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Successful mechanical eradication of spotted bass (*Micropterus punctulatus* (Rafinesque, 1819)) from a South African river

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Abstract

1. Following the discovery in 2007 of non-native spotted bass (*Micropterus punctulatus* (Rafinesque, 1819)) in the Thee River, Olifants-Doring River system, Western Cape Province, South Africa, a mechanical removal project was initiated in 2010 to eradicate them to protect the unique native fish assemblage in the river.
2. A temporary gabion barrier was constructed to halt spotted bass invasion into upstream reaches and a variety of mechanical removal techniques were used throughout the project.
3. Three hundred and ninety-nine spotted bass were removed from the river during the project. Three hundred (75%) of these were captured by chasing them into gill nets or by catching them with hand nets. The remainder were removed using spearguns, seine nets and by back-pack electrofishing.
4. Spotted bass had been depleted to below detection levels downstream of the temporary barrier in the second year of the project in 2013. A subsequent survey of the river in 2014 revealed a bass population in a reach above the temporary barrier that had previously been considered uninvaded. This population of spotted bass was removed in 2014. Subsequent annual surveys of the Thee River in 2015, 2016 and 2017 have not detected spotted bass and the population is considered to have been extirpated.
5. Three years after the extirpation of spotted bass from below the temporary barrier, native fiery redfin (*Pseudobarbus phlegethon* (Barnard, 1938)) and Cape galaxias (*Galaxias zebratus* Castelnau, 1861) were observed in pools where they had been absent during the bass invasion.

KEYWORDS
fish, mechanical removal, non-native species, recovery, restoration, stream

1 | INTRODUCTION

Globally, freshwater ecosystems are subjected to a broad range of stressors, including habitat loss and fragmentation, hydrological alteration, climate change, overexploitation of water resources and biota, pollution and the introduction of non-native species (Dudgeon et al., 2006; Vörösmarty et al., 2010). Consequently, freshwater organisms are among the most imperilled taxa world-wide (Jenkins, 2003). The introduction and spread of invasive non-native fishes is one of the most prominent factors responsible for these levels of imperillment (Leprieur, Beauchard, Blanchet, Oberdorff, & Brosse, 2008). Once established, management options for the non-native species are often reduced to eradication or controlling the spread of established populations, e.g. using barriers (Rahel, 2013). Eradication of non-native species can be costly and is rarely accomplished, with the exception on small islands, in isolated areas (such as ponds or small headwater ecosystems), or before species have spread widely (Myers, Simberloff, Kuris, & Carey, 2000; Zavaleta, 2002; Zavaleta, Hobbs, & Mooney, 2001).

The use of piscicides, e.g. rotenone, has been the most common eradication technique used (Britton, Gozlan, & Copp, 2011); however, piscicide use can be controversial (Vinson, Dinger, & Vinson, 2010). Sustained mechanical removal has only been successful at small scales (Britton et al., 2011) and requires a sustained effort and long-term financial commitment that could become more costly than piscicide treatments (Bomford & Tilzey, 1997). Mechanical removal efforts have produced successful outcomes (see Franssen, Davis, Ryden, and Gido (2014), Shepard, Nelson, Taper, and Zale (2014) and Propst et al. (2015) for examples from the USA), as well as unsuccessful outcomes (see Mueller (2005) for an example from the USA and Shelton et al. (2017) for an example from South Africa). With the exception of very short, narrow streams with simple habitat, mechanical removal is unlikely to be successful in completely eradicating non-native fish (Meyer, Lamansky, & Schill, 2006).

In South Africa, the Cape Fold Ecoregion, *sensu* Abell et al. (2008), contains a rich assemblage of endemic primary freshwater fishes, comprising 24 described species and a further 18 undescribed lineages, with 40 of these 42 taxa endemic to the ecoregion (Ellender, Wasserman, Chakona, Skelton, & Weyl, 2017). These fishes are under increasing pressure from multiple stressors including unsustainable water abstraction, habitat destruction and non-native fish introductions (Ellender et al., 2017). The presence of non-native fish has been shown to affect the behaviour and composition of the native fish assemblages (Shelton, Day, & Griffiths, 2008; Woodford & Impson, 2004; Woodford, Impson, Day, & Bills, 2005) as well as lower levels of the food web such as aquatic invertebrates and algae (Lowe, Woodford, Impson, & Day, 2008). In many cases, non-native fishes have invaded rivers up to instream barriers with native fish persisting only in headwater refugia (van der Walt, Weyl, Woodford, & Radloff, 2016). In the Olifants-Doring River system, for example, non-native black bass (*Micropterus* spp.) currently exclude small native fishes from more than 80% of available habitat (van der Walt et al., 2016). As the Olifants-Doring River contains a rich endemic freshwater fish fauna, the protection and expansion of native fish refugia are conservation priorities (Marr, Impson, & Tweddle, 2012).

