

## Short Communication

## Import, trade and culture of non-native ornamental crayfish in Java, Indonesia

Ernik Yuliana<sup>1</sup>, Yonvitner<sup>2,3</sup>, Surya Genta Akmal<sup>3,4</sup>, Rafialwan A. Subing<sup>2</sup>, Sultan A. Ritonga<sup>2</sup>, Agus Santoso<sup>5</sup>, Antonín Kouba<sup>6</sup> and Jiří Patoka<sup>4,\*</sup>

<sup>1</sup>Department of Biology, Faculty of Mathematics and Natural Sciences, Indonesia Open University, Jl. Pondok Cabe Raya, Pamulang, 15418 Tangerang Selatan, Indonesia

<sup>2</sup>Department of Aquatic Resources Management, Faculty of Fisheries, IPB University, Jl. Agathis No. 1 Kampus FPIK IPB Dramaga, 16680 Bogor, Indonesia

<sup>3</sup>Centre for Coastal and Marine Resources Studies, The Institute for Research and Community Service, IPB University, 16680 Bogor, Indonesia

<sup>4</sup>Department of Zoology and Fisheries, Faculty of Agrobiological, Food and Natural Resources, Czech University of Life Sciences Prague, Kamyčká 129, 16500 Prague - Suchbátka, Czech Republic

<sup>5</sup>Department of Statistic, Faculty of Sciences and Technology, Universitas Terbuka, 15437 Tangerang Selatan, Indonesia

<sup>6</sup>South Bohemian Research Center of Aquaculture and Biodiversity of Hydrocenoses, Faculty of Fisheries and Protection of Waters, University of South Bohemia in České Budějovice, Zátěšská 728/II, 38925 Vodňany, Czech Republic

Author e-mails: [patoka@af.czu.cz](mailto:patoka@af.czu.cz) (JP), [ernik@ecampus.ut.ac.id](mailto:ernik@ecampus.ut.ac.id) (EY), [yonvitnr@yahoo.com](mailto:yonvitnr@yahoo.com) (Y), [akmal@af.czu.cz](mailto:akmal@af.czu.cz) (SGA), [rafialwan.athariq@gmail.com](mailto:rafialwan.athariq@gmail.com) (RAS), [sultanritonga@gmail.com](mailto:sultanritonga@gmail.com) (SAR), [aguss@ecampus.ut.ac.id](mailto:aguss@ecampus.ut.ac.id) (AS), [akouba@frov.jcu.cz](mailto:akouba@frov.jcu.cz) (AK)

\*Corresponding author

**Citation:** Yuliana E, Yonvitner, Akmal SG, Subing RA, Ritonga SA, Santoso A, Kouba A, Patoka J (2021) Import, trade and culture of non-native ornamental crayfish in Java, Indonesia. *Management of Biological Invasions* 12(4): 846–857, <https://doi.org/10.3391/mbi.2021.12.4.05>

**Received:** 2 February 2021

**Accepted:** 5 July 2021

**Published:** 30 August 2021

**Handling editor:** Christoph Chucholl

**Thematic editor:** Calum MacNeil

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## Abstract

The pet trade is known to be one of the main sources of invasive species including freshwater crayfish, which cause socio-economic losses and negative impacts on native biota in many regions where introduced. Indonesia was identified as the leading supplier of ornamental crayfish globally but the local market has been neglected even though certain non-native species were reported previously. Based on the survey of pathways and culture of ornamental crayfish in Java, six non-native species were recorded: *Cherax destructor*, *C. quadricarinatus*, *C. peknyi*, *C. snowden*, *C. warsamsonicus*, and *Procambarus clarkii*. The latter species originates from North America and serves as a vector of crayfish plague, i.e. a disease lethal for non-North American crayfish species. Crayfish are cultured both in outdoor and indoor facilities as well as in natural lakes and reservoirs. Harvested crayfish are transported via numerous routes across most of the island of Java. It is obvious that the local market for ornamental crayfish is well-developed and Jakarta, Surabaya and Yogyakarta were identified as hotspots of this trade. Further monitoring, detailed analysis of the market and a ban of high-risk *P. clarkii* are recommended to improve management and existing legislation.

