Research Article

Population ecology of a wild population of red swamp crayfish *Procambarus clarkii* (Girard, 1852) in the Free State Province, South Africa and implications for eradication efforts

Leon M. Barkhuizen[1,2], Takudzwa C. Madzivanzira[3,4] and Josie South[4,5,*]

[1]*Department of Zoology and Entomology, University of the Free State, P.O. Box 339, Bloemfontein, 9300, South Africa*
[2]*Free State Department of Economic, Small Business Development, Tourism and Environmental Affairs, Private Bag X20801, Bloemfontein, 9300, South Africa*
[3]*Department of Ichthyology and Fisheries Science, Rhodes University, Makhanda, 6140, South Africa*
[4]*Department of Science and Innovation (DSI)/National Research Foundation (NRF) Research Chair in Inland Fisheries and Freshwater Ecology, South African Institute for Aquatic Biodiversity (SAIAB), Makhanda, 6140, South Africa*
[5]*Centre for Invasion Biology (CIB), Department of Botany and Zoology, Stellenbosch University, Stellenbosch, Western Cape, 7600, South Africa*

**Corresponding author*
E-mail: *j.south@leeds.ac.uk*

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Abstract

The current study reports on the second record of a wild population of the invasive alien red swamp crayfish *Procambarus clarkii* in South Africa following a report from Mimosa Dam in the Free State Province. Sampling for crayfish was conducted over an 18 month period (June 2018 to November 2019) using various methods in order to determine the extent of the invasion as well as to obtain preliminary information on the population structure within Mimosa Dam. Additionally, a gear and bait comparison experiment was conducted to determine their efficiency in mechanical removal of the *P. clarkii*. Three sampling approaches were compared: promar collapsible traps baited with either dog food or fish; and rectangular traps baited with fish, all which have been historically used in crayfish surveys. A total of 1901 crayfish with a total biomass of 27.32 kg were caught during the study and 65% of those were juveniles. The female to male sex ratio (1:1.2) in Mimosa Dam was skewed towards males. Fish head bait provided a higher catch per unit effort (CPUE) (1.2 ± 0.57 and 0.71 ± 0.08 for rectangular and promar traps, respectively) which was significantly higher than that of the dog food bait (0.14 ± 0.04). The fish bait should hence be optimised for intensive population suppression. Complete eradication of *P. clarkii* is virtually impossible, as shown by this study, but population suppression can be concentrated on months of crayfish population surges to minimise associated impacts on native biota.

Key words: freshwater crayfish; mechanical removal; population structure; gear comparison

Introduction

Africa has been a recipient of nine crayfish species, with six species introduced into South Africa alone (Madzivanzira et al. 2020). Only two crayfish species: Australian redclaw crayfish *Cherax quadricarinatus* (von Martens, 1868) and the red swamp crayfish *Procambarus clarkii* (Girard, 1852), have established naturalised populations in the wild (Madzivanzira et al. 2020). *Procambarus clarkii* is considered as the most cosmopolitan freshwater crayfish species in the world (Lodge et al. 2012; Oficialdegui et al. 2019). This species is native to northern Mexico, and southern and south-eastern USA (Hobbs 1972). Due to exhibiting favourable life history traits such as early maturation, high fecundity and rapid growth, all of which are traits selected for in aquaculture (Loureiro et al. 2015), *P. clarkii* has had considerable invasion success globally (Lodge et al. 2012; Oficialdegui et al. 2019, 2020). Adverse impacts have been reported from many invaded aquatic systems (Gherardi 2006; Jackson et al. 2014; Loureiro et al. 2015; Souty-Grosset et al. 2016, South et al. 2019), however, impact information from Africa is still sparse (Madzivanzira et al. 2020). As a polytrophic opportunistic feeder *P. clarkii* can exert predatory pressure on all trophic levels which is a considerable management concern, especially as there may be cascading effects upon fisheries productivity (Bucciarelli et al. 2019; Loureiro et al. 2019 ; Paulson and Stockwell 2020; South et al. 2019; Madzivanzira et al. 2021a). Furthermore, *P. clarkii* is a burrowing species that can cause subtle yet destructive effects due to impacts on sediment erosion, nutrient cycling dynamics and water turbidity (Rodríguez et al. 2003; Harvey et al. 2014; Faller et al. 2016; Haubrock et al. 2019).

