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Original research article

Habitat Preferences and Distribution of the Freshwater Shrimps of the Genus *Caridina* (Crustacea: Decapoda: Atyidae) in Lake Lindu, Sulawesi, Indonesia

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ABSTRACT

The objectives of this study were to reveal ecological preferences and distribution of all species of *Caridina* found in Lake Lindu and their catchment area. Specimens from 39 sampling sites were caught using tray net and hand net. There are three species of *Caridina* found in the lake system, i.e. *Caridina linduensis, Caridina kaili* and *Caridina dali*. There is no overlapping distribution among the species. *Caridina kaili* is a true riverine species and it is never encountered sympatric with *C. dali* nor *C. linduensis*. This species is abundant in streams and ditches with moderate flow running water and gravel–cobble substrate. It is mainly spread within streams west to the lake. Both *C. dali* and *C. linduensis* can be found in the lake and streams with very slow current to almost stagnant water, muddy sand substrate and associated with roots of water plants and leaf litter. However, *C. dali* is never occurred together with *C. linduensis* and they are less abundant compare to *C. kaili*. Distribution of *Caridina* spp. in Lake Lindu is probably affected by the temperature of their habitats and the occurrence of introduced fish such as Mozambique tilapia (*Oreochromis mossambicus*), common carp (*Cyprinus carpio*), and an alien riceland prawn (*Macrobrachium lanchesteri*). These introduced and alien species can have the potency to become predators or competitors for the *Caridina* spp. It is also the first record for *M. lanchesteri* present in Lake Lindu.

1. Introduction

Fresh water atyid shrimps are widely distributed in Indonesia. They can be found in various water bodies such as lake, pond, river, stream and ditch, both in surface and underground waters (Wowor *et al.* 2004). The shrimps are characterized by having chelipeds with setae on the tip of the fingers which are used for filtering small aquatic organisms or scraping detritus during feeding (Fryer 1977). The family Atyidae consisted of 469 species, a majority of them belonging to the genus *Caridina*. This genus has 290 species members (De Grave & Fransen 2011). In Indonesia, there are 62 species of atyid shrimps and 52 are reported to be found in Sulawesi and nearby islands (Roux 1904; Cai & Ng 2005; Zitzler & Cai 2006; Cai & Wowor 2007; Klotz *et al.* 2007; von Rintelen *et al.* 2008; von Rintelen & Cai 2009; Cai & Ng 2009; Cai *et al.* 2009; De Grave & Fransen 2011; Klotz & von Rintelen 2013). The majority of the species are lacustrine *Caridina* which are endemic to the island.

In the last 10 years, the study of the lacustrine *Caridina* spp. in Sulawesi has been focused in taxonomy and evolution of the species. The studied lakes are Poso and Malili lake systems which were considered by Schön & Martens (2004) as ancient lakes. Recently, the ancient status of the lakes was confirmed both in terms of their estimated age as well as their fauna (von Rintelen *et al.* 2012). In agreement with the definition of ancient lake which is usually perceived as more or less long-lived lake that was often associated with both high species numbers and endemicity in various systematic groups (Albrecht 2012).

The taxonomy and the evolution of the *Caridina* spp. in the 2 ancient lake systems of Sulawesi have been studied for more than a decade; on the contrary, Lake Lindu, a putatively ancient lake in

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Sulawesi, was almost neglected for more than a century. *Caridina linduensis* was the only atyid shrimp reported from the lake and only recently two more species are encountered, i.e. *Caridina kaili* and *Caridina dali* (Annawaty & Wowor 2015). These two new species increase the total number of *Caridina* spp. in the lake system to three times as high as previously reported.

The *Caridina* spp. from the lake occupy different habitats and have specific distribution pattern. Therefore, to reveal the habitat preferences and to map the distribution of the *Caridina* spp. in Lake Lindu and its catchment area became the objectives of this study.

