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First record of biological invasion stages of the Asian clam *Corbicula fluminea* (Müller, 1774) in the Lake Pergau, Kelantan, Malaysia

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Abstract: The present study presents the first record of Asian clam, *Corbicula fluminea* (Müller, 1774), in Lake Pergau, Kelantan, Malaysia. Currently, this freshwater bivalve was harvested at a density between 2.21-113.63 individuals per m^2. Population structure and the dates of the first records suggest that the introductions occurred in the year 2000.The *C.fluminea* existence in this lake indicates that human activity was introduced into the novel location and aided in dispersal rather than life strategy characteristics. Thus, the biological invasion stages and the importance of monitoring this species' invasion to forecast their dispersion into the upstream tributary in Kelantan.

INTRODUCTION

The Asian clam, *Corbicula fluminea* is freshwater bivalve species that natively inhabited freshwater of the South East Asia region, including Malaysia and became a daily snack in Kelantan (Yusof et al., 2020). It has a high ability to disperse in freshwater and has become an invasive species in certain continents, such as Europe and America (Ramli et al., 2020). The invasion success and subsequent dispersal of the *C.fluminea* due to its high fecundity and short life-span (r-strategy) highly associated with human activities (Schmidlin, 2011; Sousa et al., 2008).

Lake Pergau (4.6 km^2) is a man-made dam with a depth of 3-10 m, constructed in 1994 and completed in 2000, making it Kelantan's largest lake. It is located within a mountainous terrain with upstream flowing water as an input source. Previously, it was the primary source for *C.fluminea* in Kelantan (Rak et al., 2021). *Corbicula fluminea* was believed to have been accidentally introduced into the lake through sand deposited during dam construction. As a result, *C.fluminea* was introduced and established in the lake and upstream rivers. The biological invasion phases of *C.fluminea* in Pergau Lake

were determined in this paper, and significant further monitoring for invasion and saturation stages in this lake anticipate the dispersion into the upstream tributary. .

MATERIALS AND METHODS

A quantitative density survey was carried out in Lake Pergau, Jeli, Kelantan (Figure 1). The coordinates (n=10) in the lake were determined (Table 1) according to the Department of Fisheries (DOF) Kelantan and marked by using the Global Positioning System (GPS). However, due to safety concerns and benthic topography, only five locations could harvest the *C.fluminea*. The tow dredger (1.1m x 0.9m x0.3m) with the mesh at size five mm was used to obtain the *C.fluminea* from the lake benthic. For each point, a boat and rope pulled the dredger 100 m forward and backwards two times (Syed Omar et al., 2020). The clams were flushed in the lake water to retrieve. Then, the clams were kept in the zipper bags, stored in the icebox and counted in the aquaculture laboratory, Universiti Malaysia Kelantan. Mean population density (the number of live individuals per m^2) was estimated from the data. In addition, the shell length (SL) was measured to the nearest 0.1mm using a vernier calliper, and shell length-frequency distributions were demonstrated in a bar graph. The water parameters such as temperature (°C), dissolved oxygen (DO), and pH were recorded using a multiparameter (YSI, USA) (Table 2).

