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Socioeconomic impacts of Australian redclaw crayfish *Cherax quadricarinatus* in Lake Kariba

Adroit T. Chakandinakira[1*], Takudzwa C. Madzivanzira[2,3], Shantel Mashonga[4], John V. Muzvondiwa[4], Nobuhle Ndlovu[1] and Josie South[5]

[1] *Lake Kariba Fisheries Research Institute, Zimbabwe Parks and Wildlife Management Authority, Kariba, Zimbabwe*

[2] *Aquatic Ecosystem Research Group, School of Biology and Environmental Sciences, University of Mpumalanga, Nelspruit 1200, South Africa*

[3] *DSI/NRF Research Chair in Inland Fisheries and Freshwater Ecology, South African Institute for Aquatic Biodiversity (SAIAB), Makhanda 6140, South Africa*

[4] *Department of Animal and Wildlife Sciences, Faculty Agriculture, Environment and Natural Resource Management, Midlands State University, Gweru, Zimbabwe*

[5] *Centre for Invasion Biology, School of Biology, Faculty of Biological Sciences, University of Leeds, Leeds LS2 9JT, United Kingdom*

*Corresponding author email: chakandinakirat@gmail.com

ORCIDs

ATC: 0000-0002-8065-8114

TCM: 0000-0001-9683-5798

JS: 0000-0002-6339-4225

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Abstract

The rapidly spreading Australian red claw crayfish *Cherax quadricarinatus* in the Zambezi Basin is a cause for concern considering its potential impacts. The assessment of the impacts of *C. quadricarinatus* is critical for the prioritisation of policy and management actions in Africa where literature on impacts of *C. quadricarinatus* is generally scant. We quantified the socioeconomic impacts conferred by *C. quadricarinatus* on artisanal gillnetting fishery in Lake Kariba to validate anecdotal fisher reports regarding crayfish damage to fish catch on static gillnets. From the catch assessments with registered fishers, fish catch composition, catch per unit effort (CPUE), crayfish entangled on gillnets CPUE, damaged fish CPUE, and damaged areas of the fish were recorded. Basin 2 had significantly higher CPUE with respect to fish catch and crayfish, as well as catch damage, compared to other basins. Damage by crayfish on fish was recorded in all the basins except in Basin 5. There was no correlation between number of crayfish bycatch and fish catch damage. The most frequently affected species was *Oreochromis niloticus*. On all fish species, eyes, guts and the tail were the frequently damaged parts. Due to *C. quadricarinatus* damage, fishers are losing 212 tonnes per year which translates to US$ 512 352.92 in Lake Kariba. Damage losses are particularly high when the total income per household in the region, which is mainly contributed by fishing, is considered. The lack of damage in Basin 5 is likely due to fishers developing adaptive new techniques which are less likely to be affected by crayfish. This study is the first in Africa to quantify the socio-economic losses due to crayfish in the field, and the first globally to derive observed costs for *C. quadricarinatus*. Data from this study have huge conservation and management implications, as crayfish threaten food security as well as incur personal losses to fishers via damage-related costs.

Keywords: Economic cost; fisheries damage; invasion impact; scavenging; decapoda; Africa

1.0 Introduction

Biological invasions are a major anthropogenic stressor as many invasions confer negative impacts on biodiversity (Gallardo *et al.*, 2015; Seebens *et al.*, 2017; Meyerson *et al.*, 2019; Tickner *et al.* 2020) and human livelihoods (Ellender *et al.*, 2014; Blackburn *et al.*, 2019). Invasions result in new species interactions which confer a variety of negative effects upon indigenous populations such as direct predation (Weis, 2011); hybridisation (Zengeya *et al.*, 2015); disease transfer (Prenter *et al.*, 2004) and competition for resources (Raymond *et al.*, 2015). Invasive alien species (IAS) can also have detrimental socioeconomic impacts, affecting ecosystem services that are beneficial for human well-being (Vilà and Hulme, 2018). Although, conversely, IAS may give positive socio-economic benefits to societies who use or value them (Andriantsoa *et al.,* 2020). Nonetheless, the damage caused by IAS and the costs associated with their management to control them can be a significant economic burden and user conflicts may create difficulty and community resistance to management (Hoffmann and Broadhurst, 2015; Oficialdegui *et al.*, 2020).

Freshwater crayfish (Crustacea: Decapoda) are among the most successful IAS and have been introduced worldwide, with documented serious negative impacts on resident biodiversity and extortionately high economic costs (Lodge *et al.*, 2012; Madzivanzira *et al.*, 2020; Kouba *et al.*, 2021). Global crayfish introduction pathways are fisheries and aquaculture, the aquarium trade, biological control of disease vectors and for research purposes (Lodge *et al.*, 2012), with wild populations established due to accidental and/or deliberate release (Geiger *et al.*, 2005; Kouba *et al.*, 2014; Lodge *et al.*, 2012; Oficialdegui *et al.*, 2019; Madzivanzira *et al.*, 2020). Negative impacts of invasive crayfish can either be direct (consumptive) or indirect (non-consumptive) and include the loss of ecosystem services such as food provisioning services through a reduction in native species used in subsistence fisheries or of economic value;

disruption of community food webs; disease vectoring; and increased costs to agriculture and water management (Lodge *et al.*, 2012; Madzivanzira *et al.*, 2020; Kouba *et al.* 2021).