2. Materials and Methods

2.1. Study area

The Lake Lindu system (01°16′–01°23′ S, 120°1′–120°11′ E) is located in the Lindu enclave in Lore Lindu National Park, Sulawesi (previously Celebes), Indonesia. This relatively small lake covered an area of 34.5 km^2 with 72.6 m maximum depth, drain to the north *via* Rawa River, the only outlet for Lake Lindu, to Palu Bay (Lukman 2007). The lake is fed by several streams from its catchment area, where 83.3% of the catchment area belongs to the Lore Lindu National Park. However, generally the gentle sloped eastern part and several small parts in the western sites of the lake have been converted into agricultural land. Most of the converted land has been turned into rice fields and cacao plantations. The study area was divided into four, i.e. north, east, south and west area. Uwe is Kaili dialect of Central Sulawesi for stream.

2.2. Collecting specimen

Purposive sampling method was applied in 39 sampling sites (Figure 1). Samples were collected with tray net and hand net in July, August and November 2011. All specimens obtained were fixed in 96% ethanol. The ethanol was changed after 24 hours with fresh 96% ethanol. The specimens are deposited in Division of Zoology, Research Center for Biology, Indonesian Institute of Sciences (LIPI), Cibinong and Laboratory of Molecular, Division of Animal Function and Behavior, Department of Biology, Bogor Agricultural University, Bogor, Indonesia.

The habitat parameters recorded were (1) temperature of water, (2) qualitative water clarity, (3) qualitative water current (slow current water to almost stagnant or moderate flow), (4) substrate (sediment classification) based on Wentworth (1922), (5) presence or absence of water plant associated with the *Caridina* habitat, and (6) coordinate and altitude of sampling locations by using Global Positioning System.

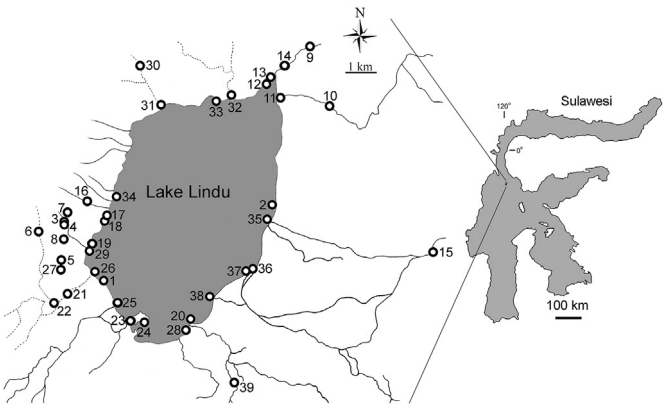

Figure 1. Location of the Lake Lindu System in Sulawesi Island (right) and overview of the sampling sites in the lake (left). Circle refer to the sampling site.

2.3. Data analysis

The data of coordinate and altitude of sampling location were overlaid to the map of Lake Lindu system published by Badan Informasi Geospasial. The percentage of each species of *Caridina* found was measured by the amount of particularly species caught to the total of *Caridina* caught.

3. Results

A total of 1743 specimens of *Caridina* were obtained. They were consisted of 89.4% *C. kaili*, 7.5% *C. dali* and 3.0% *C. linduensis*. From the 39 sampled sites, only 21 sites were inhabited by *Caridina* spp. *Caridina kaili* was the most common species and it was found in 11 sites, while *C. dali* and *C. linduensis* were only obtained from six and four sites, respectively. Water temperature of the lake and its catchment area was ranged between 18°C and 29°C, and the altitude ranged between 982 and 1020 m (Table 1).

Distribution of the species of *Caridina* in Lake Lindu and the catchment area showed there is no overlapping among the species. *Caridina linduensis* is never found in sympatry with *C. kaili* as well as *C. dali*. The species was found both in lake and the outlet of the lake with small amount of specimen. There are only three sites in the lake where *C. linduensis* are present and one site in the outlet (Figure 1). For the outlet population, the species dwell in the shore of the river with very slow current or almost stagnant. Even though this species was never found in sympatry with the other species of *Caridina*, however four specimens of *C. linduensis* were found together with riceland prawn, *Macrobrachium lanchesteri* in Tomado beach at cottage of Festival Danau Lindu (FDL).

Caridina kaili, the true riverine species only inhabit the stream or ditch with moderate flow running water (Figure 2). Most of the species are disperse in the stream and ditch in western part of the lake, and only found in two streams in the eastern part of the lake, i.e. Uwe Tokaroru and Uwe Lembosa.

