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The past and current distribution of native and non-native fish in the Kowie River catchment, Makhanda, Eastern Cape

Dumisani Khosa[1,2,4,5,*], Josie South[3,4,5], Ncumisa Y. Matam[3,8], Lubabalo Mofu[2,3], Ryan J. Wasserman[5,7] and Olaf L.F. Weyl[2,3]

[1] Savanna Node, Scientific Services, Private Bag x 402, Skukuza 1350, South Africa
[2] Department of Ichthyology and Fisheries Science, Rhodes University, P.O. Box 94, Makhanda 6140, South Africa
[3] DSI/NRF Research Chair inland Fisheries and Freshwater Ecology, South African Institute for Aquatic Biodiversity (SAIAB), Private Bag 1015, Makhanda 6140, South Africa
[4] Centre for Invasion Biology, SAIAB, Private Bag 1015, Makhanda 6140, South Africa
[5] South African Institute for Aquatic Biodiversity (SAIAB), Private Bag 1015, Makhanda 6140, South Africa
[6] School of Biology, Faculty of Biological Sciences, University of Leeds, Leeds LS2 9JT, UK
[7] Department of Zoology and Entomology, Rhodes University, Makhanda 6140, South Africa
[8] Department of Environmental Science, Rhodes University, Makhanda 6140, South Africa

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Abstract – Freshwater ecosystems show substantial loss of biodiversity as a result of anthropogenic induced stressors. In this study, we evaluated the distribution of freshwater fishes in the Kowie River catchment using historic fish distribution records supplemented by field survey data. Fishes were collected using a multi-method approach: seine nets, fyke nets and gill nets. Historic fish distribution data showed that 22 freshwater fishes from 11 families historically occurred, while in this study, we recorded a total of 16 freshwater fish species from 9 families. Overall, a decrease in the number of native species was recorded with a total of five species absent and two new non-native species recorded during the current survey. *Coptodon rendalli* constituted a new record in the Kowie River catchment while *Clarias gariepinus* was recorded for the first time in the mainstem of the Kowie River. The presence of these two non-native species in the Kowie River catchment may have implications for the conservation and management of the freshwater diversity in the catchment.

Keywords: Distribution patterns / non-native fishes / Redbreast Tilapia / Sharptooth Catfish / freshwater

1 Introduction

Uncovering biodiversity is an inherent feature of understanding ecosystem functioning (Cardinale *et al.*, 2012) and is one of the most integral goals of ecology (Pereira *et al.*, 2013; Altermatt *et al.*, 2020). Global biodiversity is changing at an alarming rate as a consequence of anthropogenic induced stressors (Rosenzweig, 2001; Tickner *et al.*, 2020), including habitat degradation, environmental pollution, invasion by non-native species and climate change (Sala *et al.*, 2000; Reid *et al.*, 2019). Freshwater ecosystems in particular show a substantial loss of biodiversity and associated ecosystem functions due to the cumulative effects of these multiple stressors (Jackson *et al.*, 2016; Birk *et al.*, 2020). Moreover, the interactions of multiple stressors have been shown to exacerbate biodiversity loss and the degradation of the ecological integrity in freshwater ecosystems (Karr, 1981; Jackson *et al.*, 2016). As a result, understanding the interactions of multiple stressors in freshwater ecosystems form an integral part of predicting ecosystem response in the changing world.

The increasing demand for freshwater resources to sustain human needs has put a strain on the global river systems resulting in their fragmentation and the subsequent decline of biodiversity (Grill *et al.*, 2019; He *et al.*, 2021). Fish metrics such as abundance, assemblage composition, assemblage richness and species spatial distributions have been used to establish a more accurate measure of ecological integrity in freshwater ecosystems (Karr, 1981; Daga *et al.*, 2012). Abiotic factors such as the *in situ* physico-chemical parameters, habitat heterogeneity and biotic interactions including competition and predation affect the spatial distribution of fish species in their environment (Karr, 1981). For example, in the Great Fish River system, Sifundza *et al.* (2021) showed a negative association between the endangered native Eastern Cape Rocky *Sandelia bainsii* and the presence of non-native predatory species Largemouth Bass *Micropterus salmoides*

*Corresponding author: Dumisani.khosa@sanparks.org

and African Sharptooth Catfish *Clarias gariepinus*. Similarly, MacRae and Jackson (2001) demonstrated that in small lakes ($\leq$50 ha) in central Ontario, the presence of the non-native predatory Smallmouth Bass *Micropterus dolomieu* drives small cyprinids to predominantly utilise complex and specific habitats whereas, in lakes without Smallmouth Bass the cyprinids inhabited a more diverse range of habitats. As such, the presence of non-native species in river systems may alter the behaviour of the native biota (Cox and Lima, 2006; Woodford *et al.*, 2017), and current evidence suggests that the impacts of such invasions are more prominent in freshwater ecosystems that are already modified or degraded by humans (Chapman *et al.*, 2020; Rodeles *et al.*, 2020).

The Kowie River catchment is located in the Eastern Cape Province of South Africa, and falls within a temperate climate zone and has a mean annual rainfall of about 650 mm occurring during spring and autumn (Heinecken and Grindley, 1982; Zengeni *et al.*, 2016). The upper reaches of the Kowie River catchment are made up of both public and privately owned dams that supply water for the pineapple, citrus, chicory, fodder crops, beef cattle and goat farms (Heinecken and Grindley, 1982; Dalu *et al.*, 2016b). The intensive levels of agricultural activities in the Kowie River catchment have resulted in increased levels of pollution, leading to the degradation of the instream habitat and water quality of the Kowie River and its tributaries (Dalu *et al.*, 2014, 2016b). The heightened levels of pollution are evident in the Bloukrans River, a major tributary of the Kowie River as it drains the Belmont Valley on the outskirts of Makhanda, an intensive agricultural area (Dalu *et al.*, 2016a, 2018).

This study evaluated the past and current distribution of freshwater fishes in the Kowie River catchment. We use historic fish distribution records obtained from published and grey literature, and collection records from the National Research Foundation-South African Institute for Aquatic Biodiversity (NRF-SAIAB) and Freshwater Biodiversity Information System (FBIS) to provide updated freshwater fish diversity and distributions in the Kowie River catchment. We further assessed fish assemblages in relation to the environmental variables in the Kowie River catchment. We hypothesised that species composition and distribution in the mainstem of the Kowie River will exhibit similarity along a longitudinal gradient due to the level of connectivity, while the presence of dams will generate dissimilar fish assemblages considering the spatial fragmentation of the selected sites. We further hypothesised that native species numbers would be lower than historical ones and that new records of non-native species would be found in the river system, given similar trends in nearby systems.

