Kamo (R7–8) and Nuta (R9–10) Rivers in Hiroshima Prefecture. Sampling stations of irrigation canal were located at in Kurashiki (C1–6, 11–12) and Sasagase (C7–10) River systems in Okayama Prefecture. Location of the sampling sites was created by processing the electronic map Vector (Geospatial Information Authority of Japan).

Nikon, Tokyo, Japan) at the aquatic ecology laboratory of Hiroshima University. The freshwater shrimp species were identified according to the methods described by Toyota and Seki (2014) and Toyota (2019). The atyid shrimp *Neocaridina denticulata* (De Haan, 1844) is distributed throughout western Japan (Toyota and Seki 2014; Toyota 2019). However, exotic *Neocaridina* shrimp species, including *Neocaridina davidi* (Bouvier, 1904), are dispersed across various parts of Japan (Mitsugi et al. 2017; Onuki and Fuke 2022). Because of the controversy regarding the identification of shrimp in the genus *Neocaridina* at the species level (Shih and Cai 2007; Niwa 2010; Yoshigo 2011; Klotz et al. 2013; Onuki and Fuke 2022), we denoted all *Neocaridina* shrimp as *Neocaridina* spp. The sampling stations were photographed
Figure 2. Occurrence of freshwater shrimp species in the pre- and post-flood surveys in river in Hiroshima Prefecture and irrigation canal in Okayama Prefecture. The data pre-flood was referred from Saito et al. (2016) and Saito (2018).

using a PENTAX WG-III digital camera (RICOH IMAGING COMPANY, LTD., Tokyo, Japan). The salinity and stream velocity at each station were measured using a YSI Model 85 water quality meter (YSI Inc., Ohio, USA) and the float method, respectively.

Results

Figure 2 shows the occurrence of freshwater shrimp species before and after the flood in the rivers of Hiroshima Prefecture and canals in Okayama Prefecture. In the river survey, *P. sinensis* was observed at the Ohota (R2), Seno (R3–4),
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Kamo (R7–8), and Nuta (R10) Rivers in the pre-flood survey. However, this species was not detected at any sampling stations in the post-flood survey. *Caridina leucosticta* was collected from the Kurose (R6) River in the pre-flood survey and was confirmed in the Kurose (R6) and Kamo (R7) Rivers in the post-flood survey. *Neocaridina* spp. were collected from the Ohota (R1–2), Seno (R3–4), Kurose (R5), Kamo (R7–8), and Nuta (R9–10) Rivers in the pre-flood survey and were confirmed in the Ohota (R1), Kurose (R5–6), Kamo (R7–8), and Nuta (R9–10) Rivers in the post-flood survey. In the canal survey, *P. sinensis* was collected at the Kurashiki (C2, 6) and Sasagase (C8–10) River systems in the pre-flood survey and was confirmed at the Kurashiki (C5–6) and Sasagase (C9–10) River systems in the post-flood survey. Among the other shrimp species, *Palaemon paucidens* De Haan, 1844 was collected from the canals of the Kurashiki (C1–2, 4–6, 11–12) and Sasagase (C7) River systems in the pre-flood survey and was confirmed at all sampling stations in the post-flood survey. *Neocaridina* spp. were collected at the Kurashiki (C2–3, 6, 12) and Sasagase (C7–10) River systems in the pre-flood survey and were confirmed at the Kurashiki (C1–3, 5, 11–12) and Sasagase (C10) River systems in the post-flood survey.

Figures 3 and 4 show photographs of the changes at the sampling stations before and after flooding. At Ohota (R2), Seno (R4), and Kamo (R8) Rivers in Hiroshima Prefecture, riverside pools were present in the pre-flood survey. However, these pools collapsed between the survey periods and were not present in the post-flood survey. In contrast, at the sampling stations of Okayama Prefecture, where *P. sinensis* was observed in the pre- and post-flood surveys, structural damage was not observed in the canals of the Kurashiki (C6) and Sasagase (C9–10) River systems. The structure of the C2 was also maintained after the flood but no *P. sinensis* was recorded.

