



Optimising invasive fish management in the context of invasive species legislation in South Africa



Authors:

Darragh J. Woodford^{1,2}
 Phillip Ivey³
 Martine S. Jordaan^{2,4} 
 Peter K. Kimberg⁵
 Tsungai Zengeya³ 
 Olaf L.F. Weyl^{2,6}

Affiliations:

¹Centre for Invasion Biology, School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Johannesburg, South Africa

²South African Institute for Aquatic Biodiversity (SAIAB), Grahamstown, South Africa

³South African National Biodiversity Institute, Cussonia, Pretoria, South Africa

⁴CapeNature Scientific Services, Stellenbosch, South Africa

⁵The Biodiversity Company (TBC), Johannesburg, South Africa

⁶Centre for Invasion Biology, SAIAB, Grahamstown, South Africa

Corresponding author:

Darragh Woodford,
 darragh.woodford@wits.ac.za

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Background: South Africa hosts a large number of non-native freshwater fishes that were introduced for various industries. Many of these species are now listed under the *National Environmental Management: Biodiversity Act* (NEM:BA) Alien and Invasive Species (A&IS) lists and regulations, though the practical options available to conservation agencies to effectively manage these fishes vary greatly among species and regions.

Objectives & methods: We assessed the history and status of national legislation pertaining to invasive freshwater fishes, and the practical implications of the legislation for managing different species with contrasting distributions, impacts and utilisation value.

Results: The smallmouth bass, despite being a potential conflict-generating species, is fairly straightforward to manage based on current legislation. Two species of trout, which remain absent from the NEM:BA A&IS lists because of ongoing consultation with stakeholders, continue to be managed in regions like the Western Cape province using existing provincial legislation. To maximise the limited capacity for management within conservation agencies, we proposed a decision-support tool that prioritises invasive fish populations that represent high environmental risk and low potential for conflict with stakeholders. Using three case studies, we demonstrated how the tool can be used to set management goals of 'eradicate', 'manage against impacts and further spread' and 'continue to monitor population' as the most pragmatic solutions given the state of an invasion, its socio-economic impact and the capacity of the responsible agency to act.

Conclusion: By choosing a pragmatic management strategy, conservation agencies can maximise the effective deployment of limited resources, while minimising avoidable conflicts with stakeholders.

Introduction

Freshwater fishes form a key component of invasive alien fauna in many countries around the world, and several regions have fish communities with high proportions of non-native species (Leprieur et al. 2008). Especially, high rates of species introductions have occurred in regions such as South America, the Iberian Peninsula and Australasia for a variety of purposes, most significantly for recreational angling, commercial harvesting and aquaculture, as well as the pet trade (Daga et al. 2016; Elvira & Almodóvar 2001; Macchi et al. 2008; Marr et al. 2010). Many of the original goals for these introductions were successfully achieved, for instance, the creation of viable and economically important fisheries based on non-native species (e.g. Macchi et al. 2008). Unfortunately, these introductions have also led to a number of negative ecological impacts (e.g. McDowell 2006; Weber & Brown 2009). As a consequence, many countries within these regions have attempted to balance the positive socio-economic benefits with the negative ecological impacts of invasive alien fishes in their management policies (Jackson et al. 2004; Macchi et al. 2008). This has included radical and, we suggest, potentially irresponsible proposed laws to 'naturalise by decree' invasive species, making them legally native to maximise their utilisation in aquaculture (Pelicice et al. 2014). Such examples illustrate the delicate balance in governance that needs to be struck between conserving the environment and acknowledging the rights of stakeholders to exploit invasive alien species as resources (Zengeya et al. 2017).

South Africa, like many countries, has a long history of alien fish introductions, dating back to the 18th century (Van Rensburg et al. 2011). Early policies actively promoted introductions and spread as these species were recognised as a valuable recreational resource (McCafferty et al. 2012). Over time, however, growing awareness of the negative impacts of key invasive species on the conservation of rare and endangered indigenous species (primarily extirpation through predation)