2 Materials and methods

2.1 Study area

The Kowie River is a perennial river with a total length of approximately 70 km, is located in the Eastern Cape Province of South Africa and drains a catchment area of approximately 800 km^2 (Heinecken and Grindley, 1982). The Kowie River originates from the hills of 'Makhanda Heights', at an altitude of approximately 600 m above sea level, from where it flows in a south-east direction and drains a major part of Bathurst. Its major tributaries are the Bloukrans, Brak and Lushington rivers, however, there are several smaller, unnamed streams entering the river along its course (Fig. 1). Although there are various structures (*e.g.*, weirs) constructed along the mainstem of the Kowie River, these structures do not appear to obstruct the normal flow of the river (Heinecken and Grindley, 1982; Whitfield *et al.*, 1994), except for the Kowie weir in the lower reaches of the Kowie River, which may constitute a major barrier for upstream fish migration during low flows (Whitfield *et al.*, 1994; Weyl and Lewis, 2006). We could not find any records on when the original Kowie weir was constructed, however, severe floods in 1979 washed away the original weir which was subsequently rebuilt a short distance upstream of the original site (Heinecken and Grindley, 1982). It is important to mention that there is a severe paucity of information on the distribution and diversity of freshwater fishes in the Kowie River catchment, as earlier studies were largely focused on the estuarine environment with little focus on the freshwater environment. The Kowie River is subjected to various anthropogenic stressors across its longitudinal profile, including pollution from agricultural activities, overflowing sewage and domestic and industrial waste (Dalu *et al.*, 2014, 2016a).

2.2 Review of fish distributions

To compile an inventory of fish species distributions in the Kowie River catchment, historic fish distribution data was compiled from the NRF-SAIAB collection records and FBIS. Fish distribution data from the FBIS requires literature reference/confirmation to be included in their distribution database. As such, distribution data from the FBIS was combined with our extensive literature review. Our literature review was conducted using the Web of Science, and supplemented by Google Scholar, starting with the catchment name (Kowie) in 'Title' searches, and then using AND, OR and NOT as Boolean operators using a combination of terms 'native', 'indigenous', 'alien', 'introduced', 'non-native', 'invasive' and 'non-indigenous'. Searches were repeated using the same terms but searching for 'topic'. Finally, grey literature was collected from the Rhodes University library and the Albany Museum. To avoid duplications of localities, we either considered the thesis or peer-reviewed publication if the source was from the same author.

2.3 Contemporary fish collections and dataset

In total, 26 sites were sampled, four in the mainstem of the Kowie River, one pool in the Bloukrans River near the confluence with the Kowie River, and 21 dams across the Kowie River catchment (Fig. 1). In the final analysis, we excluded three dam sites because they did not contain any fish. A multi-method approach was used to collect fishes: seine net (5.0×2.0 m long and 1.5 m deep with a 5.0 mm mesh size), double-ended fyke nets (8 m guiding net, first–ring diameter of 55 cm, 10 mm mesh size at the cod end) and gill nets (35 m long and 2.75 m deep) of differing mesh sizes (35, 45, 57, 73, 93, 118 and 150 mm). Upon capture, the total length (TL) of all fishes was measured to the nearest millimetre (mm) and were

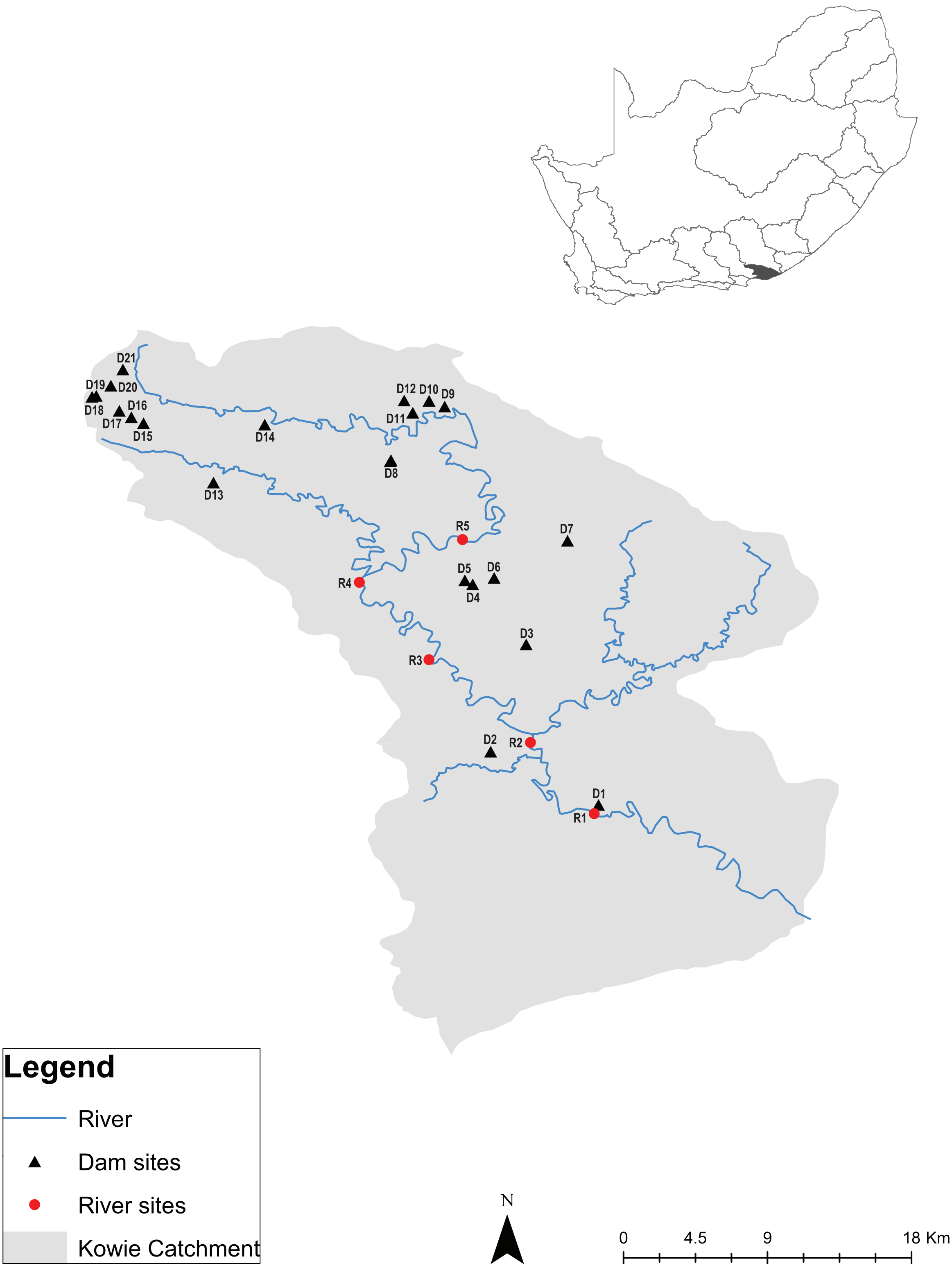

Fig. 1. Location of the study area and the selected sampling sites in the Kowie River catchment. Circles represent sites sampled in the main stem of the river (R1-R5) and triangles represent dam sites (D1-D21).

identified to species level using a guide by Skelton (2001) and returned to the water immediately.