Figure 5 shows the changes in salinity and velocity at the sampling stations in the pre- and post-flood surveys. In the river survey, *P. sinensis* had a narrow velocity range of 0–2 cm/s and salinity of 0 PSU at Ohota (R2), Seno (R3–4), Kamo (R7–8), and Nuta (R10) River sampling stations in the pre-flood survey. However, in the post-flood survey, *P. sinensis* was not found at the six sampling stations in which the velocity increased to 2.5–10 cm/s. In the canal survey, almost no change in water salinity and velocity was observed in the Kurashiki (C6) and Sasagase (C9–10) river system sampling stations where *P. sinensis* was observed in the pre- and post-flood surveys. In contrast, at the sampling stations of the Kurashiki (C2) and Sasagase (C8) River systems where *P. sinensis* was not confirmed in the post-flood survey, salinity and velocity increased to 0.5 PSU and 7.1 cm/s, respectively. However, at the sampling station in the Kurashiki (C5) River system where *P. sinensis* was confirmed in the post-flood survey, the velocity decreased to 1.4 cm/s. As for other shrimp species, *P. paucidens*
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**Figure 3.** Photographs taken of the river sampling stations R2, 4, and 8 in the pre- and post-flood surveys. Photographs by H. Saito.

*Neocaridina* spp. were observed at a wide range of velocities (0–12 cm/s) and salinities (0–0.7 PSU) at sampling stations in the rivers and canals in the pre- and post-flood surveys (Supplementary material Tables S1, S2).

**Discussion**

Riverside pools generally connect or separate from the main river owing to fluctuations in the water level, creating an important habitat for aquatic organisms that prefer lentic environments (Katano et al. 2011). *Palaemon sinensis* was confirmed at sampling stations with riverside pools in Hiroshima Prefecture in the 2015 survey (Saito et al. 2016). Previous studies have reported
that the presence of benthic invertebrates drastically decreases after floods (Lamberti et al. 1991; Foster et al. 2020). Although this study did not record data on the density of *P. sinensis* just after the 2018 flood, this shrimp was not
observed in the Ohota, Seno, and Kamo Rivers in the 2022 survey. This was mainly due to the collision of the streambed and adjacent riparian area in July 2018, and the riverside pools were not fully restored in time for the 2022 survey (Figure 3). Imai et al. (2018, 2021b) observed *P. sinensis* in the riverside pools of the Takahashi River in October 2017 and November 2020, indicating that this species is likely to remain despite flooding. *Palaemon sinensis* breeds and is recruited within the riverside pool from spring to summer (Saito et al. 2019). Although the damage caused by flooding varies from river to river, missing riverside pools would significantly impact the *P. sinensis* population. Further research is needed to determine whether *P. sinensis* can be confirmed after restoration of the riverside pools in the Ohota, Seno, and Kamo Rivers.

Aquatic species have evolved life strategies primarily in direct response to natural flow regimes (Bunn and Arthington 2002). Decapod crayfish have poor dispersal ability. Foster et al. (2020) found that the density of decapod crayfish dropped to near zero after the flood and had not recovered to pre-flood levels after five years in western Washington streams, USA.

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**Figure 5.** Profile of velocity and salinity in sampling stations in relation to the presence of *Palaemon sinensis*. The dotted line indicates the range of velocity and salinity where this shrimp appeared in the pre-flood survey. Red circles and black crosses indicate the appearance and non-appearance of this shrimp, respectively. The data pre-flood was referred from Saito et al. (2016) and Saito (2018).
Freshwater shrimps have different life-history traits that can influence their dispersal abilities. *Palaemon sinensis* and *Neocaridina* spp. are landlocked species that show direct development with no pelagic larval stages and spawn a small number of large eggs, whereas *C. leucosticta* is amphidromous, in which adults live, breed and spawn small-sized embryos in freshwater but have extended larval development in marine waters (Shokita 1981; Oonuki et al. 2010; Fujita et al. 2011; Bauer 2013). In the present study, *C. leucosticta* was observed in the rivers of Hiroshima Prefecture in the pre- and post-flood surveys. Molecular phylogenetic trees have shown several distinct clades roughly corresponding to the local populations within *N. denticulata* but no distinct clades within *C. leucosticta* (Fujita et al. 2011). The authors also reported that *N. denticulata* has little or no dispersal ability because it is commonly distributed among drainage systems isolated from marine and terrestrial habitats, whereas *C. leucosticta* has a high dispersal ability because it can disperse among rivers during its larval stages in the sea (Fujita et al. 2011). Consequently, amphidromous species can maintain their populations even after floods by migrating between the sea and river.

