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REVIEW PAPER

Managing conflicts arising from fisheries enhancements based on non-native fishes in southern Africa

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Southern Africa has a long history of non-native fish introductions for the enhancement of recreational and commercial fisheries, due to a perceived lack of suitable native species. This has resulted in some important inland fisheries being based on non-native fishes. Regionally, these introductions are predominantly not benign, and non-native fishes are considered one of the main threats to aquatic biodiversity because they affect native biota through predation, competition, habitat alteration, disease transfer and hybridization. To achieve national policy objectives of economic development, food security and poverty eradication, countries are increasingly looking towards inland fisheries as vehicles for development. As a result, conflicts have developed between economic and conservation objectives. In South Africa, as is the case for other invasive biota, the control and management of non-native fishes is included in the National Environmental Management: Biodiversity Act. Implementation measures include import and movement controls and, more recently, non-native fish eradication in conservation priority areas. Management actions are, however, complicated because many non-native fishes are important components in recreational and subsistence fisheries that contribute towards regional economies and food security. In other southern African countries, little attention has focussed on issues and management of non-native fishes, and this is cause for concern. This paper provides an overview of introductions, impacts and fisheries in southern Africa with emphasis on existing and evolving legislation, conflicts, implementation strategies and the sometimes innovative approaches that have been used to prioritize conservation areas and manage non-native fishes.

Key words: centrarchids; *Cyprinus carpio*; economic benefit; environmental impacts; salmonids.

INTRODUCTION

Stock enhancement using non-native fishes has been undertaken for centuries for reasons including a lack of suitable local species, marketability, favourable growth rates, sport-fishing prowess and ecological imperialism (Crosby, 1968; Garcia De Leaniz *et al.*, 2010). Fisheries enhancements have usually been carried out to satisfy human demand for food and leisure, with little consideration of their subsequent effects on biodiversity. This is particularly relevant in developing countries where decisions may be based on political issues or short-term economic demands (Pelicice *et al.*, 2014).

Although many species have been dispersed globally, a few species now form important components of fish assemblages on every continent (Lever, 1996). Life-history

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traits, such as large size, high fecundity and fast population turn-over rates of many species used for fisheries enhancements, have resulted in high establishment rates in novel environments but infer a competitive advantage over many native species (Marchetti *et al.*, 2004; Ribeiro *et al.*, 2008). This has resulted in considerable effects of non-native fishes on recipient environments (Gozlan *et al.*, 2010) and several fishery species are listed among the 100 worst invasive organisms (Lowe *et al.*, 2000). This has led to considerable conflicts between fisheries agencies and conservation authorities whom often have competing fisheries development and biodiversity agendas (Cowx *et al.*, 2010).

Examples of well-established non-native fisheries that threaten local species include smallmouth bass *Micropterus dolomieu* Lacépède 1802 in the Pacific-North West region of America (Carey *et al.*, 2011), brown trout *Salmo trutta* L. 1758 and rainbow trout *Oncorhynchus mykiss* (Walbaum 1792) in Australia, New Zealand and Chile (McDowall, 2006) and Nile perch *Lates niloticus* (L. 1758) in Lake Victoria, Africa (Balirwa *et al.*, 2003). These enhancements have, however, largely been successful at achieving their goals. For example, non-native salmonid introductions into New Zealand have resulted in world-class sport fisheries (McIntosh *et al.*, 2010). Nonetheless, the threat such non-native fisheries pose to conservation values has become increasingly apparent over time (Cowx, 1996; Garcia De Leaniz *et al.*, 2010; McIntosh *et al.*, 2010).