Restoration initiatives in the Olifants-Doring River system have included chemical (Weyl, Finlayson, Impson, Woodford, & Steinkjer, 2014) and mechanical (Shelton et al., 2017) approaches. In the Rondegat River, for example, non-native smallmouth bass (*Micropterus dolomieu* (Laepède, 1802)) were effectively eradicated from 4.5 km of stream using the piscicide rotenone, with clear benefits to the native aquatic biota (Weyl et al., 2014). In contrast, an attempt to eradicate rainbow trout (*Oncorhynchus mykiss* (Walbaum, 1792)) from a 9 km reach of the Krom River by mechanical means failed (Shelton et al.,

FIGURE 1 Photographs of the Thee River and its fish fauna: a) Pool 2; b) Pool 24; c) Pool 25; d) Thee River above the study reaches; e) Spotted bass *Micropterus punctulatus*; f) temporary gabion barrier constructed to prevent spotted bass colonizing the upper reaches of the Thee River; g) Clanwilliam redfin *Sedercypris calidus* (note the tubercles covering the body of the males and the eggs within the rock crevice); h) Fiery redfin *Pseudobarbus phlegethon* (note the tubercles on the male); and i) Clanwilliam rock catfish *Austroglanis gilli*. Photographs: Craig Garrow, Riaan van der Walt and Marius Wheeler

2017). Despite this, the use of mechanical methods for non-native fish removals remain popular because the putative collateral effects of piscicides on non-target organisms (Vinson et al., 2010) are often undesirable from a conservation perspective (Halfyard, 2010; Knapp & Matthews, 1998) or are the focus of groups lobbying against non-native fish removals (Ellender, Woodford, Weyl, & Cowx, 2014).

The middle and upper reaches of the Thee River, a tributary of the Olifants River in the Olifants-Doring River system, are near pristine (Figure 1a-d) and isolated from the Olifants River during the dry season (October to March) by 5 km of dry river bed, but temporarily connected during winter high flows. The Thee River is of special conservation value because it contains one of the highest native fish diversities of any tributary in the Olifants-Doring River system (van der Walt et al., 2016); it is one of only three rivers where the spotted rock catfish (*Austroglanis barnardi* (Skelton, 1981)) occur, and it is a national Freshwater Ecosystem Priority Area (Nel et al., 2011). National Ecosystem Priority Areas are areas identified as strategic spatial priorities for conserving a representation of South Africa's aquatic ecosystem types (Hill, 2009).

The presence of spotted bass (*Micropterus punctulatus* (Rafinesque, 1819)) in the Thee River was first reported in 2007 (Bills & Impson, 2013; Figure 1e). Spotted bass are opportunistic carnivores predominantly of fish, but feed on prey items found throughout the water column (Churchill & Bettoli, 2015). Although the origin of the introduction could not be determined, this species is widespread elsewhere in the Olifants-Doring River system where it has been present for 80 years since its introduction from the USA for angling purposes (van der Walt et al., 2016). In the Thee River, the presence of bass could either be the result of direct stocking or upstream migration from the Olifants main stem. The latter appears to be unlikely since spotted bass have not colonized other tributaries of the Olifants River that are only connected to the main stem during periods of winter spate. As a result of the severe adverse impacts that black basses have had on native fishes in the Olifants-Doring River system (van der Walt et al., 2016), a temporary gabion barrier (Figure 1f), made of wire mesh baskets filled with sandstone cobbles with geotextile on the upstream face and anchored to both banks, was erected to prevent further bass incursion upstream and a mechanical removal programme was initiated in 2010. This article describes the process of the spotted bass eradication, evaluates its success and demonstrates the benefit to native fishes in the Thee River.

2 | METHODS

The project was conducted in accordance with the ethics protocols of the Conservation Authority responsible for the region (CapeNature), as part of its invasive species monitoring and management programme.