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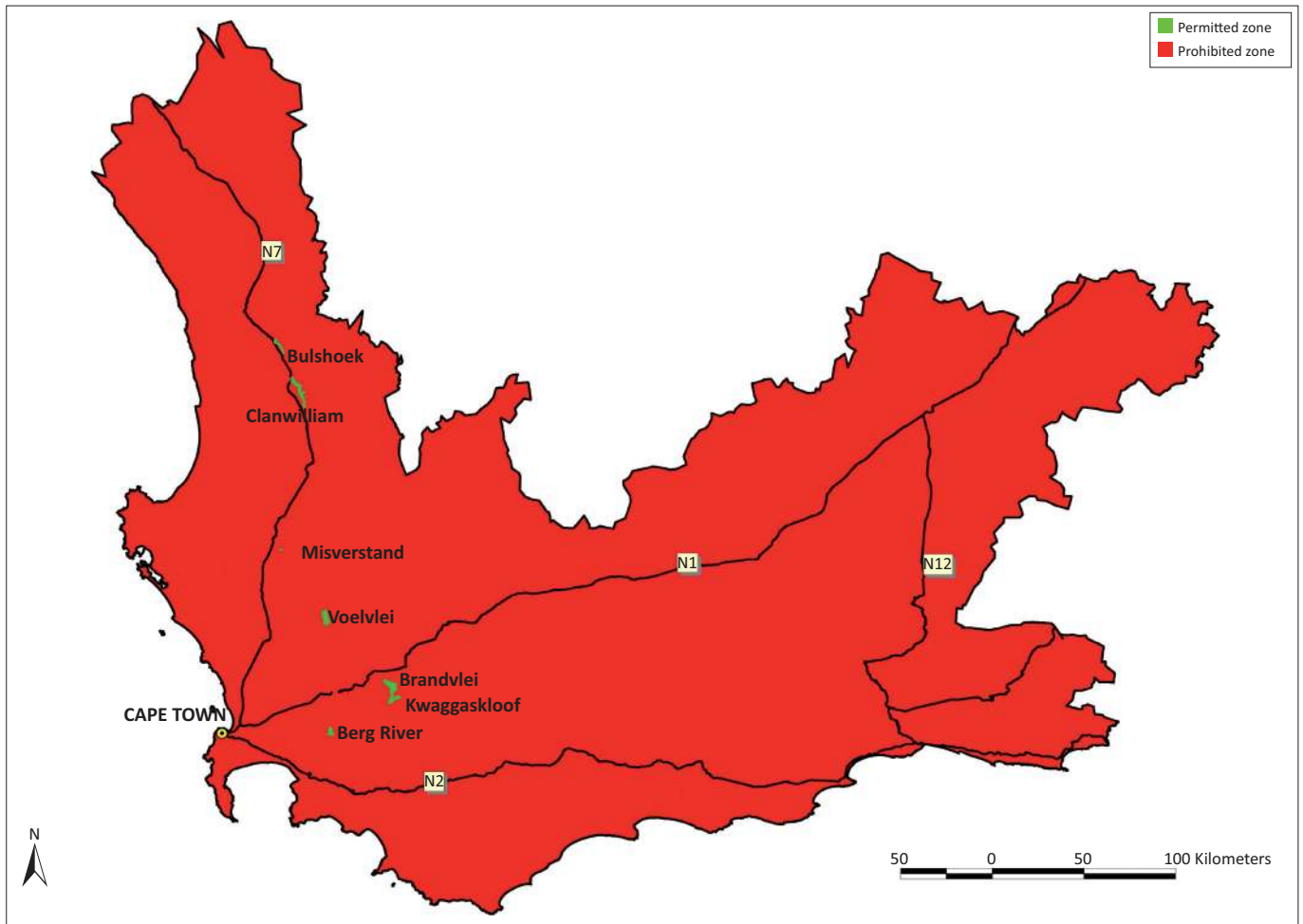
drove a policy shift to conserving these indigenous species by managing or removing alien populations with negative ecological impact (Ellender et al. 2014; McCafferty et al. 2012). This shift in policy within government and parastatal environmental management agencies has been supported by an increasing body of evidence for the negative impact of key sport fish species, such as smallmouth bass (*Micropterus dolomieu*) and rainbow trout (*Oncorhynchus mykiss*), on native biodiversity (see review by Ellender & Weyl 2014). Nonetheless, despite the change in focus of the government conservation bodies originally responsible for the introduction, propagation and distribution of introduced species, many thriving recreational and commercial fisheries have emerged based on these alien species (McCafferty et al. 2012). If not properly regulated, these activities could complicate the conservation management of freshwaters because there is a lack of national policy to effectively manage these species and the threats they pose to the environment (Marr et al. 2017; McCafferty et al. 2012). In the absence of such policy, the management of non-native sport fishing populations was taken up by national angling organisations such as the Federation for South African Flyfishers, as well as provincial organisations like the Cape Piscatorial Society (CPS), which manages trout waters in the Western Cape province (Ellender et al. 2014; Weyl et al. 2014). As a by-product of the national devolution of management of fisheries to such organisations in the mid-1980s, government regulation of these fisheries subsequently became highly variable and inconsistent from province to province. Although some provinces like the Western Cape required the purchase of an angling license for inland recreational fishing, other provinces such as the Eastern Cape completely ceased the regulation of angling activities involving alien species in the 1990s (McCafferty et al. 2012).

The principles underlying the management of invasive freshwater fishes began to shift irrevocably with the publication of the *National Environmental Management: Biodiversity Act* (NEM:BA; Republic of South Africa [RSA] 2004). This legislation stated that lists of invasive species and associated regulations for their control should be developed and promulgated. NEM:BA set in motion a sequence of consultations, negotiations and conflicts between the Department of Environmental Affairs (DEA) and key angling organisations, which to date have yet to be fully resolved. NEM:BA has also, as we will show, increased the management burden on both the DEA and severely under-resourced conservation agencies, who assist with the implementation of the new regulations. In this review, we (1) outline the logistical implications of the NEM:BA regulations for these agencies and (2) introduce a recently developed decision-support framework that is intended to minimise the logistical burden of the regulations through prioritisation of critical invasive fish populations where management action is feasible. Where provincial legislation currently supersedes the NEM:BA legislation in providing the legal mandate of provincial conservation agencies to act, we use the Western Cape province as an example for exploring case studies in the practical management of invasive fishery species.

