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Original Article

Size at maturity, maturity stages, and sex ratio of *Micropterus salmoides* (Lacepède, 1802) in Zimbabwe's largest inland reservoir, Tugwi Mukosi: a baseline study

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Abstract
Size at maturity, sex ratio and maturity stages are key population parameters that are important in fisheries management of exploited stocks as they influence survival of fish populations. The introduced largemouth bass *Micropterus salmoides* has successfully colonised freshwater bodies in southern Africa. In Tugwi Mukosi Dam, Zimbabwe's largest reservoir, largemouth bass is a fish of importance as it provides tourism, food and income for the local communities. This study investigated population parameters of *M. salmoides* in Tugwi Mukosi Dam. The study revealed that the size at 50% sexual maturity (L_{50}) value for male and female was 204 mm and 261 mm respectively. The logistic equation for female largemouth bass was M(L) = 1 / [1 + exp (–0.256L + 6.402)]. For male largemouth bass the logistic equation was M(L) = 1 / [1 + exp (–0.1375L + 4.129)]. The results showed that reproductive activity peaked in October. The male to female ratio was 1:1.04 which is typical of healthy populations. More research and monitoring of the population parameters of largemouth bass is needed so as to be able to predict long term effects of overexploitation and enable responsible authorities to protect the fish stock from collapsing.

Keywords: Breeding; determination index; gonadal reproductive stage; largemouth bass; sexual maturity

1 | INTRODUCTION

Biological knowledge in exploited fisheries has become evidently important in the last 20 years in view of the collapse of some notable fisheries such as the Pacific salmon and Atlantic cod (Lopes *et al.* 2014). Unbiased fish demographic details such as length frequency distributions, length-weight relationships, sexual maturity size and gonadal maturity stages are crucial for managing fisheries resources (Sarkar and Banerjee 2010; Alam *et al.* 2012; Dalu *et al.* 2013). Size at maturity (L_{50}) defined as the length at which 50% of a population become sexually mature for the first time, is a key population parameter that is important in fisheries management of exploited stocks (Karna and Panda 2011). Age-at-maturity is also equally important as it strongly influences population model estimates of sustainable harvest rates (Hannah *et* *al.* 2008; Dalu *et al.* 2013) and, along with mean body size, is an important predictor of overexploitation risk (Day and Rowe 2002).

For a management regime to ensure that a sufficient number of juveniles reach sexual maturity, usually requires information on the size at first maturity (Moutopolous *et al.* 2013). Sexual maturity has been known to be associated with physiological and behavioural changes (Peixoto *et al.* 2018). Size at sexual maturity is strongly correlated with growth, maximum size and longevity of a particular fish species (Tsikliras 2010). It not only influences how individuals in a population start to reproduce, but also how much they can reproduce because fecundity is often closely associated with body size. Lappalainena *et al.* (2016) highlighted that increased fishing pressure generally tends to affect the size distribution of adult stock recruited to a fishery by reducing the proportion of large (or target size) individuals. This change in the size structure is generally regarded as unhealthy for fish communities while the opposite situation, with a high frequency of large and sexually mature individuals, is often considered to indicate a healthy structure of fish stocks (Hutchings and Reynolds 2004). The selective removal of large individuals can impact life history traits and demography because fish size and age at maturity correlates with various reproductive traits. Large fish can have higher hatching success than smaller and younger fish which is attributed to egg size and quality and/or spawning time (Beldade *et al.* 2012). For example, first-time spawning cod bred for shorter periods, produced fewer egg batches, and spawned smaller eggs with lower fertilisation and hatching rates compared to older cod (Marteinsdottir and Steinarsson 1998). The positive correlation between size at maturity, egg number, and egg size has been demonstrated in various angling target species such as black rockfish, *Sebastes melanops* (Bobko and Berkeley 2004).

Size at maturity and sex ratio are also directly affected by overexploitation. According to Ojuok *et al.* (2007), size at maturity decreases when fish are overexploited over a period of time. Decrease in size at maturity is believed to be offset by an increase in adult mortality hence for fish to ensure survival, they must start reproduction at smaller sizes whilst a higher size at maturity is considered healthy.

