Coordinated approaches to rehabilitating a river ecosystem invaded by alien plants and fish

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Large sums have been spent on controlling invasive alien species in South Africa over the past two decades, but documented accounts of successes are almost non-existent. This brief account describes progress with a coordinated pioneering project to simultaneously clear invasive alien trees and predatory alien fish from a degraded but ecologically important river ecosystem in the Cederberg region of the Western Cape Province, South Africa. Dense infestations of invasive Australian *Acacia* and *Eucalyptus* species were cleared over 2 years (2010–2012) from the riparian zone of the lower reaches of the Rondegat River. This clearance was followed by the local eradication of an alien fish, smallmouth bass *Micropterus dolomieu*, from the lower reaches of the river in February 2012 and March 2013 using the piscicide rotenone, so that native threatened fish species could re-colonise from the upper reaches of the river. Overall costs of the clearance and eradication amounted to nearly R4.5 million, and early indications are that the native riparian vegetation and fish are recovering well. The project illustrates several aspects of good practice: careful planning; close and enthusiastic collaboration between affected state and private landowners; public participation to address concerns; the simultaneous and coordinated application of mechanical, chemical and biological control of alien plants and chemical control of alien fish; and direction by qualified ecologists. Although it is too early to assess the long-term success, the exercise provides useful lessons for such projects elsewhere, and paves the way for the more widespread use of similar approaches in selected areas that are a priority for conservation.

Introduction

The negative consequences of invasion by alien species – a global problem[1] – have been acutely felt in South Africa's Cape Floristic Region (CFR), which is noted for its high levels of biodiversity and endemism among plants and freshwater fish.[2,3] South Africa's response to this threat has come in the form of a large, national-scale programme that seeks to simultaneously control invasive alien species and to provide employment opportunities among poor rural communities.[4,5] This programme was focused initially on the control of invasive alien plants, for which R3.2 billion was spent over 15 years.[6] Its mandate has more recently been expanded to cover the control of invasive species from all taxonomic groups, with an increased budget of almost R1 billion per year.[7] While some concerns have been raised about the effectiveness of these interventions,[6,8] it is also widely recognised that careful planning and effective implementation can and have resulted in previously heavily invaded ecosystems being returned to a state that approaches pre-invasion conditions. Such successes are, somewhat surprisingly, rarely reported in the scientific literature. This absence is unfortunate, as published reports are needed both to demonstrate that control interventions can achieve the desired results, and to identify factors that contributed to success. Here we briefly describe a coordinated and pioneering alien species control project in which we sought to simultaneously remove invasive alien fishes and plants in order to restore native biodiversity and to protect a nationally important river.

