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1
2 **Socioeconomic impacts of Australian redclaw crayfish *Cherax quadricarinatus* in Lake Kariba**

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20
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30

31 **Abstract**

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

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

55 **1.0 Introduction**

56 Biological invasions are a major anthropogenic stressor as many invasions confer negative
57 impacts on biodiversity (Gallardo *et al.*, 2015; Seebens *et al.*, 2017; Meyerson *et al.*, 2019;
58 Tickner *et al.* 2020) and human livelihoods (Ellender *et al.*, 2014; Blackburn *et al.*, 2019).
59 Invasions result in new species interactions which confer a variety of negative effects upon
60 indigenous populations such as direct predation (Weis, 2011); hybridisation (Zengeya *et al.*,
61 2015); disease transfer (Prenter *et al.*, 2004) and competition for resources (Raymond *et al.*,
62 2015). Invasive alien species (IAS) can also have detrimental socioeconomic impacts, affecting
63 ecosystem services that are beneficial for human well-being (Vilà and Hulme, 2018). Although,
64 conversely, IAS may give positive socio-economic benefits to societies who use or value them
65 (Andriantsoa *et al.*, 2020). Nonetheless, the damage caused by IAS and the costs associated
66 with their management to control them can be a significant economic burden and user conflicts
67 may create difficulty and community resistance to management (Hoffmann and Broadhurst,
68 2015; Oficialdegui *et al.*, 2020).

69

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

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

82

83 Crayfish are phylogenetically novel in continental Africa, and nine species were introduced for
84 socioeconomic purposes (Madzivanzira *et al.*, 2020). Five crayfish species have established
85 populations. Of particular concern is globally invasive Australian red claw crayfish *Cherax*
86 *quadricarinatus* (von Martens 1868) which is rapidly spreading across Southern Africa
87 (Madzivanzira *et al.*, 2020, 2021a). *Cherax quadricarinatus* is native to Northern Australia and
88 south-eastern Papua New Guinea (Riek, 1969). In Southern Africa, *C. quadricarinatus* has
89 established in the Inkomati Basin (South Africa, Swaziland and Mozambique) (Nunes *et al.*,
90 2017; Madzivanzira *et al.*, 2020), Zambezi Basin (Zambia, Namibia, Zimbabwe, and
91 Mozambique) (Madzivanzira *et al.*, 2020, 2021a). The first documented introduction of *C.*
92 *quadricarinatus* into the Zambezi system was in 2001 when this species was introduced from
93 Swaziland to two fish farms in the Zambezi system, one at the eastern end of the Kafue Flats,
94 and the other at Siavonga on the shore of Lake Kariba in Zambia (Madzivanzira *et al.*, 2020).
95 Wild populations of *C. quadricarinatus* were first reported in the Kafue River in 2001 and in
96 2002 in Lake Kariba (Douthwaite *et al.*, 2018).

97

98 Crayfish have a damaging global invasion history (Lodge *et al.*, 2000; Twardochleb *et al.*,
99 2013). Observed global damage costs from crayfish invasions is around US \$ 4.2 million, and
100 specific losses to fisheries is around US \$6.6 million a year from a mixture of damage and
101 management costs (Kouba *et al.*, 2021). However, impact assessments need to be context
102 dependent to avoid making erroneous comparisons. In Africa, a few studies have attempted to
103 infer the impact of invasive crayfish species (Jackson *et al.*, 2016; South *et al.*, 2019, 2020;
104 Madzivanzira *et al.*, 2021b, 2022). Nonetheless, there is very little data evidencing field impact

105 or providing accurate estimates of socioeconomic cost incurred by damage to fisheries. This
106 information is essential to compel policy makers to prioritise their management and prevent
107 further introductions.