In South Africa, unconfirmed records of *P. clarkii* were reported from the early 1960s, and in the 1980s, the species was illegally sold in pet shops (van Eeden et al. 1983). During 1987, the former Directorate of Nature and Environmental Conservation confiscated *P. clarkii* from various pet shops in the Cape Province which had been illegally imported (Anonymous 1987). The first confirmed record of wild populations of *P. clarkii* in South Africa was from ponds on the farm Driehoek and a section of the Crocodile River that flows through the farm in the Mpumalanga Province, formerly known as the Eastern Transvaal (Schoonbee 1993). Subsequent efforts to mechanically remove and eradicate the crayfish were implemented, but during sampling in 2015 and 2016, an adult specimen was sampled suggesting that the initial removal program was unsuccessful in complete eradication (Nunes et al. 2017).

Acting on information from a member of the public in Welkom, Free State Province on 13 June 2018, a wild population of *P. clarkii* was discovered in a dam in the Free State Goldfields, making it the second wild record of *P. clarkii* in South Africa and the first record in the Free State Province. In South Africa, *P. clarkii* was on the "List 10: Prohibited freshwater Invertebrates", Alien and Invasive Species Regulations of 14 August 2014 (AIS 2014). According to these regulations, a permit to have *P. clarkii* in possession may not be issued as contemplated in Section 67 (1) of the National Environmental Management: Biodiversity Act (NEM:BA 2004). Prescripts in the Act also requires for the immediate eradication of this species as a responsibility of the local government. The list of regulated species under the NEM:BA Invasive Alien Species (IAS) regulations was

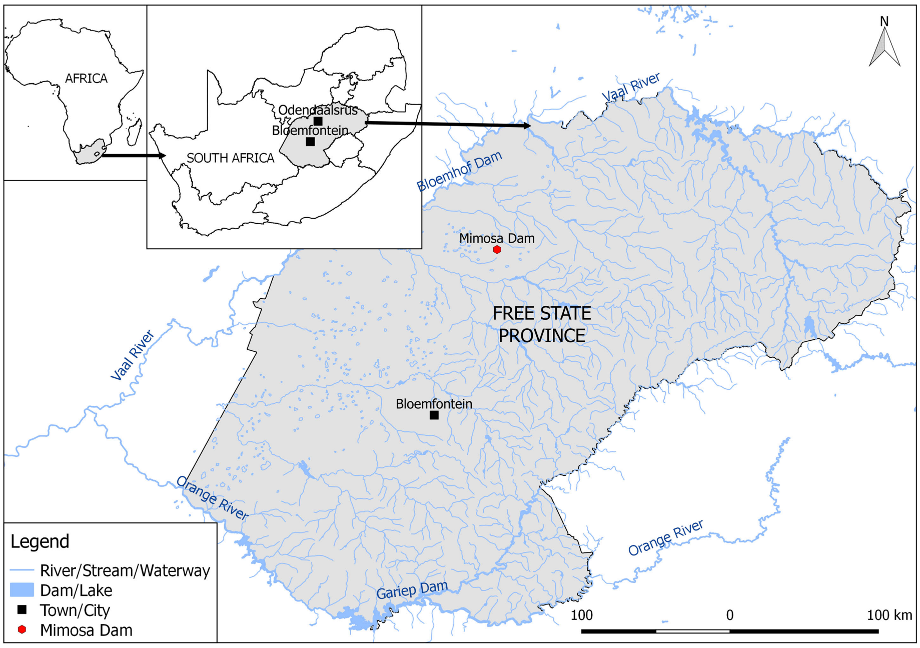

Figure 1. Location of Mimosa Dam in the Free State Province, South Africa.

recently revised in March 2021 and *P. clarkii* was not included on recent revised list (AIS 2020) This is of concern owing to the widely documented impacts outside Africa. Literature on *P. clarkii* impacts in Southern Africa is scant and only two studies (Madzivanzira et al. 2021a; and South et al. 2020) have attempted to document the potential impacts *P. clarkii* in the region.