2.1 | Study area

The Thee River is a small, clear, perennial tributary of the Olifants River, Western Cape, South Africa. Its source lies at an altitude of 1 500 masl in the Koue Bokkeveld Mountains from where it flows north west for approximately 20 km before joining the main stem of the Olifants River (Figure 2). The last 5 km of the river between the confluence with the Olifants River and an abstraction weir (lower limit of this study; Figure 2) are dry during summer. Native fishes are present for more than 10 km upstream of the water abstraction weir to an altitude of ±575 masl. The study area, 5 km of the Thee River above the abstraction weir, has a gradient of 18.1 m km^{-1} and mostly comprises a single channel, characterized by 1–2 m deep pools that are 10–80 m long and connected by shallow cobble riffles. The Thee River is home to six native fish species: Clanwilliam redfin (*Sedercypris calidus* (Barnard, 1938)) Figure 1g, fiery redfin (*Pseudobarbus phlegethon* (Barnard, 1938)) Figure 1h, Clanwilliam yellowfish (*Labeobarbus seeberi* (Gilchrist & Thompson, 1913)), spotted rock catfish, Clanwilliam rock catfish (*Austroglanis gilli* (Barnard, 1943)) Figure 1i and Cape galaxias (*Galaxias zebratus* Castelnau, 1861 - lineage *Galaxias sp*. '*zebratus nebula*') (Ellender et al., 2017). IUCN Red-list evaluations demonstrate the imperilled nature of the fishes with two species evaluated as Endangered, three as Near Threatened and one as Data Deficient (see Ellender et al., 2017). Until the 2007 discovery of spotted bass, the middle and upper reaches of the Thee River remained largely un-impacted by human activity.

2.2 | Eradication

In October 2010, a snorkel survey of the Thee River was conducted to determine the extent of the spotted bass invasion. A temporary gabion weir was constructed in November 2010 at the presumed

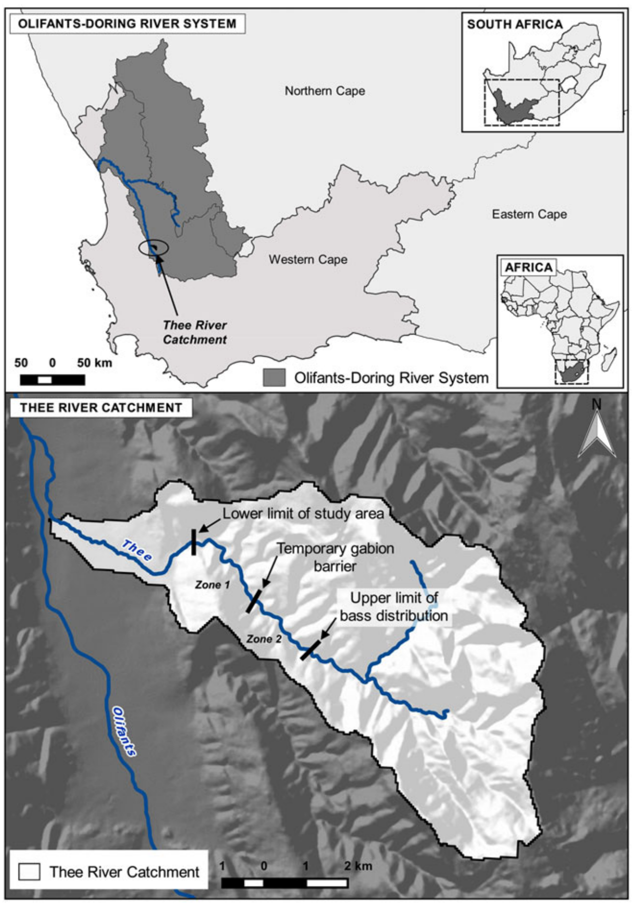

FIGURE 2 Location of the Thee River catchment in relation to the Olifants River, the Western Cape Province and South Africa, and delineation of the study area

upper limit of bass invasion to prevent further upstream incursion of spotted bass. This divided the river into two zones: Zone 1 below the temporary gabion barrier to the water abstraction weir and Zone 2 upstream of the temporary gabion barrier (Figure 2).

