

# *Cherax quadricarinatus* (von Martens) has invaded Indonesian territory west of the Wallace Line: evidences from Java

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**Abstract** – *Cherax quadricarinatus* (von Martens) (Decapoda: Astacidea: Parastacidae) is commercially exploited and has been intentionally introduced to various tropical and subtropical countries. Once established in the wild, it frequently becomes invasive. In Indonesia, this crayfish is native only to the southern part of the Papua Province. *Cherax quadricarinatus* is produced in semi-intensive farms for food as well as for ornamental purposes on most of Indonesian territory. We present here the first record of this species from Java, where this crayfish has formed at least two established feral populations. In total, eight subadult and adult crayfish of both sexes were captured in two natural lakes in the city of Bogor, West Java Province. Based on climate match, we suggest that *C. quadricarinatus* has high potential to become established within most of Indonesian territory. As a rapidly growing species with broad tolerance to varying environmental conditions, its spread is expected and it should be viewed as a possible threat to native decapod crustaceans. Detailed monitoring is therefore needed.

**Keywords:** crayfish / biological invasion / redclaw / climate match / Parastacidae

**Résumé** – *Cherax quadricarinatus* (von Martens) a envahi le territoire indonésien à l'ouest de la ligne de Wallace : preuves à Java. *Cherax quadricarinatus* (von Martens) (Décapode : Astacidé : Parastacidé) est exploitée commercialement et a été introduite intentionnellement dans divers pays tropicaux et subtropicaux. Une fois établie dans la nature, elle devient souvent invasive. En Indonésie, cette écrevisse est originaire seulement de la partie sud de la province de Papouasie. *Cherax quadricarinatus* est produite dans des exploitations semi-intensives pour la consommation, ainsi que pour des fins ornementales sur la plupart des territoires indonésiens. Nous présentons ici le premier signalement de cette espèce à Java, où cette écrevisse a formé au moins deux populations sauvages établies. Au total, huit subadultes et adultes d'écrevisses des deux sexes ont été capturés dans deux lacs naturels dans la ville de Bogor, province de Java Ouest. Basés sur les conditions climatiques, nous suggérons que *C. quadricarinatus* a un fort potentiel pour s'établir dans la plupart des territoires indonésiens. Comme c'est une espèce à croissance rapide avec une large tolérance aux conditions environnementales variables, sa propagation est attendue et elle doit être considérée comme une menace possible pour les crustacés décapodes indigènes. Une surveillance étroite est donc nécessaire.

**Mots clés :** écrevisse / invasion biologique / écrevisse bleue / climat / Parastacidés

## 1 Introduction

There exist globally many examples of human-mediated introductions of non-native crayfish species, and their negative consequences such as out-competition with native species, disease spread and habitat alternation are widely discussed

(Olden *et al.*, 2006; Coughran *et al.*, 2009; Holdich *et al.*, 2009; Kawai *et al.*, 2009; Buřič *et al.*, 2011; Chucholl, 2016).

The Australian red-claw crayfish or redclaw *Cherax quadricarinatus* (von Martens) is a large and physically robust omnivorous species with moderate fecundity and broad tolerance to varying environmental conditions (Lin *et al.*, 1999; Jones *et al.*, 2000). It belongs to the Northern group of *Cherax* crayfish and inhabits streams, billabongs, and lakes in the northern part of the Northern Territory and far north Queensland in Australia and the southern part of New Guinea

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(Munasinghe *et al.*, 2004; Bláha *et al.*, 2016). This species has been successfully introduced to, and has established feral populations within, several tropical and subtropical countries, including Jamaica (Todd, 2002), Mexico (Bortolini *et al.*, 2007; Vega-Villasante *et al.*, 2015), Puerto Rico (Williams Jr *et al.*, 2001), Singapore (Ahyong and Yeo, 2007; Belle and Yeo, 2010), and South Africa (De Moor, 2002). Only one population in the temperate zone has thus far been recorded, that being in Slovenia (Jaklič and Vrezec, 2011). Both aquaculture and the pet trade are regarded as introduction pathways for redclaw (Coughran and Leckie, 2007; Belle *et al.*, 2011; Saoud *et al.*, 2013; Kouba *et al.*, 2014).