Crayfish are phylogenetically novel in continental Africa, and nine species were introduced for socioeconomic purposes (Madzivanzira *et al.*, 2020). Five crayfish species have established populations. Of particular concern is globally invasive Australian red claw crayfish *Cherax quadricarinatus* (von Martens 1868) which is rapidly spreading across Southern Africa (Madzivanzira *et al.*, 2020, 2021a). *Cherax quadricarinatus* is native to Northern Australia and south-eastern Papua New Guinea (Riek, 1969). In Southern Africa, *C. quadricarinatus* has established in the Inkomati Basin (South Africa, Swaziland and Mozambique) (Nunes *et al.*, 2017; Madzivanzira *et al.*, 2020), Zambezi Basin (Zambia, Namibia, Zimbabwe, and Mozambique) (Madzivanzira *et al.*, 2020, 2021a). The first documented introduction of *C. quadricarinatus* into the Zambezi system was in 2001 when this species was introduced from Swaziland to two fish farms in the Zambezi system, one at the eastern end of the Kafue Flats, and the other at Siavonga on the shore of Lake Kariba in Zambia (Madzivanzira *et al.*, 2020). Wild populations of *C. quadricarinatus* were first reported in the Kafue River in 2001 and in 2002 in Lake Kariba (Douthwaite *et al.*, 2018).

Crayfish have a damaging global invasion history (Lodge *et al*,. 2000; Twardochleb *et al.,* 2013). Observed global damage costs from crayfish invasions is around US $ 4.2 million, and specific losses to fisheries is around US $6.6 million a year from a mixture of damage and management costs (Kouba *et al*,. 2021). However, impact assessments need to be context dependent to avoid making erroneous comparisons. In Africa, a few studies have attempted to infer the impact of invasive crayfish species (Jackson *et al.*, 2016; South *et al.*, 2019, 2020; Madzivanzira *et al.,* 2021b, 2022). Nonetheless, there is very little data evidencing field impact or providing accurate estimates of socioeconomic cost incurred by damage to fisheries. This information is essential to compel policy makers to prioritise their management and prevent further introductions.

In Lake Kariba, similar to other locations (e.g., Kafue River, Weyl *et al*., 2017; Madzivanzira *et al*., 2022a), fishers have reported anecdotally how *C. quadricarinatus* spoils catch through partial consumption by crayfish of fish caught in gillnets. This is of concern as fisheries are an important source of livelihood as a source of protein and income, as well as wider associated value chains for over 200 million Africans livelihoods. The losses associated with *C. quadricarinatus* damage, therefore, pose the potential for severe and escalating costs if mitigation efforts are not undertaken. The catch losses associated with crayfish spoilage have not been quantified in the field, although Madzivanzira *et al*., (2022a) attempted to estimate the losses using laboratory experimental data. We therefore quantify observed fishery losses for the first time in Africa, or for *C. quadricarinatus* globally, using the artisanal gill net fishery in Lake Kariba. Adaptive management and mitigation strategies are further suggested which are applicable to other invaded systems with valuable fisheries.

2.0 Materials and Methods

2.1 *Study area*

The study was carried out in Lake Kariba, which is the world's largest man-made lake by volume, bordering Zimbabwe and Zambia. The lake has a water volume of 185 km^3, a surface area of 5580 km^2 and a length of 280 km. The lake supports a range of biodiversity and part of it is under the UNESCO Biosphere Reserve (Magadza *et al*., 2020). Thirty-three fish species have been recorded in Lake Kariba (Zengeya and Marshall, 2008) mainly dominated by Cichlids, Cyprinids, Clarids, Characids, Momyrids and Alestids (Phiri and Mhlanga, 2014).

Lake Kariba is divided into five basins namely: Mlibizi (Basin 1), Binga (Basin 2), Sengwa (Basin 3), Bumi (Basin 4) and Sanyati (Basin 5) (Fig. 1). On the Zimbabwean shoreline of Lake Kariba, fishing camps and villages in each basin have designated fishing grounds with 1154 officially registered fishers (Frame Survey 2011). Fishers fish for ≈281 days in a year with a week of rest in each month (the "full moon" period) which is an attempt to reduce fishing effort.