108

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

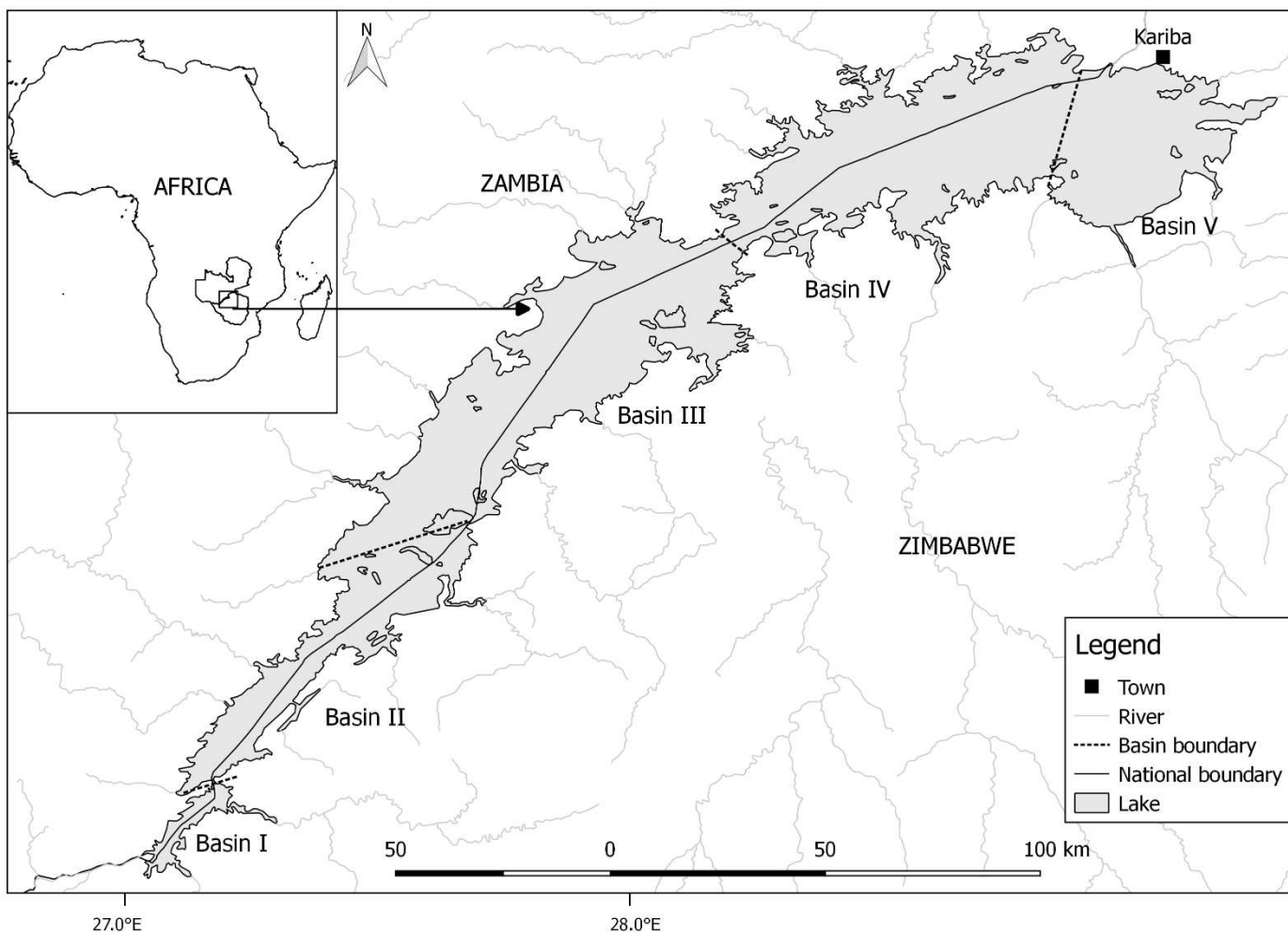
121

122 **2.0 Materials and Methods**

123 2.1 *Study area*

124 The study was carried out in Lake Kariba, which is the world's largest man-made lake by
125 volume, bordering Zimbabwe and Zambia. The lake has a water volume of 185 km³, a surface
126 area of 5580 km² and a length of 280 km. The lake supports a range of biodiversity and part of
127 it is under the UNESCO Biosphere Reserve (Magadza *et al.*, 2020). Thirty-three fish species
128 have been recorded in Lake Kariba (Zengeya and Marshall, 2008) mainly dominated by
129 Cichlids, Cyprinids, Clarids, Characids, Momyrids and Alestids (Phiri and Mhlanga, 2014).