Caridina dali is only distributed in the eastern part of the lake, particularly near the mouth of the inlet stream (Figure 2). The species were found not only in the lake but also in a stream with slow current in eastern part (Kati stream). The sympatry with *M. lanchesteri* also establish in population of *C. dali* in the western mouth of Uwe Kati.

4. Discussion

Only three species of *Caridina* were found in the Lake Lindu system which is less in number compared to the other two ancient lake systems in Sulawesi, i.e. Lake Poso (six species) and Malili Lakes system (15 species) (Von Rintelen & Cai 2009). *Caridina kaili* was found in large numbers in both western and eastern parts of the lake system. The high abundance of the shrimp is related to the large amount of accumulated vegetation debris on the bottom of the stream which in turn provides food sources for the shrimp (Bentes *et al.* 2011). The majority of streams in western and eastern part surrounded by dense primary forest belong to the Lore Lindu National Park.

In addition, *C. kaili* have very short rostrum, the shortest rostrum among the species of *Caridina* in the lake system. Other Sulawesi atyids such as *Atyopsis spinipes, C. sulawesi, C. leclersi* and *C. parvidentata* have short rostum too. They are inhabitants of fast flow running water as showed by other atyids outside Sulawesi (Felgenhauer & Abele 1983; Hartoto & Wowor 1986). The short rostrum shape is suitable for inhabiting moderate to fast flow running water because it reduces frictional resistance of the oncoming current (Felgenhauer & Abele 1983).

The high abundance of *C. kaili* in streams and ditches demonstrates the favorable habitat of the species. The large mass of

Table 1. Distribution of species of *Caridina* collected in Lake Lindu System

Area	Sampling site	No	Type loc.	Water current	Water clarity	Substrate	Associated water plant	Water Temperature °C	*Caridina kaili* (*n*)	*Caridina dali* (*n*)	*Caridina linduensis* (*n*)
North	Below Uwe Rawa waterfall	9	River	Slow current	Clear	Boulder & cobble	−	29	0	0	0
	Uwe Tokaroru	10	Stream	Moderate flow	Clear	Cobble	−	22	159	0	0
	Mouth of Uwe Tokaroru	11	Stream	Moderate flow	Clear	Coarse sand	+	27	0	0	0
	Mussel bed	12	Lake	Stagnant	Clear	Coarse sand	−	28	0	0	0
	Near mouth of Uwe Rawa	13	Lake	Stagnant	Clear	Coarse sand, pebble	+	29	0	0	0