Southern Africa has a long history of fisheries enhancements using non-native fishes that were considered essential for developing fisheries in a region that lacked appropriate native species (de Moor & Bruton, 1988). In contrast to the evolution of fisheries elsewhere where subsistence and commercial use are initial motivators (Smith, 1986), the first introductions of fishes into South Africa were for recreational purposes (McCafferty *et al.*, 2012; Ellender & Weyl, 2014). This included three groups of fishes: common carp *Cyprinus carpio* L. 1758; centrarchids, largemouth bass *Micropterus salmoides* (Lacépède 1802), *M. dolomieu* and spotted bass *Micropterus punctulatus* (Rafinesque 1819) and salmonids, *O. mykiss* and *S. trutta*. These species were then rapidly spread to establish recreational fisheries in other southern African countries (1900–1940) (Bell-Cross & Minshull, 1988). Fisheries enhancements for commercial purposes were only considered much later (post-1960s) with the constructions of large man-made impoundments in Zimbabwe (Lake Kariba), Zambia (Lake Kariba and Lake Itezhi-tezhi) and Mozambique (Lake Cahora Bassa) where commercially important enhancements included Nile tilapia *Oreochromis niloticus* (L. 1758) and kapenta *Limnothrissa miodon* (Boulenger 1906).

In South Africa, recreational fisheries are primarily based on non-native fishes that have been introduced since the late 1800s and rapidly spread through both legal and illegal stocking (Van Rensburg *et al.*, 2011; Ellender & Weyl, 2014). As concerns grew over the conservation implications of non-native fish introductions, legislation to restrict non-native fish introductions was developed (McCafferty *et al.*, 2012; Weyl *et al.*, 2014). This legislation may, however, affect subsistence, recreational and commercial fisheries development in a country where inland fisheries are poorly developed (McCafferty *et al.*, 2012) and where there is no inland fisheries policy (Weyl *et al.*, 2007). This situation contrasts with that of other southern African countries such as Zambia, Zimbabwe, Namibia and Botswana, which have established inland fisheries, several of which are based on introduced fishes (*e.g. L. miodon* in Lakes Kariba and Itezhi-tezhi or *O. niloticus* in the Kafue River, Zambia, or *M. salmoides* in reservoirs in

Botswana and Zimbabwe). These countries, however, have weak conservation policies about introduction of non-native species.

These contrasting policy landscapes have all contributed to the rising conflicts between economic and conservation objectives within southern African fisheries. This paper provides an overview of the effect of fish introductions on fisheries in southern Africa, with emphasis on existing and evolving legislation, conflicts and implementation strategies. The availability of documentation necessitates a focus on enhancements for sport fishing, although the relatively recent commercial enhancements and their possible implications are also discussed.

INTRODUCTIONS AND SPREAD

Non-native sport-fish introductions and potential conflicts in southern Africa revolve around *C. carpio*, the salmonids *O. mykiss* and *S. trutta*, and the centrarchids *M. salmoides*, *M. punctulatus*, *M. dolomieu* and *Micropterus floridanus* (LeSueur 1822). Data to illustrate the introductions and subsequent spread of these species are available for South Africa (de Moor & Bruton, 1988; Ellender & Weyl, 2014) and are illustrated in Fig. 1.

Cyprinus carpio was the first angling species to be officially introduced into South Africa in 1859, followed by the salmonids (*S. trutta* in 1890 and *O. mykiss* in 1897 both from the U.K.) and the four centrarchid species (*M. salmoides* in 1928, *M. dolomieu* in 1937, *M. punctulatus* in 1939 and *M. floridanus* in 1980). Establishment was facilitated through the active involvement of government, which invested not only in hatcheries to propagate imported stock but also co-ordinated a regional stocking programme. As a result, non-native fishes were spread widely throughout the region. After their introduction into South Africa in the early 1890s, salmonids spread fairly rapidly from three provincial hatcheries set-up to supply the Cape Province (Jonkershoek and Piri Hatcheries) and Natal (Boschfontein Hatchery). Although salmonids established in many high-altitude streams, their specific spawning requirements meant that many fisheries, and particularly those in still waters, were reliant on continual stocking. To facilitate this, government hatcheries continued to supply salmonid fingerlings to public and private waters well into the 1980s (Rouhani & Britz, 2004).

The spread of salmonids to the rest of South Africa was relatively slow through the early 1900s because the technology for transportation was poorly developed. By the time the first of the centrarchids was introduced in 1928, however, the distribution network and methods were well established and these species were distributed throughout the country within a decade of their first arrival (Fig. 1). The initial movement of *C. carpio* was rapid, but because of reports of damage resulting from their introduction (assumed to be habitat degradation), its spread was not officially supported after the 1920s (Harrison, 1959) and there are few stocking records for this species. Nevertheless, *C. carpio* now occupies most major catchments (Fig. 1). Despite the early differences in their rate of spread, currently all three groups occupy parts of every major catchment in South Africa.