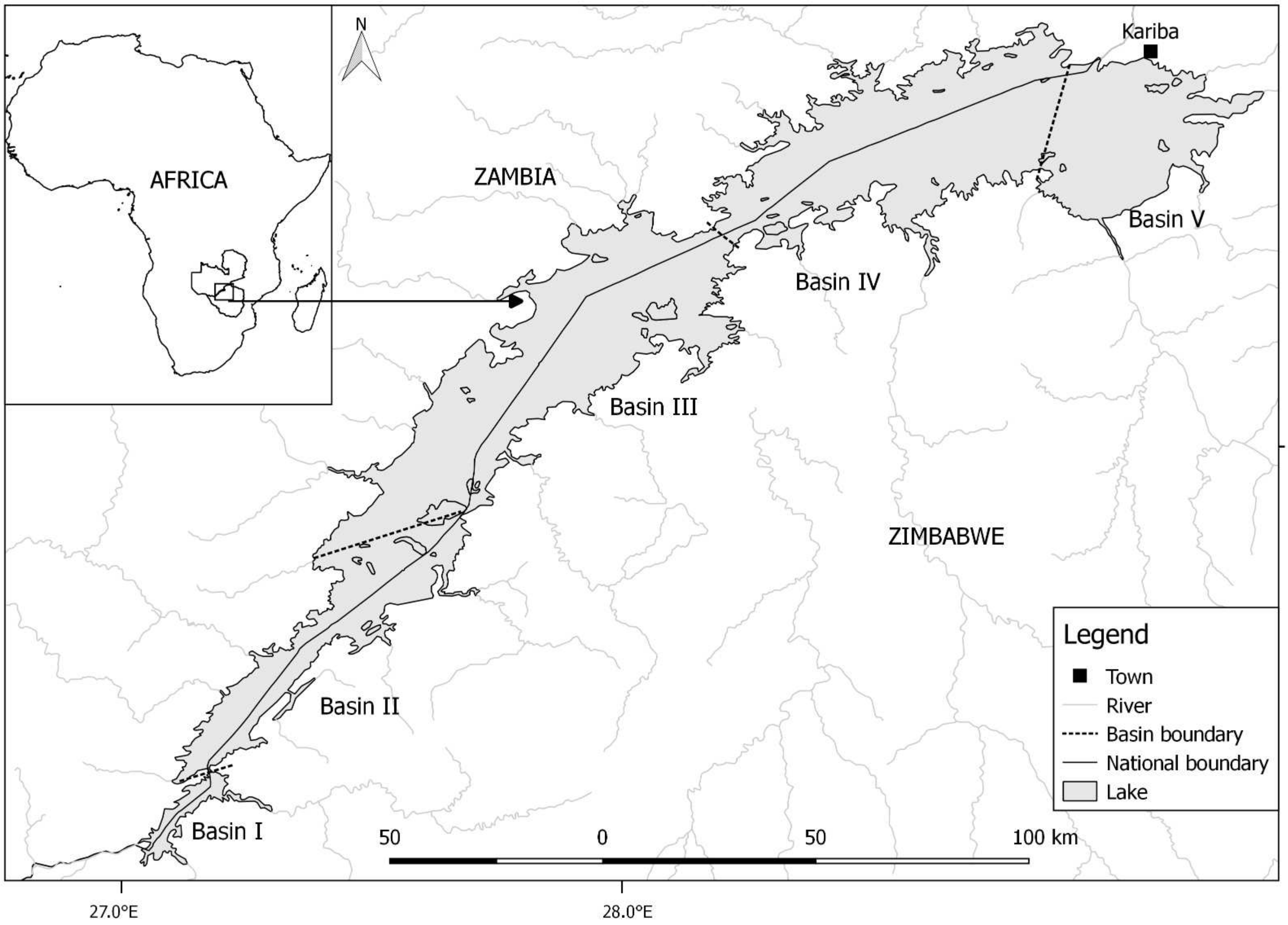

Fig. 1 Map of Lake Kariba showing the hydrological basins sampled

2.2 *Sampling*

Data were collected from 23 fishing villages and camps on the Zimbabwean shoreline of Lake Kariba during a 12-day Catch Assessment Survey in the hot dry season (August and September

2019) characterised by maximum temperatures averaging 29.3°C – 33.4°C (weather-atlas.com). Data were collected from 107 registered fishers at landing sites of 23 fishing camps/villages when they returned from retrieving their gillnets from the lake in the morning (Table 1). The fishers are allowed to have a maximum of 5 cotton/nylon nets measuring 100 m each with mesh sizes of 4 inches and above (per fishing authority guidance in Lake Kariba). These nets are laid in designated fishing zones of the lake. Fishers lay their gillnets at dusk and retrieve them at dawn with an average soak time of 12 hours. At the landing site, after the nets were retrieved at dawn, the catches were inspected and assessed for the relevant information for data collection. Fish were identified to species level to assess the catch composition and quantity, fishing effort (number and mesh size of nets), number and weight of crayfish entangled on gillnets, number and weight of both whole and damaged fish, and areas damaged were recorded from the inspection. An informal questionnaire was also administered to the same 107 fishers to get their perspective on the depredation of their gillnet catches. The questionnaire comprised of open ended questions regarding perception of fish spoilage on gill nets and suspected fish catch scavengers.