Gill nets were set during the day for 3 hours, to minimise bycatch and prevent unnecessary mortalities, specifically in rivers where the endangered Eastern Cape Rocky are known to occur. Fyke nets are considered passive gears and were set on the shoreline of dams and rivers at the depth of approximately 1–3 m. Fyke nets were fitted with an "otter guard" to prevent non-target taxa, and were set overnight (between 16 h 00 and 18 h 00) and retrieved the following day (between 07h00 and 10h00) with an average soak time of 16 h. It was not possible to sample the headwaters of the Kowie River because most of the upper sections of the river were without flowing waters. At each site, total dissolved solids, conductivity, pH and temperature were recorded from the water using a portable PCTestr 35 multiparameter probe (Eutech/Oakton Instruments, Singapore). We further recorded the altitude, substrate type of each site, and surface area (the latter was only recorded in dams).

2.4 Statistical analysis

The distribution maps presented in this study were constructed using ArcGIS version 10.8, and all statistical analyses were performed using R version 4.0 (R Development Core Team, 2020). The relationships between fish species presence-absence distribution and environmental variables were modelled through canonical correspondence analysis (ter Braak, 1986). For the analysis, the environmental variables were log-transformed $(x+1)$ and thereafter, a resemblance matrix was constructed using the Bray–Curtis similarity. The statistical significance of the CCA relationship between fish species presence-absence and environmental variables was evaluated using 999 Monte Carlo permutation test and a significance level of $p = 0.05$. All environmental variables tested in this study were screened for autocorrelation by comparing the variance inflation factors (VIFs); variables with VIF >10 were excluded for further analysis. The CCA was conducted using the function *cca* from the R library "vegan" (Oksanen *et al.*, 2019).

The differences in species richness, diversity, evenness and total abundance across the sampled sites were tested using multivariate permutational analysis of variance (PERANOVA) based on a Bray–Curtis similarity matrix of fourth root transformed abundance data with 999 permutations. PERMANOVA was performed using the function *adonis* in the "vegan" package. Furthermore, we performed nonmetric multidimensional scaling (nMDS) as an ordination method to summarise multivariate patterns in fish species distribution patterns in relation to the study sites (*i.e.* dams vs river sites) and invasion status (presence/absence of non-native species in a site), and biplots were created using the function *envfit* in the "vegan" package (Oksanen *et al.*, 2019). Finally, we used a student's *t*-test to test for differences in species richness between the dam sites and river sites.

3 Results

In our review, a total of 27 peer-reviewed studies were published on the fishes of the Kowie River catchment, including the referenced literature from the FBIS (Tab. 1). From the literature review, we recorded a total of 17 freshwater fishes from 11 families, Anabantidae (1), Anguillidae (3), Centrarchidae (3), Cichlidae (1), Clariidae (1), Clupeidae (1), Cyprinidae (2), Gobiidae (1), Monodactylidae (1), Mugilidae (2) and Poeciliidae (1) (Tab. 1 and Fig. 2A). From the SAIAB distribution database, we found that 17 freshwater fishes from nine families historically occurred in the Kowie River catchment, Anabantidae (1), Anguillidae (1), Centrarchidae (4), Cichlidae (2), Clariidae (1), Clupeidae (1), Cyprinidae (5), Gobiidae (1) and Mugilidae (1) (Tab. 1). Combined, with our review and the SAIAB distribution database we recorded a total of 21 species from 11 families, of which 9 were non-native and 12 were native in the Kowie River catchment (Tab. 1 and Fig. 2A). The Moggel *Labeo umbratus* was the only species exclusively recorded in the SAIAB distribution database.

The current field survey recorded a total of 16 freshwater fish species from nine families, Anguillidae (1), Centrarchidae (3), Cichlidae (4), Clariidae (1), Clupeidae (1), Cyprinidae (3), Gobiidae (1), Monodactylidae (2) and Mugilidae (1) (Tab. 1 and Fig. 2B). We recorded a total of 8 non-native, 7 native and 1 extralimital species (Mozambique Tilapia) in the Kowie River catchment (Tab. 1 and Fig. 2B). The Redbreast Tilapia *Coptodon rendalli* was only recorded in only one locality and represents the first record of the species in the Kowie River catchment. The African Sharptooth Catfish *Clarias gariepinus* was also recorded for the first time in the mainstem of the Kowie River.

Species richness in the mainstem of the Kowie River ranged between one and seven species, while in the dams species richness varied between one and five. We found species richness in the mainstem of the Kowie River to increase significantly from the upper reaches to the lower reaches ($p < 0.001$), while in the dams there was no noticeable increase or decrease in any direction. However, Dam 2 (D2) contained the highest number of species (five) in comparison to the other dams. In both the mainstem of the Kowie River and the surrounding dams, the Shannon–Weiner diversity index varied significantly (both $p < 0.001$) with the river and dam sites varying between 0.00 and 0.87, and 0.00 and 1.33, respectively.

The CCA ordination scores from our analysis included the relationships between seven environmental variables and 16 freshwater fish species sampled from 23 sites. The CCA analysis showed that the seven selected environmental variables explained 54% of variance in fish distributions in the Kowie River catchment ($p = 0.001$) and four of the selected environmental variables were significant, that is, altitude ($p < 0.001$), water temperature ($p = 0.05$), substrate type (cobbles, $p = 0.028$) and invasion status ($p < 0.001$) (Fig. 3). Monte Carlo permutation showed that both axes CCA axes 1 and 2 were significant, $p < 0.001$ and $p = 0.034$ respectively. The Chubbyhead Barb *Enteromius anoplus* was only found in uninvaded dam sites (D9 and D12) at higher altitudes and co-occurred with the native predatory fish the Longfin Eel *Anguilla mossambica* (Figs. 3 and 4).

There was a significant interaction effect between the study site and altitude (PERMANOVA, pseudo-$F = 2.19288$, $p = 0.005$) on fish assemblage. We found fewer species at high altitude dam sites, with only two species that is, Chubbyhead Barb and Longfin Eel recorded at D9 and Largemouth Bass and Chubbyhead Barb recorded at sites D10

Table 1. The freshwater fish species composition in the Kowie River catchment. Fish surveys for the current study were conducted between February 2017 and March 2018.

Family	Species	Status	Locality	Literature	SAIAB	Current study
Anabantidae	*Sandelia bainsii* [1–7]	Native	River	X	X	
Anguillidae	*Anguilla mossambica* [8,9]	Native	Dam/River	X	X	X
	Anguilla marmorata [8,9]	Native	River	X		
	Anguilla bicolor bicolor [9]	Native	River	X		
Centrarchidae	*Lepomis macrochirus* [#]	Non-native	Dam		X	X
	Micropterus dolomieu [9,10]	Non-native	River	X	X	
	Micropterus punctulatus [9]	Non-native	River	X	X	X
	Micropterus salmoides [9–18]	Non-native	Dam/River	X	X	X
Cichlidae	*Oreochromis mossambicus* [9,19]	Extralimital	Dam/River	X	X	X
	Tilapia sparrmanii [#]	Non-native	River		X	X
	Coptodon rendalli [*]	Non-native	Dam			X
Clariidae	*Clarias gariepinus* [20]	Non-native	Dam/River	X	X	X
Clupeidae	*Gilchristella estuaria* [9,10]	Native	River	X	X	X
Cyprinidae	*Carassius auratus* [#]	Non-native	Dam		X	X
	Cyprinus carpio [#]	Non-native	Dam		X	X
	Enteromius anoplus [21]	Native	Dam/River	X	X	X
	Enteromius pallidus [22]	Native	River	X	X	
	Labeo umbratus [#]	Native	Dam		X	
Gobiidae	*Glossogobius callidus* [9,10,23,24]	Native	Dam/River	X	X	X
Monodactylidae	*Monodactylus argenteus* [*]	Native	River			X
	Monodactylus falciformis [9,14,23]	Native	River	X		X
Mugilidae	*Mugil cephalus* [9,10,14,25]	Native	Dam/River	X		
	Myxus capensis [9,10,14,23,25,26]	Native	Dam/River	X	X	X
Poeciliidae	***Gambusia affinis*** [9]	**Non-native**	**River**	**X**		

1 Skeltonw Barbus minnow (Pisces, Cyprinidae) from the eastern Cape Province, South Africa. South African Journal of Zoology 25, 188–193 (1990).

