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# Threatened Endemic Fishes in South Africa's Cape Floristic Region: A New Beginning for the Rondegat River

Olaf L. F. Weyl[a], Brian Finlayson[b], N. Dean Impson[c], Darragh J. Woodford[d] & Jarle Steinkjer[e]

[a] South African Institute for Aquatic Biodiversity (SAIAB), Private Bag 1015, Grahamstown 6140, South Africa. E-mail:

[b] California Department of Fish and Game (retired), Camino, CA

[c] CapeNature, Stellenbosch, South Africa

[d] Center for Invasion Biology, South African Institute for Aquatic Biodiversity (SAIAB), Grahamstown, South Africa

[e] Norwegian Directorate for Nature Management, Sluppen, Trondheim, Norway

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FEATURE

# Threatened Endemic Fishes in South Africa's Cape Floristic Region: A New Beginning for the Rondegat River


**Olaf L. F. Weyl**

South African Institute for Aquatic Biodiversity (SAIAB), Private Bag 1015, Grahamstown 6140, South Africa. E-mail: o.weyl@saiab.ac.za

**Brian Finlayson**

California Department of Fish and Game (retired), Camino, CA

**N. Dean Impson**

CapeNature, Stellenbosch, South Africa

**Darragh J. Woodford**

Center for Invasion Biology, South African Institute for Aquatic Biodiversity (SAIAB), Grahamstown, South Africa

**Jarle Steinkjer**

Norwegian Directorate for Nature Management, Sluppen, Trondheim, Norway





**ABSTRACT:** *Nonnative fishes threaten native fish communities in many rivers of the world. In South Africa's Cape Floristic Region, predation by nonnative fishes has severely impacted native fish populations and more than half of the 17 endemic fish species are endangered. To preserve the unique endemic fish fauna, removal of nonnative fish from conservation areas is a priority in this region. In February 2012, South Africa's first nonnative fish eradication using rotenone took place in the Rondegat River, a small headwater stream that had been invaded by Smallmouth Bass (*Micropterus dolomieu*). The successful treatment culminated from a decade-long process that was facilitated through collaboration among a South African nature conservation authority (CapeNature), the South African Institute for Aquatic Biodiversity, and the American Fisheries Society Fish Management Chemicals Subcommittee. The successful removal of alien fish and almost instantaneous increase in biodiversity is anticipated to encourage more endemic fish restorations in South Africa.*



## Peces endémicos amenazados en la región florística de Cabo en Sudáfrica: un nuevo comienzo en el Río Rondegat

**RESUMEN:** *en muchos ríos a lo largo del mundo, las comunidades ícticas nativas se ven amenazadas por peces foráneos. En la región florística de Cabo, en Sudáfrica, la depredación ejercida por peces foráneos ha impactado severamente las poblaciones nativas de peces y más de 17 especies endémicas de peces están amenazadas. Con el fin de preservar la fauna íctica endémica, se le dio prioridad a la remoción de especies foráneas en las áreas de conservación en esta región. En febrero de 2012, la primera erradicación de peces no nativos mediante el uso de rotenona, se dio lugar en el Río Rondegat, un pequeño cuerpo de agua que ha sido invadido por la lobina boca chica (*Micropterus dolomieu*). El tratamiento fue exitoso y culminó después de un proceso de diez años facilitado por la colaboración de las autoridades de conservación de Sudáfrica (CapeNature), el Instituto Sudafricano de Biodiversidad Acuática y el subcomité de Manejo de Químicos de La Sociedad Americana de Pesquerías. Se anticipa que el incremento casi instantáneo de la biodiversidad tras la remoción efectiva de peces foráneos invite a tomar nuevos esfuerzos para restaurar más poblaciones de peces endémicos en Sudáfrica.*


## INTRODUCTION

The Cape Floristic Region (CFR) of South Africa has 24 native freshwater fish species (Table 1). Geographic isolation has resulted in high endemism in individual river systems (Linder et al. 2010) and CFR fish species are often restricted to a single river or tributary within a river system (Figure 1), making them particularly vulnerable to nonnative fish introductions, habitat destruction, and pollution (Tweddle et al. 2009). Of the 17 currently recognized endemic species, 10 are listed as endangered and another three are listed as vulnerable by the International Union for Conservation of Nature (IUCN; Tweddle et al. 2009). Hence, CFR rivers are key areas for conservation of biodiversity (Impson et al. 2002).

Intentional and unintentional introductions have made fish one of the world's most introduced groups of aquatic animals (Gozlan et al. 2010). Worldwide, intentional fish introductions have occurred to establish food fishes, create new fisheries, restore depleted fish stocks, and control plants, invertebrates, and other fishes (Kolar et al. 2010; van Rensburg et al. 2011). Although such introductions have often resulted in the desired outcome, nonnative fish introductions have had impacts on genetic, individual, population, community, and ecosystem levels in recipient environments (Cucherousset and Olden 2011) through competition, predation, habitat alteration, disease, and hybridization interactions (Moyle 2002; Clarkson et al. 2005).

Sport fish enhancement has been a major reason for nonnative fish introductions (Cambray 2003), particularly in areas with predator-poor fish faunas (Dill and Cordone 1997; Clarkson et al. 2005). Humans living in areas with species-poor fish communities were often unable to resist the temptation to establish nonnative sport fishes, and in many regions nonnative fishes outnumber native species. Nowhere is this more evident than in the freshwater environments in Mediterranean climate regions including California, central Chile, southwestern Australia, the Iberian peninsula (Spain and Portugal), and the CFR of South

**Table 1 . Native freshwater fishes, maximum length, IUCN Red list status.**[a]

| Species | Maximum length (cm SL) | IUCN status | Main threat |
|---|---|---|---|
| Anguillidae | | | |
| African Mottled Eel (*Anguilla bengalensis labiata*) | 145 | LC | 0 |
| Shortfin Eel (*Anguilla bicolor bicolor*) | 80 | LC | 0 |
| Marbled Eel (*Anguilla marmorata*) | 185 | LC | 0 |
| Longfin Eel (*Anguilla mossambica*) | 120 | LC | 0 |
| Austroglaniidae | | | |
| Barnard's Rock Catfish (*Austroglanis barnardi*)[b] | 8 | EN | 1, 2 |
| Clanwilliam Rock Catfish (*Austroglanis gilli*)[b] | 13 | VU | 1, 2 |
| Cyprinidae | | | |
| Berg-Breede River Whitefish (*Barbus andrewi*)[b] | 60 | *EN* | 1, 2, 4, 5 |
| Chubbyhead Barb (*Barbus anoplus*) | 12 | *LC* | 0 |
| Clanwilliam Redfin (*Barbus calidus*)[b] | 8 | *VU* | 1, 2 |
| Twee River Redfin (*Barbus erubescens*)[b] | 10 | *CR* | 1, 2, 3 |
| Goldie Barb (*Barbus pallidus*) | 7 | *LC* | 0 |
| Sawfin (*Barbus serra*)[b] | 50 | *EN* | 1, 2, 4 |
| Clanwilliam Sandfish (*Labeo seeberi*)[b] | 36 | *EN* | 1, 2 |
| Moggel (*Labeo umbratus*) | 50 | *LC* | 5 |
| Clanwilliam Yellowfish (*Labeobarbus capensis*)[b] | 100 | *VU* | 1, 2, 4 |
| Eastern Cape Redfin (*Pseudobarbus afer*)[b] | 11 | *EN* | 1 |
| Smallscale Redfin (*Pseudobarbus asper*)[b] | 8 | *EN* | 1, 2 |
| Burchell's Redfin (*Pseudobarbus burchelli*)[b] | 14 | *CR* | 1, 2, 3 |
| Berg River Redfin (*Pseudobarbus burgi*)[b] | 12 | *EN* | 1, 2, 5 |
| Fiery Redfin (*Pseudobarbus phlegethon*)[b] | 7 | *EN* | 1, 2 |
| Giant Redfin (*Pseudobarbus skeltoni*)[b,c] | 17 | *NA* | 1, 2 |
| Slender Redfin (*Pseudobarbus tenuis*)[b] | 8 | *NT* | 1, 2 |
| Galaxiidae | | | |
| Cape Galaxias (*Galaxias zebratus*)[b] | 8 | *DD* | 1, 2, 5 |
| Anabantidae | | | |
| Cape Kurper (*Sandelia capensis*)[b] | 20 | *DD* | *1, 2, 5* |