All eradication activities were conducted during austral summer (October–April) when river flows are low and the water is clear and warm (20–28°C). Spotted bass spawned in January and February in the Thee River and an effort was made to remove as many adult bass before their spawning. The manual removal was managed by the provincial conservation authority, CapeNature, with the assistance of volunteers and contract workers using multiple gears, including multi-meshed gill nets (stretched mesh 28, 35, 39 and 56 mm); 2 m seine net (mesh size 2 mm); hand nets; speargun (~40 cm with trident pointed spears) and an electrofisher. Selection of equipment was dictated by field conditions and effectiveness of capturing spotted bass. To improve catch success, field personnel kept the instream area clear of woody debris which the bass favoured as cover. Bass removal was mainly conducted during the day for the convenience and safety of teams. In total, eradication effort was conducted over four summers i.e. 2010–2011 (November to April), 2011–2012 (October to March), 2012–2013 (October and December), and 2013–2014 (November to March), followed by three intensive snorkel surveys in 2015, 2016 and 2017 to confirm whether the river was clear of bass. Initial eradication efforts were focused on Zone 1 but the discovery of spotted bass in Zone 2 in November 2013 prompted an expansion of the eradication effort.

Eradication work was conducted over a typical 5-h working day by small teams of 2–4 people. Snorkelling (1–2 people) was always conducted moving upstream to maximize underwater visibility and reduce the impact of sediment disturbance. Snorkelling focused on the pools while the shallow riffles were visually scanned for fish from the bank or by slowly walking up the channel. On capture, each fish was immediately killed by a blow to the head, its length estimated and categorized as young-of-year (YOY) < 8 cm total length (TL); juvenile = 8–20 cm or adult >20 cm, and the capture location (pool; Table 1 and Figure S1, supplementary material) was recorded. To assess the efficacy of spotted bass removals, the number of bass removed during each eradication season was expressed against the cumulative number of bass removed. A linear regression was fitted to the data to highlight the trend in the bass removal using the lm function in R 3.5.0 Statistical Software (R Development Core Team, 2018) and to estimate the total number of spotted bass in the Thee River.

TABLE 1 Summary of the number of spotted bass *Micropterus punctulatus* removed from pools in the Thee River. See Figure S1 (Supplementary material) for a map depicting the relative locations of the pools within the study area

Pool	Latitude	Longitude	Bass Removed
1	−32.7938	19.09533	44
2	−32.7943	19.09748	4
3	−32.7937	19.09827	7
4	−32.7935	19.09962	6
5	−32.7937	19.10013	14
6	−32.7941	19.10077	16
7	−32.7943	19.10096	3
8	−32.7947	19.10155	30
9	−32.795	19.10222	17
10	−32.7953	19.10282	1
11	−32.7958	19.10301	27
12	−32.7969	19.10242	27
13	−32.7975	19.10216	1
14	−32.7978	19.10245	2
15	−32.798	19.10328	10
16	−32.7977	19.10472	5
17	−32.7987	19.10564	52
18	−32.7988	19.10661	3
19	−32.7995	19.10709	40
20	−32.8004	19.1074	13
21	−32.8019	19.10771	1
22	−32.8033	19.10857	11
23	−32.804	19.10865	3
24	−32.8064	19.1106	6
25	−32.8083	19.11274	5
26	−32.8098	19.11689	7
27	−32.8122	19.11746	3
28	−32.8128	19.11772	6
29	−32.8132	19.1189	2
30	−32.8135	19.11973	5
31	−32.814	19.11967	12
32	−32.8153	19.1214	7
33	−32.8167	19.12451	3
34	−32.817	19.12513	6

2.3 | Native fish response to spotted bass removal

To determine the response of native fish populations to spotted bass removal, native fishes were counted in three pools above (Pools 25, 25a and 26; Table 1 and Figure S1 Supplementary Material) and three pools below the temporary gabion barrier (Pools 1, 17 and 19; Table 1 and Figure S1 Supplementary Material) by snorkel surveys in April 2011 (during the invasion) and January 2016 (3 years after the spotted bass eradication) using the method described in van der Walt et al. (2016). Snorkel surveys were completed by a single diver swimming upstream and counting all native fish by species. A land-based assistant recorded the data. The length, average width and depth of the pools were recorded such that fish densities in each pool could be expressed as number of fish per m^2. For subsequent analyses, Clanwilliam redfin and fiery redfin minnow numbers were combined because small specimens are hard to distinguish from each other under water. To test for differences in redfin densities between invaded and non-invaded zones before and after spotted bass removal, a two-way (year and zone) repeated measures ANOVA was performed using the ezANOVA function in the ez package (Lawrence, 2016) for R 3.5.0 between the two zones and within the two years. Because each factor only has two levels, the data were spherical and no test for sphericity was required (Field, Miles, & Field, 2012).