2 Skelton, P. H. South African Red Data Book - Fishes. South African National Scientific Programmes 199 (1987).

3 Cambray, J. A. Community involvement and the Eastern Cape Rocky, (Sandelia bainsii, Pisces, Anabantidae) from the perspective of a researcher. South African Journal of Wildlife Research 30, 114–117 (2000). Table 1

4 Cambray, J. A. Captive breeding and sanctuaries for the endangered African anabantid Sandelia bainsii, the Eastern Cape rocky.Aquarium Sciences and Conservation 1, 159–168 (1997).

5 Cambray, J. A. The spawning behaviour of the endangered Eastern Cape rocky, Sandelia bainsii (Anabantidae), in South Africa. EnvironBiol Fishes 49, 293–306 (1997).

6 Sifundza, D. S., Chakona, A. & Kadye, W. T. Distribution patterns and habitat associations of Sandelia bainsii (Teleostei: Anabantidae), ahighly threatened narrow-range endemic freshwater fish. J Fish Biol 98, 292–303 (2021).

7 Mayekiso, M. & Hecht, T. Conservation status of the anabantid fish Sandelia bainsii in the Tyume River, South Africa. South AfricanJournal of Wildlife Research 18, 101–108 (1988).

8 Parker, D., Weyl, O. L. F. & Taraschewski, H. Invasion of a South African Anguilla mossambica (Anguillidae) population by the aliengill worm Pseudodactylogyrus anguillae (Monogenea). Afr Zool 46, 371–377 (2011).

9 Wasserman, R. J. & Strydom, N. A. The importance of estuary head waters as nursery areas for young estuary- and marine-spawnedfishes in temperate South Africa. Estuar Coast Shelf Sci 94, 56–67 (2011).

10 Wasserman, R. J. J., Strydom, N. a. A. & Weyl, O. L. F. L. F. Diet of largemouth bass, Micropterus salmoides (Centrarchidae), aninvasive alien in the lower reaches of an Eastern Cape river, South Africa. Afr Zool 46, 378–386 (2011).

11 Weyl, O., Schirrmann, M., Hargrove, J., Bodill, T. & Swartz, E. Invasion status of Florida bass Micropterus floridanus (Lesueur, 1822) inSouth Africa. Afr J Aquat Sci 42, 359–365 (2017).

12 Hargrove, J. S., Weyl, O. L. F. & Austin, J. D. Reconstructing the introduction history of an invasive fish predator in South Africa. BiolInvasions 19, 2261–2276 (2017).

13 Hargrove, J. S., Weyl, O. L. F., Zhao, H., Peatman, E. & Austin, J. D. Using species-diagnostic SNPs to detail the distribution anddynamics of hybridized black bass populations in southern Africa. Biol Invasions 21, 1499–1509 (2019).

14 Weyl, O. L. F. & Lewis, H. First record of predation by the alien invasive freshwater fish Micropterus salmoides L. (Centrarchidae) onmigrating estuarine fishes in South Africa. Afr Zool 41, 294–296 (2006).

15 Murray, T. S. et al. Movement behaviour of alien largemouth bass Micropterus salmoides in the estuarine headwater region of the KowieRiver, South Africa. Afr Zool 50, 263–271 (2015).

Table 1. (*Continued*).

16 Magoro, M. L., Whitfield, A. K. & Carassou, L. Predation by introduced largemouth bass Micropterus salmoides on indigenous marinefish in the lower Kowie River, South Africa. Afr J Aquat Sci 40, 81–88 (2015).
17 Alexander, M. E., Kaiser, H., Weyl, O. L. F. & Dick, J. T. A. Habitat simplification increases the impact of a freshwater invasive fish. Environ Biol Fishes 98, 477–486 (2015).
18 Alexander, M. E. et al. Existing and emerging high impact invasive species are characterized by higher functional responses than natives. Biol Lett 10, 20130946 (2014).
19 Landsberg, J. & Paperna, I. Intestinal infections by Eimeria (s. l.) vanasi n. sp. (Eimeriidae, Apicomplexa, Protozoa) in Cichlid fish.Public Health 62, 283–293 (1987).
20 Cambray, J. A. The need for research and monitoring on the impacts of translocated sharptooth catfish, Clarias gariepinus, in south africa. Afr J Aquat Sci 28, 191–195 (2003).
21 Engelbrecht, J. Phylogenetic relationships between morphologically similar Barbus species, with reference to their taxonomy, distributionand conservation.
22 Skelton, P. H. Preliminary Observations on the Relationships of Barbus Species From Cape Coastal Rivers, South Africa (Cypriniformes: Cyprinidae). Zoologica Africana 11, 399–411 (1976).
23 Magoro, M., Whitfield, A. & Carassou, L. Predation by introduced largemouth bass Micropterus salmoides on indigenous marine fish inthe lower Kowie River, South Africa. Afr J Aquat Sci 40, 81–88 (2015).
24. Maake, P. A., Mwale, M., Dippenaar, S. M. & Gon, O. Mitochondrial and nuclear DNA reveals a complete lineage sorting ofGlossogobius callidus (Teleostei: Gobiidae) in southern Africa. Afr J Aquat Sci 38, 15–29 (2013).
25. Bok, A. The distribution and ecology of two mullet species in some freshwater rivers in the Eastern Cape, South Africa. Journal oflimnological society of southern Africa 5, 97–102 (1979).
26. Carassou, L., Whitfield, A. K., Moyo, S. & Richoux, N. B. Dietary tracers and stomach contents reveal pronounced alimentary flexibilityin the freshwater mullet (Myxus capensis, Mugilidae) concomitant with ontogenetic shifts in habitat use and seasonal food availability. Hydrobiologia 799, 327–348 (2017).
\# South African Institute for Aquatic Biodiversity.
* Current study.