[a] SL = standard length, LC = least concern, EN = endangered, VU = vulnerable, CR = critically endangered, NA = not assessed, NT = near threatened, DD = data deficient. Main threats (0 = no dominant threat identified; 1 = alien fish; 2 = habitat destruction; 3 = pollution; 4 = utilization; 5 = genetic integrity) in the Cape Floristic Region South Africa (after Skelton 2001; Tweddle et al. 2009).

[b] Endemic.

[c] The recently described Giant Redfin has not been formally assessed but is considered endangered (Chakona and Swartz 2013).

**Photo 1. A school of Fiery Redfin (*Pseudobarbus phlegethon*) in the Rondegat River; it had been extirpated from the lower reaches of the river by Smallmouth Bass (*Micropterus dolomieu*). Photo credit: SAIAB/O. Weyl.**

Africa (Marr et al. 2009). The introduction history, number of fishes introduced, and impacts on native fishes are remarkably similar between California and the CFR. Government-funded hatcheries were used to produce the nonnative fishes that were distributed through government-funded stocking programs and by angling organizations (Dill and Cordone 1997; McCafferty et al. 2012). The number of successfully introduced fishes in each region approximates the number of native fishes (44 vs. 45 in California and 20 vs. 24 in the CFR; Marr et al. 2009). The introduction of nonnative sunfishes (Centrarchidae) in California and throughout the western United States has had major impacts largely through predation on native minnow (Cyprinidae) populations (Moyle 2002; Clarkson et al. 2005; UCREFRP 2012a, 2012b). Native CFR minnows have experienced similar impacts from sunfish and trout (Salmonidae) introductions (van Rensburg et al. 2011). As evidence from other countries and local environmental impacts began to accumulate, South Africa began to severely restrict introductions of nonnative fish. The control of nonnative fishes and the rehabilitation of native fish habitats through the removal of the former are now conservation priorities (Marr et al. 2012).

In the CFR, management actions were implemented to rehabilitate some of the affected rivers by eradicating populations of nonnative fish (Marr et al. 2012). Eradication of nonnative fishes can be costly and controversial (Finlayson et al. 2005), and success often decreases with increasing range of the invading species, as well as size and complexity of the affected environment (Finlayson et al. 2010; Kolar et al. 2010). Knowing that eradication would likely be a difficult task and borrowing on previous experiences in the United States and Europe, South Africa began a process over a decade ago to assess various options and began planning for eradicating nonnative fish from rivers.

This article reviews the historical context of the eradication program and examines the partnerships and processes that ultimately resulted in the successful removal of alien fish and the almost instantaneous increase in fish diversity in the Rondegat River in the CFR.

## HISTORY AND IMPACTS

### Nonnative Fish Introductions

In South Africa, as elsewhere, most fish were introduced as game fish or as prey species in order to develop sport fisheries. Legislation encouraging the importation of sport fishes and government support for fisheries development (McCafferty et al. 2012) resulted in the successful establishment of 20 nonnative fish species in the CFR (Table 2). Most of these can be traced back to the government-funded Jonkershoek Hatchery, located in the CFR (van Rensburg et al. 2011). At Jonkershoek, introduced fishes were first propagated and then distributed to other government hatcheries and stocked either directly or with the help of piscatorial societies. Alien fishes were granted special protection through the formation of the Inland Fisheries Division in the Cape Province in 1943 (a precursor to CapeNature), which enacted measures for the protection of game fishes including fishing licences, closed seasons, and bag limits (McCafferty et al. 2012).

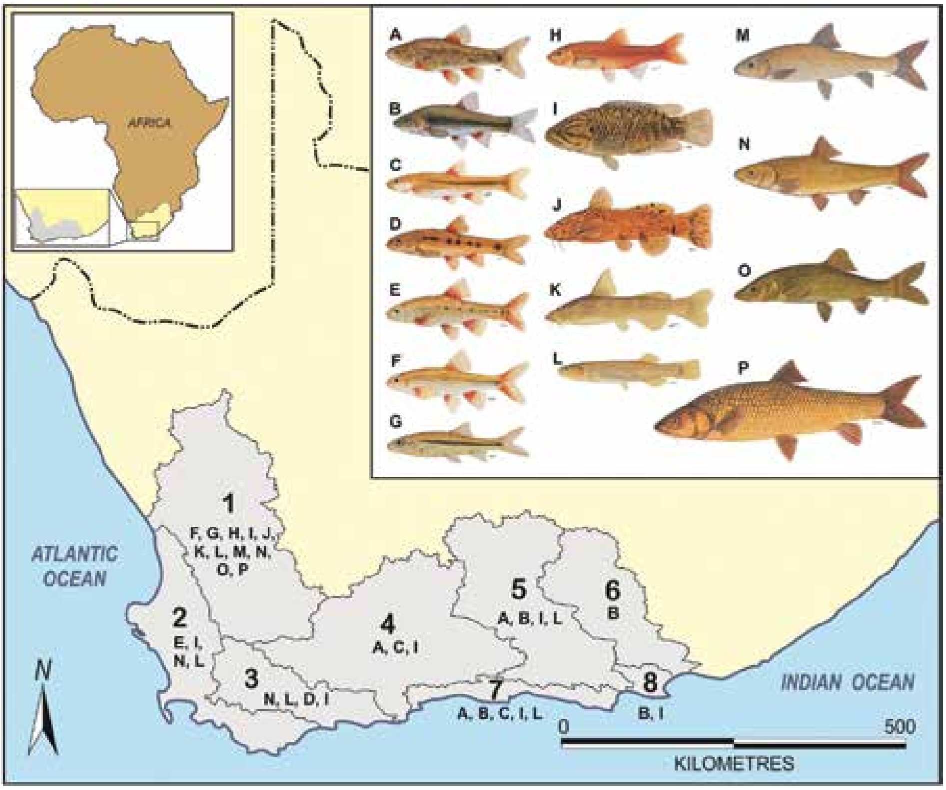


**Figure 1. Eight river basins in Cape Floristic Region and their endemic fishes. River basins: 1 = Olifants, 2 = Berg, 3 = Breede, 4 = Gouritz, 5 = Gamtoos, 6 = Sundays, 7 = Coastal drainages, 8 = Baakens. Fish: A = Smallscale Redfin (*Pseudobarbus asper*), B = Eastern Cape Redfin (*P. afer*), C = Slender Redfin (*P. tenuis*), D = Burchell's Redfin (*P. burchelli*), E = Berg River Redfin (*P. burgi*), F = Fiery Redfin (*P. phlegethon*), G = Clanwilliam Redfin (*Barbus calidus*), H = Twee River Redfin (*B. erubescens*), I = Cape Kurper (*Sandelia capensis*), J = Barnard's Rock Catfish (*Austroglanis barnardi*), K = Clanwilliam Rock Catfish (*A. gilli*), L = Cape Galaxias (*Galaxias zebratus*), M = Clanwilliam Sandfish (*Labeo seeberi*), N = Whitefish (*Barbus andrewi*), O = Sawfin (*B. serra*), P = Clanwillian Yellowfish (*Labeobarbus capensis*). Note: The Giant Redfin (*P. skeltoni*) recently described from the Breede River is not included. (Fish illustrations courtesy of SAIAB.)**

