Ecosystem responses to the eradication of common carp *Cyprinus carpio* using rotenone from a reservoir in South Africa

Tatenda Dalu1,2 | Terence A. Bellingan2,3 | Jeanne Gouws4 | N. Dean Impson4 | Martine S. Jordaan2,4,5 | Dumisani Khosa2,5 | Sean M. Marr2,5 | Lubabalo Mofu2,5 | Mandy Schumann6 | Etienne Slabbert7 | Johannes A. van der Walt8 | Ryan J. Wasserman2,9 | Olaf L. F. Weyl5,6,10

1Department of Ecology and Resource Management, University of Venda, Thohoyandou, South Africa
2South African Institute for Aquatic Biodiversity, Makhanda, South Africa
3Department of Entomology and Arachnology, Albany Museum, Makhanda, South Africa
4Biodiversity Capabilities, CapeNature, Bridgetown, South Africa
5Centre for Invasion Biology, SAIAB, Makhanda, South Africa
6DSI/NRF Research Chair in Inland Fisheries and Freshwater Ecology, SAIAB, Makhanda, South Africa
7Northern Cape Department of Environment and Nature Conservation, Nieuwoudtvil, South Africa
8Roche Sequencing Solutions, Cape Town, South Africa
9Advanced Environmental Corporation (Pty) Ltd, Porterville, South Africa
10Department of Zoology and Entomology, Rhodes University, Makhanda, South Africa

Correspondence
Tatenda Dalu, Department of Ecology and Resource Management, University of Venda, Thohoyandou 0950, South Africa.
Email: dalutatenda@yahoo.co.uk

Funding information
Water Research Commission, Grant/Award Number: Project: K5-2538; NRF Professional Development Programme, Grant/Award Numbers: 1010140, 101039 and 88746; NRF Thuthuka, Grant/Award Number: 117700; National Research Foundation – South African Research Chairs Initiative of the Department of Science and Innovation, Grant/Award Number: 110507

Abstract
1. The control of invasive alien fish populations using piscicides to alleviate impacts on native biota is a controversial conservation strategy because the collateral impacts on non-target taxa are not well documented. This article documents the responses of water quality, plankton and macroinvertebrate communities to an eradication of the globally invasive common carp *Cyprinus carpio* Linnaeus 1758, using the piscicide rotenone in a small South African reservoir.

2. Treated and untreated reservoirs were sampled before and at intervals following rotenone treatment. Sampling endpoints included water quality parameters, plankton, macroinvertebrates and fish. These endpoints were selected to gain an understanding of the ecological impacts of the treatment at various biological levels and to document possible recovery following treatment.

3. The study showed that: (i) the common carp were successfully removed; (ii) water clarity improved following the removal of fish; (iii) invertebrate communities, including macroinvertebrates and large zooplankton, recovered within 6 months of treatment; and (iv) small zooplankton (i.e. Rotifera) dynamics were complex but rotifer abundances had returned to pre-treatment levels within 6 months of treatment.

4. There was a 56% similarity between the macroinvertebrate assemblages before and 6 months after treatment, showing a substantial turnover in taxa following treatment. The phytoplankton community of the treated reservoir was dominated...
Family Leguminosae, and the two genera Lonchocarpus is a botanical compound found in plant species belonging to the Cailteux et al., 2001; Rayner & Creese, 2006; Rowe, 2003). Rotenone used globally to control invasive alien fishes (Britton & Brazier, 2006; West, & Closs, 2013; Vinson, Dinger, & Vinson, 2010) and have been effective tool for controlling fish populations (McClay, 2005; Pham, Woodford et al., 2017).

Piscicides such as rotenone are a reliable and relatively cost-effective tool for controlling fish populations (McCay, 2005; Pham, West, & Closs, 2013; Vinson, Dinger, & Vinson, 2010) and have been used globally to control invasive alien fishes (Britton & Brazier, 2006; Cailteux et al., 2001; Rayner & Creese, 2006; Rowe, 2003). Rotenone is a botanical compound found in plant species belonging to the Family Leguminosae, and the two genera Lonchocarpus and Derris (Brooks & Price, 1961; Meadows, 1973). Rotenone has a relatively short environmental half-life of <1–8 days in temperate (10–20°C) environments (Finlayson, Trumbo, & Siepmann, 2001; Rohan, Fairweather, & Grainger, 2015) and is broken down by ultraviolet light, hydrolysis, microbial activity and absorption into plant material or humic acids (Finlayson et al., 2001; Finlayson et al., 2018; USEPA, 2007).

The use of piscicides for conservation purposes can be controversial (Finlayson et al., 2005; Vinson et al., 2010; Williams, 2004), mostly because of impacts on non-target fish and aquatic invertebrates directly via toxicity-induced mortality (Dalu, Wasserman, Jordaan, Froneman, & Weyl, 2015; Kolar, Courtenay, Nico, & Hubert, 2010). In streams, for example, the immediate and short-term responses of aquatic invertebrates to rotenone treatment are characterized by reductions in invertebrate abundances and taxonomic richness (Bellingan, Woodford, Gouws, Villet, & Weyl, 2015; Pham, Jarvis, West, & Closs, 2018; Woodford et al., 2013). In lentic systems (i.e. lakes, reservoirs and ponds), rotenone effects on zooplankton are greater than on benthic organisms, and zooplankton assemblages are significantly reduced in abundance, species composition and diversity (Duggan, Wood, & West, 2015; Vinson et al., 2010). In experimental ponds treated with rotenone, benthic invertebrate assemblages generally recovered to be similar to untreated pond assemblages within 6 months, while recovery of zooplankton to pre-treatment abundances ranged from 1 month to 3 years (Vinson et al., 2010).

Despite significant risks to non-target taxa, the value of rotenone as a tool for the management of invasive fish is recognized globally (Britton, Davies, & Brazier, 2010; Davies & Britton, 2015; Rayner & Creese, 2006) and the American Fisheries Society, in partnership with rotenone registrants, have developed a Rotenone Stewardship website to encourage its safe, effective and prudent use (https://units.fisheries.org/rotenone-stewardship/). Despite this, there are few case studies regarding ecosystem responses to rotenone applications and fish removals under field conditions.

The use of rotenone to remove common carp, Cyprinus carpio L., an alien species introduced into South Africa in the eighteenth century (Ellender & Weyl, 2014), from a reservoir was identified as a conservation intervention to reduce the threat of invasion of the mainstream Oorlogs Kloof River. The Oorlogs Kloof River flows through the Oorlogs Kloof Nature Reserve, a key refuge for one of the last successfully recruiting populations of the endangered Clanwilliam sandfish, Laboeosseeberi Gilchrist & Thompson, 1911, and is one of the few rivers in the region that is not invaded by common carp. Common carp has been demonstrated to impair water quality, as its bottom-grubbing feeding behaviour increases turbidity and suspends nutrients (Chumchal, Nowlin, & Drenner, 2005; Jackson, Quist, Downing, & Larscheid, 2010; Vilizzi, Tarkan, & Copp, 2015), which can result in eutrophication and associated changes in aquatic plant and animal...