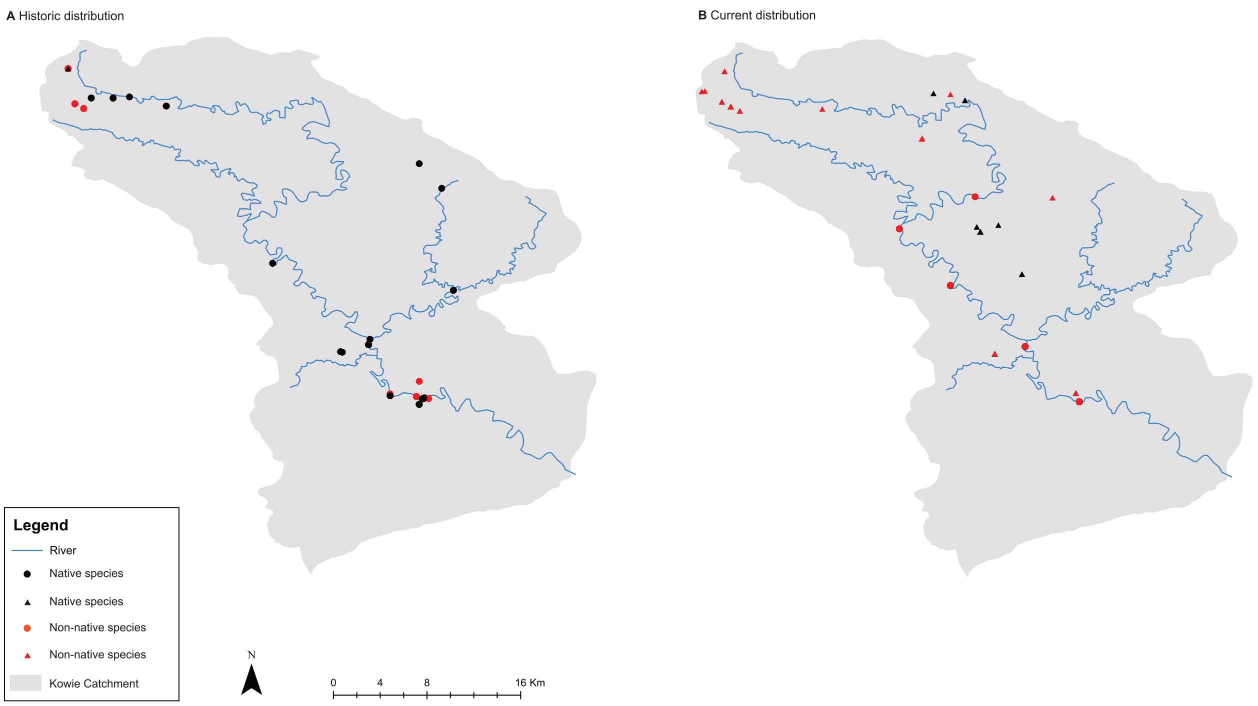

Fig. 2. Map showing the historic (A) and current (B) fish distribution in the Kowie River catchment with native species shown in black and non-native species shown in red. Circles represent river sites and triangles represent dam sites.

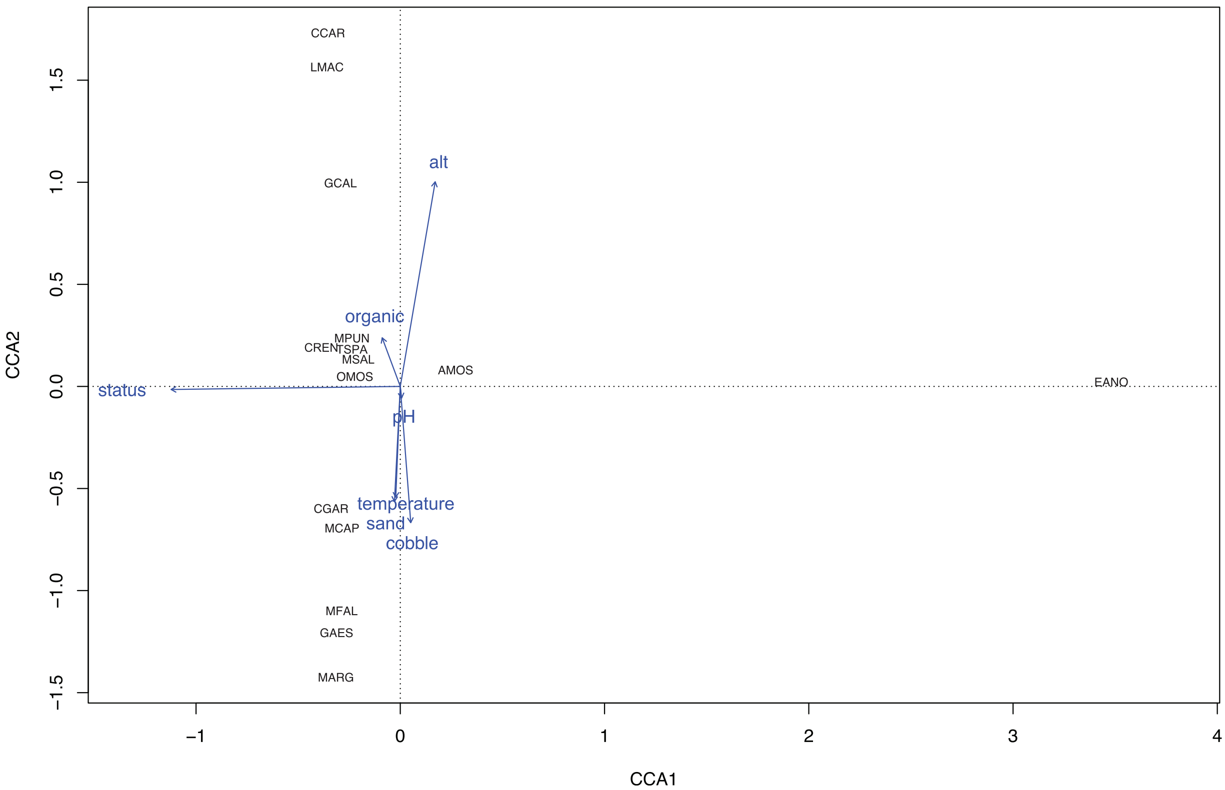

Fig. 3. Canonical correspondence analysis (CCA) showing the relationship between species composition and environmental variables across the different sites and the invasion status in the Kowie River catchment. Abbreviations: *Anguilla mossambica* (AMOS), *Clarias gariepinus* (CGAR), *Coptodon rendalli* (CREN), *Cyprinus carpio* (CCAR), *Enteromius anoplus* (EANO), *Gilchrestella aestuaria* (GEST), *Glossogobius callidus* (GCAL), *Lepomis macrochirus* (LMAC), *Micropterus punctulatus* (MPUN), *Micropterus salmoides* (MSAL), *Monodactylus argenteus* (MARG), *Monodactylus falciformis* (MFAL), *Myxus capensis* (MCAP), *Oreochromis mossambicus* (OMOS) and *Tilapia sparrmanii* (TSPA).