Late 19th-century introductions of both Rainbow Trout (*Oncorhynchus mykiss*) and Brown Trout (*Salmo trutta*) resulted in the development of a thriving sport fishery for these species in the cooler, high-altitude regions of the CFR (McCafferty et al. 2012). To develop similar angling opportunities in warmer, low-lying areas, five sunfishes (i.e., Largemouth Bass, *Micropterus salmoides*; Smallmouth Bass, *M. dolomieu*; Spotted Bass, *M. punctulatus*; Florida Bass, *M. floridanus*; and Bluegill, *Lepomis macrochirus*) were introduced between 1928 and 1980. With the assistance of informal stocking by anglers, alien game fishes spread rapidly, and on a regional scale most river basins now contain at least four alien fish species and few headwater tributaries remain noninvaded (Figure 2).

Although larger native species such as Clanwilliam Yellowfish (*Labeobarbus capensis*, Cyprinidae) are of interest to some anglers, it is recognized that the development of the large and economically important recreational fishery was the direct result of nonnative fish introductions (van Rensburg et al. 2011). Anglers that support these fisheries in the CFR are highly organized; the Federation of South African Flyfishers and the South African Bass Anglers Association, an organization affiliated to the Bass Anglers Sportsman Society in the United States, are strong proponents of trout and sunfish fisheries, respectively.

### Impacts of Nonnative on Native Fishes

Native fishes in the CFR are threatened by a variety of anthropogenic impacts including water extraction for agriculture, increasing sedimentation rates, habitat modification (e.g., canalization and dam building), and predation by and competition with alien invasive fishes (Tweddle et al. 2009). Though the individual impacts are difficult to determine, their combined effects have resulted in severe declines of mainstream populations of the large native cyprinids—Clanwilliam Yellowfish, Sawfin (*Barbus serra*), Whitefish (*Barbus andrewi*), and Clanwilliam Sandfish (*Labeo seeberi*)—and the disappearance of most endemic small minnow species in the lower reaches of CFR rivers. In more pristine environments such a headwater streams, however, the primary threat to native fishes is nonnative fish introductions (Tweddle et al. 2009).

Though initial introductions of nonnative fishes are fairly well documented, there are few published assessments of their impacts on South African aquatic ecosystems. This can be ascribed to the small number of scientists working in the field of fish invasion biology and the lack of research focus on the ecological impacts of fish introductions until the 1980s (McCafferty et al. 2012). The research that has been conducted in

**Table 2 . Currently established nonnative freshwater fishes in Cape Floristic Region with maximum length, date, and purpose of introduction.[a]**

| Species | Maximum length (cm SL) | Date | Purpose | Impact |
|---|---|---|---|---|
| Centrarchidae | | | | |
| Bluegill (*Lepomis macrochirus*) | 20 | 1938 | PR, AN | 1 |
| Smallmouth Bass (*Micropterus dolomieu*) | 55 | 1937 | AN | 2 |
| Florida Bass (*Micropterus floridanus*) | 70 | 1980 | AN | 2 |
| Spotted Bass (*Micropterus punctulatus*) | 60 | 1939 | AN | 2 |
| Largemouth Bass (*Micropterus salmoides*) | 60 | 1928 | AN | 2 |
| Cichlidae | | | | |
| Israeli Tilapia (*Oreochromis aureus*) | 30 | 1915 | AQ | 1 |
| Mozambique Tilapia (*Oreochromis mossambicus*) | 40 | 1936 | PR, AN, AQ | 1 |
| Southern Mouthbrooder (*Pseudocrenilabrus philander*) | 13 | 1980 | PR | 1 |
| Banded Tilapia (*Tilapia sparrmanii*) | 23 | 1941 | PR | 1 |
| Clariidae | | | | |
| African Sharptooth Catfish (*Clarias gariepinus*) | 130 | *1975* | AQ, AN, IB | 2 |
| Cyprinidae | | | | |
| Goldfish (*Carassius auratus*) | 25 | *1726* | OR | 3 |
| Grass Carp (*Ctenopharyngodon idella*) | 100 | *1980* | BI | 3 |
| Common Carp (*Cyprinus carpio*) | 75 | *1859* | AN | 3 |
| Orange River Mudfish (*Labeo capensis*) | 50 | *1975* | IB | 4 |
| Smallmouth Yellowfish (*Labeobarbus aeneus*) | 50 | *1953* | AN | 1 |
| Tench (*Tinca tinca*) | 64 | *1896* | PR, AN | 1 |
| Percidae | | | | |
| Yellow Perch (*Perca fluviatilis*) | 60 | *1915* | AN | 1 |
| Poecilidae | | | | |
| Western Mosquitofish (*Gambusia affinis*) | 6 | *1936* | PR, BI | 1 |
| Salmonidae | | | | |
| Rainbow Trout (*Oncorhynchus mykiss*) | 75 | *1897* | AQ, AN | 2 |
| Brown Trout (*Salmo trutta*) | 75 | 1892 | AQ, AN | 2 |

[a] SL = standard length, PR = prey species for predatory game fishes, AN = introduced for angling, AQ = aquaculture, IB = inter-basin water transfers, OR = ornamental/pet trade, BI = biocontrol. Documented impacts (1 = not assessed in South Africa; 2 = predation on and competition with native fishes; 3 = parasite/disease vector; 4 = hybridization with native fishes) in South Africa (after van Rensburg et al. 2011; Marr et al. 2012).

South Africa (e.g., Woodford and Impson 2004; Lowe et al. 2008; Weyl et al. 2010; Ellender et al. 2011) mirrors results from studies conducted elsewhere; alien game fishes' overt impact on native aquatic ecosystems is through predation (Moyle 2002; Cucherousset and Olden 2011; UCREFRP 2012a, 2012b). Predation has resulted in several local extirpations and small native fishes are typically restricted to headwater reaches of CFR streams where alien fish invasions have been impeded by barriers such as waterfalls and dams (Woodford et al. 2005; Ellender et al. 2011). As a result, the historical distribution ranges of most native CFR fish species are now severely constricted, fragmented, and genetically isolated (Swartz et al. 2004). This was similar to the situation in the western United States, where introduced sunfishes have often locally extirpated native cyprinid species (UCREFRP 2012a, 2012b).

## PLANNING FOR NATIVE FISH CONSERVATION

### Changing Attitudes and Management

South Africa lacks a national inland fisheries policy and the management of inland fisheries is the responsibility of provincial nature conservation departments. This is similar to the United States where inland fisheries are still largely managed by individual state fish and wildlife departments. Until the 1980s, South African conservation departments actively managed inland fisheries through enforcement of regulations and by enhancing fisheries through stocking programs. An increasing awareness of the impacts of nonnative fishes resulted in a change of attitude by conservation authorities, and nonnative fish production by government hatcheries stopped in the early 1990s (McCafferty et al. 2012).