Table 1 Distribution of sampled landing sites across the 5 basins in Lake Kariba

Basin	**Fishing camp/village (landing sites)**	**Number of fishers**
5	3	17
4	7	30
3	5	24
2	7	30
1	1	6
Total	23	107

*each fishing camp/village has a landing site

2.3 *Data analysis*

To standardise the data and to account for fishing effort, we calculated the catch per unit effort ($\mathrm{CPUE}_{\mathrm{intact}}$), the spoiled fish CPUE ($\mathrm{CPUE}_{spoiled}$) and the CPUE of entangled crayfish ($\mathrm{CPUE}_{crayfish}$) for each basin according to the formulas below, where effort is defined as 100m net/night:

CPUE for intact fish $(CPUE_{intact}) \quad = \quad \frac{total\ mass\ intact\ fish}{effort}$ (1)

CPUE for spoiled fish $(CPUE_{spoiled}) \quad = \quad \frac{total\ mass\ spoiled\ fish}{effort}$ (2)

CPUE for crayfish $(CPUE_{crayfish}) \quad = \quad \frac{total\ number\ of\ crayfish}{effort}$ (3)

Both CPUE by number and mass were calculated for all three metrics, although only CPUE by number was used in statistical analyses as maximum mass varies between fish species. CPUE by mass is included (S1) due to crayfish consumption rates varying by mass and fisheries commodities being sold by mass therefore $\mathrm{CPUE}_{\mathrm{spoiled}}$ by mass is needed for loss calculations (Madzivanzira *et al*. 2022).

A Generalised Linear Model (GLM) with a quasi-poisson error distribution to account for overdispersion in the model was used to determine whether there were basin level differences in $\mathrm{CPUE}_{\mathrm{crayfish.}}$ Factor differences were explored post-hoc using the package “emmeans” (Lenth, 2021).

To assess whether there were basin level differences in $CPUE_{spoiled}$, while accounting for overall fish catch (i.e. $\mathrm{CPUE}_{\mathrm{intact}}$) we calculated the ratio of $\mathrm{CPUE}_{\mathrm{spoiled}}$: $\mathrm{CPUE}_{\mathrm{intact}}$ and arcsine square root transformed the ratio. The transformed ratio was used as the response variable in a GLM with a poisson error distribution after checking qq-plots for residual distribution and overdispersion.

To determine whether the number of crayfish caught as bycatch in the nets was related to the number of fish damaged, Kendall's rank correlation was performed on the arcsine square root transformed ratio and $CPUE_{crayfish}$ to account for non-normality of data. The purpose of this was to identify whether there was proportional retention of crayfish bycatch to fish damage, which could be used as a proxy for abundance measures in the future as the standard methodology for crayfish trapping in southern Africa is generally used by practitioners rather than fishers.

To calculate the maximum monetary loss that fishers incur due to crayfish damage, the following equations were used:

$$Monetary\ loss\ per\ day = CPUEspoiled\ (kg) * maximum\ effort * \ price\ of\ fish\ per\ kg \qquad (4)$$

$$Monetary\ loss\ per\ year = \ Monetary\ loss\ per\ day\ \cdot\ 281\ fishing\ days \qquad (5)$$

$$Total\ Monetary\ loss\ per\ year = \ Monetary\ loss\ per\ year\ \cdot\ number\ of\ registered\ fishers \qquad (6)$$

Where the maximum effort is 500 m per night, the average price of all fish landed into Kariba ports is US $2.50 and the number of registered fishers in 2021 was 1154.

3.0 Results

Overall, there was a 16800 m of gillnet analysed, equating to a fishing effort of 8, 20, 60, 29 and 50 (100m per net per night), in Basins 1-5 respectively.

3.1 *Crayfish presence*

Cherax quadricarinatus were present in all the basins sampled. There was a significant effect of Basin on CPUE$_{crayfish}$ ($\chi^2 = 68.82, df = 4, p < 0.001$), where Basin 2 had a higher CPUE$_{crayfish}$ than Basin 3 (p<0.01) and Basin 5 (p<0.05) (Table 2; Fig 2).

Table 2 CPUE by number by basin

Basin	CPUEcrayfish	CPUEspoiled	CPUEintact
1	0.75±0.29	0.12±0.25	3.12±2.5
2	17.34±18.42	0.5±0.49	8.32±7.95
3	1.96±1.6	0.16±0.09	2.74±2.78
4	0.06±0.18	0.09±0.19	1.27±1.47
5	0.25±0.58	0.0±0.0	2.88±2.88