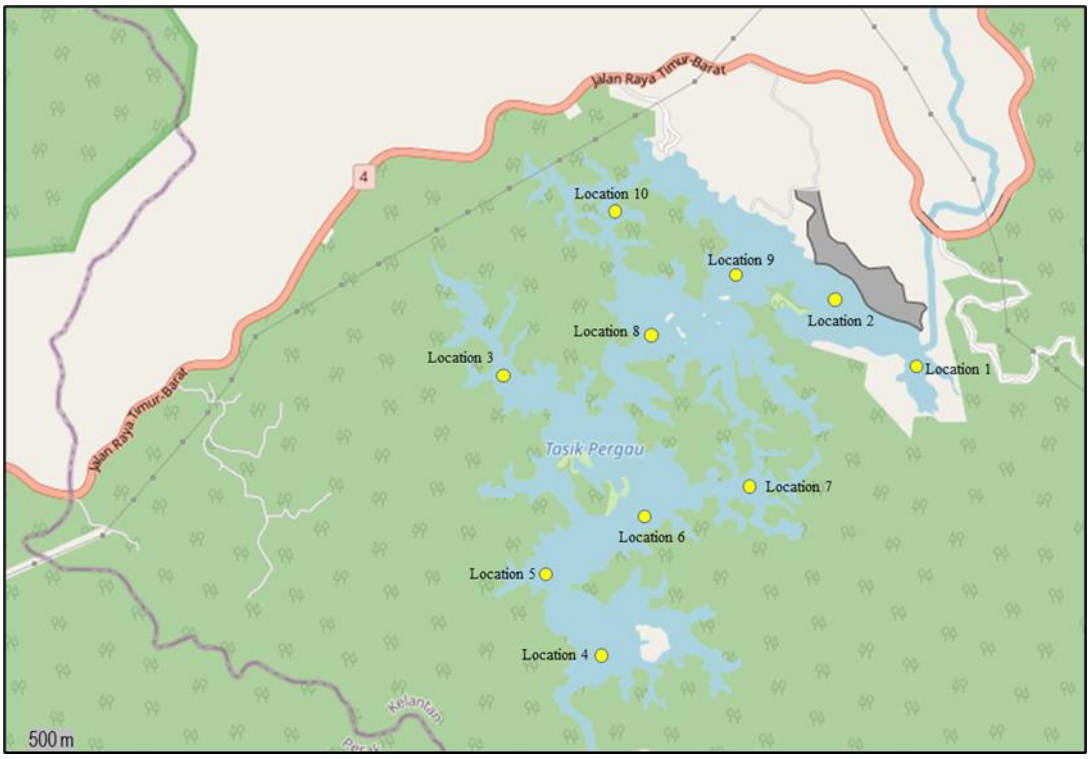

Figure 1. Sampling locations (n=10) in the Lake Pergau, Kelantan.

Table 1. Sampling locations and coordinates.

Sampling Locations	Coordinates
Location 1	5° 37' 8.4504" N, 101° 42' 18.9324" E
Location 2	5° 37' 23.5416" N, 101° 42' 2.9916" E
Location 3	5° 37' 5.3328" N, 101° 40' 52.9284" E
Location 4	5° 36' 9.9108" N, 101° 41' 12.7968" E
Location 5	5° 36' 29.1636" N, 101° 41' 3.9048" E

Location 6	5° 36' 41.9184" N, 101° 41' 23.2512" E
Location 7	5° 36' 44.2584" N, 101° 41' 40.4988" E
Location 8	5° 37' 15.2004" N, 101° 41' 24.2988" E
Location 9	5° 37' 12.6192" N, 101° 41' 43.6488" E
Location 10	5° 37' 44.868" N, 101° 41' 6.0036" E

Table 2. The water quality parameters of ten sampling locations in Lake Pergau

	Temperature (°C)	Dissolved Oxygen (ppm)	pH
Location 1	27.0	8.33	8.79
Location 2	27.9	8.65	8.58
Location 3	27.6	9.53	8.74
Location 4	22.9	8.52	8.51
Location 5	27.3	7.86	9.66
Location 6	27.5	8.59	10.2
Location 7	27.6	7.73	7.49
Location 8	27.6	8.51	8.61
Location 9	27.6	8.65	9.02
Location 10	27.4	8.58	9.01

RESULTS

A total of 1162 samples of *Corbicula fluminea* were caught in four sampling locations, absent in Location 3 (Figure 2). The collected clams were divided into five classes according to the shell length (SL): 5-7 mm; 8-10 mm; 11-13 mm; 14-16 mm; 17-20 mm (Figure 2). The highest density (individuals per m^2) of *C.fluminea* was recorded in Location 1 (113.63 individuals per m^2). The approximate age distribution of the clams in the lake is more than one year (66.61%), whereas the rest comprises one-year-old individuals (33.39%).

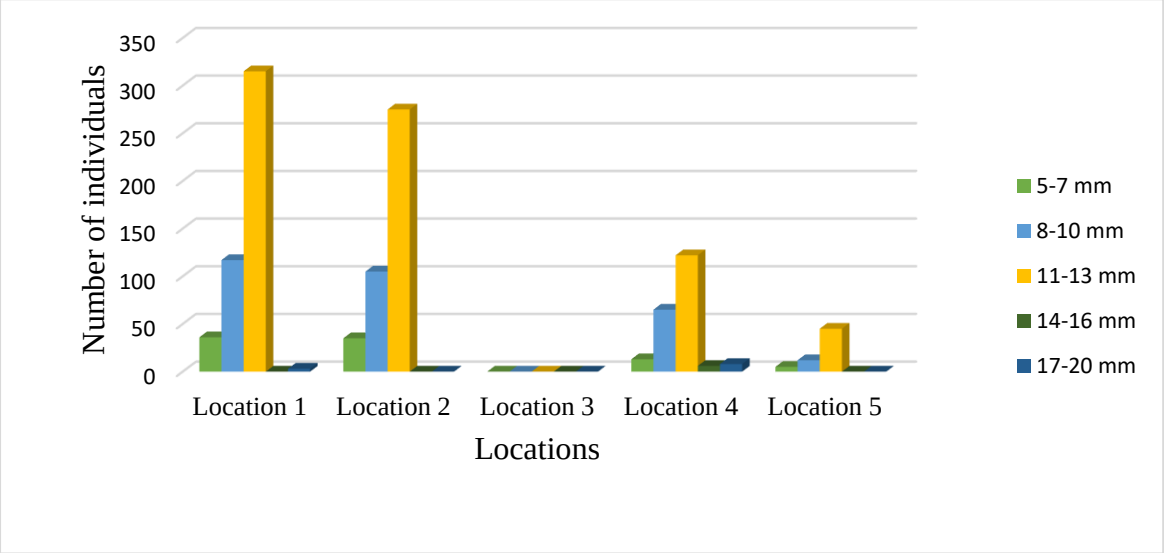

Figure 2. Size class distribution of *Corbicula fluminea* obtained from five sampling locations in Lake Pergau, Kelantan.

