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Population Ecology and Current Distribution Assessment of the Introduced Invasive Crayfish in the Kafue Floodplain and Lake Kariba, Zambia

Fish Innovation Lab

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Partners/Institutions

This project was implemented by three organizations who closely collaborated in all aspects of the research, with particular researchers having specific roles:

University of Zambia (UNZA): UNZA was the host organization in Zambia, and led and hosted the inception and final meeting. Three UNZA faculty participated in the study: 1) Eva Nambeye Kaonga, the co-Principal Investigator (PI) for UNZA and researcher in the socioeconomic components of the study, i.e., the focus group discussion (where she was the lead), the survey, and the poll. 2) Bernadette Chimai, also researcher in the socioeconomic components of the study, i.e., the survey (lead), focus group discussions, and the poll. 3) Hangoma Gordon Mudenda, researcher for the ecological component of the study. Additionally, an M.Sc. student from UNZA, Chibwe Katapa, conducted her M.Sc. dissertation research in the project; she was co-chaired by Gordon Mudenda. Additionally, the School of Agricultural Sciences Deans, Benson Chishala and Thomson Kalinda, provided institutional support for the project.

University of Rhode Island (URI): URI was the lead institution for the study, with Michael A. Rice as the PI. He provided overall leadership, management, and coordination, communicated with Mississippi State University's (MSU) Fish Innovation Lab, and led the ecological component of the study.

Cultivating New Frontiers in Agriculture (CNFA): From CNFA, Marjatta Eilitta participated in the study as a researcher in the socioeconomic component of the study, including the poll (lead role), the socioeconomic survey, and the focus group discussions.

The study group collaborated closely with the Zambian Fisheries Department which participated in the inception and final meeting, and supported the project's field research, poll distribution, and information gathering.

Abbreviations and Acronyms

CL	Carapace Length
CNFA	Cultivating New Frontiers in Agriculture (a Washington, D.C.-based NGO)
DAFEE	Department of Agricultural Economics and Extension Education (UNZA)
DAS	Department of Animal Science (UNZA)
DBS	Department of Biological Sciences (UNZA)
ELEFAN	Electronic length-frequency analysis
FAVS	Department of Fisheries, Animal & Veterinary Sciences (URI)
FGD	Focus Group Discussion
KRB	Kafue River Bridge
MSU	Mississippi State University
NGO	Non-governmental organization
TL	Total Length
PI	Principal Investigator
UNZA	University of Zambia
URI	University of Rhode Island
VGBF	Von Bertalanffy Growth Formula

Glossary

Electronic length-frequency analysis (ELEFAN) – A method of determining the growth dynamics of fish populations by comparing length frequency diagrams produced by sampling at known time intervals.

Von Bertalanffy Growth Formula (VBGF) – A negative exponential formula for describing asymptotic organismal growth first described by Ludwig von Bertalanffy in 1938 characterized by rapid growth in earlier stages of life and no growth in the later stages of life.

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Abstract

Since the 1990s, the exotic Australian redclaw crayfish, *Cherax quadricarinatus*, has been spreading in the Zambezi River basin in Zambia. The population structure of crayfish was determined at locations along the north shore of Lake Kariba near Siavonga (~16.5ºS; 28.7ºE) and from the Kafue River (~15.94ºS; 28.88 ºE) by sampling on a monthly basis. Population structure was analyzed by length-frequency plots using TL or CL measurements. Estimates of population growth rates were estimated using cohort analysis using the ELEFAN protocols using R Fisheries Statistics Software. Data reveal that the crayfish population structures of crayfish in both sites are robust with multiple year classes present. Estimates of the mean von Bertalanffy growth parameters of crayfish trapped in Zambian waterways were L_∞ = 215.25 mm (TL), k = 0.695y^{-1} and mean t_o = -0.14 y. The presence or absence of crayfish at sites throughout Zambia was determined by use of a Qualtrics-XM survey administered to members of the staff of the Zambian Department of Fisheries assigned to various districts around the country, and local government officials at villages and towns along the Zambezi, Kafue, and Kwando Rivers in areas where crayfish are likely to have extended their range. The crayfish have appeared in seven previously unreported locations in the Zambezi River basin, including the Mwembeshi Stream in the Northern Province, the Kabompo River in the Northwestern Province and the Chingola Reservoir in the Copperbelt Provinces, as well as in the Kwando sub-watershed of the Zambezi Basin in Western Province that borders with Angola and has a seasonal aquatic connection to the critical Okavango Delta Wildlife Refuge in Botswana. Information was gathered about the utilization of crayfish that are largely viewed as a nuisance with >60% being discarded, however there is a growing acceptance of crayfish as a food source, in the Kafue River and Lake Kariba regions. There is a small and growing number of fishers that are fishing for crayfish as a target species, particularly if nearby markets are available.

Introduction

The invasive Australian redclaw crayfish *Cherax quadricarinatus* has been spreading since the 1990s in the Zambezi River basin of Zambia (Makwelele, 2017; Douthwaite et al., 2018), and it has also been spreading into various locations in Zimbabwe as well (Marufu et al., 2014; Douthwaite et al., 2018; Marufu et al., 2018: Marufu et al., 2020; Madzivanzira, 2021). By 2016, redclaw crayfish were found upstream in the Zambezi River in Northeastern Namibia near the border town of Katima Mulilo and further downstream into Mozambique (Douthwaite et al., 2018).

Introduction of crayfish into continental Africa where there are no native species of crayfish has a long history associated with the establishment of fisheries where none had existed before. Recently, Madzivanzira et al. (2021) provided a comprehensive review of crayfish introductions into the African continent since the first attempt in 1914. Despite over a century of attempted and successful crayfish introductions into the African continent, the practice remains controversial. Indeed, proposals to use crayfish as a public health measure for controlling freshwater gastropods serving as vectors for schistosomiasis (e.g. Monde et al., 2017) have been strongly rebutted by Weyll et al. (2017) who pointed out that disruption of benthic communities by the invasive crayfish can negatively impact existing food webs and can profoundly affect traditional fishery landings (Lodge et al., 2012; Madzivanzira, 2021). Additionally, there is a concern that crayfish may spread to the ecologically and economically critical Okavango Delta wetlands that are geographically close to the Zambezi River watershed and support considerable ecotourism activity (Nunes et al., 2016). On the balance, the environmental and social risks posed by spread of the Australian redclaw and other crayfish in continental Africa may outweigh any of the benefits of their continued spread, and best consensus management advice is to focus on preventing introductions into naïve regions, to undertake management activities to prevent their spread, and to attempt to extirpate populations once they have become established (Rice, 2021).

The purpose of this study is to document the population dynamics and continued spread of redclaw crayfish in the Zambezi River basin of Zambia, and to begin documentation of the socioeconomic impacts of crayfish on traditional fishing communities. The study consisted of the following components, with following specific purposes: 1) An ecological study focusing on crayfish population dynamics; 2) An online poll to document the spread of crayfish in Zambia; 3) A socioeconomic survey to assess fishers' awareness of crayfish, their crayfish trapping and relevant fishing activities, and overall experience with the invasive the crayfish; and 4) Focus group discussions in fisher communities, with specific groups such as women, youth, crayfish trappers, and fishers, to inform the community of the purpose and objectives of the study, provide higher level validation of the individual surveys and a context for it and make it possible to have discussions in specific groups. All but the poll were conducted in four study locations as outlined below where responses were Zambia-wide.

Research Methods

The main study locations were the districts of Siavonga (16.4943ºS; 28.6931ºE) and Sinazongwe (17.2706ºS; 27.4648ºE) for sites within Lake Kariba, and Kafue (15.8368ºS; 28.2377ºE), and Itezhi-tezhi Reservoir (15.7470ºS; 26.0088ºE) for Kafue River sites.

Population dynamics

The study on population dynamics through crayfish trapping was conducted in the four sites mentioned above and, for Kafue, one additional site in Chanyanya (15.6898ºS; 28.0068ºE). Trapping data was collected monthly from the Kafue River (August 2021 to November 2022) and Lake Kariba (August 2022 to November 2022) locations.

For the analysis of the population dynamics of *Cherax quadricarinatus,* there was a length-frequency analysis of crayfish caught in two water bodies known to harbor well-established crayfish populations, Lake Kariba and the Kafue Floodplain. Crayfish were obtained from fishers or their associated vendors and the location their trapping reported by the fishers was noted. Sequential crayfish trapping data from three-week intervals were used as the basic data set for calculating von Bertalanffy growth parameters for the crayfish taken from the two water bodies. The von Bertalanffy Growth Formula (VBGF) was chosen for growth modeling because it has been shown to be the best model to describe growth in *C. quadricarinatus* in comparison to alternative models (Coronado-Castro et al., 2010). The electronic length-frequency analysis (ELEFAN) was performed using the open source fisheries science software 'R' according to the procedures of Taylor and Mildenberger (2017).