South Africa provided a source for the introduction of non-native fishes to other southern African countries. For example, *S. trutta* and *O. mykiss* (ova) were distributed to Zimbabwe in 1907 and 1910, respectively, and from there to Mozambique, and independently to Swaziland in 1908 and Zambia in 1942 (FAO

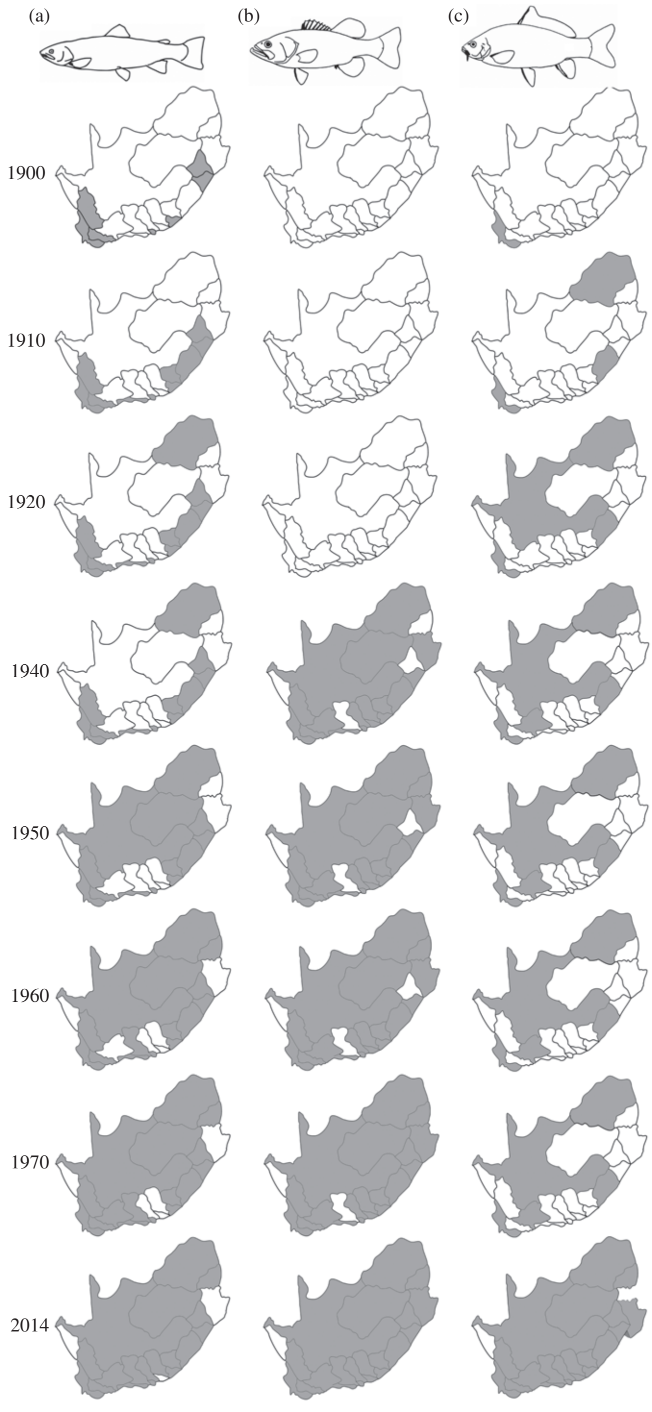

FIG. 1. The rapid early spread of fishery species in South Africa indicated by using (a) salmonids, (b) centrarchids and (c) *Cyprinus carpio*. Data sources: de Moor & Bruton (1988), Scott *et al.* (2006) and South African Institute for Aquatic Biodiversity (unpubl. data).