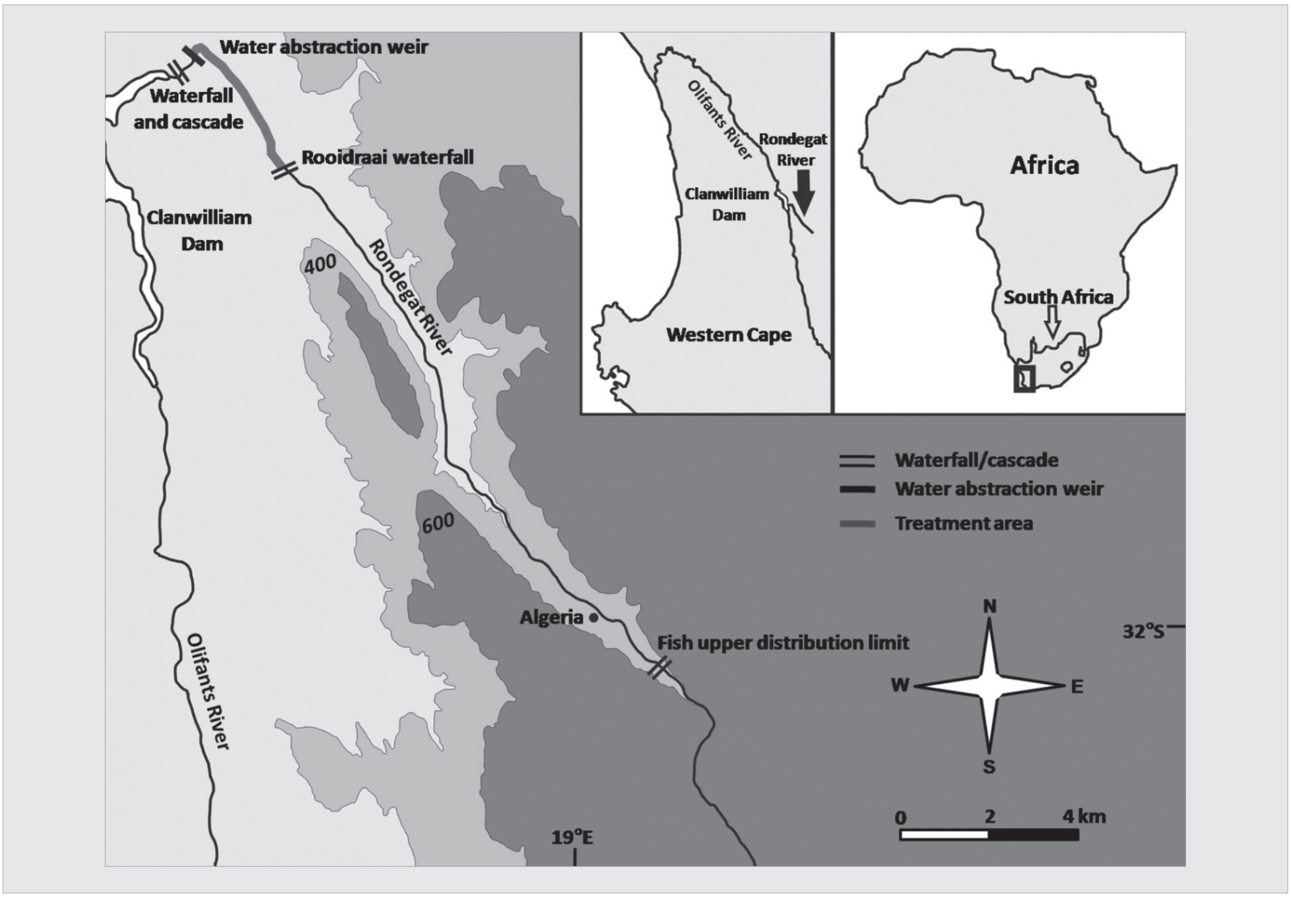
Study area

The restoration took place along the lower reaches of the Rondegat River (32º14' S; 18º56' E, total length about 20 km), a small perennial tributary of the Olifants River in the northwestern CFR (Figure 1). Its catchment is in the Cederberg Wilderness Area, an important protected mountain fynbos area. The upper reaches and headwaters are wholly within the protected area, while the lower reaches cross privately owned land before flowing into the Clanwilliam Dam on the Olifants River. The Rondegat is recognised as one of South Africa's Freshwater Ecosystem Priority Areas,[9] representative of the mountain streams, upper foothills, and lower foothills of the Western Folded Mountains, which contains a conservation-worthy assemblage of threatened fish species.

Natural vegetation along the river would have been typical of the lower foothills, but there has been no detailed study of the pre-invasion vegetation of the riparian zone. Prior to this project, the middle and lower river reaches were heavily invaded by alien (Australian) trees, mainly black wattle (*Acacia mearnsii* De Wild.), blackwood (*Acacia melanoxylon* R.Br.; Figure 2) and red river gum (*Eucalyptus camaldulensis* Dehnhardt). These trees were introduced to South Africa between 1850 and 1870,[10,11] and probably spread down the river from plantings at the upstream Algeria Forest Station in the (then) Cederberg State Forest, displacing the native riparian vegetation and reducing river flows, especially during the dry summer.