Online poll

To determine the extent to which crayfish have spread in Zambian waters was done by using a web-enabled survey using the Qualtrics-XM online survey software (https://www.qualtrics.com/core-xm/survey-software/). The link to the survey was sent to provincial Fisheries Department directors and to local Fisheries Department officers whose contacts were received, to African Park officials, lodge operators and their associations, and to a listserv that was expected to reach individuals who spend time in waterways recreationally. Effort was taken to periodically remind cooperators by email or by telephone over the six-month period of the survey administration to complete the survey and to suggest colleagues who might be interested in becoming cooperators in the survey as well.

Socioeconomic study

A fisher survey was conducted between October 29-November 15, 2022. In Sinzazongwe, Kafue and Itezhi-tezhi, two fishing camps were selected randomly from each district from lists provided by the Department of Fisheries. In Siavonga, the camps were selected based on accessibility by land because poor weather conditions hindered boat transportation to locations that had been planned. Interviews were conducted one-on-one by a team of three enumerators using a structured questionnaire with responses recorded on tablets. The questionnaires included sections on demographic characteristics and access to amenities, crayfish awareness, crayfish population dynamics and seasonality, crayfish utilization, perception and impacts, and historical trends.

Data analysis included frequencies and summary statistics such as means and fractions with relevant statistical tests of differences across sub-groups such as districts, crayfish trapping activities and utilization (t-tests for two-2 group mean comparisons and chi-squares tests for multiple groups). The null hypothesis in each case was no difference against a two-sided alternative hypothesis of a difference. To understand the factors affecting utilization, we run a logistic regression with the dependent variable defined as equal to 1 if the fisher uses crayfish by consuming, selling or feeding livestock and zero otherwise.

Focus group discussions

Focus group discussions (FGDs) were carried out from April 27-28th and 5-9 June, 2023 in Sinazongwe (Nzenga fishing village) and Siavonga for Lake Kariba and Itezhi-Tezhi town and Kafue (Chanyanya fishing village) for Kafue River. The themes for discussions were around crayfish dynamics, management, harvest and utilization and general perspectives on crayfish.

Research Results

Population dynamics

Length-frequency TL and CL data were collected on a monthly basis from *C. quadricarinatus* that were trapped in the various water bodies in Zambia. Example monthly length-frequency data are presented in Figure 1. Overall, the maximum crayfish length observed was a 205 mm TL (122 mm CL) male collected in the Kafue Floodplain and a 201 mm TL (115 mm CL) female collected at Siavonga, Lake Kariba. At the Kafue sites, 59.9% were female (n=691) and 40.1% were male (n= 462). In Lake Kariba, 54.66% (n=932) were female and 45.34% (n=773) were male.

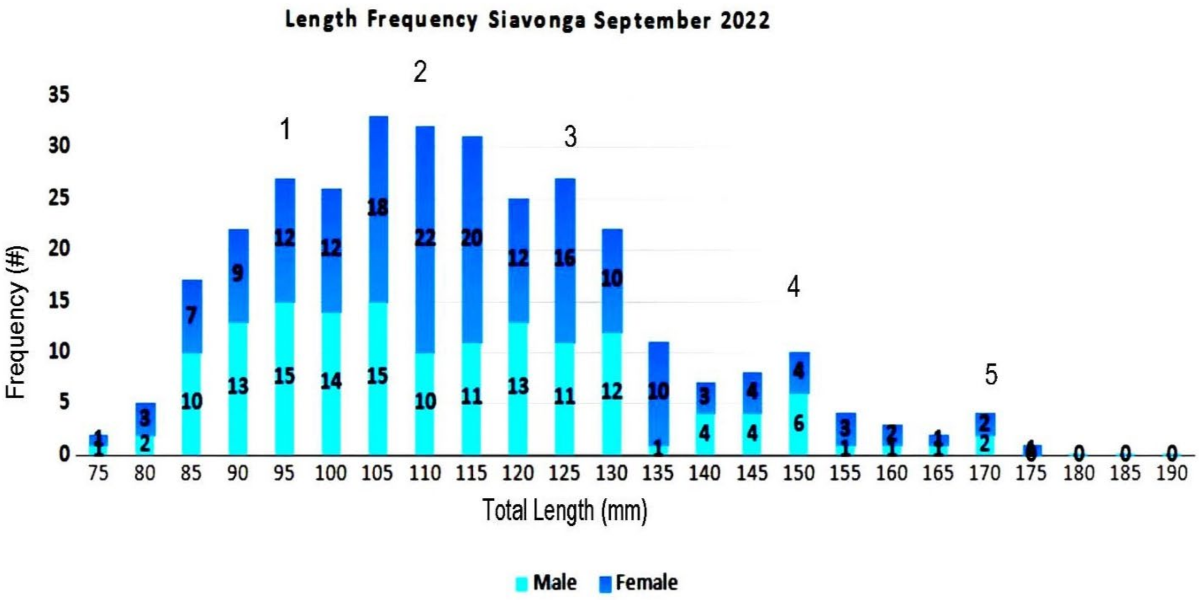

Figure 1. *Length-frequency diagram of crayfish trapped at Siavonga in September 2022 showing numbers of male and females in different TL size categories. Five presumably annual size cohorts are evident.*

Based upon ELEFAN analysis, the Von Bertalanffy Growth parameters for crayfish caught at the various sampling sites are presented in Table 1. Overall mean VBGF values of crayfish trapped in Zambian waterways were L_∞ = 215.25 mm (TL), k = 0.695y^{-1}, and mean t_o = -0.14 y (Table 1A). Tables 1B, 1C and 1D were based upon Carapace Length (CL) measurements. Despite the change in data analysis mode, the growth performance parameter (ϕ') remained constant, suggesting that the data sets are comparable.

The mean overall t_{max} = y, 4.5 y and the overall mean mortality rate is Z = 1.4045. Among the Kafue Floodplain sites (Figure 1D), the Kafue Bridge *C. quadricarinatus* population is exhibiting characteristics of moderately high fishing pressure as evidenced by decreased $L\infty$ values and increased overall mortality rates (Z) in comparison to the lightly exploited population in Chanyanya.

Table 1A. Von Bertalanffy Growth Parameters based on TL measurements in mm of *C. quadricarinatus* in Kafue Floodplain (n= 1153) and Lake Kariba (n=1705) from crayfish collected between June 2022 and November 2022

Site	TL∞	k	Φ′	t_0	t_{max}	z
Kafue Floodplain	215.25mm	0.51/year	4.37	-0.18years	5.7years	1.310/year
Lake Kariba	215.25mm	0.88/year	4.6	-0.1years	3.3years	1.499/year

Table 1B. Von Bertalanffy Growth Parameters based on CL measurements in mm of *C. quadricarinatus* in Kafue Floodplain (n=1153) and Lake Kariba (n=1705) from crayfish collected between June 2022 and November 2022

Site	CL∞	*k*	Φ′	t_0	t_{max}	z
Kafue Floodplain	120.75	0.46/year	3.83	-0.24years	6.3years	0.927/year
Lake Kariba	120.75	0.65/year	3.97	-0.17years	4.4years	1.282/year

Table 1C. Von Bertalanffy Growth Parameters based on CL (rostral) measurements in mm of *C. quadricarinatus* in Lake Kariba (n= 533 at Siavonga and 1172 at Kabyobyo) collected between June 2022 and November 2022.

Site	K		L∞		Φ′		t_0		t_{max}		Z	
	M	F	M	F	M	F	M	F	M	F	M	F
Siavonga T	1.5	1.6	94.5	94.5	4.13	4.15	-0.08	-0.07	1.9	1.8	3.57	3.42
Kabyobyo	0.56	0.65	120.75	120.75	3.91	3.97	-0.2	-0.17	5.15	4.44	1.831	2.137
Mean	1.03	1.12	107.63	107.63	4.02	4.06	-0.14	-0.12	3.52	3.12	2.701	2.778
SD ±	0.47	0.47	13.13	13.13	0.11	0.09	0.06	0.05	1.62	1.32	0.87	0.641

Table 1D. Von Bertalanffy Growth Parameters based on CL (rostral) measurements in mm of *C. quadricarinatus* in Kafue Floodplain (KRB = Kafue River Bridge; n = 897) and at Chanyanya (n = 256) collected between June 2022 and November 2022.

Site	K		L∞		Φ′		t_0		t_{max}		Z	
	M	F	M	F	M	F	M	F	M	F	M	F
KRB	1.2	1.9	94.5	84	4	4.1	-0.1	-0.06	2.4	1.5	2.107	2.443
Chanyanya	0.31	0.28	120.75	110.25	3.65	3.5	-0.36	-0.42	9.3	10.3	0.404	0.488
Mean	0.75	1.09	107.63	97.12	3.82	3.8	-0.23	-0.24	5.8	5.9	1.255	1.465
SD±	0.44	0.81	13.12	13.12	0.17	0.3	0.13	0.18	3.46	4.4	0.8515	0.9775

NB: KRB= Kafue Road Bridge

Online poll

In the Qualtrics-XM poll, a total of 104 responses were received, of which, 26 had no names nor responses to the substantive questions, and five had only a name given, but had no replies to the substantive questions. Therefore, data from 73 surveys could be analyzed. The majority of the those who had indicated their background were Fisheries Department staff (35), followed by "other" (12); others were in tourism industry (7), government (3), researchers 3), recreational fisher (1), national parks staff (1), and they reported on crayfish presence or absence for Lusaka (16), and Southern (17), Central (10), Northern (7), Western (7), Luapula (4), Eastern (2), and Muchinga and Northwestern (each 1) Provinces. The largest part, 42%, of the respondents reported on Lake Kariba, followed by Lake Tanganyika (13%) and Upper Kafue (10%). The remaining 36% covered diverse waterbodies. Crayfish was present in 87% of locations reported by the respondents and not present in 9%; the remainder reported that they did not know.