	Uwe Rawa	14	River	Almost Stagnant	Clear	Coarse sand, mud, leaf litter	−	29	0	0	21
	Uwe Kumo	30	Stream	Moderate flow	Clear	Cobble	+	23	66	0	0
	Mouth of Uwe Kumo	31	Stream	Slow current	Clear	Coarse sand, mud	+	29	0	0	0
	Uwe Bamba	32	Stream	Slow current	Clear	Coarse sand, mud	+	23.5	0	0	0
	Bamba beach	33	Lake	Stagnant	Clear	Coarse sand	+	29	0	0	0
East	North of Kanawu	2	Lake	Stagnant	Clear	Coarse sand	+	28	0	0	0
	Uwe Lembosa	15	Stream	Moderate flow	Clear	Pebble, Cobble	+	22	184	0	0
	Kanawu beach	35	Lake	Stagnant	Clear	Coarse sand	−	28	0	0	0
	Uwe Poweroa	36	Lake	Stagnant	Clear	Coarse sand	+	28	0	2	0
	Mouth of Air Dingin	37	Lake	Stagnant	Clear	Coarse sand	+	22	0	12	0
	Jambu-Jambu	38	Lake	Stagnant	Clear	Coarse sand	+	28	0	15	0
South	Eastern mouth of Uwe Kati	20	Lake	Stagnant	Clear	Coarse sand	+	28.5	0	2	0
	West coast of Pulau Bola	23	Lake	Stagnant	Clear	Coarse sand	+	28	0	0	16
	South coast of Pulau Bola	24	Lake	Stagnant	Clear	Coarse sand	+	28	0	0	0
	Western mouth of Uwe Kati	28	Lake	Stagnant	Clear	Coarse sand	+	28	0	3	0
	Uwe Kati	39	Stream	Slow current	Murky	Coarse sand, mud	+	22	0	94	0
West	Langko	1	Lake	Stagnant	Clear	Coarse sand	+	28	0	0	0
	Uwe Posangkara	3	Ditch	Moderate flow	Clear	Pebble, leaf litter	−	19	173	0	0
	Uwe Boby	4	Ditch	Moderate flow	Clear	Pebble, leaf litter	−	21	110	0	0
	Uwe Karatambe	5	Ditch	Moderate flow	Clear	Pebble, leaf litter	−	20	189	0	0
	Uwe Pada	6	Stream	Moderate flow	Clear	Pebble, coarse sand, leaf litter	−	21	78	0	0
	Uwe Lumonga	7	Ditch	Moderate flow	Clear	Pebble, leaf litter	−	21	2	0	0
	Uwe Laga	8	Ditch	Moderate flow	Clear	Pebble, leaf litter	−	21	190	0	0
	Uwe Kaongko	16	Stream	Moderate flow	Clear	Cobble	+	22	243	0	0
	Pongku beach at Anca 1	17	Lake	Stagnant	Clear	Coarse sand	−	28	0	0	0
	Anca 2	18	Lake	Stagnant	Clear	Coarse sand	−	28	0	0	0
	Tomado beach at cottage FDL	19	Lake	Stagnant	Clear	Coarse sand	+	28	0	0	1
	Uwe Kulovo	21	Ditch	Moderate flow	Clear	Pebble	+	30.5	0	0	0
	Uwe Salutui	22	Ditch	Moderate flow	Clear	Pebble	+	32	0	0	0
	Mouth of Uwe Langko	25	Lake	Stagnant	Clear	Coarse sand, mud	+	29	0	0	14
	Mouth of Uwe Kulovo	26	Lake	Stagnant	Clear	Coarse sand	+	26	0	0	0
	Uwe Kana[**)]	27	Ditch	Moderate flow	Clear	Pebble, leaf litter	−	18	129	0	0
	Tomado beach at cottage FDL	29	Lake	Stagnant	Clear	Coarse sand	+	28	0	0	0
	Anca 3	34	Lake	Stagnant	Clear	Boulder	−	28	0	0	0