130 Lake Kariba is divided into five basins namely: Mlibizi (Basin 1), Binga (Basin 2), Sengwa
 131 (Basin 3), Bumi (Basin 4) and Sanyati (Basin 5) (Fig. 1). On the Zimbabwean shoreline of
 132 Lake Kariba, fishing camps and villages in each basin have designated fishing grounds with
 133 1154 officially registered fishers (Frame Survey 2011). Fishers fish for ≈ 281 days in a year
 134 with a week of rest in each month (the “full moon” period) which is an attempt to reduce fishing
 135 effort.



136 27.0°E 28.0°E
 137 **Fig. 1** Map of Lake Kariba showing the hydrological basins sampled

138
 139 **2.2** *Sampling*

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

142 2019) characterised by maximum temperatures averaging 29.3°C – 33.4°C (weather-
 143 atlas.com). Data were collected from 107 registered fishers at landing sites of 23 fishing
 144 camps/villages when they returned from retrieving their gillnets from the lake in the morning
 145 (Table 1). The fishers are allowed to have a maximum of 5 cotton/nylon nets measuring 100 m
 146 each with mesh sizes of 4 inches and above (per fishing authority guidance in Lake Kariba).
 147 These nets are laid in designated fishing zones of the lake. Fishers lay their gillnets at dusk and
 148 retrieve them at dawn with an average soak time of 12 hours. At the landing site, after the nets
 149 were retrieved at dawn, the catches were inspected and assessed for the relevant information
 150 for data collection. Fish were identified to species level to assess the catch composition and
 151 quantity, fishing effort (number and mesh size of nets), number and weight of crayfish
 152 entangled on gillnets, number and weight of both whole and damaged fish, and areas damaged
 153 were recorded from the inspection. An informal questionnaire was also administered to the
 154 same 107 fishers to get their perspective on the depredation of their gillnet catches. The
 155 questionnaire comprised of open ended questions regarding perception of fish spoilage on gill
 156 nets and suspected fish catch scavengers.

157

158 **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

159 *each fishing camp/village has a landing site

160

161 2.3 *Data analysis*

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

$$166 \quad CPUE \text{ for intact fish } (CPUE_{intact}) = \frac{\text{total mass intact fish}}{\text{effort}} \quad (1)$$

$$167 \quad CPUE \text{ for spoiled fish } (CPUE_{spoiled}) = \frac{\text{total mass spoiled fish}}{\text{effort}} \quad (2)$$

$$168 \quad CPUE \text{ for crayfish } (CPUE_{crayfish}) = \frac{\text{total number of crayfish}}{\text{effort}} \quad (3)$$

169

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

175

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

180

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

186

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

193

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

196

$$197 \text{ Monetary loss per day} = CPUE_{\text{spoiled}} (\text{kg}) * \text{maximum effort} * \text{price of fish per kg} \quad (4)$$

198

$$199 \text{ Monetary loss per year} = \text{Monetary loss per day} \cdot 281 \text{ fishing days} \quad (5)$$

200

$$201 \text{ Total Monetary loss per year} = \text{Monetary loss per year} \cdot \text{number of registered fishers} \quad (6)$$