DIAS; www.fao.org/fishery/dias/en). Although the dates of translocation are not well recorded, *C. carpio* has been distributed to Botswana, Lesotho (1965), Namibia, Zambia (1980) and Zimbabwe (1925). Centrarchids have been spread across the southern continent, mostly in the 1930s shortly after their introduction into South Africa in 1928: for example, *M. salmoides* into Namibia and Zimbabwe in 1932, Botswana and Lesotho in 1937, Swaziland in 1947 and from Swaziland to Mozambique in 1947 (Bell-Cross & Minshull, 1988; FAO DIAS).

While South Africa was the source of several non-native fishes, *O. niloticus* was first introduced into Zambia and Zimbabwe for aquaculture and fisheries enhancements in 1980 (Brummett, 2007) reportedly from Scotland, U.K. (presumably Institute of Aquaculture, University of Stirling) and escaped into the Kafue system (Cowx *et al.*, 2011). There are also reports of introductions to aquaculture units on Lake Kariba from Kenya in 1990, although records are vague. *Limnothrissa miodon* was first transferred from Lake Tanganyika, where it is an endemic small pelagic species, to Lake Kariba during 1967–1968 to fill the vacant pelagic niche in the newly flooded reservoir (Marshall, 1991). It was later introduced into Lake Itezhi-tezhi in the early 1990s and dispersed down the Zambezi River to Cahora Bassa where it has established a viable commercial fishery.

Although southern Africa can be considered data-poor with regard to introduction records, presence and absence data for *C. carpio*, centrarchids, salmonids and *O. niloticus* were compiled for 66 impoundments using multiple data sources including published and popular literature, the South African Institute for Aquatic Biodiversity (SAIAB) database and expert knowledge (see Appendix; *L. miodon* introductions were too few to be included in analyses). Canonical correspondence analysis (CCA; ter Braak, 1995) was used to investigate the relationship between species presence and absence data and the surface area, latitude and altitude of environmental variables from the 66 impoundments. This not only gives a good indication of the extent of establishment but also allowed analysis of the potential factors influencing the distribution of non-native recreational species in southern Africa (Fig. 2). Salmonids tend to be present in high-altitude areas that suit their specific thermal requirements, *O. niloticus* is predominantly limited to the tropical latitudes (<23° S) and centrarchids and *C. carpio* are ubiquitous in the region. Only eight impoundments did not contain established populations of salmonids, centrarchids, *C. carpio* or *O. niloticus*. These were either located in tropical areas where suitable native sport fishing species, such as tigerfish *Hydrocynus vittatus* Castelnau 1861, and large native cichlids, such as three-spot tilapia *Oreochromis andersonii* (Castelnau 1861) and nembwe *Serranochromis robustus* (Günther 1864), are present (*e.g.* Lake Itezhi-tezhi in Zambia) or in new (*e.g.* Mohale Dam in Lesotho and Dikgatlhong Dam and Ntimbale Dam in Botswana) or in very rurally situated dams with low sport fishing potential (*e.g.* Ngotwane Dam and Madiwke Dam in South Africa; Weyl *et al.*, 2007).

EFFECTS OF FISH INTRODUCTIONS IN SOUTHERN AFRICA

SOCIO-ECONOMIC BENEFITS

Although the introduction of non-native fishes into southern Africa achieved its desired objective, the establishment of fisheries is undeniable. While there is no