The current study reports on the second record of a wild population of *P. clarkii* in South Africa and also presents preliminary data on its population structure investigated over an 18-month period, including a once off bait and gear comparison experiment for future management recommendations. Data on occurrence of IAS are an essential component of their management because they provide environmental managers and policy makers with the information necessary to target and undertake appropriate management and conservation actions (Sibley et al. 2002). Early detection of *P. clarkii* can facilitate rapid response actions which can reduce the long-term costs of managing this IAS, economic burden, and associated ecological impacts. Although the complete eradication of any aquatic IAS is extremely difficult, future mitigation measures to decrease the *P. clarkii* population in Mimosa Dam will also be highlighted in this study. This study is therefore a baseline assessment survey of the population structure and corresponding comments on eradication effort efficacy in the context of South African legislation mandated removal.

Materials and methods

Study site

Procambarus clarkii was recorded in Mimosa Dam (27°52′54″S; 26°41′39″E), a small municipal dam situated next to the suburb of Mimosa Park in Odendaalsrus in the Free State Goldfields (Figure 1). The dam has a surface area of ≈ 7 ha and an average depth of ≈ 2 m. Due to its close proximity to the town, it is a popular recreational angling venue, mostly for largemouth black bass *Micropterus salmoides*, also a listed invasive alien species according to the Alien and Invasive Species Regulations (AIS 2014). The dam completely dried up during April 2016, only filling up after heavy rains during June 2016. The dam is not situated within a natural watercourse and is mainly fed with rainwater. Based on anecdotal reports, recreational anglers released a number of fish species in the dam after it filled up during 2016. During a fish survey conducted by the fishery scientist from the Free State Department of Economic, Small Business Development, Tourism and Environmental Affairs (FS DSTEA) during September 2018, the following fish species were recorded: sharptooth catfish *Clarias gariepinus,* common carp *Cyprinus carpio, M. salmoides,* southern mouth brooders *Pseudocrenilabrus philander,* banded tilapia *Tilapia sparrmanii,* and mosquito fish *Gambusia affinis.* Of these species, *C. gariepinus*, *P. philander* and *T. sparrmanii* are native to the Free State Province. Based on unconfirmed reports from local residents and anglers, and the parks manager from Matjhabeng Local Municipality, no crayfish were present in Mimosa Dam before June 2016 (Mr. Moeketsi *pers. communication*, August 2018).

Crayfish sampling methods

A conglomerate approach was used for *P. clarkii* capture to maximise time and effort expenditure considering limitations on human power and funding. The following static gears were used to catch *P. clarkii* for the period June 2018 until November 2019: 3 large rectangular traps, 1 m × 0.5 m × 0.5 m; three medium rectangular traps, 1 m × 0.25 m × 0.25 m; 15 small rectangular traps, 0.5 m × 0.25 m × 0.25 m) covered with black shade cloth with a funnel shape opening with a diameter varying from 5 to 8 cm; and 11 Promar collapsible traps (61 cm × 46 cm × 20 cm; mesh size: 10 mm). In addition to the trapping gears, a D-net was also used to scoop the shores of the dam to capture *P. clarkii*. Traps were baited with dog pellets, canned cat food (fish flavour) or fish heads of common carp *Cyprinus carpio,* Orange River mudfish *Labeo capensis* and moggel*, Labeo umbratus*. All traps were set in the littoral zones at a depth 1.5 to 2 m, 1 to 3 m from the shoreline, and lifted after two to four days to retrieve specimens, and then rebaited and redeployed. Unfortunately it was not possible to check retention time of crayfish in traps nor check the traps every day due to limitations on time and funding. Crayfish caught were measured for carapace length (CL), weighed (to the nearest gram) and sexed.