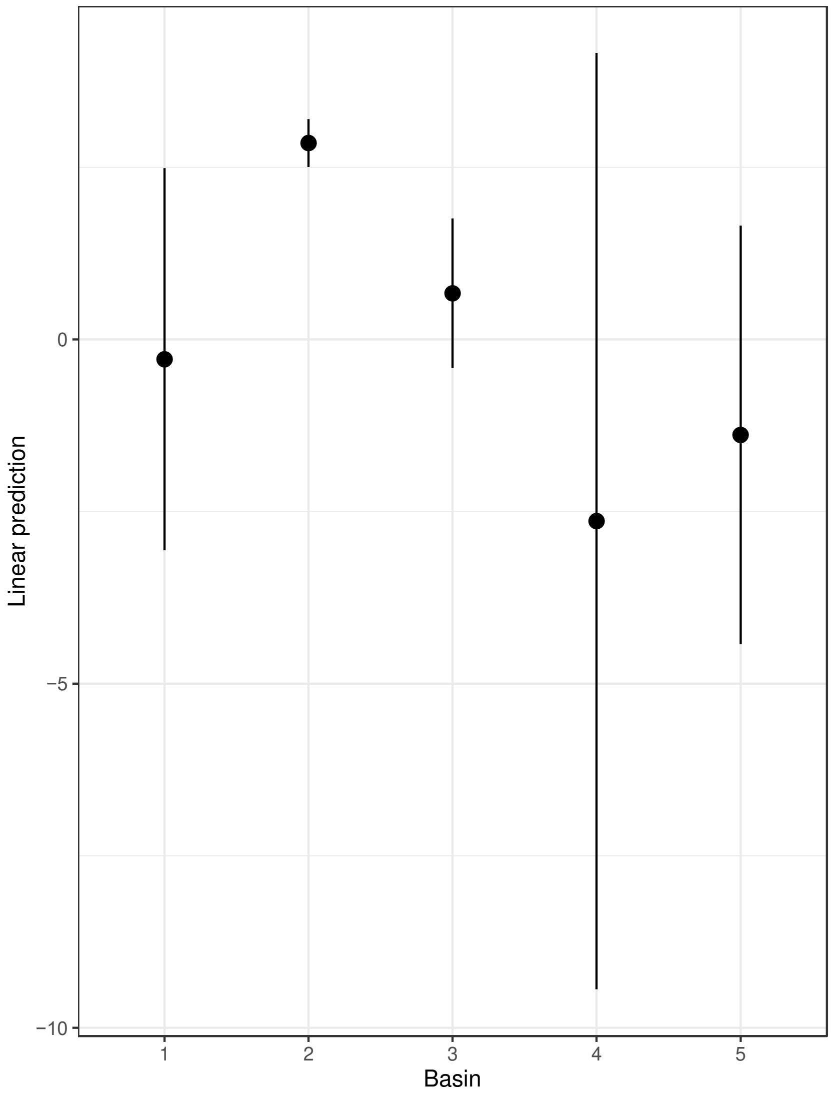

Fig 2: Linear predictions (indicating level of predicted differences using estimated marginal means) of~~of~~ CPUE$_{crayfish}$ in each Basin of Lake Kariba from a GLM with quasi-poisson error distributions