DISCUSSION

The *C.fluminea* reached maturity at 10 mm (Zeswita et al., 2016; Sousa et al., 2008), where 90.87% (1056 individuals) of the evaluated samples in the Lake Pergau were categorised as a mature clam. Based on these age estimates, density, and the date of first records, the biological invasion stages can be divided into four stages: introduction, establishment and adaptation, invasion, and saturation (Schmidlin, 2011). In history, the introduction of *C.fluminea* in Lake Pergau was circa 2000. A recent study found that *C.fluminea* is dispersed in all lake areas. However, during sampling work, the live *C.fluminea* was absent in Location 3 due to high siltation loads in that area. The highest population density was found in Locations 1 (Figure 2). This location was located adjacent to the turbine and wall of the dam. This finding elucidates that sand dumping activity in the lake happened in that area. The sands were obtained from the Kelantan River, which deposited *C.fluminea* seeds in the lake. In addition, the dam watergate was located in this area, and flowing water through the gate also carries drifted *C.fluminea* into this area. Since there are no scientific records on the *C.fluminea* in this lake, hence current study may become the first record where biological invasion stages were determined after almost 20 years of this freshwater bivalve introduction.

The density of the *C.fluminea* in Lake Pergau was recorded at 2.21-113.63 individuals per m^2. Compared to a previous study, the *C.fluminea* was more significant at 87-1249 individuals per m^2 in Lake Maggiore, Italy (Kamburska et al., 2013). The current report may be a reference to monitor the escalation density of *C.fluminea* in Lake Pergau in the future. For instance, the *C.fluminea* was found at low density (2-20 individuals per m^2) in 2002, but in 2008, the population density surged to 6000 individuals per m^2 within six years in Lake Tahoe (Wittmann et al., 2011). Meanwhile, 55 individuals per m^2 in Lake Seminole, USA, where the total population was estimated at 4.3 billion adults *C.fluminea* (Patrick et al., 2017). This rapid establishment and invasion in the lake altered organic matter cycling, decreased the phytoplankton, increased substrate for other species, altered biodiversity, and changed the water chemistry to toxic levels for other species (Wittman et al., 2011). Schmidlin (2011) emphasised that the establishment may take several decades, low impact on native biodiversity, and depend on life-history traits. With the current density in the lake and all considerations above-mentioned, it is appropriate to conclude that the *C.fluminea* is at the establishment and adaptation stages. Further study is needed to investigate the effect towards the native benthic fauna associated with *C.fluminea* in the lake.

On the other hand, the Pergau River (5 km) is the only river connected with this lake. No density of population structure data is available yet for the latter location. However, it existed at this location. The *C.fluminea* in this river has become an attraction for locals to collect this clam for food and ornamental purposes. Since the *C.fluminea* occurs in this river (upstream), it can be anticipated that this bivalve's existence in all its downstream tributaries in Kelantan. For example, Shannon River is an upstream connection with 105 km^2 Lough Ree Lake in Ireland. The spreading *C.fluminea* was introduced in 2006, and this species was found at a density of 400-750 individuals per m^2 in 2010 (Minchin & Boelens, 2018). Hence, the current study provides an insight view on the introduction of *C.fluminea* in the Pergau River and its tributaries.

In this study, only freshwater mussel, *Pilsbryoconcha exilis* was found together with the *C.fluminea* instead of the other gastropods. However, the population of this mussel was little compared to *C.fluminea.* Both species were endemic to Lake Pergau. The *C.fluminea* present in the lake does not foul native bivalves in the same way that the zebra mussel (*Dreissena polymorpha*) does, but still, it is competing for space and food (Pérez-Bote & Fernández, 2008). Therefore, the competition for basic needs probably endangered other bivalves or aquatic species in the vicinity.

CONCLUSION

Therefore, recent work disclosed the *C.fluminea* establishment in the Lake Pergau which potentially further invasion into the upstream tributaries. The need for extend monitor the dispersion in upstream tributaries in Kelantan should be noted.

Patents

Not applicable.

Author Contribution

Conceptualization, Zharif Ramli and Aweng Eh Rak.; methodology, Aweng Eh Rak.; software, Dee Koh Han.; validation, Zulhisyam Abdul Kari and Lee Seong Wei; formal analysis, Dee Koh Han; investigation, Zharif Ramli; resources, Aweng Eh Rak.; data curation, Faizuan Abdullah; writing—original draft preparation, Zharif Ramli.; writing—review and editing, Zulhisyam Abdul Kari.; supervision, Aweng Eh Rak, Faizuan Abdullah; project administration, Aweng Eh Rak.; funding acquisition, Lee Seong Wei. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare that they have no conflict of interest.

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