Several methods have been used in the past to determine size at sexual maturity and the widely used method is to observe the seasonal development changes in fish gonads. A study on size at sexual maturity of *M. salmoides* in Malilangwe Reservoir by Dalu *et al.* (2013) used visual assessment in gonad staging of male and female largemouth bass so as to determine when sexual maturity is reached and concluded that it was bi method of estimating size at sexual maturity.

The largemouth bass, *Micropterus salmoides* Lacépède 1802, is estimated as one of the five most introduced species in inland waters of several countries (Welcomme 1992). This Centrarchid species is native to North-American freshwater systems (from Canada to Florida and Mexico) and inhabits lentic and lotic habitats showing particular preference for marshy environments and shallow waters of large lakes. It was introduced into Zimbabwe in 1932 (Toots 1972) to compliment trout in rivers and dams for recreational fishing. This species has been shown to be successful in colonizing areas outside its native range (Weyl and Hecht 1999) which has been exacerbated by an aggressive stocking programme by recreational anglers.

In Tugwi Mukosi, largemouth bass is a fish of importance for local communities as they depend on it for both income and food. The fish is also a fish of economic importance in Zimbabwe as it supports the recreational fishing industry which attracts international anglers who bring in foreign currency into the country. The Bass Masters tournament held in Lake Manyame, Zimbabwe is one of the biggest bass fishing tournaments in Southern Africa. There have been no studies on the reproductive biology of *M. salmoides* in Tugwi Mukosi since the dam impoundment hence this present study aimed to assess the size at sexual maturity, sex ratio and maturity stages of this species based on gonad development. This study is also a baseline study for largemouth bass in Tugwi Mukosi for future studies that will follow.

2 | METHODOLOGY

2.1 Study area

The Tokwe Mukosi Dam is situated in the semi-arid area of southern Masvingo region in Chivi District. The Dam is built on the point where two rivers namely, Tokwe and Mukosi converge, giving rise to the use of the name Tokwe Mukosi Dam (Figure 1). The area lies in Zimbabwe's agro-ecological Region IV (Chazireni and Chigonda 2018). Average rainfall of this area is less than 600 mm year^{-1} and average annual temperature is about 20°C. The soils are mainly chromic luvisols with isolated patches of calcaric fluvisols. The geology is composed of paragneiss and other high-grade sediments with structural trends. Tokwe-Mukosi has become Zimbabwe's largest inland water body with a 90-m dam wall, a back throw of over 35 km and capacity to hold more than 1.8 billion cubic metres of water, capable of irrigating more than 25000 hectares. The dam started impounding water in December 2016 and held 210 million cubic metres of water from January 2017 (Maponga 2017).

2.2 Sampling

Fish sampling was carried at the Shindi, Zunga and Chepore fishing grounds. A total of 798 *M. salmoides* were caught using gill and seine nets between January and November 2018. Fish specimens were collected over the 11 month period except for July when no largemouth bass catches were made. For seine netting, two hauls were performed every month at the shallow areas of the sampling site. Gillnets were set every fortnight at the sampling sites. Gillnets of mesh size 1.5 – 7 inches with a length of 45 m and a width of 2.5 m were set late in the afternoon at 1630 hours and collected the next day in the morning at 0630 hours. In the field, the fish were weighed using a digital CAS SWII scale to the nearest gram. The total length (TL) and standard length (SL) were measured using a 1 m fish measuring board.