*Palaemon sinensis* was not observed in the rivers of the Hiroshima Prefecture in the post-flood survey, whereas *Neocaridina* spp. was observed at seven stations. There are two possible explanations for the observation of *Neocaridina* spp. after the flood. One explanation is that they flowed downstream from upstream dams and ponds. The second explanation is related to their ecological characteristics; our results showed that the upper limit of the velocity (12 cm/s) at the stations in which *Neocaridina* spp. inhabits was greater than that of *P. sinensis* (2 cm/s). In addition, previous studies have established that *Neocaridina* spp. may show positive stereotaxis to submerged vegetation, thereby improving their chances of remaining in freshwater habitats during flooding events (Niwa and Yokoyama 1993; Saito et al. 2012). *Palaemon sinensis* on the other hand, was observed to spend time on sandy sediments as well as on submerged plants and moved occasionally by swimming in the water column (Saito et al. 2019). Because landlocked species cannot maintain populations by migrating between the sea and river, their ability to stay on substrates such as aquatic plants during floods may reflect their appearance after floods.

No structural damage was observed in the canals of Okayama after the flood. Although the occurrence of *P. sinensis* changed locally in the canals because of changes in salinity and stream velocity before and after the flood, this species appeared at 4 sampling stations. Imai et al. (2021b) confirmed *P. sinensis* in the Asahi River and Yoshii River, irrigation canals of the Tame River, Lake Kojima, and Kojima Bay, and two ponds in Okayama and Setouchi from October 2018 to November 2020. This suggests that this species is spreading rapidly in Okayama Prefecture. Although imports of palemonid shrimp have stopped since 2016, *P. sinensis* has become established
as a source of fishing bait in Okayama Prefecture and there is a possibility that it will spread to other areas through the marketing routes of fishing bait (Saito 2018; Imai et al. 2021b).

In Japan, *P. sinensis* was first confirmed in 2005 (Oonuki et al. 2010) and has been reported in 28 of 47 prefectures (Imai and Oonuki 2014; Imai et al. 2021a, b, c; Uchida et al. 2023). The present study is the first follow-up survey after the 2018 flooding and indicates that *P. sinensis* has a relatively low resistance to flooding compared to other freshwater shrimps. However, irrigation canals were found to be less susceptible to flood disturbances than rivers as habitats for this species. Previous studies have highlighted the possible effects of the invasive *P. sinensis* on local communities. Parasitic species such as *Tachaea chinensis* Thielemann, 1910, may have been unintentionally imported from China to Japan along with the host shrimp, *P. sinensis* (Imai et al. 2021a). The rapid decline and extinction of the endangered freshwater fish *Hemigrammocypris neglectus* (Stieler, 1907) in local areas has been related to the introduction of palemonid shrimp, especially *P. sinensis* (Ministry of the Environment 2023). In a lentic environment where native *P. paucidens* and exotic *P. sinensis* coexist, native shrimp may be replaced by exotic shrimp owing to competition for food and space (Saito et al. 2016; Imai et al. 2021a). In the present study, both palemonid shrimps were confirmed in irrigation canals; hence, it is necessary to continue monitoring the population dynamics of both species.

**Authors’ contribution**

Individual author contributions to the manuscript using the relevant roles as follows: research conceptualization; YA and HS, sample design and methodology; YA and HS, investigation and data collection; YA, YS, ST, AMK and HS, data analysis and interpretation; YA, YS, TI, ST, PAT, AMK and HS, funding provision; HS, roles/writing – original draft; writing – review and editing; YA, TI, ST, PAT, AMK and HS.

**Acknowledgements**

We are grateful to Professor Koichiro Kawai for his contributions and recommendations. We thank the anonymous referees for their thorough and useful comments. We would like to thank Editage (www.editage.jp) for English language editing. This study was partly supported by a Grant-in-Aid for Scientific Research from the Japan Society for the Promotion of Science (KAKENHI), grant number 22K05690.

**Funding declaration**

This work was partly supported by a Grant-in-Aid for Scientific Research (C) from the Japan Society for the Promotion of Science (KAKENHI), Grant Number 22K05690.

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Supplementary material
The following supplementary material is available for this article:

Table S1. Collection of freshwater shrimps in the pre- and post-flood surveys in rivers of Hiroshima Prefecture.

Table S2 Collection of freshwater shrimps in the pre- and post-flood surveys in irrigation canals of Okayama Prefecture.

This material is available as part of online article from:
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