The NEM:BA alien and invasive species legislation

The first comprehensive list of invasive alien fishes produced under NEM:BA (Government Notice 350; RSA 2009) was released for public comment (i.e. not a regulatory tool at this point) on 3 April 2009. Invasive sport fishes such as rainbow trout and smallmouth bass were listed as Category 2 species, meaning that they were to be regulated by area: permitted in some catchments but not others. In anticipation of this management regime becoming law, the DEA contracted the South African National Biodiversity Institute (SANBI) to initiate a consultative mapping process with angling organisations and the aquaculture industry. Coordinated by the South African Institute for Aquatic Biodiversity (SAIAB), this process sought to divide the country to sub-quaternary level for each listed species into 'green' (permitted), 'red' (prohibited) and 'orange' (data-deficient) zones. Stocking and utilisation would be permitted under permit for green and orange zones, the latter following an environmental risk assessment and final approval by the responsible conservation agency.

The consultation process proceeded through 2009 and by 2010 zonation had been developed for key taxa in some provinces. Smallmouth bass in the Western Cape, for example, was permitted in only seven artificial impoundments where established populations were being utilised for recreational fishing (Figure 1) and prohibited from all other water bodies within the province. Rainbow trout, in comparison, presented a complex patchwork of red, green and orange catchments within the Western Cape (Figure 2). This process was, however, set aside by the DEA when, in 2013, it published the new iteration of the NEM:BA lists and regulations for invasive species (RSA 2013). These new lists published for public comment categorised all alien freshwater fish species as 'Category 1b invasive species', meaning that they would 'require control by means of an invasive species management programme' (RSA 2013). This proposed categorisation of commercially important angling species, especially rainbow trout which is the cornerstone of South Africa's freshwater aquaculture industry, took many of these stakeholders by surprise and resulted in significant concern over their future viability (Cox 2013). The result was the formation of a new industry group called 'Trout SA', which challenged this proposed listing through both consultation with the DEA and direct lobbying of key politicians and decision-makers. The results of these efforts, which also stimulated renewed consultation between other angling organisations (e.g. the South African Bass Angling Association) and the DEA, were the promulgation of a third iteration of the lists and regulations (RSA 2014). These lists allocated multiple, context-specific categorisations for each listed alien freshwater fish and excluded rainbow trout and brown trout (*Salmo trutta*) altogether. At present, the DEA continues to negotiate with Trout SA over the terms for which these two species will be listed under the Alien and Invasive Species (A&IS) regulations in the future.