**Key words:** Parastacidae, Cambaridae, aquaculture, invasive species, pathway, transport, Asia

## Introduction

Freshwater crayfish (Decapoda: Astacida) inhabit various lotic and lentic habitats such as rivers, brooks, lakes, swamps, and even caves (Kozák et al. 2015; Stern and Crandall 2018). Several crayfish species are exploited by humans for various purposes such as consumption, pet trade, fish bait, food for fish, educational and scientific activities (Peay et al. 2010; Faulkes 2015a; Patoka et al. 2015b, 2016a; Hossain et al. 2018; Oficialdegui et al.

2019). In comparison with a long history of ornamental fish aquaculture (Novák et al. 2020), culture and trade with ornamental crayfish started not earlier than in the 1990s (Chucholl 2013; Faulkes 2015a). Crayfish are cultured both in outdoor and indoor facilities and also harvested from the wild (Holdich 1993; Jones and Geddes 1997; McClain 2020). Certain ornamental crayfish have escaped or were intentionally released out of their native range, subsequently establishing feral populations and behaving as invaders despite wildlife management activities and related legislative restrictions (Weiperth et al. 2017; Patoka et al. 2018b; Oficialdegui et al. 2020). Invasive crayfish cause environmental and socio-economic losses with negative impacts on the native biota and the entire ecosystem, and also on human communities (Ficetola et al. 2012; Oficialdegui et al. 2019). Crayfish are hard to detect in the early stages of an invasion and their later effective eradication is extremely difficult or even impossible, leaving prevention of further harmful introductions as the most effective management strategy (Gherardi et al. 2011; Lidova et al. 2019).

While the ornamental fish trade is led by Singapore (Evers et al. 2019), Indonesia has been identified as the leading exporter of ornamental crayfish (Faulkes 2015b; Patoka et al. 2015c). Indonesia is the world's largest island country covering three biodiversity hotspots, Sundaland, Wallacea and Sahul, with very rich endemic biota (Myers et al. 2000). The territory of Indonesia also includes the western part of the island of New Guinea (Dutch New Guinea in the past, currently Papua and West Papua Provinces), with numerous endemic *Cherax* crayfish species (Bláha et al. 2016). This group includes also the recently discovered and described *Cherax acherontis* Patoka, Bláha and Kouba, 2017, *C. alyciae* Lukhaup, Eprilurahman and von Rintelen, 2018, *C. gherardii* Patoka, Bláha and Kouba 2015a, *C. mosessalossa* Lukhaup, Eprilurahman and von Rintelen, 2018, *C. pulcher* Lukhaup, 2015, *C. snowden* Lukhaup, Panteleit and Schrimpf, 2015, and *C. warsamsonicus* Lukhaup, Eprilurahman and von Rintelen, 2017. Their scientific description has been promoted by a high popularity as ornamental pets due to their attractive colouration (Chucholl and Wendler 2017). These crayfish are exclusively collected from the wild and exported through the main crayfish market in Sorong, West Papua Province, Indonesia (Lukhaup 2015). More scientifically as-yet unknown species with a potential to be also pet-traded are expected to occur in this island (Patoka 2020; Weiperth et al. 2020).

Apart from these wild-captured crayfish, there is also one native *Cherax* crayfish which is relatively easy to rear and breed, i.e. *C. quadricarinatus* (von Martens, 1868). The species is native to the southern part of New Guinea and northwestern Australia (Haubrock et al. 2021) and has been introduced out of its native range to numerous new localities across the Indonesian territory where it is farmed and exploited for human consumption as well as for the pet trade (Patoka et al. 2016b, 2018a; Akmal et al. 2021).

Semi-intensive farms producing *C. quadricarinatus* were established in Indonesia as early as 2003 (Edgerton 2005).

In contrast to the previous assumption that just *Cherax* crayfish are cultured in Indonesia (Patoka et al. 2015c), the North American *Procambarus clarkii* (Girard, 1852) was recently also found being farmed as ornamental crayfish. As reported by Putra et al. (2018), this species is a vector of the crayfish plague pathogen (*Aphanomyces astaci* Schikora) whose occurrence was recorded in outdoor farming ponds with *P. clarkii* in Java. Infection with *A. astaci* was also confirmed in two other decapod species, i.e. the freshwater crab *Parathelphusa convexa* de Man, 1879 and the freshwater shrimp *Macrobrachium lanchesteri* (de Man, 1911). *Aphanomyces astaci* is known to be one of the most serious pathogens affecting decapod crustaceans (Lowe et al. 2000; Svoboda et al. 2017). Despite this serious threat to the native biota and the fact that importation of *P. clarkii* to Indonesia has been banned by Regulation No. 41/PERMEN-KP/2014, culture of this crayfish species and its transport within the country are legal (Putra et al. 2018).