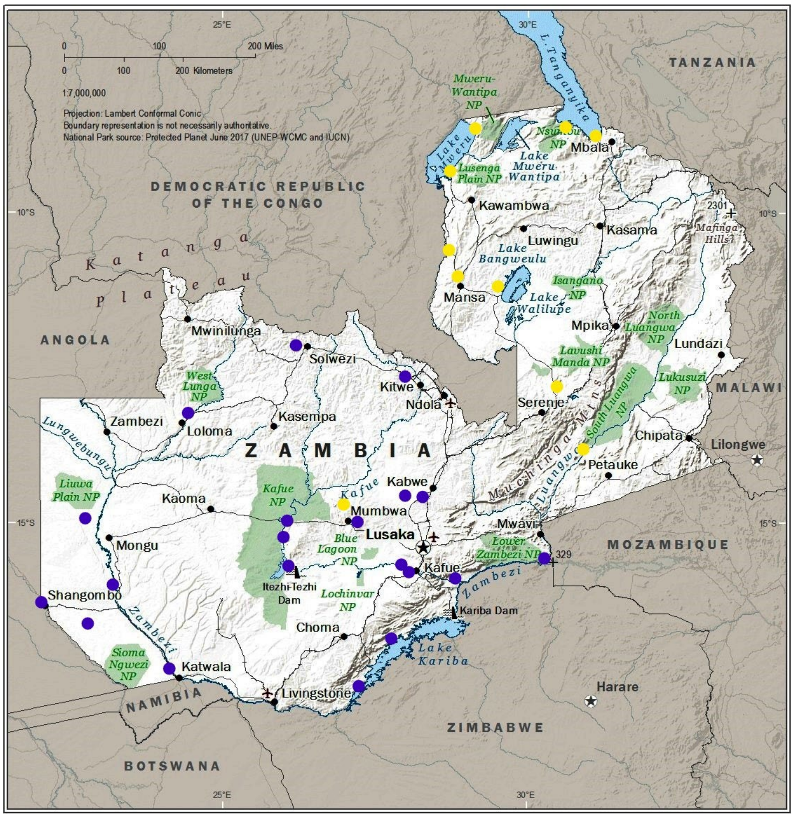

Figure 2. *Map of Zambia showing the locations of sightings of* Cherax quadricarinatus *as of May 2023. Blue dots refer to locations of crayfish sightings and yellow dots refer to sites reported with absence of crayfish. Map modified from US Central Intelligence Agency World Factbook.*

Notably, no one reported that it used to be present, but no longer is. About 21% reported seeing it daily, 26% no more than once a week, and 23% no more than once a month. The respondents were also asked about what they observed about the growth patterns of crayfish populations and crayfish sizes (Table 2). The largest group of respondents had observed that sizes and populations had increased. Altogether 70% reported that there is trapping in the location, and 57% that trapping is for sale and 43% report that it is for home consumption (both alternatives could be selected simultaneously). Almost three quarters (72%) reported that since introduction, sales have increased and only 17% report that they had decreased. Equal number (45%) report that home consumption has increased since introduction and that it has stayed the same, 10% reported that home consumption first decreased, then increased (but low n=10). The poll also included a section where respondents could include their observations about crayfish and its spread. This part provided some interesting observations, some of which are included in the Text Box below.

Text Box 1.

Kafue National Park

- Is present, as confirmed by trapping for monitoring purposes, including in open body of water that is fast moving. In one location, eight years of continuous trapping did not result in catches before 2022, although fishers had been trapping only 10 km south.
- In one location, catfish has been observed to eat smaller crayfish, and in another, all crayfish seen, which have been many, have been in the mouth of Giant Kingfisher.

Kafue River

- Significant increase in the spread and acceptance reported, with people previously reporting that it brought bad luck in fishing and having negative view due to damage in fishing. Increased exploitation and marketing has increased number of people in harvest and trade.
- One respondent reported that it is highly likely that the Lukanga Swamp into which the Kafue river drains is also affected.
- One respondent studying population dynamics on the Barotse floodplain (2018 - 2019) reported that the species is usually reported every year during rescending waters in lagoons and pools.

Zambezi

- Are established in the Lower Zambezi, but have not reached very high population densities. Reported by recreational and artisanal fishers, but not in the numbers that would encourage commercial exploitation.
- One respondent reported seeing in high densities only in one location, in irrigation ponds on the Chiawa estate where it was likely introduce accidentally through water.
- Mentioned that they can cause some damage to fish, but are not mentioned as a major issue .

Survey results of crayfish distribution throughout Zambia are presented in Table 2. They show that the *C. quadricarinatus* crayfish are continuing to spread unabated across Zambia, with crayfish present in seven previously unreported sites. In Lake Lusiwashi, Central Province, there have been no sightings as of 2020. In Mulungushi River, the spread of crayfish is rapid and steadily increasing. One survey respondent considered that it is highly likely that the Lukanga Swamps (into which a distributary of the Kafue River drains) are also affected by the crayfish invasion. In Kaingu, Kafue National Park, *C quadricarinatus* were first encountered in October 2022 after 8 years of observations. Park officials had been monitoring because fishers had been trapping them for years in Lake Itezhi-tezhi 10 km to the south of the park. Despite their current presence in Kafue National Park waters, there is no fishing due to park regulations. In the Lower Zambezi River from the Kariba Dam to Luangwa near the border with Mozambique, *C. quadricarinatus* are established, but not at very high densities as reported by recreational and artisanal fishers. There are high density populations of crayfish in irrigation ponds on the Zambezi Chiawa estate; they probably entered with water from the Zambezi River. In the Western Province, *C. quadricarinatus* have been observed in Kaoma since 2020 and in Shangombo since 2015. It was reported that in Kalabo, the population of crayfish is declining. In the Barotse Floodplain of the Zambezi River adjacent to the Mongu-Kalabo Road, crayfish have been reported annually in lagoons and pools since 2018, and local fishers started collecting crayfish for sale in the last few years. Survey respondents from the Western Province opined that crayfish near the Mongu-Kalabo Road were possibly spread during road construction by a Chinese company. *C. quadricarinatus* were observed in small ponds in the Matebele Plains in 2020.

The Table 2 data also show the recent appearance of crayfish in Chingola in the Copperbelt Region, as well as in waterways in the Northern and Northwestern Provinces. In Northwestern Province, crayfish were reported to be present in the Kabompo River at Kabombo and Manyinga. In the Kabompo River, the crayfish population was reported to have increased some, and have been spreading rapidly. In Southern Province, at Sinazongwe on the northern shore of Lake Kariba, large amounts of crayfish were reported from 2016 to 2020 but populations were declining, possibly due to fishing pressure.

Table 2. Locations and coordinates of reported presence or absence of crayfish, *Cherax quadricarinatus* in Zambian waterways. Blue highlighted boxes are areas of previously unreported sightings. Light blue boxes refer to an area in which the respondent was uncertain about crayfish presence but likely to be absent, and numbers in parentheses indicate multiple survey respondents from the same area.