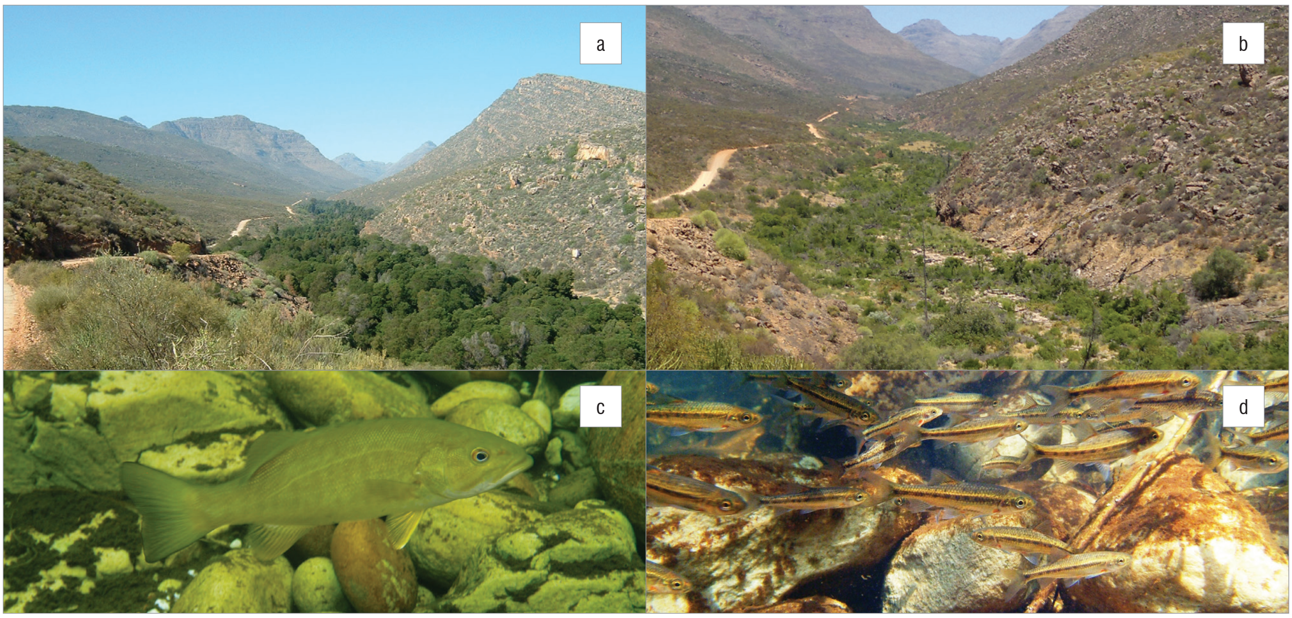
The Rondegat River is an important refuge for five species of threatened and regionally endemic freshwater fishes: the Clanwilliam rock catfish, *Austroglanis gilli* (Barnard, 1943); the Clanwilliam redfin, *Barbus calidus* (Barnard, 1938); the Cape Galaxias, *Galaxias zebratus* (Castelnau, 1861); the Clanwilliam yellowfish, *Labeobarbus capensis* (A. Smith, 1841); and the fiery redfin, *Pseudobarbus phlegethon* (Barnard, 1938).[12,13] The lower reaches of the river from the dam up to a waterfall barrier had been invaded by the alien North American smallmouth bass, *Micropterus dolomieu* (Lacepède, 1802), a voracious predatory fish that was introduced to South Africa in 1937 to provide angling opportunities,[14] and extirpated two species of redfin and Clanwilliam rock catfish from below the waterfall barrier.[12,13]

Alien smallmouth bass were to be eradicated from the lower 4 km of the river, from the Rooidraai waterfall to a small weir about 1 km above the Clanwilliam Dam (Figure 1). In this invaded area, only sub-adult and adult Clanwilliam yellowfish that were too large to be consumed were able to co-exist with bass,[13] but native fishes occurred at densities expected under undisturbed conditions in the non-invaded reach above the waterfall.[13]



Source: *Weyl et al.*[13]
Shadings represent 200-m contours.