Although detailed information about crayfish production in Asian countries other than China are mostly not available, it is known that commercial production of redclaw was started in the late 1980s (Jones *et al.*, 2000; Lawrence and Jones, 2002). Since redclaw is very tolerant to high water temperatures (Tropea *et al.*, 2010) and least adaptable to the low water temperature conditions (Veselý *et al.*, 2015), it has high potential for aquaculture farming in South East Asia; it is easy to breed, easy to feed, has a rapid growth rate, is easy to harvest, is tolerant to crowding and handling, and, finally, has good marketability (New, 2003; Edgerton, 2005). In Indonesia, semi-intensive farms producing redclaw for food and subsequently also for ornamental purpose were established early as 2003 (Edgerton, 2005). Redclaw is one of the most popular crayfish species kept in aquaria (Chucholl, 2013; Papavaslopoulou *et al.*, 2014; Patoka *et al.*, 2014a; Faulkes, 2015). Although Snovsky and Galil (2011) mentioned ornamental production in Israel, Indonesia has been recently identified as the leading exporter of redclaw into Europe *via* the international pet trade (Patoka *et al.*, 2015).

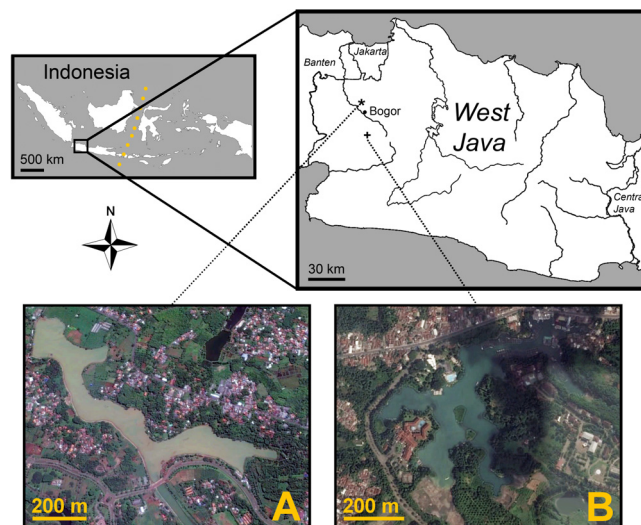
To date, there has been little information about the possible occurrence of redclaw and its probability to become established outside its area of native distribution, west of the Wallace Line delineating Australian and Southeast Asian fauna. Therefore, we surveyed selected localities in West Java province and ascertained the probability that this crayfish had established feral populations within Indonesian territory.

## 2 Materials and methods

### 2.1 Study sites

Sampling was conducted at two sites: Cilala Lake and Lido Lake, both in Bogor, West Java Province, Indonesia (Fig. 1). This urban area of the city Bogor is located approximately 60 km south of the national capital of Jakarta.

Cilala Lake (12 ha, GPS S06°28'26 E106°43'01) is a natural lake with muddy bottom, situated at an altitude of 120 masl, with average depth of 1.9 m and maximum depth of 4.8 m. The lake is fed by groundwater and two small streams. Only one stream, named Ciseeng, flows out of the lake. The area around the lake is densely inhabited and agriculturally cultivated. The lake serves as a water source for surrounding communities and also as fish supply. Common carp (*Cyprinus carpio* L.) and Mozambique tilapia (*Oreochromis mossambicus*, Peters) are the most common species exploited for food purposes. Moreover, circa 30 ornamental fish species, such as goldfish (*Carassius auratus*, L.), black molly (*Poecilia sphenops*, Valenciennes), and freshwater angelfish



**Fig. 1.** Map showing localities where *Cherax quadricarinatus* was collected from natural lakes in Java, Indonesia: Cilala Lake (indicated by black asterisk and letter A); Lido Lake (indicated by black cross and letter B) (adapted from: www.d-maps.com and Google Earth). Yellow dotted is the Wallace Line.