Reported as Present			
Province	District	Water body	Coordinates
North-Western	Solwezi	Kabompo River	-12.1498 S 26.3631 E
	Manyinga	Kabompo River	-13.4004 S 24.3101 E
Northern	Nsama	Nwambeshi Stream	-8.8986 S 29.9537 E
Central	Ngabwe	Kafue River	-14.1544 S 27.4280 E
	Kabwe	Mulungushi River	-14.3363 S 28.4587 E
	Mumbwa (4)	Kafue River	-14.9883 S 27.0695 E
	Mumbwa	Lukanga Swamp	-14.4379 S 27.5755 E
	Kafue	Kafue River Bridge	-15.8362 S 28.2380 E
Lusaka	Chipepo	Chipepo Wetlands	-14.2052 S 28.1850 E
Southern	Itezhi-tezhi	Lake Itezhi-tezhi	-15.7460 S 26.0092 E
	Kafue	Kafue River Gorge	-15.8093 S 28.4188 E
	Kaingu (Kafue NP)	Kafue River	-15.2955 S 25.9779 E
	Siavonga (Chiawa)	Small Ponds	-15.8828 S 29.0614 E
	Siavonga (Luangwa)	Lower Zambezi River	-15.6225 S 30.4160 E
	Sinazongwe	Lake Kariba	-17.2673 S 27.4519 E
Western	Shangombo	Kwando River	-16.3228 S 22.0943 E
	Kaoma	Luena River	-14.7844 S 24.7872 E
	Sioma	Ponds on Matebele Plains	-16.3767 S 22.6955 E
	Kalabo	Luanginga River	-14.9870 S 22.6834 E
	Sesheke	Upper Zambezi River	-17.4792 S 24.2834 E
	Senanga	Zambezi River	-16.1258 S 23.2870 E
Copperbelt	Chingola	Chingola Reservoir	-12.6595 S 27.8619 E

Reported as Absent			
Province	District	Water body	Coordinates
Northern	Mpulungu (4)	Lake Tanganyika	-8.7726 S 31.1094 E
Central	Serenje	Lake Lusiwasi	-12.9690 S 30.6659 E
	Chunga	Kafue River	-15.0510 S 26.0047 E
Luapula	Chiengi	Lake Mweru	-8.6546 S 29.1553 E
	Nchelenge	Lake Mweru	-9.3502 S 28.7334 E
	Mansa	Mansa River	-11.1932 S 28.8893 E
	Samfya	Lake Bangweulu	-11.3550 S 29.5629 E
	Mwense	Luapula River	-10.7253 S 28.6657 E
Eastern	Mambwe	Luangwa River	-13.3469 S 31.6403 E
Muchinga	Mpika	Mwaleshi River	-11.8348 S 31.3919 E

There is new evidence that local wildlife are becoming predators upon the introduced crayfish. Two survey respondents reported predation of crayfish, with one commenting that it is often seen in the beak of the Giant Kingfisher (*Megaceryle maxima*) and another that catfish including the vundu catfish (*Heterobranchus longifilis*) and the African sharptooth catfish (*Clarias gariepinus*) were seen eating small crayfish.

Socioeconomic survey

Survey fisher profile

Table 3 summarizes the demographic characteristics and fishing activities of all sampled fishers in the study and dissagregated according to crayfish fishing by intentional crayfish trapping and unintentional fishing. All the fishers interviewed were male and primary owners of the fishing businesses they were reporting on. Across the four districts, the average fisher in the study districts was middle-aged, about 40 years old, with fishing as their main income generating activity for most of their adult life. Most of the fishers have some formal education with an average highest level of education of grade 6. Typically, the fishers resided in a household with six other members, including the fisher.

Fishers intentionally trapping crayfish (trappers) and others catching it as bycatch (non-trappers) are statistically significantly different form each other in location of their residences, fish selling practices, and their perceptions of crayfish and its utilization (for sale or as a food or feed). Trappers primarily catch crayfish for sale and know at least one other fisher selling crayfish in their local area. More fishers sold crayfish to restaurants, were familiar with crayfish earlier, had a positive perception of crayfish, and had larger average crayfish catch sizes in comparison to non-trappers. While the share of trappers who had no formal education was higher than non-trappers, there was no significant differences in terms of actual highest level of education attained. Similarly, there were no differences between trappers and non-trappers in terms of age, household size, period of residence in a location at the time of the study and their distances to key market facilities.

Table 3. Fisher household and demographic characteristics

Variable	Non-Trappers	Trappers	All fishers	
Total number of fishers surveyed and their crayfish trapping activity	328	13	341	**
At Itezhi-Tezhi	82	2	84	
At Kafue	81	2	83	
At Siavonga	75	9	84	

At Sinazongwe	90	0	90	
Fraction using crayfish for food, sale, or feed	0.40	1.00	0.42	**
Fraction knowing others selling crayfish in area	0.23	1.00	0.26	**
Experience in fishing in years	16.79	14.39	16.70	
Age of the respondent in years	40.99	35.92	40.80	
Fraction with no formal education	0.11	0.39	0.12	**
Highest level of education attained in years	6.44	4.92	6.38	
Number of years in current location	21.50	25.77	21.66	
Total number of household members	6.23	5.46	6.20	
Distance to local market in km	5.00	4.52	4.98	
Distance to main supplier of fishing gear and materials (km)	90.10	98.43	90.41	
Main buyers of fish (fraction)				
Direct consumers	0.44	0.30	0.43	
Wholesalers/retailers	0.94	0.92	0.94	
Restaurants	0.006	0.08	0.01	**
Form of fish sold (fraction)				
Fresh	0.88	1.00	0.89	
Sun-dried	0.30	0.15	0.29	
Salted	0.11	0.15	0.11	
Distance to main fish selling point from fishing point (km)	169.30	261.62	172.82	
Years since first crayfish sighting	10.14	15.77	10.36	**
Average catch size during peak (kgs)	4.24	530.22	24.47	**
Fraction catching crayfish daily	0.88	0.85	0.88	
Fraction having a positive perception of crayfish	0.42	1.00	0.45	**

*, ** *represent statistical significance at $p < 0.05$ and $p < 0.01$ respectively*

Crayfish awareness and perceptions

All the fishers interviewed had heard about or seen crayfish in water bodies in their locations. The earliest reported sighting amongst the fishers interviewed was in 1990; at least 50 percent of the respondents had seen or caught crayfish by 2013 (Figure 1). First reported sightings were in Kafue, followed by Itezhi-Tezhi a year later, in 1991. On Lake Kariba, the earliest reported sighting was in Siavonga in 199 while the first reported sighting in Sinazongwe was in 1995. None of the fishers reported any disappearances of crayfish after first sighting, suggesting that once established, the crayfish persist in an area.

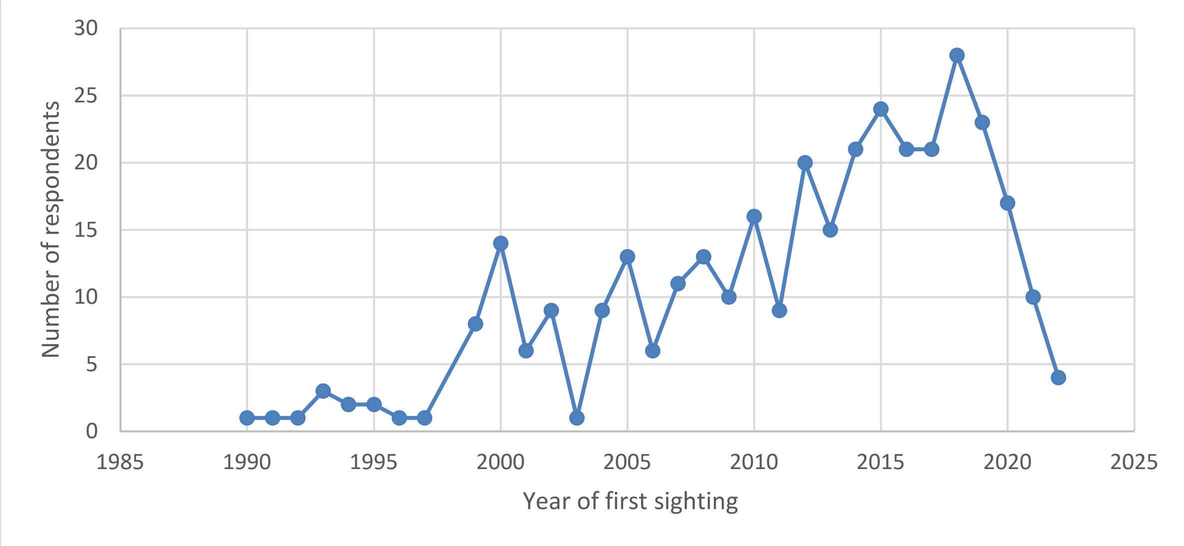

Figure 3. *Number of respondents reporting the year of first sighting of crayfish.*

First impressions of crayfish were typically negative across the districts with 60% perceiving the crayfish as dangerous/harmful or a nuisance/useless (Table 4). However, there were significant variations across the districts with regards to threats to fishing with more fishers in the more remote Itezhi-tezhi and Sinazongwe locations seeing it as a threat compared to the more sub-urban Kafue and Siavonga locations. Over time, more fishers experienced shifts to positive perceptions, especially in Kafue and Siavonga (Table 5). However, percentage of fishers seeing crayfish as a threat to livelihoods varies by district with fishers in Sinazongwe and Itezhi-tezhi having higher shares of fishers who consider it a threat (Table 6).