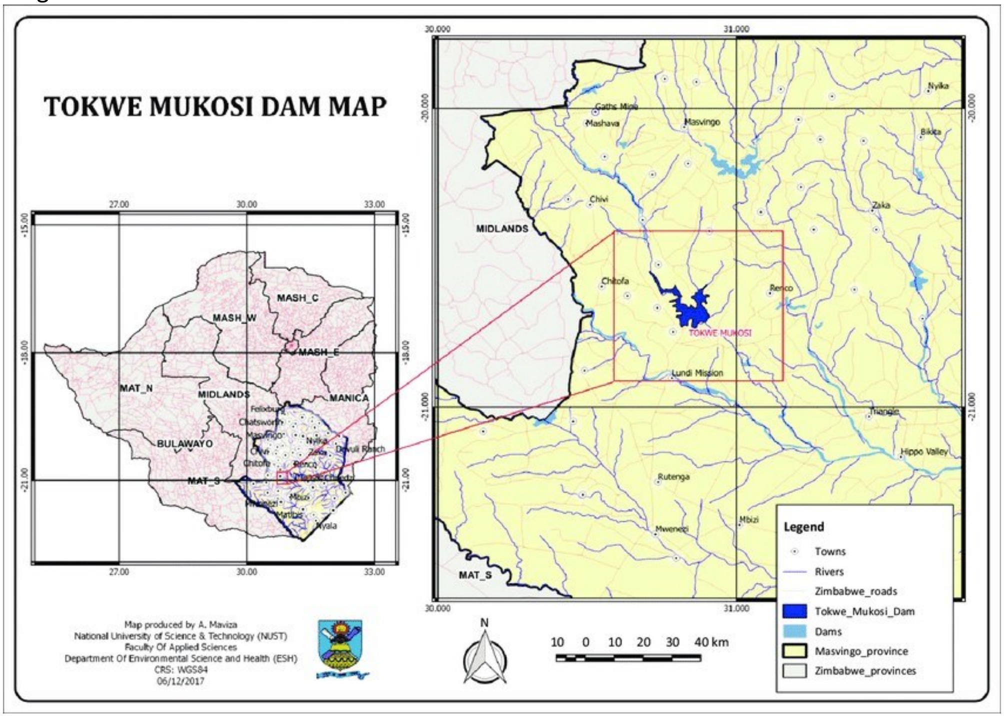

FIGURE 1 The location of Tugwi Mukosi Dam in Masvingo Province, Zimbabwe (source: Chipangura *et al.* 2019).

2.3 Size at maturity and gonad maturation

Gonad maturation was visually assessed using a simplified scale (Bagenal and Braum 1968). Inactive gonads were described as immature, fish and adults in resting stage with sexual gonads not yet developed with gonads very small and eggs indistinguishable to the naked eye whilst active ripe gonads were described as eggs, distinguishable to the naked eye with the testes having a pale white colour. Ripe running gonads were described as eggs clearly distinguishable to the naked eye with testes white in colour and sometimes enlarged. The sexual products could be discharged in response to light pressure on the abdomen of the specimen. Lastly, spent gonads had sexual products which had been discharged and gonads appeared deflated.

2.4 Data analysis

To calculate the length at 50% maturity (L_{50}), the percentage of mature fish, were observed and assigned maturity stages. The percentage of mature fish was also calculated for each body length class at 50 mm intervals.

To test for differences between monthly and total sex ratio, the independent samples *t*-test was used in R (Calenge 2006). The L_{50} was estimated using the following logistic curve equation $M(L)=1 / [1+\exp(-aL+b)]$ where a and b are constants calculated by maximising the likelihood of binomial distribution using Excel add in tool (Karna and Panda 2011). The logistic equation for female largemouth bass was $M(L) = 1 / [1 + \exp(-0.256L + 6.402)]$. For male largemouth bass the logistic equation was $M(L) = 1 / [1 + \exp(-0.1375L + 4.129)]$.

3 | RESULTS

In total, males and females comprised 49% and 51% of largemouth bass caught respectively. There was no significant difference between total proportion of males and females as the total sex ratio of males to females was 1 : 1.04 ($t = 1.341$, $p = 0.277$). The lowest monthly male to female ratio of 1 : 0.52 was recorded in August and the highest of 1 : 1.81 was recorded in April (Table 1). The male to female sex ratio was almost 1 : 1 during the hot-rainy period and at its low during winter months.

The number of fish in each size class is shown in Table 2. The highest number of fish for males was found in the size class 240 – 269 mm whilst there were no male fish recorded in size class 0 – 29 mm, 420 – 449 mm and 450 – 479 mm. Size class 300 – 329 mm had the highest number of female fish. As observed in the male size classes, no fish were caught in the size class 0 – 29 mm. Bigger individuals were observed in females than in males. The biggest fish caught was a female with a total length of 461 mm (Table 2).

TABLE 1 The monthly and total sex ratio for male and female *Micropterus salmoides* sampled between January and November 2019 in Tugwi Mukosi Reservoir. Bold typeface indicates significant differences ($p < 0.05$) in sex ratios.