(*Pterophyllum scalare*, Schultze) are cultured in net cages (Novita, 2013; Novita *et al.*, 2015).

Lido Lake (19.9 ha, GPS S06°44'38 E106°48'31) is a natural lake with muddy bottom, situated at an altitude of 506 masl, with average depth of 9.7 m and maximum depth of 18.0 m. The lake is fed by groundwater and a small stream from the southwest. The area around the lake is surrounded by paddy fields and houses. Ornamental fish such as goldfish are cultured in net cages near the outlet of the lake (Wardiatno and Krisanti, 2013).

### 2.2 Data collection

Cilala Lake was sampled by line fishing during one night. Lido Lake was sampled also during one night using 10 baited bamboo traps, the method usually used by local fishermen. The traps were baited by meat of freshwater gastropod *Pomacea* sp. All crayfish were measured immediately after capture and subsequently preserved in pure alcohol or kept alive in aquaria at Bogor Agricultural University. The carapace length was measured from the tip of the rostrum to the posterior end of the carapace. We additionally asked local people living around the lake for information regarding the crayfish's occurrence.

### 2.3 Morphological identification

The morphological identification followed Holthuis (1949) and Souty-Grosset *et al.* (2006).

### 2.4 Molecular analysis

Due to confusion in taxonomy of some *Cherax* species (see Austin, 1996; Bláha *et al.*, 2016), we included DNA analysis in to our study. Moreover, the importance of DNA identification was previously highlighted in many non-native crayfish species (e.g. Filipová *et al.*, 2011).

The morphological identification of each specimen was confirmed by two molecular markers that were amplified by polymerase chain reaction. Selected for identification purposes were genes of mitochondrial cytochrome oxidase subunit I (COI) and 16S ribosomal RNA. We used for the COI gene the universal primer pair LCO1490 (5'-GGTCAACAAATCA-TAAAGATATTGG-3') and HCO2198 (5'-TAAACTT-CAGGGTGACCAAAAATCA-3') (Folmer *et al.*, 1994) and primer pair 1471 (5'-CCTGTTTANCAAAAACAT-3') and 1472 (5'-AGATAGAAACCAACCTGG-3') for the 16S gene (Crandall and Fitzpatrick, 1996). The samples were sequenced using the MacroGen sequencing service in the Netherlands ([www.macrogen.com](http://www.macrogen.com)). Chromatograms were assembled and checked for potential errors. Edited sequences were aligned using Clustal W, as implemented in the BioEdit software package (Hall, 1999).

## 2.5 Climate match

The climate match between source and target area was computed using the Climatch tool (v.1.0, Invasive Animals Cooperative Research Centre, Bureau of Rural Sciences). This tool was used in previous climate matching of non-native crayfish species (e.g. Chucholl, 2013; Kotovska *et al.*, 2016). Climatic data were obtained from the database of the WordClim project (Hijmans *et al.*, 2005). The region of redclaw's native geographic range (130 meteorological stations) was used (Bláha *et al.*, 2016; Munasinghe *et al.*, 2004) as the source area. The target area was defined as the territory of Indonesia (164 meteorological stations). The territory of the Papua was excluded from evaluation due to native occurrence of the species there. Temperatures during the coldest, warmest, wettest, and driest quarter of the year have been used as variables. In accordance with Kalous *et al.* (2015) we considered a score  $\geq 7.0$  as indicating there to be no environmental barrier to survival.

## 3 Results

In Cilala Lake, we captured 1 male crayfish and 3 females with average carapace length 56.8 mm and ranging from 31 mm to 78 mm. In Lido Lake, we caught 1 male and 3 females with average carapace length 53.5 mm and varying from 34 mm to 68 mm. All captured individuals were vital and without visible injuries. Subsequently, one berried female (carapace length 42 mm) was captured by local fisherman by trap in Lido Lake (Fig. 2).