Comparison between bait types and different traps

During January 2019 a once off investigation was done to determine which bait type and which trap type were more likely to catch *P. clarkii*. We compared a standardised method for sampling *C. quadricarinatus* which comprises of collapsible Promar traps baited with dry dogfood bait (Madzivanzira et al. 2021b: hereafter referred to as $Promar_{df}$) with rectangular traps baited with either dogfood or fish heads. These different traps and bait are hereafter referred to as: $Promar_{df}$ (collapsible traps with dog food bait) and $Promar_{f}$ (collapsible traps with fish head bait) and $Rectangular_{f}$ (rectangular minnow traps baited with fish heads). Catch data was recorded after a 15 h soak time and Catch Per Unit Effort (CPUE) calculated (n = 56 $Promar_{df,}$ n = 35 $Promar_{f}$ and n = 30 $Rectangular_{df}$). Crayfish caught were also measured for CL, weighed and sexed.

Data analysis

For the crayfish sampling, the total mass of all crayfish caught in a range of days sampled were combined from all the sampling methods and the CPUE was reported as the mass of crayfish caught per day (g/day). For the comparison between bait types and traps, the CPUE was reported as the number of individuals per trap per night from the different sampling methods. Differences in CPUE between gears used was determined using a two-way non-parametric Kruskal-Wallis test and pairwise Wilcoxon test post-hoc with Benjamini-Hochberg corrections applied for multiple comparisons.

Results

Crayfish samples

The total catch from all the sampling methods employed from June 2018 until November 2019, comprised of 354 males, 307 females and 1241 juveniles of indeterminate sex (Table 1). This equated to a total biomass of 27.32 kg of *P. clarkii* that were removed. The largest biomass (3.00 kg) was removed during April 2019 (Table 1; Figure 2). The individual mass of *P. clarkii* from Mimosa Dam ranged from 0.1 to 110 g (mean ± SE: 35.78 ± 24.55 g) and the CL ranged from 6 to 80 mm (mean ± SE: 47.1 ± 16.3 mm). The average CL and mass for *P. clarkii* recorded in the months sampled from 2018 – 2019 is presented in Table 1.

Individuals with the carapace range of 30–66 mm constituted 82% and 91% of female and male *P. clarkii* respectively (Figure 3). The female to male sex ratio between the sampled months differed significantly from unity (χ^2 = 53.48, df = 8, p < 0.0001) as there were more males than females. Five berried females were caught during the survey.

Comparison between bait types and different traps

The CPUE of the gears used differed significantly (H (2) = 10.57, p < 0.01). $Promar_{df}$ had a CPUE (mean ± SD: 0.14 ± 0.04) which was significantly lower than that of $Promar_{f}$ (mean ± SD: 0.71 ± 0.08) (p < 0.01) and $Rectangular_{f}$

Table 1. Average sizes, carapace length and mass (mean ± SE) and the number (N) of males, females and juveniles sampled in different months combined from June 2018 to November 2019.

Sampling date(s)	N	N Females	N Males	Juveniles	Adults	CPUE (g/day)	CL (mm)	Mass (g)
13 June 2018	11	5	3	9	2	11.00	22.91 ± 1.26	1.00 ± 0.00
19–22 June 2018	44	4	7	38	6	37.50	17.50 ± 1.33	3.41 ± 0.71
01–08 August 2018	23	3	7	15	8	15.84	25.30 ± 2.17	5.51 ± 2.21
28–30 August 2018	22	7	10	6	16	152.00	38.73 ± 3.14	20.73 ± 3.61
01–04 September 2018	23	16	7	1	22	225.25	49.78 ± 2.52	39.17 ± 37.03
05–11 September 2018	18	12	5	1	17	88.14	51.56 ± 3.63	34.28 ± 5.69
12–18 September 2018	19	8	11	0	19	93.57	51.84 ± 2.14	34.47 ± 3.31
28 September 2018	36	17	5	10	26	265.00	31.47 ± 1.61	7.36 ± 1.23
09–12 October 2018	48	21	27	0	48	637.75	59.13 ± 1.20	53.15 ± 2.91
13–19 October 2018	37	21	16	0	37	216.00	56.51 ± 1.24	40.87 ± 2.83
20–23 November 2018	22	10	12	0	22	429.67	59.64 ± 1.21	58.59 ± 2.77
28–31 January 2019	99	43	43	0	99	1215.00	58.08 ± 0.57	49.09 ± 1.34
11–15 March 2019	105	24	81	0	105	1172.20	57.43 ± 0.70	55.82 ± 1.54
04 April 2019	63	13	43	6	57	2996.10	50.87 ± 1.96	47.56 ± 3.08
06–10 May 2019	493	13	8	472	21	204.60	57.81 ± 2.44	48.81 ± 3.40
10–14 June 2019	721	27	17	679	42	254.00	36.98 ± 2.16	20.16 ± 2.85
28–30 August 2019	15	9	6	0	15	207.33	51.33 ± 2.37	41.47 ± 5.41
01–13 September 2019	66	34	30	4	62	76.23	36.64 ± 1.38	15.02 ± 1.92
13 September–11 October 2019	19	12	7	0	19	23.48	49.84 ± 2.06	35.84 ± 3.98
11 October–7 November 2019	17	8	9	0	17	17.07	49.12 ± 2.23	28.12 ± 3.80