The purpose of this study was to survey the history and pathways of non-native crayfish introductions in Java in order to prepare a recommendation on how to improve regulation and management of these decapod crustaceans.

## Materials and methods

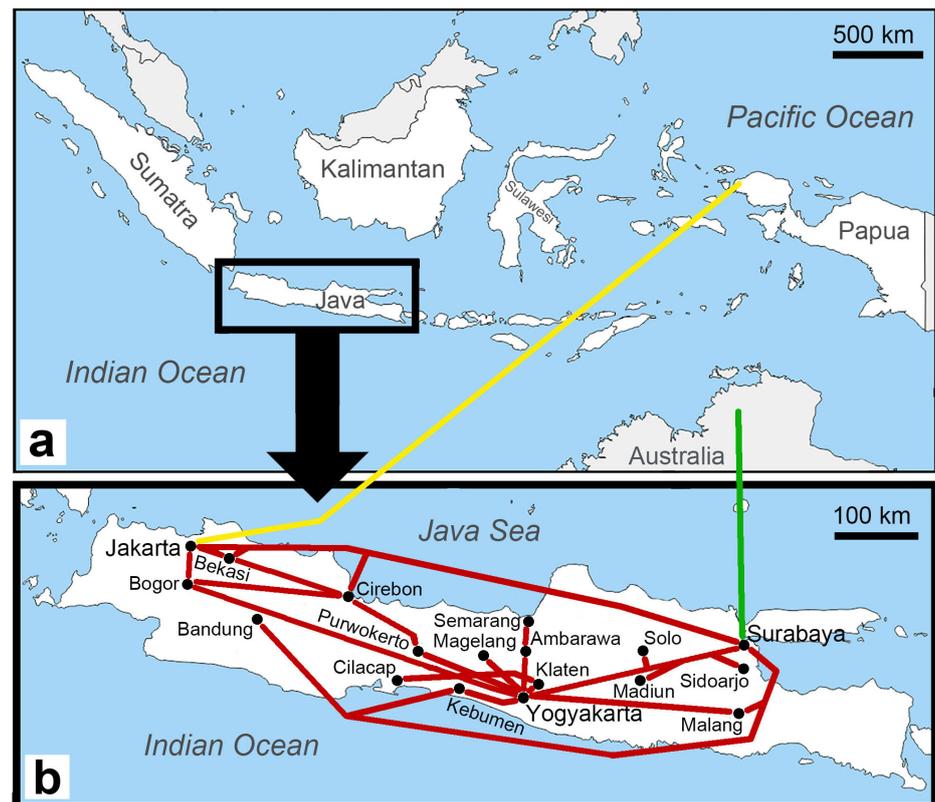
In total, 33 localities in Bogor, Cilacap, Cirebon, Jakarta, Klaten, Magelang, Malang, Semarang, Surabaya, Tangerang, Wonosobo, and Yogyakarta regions were personally surveyed between August and November 2019 in Java, Indonesia (Supplementary material Table S1). To obtain details about pathways and traded crayfish species, 13 farmers, 10 traders, four middlemen and eight crayfish owners were individually interviewed in Indonesian language (*Bahasa Indonesia*) on details such as the type of crayfish culture and management, lists of the stocked species and their origin, trends in their production, prices and sales, and distribution routes. The crayfish samples were identified morphologically based on previous descriptions (e.g. Clark 1936; Lukhaup and Herbert 2008; Yuliana et al. 2019).

## Results

In total, six non-native ornamental crayfish species were found to be cultured or imported. Five species belong to the genus *Cherax* (family Parastacidae), i.e., *Cherax destructor* Clark, 1936, *C. peknyi* Lukhaup and Herbert, 2008, *C. quadricarinatus*, *C. snowden* and *C. warsamsonicus*; and one species belongs to the genus *Procambarus*, i.e. *P. clarkii* (family Cambaridae). Of the recorded *Cherax* species, *C. destructor* is native to south-eastern Australia, while *C. peknyi*, *C. snowden* and *C. warsamsonicus*

**Table 1.** List of crayfish species exploited in Java, Indonesia: name of the species, native range, year of the introduction in Java, status (cultured or traded only), number of Javanese regions where the species occur, common price of adult individual (in USD).