The crayfish was identified morphologically as *C. quadricarinatus*. All individuals express the same identification characters given in Holthuis (1949) and Souty-Grosset *et al.* (2006). Four individuals are stored under the numbers JP2016/Y01-04 in the Collection of Aquatic Crustaceans at the Department of Zoology and Fisheries, Czech University of Life Sciences Prague, Czech Republic. Three individuals are stored under the numbers CQB01-03 in the Collection of Aquatic Organisms at the Aquatic Biomolecular Laboratory, Department of Aquatic Resources Management, University of Bogor, Indonesia.

The obtained DNA sequences (COI gene: KX377345, KX377346, KX377347, KX377348; and 16S gene: KX258721, KX258722, KX258723, KX258724) confirmed the morpholog-



Fig. 2. Berried female captured in Lido Lake.

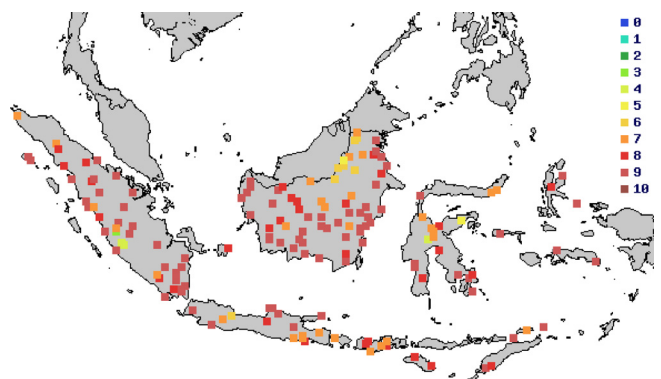
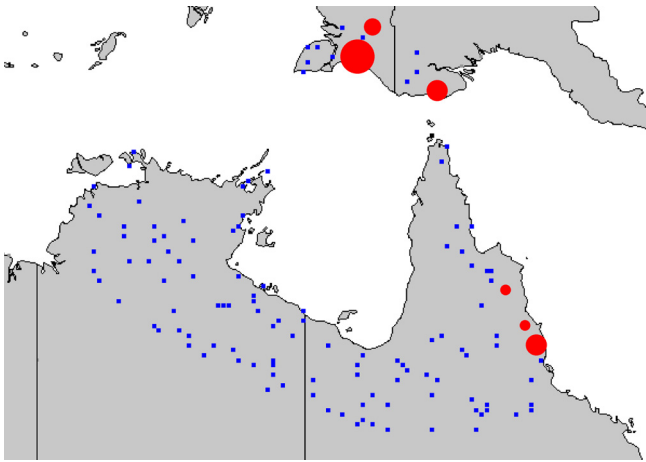


Fig. 3. Map of Indonesia showing the probability for establishment of *Cherax quadricarinatus*. The Papua Province has been excluded due to the native occurrence of this species (<http://data.daff.gov.au:8080/Climatch/climatch.jsp>).

ical identification of the captured crayfish as *C. quadricarinatus*. The COI and 16S fragments obtained completely with the publicly available reference sequences of the redclaw from GenBank (acc. nos. KF649850.1 and KJ920762.1).

Based on climate match, redclaw has a high probability to become established within the vast majority of Indonesian territory (Fig. 3). The native redclaw's population occurring in the south of the Papua Province has been identified *via* processed climate matching as the most adaptable to target area conditions (Fig. 4).





**Fig. 4.** Map of meteorological stations and potential match to the source region. Blue points indicated stations that were not matching; red points represent matching stations. The area with the greatest climatic similarity within redclaw's native range and rest of Indonesian territory is indicated by the largest red circle (<http://data.daff.gov.au:8080/Climatch/climatch.jsp>).