3 | RESULTS

In total, 442 man-days (41 field days) were expended on the eradication of spotted bass from the Thee River, which included footpath and gabion weir construction, of which 174 man-days were used for the actual eradication effort (Table 2). Most eradication effort was expended in the 2010–2011, 2011–2012 and 2013–2014 summers; these were 50, 42 and 53 man-days, respectively. Eradication effort was reduced to 10 man-days in the 2012–2013 summer owing to the false belief that all bass had been eradicated in the previous season. Effort was reduced from 2014–2015 to an annual intensive fish survey to search for any evidence of spotted bass. Additional man-hours were expended in constructing the gabion barrier (externally funded; 2010–2011), upgrading an existing road alongside the river (funded by the landowner; 2010–2011), trimming riparian vegetation to facilitate working in the river (funded by the Department of Environmental Affairs: Natural Resource Management Programme (DEA: MRN) and managed by CapeNature; 2011–2012) and in constructing a footpath along the river (funded by DEA:MRN and managed by CapeNature; 2012–2013). Of these, the riparian zone trimming and road construction required the greatest investments; 120 and 80 man-days, respectively (Table 2). Overall, the total effort was highest in 2010–2011 and 2011–2012 at about 160 man-days, decreasing to about 50 man-days for 2012–2013 and 2013–2014. Thereafter, the total effort was reduced to an average of 7 man-days per season.

3.1 | Capture techniques

Of the capture techniques used, snorkelling with small hand-nets and gill nets, individually and in combination, resulted in the capture of 75% of the spotted bass. The remainder of the bass were captured using seine nets, spear guns and with an electrofisher (Figure 3 inset). The use of the electrofisher was limited because of the exceptionally low conductivity of the Thee River (<40 μS cm^{-1}). Night snorkelling with hand nets was used to capture particularly elusive individuals during season 2.

3.2 | Bass removal

The number of spotted bass removed from each pool on the river is summarized in Figure 3. During the 2010–2011 summer, 205 spotted bass were removed from Zone 1 and four from the first pool above the gabion barrier in Zone 2 (Figure 4a). The size structure was dominated by YOY and juvenile fish (Figure 4a). The temporary gabion barrier washed away during the winter of 2011. During the 2011–2012

TABLE 2 Summary of the number of man-days per activity per catch season to eradicate spotted bass *Micropterus punctulatus* from the Thee River, Western Cape, South Africa

Season	Eradicate fish	Barrier	Road construction	Clear riparian zone	Construct footpath	Impact survey	Total
2010–2011	50	24	80			2	156
2011–2012	42			120			162
2012–2013	10				40		50
2013–2014	53						53
2014–2015*	7						7
2015–2016*	10					2	12
2016–2017*	2						2
Total	174	24	80	120	40	4	442

*Note: the man-days recorded in these seasons were for the annual surveys of the Thee River to ensure that spotted bass had been completely eradicated.

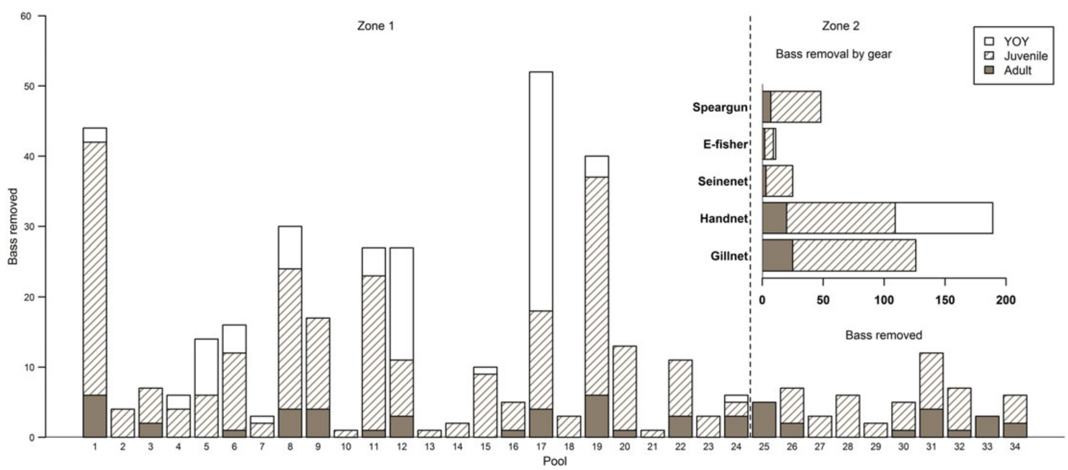

FIGURE 3 Summary of the catches of spotted bass for each pool by age class. The pool numbers are presented in Table 1. The dotted line between sites 24 and 25 represents the position of the temporary gabion weir. The inset summarizes of the catches of spotted bass, by age class, for the different gears employed