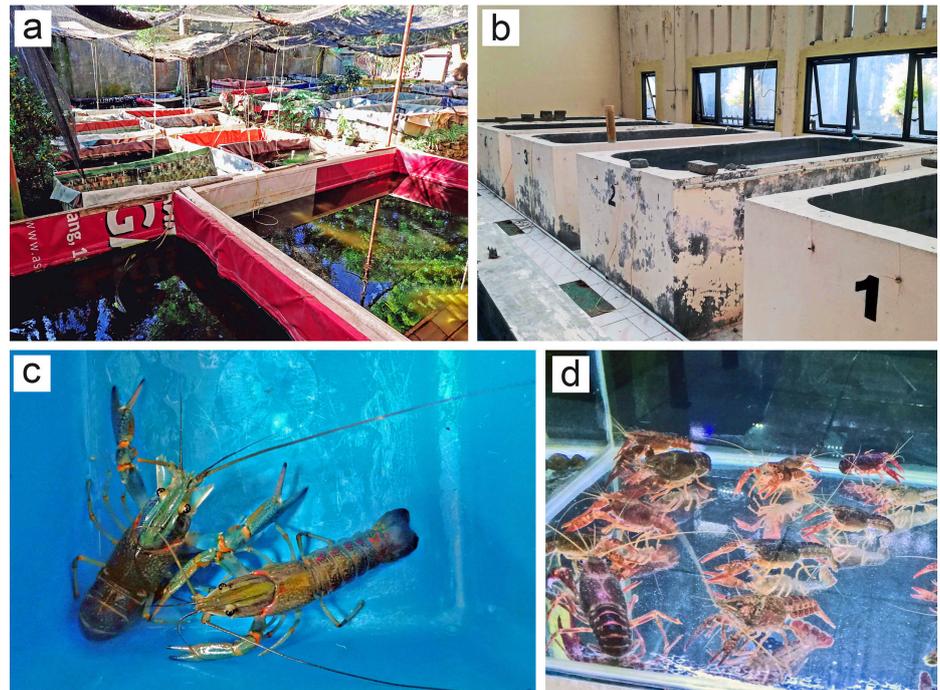
Species	Native range	Year of introduction	Status in Java	Regions	Common price for adults (USD)
<i>Cherax destructor</i>	Australia	2005	cultured	2	50
<i>Cherax peknyi</i>	New Guinea	2005	traded	1	18
<i>Cherax quadricarinatus</i>	Australia/New Guinea	2000	cultured	24	7.5
<i>Cherax snowden</i>	New Guinea	2005	traded	1	18
<i>Cherax warsamsonicus</i>	New Guinea	2005	traded	2	18
<i>Procambarus clarkii</i>	North America	2009	cultured	13	2.5



**Figure 1.** Map of Indonesia (a) and enlarged map of Java island (b) with the main routes of ornamental crayfish transportation highlighted as red lines. The first documented import is indicated by a green line. A yellow line indicates the main route used to transport of crayfish from Sorong in New Guinea to Jakarta for subsequent export abroad. Given lines do not show real traffic routes.

are native to New Guinea, and *C. quadricarinatus* is native to both Australia and New Guinea. *Procambarus clarkii* is from North America (Table 1).

The first recorded import of ornamental crayfish to Java was to Surabaya in 2000, involving *C. quadricarinatus* imported from Australia. Two peaks in the economic value of crayfish were recorded, one between 2008 and 2010 and one between 2014 and 2015. Surabaya and Yogyakarta were identified as hotspots of ornamental crayfish production in Java, while Jakarta was identified as the city where most of wholesalers and exporters are located. The main routes of ornamental crayfish transportation are given in Figure 1. Crayfish are cultured in outdoor ponds, concrete tanks, indoor aquaria and in natural lakes and reservoirs (Figures 2, 3c, d). Worms, bean sprouts, rice, corn, cassava, and pest gastropods from paddy fields



**Figure 2.** Culture of non-native ornamental crayfish in Indonesia: outdoor farm close to Purwokerto (a); indoor concrete tanks in Magelang (b); *Cherax quadricarinatus* produced in outdoor concrete reservoirs in Cirebon (c); *Procambarus clarkii* in a pet shop in Bogor (d). Author of the pictures: JP.