202

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

205

206 **3.0 Results**

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

209

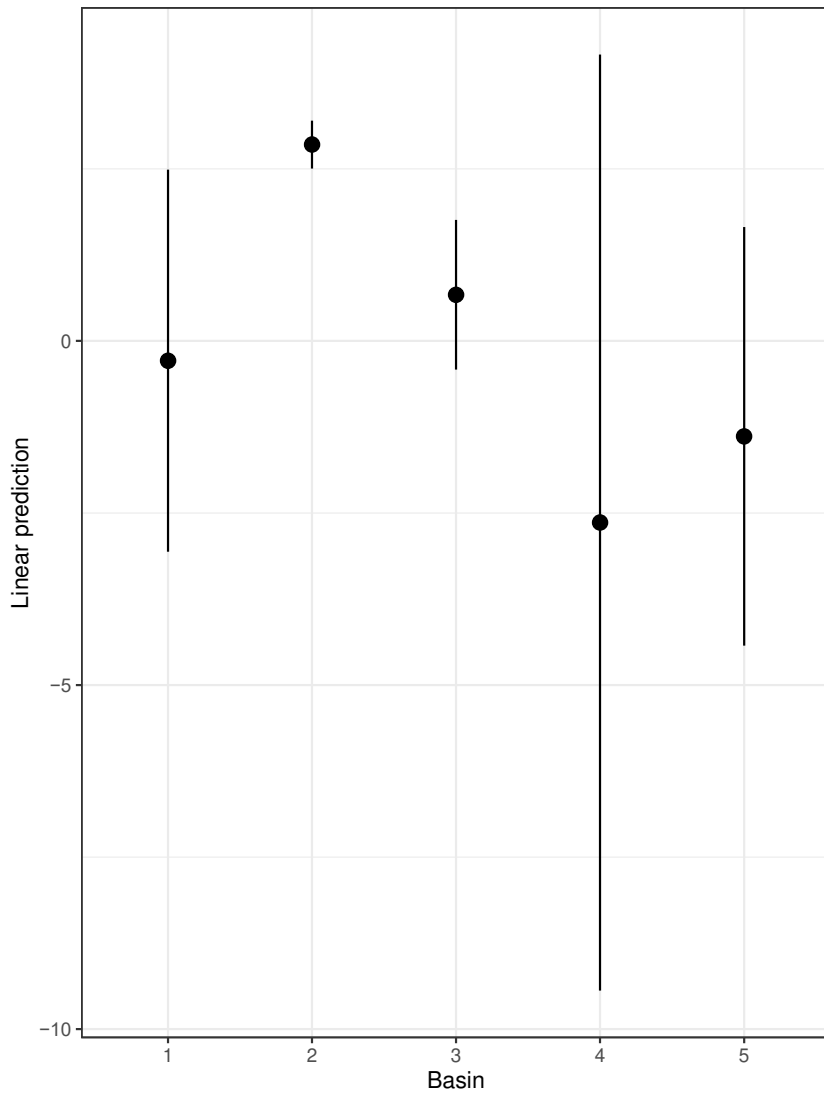
210 3.1 *Crayfish presence*

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

214
215 **Table 2** CPUE by number by basin
216

Basin	CPUE_{crayfish}	CPUE_{spoiled}	CPUE_{intact}
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

217



218

219 **Fig 2:** Linear predictions (indicating level of predicted differences using estimated marginal
 220 means) of CPUE_{crayfish} in each Basin of Lake Kariba from a GLM with quasi-poisson error
 221 distributions

222

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

237

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

244

245 The highest percentage catch loss was recorded in Basin 2 (20% of catch), Basin 1 experienced
246 13% catch loss from crayfish, and Basin 3 and 4 had less than 15% loss (Table 3). Damage
247 marks were detected on 43 individual fish, species damaged include: *Oreochromis niloticus*
248 (45%), *Clarias gariepinus* (10%), *Mormyrus longirostris* (15%), *Synodontis zambezensis*
249 (20%), *Coptodon rendalii* (5%) and *H. vitattus* (5%). In all fish species, the eyes, guts and the
250 tail were all frequently damaged.

251

252

253 **Table 3** CPUE of intact and spoiled fish in and monetary value (in US \$) per night in Lake
254 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

255

256

257 3.4 *Economic losses*

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

262

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

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

265

266 4.0 Discussion

267 Socioeconomic impacts of IAS provide crucial insights for efficient management and policy,
268 yet reliable syntheses are still lacking (Diagne *et al.*, 2021). Socioeconomic impacts of IAS are
269 also more easily perceived and more likely to be addressed by stakeholders than ecological
270 losses. Here, we provide the first observed economic cost assessment of *C. quadricarinatus*
271 globally and the first observed cost assessment for crayfish in Africa. The catch assessment
272 survey conducted in the small-scale artisanal gillnet fishery of Lake Kariba identified high
273 observed fisheries damage costs due to *C. quadricarinatus*. We demonstrate the presence of *C.*
274 *quadricarinatus* in all the sampled basins, indicating that the invader is still well established,
275 19 years after its introduction (Madzivanzira *et al.*, 2020). High costs are seen, not as a result
276 of high damage rates, but due to the discarding of whole fish as they are considered culturally
277 to be contaminated. The establishment of *C. quadricarinatus* throughout the Zambezi Basin
278 may pose a major threat to livelihoods in the Zambezi Basin relying on fisheries.