Alien invasive species management is now a legislated priority in South Africa. The National Environmental Management: Biodiversity Act (Act No. 10 of 2004; NEMBA), for example, lists alien invasive species as a threat to biodiversity and includes legislation intended to prevent their unauthorized introduction and spread. To support the NEMBA, Alien and Invasive Species Regulations were published in July 2013. These regulations include prohibited species lists that prohibit the import, possession, movement, and release of more than 100 listed fish taxa and require an Invasive Species Management Program for nonnative game fish species (e.g., Brown Trout, Rainbow Trout, Common Carp, Largemouth Bass, and Smallmouth Bass). The Invasive Species Management Programs are expected to regulate these fish species through a zoning scheme on national maps, which include permitted and prohibited zones. All government departments and management authorities of protected areas are also obligated to develop monitoring, control, and eradication plans. Private land owners have to report the presence of listed invasive species and take steps to manage, eradicate, or prevent them from spreading.

Though conservation authorities considered the NEMBA as one of the most important pieces of conservation legislation for South African inland waters (Roux et al. 2006), some anglers and angling organizations saw this legislation as a direct attack on their sport and directly opposed NEMBA through public and political lobbying (McCafferty et al. 2012).

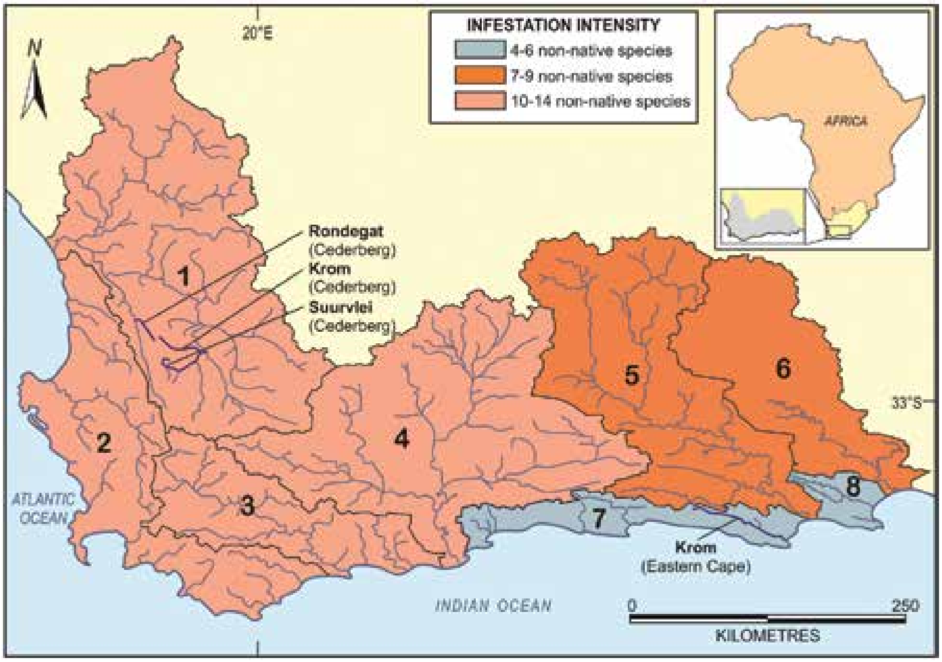


**Figure 2. Location of the four rivers selected for rotenone treatment (Rondegat, Krom-Cederberg, Suurvlei, and Krom-Eastern Cape) within the eight Cape Floristic Region river basins indicating the number of alien fish species present: 1 = Olifants, 2 = Berg, 3 = Breede, 4 = Gouritz, 5 = Gamtoos, 6 = Sundays, 7 = Coastal drainages, 8 = Baakens. Note: 2 and 7 incorporate smaller river basins and have been combined for illustration purposes. (Adapted from Marr et al. 2012.)**

## CapeNature, South African Institute of Aquatic Biodiversity, and the American Fisheries Society Collaboration

In 2000, the Cape Action for People and the Environment (CAPE) Program was started to more effectively conserve the CFR (Lochner et al. 2003). Recognizing the increasing impacts of nonnative fishes on native biodiversity, CapeNature, as part of the CAPE Program, developed conservation plans for aquatic ecosystems (Impson et al. 2002). CapeNature subsequently consulted with key conservation stakeholders, including the South African Institute of Aquatic Biodiversity (SAIAB) and the American Fisheries Society's (AFS) Fish Management Chemicals Subcommittee, to determine realistic fish eradication strategies and priorities.

A series of workshops were held at SAIAB in 2003 and 2004 that focused on identifying criteria for evaluating rivers for alien fish control. The criteria used were (1) severity of threat to native fishes, (2) current land use, (3) presence of geographic or man-made barriers that would prevent reinvasion after successful eradication, (4) logistic feasibility, and (5) degree of recreational angling affected (Marr et al. 2012). These criteria resulted in a list of four priority rivers where eradication was considered feasible (Figure 2).

Control of alien fish to benefit native fish is often recognized as difficult. Direct intervention through the use of piscicides was chosen as the most appropriate method because complete removal of nonnative fish from a particular area is usually required to recover the ecosystem's ability to support native species. Typically, if all fish are not removed from an isolated area, they are able to reproduce and the problem continues (Finlayson et al. 2010; Kolar et al. 2010). Discussions around the most appropriate method for fish removal were guided by experiences throughout the world. The use of piscicides or complete dewatering has the highest success rate in eliminating fish populations from isolated areas. Of the two available general piscicides rotenone and antimycin, rotenone was chosen because it had recently been approved for reregistration (U.S. Environmental Protection Agency 2007), and a Rotenone Standard Operating Procedures Manual (Rotenone SOP Manual) to guide safe and effective use has been recently published by AFS (Finlayson et al. 2010). Rotenone, a phosphorylation inhibitor, is a botanical material produced by various members of the bean family Leguminosae (McClay 2000). The substance has been widely used as a piscicide over the past 50-plus years in North America, Europe, New Zealand, and Australia for fisheries management and conservation purposes (McClay 2000; Britton and Brazier 2006; Rayner and Creese 2006; Pham et al. 2013). Rotenone is an unstable compound in nature and dissipates quickly from water through hydrolysis and photolysis, resulting in aquatic half-life values of 0.6 to 7.7 days (Finlayson et al. 2001, 2010).

## Environmental Impact Assessment

A key component of the CAPE Program was an Environmental Impact Assessment (EIA), which assessed whether the preferred method of alien fish eradication was ecologically and socially acceptable and whether the four chosen rivers were good candidates for restoration (Enviro-Fish Africa [EFA] 2009). Funding for the EIA was provided by the Global Environment Facility of the World Bank through a project administered by CapeNature. Although the use of piscicides is not a "Listed Activity" in South Africa's National Environmental Management Act (Act No. 107 of 1998) and did not require a mandatory risk assessment, environmental safeguards of the World Bank required that the project be subject to a rigorous, independent environmental analysis. The EIA recommended the Rondegat River as the first pilot project for removal of alien fishes using the piscicide rotenone (EFA 2009).