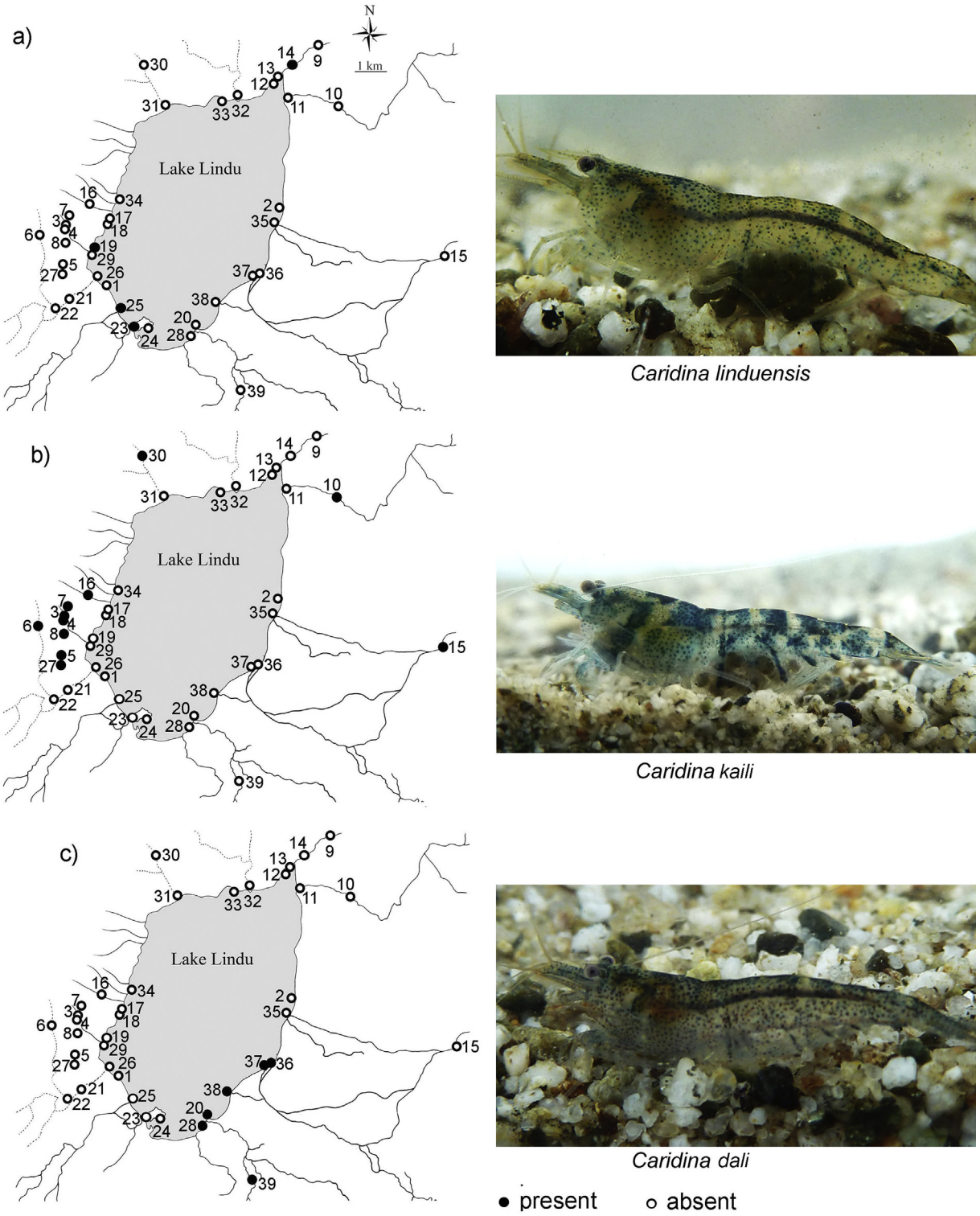

Figure 2. Map of the Lake Lindu System, showing distribution of (A) *C. kaili*, (B) *C. dali*, and (C) *C. linduensis*, presence and absence as indicated.

detritus from the surrounding forest and plantation, which is deposited on the bottom of ditch, offers a large diversity of habitats and provides important source of food for them (Bentes *et al.* 2011).

However, *C. kaili* was not found in the lake. The limiting factor restricting *C. kaili* to disperse into the lake probably associated with the stream's physical condition which is not present in the lake. Most of the streams west to the lake have moderate running water with boulder and pebble substrate and the slope varies between 15% and 40% (Lukman 2007). The other limiting factor was caused by the porous stream bed where water infiltrates into the ground and decreases the amount of water before entering the lake. For example, in some cases such as Pada and Lumonga streams, the water never reached the lake directly.

The streams in the eastern side are flat with slope varying between 0% and 3% (Lukman 2007). *Caridina kaili* distributed in the eastern part of the lake is restricted to the moderate-fast flow running water of Tokaroru and Lembosa streams which are about 3 and 7 km away from the lake shore, respectively. Apparently this species is prevented to disperse into the lake by the difference temperature between the stream and the lake. The maximum temperature of *C. kaili* habitat is 23°C, while the water temperature in the lake ranges between 28°C and 29°C. The higher water temperature may play a role as an ecological barrier for *C. kaili* to distribute into the lake.

Caridina dali was found most abundantly in Kati stream at about 3 km away from the mouth of the stream. So far, this place is the only site where *C. dali* can be found in a stream. It is probably caused by the similar water temperature of the stream site and the mouth of the other streams where *C. dali* has never been found at water temperature more than 22°C.

Caridina dali was found in small populations in some site i.e. Poweroa, west and east of the mouth of Kati stream. This might be caused by the presence of the hard and sparse root of the water plant which is not flexible enough for the shrimp to cling around and therefore it is not a good habitat for the species. Besides that, *M. lanchesteri*, an alien riceland prawn is also present at this area and this alien species is a predator and competitor for *C. dali* in terms of habitat and food.