Source: CapeNature Scientific Services

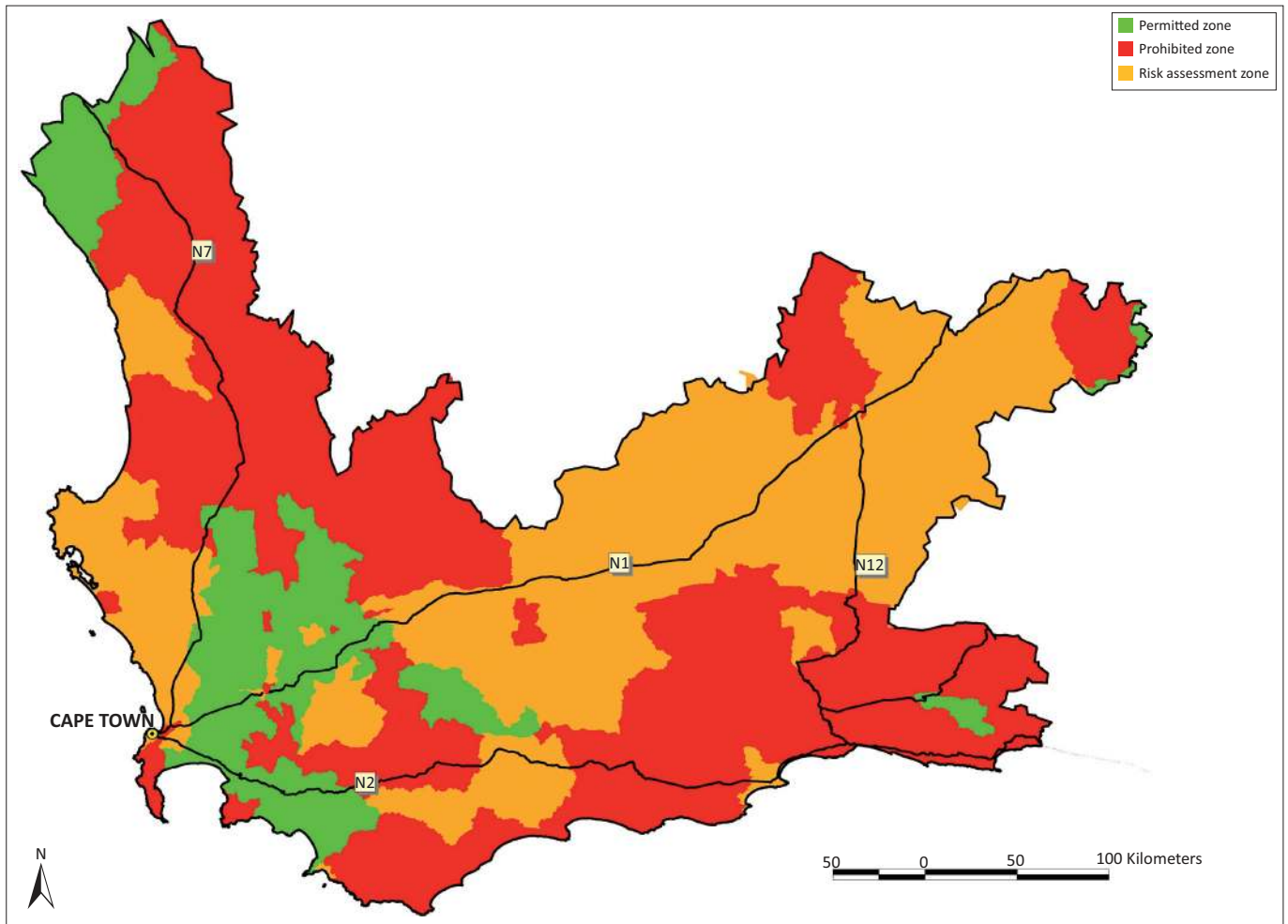
Red areas were to be prohibited for bass, whereas green areas were to be permitted areas. The red areas correspond to where smallmouth bass is listed as a Category 1b or 3 invasive species in the province, whereas green areas are dams where the species is listed as a Category 2 species under the current regulations.

FIGURE 1: Map of smallmouth bass management zones in the Western Cape from the 2009 mapping consultation process, coordinated by SAIAB.

To illustrate the practical implications of the promulgated NEM:BA A&IS regulations, we examine regulations for smallmouth bass (Table 1). Smallmouth bass is listed as Category 1b for formal conservation areas and 'mountain catchment areas'. The latter point recognises that headwater streams are likely to have high conservation value regardless of whether they fall within formally and legally conserved areas and rivers (Nel et al. 2011; Weyl et al. 2014). The species should not be introduced into these areas and if present should be managed appropriately (eradicated if feasible). Smallmouth bass is listed as Category 2 in impoundments where it currently occurs, which means it can be caught, released and stocked with a permit in these water bodies. It is also listed as Category 3 in wetlands, rivers and estuaries where it currently occurs meaning that the species can remain in these areas without the need for managing or controlling them, but further movement or breeding or trading is not permitted. Aside from the artificial impoundments where it is listed Category 2, the release of the species into any water body within catchments where it does not already occur is prohibited (Table 1). The net result of these complexly worded regulations is that they generally reflect the negotiated spatial management regime coordinated by SAIAB under the 2009 draft A&IS regulations (Figure 1).

The practical upshot of the latest regulations for smallmouth bass is that the management of the species in the Western Cape has not really changed in the years because the NEM:BA was originally promulgated in 2004. Within the permitting context, freshwater fish permits have been issued by CapeNature, the provincial conservation agency under the requirements of the Western Cape Nature Conservation Ordinance (Ordinance No. 19 of 1974), amended in 2000 to the *Western Cape Nature Conservation Laws Amendment Act* (Act No. 3 of 2000). Review of permit applications at a provincial level has since 2010 included the draft 2009 A&IS maps as a decision-support tool with the result that, with the exception of the seven impoundments where significant recreational bass fisheries exist (Figure 1), no permits were granted for the stocking of smallmouth bass into farm dams or rivers. It must however be noted that smallmouth bass permits were not regularly applied for and that between 2010 and 2015, only a single smallmouth bass application was received (and not approved) versus 47 applications for largemouth bass (*Micropterus salmoides*), of which 46 were approved.

Moreover, CapeNature has led the country in its proactive management of smallmouth bass, coordinating the removal



Source: CapeNature Scientific Services.

Red areas were to be prohibited for trout, green areas were permitted areas and orange areas would require a risk assessment before permits to stock can be granted.

FIGURE 2: Map of rainbow trout management zones in the Western Cape from the 2009 mapping consultation process, coordinated by SAIAB.

TABLE 1: Regulations for the management of smallmouth bass.