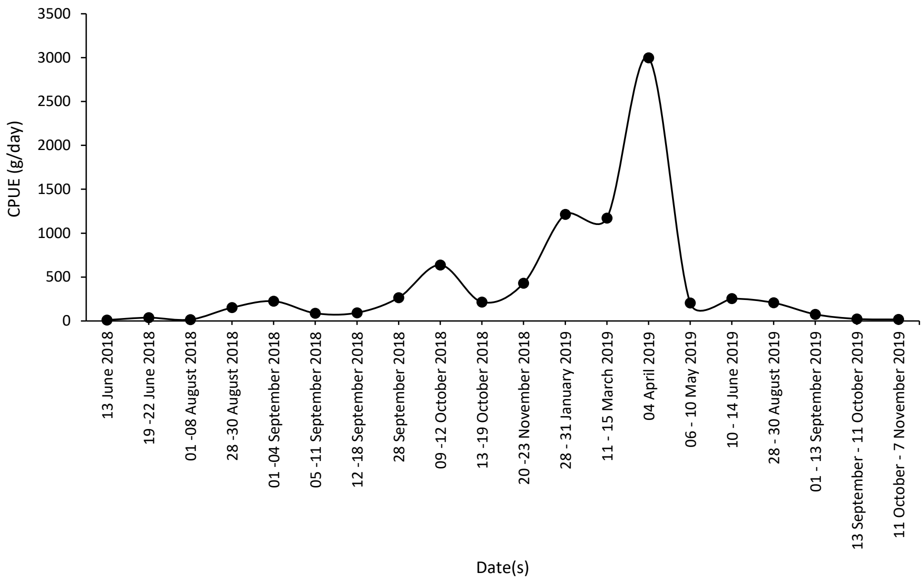

Figure 2. Variation in *Procambarus clarkii* CPUE in Mimosa Dam from June 2018 to November 2019.

(mean ± SD: 1.2 ± 0.57) (p < 0.05) (Figure 4). There was no difference in CPUE between Promar_f and Rectangular_f (p = 0.89).

Discussion

Once crayfish establish, eradication is almost impossible and management is extremely difficult (Hobbs et al. 1989; Gherardi et al. 2011). This study showed that after 18 months of *P. clarkii* removal effort by local government, they are still highly abundant in Mimosa Dam. *Procambarus clarkii* is notoriously difficult to suppress due to its burrowing activities, movement across land and high fecundity (Gherardi et al. 2011; Loureiro et al. 2018).