279
280 Within the present study, we have validated anecdotal reports of fisheries damage by *C.*
281 *quadricarinatus* in gillnet fisheries. Similar complains of spoilage of fish on gillnets and the
282 damage caused to gillnets when pulling the crayfish off the gillnets have been reported
283 (Lowery, and Mendes, 1977). The crayfish are attracted to any fish caught in the net and
284 partially consume the catch, while simultaneously spoiling the value of the catch (Weyl *et al.*,
285 2017; Madzivanzira *et al.*, 2022). Crayfish have been proved by an experimental study by
286 Madzivanzira *et al.*, 2022, to be fish catch scavengers and images of the damage are provided.
287 The proportion of spoiled to intact fish did not change with basin, suggesting that despite
288 differences in overall fish catch CPUE there is a similar extent of damage expected if there are
289 fish caught in the nets. As crayfish are opportunistic generalists scavenging is common and can
290 substantially mediate phosphorous recycling rates by sequestering carcass nutrients (Boros *et*

291 *al.* 2020). The extent of impact on catch was weakly related to the abundance of crayfish
292 entangled in the net. Retention of crayfish in the gillnets is not quantified but compared to
293 trapping methods it is extremely low (Mhlanga *et al.* 2020; Madzivanzira *et al.*, 2021a,c;
294 Madzivanzira *et al.* 2023). We caution that the relationship between crayfish bycatch and fish
295 damage is not truly informative without also performing standard methods for estimating
296 abundance (See Madzivanzira *et al.* 2021c). Low total numbers of crayfish scavenging are
297 reflected in Lake Kariba, where stable isotope analysis indicated a prevalence of fish in up to
298 12% of medium sized crayfish (30-59 mm carapace length) diets (Marufu *et al.*, 2018). Similar
299 to laboratory studies, the eyes, stomach and tail were frequently damaged which suggests
300 opportunistic damage to accessible parts of the fish (Madzivanzira *et al.*, 2022). In the Lake
301 Kariba fishery, and indeed others in the Upper Zambezi (e.g. Barotse floodplain), aesthetic
302 damage to catch often translates to economic loss regardless of extent. When crayfish causes a
303 percentage of the catch to be unmarketable, targets are not met and the impacts cascade through
304 the value chain (Madzivanzira *et al.*, 2022). If crayfish bycatch in the nets was considerable it
305 could be recommended to create a supplemental market to offset this. However, as bycatch is
306 low, we recommend instead the use of misdirection traps to simultaneously catch crayfish for
307 bycatch, reduce damage to fish catch, and suppress population (Madzivanzira *et al.* 2022).

308

309

310 Fisheries in Lake Kariba contribute to livelihoods through both local sale and the international
311 export market. However, any fish damaged by crayfish are not marketable and, in most cases,
312 will not be consumed even by the fishers. The most damage impacted fish species by *C.*
313 *quadricarinatus* was *O. niloticus* which is likely due to the species higher relative abundance
314 in the lake among other cichlids, as well as the type of gears (e.g. large mesh gillnets) that are
315 used by fishers (which targets mostly tilapia species). This, therefore, does not necessarily

316 mean that *C. quadricarinatus* highly preferred *O. niloticus* to other fish species. *Oreochromis*
317 *niloticus* makes up to 80% of the catch in Lake Kariba (excluding kapenta)
318 (<https://www.fao.org/fi/oldsite/FCP/en/ZWE/profile.htm>). Despite *O. niloticus* being an
319 introduced species in Lake Kariba, the species contributes significantly to the fishery of Lake
320 Kariba as well as other aquatic systems in southern Africa (Ellender *et al.*, 2014; Madzivanzira
321 *et al.*, 2022a). *Oreochromis niloticus* from Lake Kariba is sold locally in Zimbabwe and
322 exported as frozen whole fish or fillets to the European market mainly supermarket chains
323 across northern Europe and Spain and in the southern Africa region
324 (<https://www.fao.org/fishery/en/facp/zwe>). Therefore, the damage caused by *C.*
325 *quadricarinatus* is a cause for concern across multiple scales as it threatens both local food
326 security as well as the broader economy as damaged fish cannot be sold at the international
327 scale.