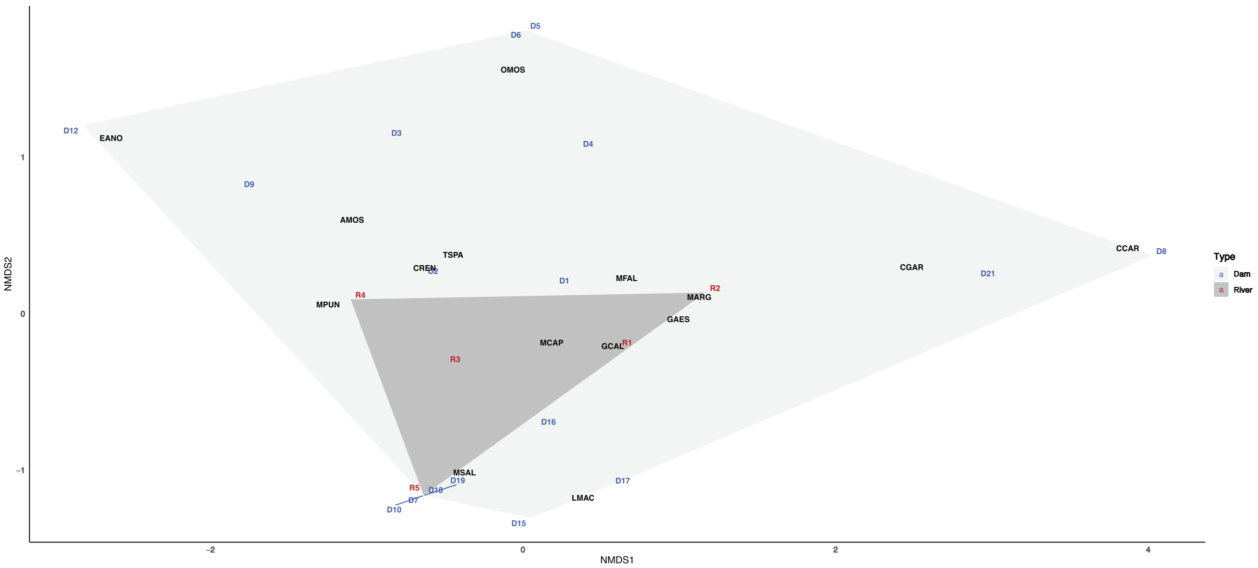

Fig. 4. Non-metric multidimensional scaling (nMDS) ordination showing the spatial distributions of all fish species collected across different habitat types that is, dams and rivers in the Kowie River catchment. Abbreviations: *Anguilla mossambica* (AMOS), *Clarias gariepinus* (CGAR), *Coptodon rendalli* (CREN), *Cyprinus carpio* (CCAR), *Enteromius anoplus* (EANO), *Gilchrestella aestuaria* (GEST), *Glossogobius callidus* (GCAL), *Lepomis macrochirus* (LMAC), *Micropterus punctulatus* (MPUN), *Micropterus salmoides* (MSAL), *Monodactylus argenteus* (MARG), *Monodactylus falciformis* (MFAL), *Myxus capensis* (MCAP), *Oreochromis mossambicus* (OMOS) and *Tilapia sparrmanii* (TSPA).

and D12 respectively. At site D11 we found no fish species. There was also the main effect of invasion status (PERMANOVA, pseudo-$F = 2.85147$, $p = 0.003$), indicated by the absence of the Chubbyhead Barb in the species assemblage when non-native species were present. Results of the nMDS analysis indicated excellent representation (2D stress = 0.04), showing clear separation of the study sites (river sites and dam sites), with three environmental variables being significant, that is, altitude, water temperature and substrate type (cobble) (randomisation permutation tests, $p = 0.05$) in explaining the spatial patterns of fish distribution observed in the Kowie River catchment (Fig. 4). The nMDS showed that dam sites had a broader variation in species composition compared to the river sites (Fig. 4), however, we found no significant difference in species composition between the river sites and dams sites ($t = 0.99$, $p = 0.32$).

4 Discussion

This study aimed to assess the distribution of fish species in the Kowie River catchment. To achieve this, we used multiple information sources to identify any changes in fish distributions, that is, a comparison of historic distribution data and the current field survey. Our results showed that the number of species in impoundments was, indeed, elevated in comparison to river sites as per the first hypothesis. Overall, a decrease in the number of native species was recorded in the Kowie River catchment with a total of five species absent and two new non-native species recorded during the current survey, in line with our second hypothesis. A notable absence was the endangered Eastern Cape Rocky, which has been showing an ongoing decline in its native range over the years (Mayekiso and Hecht, 1988; Cambray, 1997). In a recent survey of the Kowie River, Chakona *et al.* (2018) found no specimens of the Eastern Cape Rocky, and they postulated that the Eastern Cape Rocky may be extirpated as a consequence of increased competition for resources or predation by non-native species particularly the Black Basses of the genus *Micropterus*. This notable decreasing trend in abundance and distributions of the Eastern Cape Rocky was also recorded over time in the Great Fish River system (Sifundza *et al.*, 2021) and Keiskamma River systems (Ellender, 2013) of the Eastern Cape, South Africa respectively. Another notable absence was the two Anguillidae species, the Mottled Eel *Anguilla marmorata* and Shortfin Eel *Anguilla bicolor bicolor*, known migratory species, occurring in low abundance in the Kowie River catchment (Wasserman and Strydom, 2011). Despite the multiple gears used in the contemporary sampling effort, the eels may have been hard to detect as they can only be effectively sampled using fyke nets, and the fyke net effort was comparatively low (Wasserman *et al.*, 2011).

The river continuum concept predicts that longitudinal variations in fish diversity, richness, abundance and trophic interactions will occur along a river gradient (Vannote *et al.*, 1980). Habitats and primary productivity dynamics increase in complexity from the headwater streams to the lower reaches, facilitating increased niche availability with implications for diversity (Vannote *et al.*, 1980; Bertora *et al.*, 2021). Similarly, our results show a significant downstream increase in species diversity (R5 to R1) with sites R1 and R2 harbouring the highest species diversity in the mainstem of the Kowie River. This increase in species diversity is likely a result of downstream river widening and the presence of larger pools. These habitats are known to host increased species diversity, specifically larger and more predatory fishes (Bertora *et al.*, 2021; Walsh *et al.*, 2022). At both sites (R1 and R2), we found larger and more piscivorous fishes (Mozambique Tilapia, African Sharptooth Catfish, and Largemouth Bass) occupying larger pools. Although we recorded a significant increase in species diversity on a longitudinal profile, the river sites held a lower fish diversity than the dam sites with both native and non-native fishes accounted for.

Dams often serve as hubs for new biological invasions (Johnson *et al.*, 2008; Chapman *et al.*, 2020; Wang *et al.*, 2021) and the dams in the Kowie River catchment are no exception. The Redbreast Tilapia was recorded in D2 representing the first record in the Kowie River catchment. There is currently no data detailing when the species was introduced into the Kowie River catchment. The presence of Redbreast Tilapia is a major concern as the species was thought to have limited survival potential in the Eastern Cape as a result of little tolerance to lower winter temperatures. Regardless of how the Redbreast Tilapia entered the Kowie River catchment, the site D2 may serve as a source population for future invasions into the mainstem of the Kowie River and its tributaries. There are no records of African Sharptooth Catfish introduction dates, however, previous studies (Cambray, 2003, 2004) have documented occurrence in the dams in the upper reaches of the Kowie River catchment. The high level of connectivity between the dams and the Bloukrans River, a tributary of the Kowie River may have resulted in the African Sharptooth Catfish naturally moving into the Kowie River. Previous efforts have been made to eradicate the African Sharptooth Catfish in dams using piscicide rotenone. Unfortunately, this benefit was short-lived as anglers reintroduced the African Sharptooth Catfish and other predatory non-native fishes soon after the intervention (Cambray, 2003).