Table 4. Crayfish perceptions at first sighting (percent of responses per district)

Perception	Itezhi-tezhi	Kafue	Siavonga	Sinazongwe	Total	
Nuisance/useless	24.8	23.53	24.78	31.01	26.11	
Useful as food	3.76	2.52	4.42	0	2.63	
Useful as a source of income	0	0.84	0	1.55	0.61	
Threat to fishing livelihood	21.8	5.88	7.08	15.5	12.96	**
Not food	21.05	24.37	23.01	23.26	22.87	
Dangerous / harmful	27.07	42.86	38.94	27.91	33.81	
Other	1.5	0	1.77	0.78	1.01	

**, ** represents statistical significance at $p < 0.05$ and $p < 0.01$ respectively*

Table 5. Change experienced in crayfish perceptions from first sighting (percent of responses per district)

	Itezhi-tezhi	*Kafue*	*Siavonga*	*Sinazongwe*	*Pooled Total*	
Perception improved	29.76	56.63	54.12	21.11	40.06	**
Perception deteriorated	2.38	3.61	1.18	0	1.75	

*, ** *represents statistical significance at p < 0.05 and p < 0.01 respectively*

Table 6. Current perceptions of crayfish (percentage of responses per district)

Perception	*Itezhi-Tezhi*	*Kafue*	*Siavonga*	*Sinazongwe*	*Pooled Total*	
Nuisance/useless	24.82	16.3	16.8	16.94	18.86	
Useful as food	20.57	29.63	35.2	14.52	24.95	**
Useful as a source of income	7.09	11.85	19.2	7.26	11.24	*
Threat to fishing livelihood	34.04	29.63	14.4	34.68	28.38	**
Not food	11.35	12.59	8.8	23.39	13.9	
Dangerous / harmful	1.42	0	4.8	0.81	1.71	
Other	0.71	0	0.8	2.42	0.95	

*, ** *represents statistical significance at p < 0.05 and p < 0.01 respectively*

Crayfish fishing and utilization

Table 7 summarizes the main attributes of crayfish fishing among the study participants. Most of the crayfish (99 percent) is caught unintentionally as by-catch in gill nets. Average crayfish catches are higher for intentional trapping in both peak and low seasons. The proportion of fishers intentionally trapping crayfish varied significantly by district with the highest in Siavonga at 11 percent of the sample while Itezhi-tezhi and Kafue had two percent only; there were no crayfish trappers in Sinazongwe.

Table 7. Crayfish fishing attributes

	Itezhi-tezhi	*Kafue*	*Siavonga*	*Sinazongwe*	*Pooled Total*	
Fraction catching intentionally	0.02	0.02	0.11	0.00	0.04	**
Fraction eating crayfish	0.26	0.40	0.32	0.08	0.26	**
Average catch sizes in kgs						
Peak season	4.09	1.95	84.86	8.98	24.47	
Low season	1.46	0.67	35.91	2.79	9.98	
Main catch (peak season)	16.69	4.07	1,295.54	0	900.11	

Main catch (low season)	8.34	0.28	417.26	0	290.20
By-catch (peak season)	3.94	1.90	26.46	8.98	10.27
By-catch (low season)	1.38	0.66	25.65	2.79	7.49
Average price ZMW per piece	5.33	3.21	0.77	0	2.87
Average price ZMW per kg	144.00	86.68	20.83	10.00	77.39

**, * represents statistical significance at 1% and 5% respectively

Utilization of crayfish (Table 8) was generally low across the sample with 40 percent using crayfish as food, for sale and feed for livestock. There were significant variations across districts in overall utilization and across use categories. Kafue had the highest percentage consuming and selling crayfish while Sinazongwe had the least (Table 9).

Table 8. Utilization of crayfish by district (percentage of respondents)

	Itezhi-tezhi	*Kafue*	*Siavonga*	*Sinazongwe*	*Pooled Total*	
Sell	6.09	17.32	8.26	0.89	8.42	**
Consume at home	19.13	25.2	20.66	4.46	17.68	**
Give away to others	12.17	18.11	9.92	13.39	13.47	
Dispose (throw away)	62.61	39.37	61.16	75	58.95	**
feed pigs	0	0	0	6.25	1.47	**

**, ** represents statistical significance at p < 0.05 and p < 0.01 respectively*

Table 9. Crayfish utilization (as food, feed, or for sale) v. non-utilization by district

	Itezhi-tezhi	*Kafue*	*Siavonga*	*Sinazongwe*	*Pooled Total*
No	61.9	34.94**	62.35	72.22	58.19
Yes	38.1	65.06**	37.65	27.78	41.81
Pearson chi (3)	26.8072	Pr = 0.000			

Logistic regression results on determinants of crayfish utilization among the fishers show that only four factors explained crayfish utilization in the sample: knowledge of other crayfish sellers in the area, positive perceptions of crayfish, who the fishers usually sell fish to and year of first sighting

(Tables A.1 and A.2 in the appendix). None of the demographic characteristics considered, location, nor distances to markets and fishing suppliers had statistically significant effects on probability of utilization[1].

Table 10 shows the marginal effects of each of the statistically significant variables to highlight the contribution of each attribute to the observed variation in utilization in the study sample, after controlling for the effect of the others in the model. For this study, the individual marginal effects are small but are still statistically significantly different from zero. This could indicate a lesser importance of fisher characteristics in potential utilization relative to other factors, such as demand side attributes like presence of a ready buyer or proximity to consumption centers, not included in the study.

Table 10. Marginal effects of significant variables on utilization.

Variable	*Marginal effects*	*Standard errors*	
Any selling	0.91	0.36	*
Selling to wholesalers	3.14	1.18	**
Year of first sighting	-0.06	0.02	*
Positive perspective about crayfish	2.52	0.34	**
Constant	112.80	48.02	*
Observations	338		

**, ** represents statistical significance at $p < 0.05$ and $p < 0.01$ respectively*

Fishers who sell fish to wholesalers or other middlemen are 3.14 percent more likely to use crayfish than those selling directly to consumers. A possible explanation for the importance of wholesaling could be that most crayfish consumers are located in Lusaka and tourist areas that are not typically accessible to the average fisher unless through agents. Similarly, knowing other people selling crayfish in the area increases probability of utilization by 0.91 percent probably through potential access to markets through others already in the business and potential for aggregating

[1] While Table 9 shows significant variation in crayfish utilization by district, being located in a particular district was not important in explaining the probability of using crayfish once other ways the fishers are different are controlled for. Only being located in Kafue had some positive effect but not at conventionally acceptable significance levels with it's p-value of 0.095

product before sending off to the consumer markets. Having a positive perception on crayfish and longer experience with crayfish both expectedly amplify the possibility of utilization by 2.52 percent and 0.06 percent respectively.

Crayfish experiences

General experiences with crayfish in terms of interaction with other creators in the water bodies and fishing activities was consistent across the sampled fishers in the districts. Only about 27 percent reported observing crayfish being eaten or attacked by other animals; most of the predation was by other larger fish like tiger fish and birds.

Most of the fishers experienced damage to fish catches (death due to crayfish eating or damaging the flesh) especially in Itezhi-tezhi and Sinazongwe (Table 11). Of the respondents, 96% reported damage to fish whereas 57% reported damage to fishing gear (not statistically analyzed). Damage to fish appeared to be consistently reported in high numbers in all districts, whereas damage to fishing gears appeared to have more variability from one district to another (not statistically analyzed). Almost half of the fishers wanted the crayfish to be removed and most of them were willing to participate in the removal or pay (money or in-kind) for removal (Table A.3 in appendix).

Table 11. Percent reporting damage to fish and fishing gear

	Damage to fishing gear	*Damage to fish*
Itezhi-Tezhi	67%	100%
Kafue	55%	92%
Siavonga	37%	93%
Sinazongwe	70%	99%
Sample	57%	96%

Focus Group Discussions

In Itezhi-Tezhi, the team held discussions with two groups near the harbor of Lake Itezhi-Tezhi. The first group was composed of a youthful all-male crayfish trapping group. These were not locals of the district but had migrated from Kafue Gorge in search for abundant and larger sized crayfish. A few were married with their families still living in Kafue. This group of trappers all lived together in one place. Their arrival in Itezhi-Tezhi was facilitated by a Kafue native who had lived in Itezhi-Tezhi for a while, and who also marketed their crayfish. They had an already established market.

The discussants described crayfish population in Itezhi-Tezhi as “plentiful” and pointed out that there was likely more crayfish in the Kafue National Park area than in the adjoining game management area since only fishers who had paid for a specific licence for the national park could fish there. The trappers thought that those fishing in the national park only focused on fishing which would result in higher crayfish populations. The trappers also said that there were no government interventions, such as management policies, which were specific to crayfish. Crayfish trappers were also affected by the annual fishing ban since although it does not formally cover crayfish, anyone on the waters can be stopped. The discussants appealed for promoting removal of crayfish from the water bodies by having everywhere a “no license” policy for those purely trapping crayfish.

The second FGD in Itezhi-Tezhi was with local fishers and their helpers. These were mostly not involved in trapping crayfish as they had no skills to trap and market the crayfish. They complained about reduced space for fishing because fishers had started to avoid some areas with high crayfish population. Some of the kapenta fishers who used nets were moving their nets in deeper waters, to avoid crayfish which were found in abundance in shallow waters.

Figure 4. *Crayfish trappers in Itezhi-Tezhi in the process of constructing traps from plastic buckets during FGD.*

As with Itezhi-Tezhi local fishers, Sinazongwe (Nzenga fishing village) and Kafue (Chanyanya) discussants were not crayfish trappers and instead, they complained of severe negative socioeconomic impacts from the crayfish invasion. They disliked the crayfish and were not interested in learning how to prepare or consume it. They did, however, say that they needed to utilize crayfish in order to reduce its population, which could eventually reduce the negative impacts. They reported that they had interest in learning how to process crayfish for market or for feed, and requested assistance in ways to effectively trap, store, transport and market crayfish. The groups also pointed out that fish partially bitten by crayfish lost taste and color and therefore caused more losses to fishers because the fish was discarded and not eaten.