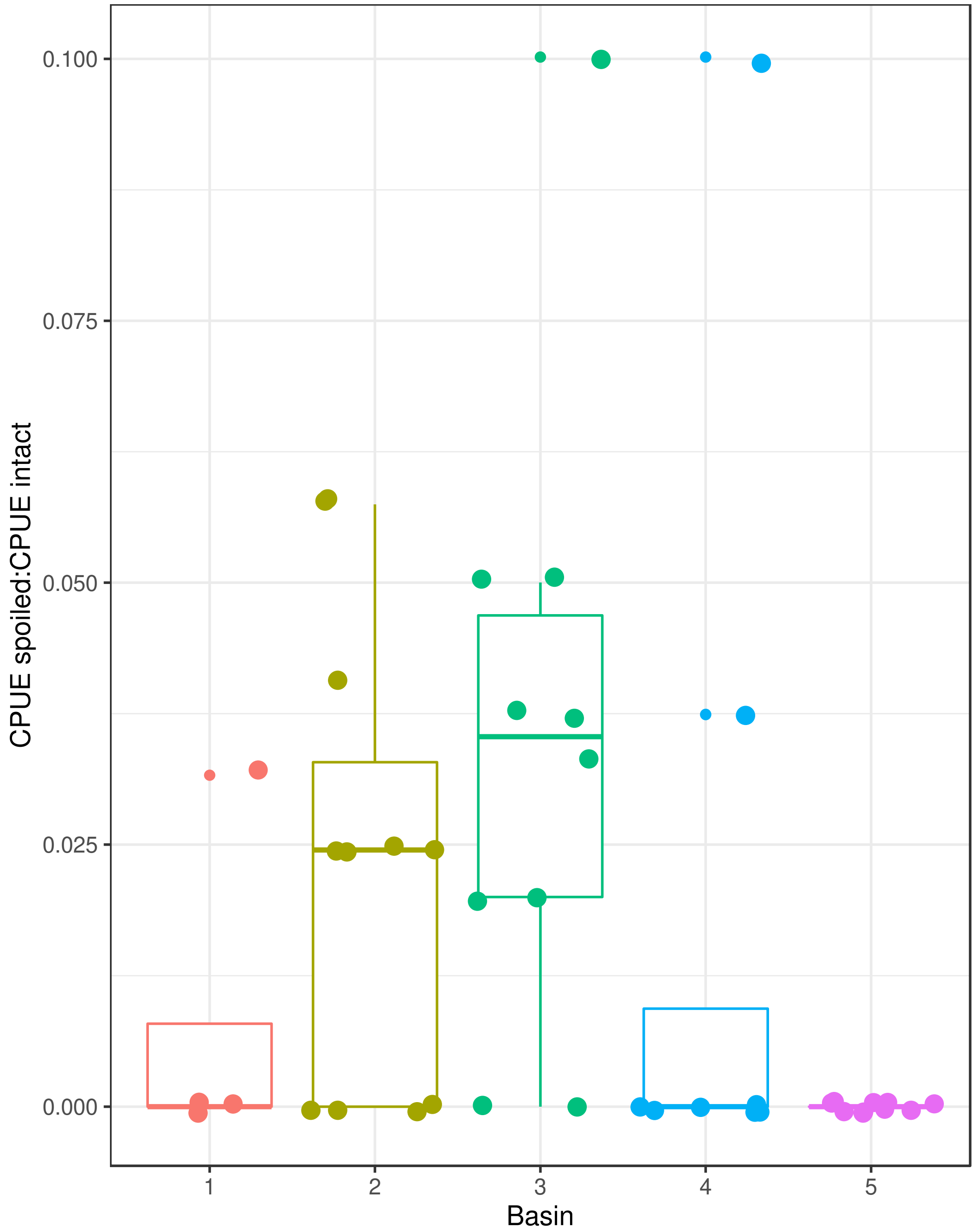

Fig. 3: Arcsine square root transformed ratio of CPUE$_{spoiled}$:CPUEintact of fish catch in gillnets in each Basin of Lake Kariba. CPUE$_{spoiled}$ indicates that fish have scavenging damage from crayfish. Points indicate raw data, lower and upper limits indicate 25-75% quantiles and line indicates median. Smaller points indicate outliers.

3.2 *Crayfish damage*

From the questionnaire, fishers claimed the primary species scavenging their catch were Nile crocodiles (*Crocodylus niloticus*) (51.4%), redclaw crayfish (44.9%), African helmeted turtle (*Pelomedusa subrufa*) (0.9%), and 2.8% of the fishers did not experience catch damages. Fishers determined catch damage by crayfish by presence on the net, stereotypical visible slicing wounds on the fish, and the fish rotting quickly. The fishers also reported that, damage as a result from crocodile scavenging usually results in large holes and damage to the nets, as well as loss of substantial parts of the fish.

Damage by crayfish on fish was recorded in all the basins except in Basin 5, however, there was no effect of basin on ratio of spoiled:intact fish CPUE ($\chi^2 = 0.52,\ df = 4, p = \ 0.97$) (Table 3; Fig. 3). There was a significant weak relationship between ratio of spoiled:intact fish CPUE and CPUE$_{\text{crayfish}}$ (z = 3.59, R=0.45, p<0.001; Fig 4). In one instance there were typical crayfish damage marks recorded on *Hydrocynus vitattus* but no crayfish were caught in the net, indicating that crayfish are not readily retained by the gillnets mesh size.

The highest percentage catch loss was recorded in Basin 2 (20% of catch), Basin 1 experienced 13% catch loss from crayfish, and Basin 3 and 4 had less than 15% loss (Table 3). Damage marks were detected on 43 individual fish, species damaged include: *Oreochromis niloticus* (45%), *Clarias gariepinus* (10%), *Mormyrus longirostris* (15%), *Synodontis zambezensis* (20%), *Coptodon rendalii* (5%) and *H. vitattus* (5%). In all fish species, the eyes, guts and the tail were all frequently damaged.

Table 3 CPUE of intact and spoiled fish in and monetary value (in US $) per night in Lake Kariba

Basin	$CPUE_{intact}$ (kg/100 m net)	$CPUE_{spoiled}$ (kg/100 m net)	% loss	Monetary value of loss per 100m ($)
1	1.26	0.19	13.34	0.48
2	9.04	2.25	19.97	5.63
3	2.75	0.45	14.16	1.13
4	2.21	0.25	10.04	0.63
5	1.05	0.00	0.00	0.00

3.4 *Economic losses*

The highest damage was recorded in Basin 2, where an average CPUE of 2.3 kg/100m of fish are being lost per day per fisher due to crayfish damage. The loss due to crayfish spoilage in Lake Kariba is 0.63 kg/fisher/day (Table 4). When all losses are combined, 212 tonnes are lost annually which translates to ≈ US$ 512 352.92 (Table 4).