Invasions by non-native species are one of the leading stressors in the freshwater ecosystem (Sala *et al.*, 2000; Birk *et al.*, 2020). Our results indicate that large bodied non-native predators such as Black Basses of the genus *Micropterus* and African Sharptooth catfish have been introduced into sections of rivers where native fauna is characterised by high levels of endemism and naïveté to predators (Cox and Lima, 2006; Weyl *et al.*, 2016; Woodford *et al.*, 2017). This can result in the local extirpations of the resident biota, especially small cyprinids (Weyl *et al.*, 2010; Shelton *et al.*, 2017; Ellender *et al.*, 2018). The absence of non-native predators in site D9 is likely the reason we found the Chubbyhead Barb, now constricted to the upper reaches of the Kowie River catchment. Conservation efforts of native biota need to mitigate the introductions and the spread of predatory non-native fish species into areas where they do not currently occur (Khosa *et al.*, 2019; Zengeya *et al.*, 2020). Developing sanctuaries for native or endangered species to thrive, forms part of the South African National Freshwater Ecosystem Priority Area (NFEPA), which is a national strategy that aims to address the conservation and sustainable use of freshwater resources in South Africa (Nel *et al.*, 2011).

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References

Altermatt F, Little CJ, Mächler E, Wang S, Zhang X, Blackman RC. 2020. Uncovering the complete biodiversity structure in spatial networks: the example of riverine systems. *Oikos* 129: 607–618.

Bertora A, Grosman F, Sanzano P, Rosso JJ. 2021. Fish assemblage structure in a Neotropical urbanised prairie stream exposed to multiple natural and anthropic factors. *Ecol Freshw Fish* 31: 224–242.

Birk S, Chapman D, Carvalho L, Spears BM, Andersen HE, Argillier C, Auer S, Baattrup-Pedersen A, Banin L, Beklioğlu M, Bondar-Kunze E, Borja A, Branco P, Bucak T, Buijse AD, Cardoso AC, Couture R-M., Cremona F, de Zwart D, Feld CK, Ferreira MT, Feuchtmayr H, Gessner MO, Gieswein A, Globevnik L, Graeber D, Graf W, Gutiérrez-Cánovas C, Hanganu J, Iskın U, Järvinen M, Jeppesen E, Kotamäki N, Kuijper M, Lemm JU, Lu S, Solheim AL, Mischke U, Moe SJ, Nõges P, Nõges T, Ormerod SJ, Panagopoulos Y, Phillips G, Posthuma L, Pouso S, Prudhomme C, Rankinen K, Rasmussen JJ, Richardson J, Sagouis A, Santos JM, Schäfer RB, Schinegger R, Schmutz S, Schneider SC, Schülting L, Segurado P, Stefanidis K, Sures B, Thackeray SJ, Turunen J, Uyarra MC, Venohr M, von der Ohe PC, Willby N, Hering D. 2020. Impacts of multiple stressors on freshwater biota across spatial scales and ecosystems. *Nat Ecol Evol* 4: 1060–1068.

Cambray JA. 1997. Captive breeding and sanctuaries for the endangered African anabantid *Sandelia bainsii*, the Eastern Cape rocky. *Aquar Sci Conserv* 1: 159–168.

Cambray JA. 2003. The need for research and monitoring on the impacts of translocated sharptooth catfish, *Clarias gariepinus*, in South Africa. *Afr J Aquat Sci* 28: 191–195.

Cambray JA. 2004. Barbel, a catfish on the move. *Piscator* 74–80.

Cardinale BJ, Duffy JE, Gonzalez A, Hooper DU, Perrings C, Venail P, Narwani A, MacE GM, Tilman D, Wardle DA, Kinzig AP, Daily GC, Loreau M, Grace JB, Larigauderie A, Srivastava DS, Naeem S. 2012. Biodiversity loss and its impact on humanity. *Nature* 486: 59–67.

Chakona A, Sifundza D, Kadye WT. 2018. *Sandelia bainsii*. The IUCN Red List of Threatened Species 2018: E.T19889A99447325.

Chapman DS, Gunn IDM, Pringle HEK, Siriwardena GM, Taylor P, Thackeray SJ, Willby NJ, Carvalho L. 2020. Invasion of freshwater ecosystems is promoted by network connectivity to hotspots of human activity. *Glob Ecol Biogeogr* 29: 645–655.

Cox JG, Lima SL. 2006. Naiveté and an aquatic-terrestrial dichotomy in the effects of introduced predators. *Trends Ecol Evol* 21: 674–680.

Daga VS, Gubiani ÉA, Cunico AM, Baumgartner G. 2012. Effects of abiotic variables on the distribution of fish assemblages in streams with different anthropogenic activities in southern Brazil. *Neotrop Ichthyol* 10: 643–652.

Dalu T, Froneman PW, Chari LD, Richoux NB. 2014. Colonisation and community structure of benthic diatoms on artificial substrates following a major flood event: a case of the Kowie River (Eastern Cape, South Africa). *Water SA* 40: 471–480.

Dalu T, Bere T, Froneman PW. 2016a. Assessment of water quality based on diatom indices in a small temperate river system, Kowie River, South Africa. *Water SA* 42: 183–193.

Dalu T, Weyl OLF, Froneman PW, Wasserman RJ. 2016b. Trophic interactions in an austral temperate ephemeral pond inferred using stable isotope analysis. *Hydrobiologia* 768: 81–94.

Dalu T, Wasserman RJ, Wu Q, Froneman WP, Weyl OLF. 2018. River sediment metal and nutrient variations along an urban – agriculture gradient in an arid austral landscape: implications for environmental health. *Environ Sci Pollut Res* 25: 2842–2852.

Ellender B. 2013. Ecological consequences of non-native fish invasion in Eastern Cape headwater streams. Rhodes University.

Ellender BR, Weyl OLF, Alexander ME, Luger AM, Nagelkerke LAJ, Woodford DJ. 2018. Out of the pot and into the fire: Explaining the vulnerability of an endangered small headwater stream fish to black-bass Micropterus spp. invasion. *J Fish Biol* 92: 1035–1050.

Grill G, Lehner B, Thieme M, Geenen B, Tickner D, Antonelli F, Babu S, Borrelli P, Cheng L, Crochetiere H, Ehalt Macedo H, Filgueiras R, Goichot M, Higgins J, Hogan Z, Lip B, McClain ME, Meng J, Mulligan M, Nilsson C, Olden JD, Opperman JJ, Petry P, Reidy Liermann C, Sáenz L, Salinas-Rodríguez S, Schelle P, Schmitt RJP, Snider J, Tan F, Tockner K, Valdujo PH, van Soesbergen A, Zarfl C. 2019. Mapping the world's free-flowing rivers. *Nature* 569: 215–221.