The discussants in Siavonga (Kamimbi Village) reported that crayfish had been present for some time in Siavonga but that only trappers in one village, Kabyobyo, were earning a living out of trapping crayfish but were not sharing their trapping skills with the fishers of Kamimbi village despite their interest. These fishers also requested training in trapping, processing and marketing the crayfish.

Outputs and Conclusions

Outputs

Population dynamics

Makwelele (2017) using an ELEFAN protocol used Total Length (TL) measured from rostrum tip to telson tip, and found VBGF parameters ranging from L_∞ = 172.6 to 187.4 mm (TL) asymptotic length, and k = 1.805 to 2.298 y^{-1} curvature parameter. However in this study, the t_o time-zero parameter was not reported in crayfish collected from two sites in the Kafue River Floodplain region. Our data from the same waterway show VBGF values, L_∞ = 215.25 mm (TL), and k values ranging from= 0.51 to 0.88 y^{-1} with t_o values ranging from -0.18 to -0.1 y. (Table 1). These growth parameters are similar to those reported by Marufu et al. (2018), L_∞ = 112.88 mm (CL), k = 0.72 y^{-1} and t_o = -0.09 y, from crayfish collected from 13 locations on the Zimbabwe shoreline of Lake Kariba across the Kariba dam wall, and all within 20 km of the Lake Kariba our crayfish trapping site in Siavonga as part of this study. By converting their estimate of L_∞ based upon CL to TL by using the 1.98 conversion factor, their L_∞ estimate becomes 223.5 mm (TL) and comparable to our average L_∞ estimate of 215.25 mm. Furthermore, their estimate of average life expectancy (t_{max}) of 4.17 y is consistent with our findings of 4.5 y

Online poll

The spread of Australian redclaw crayfish, *Cherax quadricarinatus,* continues unabated since its introduction into Zambian waters, now being found well beyond their initial areas of first introduction. The most recent comprehensive review of their presence in Zambian waters (Douthwaite et al., 2018) reports their presence at areas corresponding to their initial introductions, including the Kafue River (2001), Siavonga, Lake Kariba (2002), Lake Itezhi-tezhi (2008), Kafue Flats (2009), Nsobe Reservoir, Ndola (2012), Lealui, Mongu (2012), Mushingashi Conservancy (2013), and downstream in the Kafue River and the Lower Zambezi downstream from the Kariba Dam (2014-2017). We show (Table 2) that in the intervening years the crayfish have continued to spread to other sites in Zambia, including Shangombo on the Kwando River in the west, and Chingola in the north-central part of the country. The provinces in the northeastern region are relatively free of established *C. quadricarinatus* populations.

One concern about the potential for spread of *C. quadricarinatus* into the North and Northeastern provinces is the threat to Lake Tanganyika, a water body that is known to be a site of extraordinary benthic biodiversity (e.g. Yuma et al., 2006). *C. quadricarinatus* are known to burrow and engage in sediment disturbance. Niche competition from crayfish could affect populations of the endemic Lake Tanganyika freshwater crab, *Potamonautes platynotus* (Marijnissen et al., 2006), or alternatively, several other species of Lake Tanganyika crabs on the genus *Platythelphusa* of the family Potamonautidae. From our data, it is doubtful that *C. quadricarinatus* have already established a presence in Lake Tanganyika. However, given the level of aquatic biodiversity of crustaceans in the lake and the sensitivity of its benthic environment, it is recommended that the lake continues to be surveyed for the appearance of crayfish, and a high priority be placed on conducting educational programs for stakeholders about the ecological risks. Likewise in Muchinga Province, a single survey informant reported that they did not know whether there were crayfish found in the province or not, so that region is also recommended for further monitoring for the appearance of crayfish.

The observation of predation upon crayfish by predatory catfish and kingfishers suggests that local species are beginning to adapt to the locally abundant populations of *C. quadricarinatus*. There are several reports from elsewhere that kingfishers are known to be predators of crayfish (e.g. Antonio-Garcia et al., 2022). To date, reports of predation upon *C. quadricarinatus* in Zambia do remain scarce, but there is evidence that some local predatory species, both avian and aquatic, are expanding their prey selection to include crayfish.

Fisher survey

Community awareness of the existence of Australian redclaw crayfish, *Cherax quadricarinatus,* was high among the fishing communities in the Kafue floodplains and Lake Kariba areas while utilization was low. Most crayfish was caught unintentionally in gillnets used for catching fish like Tilapia; there was some willful crayfish trapping for sell among fishers with access to urban and tourist consumer market and very little at-home utilization. We found that fishers' perceptions generally became more positive from initial fears of the species as they realize the potential for economic benefit from niche markets for crayfish outside their communities. This relationship between economic benefit and positive perceptions is consistent with findings of studies on other invasive species of economic value such as Marshall et al. (2011) on buffel grass who also found that pastoralists who derive economic benefit from the grass and were dependent on it mostly held positive views of the invasive grass. Previous studies of *C. quadricarinatus* and other species found that once established, these species could lead to development of commercial (Wang, 2018) and artisanal fisheries supplementing household income and nutrition such as full-time fishers with limited income generating alternatives (Pienkowski et al. 2015; Andriantsoa et al. 2020) At the same time, communities became more aware of the harm crayfish could cause to their livelihoods as the species population grew and they experienced damage to fishing gear and fish. However, limited at-home uses entails beneficial exploitation is limited to communities with access to markets in urban centers and tourist areas leaving more vulnerable rural communities like Sinanzongwe experiencing losses in their livelihoods without compensation. The economic value of *C. quadricarinatus* presents both opportunities for improving outcomes as well as potential for willful spread to new areas.

Focus Group Discussions

The dynamics in the four locations were quite different; mostly related to time of introduction of the crayfish. Although in all locations, both the positive and negative impacts were reported, the discussants focused more on negative impacts in areas with later introduction of crayfish and fewer trappers (Sinazongwe and Chanyanya). Clearly, learning a new skill, crayfish trapping, takes time and in Itezhi-tezhi, it was outsiders with skills in trapping, who had to come in. Finally, crayfish was reported to be more in shallow waters which may impact women's fishing efforts more. Given the more limited quantities of fish caught by women, the negative impact of crayfish on the quantity of fish caught may not be large, but given women's importance in family food security, the impact on food security may be significant. The women, young and old, expressed interest in gaining skills to process crayfish into useful products.

Final workshop

During the final workshop of the project, the workshop participants divided into two working groups, each of which deliberated on what future research and policy efforts should be conducted. These topics are presented below. Given how numerous the ecological research topics were, they are organized in the order of importance, as seen by the research team.

Ecological research

1. Habitat preference and characterization: Characterizing factors contributing to the level of establishment and adaptation of crayfish in different water bodies
2. Impact of trapping on the abundance of crayfish and *on fish breeding*: a comparative study on adjoining areas
3. Impacts of pollutants on crayfish population *and food quality* in the Kafue River
4. Environmental impacts and efficacy assessment of trapping gear and practices
5. Continued study on population dynamics, including attention to direct age determination of crayfish (e.g. Leland et al., 2015)
6. Effects of crayfish on the food chain of native species
7. Continued study on seasonal variation *in reproduction*
8. Inventory of lower taxa affected by crayfish
9. Disease profiling of crayfish including crayfish as a disease vector and susceptibility to native parasites
10. Genetic characterization of the different strains

11. Use of e-DNA to determine presence of crayfish
12. Aquarium studies on interactions between crayfish and other crustaceans

Socioeconomic research

- Crayfish value chain analysis to assess economic and social benefits and costs at household and higher levels
- Assessment of the economic viability of overfishing as a management strategy.
- Better describe crayfish trapper demographics and impacts of crayfish on families.

Policy recommendations

- Support assessment of how an aquatic invasive species like crayfish should be managed in the context of the Fisheries Act and what impediments to effective crayfish management and containment may be caused by the Act and other current policies.
- Conduct a sensitization effort on the impacts of crayfish on other fish and fishing livelihoods
- Develop a transnational platform on policy engagement for regional crayfish management
- Conduct an environmental assessment to inform policies to manage the crayfish.
- Through the Ministry of Foreign Affairs, work with neighboring countries to foster trans-border awareness and cooperation in managing crayfish (e.g. Linell et al. 2019).

Conclusions

The data are showing that the exploitation rates of the crayfish are relatively low in comparison to rates needed to control the populations. There are areas of fairly high fishery exploitation in comparison to other areas, but none are exploited at a rate that is able to cause recruitment overfishing. This points to an inevitable conclusion that when crayfish do get established, they may be nearly impossible to get rid of, so prevention of their spread into new naive areas like the Okavango and Great Rift Lakes becomes critical. As noted previously, Nunes et al. (2016) have expressed grave concern about the critical threat that spread of crayfish into the Okavango Delta that has been designated as a United Nations World Heritage Site. Further, Gomo et al. (2018) have suggested that water and land management strategies can be complicated by watersheds and wetland systems that cross several transnational boundaries in the region and that remote sensing may be a valuable tool for policy makers and resource managers.