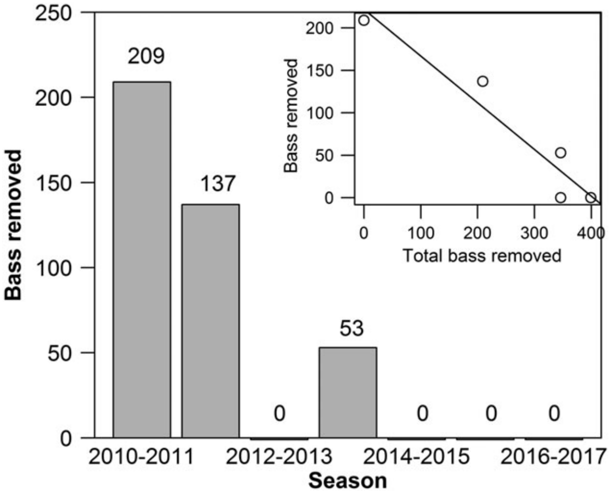

FIGURE 4 Summary of spotted bass length classes removed for the entire period broken down by austral summer seasons and river zones: a) 2010–2011, b) 2011–2012, c) 2013–2014 and d) Summary for the removal effort 2010–2014. No eradication activities took place in 2012–2013 because it was believed that the eradication had been successfully accomplished

summer a further 137 spotted bass were removed from Zone 1 (Figure 4b). Size structure was again dominated by juvenile fishes. In the 2012–2013 summer, Zone 1 was surveyed completely in September 2012, November 2012 and January 2013 and no spotted bass were observed. In November 2013, a survey of both Zone 1 and Zone 2 detected spotted bass in reaches in Zone 2 that had previously been assumed to be bass-free. In the 2013–2014 summer, 54 spotted bass, mainly juveniles, were removed from Zones 1 and 2 (Figure 4c). No spotted bass have been observed during subsequent snorkel surveys conducted in January 2015, January 2016 and March 2017. Densities are thus below the detection threshold for snorkel surveys and the mechanical removals are considered to have been successful (Figure 5).

Non-native banded tilapia (*Tilapia sparrmanii* A. Smith, 1840) were recorded in the river for the first time during the spotted bass removal programme. In January and February 2011, 42 YOY banded tilapia were removed from Zone 1 and a further 200 YOY and three adults were removed in January 2016. Banded tilapia were not recorded in the 2017 survey.

3.3 | Native fish

Neither of the two mostly nocturnal rock catfish species – spotted rock catfish and Clanwilliam rock catfish – were recorded during the 2011 and 2016 surveys. Clanwilliam yellowfish and Cape galaxias were present in numbers that were not large enough for meaningful analysis. Overall, native fish density (mean ± S.E) increased from 1.87 ± 1.76 fish m^{-2} in 2011 (bass present) to 3.37 ± 1.06 fish m^{-2} in 2016 (bass extirpated) while the combined Clanwilliam redfin minnow and fiery redfin minnow density increased from 1.82 ± 1.71 fish m^{-2} in 2011 to 2.60 ± 0.88 fish m^{-2} in 2016. Before complete bass eradication, the mean native fish and combined minnow densities in the invaded Zone 1 were both about 10% of the densities in Zone 2 (Table 3). During the bass invasion, there was a significant difference in the combined minnow density between the zones (ANOVA $F = 39.023$, df = 1, $P = 0.003$), but this difference was no longer significant following the bass eradication (ANOVA $F = 1.177$, df = 1, $P = 0.339$). The mean combined minnow density in Zone 1 following eradication was not significantly different from the mean combined minnow density in Zone 2 during the bass invasion (ANOVA $F = 0.000102$, df = 1, $P = 0.992$). The mean combined minnow density in Zone 1 following eradication was not significantly different from the mean combined minnow density in Zone 2 during the bass invasion (ANOVA $F = 2.159$, df = 1, $p = 0.216$). A two-way repeated measures ANOVA showed that combined minnow densities differed