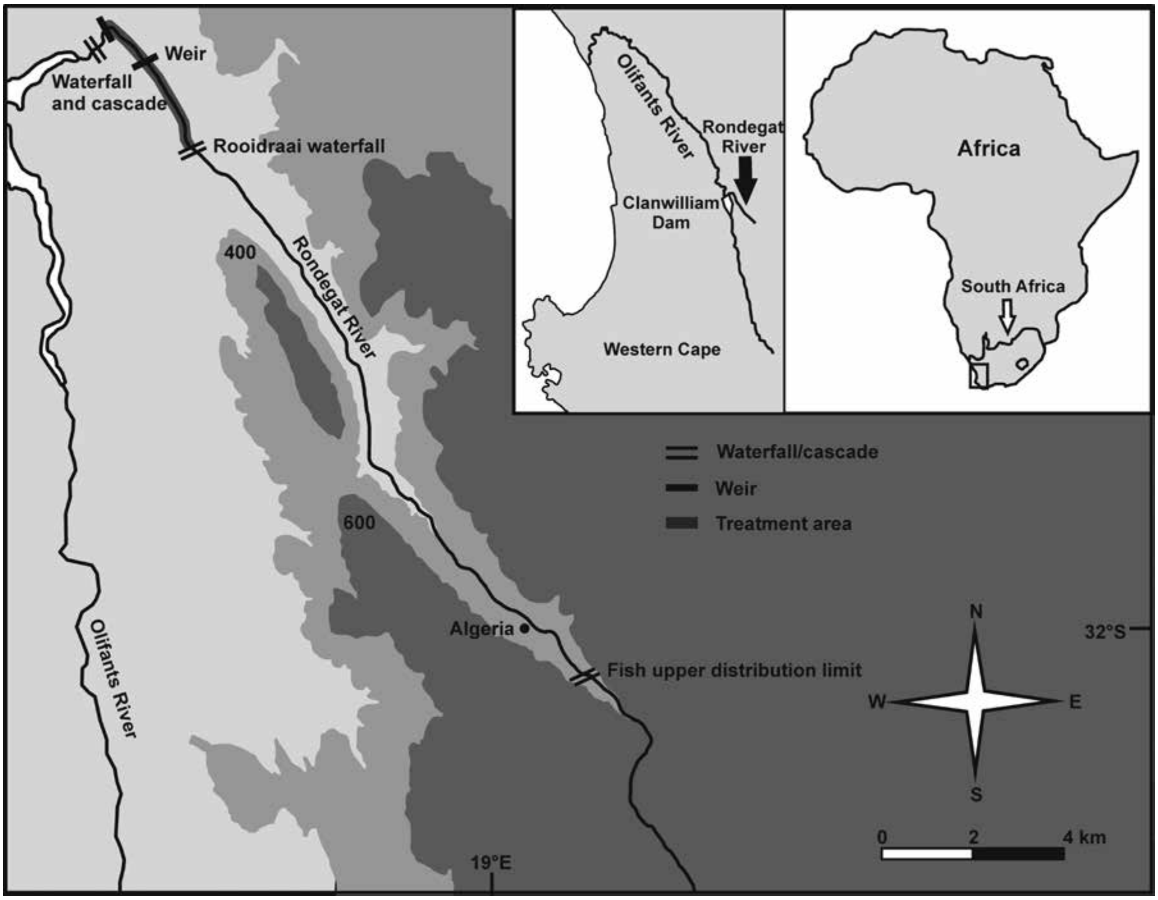


Figure 3. Rondegat River treatment area.



## RONDEGAT RIVER PILOT PROJECT

### Study Site

The Rondegat River (Figure 3) is typical of many invaded CFR streams. The 28-km-long single-channel river is shallow (<1 m deep) and relatively narrow (2–4 m wide). The river receives most of its flow in winter and early spring (May to September), and the groundwater-dependent summer discharge is very low (0.07–0.08 $m^3/s$). The geology of the catchment is primarily sandstone resulting in river water of great clarity (summer turbidity 0.5–2.8 NTU), moderate acidity (pH 5.4–6.3), and relatively low conductivity (14–120 µS/cm). Water temperature varies from about 8°C in winter (June–August) to 27°C in summer (December–February). These physical characteristics are very similar to those of many small headwater streams in the Western United States where rotenone has been used in the successful eradication of introduced species, allowing for the recoveries of native trout (*Oncorhynchus*) and char (*Salvelinus*) species (e.g., Finlayson et al. 2005).

The river flows into a 1,124-ha warmwater impoundment, Clanwilliam Dam, where alien Largemouth, Smallmouth, and Spotted Bass populations have been established since 1948 (Weyl et al. 2013). The lower river has three barriers to fish invasions from the impoundment: (1) a 1-m-high waterfall and bedrock cascade located 0.6 km above the high water mark of the impoundment; (2) a 2-m-high weir 0.4 km upstream of the bedrock cascade, and (3) the 1.3-m-high Rooidraai waterfall located 4 km upstream of the weir (Weyl et al. 2013). We thought this treatment area of the Rondegat River was ideal for native fish recovery because, like many small headwater streams in the Western United States, it was protected from reinvasion by fish barriers and thus had a high chance of success (Finlayson et al. 2005). Pretreatment electrofishing and snorkel surveys demonstrated that Smallmouth Bass had invaded to the Rooidraai waterfall (Woodford et al. 2005; Weyl et al. 2013). In the invaded reach, Clanwilliam Yellowfish were the only native fish able to coexist with Smallmouth Bass but native Fiery Redfin, Clanwilliam Redfin, and juvenile Yellowfish were abundant above Rooidraai. The project was implemented based on the assumption that the removal of Smallmouth Bass from the bounded section of river (i.e., between the weir and Rooidraai) would result in the recovery of the native fish. This assumption was supported by previous examples of native fish recovery following alien fish removal in other countries (e.g., Demarais et al. 1993; Lintermans 2000; Finlayson et al. 2005).

### Rotenone Application

The Rondegat River was first treated on 29 February 2012, when water temperatures were between 23°C and 27°C and stream discharge (0.07 $m^3/s$) and velocity (0.5 km/h) were low. Treatment was conducted according to the guidelines in the AFS Rotenone SOP Manual (Finlayson et al. 2010). Rotenone was applied to the river using a series of drip cans sited at seven locations spaced approximately at 1-h water travel time intervals to maintain the recommended treatment concentration of 1 mg/L CFT Legumine (Jordaan and Weyl 2013) during a 6-h treatment. Six backpack sprayers were used to treat the backwater, seep, and spring areas with a 1% v/v CFT Legumine solution. To minimize off-target effects, deactivation of rotenone downstream of the water diversion weir was accomplished using a 2.5% w/v solution of potassium permanganate ($KMnO_4$). Deactivation began at the same time as the rotenone treatment and lasted until 2 March 2012. To monitor the effectiveness of the treatment and deactivation, sentinel Smallmouth Bass were placed in net enclosures upstream of the emitters and at the 30-min travel time location downstream of the deactivation point. A second treatment was conducted one year after the first treatment on 13 March 2013.

## Fish Response

The response of the fish community to rotenone treatment was assessed during two pre-rotenone surveys (February 2011, February 2012) and three post-rotenone (March 2012, October 2012, and February 2013) surveys. The first three surveys utilized multiple methods including underwater video analysis, electrofishing, and snorkel surveys and are described in detail in Weyl et al. (2013). During subsequent surveys (October 2012 and February 2013) only snorkel surveys were conducted. These snorkel surveys included both qualitative assessments of snorkeling through the entire 4-km treatment zone as well as quantitative two-pass fish counts in 20 monitoring sites (Weyl et al. 2013). The entire 4-km treatment area was patrolled during and immediately after the two rotenone treatments and all dead fish were collected, identified, counted, and measured.