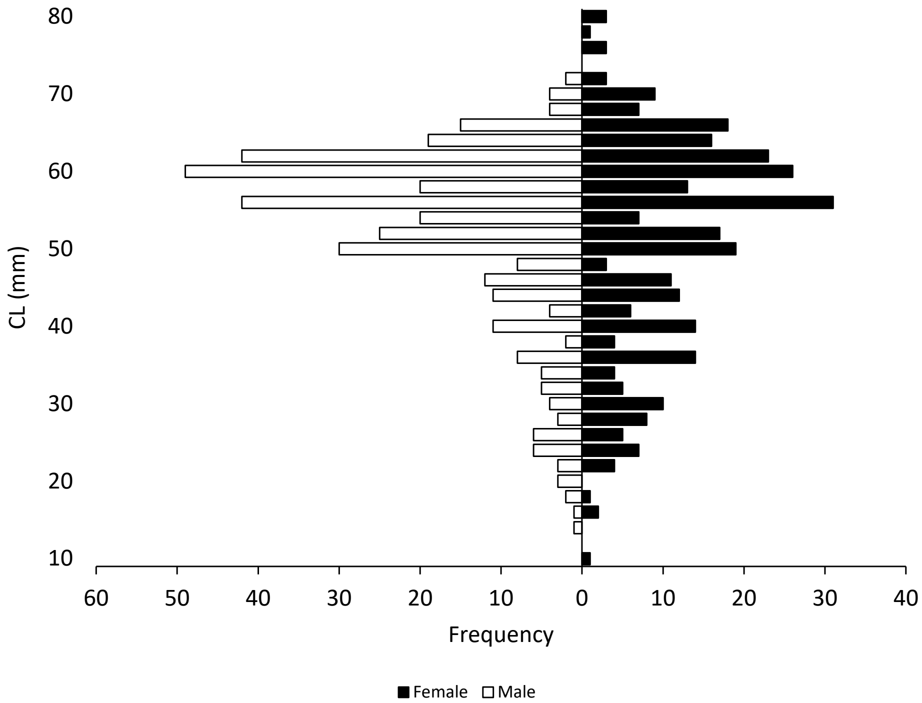

Figure 3. The frequency distribution of carapace length of female and male *Procambarus clarkii* caught in Mimosa Dam, June 2018–November 2019.

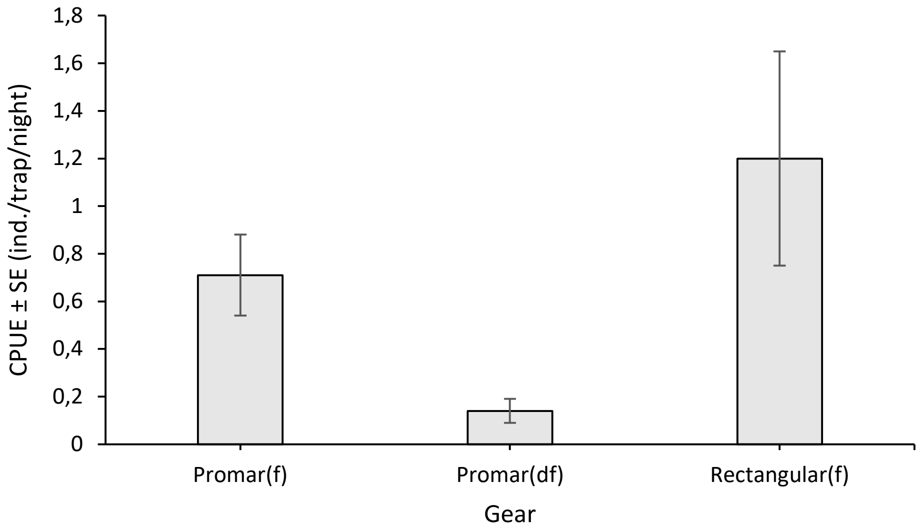

Figure 4. Mean (± SE) CPUE of $Promar_f$, $Promar_{df}$ and $Rectangular_f$ from Mimosa Dam, February 2019.

A previous attempt of eradicating *P. clarkii* in South Africa was thought to be successful but a mature individual was found 22 years after the intervention, suggesting that this species is able to breed and persist at low detection levels (Nunes et al. 2017). Crayfish mechanical population suppression is possible but follows the same practical difficulties regarding management of aquatic invasive species (i.e. cryptic species, hard to detect, specialist equipment necessary) (Hein et al. 2007; Stebbing et al. 2014). This however, takes considerable stakeholder engagement in order to work and success is largely dependent upon the natural state of the invaded community (Freeman et al. 2010; Gherardi et al. 2011; Smith et al. 2017).