The non-native aquatic fauna which are predators for *Caridina* spp. are not present in Kati stream. At least there are three species of introduced fish present in the Lake Lindu such as Mozambique tilapia (*Oreochromis mossambicus*) which is quite common, and few common carp (*Cyprinus carpio*) and walking catfish (*Clarias batrachus*). Therefore, the more internal side of Kati stream may serve as a suitable refuge for the shrimp. It is also more productive because the environment provides greater efficiency with regard to the vital processes of the species such as feeding, breeding and running away from predator (Bentes *et al.* 2011).

On the contrary with the large amount of *C. kaili* in streams, *C. dali* and *C. linduensis* were found in very small population sizes in the lake and near the inlet (Table 1). While high water temperature in the lake may perform as a limiting factor for *C. kaili* to disperse into the lake, the lower water temperature in the streams prohibit *C. linduensis* to distribute into the streams around the lake (Table 1). *Caridina linduensis* are only found in the lake and near the mouth of the outlet where the water temperature is similar, i.e. 28°C–29°C.

The small populations of *C. dali* and *C. linduensis* in the lake are also affected by the occurrence of the introduced predator fish and a native predator eel (*Anguilla marmorata*). According to Whitten *et al.* (1987), introduction of tilapia has led to the near extinction of indigenous fish species and mussels in the Lake Lindu. The exotic fishes were begun to be introduced in 1950 to increase commercial–fish production in the lake (Acciaioli 2000; Lukman 2006). Since 1970, the introduced fishes, particularly the Mozambique tilapia, have become the most common fish in the lake (Carney 1991), successfully competed with climbing perch (*Anabas testudineus*), the native fish in the lake (Graczyk & Fried 1998). The introduced fish also correspond with the decline of freshwater mollusk in the lake particularly the genus *Corbicula*. The decline and near extinction of the mollusk were probably due to competition of the tilapia fish for phytoplankton and/or predation by the tilapia fish, known to be zooplankton feeders on the veliger stage of the mollusk (Carney 1991).

During the study, it was observed that there was a high abundance of tilapia both adults and juveniles in the lake, in the outlet and in the mouth of the inlets. It seems that the tilapia has affected the *Caridina* spp. populations, because no *Caridina* could be found where the juveniles of tilapia are present in large numbers in the lake as well as in the mouth of the tributaries such as mouth of Uwe Tokaroru and Uwe Kumo in the north, northern Kanawu in the east, and Langko in the west. Herder *et al.* (2012) reported that the stomach content of introduced fish, flowerhorn cichlid, in Lake Matano of the Malili lake system consisted of endemic fauna, including atyid shrimps.

Macrobrachium lanchesteri is another alien prawn species which can give negative impact to the native species (Wowor *et al.* 2004), in this case the population of *Caridina* in the lake. This alien prawn is a potential competitor and predator for the *Caridina*. During the study, this prawn was found together with *C. dali* in the western part of the mouth of Kati stream, and this species was also occurred together with *C. linduensis* in Tomado beach at the front of FDL cottage. In contrast, there was no *M. lanchesteri* found in the streams or ditches. It is similar to Johnson's (1961) report about the distribution of *M. lanchesteri* in Malaysian region where *M. lanchesteri* is usually found in slow flowing waters in open country.

The existence of *M. lanchesteri* in the lake seems most probably by inadvertent introduction along with other introduced commercial fish, because there is no previous record of the presence of *M. lanchesteri* in Lake Lindu or adjacent water bodies that flows to and from the lake. The small population sizes of *C. linduensis* and *C. dali* in the lake are quite worrying because the occurrence of the introduced fish in the lake threatens the shrimps' life. Besides that, the progressive encroachment of agriculture around the lake, human disturbance and buffalo grazing activity at the bank of the lake are likely to modify the lake ecosystem. In addition, the small population of these endemic shrimps in this isolated locality can cause their seriously endangered and might be led to their extinction.

The Lake Lindu as a putative ancient lake is very important to be conserved because the lake harbors many endemic fauna, indicating its long term isolation. For example, the endemism is present not only in the shrimp but also in other aquatic fauna species such as freshwater crab (*Parathelphusa linduensis*), ricefishes (*Oryzias sarasinorum* and *Oryzias bonneorum*), a bivalve (*Corbicula linduensis*) and one semi-terrestrial gastropod (*Oncomelania hupensis lindoensis*) (Wowor & Annawaty 2013).

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