The responses to our Qualtrics-XM survey questions about crayfish presence or absence suggest that crayfish have been found in the Kwando River sub watershed that raises the threat to waterways in Zambia that flow into the proximity to the Okavango Delta (Figure 5). During wet seasons, a connection may form between the Okavango Delta and the Zambezi River by way of the usually dry Selinda River (Spillway). The Selinda Spillway connects directly to the Linyanti River and the Chobe River that are extensions of the Kwando River, and it eventually flows into the Zambezi River, which in turn feeds Lake Kariba that does harbor a robust population of *C. quadricarinatus*. Complicating any potential management of crayfish in the Okavango Delta region is that the nearby interconnected watersheds are under the political jurisdiction of five different nation states: Angola, Botswana, Namibia, Zambia and Zimbabwe suggesting that cooperation by way of multilateral diplomacy (e.g. Imbwae et al., 2023) and a regional treaty may be the best means to prevent the spread of crayfish into the region, and manage the invasion if the crayfish do become established.

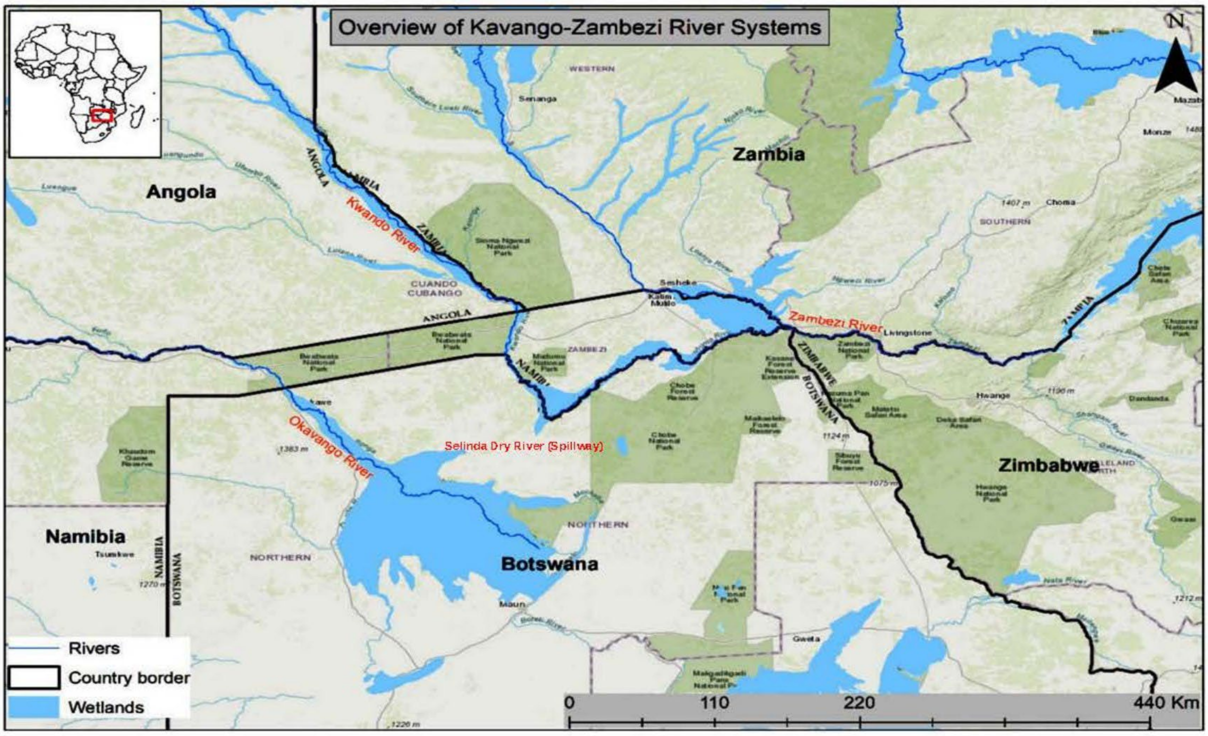

Figure 5. *Map showing national boundaries and the interconnected nature of the three major river systems of the South Central African Region, and the Selinda Dry River Spillway potentially connecting the Zambezi River Basin and the Okavango Delta wetland system. Map is based on a figure in Linell et al. (2019).*

The socio-economic studies (Fisher survey and FGDs) provided useful information on the impact of the *C. quadricarinatus* invasion on livelihoods of communities that dependent on artisanal fisheries in the affected waterbodies. Management strategies for the invasive crayfish species in Zambia will need to take into account the dichotomous economic dimensions of household income generation, costs of damage to fisheries livelihoods and potential spread to other waterbodies for economic exploitation. While current utilization is low, the existence of a market for crayfish and willingness of fishers to participate in mitigating the effects of the invasion presents opportunities for successful implementation of strategies such as recruitment overfishing as suggested in Rice (2021). Gretchi et al. (2011) suggest a theoretical framework for incorporating the negative and positive effects of invasives in cost-benefit analysis and devising wholistic management strategies.

Technologies/Innovations developed, and what phase was achieved

Two key technologies were developed:

- The adaptation of the technology of fisheries stock assessment by length-frequency to the analysis of invasive crayfish populations in Zambia. This technology was field tested.
- The development of an online Qualtrics poll to monitor the spread of the crayfish. The research phase could be considered as a field testing of this innovation which is now available for use by Zambian partners.

Key Beneficiaries

Key beneficiaries of this work include Fisheries Scientists in the Zambia Department of Fisheries and the Department of Environment and Conservation. Additionally the long-term traineeship of M.S. student Ms. Chibwe Katapa of UNZA, has developed some deep expertise in ELEFAN methods that can be applied to a variety of aquatic stock analyses throughout the country.

How the scientific results were disseminated

The scientific results were or are being disseminated first, in the closing workshop held on 16 August 2023 as well as a report to the USAID Mission in Zambia held on 17 August 2023. In addition, Prof. Eva Nambeye-Kaonga presented a paper on invasive crayfish in Zambia at the Symposium on the Detection, Control, and Eradication of Invasive Crayfishes at the 153rd Meeting of the American Fisheries Society, held August 20 to 24 in Ann Arbor, Michigan. Additionally, three peer-reviewed publications are expected to be produced and are in various stages of production:

a) Rice, M.A. 2021. Intensive Fishing Effort and Market Controls as Management Tools for Invasive Aquatic Species: A Review. Asian Fisheries Science 34(4):383–392.

b) Nambeye, E., C. Katapa, B. Chimai-Mulenga, H.G. Mudenda, M. Eilitta, and M.A. Rice. The Population Dynamics and Spread of the Invasive Redclaw Crayfish, *Cherax quadricarinatus*, in Zambian Waters. Western Indian Ocean Journal of Marine Science (in submission)

c) Chimai-Mulenga, B., E. Nambeye, M. Eilitta and M.A. Rice. The Fishery and Post-harvest Utilization of the Invasive Crayfish, *Cherax quadricarinatus* in Zambia. (in preparation).

In September 2023 the research team also plans to present the results to the Director of the Zambian Fisheries Department who was unable to attend the final workshop.

References

Andriantsoa, R., Jones, J.P., Achimescu, V., Randrianarison, H., Raselimanana, M., Andriatsitohaina, M., Rasamy, J. and Lyko, F., 2020. Perceived socio-economic impacts of the marbled crayfish invasion in Madagascar. *PLoS One*, *15*(4), DOI: 10.1371/journal.pone.0231773

Antonio-Garcia, J., M. Ángeles-Hernández, L. Nunes, L.F. Sánchez-Sastre, P. Casanueva, and F. Campos. 2022. Predation by the common kingfisher *Alcedo atthis* of non-native fish species during the winter. Bird Study 69(3-4): 97-102. DOI: 10.1080/00063657.2022.2162478

Douthwaite, R.J., E.W. Jones, A.B. Tyser, and S.M. Vrdoljak. 2018. The introduction, spread, and ecology of redclaw crayfish *Cherax quadricarinatus* in the Zambezi catchment. African Journal of Aquatic Science 43(4):353-366. DOI: 10.2989/16085914.2018.1517080

Grechi, I., Chadès, I., Buckley, Y.M., Friedel, M.H., Grice, A.C., Possingham, H.P., Van Klinken, R.D. and Martin, T.G., 2014. A decision framework for management of conflicting production and biodiversity goals for a commercially valuable invasive species. *Agricultural Systems*, *125*, pp.1-11. DOI: 10.1016/j.agsy.2013.11.005

Gomo, F. F., Macleod, C., Rowan, J., Yeluripati, J., and Topp, K. 2018. Supporting better decisions across the nexus of water, energy and food through earth observation data: case of the Zambezi basin. Proceedings of the International Association of Hydrological Sciences 376:15–23. DOI: 10.5194/piahs-376-15-2018.