Species	Category/area regulations	Exemptions/prohibitions
Smallmouth bass (<i>Micropterus dolomieu</i>)	<p>a. 1b in National Parks, Provincial Reserves, Mountain Catchment Areas and Forestry Reserves declared in terms of the Protected Areas Act.</p> <p>b. 2 for release into dams within discrete catchment systems in which it occurs</p> <p>c. 3 in all rivers, wetlands, natural lakes and estuaries in which it occurs.</p> <p>d. Subject to (b), each listed bass species is not listed for dams within discrete catchment systems in which it occurs.</p>	<p>a. The transfer or release of the species from one discrete catchment system in which it does not occur, or from within a part of a discrete catchment system where it does occur to another part where it does not occur as a result of a natural or artificial barrier, is prohibited.</p> <p>b. The release of the listed bass species in National Parks, Provincial Reserves, Mountain Catchment Areas and Forestry Reserves declared in terms of the Protected Areas Act is prohibited.</p> <p>c. The release of the listed bass species in any rivers, wetlands, natural lakes or estuaries is prohibited.</p> <p>d. The species is exempted for a period of 2 years from the date of promulgation, from requiring a permit for any restricted activity in terms of the Act, provided a person is in possession of a valid provincial permit.</p> <p>e. Catch and release of the listed bass species is exempted in discrete catchment systems in which they occur.</p>

Source: Adapted from Government Notice No. 37885 (RSA 2014).

These regulations also apply for spotted bass, Florida bass and hybrids of Florida bass and largemouth bass.

of both the fish species and invasive alien trees (*Acacia* and *Eucalyptus* species, also listed under NEM:BA) from the Rondegat River in the Greater Cederberg Biodiversity Corridor (Impson, Van Wilgen & Weyl 2013; Weyl et al. 2014). The significance of the operation from a regulation standpoint is that the Rondegat River represented a water body where the species was Category 1b (a mountain catchment area), but flowed into Clanwilliam Dam – a reservoir where smallmouth bass is Category 2. By successfully removing a Category 1b population without impinging upon an adjacent Category 2 population (and its stakeholders), the operation demonstrated how direct

control of environmentally damaging invasive fishes can be achieved within the current legal framework.

Managing trout in a national regulatory vacuum

Following the publication of the promulgated list of invasive alien species (RSA 2014), DEA has engaged in ongoing negotiations with stakeholders to list trout through an amendment of the lists and regulations. Consultations have focussed on mapping the present distribution of trout and their users in the country, so that stocking and utilisation can

be exempt from NEM:BA permitting in areas that have long-established trout populations. Streams that undergo regular stocking of trout for 'put and take' fisheries, and those which have existing aquaculture facilities in their catchments are a particular focus of these discussions. The mapping of these so-called trout waters has been difficult and is ongoing; the process attempts to balance the needs of vested-interest groups (particularly aquaculture and fly fishing) and the safeguards articulated by conservation authorities in the DEA, the provinces and biodiversity authorities such as SAIAB. In particular, there are currently several areas of dispute about where trout occur, and opposition to proposed restrictions on utilisation and additional stocking in some 'trout waters' because of local biodiversity concerns (e.g. co-occurrence with threatened native fish). Consultations are ongoing, primarily between Trout SA and the DEA, to find a resolution to these issues, but the issue of national regulation of trout-based activities remains a highly polarised issue (Woodford et al. 2016). Although this national legislative impasse continues, both rainbow and brown trout remain regulated under provincial ordinances. Environmental impacts of aquaculture activities involving these species are regulated by the Department of Agriculture, Forestry and Fisheries.

The Western Cape has an established recreational riverine trout fishing sector, formalised mainly within the CPS and a few other angling clubs such as the Worcester Trout Anglers and Cape Fly Fishers, as well as a commercial trout aquaculture sector that form the Western Cape Trout Association (WCTA). Collectively these stakeholders form the backbone of trout utilisation within the Western Cape, and the distribution of their activities is reflected in the 'green' trout areas negotiated to produce the 2009 A&IS maps (Figure 2). Stocking and transport permits have been issued annually to WCTA members as all commercial farms, barring two, are located in 'green' trout zones. The two commercial farms outside of formal trout zones also received permits but ad hoc stocking of farm dams in this catchment was not permitted and a request to expand commercial aquaculture operations into the headwater zone of the river was also not approved.

In terms of recreational trout angling on rivers, many areas managed by the CPS are located on provincial nature reserves and in mountain catchment areas where trout have a long history of establishment. Angling activities on these rivers are currently managed by the CPS based on an agreement made in 1992 and an amended agreement in 2008. This agreement has since lapsed and a new agreement is in the process of being negotiated between CapeNature and the CPS (Dean Impson [CapeNature] pers. comm.). As the trout populations of interest to the CPS and most other angling clubs are largely self-sustaining, less than 5 applications have been received since 2010 for the stocking of rivers. Such applications have included the Hex River, which is stocked every 2–3 years with a small number of hatchery-bred trout to maintain a viable recreational fishery in the river.

The Hex River catchment area is currently zoned 'green' in the 2009 A&IS maps and permits were thus granted.