Based on unconfirmed reports from local people, art lure anglers during 2016 illegally obtained *P. clarkii* from the pet shop trade and released them into Mimosa Dam to serve as a food source for *M. salmoides.* As *P. clarkii* is a main prey item for *M. salmoides* within the species natural distribution range in North America, art lure anglers were of the opinion that bass will grow bigger and faster if provided with its natural prey. This adds to the rising concern regarding the aquarium trade and recreational angling as major pathways for biological invasions (Chang et al. 2009; Kilian et al. 2012). Considering the extent of invasion and establishment in Mimosa Dam, the reservoir is now an incubator for further invasions (Havel et al. 2005). This is especially concerning as the population of *P. clarkii* was able to establish a self-sustaining population as indicated by the many juveniles as well as berried females caught during the study period. The sex ratio of *P. clarkii* caught was biased towards males potentially due to males being more mobile and more susceptible to trapping efforts (Dorn et al. 2005; Green et al. 2018).

Despite the bait test not being fully factorial the data indicates that fish head bait is superior to dogfood and should be used in this situation for continued mechanical removal. Other baits e.g. liver and cooked maize meal, were also used by Mhlanga et al. (2020) to trap *C. quadricarinatus*. However, for research purposes and standardisation these baits are not advised (Madzivanzira et al. 2021b). Standardisation and affirmation of *P. clarkii* trapping gear capacities in the southern African region is essential information for further work on the subject. Regardless, the data from the overall long-term sampling and removal effort indicate that if manual eradication is to be completed then the efforts ought to focus on periods of reproduction and high abundance to contain and suppress the population (per definitions in Robertson et al. 2020). To optimise this, Artificial Refuge Traps (ARTs) deployed for up to 6 days may have a better capacity to remove females and small individuals (Green et al. 2018) due to less sex bias in the method.

This study reported on the second record of *P. clarkii* in South Africa. It is recommended that future control and eradication efforts should focus on containing the spread of this species into other water bodies in the vicinity of Mimosa Dam to prevent associated impacts on other biotic components as well as human livelihoods. Our results show poor response to manual removal at the capacity of the local government. As it is almost impossible to eradicate an established crayfish species (Madzivanzira et al. 2020), population suppression can be an option especially in a contained dam like Mimosa Dam. The targeted population suppression management action in Mimosa Dam should be concentrated in periods of crayfish population bursts (e.g. January–June as shown by this study) to minimise impacts on other native species. More drastic measures (e.g. draining of the dam) could also be considered in order to halt any further spread in the region and the size of Mimosa Dam is feasible to drain to remove IAS, and indeed this has been completed before in Dullstroom, Mpumalanga Province, when the first record of *P. clarkii* was recorded (Nunes et al. 2017). In the case of Mimosa Dam, as it is a municipal dam, there would be far less contention regarding harsh measures such as draining compared to that in the Dullstroom case wherein the dam was used for lucrative trout fishing activities. Awareness campaigns also should be put in place by conservationists and environmental managers to educate communities, anglers, and other stakeholders on the dangers of introducing and spreading crayfish (Madzivanzira et al. 2021c). Lastly, *P. clarkii* should be re-included in the NEM: BA list of prohibited species in South Africa as its exclusion is a cause for concern owing to its devastating documented impacts.

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Authors' contribution

LMB, TCM, JS: research conceptualisation, sample design and methodology, investigation and data collection; LMB, TCM, data analysis and interpretation; LMB: original draft. LMB, TCM; JS: writing – review and editing.

Ethics and permits

Permits to conduct the study were issued by the Free State Department of Economic, Small Business Development, Tourism and Environmental Affairs (Permit number 01/28643), Department of Environmental Affairs (DEA) (Permit Numbers: 50869181001113030 and 50869181002121045). This research was given ethics clearance by the Animal Ethics Subcommittee, Rhodes University (Ethics No. DIFS2718).

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