Figure 1: Map showing location of the Rondegat River. The area targeted for fish rehabilitation was between the Rooidraai waterfall and the water abstraction weir; alien plants were cleared from this area and a further 10 km upstream.



Photos: (a) D Woodford; (b-d) ND Impson.

Figure 2: (a) View of the Rondegat River in 2004, showing heavy invasion by black wattle (*Acacia mearnsii*). (b) The same site early in 2013, following clearing and removal of invasive wattles, and the initiation of recovery of the native riparian vegetation. (c) Smallmouth bass, native to North America, were the dominant fish in the lower river reaches prior to restoration, having eliminated all smaller native fish. (d) A mixed school of endangered fiery redfin and vulnerable Clanwilliam redfin, which have started re-colonising the lower reaches of the Rondegat River following the local eradication of smallmouth bass.

History of the project

The Rondegat restoration project had its origins in the Cape Action Plan for People and the Environment (CAPE) in 2003.[15] CAPE recognised the need to address the threat that alien fish posed to the unique freshwater fish fauna of the CFR, leading to a proposal to eradicate alien fish from four priority rivers (Rondegat, Krom, Suurvlei and Kromme) using the piscicide rotenone, and to monitor the recovery of native fishes.[16] The proposed project was controversial, in particular the proposal to eradicate rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792) from the Krom River, resulting in resistance from the vocal freshwater fly-fishing community, and several negative reports in the press.[17-19] An environmental impact assessment (EIA) was therefore carried out to address these concerns, as well as to satisfy the requirements of national legislation. The EIA (which cost ~R250 000) concluded that the projects were justified, that the Rondegat River should be the first pilot, and that the choice of rotenone was appropriate.[16]

Following the EIA, several organisations collaborated to initiate the Rondegat pilot project. Funding was allocated from the Department of Environmental Affair's Working for Water Programme to simultaneously fund alien plant control and fish eradication, and the Citrusdal Irrigation Board was appointed to manage the plant control operation. The provincial conservation authority (CapeNature) took responsibility for the fish eradication. The South African Institute for Aquatic Biodiversity carried out pre- and post-treatment monitoring of aquatic fauna with funding from the Water Research Commission.[20] CapeNature also focused on raising awareness by organising meetings with riparian landowners and water users, and by providing regular progress reports to stakeholders.

Invasive alien fish control

The project employed international best practice in piscicide treatments,[21] and was further guided by on-site advice from experts from the USA and Norway. The project began with a determination of flow rates, which were needed to estimate appropriate dosages of piscicide. Following this determination, volunteers caught live fish from the targeted stretch of river, which were either released into the Clanwilliam Dam (Clanwilliam yellowfish), or used in ecotoxicological studies (smallmouth bass) to determine the concentration of piscicide that would be needed to ensure complete mortality.[22]

The target area was first treated on 28 February 2012 by dispensing rotenone at seven treatment stations. Eight backpack sprayers treated side channels and pools. At the end of the treatment area, immediately downstream of the weir, rotenone was de-activated using potassium permanganate (at a concentration of 2.5%). The effectiveness of the rotenone, and of the de-activation agent, was monitored through the response of sentinel fish (bass) in keep-nets. All fish in the treatment area died within 2 h of treatment, whereas sentinel bass below the de-activation station survived the treatment, indicating a successful de-activation of the rotenone outside of the target area.

During the 2012 rotenone operation, 470 smallmouth bass and 139 Clanwilliam yellowfish were collected. According to standard operating procedure,[21] a second treatment was conducted on 13 March 2013, and no further bass were collected, indicating that the prime objective had been met. During the 2013 treatment, ~3000 young-of-year (<10 cm) native fishes were collected from the treatment area, including Clanwilliam yellowfish, fiery and Clanwilliam redfins and Clanwilliam rock catlets. These fish were absent from the treatment area prior to bass removal[13] and their presence 1 year later suggests that a large number of native fishes were previously consumed by bass, and also that native fishes are likely to rapidly recolonise areas where bass are eradicated. Preliminary results of monitoring the aquatic invertebrate community response to the rotenone treatment indicated that invertebrate biomass and diversity is also recovering rapidly after treatment.[20]

The total cost of the fish eradication project was ~R3.3 million, of which R2 million was received from Working for Water, R1 million from CapeNature, and R300 000 from the Water Research Commission.