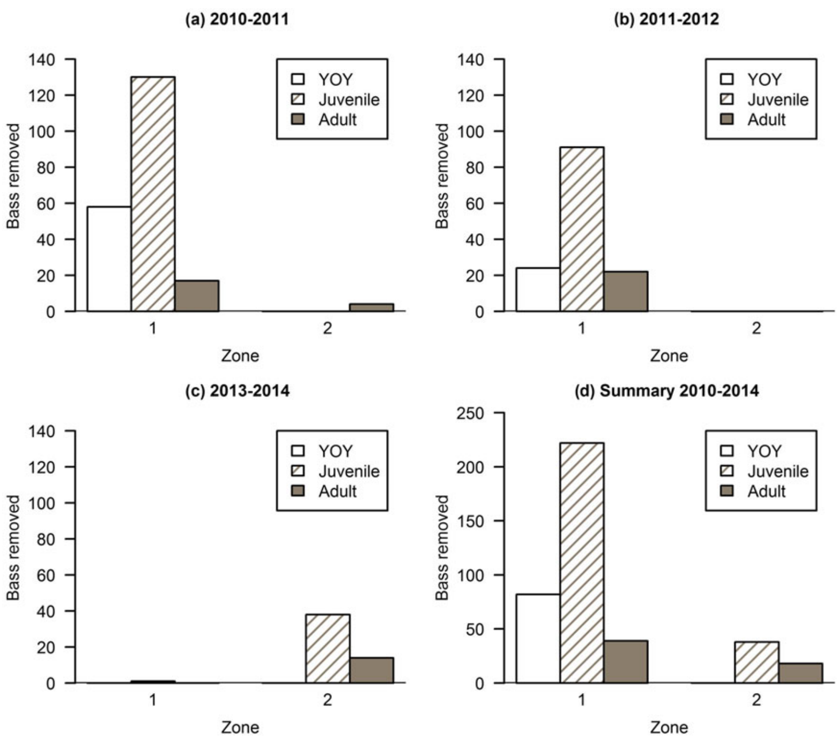

FIGURE 5 Total spotted bass catches per austral summer. The inset shows a depletion plot to estimate the total population of spotted bass in the Thee River

TABLE 3 Mean native fish and combined minnow (Clanwilliam redfin and fiery redfin) density in the Thee River, Western Cape, South Africa, in three pools below (Zone 1) and above (Zone 2) a temporary gabion barrier during the spotted bass *Micropterus punctulatus* invasion (2011) and after bass eradication (2016)

		Minnow density (fish m^{-2})		Native fish density (fish m^{-2})	
Year	Zone	mean	SD	mean	SD
2011	Zone 1	0.33	0.22	0.34	0.20
	Zone 2	3.31	0.80	3.40	0.81
	Total	**1.82**	**1.71**	**1.87**	**1.76**
2016	Zone 1	3.31	0.80	4.13	0.27
	Zone 2	2.54	0.92	2.61	1.01
	Total	**2.92**	**0.88**	**3.37**	**1.06**

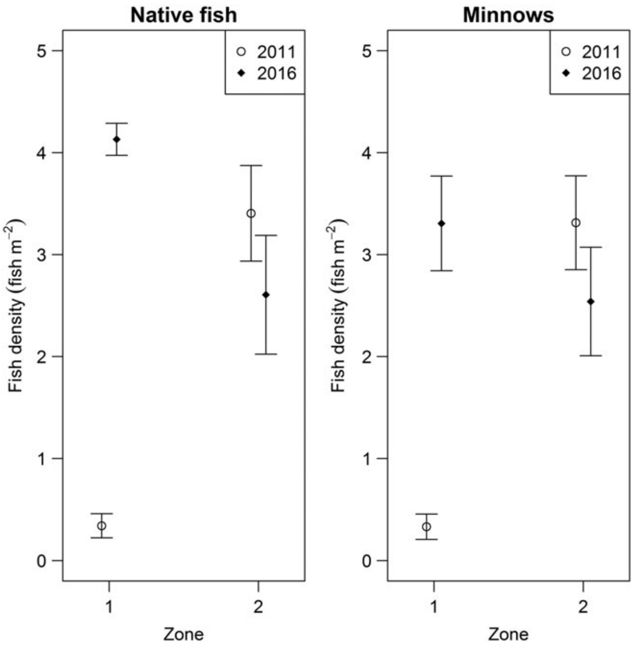

FIGURE 6 Native fish and combined minnow (Clanwilliam redfin and fiery redfin) density in six pools in the Thee River; before (2011) and after (2016) the spotted bass eradication. Pools 1, 17 and 19 are in Zone 1 while Pools 25, 25a and 26 are in Zone 2; see Figure S1 Supplementary material

significantly between Zones, with significant interaction between Zone and Year (Figure 6). The outputs of the repeated measures ANOVA are presented in Table S2, Supplementary Material.