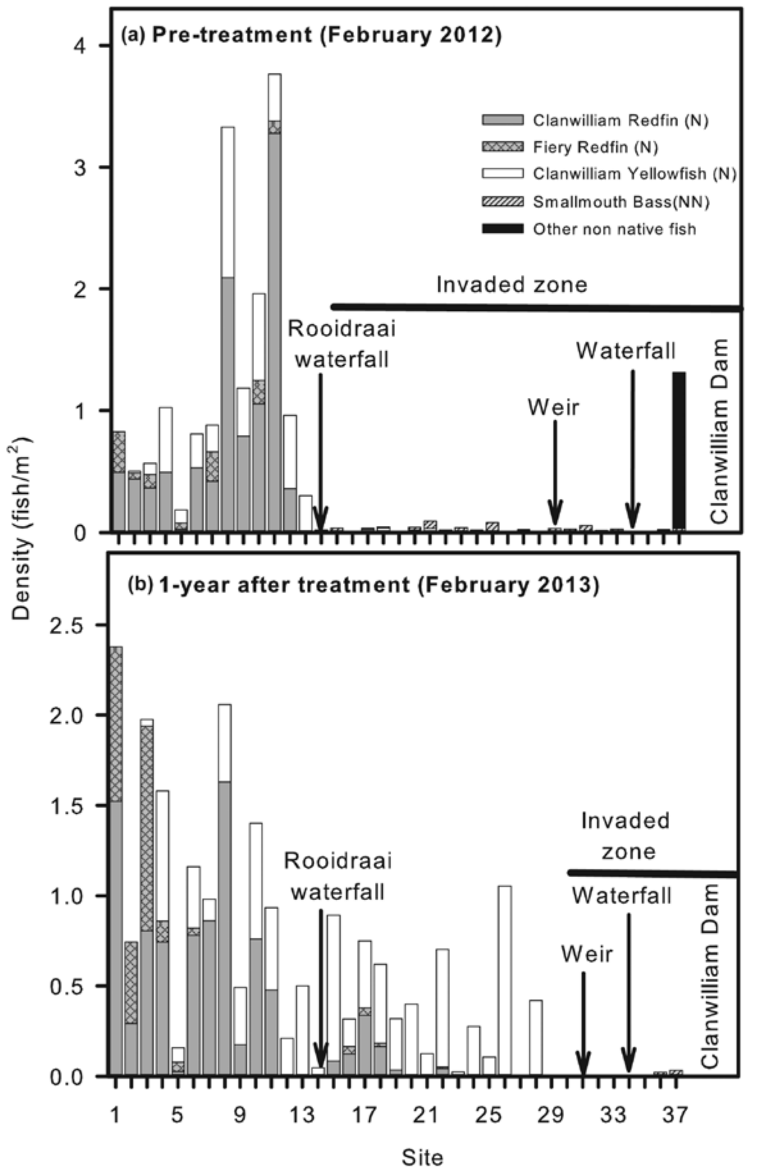


**Figure 4. Fish density in invaded and noninvaded survey sites of the Rondegat River determined from snorkel surveys conducted in (a) February 2012 immediately before the rotenone treatment and (b) February 2013 one year after the first treatment. Potential barriers to upstream migration of Smallmouth Bass are the lower waterfall, weir, and the Rooidraai waterfall. N = native; NN = nonnative.**

Pretreatment snorkel survey fish density estimates (mean ± SE) in the treatment area were 0.68 ± 0.33 fish/100 m$^2$ and Smallmouth Bass densities were 2.29 ± 0.56 fish/100 m$^2$ (Weyl et al. 2013). During the first rotenone treatment, 470 Smallmouth Bass and 139 Clanwilliam Yellowfish were removed from the river (Weyl et al. 2013). The total biomass of fish removed from the 4-km treatment section was 63 kg, of which 27.2% (17.2 kg) were Smallmouth Bass and 72.8% (45.8 kg) were Clanwilliam Yellowfish. All sentinel bass in the treatment area were killed, indicating an efficacious treatment, and the sentinel bass below the treatment area survived, indicating an effective deactivation of rotenone with $KMnO_4$. There was no evidence of treatment effects downstream and posttreatment surveys conducted one day after treatment detected no fish in the treatment area (Weyl et al. 2013). No Smallmouth Bass were detected in the treatment area during subsequent snorkel surveys but native fish densities were observed to respond positively. By October 2012, native fish density (mean ± SE) in the treatment area had increased to 9.6 ± 7.0 fish/100 m$^2$, and one year after the first treatment snorkel surveys estimated native fish densities at 38.7 ± 7.0 fish/100 m$^2$. These native fish densities were significantly higher than those observed in the treatment area prior to rotenone application (Mann-Whitney $U$ test: $U = 17.0$; $N = 16, 20$; $P < 0.0001$). Native fishes were now present at most survey sites in the treatment area but were still absent in downstream invaded zones (Figure 4). These findings were validated by comparing the numbers of fish recovered after the second treatment. Whereas the only native fish recovered during the first treatment were 139 Clanwilliam Yellowfish (mostly adult), 2,425 Clanwilliam Yellowfish (mostly juveniles), 349 Clanwilliam Redfin, 190 Fiery Redfin, and 11 Clanwilliam Rock Catfish were recovered during the second treatment (Figure 5). The almost instantaneous increase of fish diversity following Smallmouth Bass eradication from the Rondegat River not only exemplifies the impact that Smallmouth Bass have on native fish communities

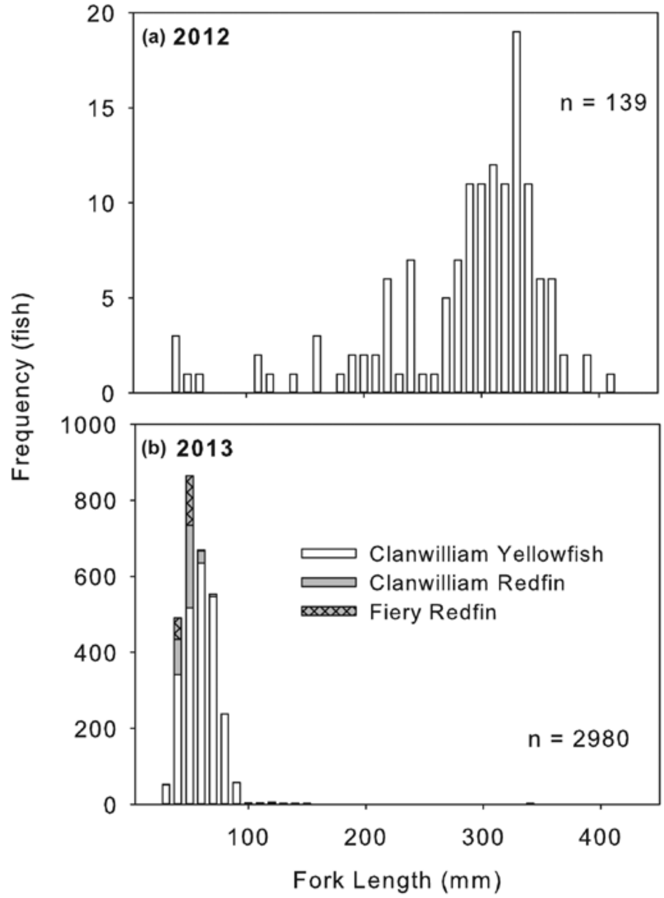


**Figure 5. Length frequency histograms of native fishes recovered from the treatment zone during the (a) 2012 and (b) 2013 rotenone treatments.**

**Photo 2. Melanie Duthie prepares to apply rotenone to the Rondegat River using a drip can. Photo credit: Bruce Ellender.**



but also demonstrates that recovery is likely to be rapid following the second treatment.