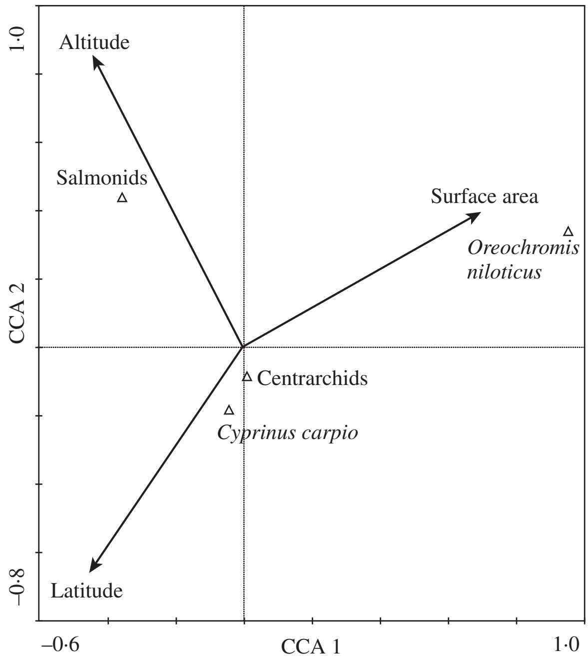

FIG. 2. Canonical correspondence analyses ordination bi-plot of species and environmental variables for the four primary angling species or families based on presence or absence data from 66 impoundments throughout southern Africa.

formal estimate of increased yield or participation, nor the proportion of fishers and anglers that directly benefit from introduced species, several high profile fisheries have been established, *e.g. L. miodon* in Lakes Kariba, Itezhi-tezhi and Cahora Bassa and a number of formal recreational angling organizations specifically targeting introduced species have emerged. In South Africa, for example, angling is a sport that is officially recognized by the South African Sports Confederation and Olympic Committee. Facets of the sport include non-native species specializations [*e.g.* South Africa Bass Angling Association (SABAA; www.sabaa.co.za)]. For example, international black bass *Micropterus* spp. tournaments in southern Africa include teams from South Africa, Swaziland, Mozambique, Namibia and Zimbabwe and many anglers in the region are affiliated to the Bass Anglers Sportsman Society (BASS) in the U.S.A. Members of the South African Freshwater Bank Angling Federation (5309 members in 2010) primarily target *C. carpio*, while the primary target species for many members of fly-fishing organizations such as the Cape Piscatorial Society (CPS) and the Federation of South African Fly-Fishers (FOSAF), are *O. mykiss* and *S. trutta*.

Although the effects of these fisheries have never been fully quantified, based on broad estimates from South Africa (McCafferty *et al.*, 2012) and on examples from the U.S.A. and Europe (Gozlan *et al.*, 2010), the benefits arising from the introductions of non-native centrarchids, salmonids, *C. carpio*, *O. niloticus* and *L. miodon* in southern Africa are likely to be significant (Table I). In southern Africa, these non-native fishes contribute to subsistence and commercial fisheries (Weyl *et al.*, 2007; Ellender *et al.*,

Table I. Summary of conflicting negative environmental and positive socio-economic effects of key species involved in stock enhancement projects throughout southern Africa

Species	Effect	*Cyprinus carpio*	Salmonids	Centrarchids	*Oreochromis niloticus*	*Limnothrissa miodon*
Negative environmental effects	Predation		●[d]	●[g]		
	Competition		●[e]	●[h]	●[i]	
	Hybridization				●[j]	
	Introduction of pathogens	●[a]				
	Environmental modification	○[b]	○[f]		○[k]	●[m]
Positive socio-economic effects	Recreational fishery	●[c]	●[c]	●[c]		
	Subsistence and small-scale fishery	●[c]				●[n]
	Commercial and aquaculture	●[c]	●[c]		●[l]	●[m]

●Effect documented within southern Africa.
○Effect documented in international literature.
[a]Bruton & Van As (1986); [b]Weber & Brown (2009); [c]McCafferty *et al.* (2012); [d]Woodford & Impson (2004); [e]Kadye *et al.* (2013); [f]Simon & Townsend (2003); [g]Gratwicke & Marshall (2001); [h]Mayekiso & Hecht (1988); [i]Zengeya *et al.* (2011); [j]D'Amato *et al.* (2007); [k]Starling *et al.* (2002); [l]Canonico *et al.* (2005); [m]Marshall (1991); [n]Cowx & Kalonga (2013).