The policy-implementation gap and the need for prioritisation tools

The conservation management of freshwater ecosystems in South Africa currently falls under the purview of the DEA and its provincial departments and agencies. The enforcement of NEM:BA A&IS legislation, including regulating the transport and stocking of alien fishes, identifying invasive populations where they are prohibited, as well as developing conservation management plans for such populations, is the joint responsibility of these national and provincial bodies. Besides these obligations, the provincial agencies must also, *inter alia*, monitor aquatic ecosystems, provide land use and conservation planning documentation, and process permit applications for a wide variety of private and commercial activities with environmental impacts (Impson 2016). Given these wide-ranging responsibilities, there is currently a critical shortage in inland aquatic science capacity at most provincial conservation departments. For example, the Western Cape province currently employs four aquatic specialists within CapeNature's Scientific Services, whereas six of the eight remaining provincial agencies have two or fewer staff members with aquatic science qualifications (Impson 2016).

This lack of capacity, together with generally constrained management budgets within provincial government, makes conservation interventions such as the rehabilitation of the Rondegat River extremely challenging to execute. That project took 10 years from conception to implementation and cost more than R1 million per kilometre of treated stream (Impson et al. 2013); such costs are clearly beyond the means of many provincial conservation agencies. It should also be noted that many of the early years of that project were devoted to repeated rounds of consultation with angling bodies and other stakeholder groups, who were initially opposed to CapeNature's proposed management of angling species (Ellender et al. 2014; Marr, Impson & Tweddle 2012).

Human resource and budgetary constraints as discussed above are a reality, and the comprehensive enforcement of the NEM:BA regulations is unlikely to be feasible in most provinces. Moreover, lessons from the Western Cape and the national trout debate show that angling lobby groups can tie up a significant amount of time and resources in fighting against the implementation of the NEM:BA regulations, if such implementation threatens key stakeholder activities. We, therefore, suggest that there is a need for simple, universally applicable prioritisation principles that will ensure that any planned conservation interventions targeting listed alien fish species (or trout) have (1) a high chance of success given available resources and (2) a low chance of triggering pushback from other stakeholders.

A decision-support tool that meets these requirements was recently developed as part of a project funded by the Water

Research Commission to assess national best practice for alien fish management based on a series of lessons learned from research into the introduction, spread and impacts of alien fishes (Kimberg et al. 2014). The tool can be used to prioritise invasive alien fish populations for conservation management and indicate the most pragmatic management approach on a case-by-case basis. For the remainder of this review, we will describe the procedures and decision-support criteria that underpin the tool and use three case studies to illustrate its applicability to real-world alien fish management challenges in South Africa.

A decision-support tool for managing invasive fishes in South Africa

The tool was adapted from the International Union for Conservation of Nature (IUCN) Global Invasive Species Programme toolkit for managing invasions (Wittenberg & Cock 2001), altering the original decision tree to focus on four key questions for environmental managers dealing with alien fish populations (Figure 3). For all the questions, the focus of the investigation should be a single, easily defined population of the alien species, bounded by clear barriers to migration and subject to a single management approach. To aid in defining the limits of such populations, we recommend using the IUCN Red List of Threatened Species definition of 'location', which refers to the geographic extent of a population that is subject to the same overarching threat to survival (e.g. occurs on one property and occurs in one isolated tributary) and can thus be taken as a reasonable management unit for conservation interventions (IUCN Standards and Petitions Subcommittee 2014).

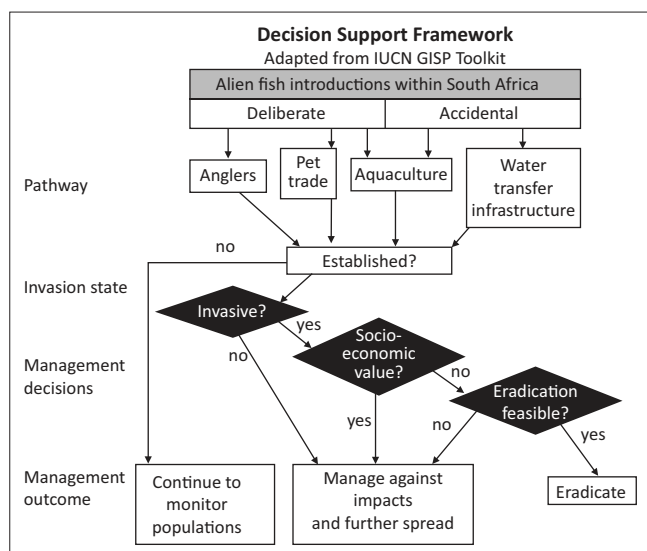
The first question asks whether a particular invasive fish population is established. Establishment can be ascertained using the invasion framework of Blackburn et al. (2011),