Table 4 Monetary losses incurred by fishers due to crayfish damage in Lake Kariba, Zimbabwe

	Weight value (kg)	Monetary value (US$)
Catch Loss/Fisher/Day (kg)	0.63	1.58
Catch Loss/day × 1 154 Fishers (kg)	756.03	1 823.32
Annual Loss × 281 fishing days	199 591.92	512 352.92

4.0 Discussion

Socioeconomic impacts of IAS provide crucial insights for efficient management and policy, yet reliable syntheses are still lacking (Diagne *et al*., 2021). Socioeconomic impacts of IAS are also more easily perceived and more likely to be addressed by stakeholders than ecological losses. Here, we provide the first observed economic cost assessment of *C. quadricarinatus* globally and the first observed cost assessment for crayfish in Africa. The catch assessment survey conducted in the small-scale artisanal gillnet fishery of Lake Kariba identified high observed fisheries damage costs due to *C. quadricarinatus.* We demonstrate the presence of *C. quadricarinatus* in all the sampled basins, indicating that the invader is still well established, 19 years after its introduction (Madzivanzira *et al*., 2020). High costs are seen, not as a result of high damage rates, but due to the discarding of whole fish as they are considered culturally to be contaminated. The establishment of *C. quadricarinatus* throughout the Zambezi Basin may pose a major threat to livelihoods in the Zambezi Basin relying on fisheries.

Within the present study, we have validated anecdotal reports of fisheries damage by *C. quadricarinatus* in gillnet fisheries. Similar complains of spoilage of fish on gillnets and the damage caused to gillnets when pulling the crayfish off the gillnets have been reported (Lowery, and Mendes, 1977). The crayfish are attracted to any fish caught in the net and partially consume the catch, while simultaneously spoiling the value of the catch (Weyl *et al*., 2017; Madzivanzira *et al*., 2022). Crayfish have been proved by an experimental study by Madzivanzira *et al*., 2022, to be fish catch scavengers and images of the damage are provided. The proportion of spoiled to intact fish did not change with basin, suggesting that despite differences in overall fish catch CPUE there is a similar extent of damage expected if there are fish caught in the nets. As crayfish are opportunistic generalists scavenging is common and can substantially mediate phosphorous recycling rates by sequestering carcass nutrients (Boros *et* *al*. 2020). The extent of impact on catch was weakly related to the abundance of crayfish entangled in the net. Retention of crayfish in the gillnets is not quantified but compared to trapping methods it is extremely low (Mhlanga *et al*. 2020; Madzivanzira *et al*., 2021a,c; Madzivanzira *et al*. 2023). We caution that the relationship between crayfish bycatch and fish damage is not truly informative without also performing standard methods for estimating abundance (See Madzivanzira *et al*. 2021c). Low total numbers of crayfish scavenging are reflected in Lake Kariba, where stable isotope analysis indicated a prevalence of fish in up to 12% of medium sized crayfish (30-59 mm carapace length) diets (Marufu *et al,*. 2018). Similar to laboratory studies, the eyes, stomach and tail were frequently damaged which suggests opportunistic damage to accessible parts of the fish (Madzivanzira *et al*., 2022). In the Lake Kariba fishery, and indeed others in the Upper Zambezi (e.g. Barotse floodplain), aesthetic damage to catch often translates to economic loss regardless of extent. When crayfish causes a percentage of the catch to be unmarketable, targets are not met and the impacts cascade through the value chain (Madzivanzira *et al*., 2022). If crayfish bycatch in the nets was considerable it could be recommended to create a supplemental market to offset this. However, as bycatch is low, we recommend instead the use of misdirection traps to simultaneously catch crayfish for bycatch, reduce damage to fish catch, and suppress population (Madzivanzira *et al*. 2022).

Fisheries in Lake Kariba contribute to livelihoods through both local sale and the international export market. However, any fish damaged by crayfish are not marketable and, in most cases, will not be consumed even by the fishers. The most damage impacted fish species by *C. quadricarinatus* was *O. niloticus* which is likely due to the species higher relative abundance in the lake among other cichlids, as well as the type of gears (e.g. large mesh gillnets) that are used by fishers (which targets mostly tilapia species). This, therefore, does not necessarily mean that *C. quadricarinatus* highly preferred *O. niloticus* to other fish species. *Oreochromis niloticus* makes up to 80% of the catch in Lake Kariba (excluding kapenta) (https://www.fao.org/fi/oldsite/FCP/en/ZWE/profile.htm). Despite *O. niloticus* being an introduced species in Lake Kariba, the species contributes significantly to the fishery of Lake Kariba as well as other aquatic systems in southern Africa (Ellender *et al*., 2014; Madzivanzira *et al*., 2022a). *Oreochromis niloticus* from Lake Kariba is sold locally in Zimbabwe and exported as frozen whole fish or fillets to the European market mainly supermarket chains across northern Europe and Spain and in the southern Africa region (https://www.fao.org/fishery/en/facp/zwe). Therefore, the damage caused by *C. quadricarinatus* is a cause for concern across multiple scales as it threatens both local food security as well as the broader economy as damaged fish cannot be sold at the international scale.