Month	Male	Female	Total	Ratio	*p*-values
Jan	44	45	89	1 : 1.02	0.448
Feb	42	55	97	1 : 1.31	0.136
Mar	37	26	63	1 : 0.7	0.497
Apr	21	38	59	1 : 1.81	0.581
May	39	27	66	1 : 0.69	**0.029**
Jun	37	24	61	1 : 0.65	**0.001**
Aug	27	14	41	1 : 0.52	**0.002**
Sep	49	62	111	1 : 1.27	0.12
Oct	59	61	120	1 : 1.03	0.44
Nov	36	55	91	1 : 1.53	0.407
Total	391	407	798	1 : 1.04	

TABLE 2 The number of *Micropterus salmoides* individuals in each size class for both males and females.

Size class (mm)	Males	Females
0–29	0	0
30–59	4	2
60–89	22	15
90–119	43	19
120–149	29	27
150–179	31	47
180–209	36	49
210–239	50	39
240–269	56	43
270–299	34	50
300–329	22	52
330–359	50	26
360–389	13	25
390–419	2	9
420–449	0	1
450–479	0	3
Total	391	407

3.1 Gonad maturation stages and size at maturity

Inactive female gonads were observed throughout the whole year in Tugwi Mukosi with a high proportion being recorded in April 2019 (Figure 2). Female gonads in the active ripe stage were also recorded during most months except for July and August 2019. The proportion of female gonads in active ripe stage was observed to be high in the hot periods and hot-rainy periods (September-November). Female gonads in the ripe-running period were recorded in most of the months except for May, June and July. In all months they were recorded in low numbers except for January, September and November were higher numbers were recorded. Fish with in the spent gonad stage were only recorded in four months through the whole year (February, May, October and November).

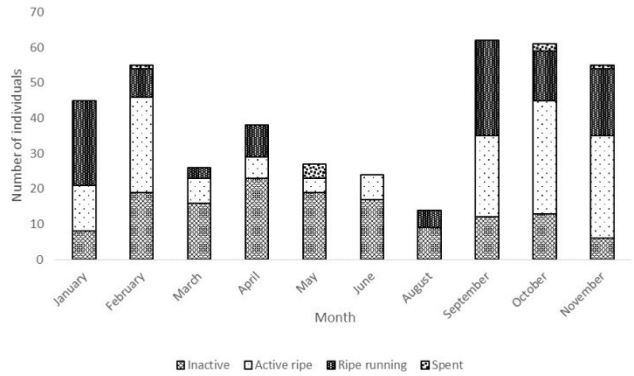

FIGURE 2 Maturity stages of female of *Micropterus salmoides* in the different months.

Male *M. salmoides* with inactive fish were also throughout the year as observed in males (Figure 3). Unlike in female the highest number of male fish with inactive gonads was found in May which corresponds to the dry-winter period. Inactive gonad male fish were low in November (hot-rainy period). Fish with active-ripe gonads were observed in all sampling months but were however low in the months April and June. The number of fish the active-ripe gonads peaked in February 2019 and declined in March before starting to increase again in August. Gonads in the ripe-running stage were few thought the entire study period (Figure 3). They were highest in the months of September, October, November and January as observed in females. Numbers were low during the dry winter period (April – June) but were lowest in February. Male fish with spent gonads were only observed in February, June, September and October.

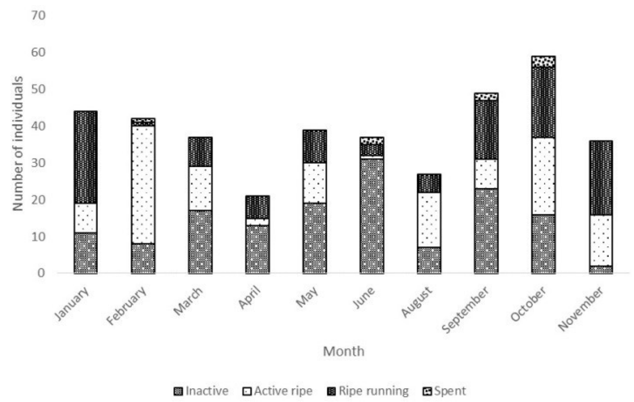

FIGURE 3 Maturity stages of male of *Micropterus salmoides* in the different months.