whereby any population that displays the characteristics of Category C3 (i.e. population with self-sustaining reproduction in the wild) can be considered established in the environment (see Kimberg et al. [2014] for full details on decision-support criteria). The next question, 'is the population invasive?', can be answered in the affirmative in one of two ways. Either the population meets the criteria for categories D1–E (i.e. self-sustaining populations occurring a significant distance away from the initial introduction point) in the invasion framework (Blackburn et al. 2011), or else it can be classed as an invasive population on a precautionary basis if the species under assessment presents a sufficient environmental risk. Environmental risk can be established through an *ad hoc* literature search for known ecological or conservation impacts, evidence for co-occurrence with threatened native species or through a more formalised process such as the application of dedicated risk assessment tools (e.g. Fish Invasiveness Scoring Kit [FISK], Copp, Garthwaite & Gozlan 2005; see also Marr et al. 2017). Should the answer be yes, the next question is whether the population has socio-economic value? The answer to this question must be spatially constrained to the specific population under assessment (i.e. do people fish for this species in this particular water body?), and the spatial extent of the population (i.e. the location) should be explicitly defined (e.g. does the species occur downstream of a barrier to movement and not upstream of it?).

Should the question of socio-economic value be answered in the negative, the feasibility of eradication can be explored. This is likely to be highly dependent on the capacity of the management entity conducting the assessment, but should follow the general guiding principles laid out by Kimberg et al. (2014). Should it be determined that eradication is not feasible, either for logistical reasons or because of potential conflicts with stakeholders, a management approach of mitigating against environmental impacts and further spread should be followed (Figure 3). Likewise, if the species is not established or does not represent sufficient environmental risk, a passive approach of ongoing monitoring can be adopted. To illustrate the practicality of this decision-support tool, we demonstrate its hypothetical use with three real-world management scenarios from the present or recent past in South Africa.

Case study 1: Smallmouth bass in the Rondegat River

Smallmouth bass is highly invasive in the Western Cape and the species has invaded approximately 81% of the tributaries comprising the Olifants-Doring catchment (Van der Walt et al. 2016). They have been consistently found to eliminate small-bodied native cyprinid fishes within invaded reaches, with consequences for the structure and function of macroinvertebrate communities (Lowe et al. 2008; Van der Walt et al. 2016). Located within the Olifants-Doring catchment is Clanwilliam Dam, a large impoundment that represents the most important smallmouth bass fishery in the country (Hargrove et al. 2015). The Rondegat River is a



Source: Reproduced from Kimberg et al. 2014

FIGURE 3: Decision-support tool for managing invasive freshwater fish populations in South Africa.

tributary that flows into the reservoir, and its lower reaches were invaded by smallmouth bass up to a waterfall 4 km upstream of the impoundment. The impact of bass in this invaded reach included the loss of native fishes and the altering of the macroinvertebrate community (Lowe et al. 2008; Woodford et al. 2005). Critically, the bass population was separated from the population in the reservoir by an abstraction weir, which allowed the Rondegat bass to be managed as a discreet population unit or location.

Applying the decision-support tool, we can retrospectively ask whether the population of smallmouth bass was established and invasive. Although the population was not expanding its range within the river because of the upstream waterfall barrier, its known environmental risk (i.e. recorded ecological impacts) meant it could be classified as invasive. Furthermore, under the NEM:BA A&IS invasive species regulations, it was Category 1b within the river, meaning 'control via a management plan' was the legally mandated management strategy. Whether such 'control' would equate to 'manage against impacts and further spread' or 'eradicate' is predicated on the following steps in the tool. One could answer the question of 'socio-economic impact' as no, because CapeNature's pre-eradication consultation had demonstrated that no bass anglers utilised the population, unlike in the reservoir downstream. The feasibility of eradication was answered 'yes', because of the self-contained nature of the river, ease of access and the financial support available to CapeNature (Impson et al. 2013). Thus, the appropriate management strategy for smallmouth bass in the lower Rondegat River was 'eradicate', and this was successfully carried out in February 2012 (Weyl et al. 2014).

Case study 2: Rainbow trout in the upper Molenaars River catchment

Trout have been present in the Breede River catchment of the Western Cape since the mid-1900s, having been stocked in the Elandspad, a tributary of the Molenaars River, in 1958 (De Moor & Bruton 1988). They are now found in most of the Molenaars tributaries, of which three (Elandspad, du Toits Kloof, Krom) are managed by the CPS as trout fishing waters (www.piscator.co.za). This management is administered under a 'Memorandum of Understanding' with CapeNature, as these waters fall within the Limietberg Provincial Nature Reserve (Weyl et al. 2015). There is also a trout hatchery established on the Molenaars River, which is run under permit from CapeNature (Permit no 1243/2013). The management of the trout fishery has been complicated by the recent discovery of a threatened native cyprinid (the giant redfin, *Pseudobarbus skeltoni*) in the Krom River. This species is only known from one other stream and is thus highly threatened (Chakona & Swartz 2013). Given the known impacts of rainbow trout on native cyprinids in other parts of the Breede catchment (Shelton, Samways & Day 2015), the trout population in the Molenaars sub-catchment now represents a genuine conflict between conservation and the recreational fishery.