He F, Thieme M, Zarfl C, Grill G, Lehner B, Hogan Z, Tockner K, Jähnig SC. 2021. Impacts of loss of free-flowing rivers on global freshwater megafauna. *Biol Conserv* 263: 109335.

Heinecken T, Grindley J. 1982. Estuaries of the Cape part II: synopses of available information on individual systems. 1–58.

Jackson MC, Loewen CJG, Vinebrooke RD, Chimimba CT. 2016. Net effects of multiple stressors in freshwater ecosystems: a meta-analysis. *Glob Chang Biol* 22: 180–189.

Johnson PTJ, Olden JD, Vander Zanden MJ. 2008. Dam invaders: impoundments facilitate biological invasions into freshwaters. *Front Ecol Environ* 6: 357–363.

Karr JR. 1981. Assessment of biotic integrity using fish communities. *Fisheries (Bethesda)* 6: 21–27.

Khosa D, Marr SM, Wasserman RJ, Zengeya TA, Weyl OL. 2019. An evaluation of the current extent and potential spread of Black Bass invasions in South Africa. *Biol Invasions* 21: 1721–1736.

MacRae PSD, Jackson DA. 2001. The influence of smallmouth bass (Micropterus dolomieu) predation and habitat complexity on the structure of littoral zone fish assemblages. *Can J Fish Aquatic Sci* 58: 342–351.

Mayekiso M, Hecht T. 1988. Conservation status of the anabantid fish *Sandelia bainsii* in the Tyume River, South Africa. *South Afr J Wildlife Res* 18: 101–108.

Nel J, Maherry A, Petersen C, Roux D, Driver A, Hill L, van Deventer H, FUnke N, Swartz E, Smith-Adao L, Mbona N, Downsborough L, Nienaber S. 2011. Technical Report for the National Freshwater Ecosystem Priority Areas project.

Oksanen J, Blanchet FG, Friendly M, Kindt R, Legendre P, Mcglinn D, Minchin PR, O'hara RB, Simpson GL, Solymos P, Henry M, Stevens H, Szoecs E, Maintainer HW. 2019. Package "vegan" Title Community Ecology Package. *Commun Ecol Pack* 2: 1–297.

Pereira HM, Bruford MW, Brummitt N, Butchart SHM, Cardoso AC, Coops NC, Dulloo E. 2013. Essential biodiversity variables. *Science (1979)* 339: 277–278.

R Development Core Team. 2019. R: A language and environment for statistical computing. Vienna: R Development Core Team.

Reid AJ, Carlson AK, Creed IF, Eliason EJ, Gell PA, Johnson PTJ, Kidd KA, MacCormack TJ, Olden JD, Ormerod SJ, Smol JP, Taylor WW, Tockner K, Vermaire JC, Dudgeon D, Cooke SJ. 2019. Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biol Rev* 94: 849–873.

Rodeles AA, Galicia D, Miranda R. 2020. Barriers to longitudinal river connectivity: review of impacts, study methods and management for Iberian fish conservation. *Limnetica* 39: 1–19.

Rosenzweig ML. 2001. The four questions: what does the introduction of exotic species do to diversity? *Evol Ecol Res* 3: 361–367.

Sala OE, Chapin III, FS, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke LF, Jackson RB, Kinzig A, Leemans R, Lodge DM, Mooney HA, Oesterheld M, Poff NL, Sykes MT, Walker BH, Walker M, Wall DH. 2000. Global biodiversity scenarios for the year 2100. *Science (1979)* 287: 1770–1774.

Shelton JM, Dean Impson N, Graham S, Esler KJ. 2017. Down, but not out: Recent decline of Berg-Breede river whitefish (*Barbus andrewi*) in the upper Hex River, South Africa. *Koedoe* 59: 1–6.

Sifundza DS, Chakona A, Kadye WT. 2021. Distribution patterns and habitat associations of *Sandelia bainsii* (Teleostei: Anabantidae), a highly threatened narrow-range endemic freshwater fish. *J Fish Biol* 98: 292–303.

Skelton P. 2001. A complete guide to the freshwater fishes of Southern Africa. 1–395.

ter Braak CJFF. 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology* 67: 1167–1179.

Tickner D, Opperman JJ, Abell R, Acreman M, Arthington AH, Bunn SE, Cooke SJ, Dalton J, Darwall W, Edwards G, Harrison IAN, Hughes K, Jones TIM, Leclère D, Lynch AJ, Leonard P, Mcclain ME, Muruven D, Olden JD, Ormerod SJ, Robinson J, Tharme RE, Thieme M, Tockner K, Wright M, Young L. 2020. Bending the curve of global freshwater biodiversity loss: an emergency recovery plan. *Bioscience* 70: 330–342.

Vannote RL, Minshall GW, Cummins KW, Sedell JR, Cushing CE. 1980. The river continuum concept. *Can J Fish Aquat Sci* 37: 130–137.

Walsh G, Pease AA, Woodford DJ, Stiassny MLJ, Gaugris JY, South J. 2022. Functional diversity of afrotropical fish communities across river gradients in the Republic of Congo, west central Africa. *Front Environ Sci* 10.

Wang J, Chen L, Tang W, Heino J, Jiang X. 2021. Effects of dam construction and fish invasion on the species, functional and phylogenetic diversity of fish assemblages in the Yellow River Basin. *J Environ Manage* 293: 112863.

Wasserman RJ, Strydom NA. 2011. The importance of estuary head waters as nursery areas for young estuary- and marine-spawned fishes in temperate South Africa. *Estuar Coast Shelf Sci* 94: 56–67.

Wasserman RJ, Weyl OLF, Strydom NA. 2011. The effects of instream barriers on the distribution of migratory marine-spawned fishes in the lower reaches of the Sundays River, South Africa. *Water SA* 37: 495–504.

Weyl OLF, Lewis H. 2006. First record of predation by the alien invasive freshwater fish *Micropterus salmoides L.* (Centrarchidae) on migrating estuarine fishes in South Africa. *Afr Zool* 41: 294–296.

Weyl OLF, Daga VS, Ellender BR, Vitule JRS. 2016. A review of *Clarias gariepinus* invasions in Brazil and South Africa. *J Fish Biol* 89: 386–402.

Weyl PSR, de Moor FC, Hill MP, Weyl OLF. 2010. The effect of largemouth bass Micropterus salmoides on aquatic macro-invertebrate communities in the Wit River, Eastern Cape, South Africa. *Afr J Aquat Sci* 35: 273–281.

Whitfield A, Paterson A, Bok A, Kok H. 1994. A comparison of the ichthyofaunas in two permanently open eastern Cape estuari. *Southern Afr J Zool* 29: 175–185.

Woodford DJ, Ivey P, Jordaan MS, Kimberg PK, Zengeya T, Weyl OLF. 2017. Optimising invasive fish management in the context of invasive species legislation in South Africa. *Bothalia* 47.

Zengeni R, Kakembo V, Nkongolo N. 2016. Historical rainfall variability in selected rainfall stations in Eastern Cape, South Africa. *South Afr Geograph J* 98: 118–137.

Zengeya TA, Kumschick S, Weyl OL, van Wilgen BW. 2020. An evaluation of the impacts of alien species on biodiversity in South Africa using different assessment methods, 295–324 p.

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