Using the visual assessment criteria of gonad staging, the L_{50} for males was estimated to range from 180–209 mm (Figure 3). Female *M. salmoides* reached sexual maturity at bigger sizes (>240 mm) than males. There were some male *M. salmoides* which reached sexual maturity at sizes less than the L_{50} (Figure 4). In the 90–119 mm size class, 6% of the sampled population already had spermatozoa in them in small quantities whilst in the 120–149 mm size class 19% mature fish were also observed. After the L_{50} range, 34% of the male fish in the 210–239 mm size class, 21% in the 240–269 mm size class and 5% in the 300–329 mm size class were immature.

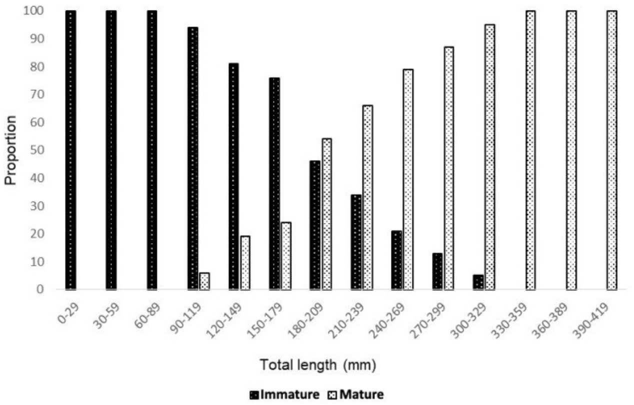

FIGURE 4 Percentage of immature and mature male *Micropterus salmoides* for each length class (*n* = 391).

On the other hand, L_{50} was reached between 240–269 mm in females (Figure 5). In this size class 53% fish were found to have mature gonads whilst 47% still had immature gonads. Mature individuals before the L_{50} size class range were also observed in 210–239 mm size class (26%), 180–209 mm size class (15%) and the 150–179 mm size class (9%). After the L_{50} size class range, 39% immature fish were observed in the 270–299 mm size class and 9% in the 330–359 mm size class.

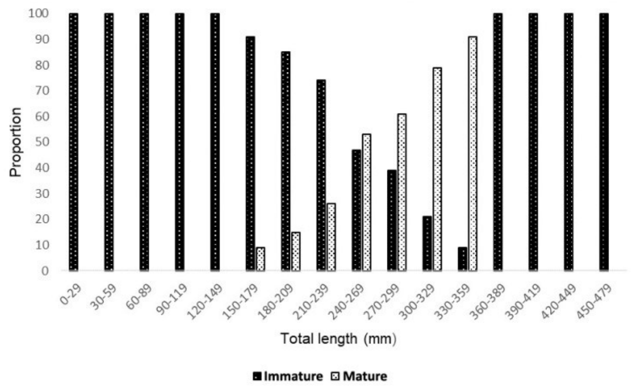

FIGURE 5 Percentage of immature and mature female *Micropterus salmoides* for each length class (*n* = 407).

4 | DISCUSSION

Information on sex ratio is important for understanding the relationship between individuals, the environment and the state of the population. In healthy fish populations, the expected sex ratio is 1 : 1 however different factors normally cause a deviation from this ratio (Lappalainena *et al.* 2016; Galib *et al.* 2020). These factors include temperature, water velocity, vulnerability of females to their predators, migratory phases and other ecological hazards, which probably change the sex composition in water bodies (Beevi and Ramachandran 2005). In this study the overall sex ratio was 1 : 1.04 which is what is expected in healthy fish populations. The analysis also revealed that month-wise and seasonal variation of male-female ratio was not similar throughout the year. It is important to indicate that the reproductive success of females is normally related to access to resources and the environmental conditions, and not to the number of mating partners as in the case of males (Oliveira *et al*. 2012). These factors were not considered in this study hence the need to consider them in future studies on the reproductive biology largemouth bass in Tugwi Mukosi.

The active-ripe and running gonads were evident from September to January and this observation suggests that largemouth bass breed during the hot-wet season. It is therefore important that the fish are protected during breeding months (September to January). Increased fishing pressure, especially during this breeding period can be a big threat to the *M. salmoides* population since not only individuals are removed from the system but also the egg pool which is supposed to ensure recruitment (Gagiano 1997; Dalu *et al.* 2012). It is also important to note that sexually active fish do occur during non-breeding seasons which emphasises on the presence and influx of breeding largemouth bass prior to the hot-wet season. In Lake Manyame, Harare, largemouth bass spawned over a four-month period between July and October with reproductive activity peaking in August (Beamish *et al.* 2004). Their observation is slightly different from what was observed in Tugwi Mukosi because reproductive activity in this study peaked in October.