**Figure 3.** Culture of non-native ornamental crayfish in Indonesia: two types of outflow from farm, drainage (a) and hole (b); concrete tank equipped with shelters (c); outdoor concrete tank (d). Author of the pictures: JP.

(*Pomacea* sp.) are commonly used as feed for farmed crayfish. Since there are no official standard prices in Indonesia, the recorded prices can vary depending on the current demand. Waste water outflow is usually directly connected with streams in vicinity via drainage (Figure 3a, b).

### *Details of surveyed regions:*

#### Bogor

Several pet shops in Bogor city trade in *C. quadricarinatus* and *P. clarkii* as ornamental crayfish. The latter is advertised in various colouration forms such as wild, white, orange, and full red (also known as “Marlboro”). The vast majority of these crayfish are locally produced in outdoor facilities in quantities of more than 1,000 individuals per month. Crayfish are reared in net cages in lakes and also in artificial pond systems from both of which they can easily escape.

#### Cilacap

The only crayfish species produced in this region is *C. quadricarinatus*. Middlemen in Cilacap town collect crayfish from three main local producers and obtain 1–5 kg of crayfish per week. Crayfish are produced mainly during the rainy season, from November to March. The common price is USD 6.80 per kg for adults, and USD 5.10 per kg for subadults. There are 5–6 crayfish collectors around Wadasilintang dam circa 120 km east of Cilacap town who harvest 3 kg of crayfish per day and collector. The harvested crayfish are usually delivered 160 km eastwards to Klaten city.

#### Cirebon

In three pet shops in Kanoman fishmarket in Cirebon, *C. destructor*, *C. quadricarinatus*, *C. snowden*, *C. warsamsonicus* and *P. clarkii* are traded. These crayfish are partly delivered from Bogor, Purwokerto and Surabaya, partly locally produced. *Cherax snowden* and *C. warsamsonicus* are strictly imported from West Papua Province and not bred in Java. *Cherax destructor* is rare and has a high price compared to other crayfish species, ranging from USD 49.25 to USD 56.28 per adult pair. The number is limited and the species is usually sold as adults. The common price for *C. quadricarinatus* is USD 0.34–0.68 per subadult individual, which are relatively common in the market, and USD 15.33 per adult pair. The common price for *C. snowden* and *C. warsamsonicus* is USD 3.52–5.63 per subadult individual and USD 35.18 per adult pair. The price is expensive because these species are rare in the market. The common price for *P. clarkii* is USD 0.34–1.02 per adult individual. In 2010, circa 100 individuals of all mentioned species were sold per week but subsequently the demand has gradually declined while the number of local producers has been increasing. Therefore, the production and trade in crayfish is currently perceived as unattractive in this region and is likely to be abandoned in the near future.

#### Jakarta

Ornamental crayfish of all recorded species are delivered to wholesaler facilities in the capital city Jakarta. These crayfish are stocked and subsequently

offered and exported to the European Union, United States and Japan. Part of them is also delivered to local retailers, including pet shops and street markets. As previously reported, endemic crayfish (e.g. *Cherax boesemani*, *C. gherardii*, *C. holthuisi* or *C. pulcher*) wild-harvested in New Guinea are transported from Sorong to Jakarta but no local trade was recorded. Many New Guinean crayfish are injured and mortality is high (up to 90% depending on the experience of the importers). In pet shops, crayfish of different taxa are usually stocked in the same tank including *Cherax* species susceptible to crayfish plague, and *P. clarkii*, which is a carrier of the disease agent.

### Malang

*Cherax quadricarinatus* is cultured in outdoor facilities around Karangates reservoir, about 35 km south of Malang. In 2018, the demand for crayfish declined and just a single producer with 12 ponds continues in their production. Most crayfish are produced for human consumption, sold locally, transported to Bali and also delivered to Surabaya and exported to Japan. Some of these crayfish may also be sold as ornamentals even if clear evidence of this is lacking.