## 4 Discussion

Based on information from local people, we confirmed the occurrence of two populations of redclaw in natural lakes in West Java province (Fig. 1). Although it is known that the species is produced at several semi-intensive farms in Indonesia (Edgerton, 2005), this is the first record from the wild west of the Wallace line in this country. It is not clear whether crayfish have been released intentionally or unintentionally. According to information from the local people, the crayfish are captured and sold for food (Cilala Lake) and as ornamentals (Lido Lake). Since berried females are frequently seen inhabiting the riparian zone and one was captured (Fig. 2), we suggest to consider both populations as established.

Despite low levels of dissolved oxygen and elevated nitrite levels in both lakes due to aquaculture activities (Novita, 2013; Wardiatno and Krisanti, 2013), it seems that poor water quality conditions do not limit local populations of redclaw. This reconfirms the reports of Karplus *et al.* (1998), Lin *et al.* (1999), and Saoud *et al.* (2013), who considered this crayfish species as very adaptable to poor water quality conditions.

Moreover, climatic conditions present no obstacles to successful spreading inasmuch as they are very similar across the vast majority of Indonesian territory and the area of this crayfish's native origin. We identified the redclaw population occurring in the southern part of the Papua Province (Munasinghe *et al.*, 2004) having the highest potential for dispersing when introduced new regions in rest of Indonesia (Fig. 4).

It is well known that introduction of non-native crayfish species can lead to competitive interactions with native species; decline in biomass of macroinvertebrates, macrophytes, periphyton, and certain fish and amphibians due to preying and grazing; food web alterations; the addition of associated symbionts; habitat modification; and disease introductions (Horwitz, 1990; Gherardi, 2007). Although no crayfish species are native to Indonesia with the exception of

West Papua and Papua Provinces, there are many unique freshwater habitats (Vaillant *et al.*, 2011) with occurrence of endemic decapods such as shrimps (*e.g.* Zitzler and Cai, 2006; von Rintelen *et al.*, 2008) and crabs (Ng, 1989; Ng *et al.*, 2015) which can potentially be threatened by spread of non-native crayfish. A negative influence of redclaw on Javanese biota is therefore expected due to its ability to replace or prey upon native freshwater decapods and through habitat modification (*cf.* Belle *et al.*, 2011).

We expect possible economic impact to two long-arm shrimps, *Macrobrachium dacqueti* (Sunier) and *Macrobrachium rosenbergii* (De Man), which are produced largely in Indonesia (Wowor and Ng, 2007). These effects could be manifested by predation, disease transmission and also by habitat alteration. In addition, small freshwater shrimps from the genus *Neocaridina* cultured and exported from Indonesia in large quantities *via* the pet trade (Patoka *et al.*, 2016) may be affected. Moreover, redclaw has been identified as a host and vector of various pathogens (*e.g.* Cannon, 1991; Edgerton and Owens, 1999; Bowater *et al.*, 2002; Saoud *et al.*, 2013) potentially posing a threat to native decapods.

Based on aforementioned information, the release of redclaw into lakes in West Java Province is most likely caused by people's intention for future harvests. This may imply much higher propagule pressure than in countries, where hobbyists are responsible for uncontrolled spreading of kept crayfish in general (Patoka *et al.*, 2014b).

The impact of invasive species in South East Asia is not considered the main environmental problem (Sodhi *et al.*, 2004) inasmuch as the rich biodiversity of the tropical ecosystems minimizes the probability for invaders to become successfully established due to biotic resistance (Rejmánek, 1996). The situation has been changing dramatically in recent years, however, and ever-expanding human-modified landscape creates more vulnerability to biological invasion, especially in the case of freshwater ecosystems (Pelicice *et al.*, 2014). The tropical zone is not only a donor but also a receiver of non-native potentially invasive species, and these may become a threat to local biota within Indonesian territory. In view of these facts, we strongly recommend further detailed monitoring of redclaw to assess its environmental impacts and spread while at the same time working to improve wildlife management (including possible eradication) and relevant local legislation.

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