Most of the fish living in the temperate zones exhibit an annual reproductive cycle. Reproduction or spawning occurs when food is available for the fry. Therefore, reproduction is closely related to environment (Lorenzi *et al.* 2009). Lee (2008) also postulated that falling water temperatures and decreasing photoperiod were main cues in the onset of spermatogenesis and oocyte maturation in *M. novemaculeata*, with flooding acting as the proximal factor. In this study, *M. salmoides* spawned mainly from September to January, with a peak in October. During this period temperatures are usually moderately high. This is different from what was observed by Lee (2008). The differences can be explained by the different localities where the research was done and that perhaps the increasing temperatures could be the ideal growing conditions for phytoplankton and zooplankton which are food for *M. salmoides* fry.

Currently Zimbabwe Parks and Wildlife Management Authority (ZPWMA) is the responsible authority with regards to managing the dam hence it should ensure that law enforcement in terms of monitoring poaching activities during the breeding season of the fish especially in the river mouths where they are believed to breed are intensified. In Kariba where tigerfish are known to travel upstream during their breeding period, the fish poachers lay nets across the rivers where the fish are caught in large numbers (Magqina *et al.* 2020). The large males and females migrating upstream for breeding are mainly caught in the nets. This is also believed to be having an impact on the tigerfish population in Lake Kariba due to the continued mortalities of breeding population (Kemuir 1973). This has to be guarded against in Tugwi Mukosi by ZPWMA so as to protect the fishery stock from poaching since *M. salmoides* has been shown to be also potamodromous (Wallus and Simon 2006).

The results indicated that males mature earlier and at a smaller size than females which explains the greater duration of life of the female that mature later. This observation is consistent with what was observed by other previous authors. Lorenzi *et al.* (2009) observed that females were bigger than males at first maturity. They also observed that females were bigger than males at all ages and that they grew faster than males. In this study the L_{50} for males and females was 204 mm and 261 mm respectively. In Zimbabwe there are no previous studies on the size at maturity of *M. salmoides*. In Mankazana impoundment of South Africa, Taylor and Weyl (2017) observed that the L50 of males and females were 238 mm and 248 mm respectively whilst in Wriggleswade impoundment they observed that the L_{50} for males and females was 236 mm and 254 mm respectively. In Lake Chicamba, Mozambique, Weyl and Hetch (1999) observed that the L_{50} for males and females was 290 mm and 305 mm respectively whilst the size at sexual maturity of Lake Goe-san largemouth bass in Korea was 215 mm and 242 mm for males and females respectively (Zhang *et al.* 2013). Although all these studies where done in different localities with different conditions the L_{50} value of this study falls within range of what has been observed in other water bodies outside Zimbabwe.

The maturation of males at smaller sizes than that of females is consistent with findings of other previous authors (Weyl and Hecht 1999; Orlando *et al.* 1999; Zhang *et al.* 2013) and has been suggested to be likely due to different growth rates between the sexes. According to Walsh *et al.* (2000), the onset of sexual maturity in male and female *M. salmoides* coincides with an overall decrease in growth rates and is likely due to energy being invested in reproduction other than somatic growth. Further studies in Tugwi Mukosi are required to definitively determine the causal mechanisms influencing spawning and recruitment in *M. salmoides* populations, including the effects of environmental factors.

This research demonstrated that *M. salmoides* population in Tugwi Mukosi has managed to successfully occupy the new environment. As expected the maturity lengths and breeding patterns in this current study are different from what has been observed in temperate *M. salmoides* populations. This adaptation of life history traits by *M. salmoides* populations across its non-native range demonstrates this species' life-history plasticity, a product of phylogenetic history. Studies such as this one which assess parameters such size at maturity, sex ratio and maturity stages of *M. salmoides* are important as they provide fisheries managers and biologist with important indicators of the viability status of the concerned fishery. The knowledge on length at maturity and spawning season determines when and at which length the fish should be protected. Proper management and conservation policies should be put in place to conserve the *M. salmoides* population in Tugwi Mukosi Dam.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

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TM designed this research. **TM** and **AM** carried out the field research, analysed the data and prepared the manuscript. Both authors read and approved the final manuscript.

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