Invasive alien plant control

Systematic clearing of the alien invasive trees began in July 2010, and continued for 2 years until June 2012. The trees were felled, and the stumps treated with herbicides to prevent re-sprouting. Felled material was removed for use as firewood, or was piled on sandbanks and burnt. In total, 437 ha was cleared at a cost of R900 000. No attempts were made to re-establish native plants, which were expected to regenerate from isolated and previously suppressed plants, and from soil-stored seed banks. Research has shown that, even after heavy and extensive invasion, riparian seed banks have the potential to initiate the restoration process,[23] but outcomes vary across sites, and more research is needed to better understand the drivers of different responses.[24] By January 2013, native vegetation had already begun to dominate the riparian zone (Figure 2). There was a relatively high cover of native grasses on the cleared sites. Clearing invasive nitrogen-fixing alien wattles is known to increase the growth rates of weedy native grasses such as *Ehrharta calycina* J.E.Sm.[25] This increased growth is not expected to persist in the long term, although it may take several years for soil nutrients and processes to return to pre-invasion levels following the removal of nitrogen-fixing wattles.[26] There has been some germination of alien wattles from soil-stored seed banks, but it has not been extensive and regular follow-up treatments have been scheduled to clear them.

The likelihood of success of the wattle removal project has been substantially increased through the development of biological control that reduces the seed output of these invasive trees.[27] Two biological control agents have been released against *Acacia mearnsii.*[28] The first, a seed-feeding weevil, was released in 1993, and has reduced the seed production of *A. mearnsii* by half (and in some cases up to 78%). The second, a gall-forming fly, was released in 2006, and, where established, has led to the virtual cessation of pod production.[28] In the case of *A. melanoxylon*, another species of seed-feeding weevil was released in 1986, and has reduced seed production by over 90%.[28] The cleared sites will have to be regularly monitored to ensure that the early gains are not reversed by re-invasion, but the addition of biological control as a supplement to mechanical control has improved the chances of long-term success. Before the introduction of biological control agents, mechanical clearing operations were far less feasible because of the very dense seedling regeneration that followed clearing of Australian wattles.[29] By reducing the pool of seeds, the follow-up treatments are now far less onerous.

Conclusions

The direct costs of this project may appear to be high (> R1 million/km), but many of the costs need not be repeated. For example, the use of international experts will not be required again and EIA costs should be substantially reduced. Now that the protocols have been established, a precedent set, and a team trained, the costs can reasonably be expected to be much less in future. The project reported here has a good chance of success because the fundamentals of good practice have been employed. These include:

- The adoption of a clear goal – in this case the desire to restore the biodiversity of a particular river reach to an agreed condition.
- The involvement of key stakeholders in the assessment of trade-offs and risks, through an appropriate EIA.
- Careful planning, incorporating international best practice in the setting of goals, the scheduling of follow-up treatments, and the monitoring and evaluation of outcomes.
- Close collaboration between affected state agencies, private landowners and interested parties.
- Public participation to address concerns, ongoing awareness-raising, and regular communication of progress to stakeholders.
- Adequate funding allowing for the simultaneous and coordinated application of mechanical, chemical and biological control of alien plants and chemical control of alien fish.
- The direction of the project by qualified ecologists.

While the need for these practices may appear self-evident, they have been, and often still are, absent when control operations are implemented.[6,8,30] We would recommend that in future all ecosystem rehabilitation projects that aim to reduce the impacts of invasive alien species should adopt approaches that include all of the above elements. This recommendation is particularly important in South Africa, where substantial sums are spent on control operations, and where the adoption of best practice will reap many rewards. In particular, we would strongly encourage the adoption of a prioritised approach to control operations, so that limited funds can be utilised to bring about more successes similar to the one outlined here.

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