## Impacts on Nontarget Biota

Monitoring of aquatic invertebrates within the treated reach, which had detected 50 taxa in the week prior to treatment, found that 18 (36%) of these taxa were missing in the week following treatment. Follow-up surveys in May 2012 found 9 of these missing taxa back in the treatment zone, indicating a 50% recovery rate within 2 months of treatment. This rapid recovery was consistent with the expectation that the low level (≈ 1 mg/L formulation for less than 18 h) rotenone exposure would not have significant long-term effects on the macroinvertebrate assemblage (Finlayson et al. 2009). Of the 18 species initially lost following treatment, 5 were endemic to the mountain range drained by the Rondegat River, and all of these were present upstream of the treated reach, from where they could recolonize (Woodford et al. 2013). Amphibian diversity was not a conservation concern for the operation, as no frog taxa present in the catchment were restricted to the treated stream channel. The species present in the stream are widespread and common (e.g., Clicking Stream Frog, *Strongylopus grayii*; and Cape River Frog, *Amietia fuscigula*), also occurring upstream and in a variety of nearby wetland habitats that were not affected by the treatment (EFA 2009).

## MOVING FORWARD TO A NEW BEGINNING FOR NATIVE FISH

In South Africa, the responses of angling sectors to conservation projects that involve the control of alien fish species have varied. The South African Bass Anglers Association, whose members fish primarily on impoundments from boats for established populations of bass, do not formally object to conservation efforts in streams because these are not greatly utilized by their members. This differs considerably from the interests of the fly fishers who target alien trout in small mountainous streams. There are prime waters for trout fishing within protected areas of the CFR, and because many of these streams are considered a high conservation priority, rehabilitation projects were considered a direct threat to the fly angling community. For this reason the fly angling community took the lead in challenging CapeNature's river rehabilitation projects in newspapers, popular magazines, and the Internet (Marr et al. 2012). To improve awareness on the impacts of alien fishes and gain public support, CapeNature has written popular articles in local angling magazines promoting native fishes and associated conservation issues. In response, the general public and stakeholders from local communities expressed concerns about the necessity of removing alien game fish and the risks of using rotenone on nontarget taxa such as aquatic insects, native fishes, amphibians, and humans. The EIA addressed those concerns and included an independent scientific assessment of the proposed program including the rotenone treatment of the Rondegat River (Marr et al. 2012). This was a crucial first step to moving forward in changing the public's perception of native fish restoration projects that are scheduled in South Africa. Following the conclusion to the EIA, CapeNature convened a meeting with all stakeholders in August 2009 with no formal opposition to the project.

The almost instantaneous increase in biodiversity following the first treatment of the Rondegat River will likely encourage more native fish recovery programs in South African rivers. Apart from the four rivers mentioned, CapeNature recently held a stakeholder workshop that concluded that a further 14 CFR rivers were priorities for alien fish control. Fish and invertebrate responses in treated rivers will therefore continue to be monitored for the foreseeable future. An initially skeptical public, especially anglers, are likely to be more receptive to these projects if their angling needs are addressed and if projects yield biodiversity recovery. There is now a much greater public awareness of the plight of native CFR fishes and impacts of alien fishes in South Africa. The interaction among angling associations, local landowners, and CapeNature that occurred during this project resulted in a mechanism of better communication and understanding that is useful as a model for future treatments. Technical guidance from the AFS Rotenone SOP Manual (Finlayson et al. 2010) and on-site support from AFS and SAIAB were instrumental in the planning and successful eradication of Smallmouth Bass from the Rondegat River upstream of Clanwilliam Dam. This information has been transferred to CapeNature for use in future rotenone projects.

We are all aware that it is much easier to introduce unwanted fish into new environments than it is to remove these fish because of biological, social, political, and physical impediments. To prevent new infestations and ensure success of the alien fish eradication pilot program, CapeNature and SAIAB will continue to raise public awareness of the impacts of alien fish on CFR native fishes through information transfer at public meetings, websites, and news media productions. After completion of the four pilot projects now scheduled, the experiences will hopefully dictate a clear path forward and a new beginning for native fishes in South Africa.



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## REFERENCES

Britton, J. R., and M. Brazier. 2006. Eradicating the invasive topmouth gudgeon, *Pseudorasbora parva*, from a recreational fishery in northern England. Fisheries Management and Ecology 13:329–335.

Cambray, J. A. 2003. Impact on indigenous species biodiversity caused by the globalisation of alien recreational freshwater fishes. Hydrobiologia 500:217–230.

Chakona, A., and E. R. Swartz. 2013. A new redfin species, *Pseudobarbus skeltoni* (Cyprinidae, Teleosti) from the Cape Floristic Region, South Africa. Zootaxa 3686:565–575.

Clarkson, R., P. Marsh, S. Stefferud, and J. Stefferud. 2005. Conflicts between native fish and nonnative sport fish management in the Southwestern United States. Fisheries 30:20–27.

Cucherousset, J., and J. D. Olden. 2011. Ecological impacts of non-native freshwater fishes. Fisheries 36:215–230.

Demarais, B. D., T. E. Dowling, and W. L. Minckley. 1993. Post-perturbation genetic changes in populations of endangered Virgin River Chubs. Conservation Biology 7:334–341.

Dill, W. A., and A. J. Cordone. 1997. History and status of introduced fishes in California, 1871–1996: conclusions. Fisheries 22:15–18.

EFA (Enviro-Fish Africa). 2009. Environmental impact assessment of the proposed eradication of invasive alien fishes from four river sections in the Cape Floristic Region. Available: www.capenature.co.za/docs/1962/EIA%20exec%20summary.pdf. (October 2013).

Ellender, B. R., O. L. F. Weyl, and E. R. Swartz. 2011. Invasion of a headwater stream by non-native fishes in the Swartkops River system, South Africa. African Zoology 46:39–46.

Finlayson, B., R. Schnick, D. Skaar, J. Anderson, L. DeMong, D. Duffield, W. Horton, and J. Steinkjer. 2010. Planning and standard operating procedures for the use of rotenone in fish management. American Fisheries Society, Bethesda, Maryland.

Finlayson, B., W. Somer, D. Duffield, D. Propst, C. Mellison, T. Pettengill, H. Sexauer, T. Nesler, S. Gurtin, J. Elliot, F. Partridge, and D. Skaar. 2005. Native inland trout restoration on National Forests in the Western United States: time for Improvement. Fisheries 30:10–19.

Finlayson, B., W. Somer, and M. R. Vinson. 2009. Rotenone toxicity to rainbow trout and several mountain stream insects. North American Journal of Fisheries Management 30:102–111.

Finlayson, B., J. Trumbo, and S. Siepmann. 2001. Chemical residues in surface and ground waters following rotenone application to California lakes and streams. Pages 37–53 *in* R. Cailteux, L. DeMong, F. Finlayson, W. Horton, W. McClay, R. Schnick, and C. Thompson, editors. Rotenone in fisheries: are rewards worth the risks? American Fisheries Society, Trends in Fisheries Science and Management I, Bethesda, Maryland.