The fishery impacts from *C. quadricarinatus* are a food security concern as riparian communities in Lake Kariba, as well as the entire African continent (associated with high levels of poverty) highly rely on fish for protein. The potential losses in catch and income as recorded and calculated for Lake Kariba could be more than half a million US$ per year due to spoilage by *C. quadricarinatus*. From this annual loss, each fisher is likely to be losing ≈ US$ 50 per month. This amount lost is significant, considering that the total income per household in Kariba fishing camps ranges between US$ 140 – 233 per month (Magqina *et al*., 2020). Despite the catch assessment being the most comprehensive to date, some uncertainties remain in the dataset. For example, not all of the 957 registered fishers fish every day of the 281 fishing days (over estimation) and poaching by unregistered fishers during the full moon period is highly likely (under estimation). The potential overall loss in catch and income shown in this study could be less in the winter season and greater in the summer season as impacts of crayfish increase with temperature (Madzivanzira *et al*., 2021b, 2022a). This is because of the effects of temperature on crayfish physiology (Uiterwaal and DeLong, 2020; Madzivanzira *et al*., 2021b, 2022a), as well as the effects of season on water levels. Water levels in Lake Kariba decline during the summer season before significant rains (September – December) which could increase the rate of crayfish/caught fish encounters, and this drives the additive impact during this season. A combination of these factors which are both driven by summer temperatures could act in tandem thereby further causing devastating socioeconomic impacts. As crayfish entangle themselves on the gillnets, they reduce their efficiency and result in low fish catches (Weyl *et al*., 2017). The gillnets are also damaged when crayfish are removed from the gillnets. Fishers must then increase their fishing effort to compensate for the lost catch, and in some cases, they resort to the use of illegal methods such as fish driving, as well as using illegal gears (pers obs ATC, TCM) .

Economic aspects are critical in this context, especially regarding the limited economic capacity of most African countries to counteract invasions. Indeed, information on the economic impacts of biological invasions is important at several levels, especially for increasing societal awareness of the substantial losses caused by invasions (Diagne *et al.,* 2020). It was therefore vital to calculate the losses associated with *C. quadricarinatus* invasions in the field, as socioeconomic impacts are more easily perceived and more likely to be addressed by stakeholders to avoid further escalating cost (Cuthbert *et al.,* 2022). While various studies have demonstrated how virtually impossible it is to eradicate crayfish once they have established owing to the interconnected nature of aquatic environments and at times human-mediated movement (Madzivanzira *et al*., 2021a; Barkhuizen *et al.,* 2022), the irreversible socioeconomic impacts are likely to persist and worsen (Kerby *et al.,* 2005), especially considering the low level of conservation management resources in many African countries.

Adaptive measures may be a useful tool in socially combatting the economic loss from crayfish. Fishers might need to redesign their fishing techniques in order to reduce the associated losses. Fishers in some basins of Lake Kariba where *C. quadricarinatus* impacts were low stated that they were setting their nets in such a way that the bottom parts of the nets do not touch the bottom of the lake making the nets inaccessible to *C. quadricarinatus* (ATC pers obs.). This technique was likely responsible for the lack of crayfish incurred losses in Basin 5 (Sanyati) and may be attributed to the fact that the Sanyati Basin was the initial introduction site (Madzivanzira *et al*. 2020) and therefore social adaptation is more likely with longer invasion time. Setting nets when the weather is bad should be avoided by all means as this will increase the soak time of nets, increasing the exposure time of caught fish to *C. quadricarinatus* spoilage since the fishers will not be able to retrieve the nets during the bad weather. As crayfish damage is related to crayfish abundance, methods of population suppression should be developed to keep abundances low (Manfrin *et al*., 2019; Madzivanzira *et al*. 2022).

Mitigation of invasion impacts is essential as the food security and livelihoods in invaded regions is being affected, which further strains the attainment of Sustainable Development Goal 1 (No Poverty), 2 (Zero Hunger) and Decent Work and Economic Growth (SDG 8) ;see https://www.un.org/sustainabledevelopment/. This is especially concerning in southern Africa where there are high levels of poverty and little cohesive transboundary policy despite multiple shared watersheds. Crayfish invasions have clear capacity to cause damage across many sectors and need to be prioritised with respect to research, policy and community engagement to limit further spread.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Author Contributions

All authors conceived the study. Adroit Takudzwa Chakandinakira, Shantel Mashonga and Nobuhle Ndlovu conducted the fieldwork. Adroit Takudzwa Chakandinakira, Takudzwa Comfort Madzivanzira, Shantel Mashonga, John Vengai Muzvondiwa and Josie South analysed the data. Adroit Takudzwa Chakandinakira led writing of the manuscript and all authors contributed critically to the drafts and gave final approval for publication.

Data availability statement

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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