328

329 The fishery impacts from *C. quadricarinatus* are a food security concern as riparian
330 communities in Lake Kariba, as well as the entire African continent (associated with high levels
331 of poverty) highly rely on fish for protein. The potential losses in catch and income as recorded
332 and calculated for Lake Kariba could be more than half a million US\$ per year due to spoilage
333 by *C. quadricarinatus*. From this annual loss, each fisher is likely to be losing \approx US\$ 50 per
334 month. This amount lost is significant, considering that the total income per household in
335 Kariba fishing camps ranges between US\$ 140 – 233 per month (Magqina *et al.*, 2020). Despite
336 the catch assessment being the most comprehensive to date, some uncertainties remain in the
337 dataset. For example, not all of the 957 registered fishers fish every day of the 281 fishing days
338 (over estimation) and poaching by unregistered fishers during the full moon period is highly
339 likely (under estimation). The potential overall loss in catch and income shown in this study
340 could be less in the winter season and greater in the summer season as impacts of crayfish

341 increase with temperature (Madzivanzira *et al.*, 2021b, 2022a). This is because of the effects
342 of temperature on crayfish physiology (Uiterwaal and DeLong, 2020; Madzivanzira *et al.*,
343 2021b, 2022a), as well as the effects of season on water levels. Water levels in Lake Kariba
344 decline during the summer season before significant rains (September – December) which
345 could increase the rate of crayfish/caught fish encounters, and this drives the additive impact
346 during this season. A combination of these factors which are both driven by summer
347 temperatures could act in tandem thereby further causing devastating socioeconomic impacts.
348 As crayfish entangle themselves on the gillnets, they reduce their efficiency and result in low
349 fish catches (Weyl *et al.*, 2017). The gillnets are also damaged when crayfish are removed from
350 the gillnets. Fishers must then increase their fishing effort to compensate for the lost catch, and
351 in some cases, they resort to the use of illegal methods such as fish driving, as well as using
352 illegal gears (pers obs ATC, TCM) .

353

354 Economic aspects are critical in this context, especially regarding the limited economic
355 capacity of most African countries to counteract invasions. Indeed, information on the
356 economic impacts of biological invasions is important at several levels, especially for
357 increasing societal awareness of the substantial losses caused by invasions (Diagne *et al.*,
358 2020). It was therefore vital to calculate the losses associated with *C. quadricarinatus* invasions
359 in the field, as socioeconomic impacts are more easily perceived and more likely to be
360 addressed by stakeholders to avoid further escalating cost (Cuthbert *et al.*, 2022). While various
361 studies have demonstrated how virtually impossible it is to eradicate crayfish once they have
362 established owing to the interconnected nature of aquatic environments and at times human-
363 mediated movement (Madzivanzira *et al.*, 2021a; Barkhuizen *et al.*, 2022), the irreversible
364 socioeconomic impacts are likely to persist and worsen (Kerby *et al.*, 2005), especially
365 considering the low level of conservation management resources in many African countries.

366

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

380

381 Mitigation of invasion impacts is essential as the food security and livelihoods in invaded
382 regions is being affected, which further strains the attainment of Sustainable Development Goal
383 1 (No Poverty), 2 (Zero Hunger) and Decent Work and Economic Growth (SDG 8) ;see
384 <https://www.un.org/sustainabledevelopment/>. This is especially concerning in southern Africa
385 where there are high levels of poverty and little cohesive transboundary policy despite multiple
386 shared watersheds. Crayfish invasions have clear capacity to cause damage across many sectors
387 and need to be prioritised with respect to research, policy and community engagement to limit
388 further spread.

389

390 **Conflict of Interest**

391 The authors declare that there are no conflicts of interest.

392

393 **Author Contributions**

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

399

400 **Data availability statement**

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

403

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