Gozlan, R. E., J. R. Britton, I. G. Cowx, and G. H. Copp. 2010. Current knowledge on non-native fish introductions. Journal of Fish Biology 76:751–786.

Impson, N. D., I. R. Bills, and J. A. Cambray. 2002. A conservation plan for the unique and highly threatened freshwater fishes of the Cape Floristic Kingdom. Pages 432–440 *in* M. J. Collares-Pereira, I. G. Cowx, and M. M. Coelho, editors. Conservation of freshwater fishes: options for the future. Fishing News Books, Blackwell Science, Oxford, England.

Jordaan, M. S., and O. L. F. Weyl. 2013. Determining the minimum effective dose of rotenone for the eradication of alien Smallmouth Bass (*Micropterus dolomieu*) from a South African river. African Journal of Aquatic Science [online serial]. 38(sup1):91–95.

Kolar, C. S., W. R. Courtenay, and L. G. Nico. 2010. Managing undesired or invading species. Pages 213–259 in W. A. Hubert and M. C. Quist, editors. Inland Fisheries Management in North America, 3rd edition. American Fisheries Society, Bethesda, MD.

Linder, H. P., S. D. Johnson, M. Kuhlmann, C. A. Matthee, R. Nyffeler, and E. R. Swartz. 2010. Biotic diversity in the southern African winter rainfall region. Current Opinion in Environmental Sustainability 2:109–116.

Lintermans, M. 2000. Recolonization by the mountain galaxias *Galaxias olidus* of a montane stream after the eradication of Rainbow Trout *Oncorhynchus mykiss*. Marine and Freshwater Research 51:799–804.

Lochner, P., A. Weaver, C. Gelderblom, R. Peart, T. Sandwith, and S. Fowkes. 2003. Aligning the diverse: the development of a biodiversity conservation strategy for the Cape Floristic Region. Biological Conservation 112:29–43.

Lowe, S. R., D. J. Woodford, N. D. Impson, and J. A. Day. 2008. The impact of invasive fish and invasive riparian plants on the invertebrate fauna of the Rondegat River, Cape Floristic Region, South Africa. African Journal of Aquatic Science 33:51–62.

Marr, S. M., N. D. Impson, and D. Tweddle. 2012. An assessment of a proposal to eradicate non-native fish from priority rivers in the Cape Floristic Region, South Africa. African Journal of Aquatic Science 37:131–142.

Marr, S. M., M. P. Marchetti, J. D. Olden, E. García-Berthou, D. L. Morgan, I. Arismendi, J. A. Day, C. L. Griffiths, and P. H. Skelton. 2009. Freshwater fish introductions in Mediterranean-climate regions: are there commonalities in the conservation problem? Diversity and Distributions 16:606–619.

McCafferty, J. R., O. L. F. Weyl, B. R. Ellender, and P. Britz. 2012. The use of water resources for inland fisheries in South Africa. Water SA 38:327–343.

McClay, W. 2000. Rotenone use in North America (1988–1997). Fisheries 20(5):15–21.

Moyle, P. 2002. Inland fishes of California. University of California Press, Berkeley.
Pham, L., D. West, and G. P. Closs. 2013. Reintroduction of a native galaxiid (*Galaxias fasciatus*) following piscicide treatment in two streams: response and recovery of the fish population. Ecology of Freshwater Fish 22:361–373.
Rayner, T., and R. Creese. 2006. Review of rotenone use for the control of non-indigenous fish in Australian fresh waters, and an attempted eradication of the noxious fish, *Phalloceros caudimaculatus*. New Zealand Journal of Marine and Freshwater Research 40:477–486.
Roux, D. J., J. L. Nel, H. M. MacKay, and P. J. Ashton. 2006. Cross-sector policy objectives for conserving South Africa's inland water biodiversity. Report No. TT 276/06. Water Research Commission, Pretoria, South Africa.
Skelton, P. H. 2001. A complete guide to the freshwater fishes of southern Africa. Struik Publishing, Cape Town.
Swartz, E. R., A. F. Flemming, and P. F. N. Mouton. 2004. Contrasting genetic patterns and population histories in three threatened redfin species (Cyprinidae) from the Olifants River system, western South Africa. Journal of Fish Biology 64:1153–1167.
Tweddle, D., R. Bills, E. Swartz, W. Coetzer, L. Da Costa, J. Engelbrecht, J. Cambray, B. Marshall, D. Impson, P. Skelton, W. R. T. Darwall, and K. G. Smith. 2009. The status and distribution of freshwater fishes. Pages 21–37 *in* W. R. T. Darwall, K. G. Smith, D. Tweddle, and P. Skelton, editors. The status and distribution of freshwater biodiversity in Southern Africa. International Union for Conservation of Nature, Gland, Switzerland, and South African Institute for Aquatic Biodiversity, Grahamstown, South Africa.
UCREFRP (Upper Colorado River Endagered Fish Recovery Program). 2012a. Nonnative fish management questions and answers—2012 (Colorado). Available: www.coloradoriverrecovery.org/events-news/news/NNF-Q&A-CO-2012.pdf. (October 2013).
———. 2012b. Nonnative fish management questions and answers—2012 (Utah). Available: www.coloradoriverrecovery.org/events-news/news/NNF-Q&A-UT-2012.pdf. (October 2013).
U.S. Environmental Protection Agency. 2007. Reregistration eligibility decision for rotenone. 738-R-07-005. USEPA, Washington, D.C.
van Rensburg, B. J., O. L. F. Weyl, S. J. Davies, L. J. van Wilgen, D. S. Peacock, D. Spear, and C. T. Chimimba. 2011. Invasive vertebrates of South Africa. Pages 326–378 *in* D. Pimentel, editor. Biological invasions: economic and environmental costs of alien plant, animal, and microbe species, 2nd editon. CRC Press, Boca Raton, Florida.
Weyl, P. S. R., F. C. DeMoor, M. P. Hill, and O. L. F. Weyl. 2010. The effect of largemouth bass *Micropterus salmoides* on aquatic macroinvertebrate communities in the Wit River, Eastern Cape, South Africa. African Journal of Aquatic Science 35:273–282.
Weyl, O. L. F., B. R. Ellender, D. J. Woodford, and M. S. Jordaan. 2013. Fish distributions in the Rondegat River, Cape Floristic Region, South Africa, and the immediate impact of rotenone treatment in an invaded reach. African Journal of Aquatic Science 28:201–209. DOI: 10.2989/16085914.2012.753401.
Woodford, D. J., H. M. Barber-James, T. A. Bellingan, J. A. Day, F. C. de Moor, J. Gouws, and O. L. F. Weyl. 2013. Immediate impact of piscicide operations on a Cape Floristic Region aquatic insect assemblage: a lesser of two evils? Journal of Insect Conservation 17:959–973.
Woodford, D. J., and N. D. Impson. 2004. A preliminary assessment of the impact of alien Rainbow Trout (*Oncorhynchus mykiss*) on indigenous fishes of the upper Berg River, Western Cape Province, South Africa. African Journal of Aquatic Science 29:109–113.
Woodford, D. J., N. D. Impson, J. A. Day, and I. R. Bills. 2005. The predatory impact of invasive alien Smallmouth Bass, *Micropterus dolomieu* (Teleostei: Centrarchidae), on indigenous fishes in a Cape Floristic Kingdom mountain stream. African Journal of Aquatic Science 30:167–173.