### Semarang

There are two species produced in Semarang, i.e. *C. quadricarinatus* and a red form of *P. clarkii*. The production of crayfish started more than 10 years ago in this region. The peak was documented in 2010 with a price of USD 10.23 per kg of *C. quadricarinatus*. Currently, more producers are rearing *P. clarkii* than *C. quadricarinatus*.

### Surabaya

Surabaya is the first place where the ornamental crayfish were introduced in Java. In 2000, *C. destructor* and probably also *C. quadricarinatus* were imported here from their native range in Australia. In subsequent years, *C. peknyi*, *C. warsamsonicus*, and *P. clarkii* were also introduced to the market as ornamentals. The common price was up to USD 6.80 per kg but fell to USD 3.40 per kg in 2008. In 2012, the price increased again to USD 6.80 per kg and production began to rise. Crayfish were delivered to the cities of Bandung, Bekasi, Jakarta, Madiun, Malang and Yogyakarta, and to the islands of Bali, Lombok, Sulawesi and Sumatra in Indonesia; and also to Japan, Malaysia, Singapore, Thailand, Taiwan, and Vietnam. Both purposes, for human consumption and the pet trade, were recognized within this period. Currently, exports to the mentioned countries have been largely terminated but some shipments are delivered to Taiwan, Thailand, and Vietnam.

### Yogyakarta

Yogyakarta (also known as Jogja) represents the hotspot of crayfish production in Java. There are three species produced in Yogyakarta, namely

*C. quadricarinatus*, *C. destructor* and *P. clarkii*. Moreover, another species *C. peknyi* is imported from Surabaya and its culture was trialled in 2015 in Magelang but terminated after a short period due to its aggressiveness and the ineffectiveness of the culture. Crayfish produced in Yogyakarta are delivered to the cities of Ambarawa, Cirebon, Jakarta, Kebumen, Klaten, Magelang, Malang, Purwokerto, Semarang, Sidoarjo, Solo and Surabaya, and to Sulawesi island. Local farms were established also in the mentioned cities and in their vicinity, such as the outdoor facility close to Purwokerto. Farms in Yogyakarta are in intensive cooperation with those in Klaten. *Procambarus clarkii* is produced for further culture for ornamental purposes at a size of 2.5–4.0 cm and up to 1,000 individuals are sold per week. The common price for *P. clarkii* is USD 2.56–2.93 per individual. From 2004 to 2015, the production and prices of *P. clarkii* were the highest and declined from 2016. There were 14 pet shops in Yogyakarta before 2008 but after the price decline just four currently advertise crayfish as ornamentals, with up to 100 individuals sold per week. The common price for *C. quadricarinatus* and *C. destructor* is USD 0.34–21.34 per individual depending on the size class of the crayfish.

## Discussion

Since 2000, when the first crayfish were imported to Java, six ornamental crayfish species were found to be more or less frequently traded and transported to several places on this island. The list of species is probably incomplete with regard to highly valued endemic crayfish collected in the wild in New Guinea, which are not cultured in Java due to their high aggressiveness. Based on previous studies (Patoka et al. 2014; Faulkes 2015a; Kotovska et al. 2016), we assume that there are plenty of New Guinean crayfish harvested and exported directly from Papua Province for trade and keeping in aquaria worldwide.

Just one North American crayfish species was recorded in Indonesia, i.e. *P. clarkii*; we did not record more North American species, even if they might be expected to occur due to their popularity as ornamentals (Yonvitner et al. 2020). Further, *P. clarkii* was confirmed to be a vector of the crayfish plague pathogen (Putra et al. 2018). Its spread in Java is therefore highly alarming and a threat both to crayfish aquaculture and to the native freshwater biota in general.

The most commonly cultured crayfish is *C. quadricarinatus*. The species has escaped from aquacultural facilities such as net cages and established self-sustainable populations in many water bodies in Java. Since it is a large-growing, omnivorous crustacean able to prey on invertebrates and small vertebrates, this crayfish poses a threat to the native biota despite its sensitivity to crayfish plague (Hsieh et al. 2016; Haubrock et al. 2021).