Using the decision-support tool to determine a way forward, we can say with confidence that the Molenaars trout population is established and invasive on the grounds of environmental impact (Shelton et al. 2015). However, the presence of the hatchery and recreational fishery means that one must answer 'yes' to the question of socio-economic impact for this particular trout population. We are thus left with the recommended management strategy of 'manage against impacts and further spread'. From a conservation point of view, a possible solution would entail reducing contact between the threatened minnow and the trout, potentially by erecting a fish barrier on the lower Krom River and eradicating the trout upstream through physical or chemical methods. To avoid direct conflict over such planned actions, scenario-based planning workshops could be conducted involving all stakeholders, where different scenarios of trout population management could be discussed (Game et al. 2014; Woodford et al. 2016). Participants would include CapeNature, the CPS, the trout hatchery owners, fish biologists to provide relevant ecological information to the process, and any other interested and affected parties. Through such negotiation, the best compromise solution that satisfies most stakeholders could be agreed upon.

Case study 3: Loricariid catfish in the Nseleni River

The status of the loricariid catfish *Pterygoplichthys disjunctivus*, a popular aquarium fish that has been imported into South Africa since the 1970s, was assessed as a stage 'D2' invasion: 'self-sustaining population in the wild, with individuals surviving and reproducing a significant distance from their original point of introduction' by Jones et al. (2013). The basis for this assessment was that the species had spread from Lake Mpangeni in the Mthlatuze River system where it was first reported in 2000 to the adjacent Nseleni River where it was now fully established, widespread and abundant. The species also qualifies as invasive based on potential environmental risk, because reported impacts of their invasions include the effects of burrowing on river bank stability and concerns about competition with native biota (e.g. Lienart, Rodiles-Hernandez & Capps 2013; Nico, Loftus & Reid 2009) and effects on ecosystem energy flows (Hill et al. 2015). Although the species is considered economically important in the pet trade, wild populations are not utilised and there is no socio-economic value to this fish once it escapes captivity. As Jones et al. (2013) considered that the only barrier to it becoming a fully invasive species (stage 'E') was its inability to cross catchments without human assistance, either 'eradicate' or 'manage against impacts and further spread' can be considered appropriate management strategies for this species.

However, the Nseleni and Mthlatuze rivers are relatively large rivers in a South African context, meaning that eradication is neither logistically nor economically feasible. Following the decision-support tool, this leaves us with the management strategy 'manage against impacts and further spread' for *P. disjunctivus* in the Nseleni River (the same is

true for the Mthlathuze River). In this case, the management measures of containment and mitigation suggested by Blackburn et al. (2011) for stage D invasions were considered the most appropriate response strategy (Jones et al. 2013). As there are no practical options available to manage the population, educating the public to avoid new introductions into neighbouring systems falls under this goal. This is also reflected in the NEM:BA A&IS listing of this species under Category 3 as a species where use is restricted, but eradication is not a legal obligation. As the risk of further invasions is linked to escape from captivity, Jones et al. also suggested that the trade of *P. disjunctivus* be prohibited to avoid further introductions.

Conclusions

The currently promulgated lists and regulations for alien and invasive freshwater fishes provide a practical legal framework under which the further spread of invasive species can be actively discouraged, through the prosecution of parties guilty of illegal transport and stocking. The regulations also provide a legal context for active control, in that areas where a particular species is listed as Category 1b can be earmarked for either eradication or population management, depending on the situation and the resources available to the managing authority. If an invasive freshwater fish species is present in a river that is deemed to be of high conservation importance and traverses privately owned land, then conservation authorities need to engage with the land owners to develop an appropriate management plan for the specific species and area.

Given the extremely limited capacity for active management of fish populations within provincial conservation agencies, it is crucial to prioritise alien fish populations with high conservation risk, which are also logistically feasible to manage. Moreover, agencies must be able to rapidly determine whether they should cut their losses and redirect their limited resources to more practical targets. The proposed decision-support tool attempts to simplify this process, while simultaneously highlighting the potential for conflict with user groups that might delay or otherwise hamper conservation interventions. The 10-year lesson of the Rondegat River rehabilitation is that it takes time, money and significant investment in stakeholder engagement to ensure ultimate success (Impson et al. 2013; Weyl et al. 2014). The decision-support tool provides a way to hone in on potential management cases with limited risk and high reward, but will only be effective if the scientific information underpinning the decision-making is of sufficient quality. We, therefore, strongly advocate for ongoing investment in baseline field data that can improve our understanding of the environmental risk posed by invasive freshwater fishes in South Africa, together with improved support for the government and parastatal agencies charged with their management.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

D.J.W. was the lead author, responsible for aims and scope and the choice of case studies. P.I. and T.Z. provided updated information on the legal status of fishes under NEM:BA and the ongoing trout engagement process. M.J. provided provincial regulatory and licencing data. P.K.K. and O.L.F.W. co-developed the decision-support tool for managing invasive fishes in South Africa with D.J.W.

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