Imbwae I., S. Aswani, W. Sauer, and C. Hay. 2023. Transboundary fisheries management in Kavango–Zambezi Transfrontier Conservation Area (KAZA-TFCA): Prospects and dilemmas. Sustainability 15(5):4406. DOI: 10.3390/su15054406

Leland, J.C., D.J. Bucher, and J. Coughran. 2015. Direct age determination of a subtropical freshwater crayfish (Redclaw, *Cherax quadricarinatus*) using ossicular growth marks. PLoS ONE 10(8): e0134966. DOI: 10.1371/journal.pone.0134966

Linell, A., M. Sjöstedt, and A. Sundström. 2019. Governing transboundary commons in Africa: The emergence and challenges of the Kavango–Zambezi Treaty. International Environmental Agreements 19:53–68. DOI: 10.1007/s10784-018-9420-2

Lodge, D.M., A. Deines, F. Gherardi, D.C.J. Yeo, T. Arcella, A.K. Baldridge, M.A. Barnes, W.L. Chadderton, J.L. Feder, C.A. Gantz. 2012. Global introductions of crayfishes: evaluating the impact of species invasions on ecosystem services. Annual Reviews of Ecological and Evolutionary Systems. 43(1):449-472. DOI:10.1146/annurev-ecolsys-111511-103919

Madzivanzira, T.C. 2021. Evaluating and predicting impacts of Australian redclaw crayfish *Cherax quadricarinatus* and Louisiana red swamp crayfish *Procambarus clarkii* invasions. Ph.D. Dissertation, Rhodes University, Makhanda, Eastern Cape Province, South Africa. 291pp.

Madzivanzira, T.C., J. South, L.E. Wood, A.L. Nunes, and O.L.F. Weyl. 2021. A review of freshwater crayfish introductions in Africa. Reviews in Fisheries Science and Aquaculture, 29(2):218-241. DOI: 10.1080/23308249.2020.1802405

Makwelele, G. 2017. Reproductive biology, growth and mortality of the introduced red claw crayfish, *Cherax quadricarinatus* in Kafue floodplain fishery. MS Thesis, University of Zambia, Lusaka. 81pp.

Marshall, N.A., Friedel, M., van Klinken, R.D. and Grice, A.C., 2011. Considering the social dimension of invasive species: the case of buffel grass. *Environmental science & policy*, *14*(3), pp.327-338. DOI: 10.1016/j.envsci.2010.10.005

Marijnissen, S.A.E., E. Michel, S.R. Daniels, D. Erpenbeck, S.B.J. Menken, and F.R. Schram. 2006. Molecular evidence for recent divergence of Lake Tanganyika endemic crabs (Decapoda: Platythelphusidae). Molecular Phylogenetics and Evolution. 40(2):628–634. DOI: 10.1016/j.ympev.2006.03.025

Marufu LT, C. Phiri, and T. Nhiwatiwa. 2014. Invasive Australian crayfish *Cherax quadricarinatus* in the Sanyati basin of Lake Kariba: a preliminary survey. African Journal of Aquatic Science 39(2):233-236. DOI:10.2989/16085914.2014.922457

Marufu, L.T., M. Barson, P. Chifamba, M. Tiki and T. Nhiwatiwa. 2018. The population dynamics of a recently introduced crayfish, *Cherax quadricarinatus* (von Martens, 1868), in the Sanyati Basin of Lake Kariba, Zimbabwe, African Zoology 53(1):17-22, DOI: 10.1080/15627020.2018.1448719

Marufu, L.T., M. Barson, C. Phiri, and T. Nhiwatiwa. 2020. Spatial and temporal distribution of an invasive crayfish (*Cherax quadricarinatus*) in Lake Kariba, Zimbabwe. Lakes and Reservoirs 25(4):394-402. DOI: 10.1111/lre.12345.

Mildenberger, T.K., M.H. Taylor, and M. Wolff. 2017. TropFishR: an R package for fisheries analysis with length-frequency data. Methods In Ecology and Evolution 8(11):1520-1527. DOI: 10.1111/2041-210X.12791

Nunes, A.L., R.J. Douthwaite, B. Tyser, G.J. Measey, and O.L.F. Weyl. 2016. Invasive crayfish threaten Okavango Delta. Frontiers in Ecology and the Environment 4(5):237–238. DOI: 10.1002/fee.1287

Pienkowski, T., Williams, S., McLaren, K., Wilson, B. and Hockley, N., 2015. Alien invasions and livelihoods: Economic benefits of invasive Australian Red Claw crayfish in Jamaica. *Ecological Economics*, *112*, pp.68-77. DOI: 10.1016/j.ecolecon.2015.02.012

Rice, M.A. 2021. Intensive fishing effort and market controls as management tools for invasive aquatic species: A review. Asian Fisheries Science 34(4):383-392. DOI: 10.33997/j.afs.2021.34.4.011

Taylor, M.H. and T.K. Mildenberger. 2017. Extending electronic length frequency analysis in R. Fisheries Management and Ecology 24(4):330-338. DOI: 10.1111/fme.12232

Wang, Q., Ding, H., Tao, Z. and Ma, D., 2018. Crayfish (Procambarus clarkii) cultivation in China: a decade of unprecedented development. *Aquaculture in China: success stories and modern trends*, pp.363-377. DOI: 10.1002/9781119120759.ch4_1

Weyl1, O.L.F., A.L. Nunes, B.R. Ellender, P.S.R. Weyl, A.C. Chilala, F.J. Jacobs, M. Murray-Hudson, and R.J. Douthwaite. 2017. Why suggesting Australian redclaw crayfish *Cherax quadricarinatus* as biological control agents for snails is a bad idea. African Journal of Aquatic Science 42(4):325–327. DOI: 10.2989/16085914.2017.1414685

Yuma, M., O.A. Timoshkin, N.G. Melnik, I.V. Khanaev, and A. Ambali. 2006. Biodiversity and food chains on the littoral bottoms of Lakes Baikal, Biwa, Malawi and Tanganyika: working hypotheses. Hydrobiologia 568 (Suppl 1): 95–99. DOI: 10.1007/s10750-006-0327-5

Appendix

Table A.1 Logistic regression results: Determinants of crayfish utilization

Variables	Coefficient	Standard error	
Kafue	0.99	(0.58)	
Siavonga	-0.96	(0.58)	
Sinazongwe	-0.01	(0.50)	
anyselling, eq 1 if fisher knows someone	0.91	(0.36)	*
experience in fishing	0.00	(0.02)	
age	-0.02	(0.02)	
Education	-0.05	(0.05)	
Number of years in area	0.01	(0.01)	
Household size	0.00	(0.05)	
Distance to local market (km)	0.12	(0.06)	
Distance to fishing gear and materials (km)	0.00	(0.00)	
eq to 1 if selling to whosalers/retailers	3.14	(1.18)	**
dsundried, eq to 1 if sell fish as sundried	0.00	(0.45)	
dsalted, eq to 1 if sell fish salted	0.11	(0.60)	
Distance to main fish market	0.00	(0.00)	
Year of first sighting	-0.06	(0.02)	*
catcht size at peak, in kg	0.02	(0.02)	
dailycatch, eq 1 if catch crayfish daily	0.70	(0.51)	
eq to 1 if have a positive perspective of crayfish	2.52	(0.34)	**
Constant	112.80	(48.02)	*
Observations	338		

Standard errors in parentheses. ** $p<0.01$, *$p<0.05$

Table A.2. Logistic regression marginal effects: Determinants of crayfish utilization

Variable	Marginal effects	Std errors	
Kafue	0.99	0.58	
Siavonga	-0.96	0.58	
Sinazongwe	-0.01	0.50	
Aany selling, eq 1 if know someone	0.91	0.36	*
Experience in fishing	0.00	0.02	
Age	-0.02	0.02	
Education	-0.05	0.05	
Number of years in area	0.01	0.01	
Household size	0.00	0.05	
Distance to local market (km)	0.12	0.06	
Distance to fishing gear and materials (km)	0.00	0.00	
Selling to wholesalers/retailers, eq to 1 if selling	3.14	1.18	**
Sundried, eq to 1 if sell fish as sundried	0.00	0.45	
Salted, eq to 1 if sell fish salted	0.11	0.60	
Distance to main fish market	0.00	0.00	
Year of first sighting	-0.06	0.02	*
Catch size at peak, in kg	0.02	0.02	
Dailycatch, eq 1 if catch crayfish daily	0.70	0.51	
Positive perspective of crayfish, eq to 1 if yes	2.52	0.34	**
Constant	112.80	48.02	*
Observations	338		

Standard errors in parentheses. ** p<0.01, *p<0.05

Table A3. Crayfish action

	Itezhi-Tezhi	*Kafue*	*Siavonga*	*Sinazongwe*	*All fishers*
Want it removed	63.1	43.37	53.57	77.78	59.82
Willing to participate	86.79	94.44	95.56	98.57	94.12
Willing to pay for removal	79.25	83.33	48.89	88.57	76.47