Endemic New Guinean crayfish such as *C. peknyi*, *C. snowden*, and *C. warsamsonicus* are stocked and traded in much lower quantities than

both the aforementioned species. Moreover, culture of these species is unprofitable because they are more difficult to rear and their environmental plasticity is probably limited. Their potential invasiveness is therefore presumably low and these species can be classified as low risk to the Javanese biota. Furthermore, New Guinean endemic crayfish usually have very restricted native ranges (Bláha et al. 2016; Patoka 2020) and ongoing harvest for the international pet trade may cause dramatic consequences for these taxa (Tapkir et al. 2021). Unambiguous identification of collected and traded species is crucially important; in New Guinean crayfish, much confusion exists in the morphological characteristics used in species identification. Even if recent publications suggest some new characteristics (Kawai and Patoka 2020, 2021), the detailed revision of this group of parastacids is greatly needed.

Part of ornamental *Cherax* crayfish is exported from Jakarta and Surabaya abroad: to other Southeast Asian countries, to the Japan, European Union, and to the United States. Their assessed risks of biological invasion are low and hence these crayfish are not banned there (Patoka et al. 2014). Surprisingly, despite the higher price of ornamental New Guinean crayfish (Chucholl 2013; Patoka et al. 2015c), several individuals were recently recorded released in Hungarian thermal waters (Weiperth et al. 2020) where also tropical shrimps were previously found (Weiperth et al. 2019). The possibility of a future ban proposal based on further monitoring cannot be excluded. This assumption should reach the attention of Indonesian traders and wildlife managers who are dealing with the mentioned group of species.

Indonesia is generally perceived as being the supplier of ornamental aquatic organisms on a global scale but the local market is usually ignored or neglected (Patoka et al. 2015c; Evers et al. 2019). Based on the presented findings, it is obvious that the local market is well-developed and several crayfish are sold as ornamentals each week in plenty of places in Java, especially in the three identified hotspots Jakarta, Surabaya and Yogyakarta. It is likely that recorded trading routes connect the vast majority of the island and crayfish are commonly available for ornamental aquaculture enthusiasts in huge quantities. Since crayfish infected by the crayfish plague pathogen were previously found in a pet shop in Bogor (Putra et al. 2018), there is a high risk of further spread of the pathogen via this pathway. As is our knowledge, the farmers do not rigorously control neither potential escapes of crayfish larvae nor pathogen transmission via the waste water runoff. This is alarming especially for the conservation of endemic New Guinean parastacids (Yonvitner et al. 2020). For instance, stocking of North American and New Guinean crayfish in the same tank should be prohibited due to the high probability of crayfish plague pathogen transmission. Moreover, focused rigorous biocontrol measures in the existing

culture of *P. clarkii* should be mandatory to prevent the pathogen spreading: different gear, separate water supply and disinfection of water runoff.

While the Indonesian government endorsed the inland water bodies management to regulate invasive species including crayfish, the further spread of at least *C. quadricarinatus* and *P. clarkii* is likely. Therefore, continuous monitoring of the distribution, trade and related environmental and socio-economic impacts of non-native crayfish are strongly recommended. Since *P. clarkii* is generally classified as a high-risk species and successful invader (Chucholl 2013; Patoka et al. 2014; Putra et al. 2018), spread of this crayfish poses a serious threat for Indonesian biota and, in case of crayfish plague transmission, also for the aquaculture. For this reason, we propose the total ban of this species in Indonesia.

### Acknowledgements

Dr Julian Reynolds of Trinity College Dublin, checked the English language in this article. We thank the anonymous reviewers for their helpful and constructive comments and suggestions.

### Funding declaration

This study was supported by The Indonesian Crayfish Research Group. AK acknowledges the Czech Science Foundation (project no. 19-04431S). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

### Authors' contribution

EY, Y, JP: sample design and methodology; SGA, RAS, SAR: investigation and data collection; SGA, JP: data analysis and interpretation; JP: author of pictures; EY, Y, AS: ethics and field work approval; EY, Y, AK: funding provision; EY, Y, SGA: writing – original draft; JP, AK: writing – review and editing.

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### Supplementary material

The following supplementary material is available for this article:

**Table S1.** List of surveyed localities in Java, Indonesia: name of the region and GPS coordinates. This material is available as part of online article from:

[http://www.reabic.net/journals/mbi/2021/Supplements/MBI\\_2021\\_Yuliana\\_etal\\_SupplementaryMaterial.xlsx](http://www.reabic.net/journals/mbi/2021/Supplements/MBI_2021_Yuliana_etal_SupplementaryMaterial.xlsx)