4 | DISCUSSION

The project appears to have successfully eradicated spotted bass from the Thee River by mechanical methods. The bass removal programme began three years after spotted bass were first reported (2007). In retrospect, the removal could have been completed in two years, instead of four, if the upper limit of the invasion front had been accurately identified, highlighting the importance of thorough surveys of the entire river before planning a fish control project and for each removal season. The presence of bass above the removal zone also confounded the retrospective analysis of the impact of spotted bass on native fishes. Analyses do, however, indicate an increase in native fish abundance in pools from which spotted bass were removed.

The key factors contributing to the success of this project were the very clear and shallow water, having an accessible single river channel, the ease with which spotted bass could be caught, and having a dedicated team committed to success. Other factors of importance included an absence of thick instream vegetation, such as palmiet (*Prionium serratum* (L.f.) Drège), the installation of a temporary barrier to stop the upstream movement of the invasive fish, a discrete lower boundary to the intervention area, and landowner support for the removal efforts.

This project demonstrated that the use of temporary barriers can be used to halt the incursion of invasive fish species (Rahel, 2013), but also that such barriers are susceptible to being washed away during spate events. van der Walt et al. (2016) demonstrated that a natural or artificial barrier with a vertical drop of at least 80 cm is successful at halting the upstream migration and invasion of *Micropterus* species in the Cape Fold Ecoregion. Thus a 1 m high temporary barrier could be used to divide the intervention area into smaller treatment reaches for eradication to commence at smaller scales, either using piscicides or mechanical techniques, as suggested by Clarkson, Marsh, Stefferud, and Stefferud (2005) for the Colorado River, USA.

Some mechanical, non-native, fish removal programmes fail because of difficulties in removing the YOY (Thompson & Rahel, 1996). Spotted bass YOY were only present from February to April, indicating that breeding took place in late summer. In their native range, spotted bass breed at water temperatures between 14 and 23°C on hard substrates near cover and at nest depths averaging between 2.3 to 3.7 m, with a range of 0.9 to 6.7 m (Churchill & Bettoli, 2015). It is unclear why spotted bass bred so late in the Thee River, but it may be related to low water temperatures and high spring flows following the winter rainfall of this Mediterranean climate region. In the Thee River, spotted bass YOY readily approached snorkellers and were easy to capture using an aquarium net or small seine net.

Removal programmes may also fail owing to strong compensatory responses to harvesting by adult fish (Zipkin et al., 2008). This did not appear to have occurred in the Thee River, possibly due to the early stage of the invasion when the mechanical removal programme was initiated, and because the breeding population may not have reached a level where it was able to compensate for the harvesting. In addition, the river is small with relatively shallow pools and is perhaps a marginal environment for spotted bass.

This project demonstrated that manual eradication of spotted bass from small streams in the Cape Fold Ecoregion is feasible and has been followed by strong recovery of several threatened fish species. Whether the mechanical removal techniques used successfully for spotted bass would be successful for other centrarchids that have invaded this region, such as smallmouth and largemouth bass, or salmonids such as rainbow trout, needs to be evaluated. In this regard, it is important to note that the success of mechanical removal is context-specific, and in South Africa it has only been successful for one very small stream in the Cape Fold Ecoregion and on a naïve non-native species which was highly susceptible to netting. Mechanical removals are unlikely, therefore, to replace piscicides for the eradication of non-native fishes, but should rather be evaluated as a potential alternative to piscicides in small clear streams and could be used in conjunction with piscicide treatments in streams where sensitive taxa are present in the invaded reaches.

It is also important to note that non-native fish eradications are pointless if reintroductions cannot be prevented (Lee, 2001). For this reason, CapeNature have erected fish conservation awareness signage at the lowest pool on the Thee River and have held fish and river information/awareness sessions with all landowners and the local community in the vicinity of the Thee River. It is important, however, that annual monitoring surveys are conducted to allow for a rapid response if a re-invasion is detected.

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