2010; Tweddle, 2010; Deines *et al.*, 2013) but their direct effects are difficult to judge as there are few long-term time series upon which to base native *v*. non-native fisheries yield comparisons. Indications are that they are significant contributors to local and regional economies (Du Preez & Lee, 2010; McCafferty *et al.*, 2012): participation in centrarchid recreational fisheries in South Africa in 2007 was estimated to be around 20 000 anglers (M. Leibold & C. J. van Zyl, unpubl. data); however, no recent assessment data exist. The number of fly-fishermen who predominantly target salmonids is thought to be around 45 000 (M. Leibold & C. J. van Zyl, unpubl. data). Despite high participation and the perceived socio-economic contribution of these fishes to local and regional economies, this remains largely un-quantified (Du Preez & Lee, 2010; McCafferty *et al.*, 2012). The contribution of salmonid fly-fishing to the economy of Rhodes village, North Eastern Cape, South Africa was *c*. 5 658 240 R and per annum and sustained a minimum of 39 jobs, which is a significant contribution in a rural area (Du Preez & Lee, 2010). The largest inland angling sectors are the freshwater bank anglers (estimated 1·5 million participants), who target *C. carpio* (M. Leibold & C. J. van Zyl, unpubl. data). *Cyprinus carpio* is also the primary target of subsistence fishers in South Africa's largest impoundment (Lake Gariep) and provides a livelihood for *c*. 500 fishers (Ellender *et al.*, 2009, 2010). Namibia, Zimbabwe and Botswana also have significant recreational fisheries specifically targeting centrarchids or salmonids; however, information on participation is scant.

Commercial lift-net and small-scale light fisheries have established on the major reservoirs of southern Africa to exploit the introduced *L. miodon*. These annually produce some 20 000 t in Lake Kariba, 3–4000 t in Lake Itezhi-tezhi and 10 000 t in Lake Cahora Bassa. Several aquaculture enterprises have also evolved to produce

O. niloticus, the most important are Lake Harvest cage-farming unit on Lake Kariba producing *c.* 5000 t per annum and Kafue Fish Farm on the Kafue River in Zambia producing about 1000 t. In addition, wild production arising from escape and invasion from fish farms into the Kafue River system now contributes *c.* 3000 t per annum, displacing much of the production of indigenous tilapia species (Cowx & Kalonga, 2013; Deines *et al.*, 2014).

These data indicate that non-native fishes provide a source of recreation, and support subsistence and commercial fisheries, which therefore contribute significantly to the economies of southern African countries. Although significant, these benefits come with environmental cost, and non-native fishes have had demonstrable negative effects on aquatic biodiversity in southern Africa and globally (Table I).

NEGATIVE ENVIRONMENTAL EFFECTS

Centrarchids have been associated with predation of and competition with native fishes. Centrarchid interactions with native southern African ichthyofauna include alteration of habitat selection and reduced abundance or even local extirpation of native fishes from invaded river reaches (Gratwicke & Marshall, 2001; Woodford *et al.*, 2005; Shelton *et al.*, 2008; Ellender *et al.*, 2011; Weyl *et al.*, 2013). Salmonids have also been shown to affect native fishes and amphibians in South Africa and Zimbabwe (Woodford & Impson, 2004; Karssing *et al.*, 2012; Kadye *et al.*, 2013). In the Berg River system Western Cape, South Africa, native *Galaxias zebratus* (Castelnau 1861) have been found in the stomachs of *O. mykiss* and was the only native species not observed co-occurring with *O. mykiss* (Woodford & Impson, 2004). Similar patterns were evident in salmonid-invaded streams of the Khahlamba Drakensberg Park World Heritage site, South Africa, where major differences in the abundance of tadpoles of the Natal cascade frog *Hadromophryne natalensis* were detected above and below salmonid invasion barriers (Karssing *et al.*, 2012).

In South Africa, *C. carpio* is the primary vector for introduced parasites and diseases (Bruton & Van As, 1986). The Asian tapeworm *Bothriocephalus acheilognathi* has made a shift from non-native *C. carpio* to native fishes such as *Labeobarbus aeneus* (Burchell 1822) and *Labeobarbus kimberleyensis* (Gilchrist & Thompson 1913) (Bertasso & Avenant-Oldewage, 2005). Although the effects of *C. carpio* have not been assessed in South Africa (Ellender & Weyl, 2014), there are multiple examples of the species altering invaded habitats (*e.g.* eutrophication and increased turbidity) in other countries (Weber & Brown, 2009).

The introduction of *O. niloticus* threatens native *Oreochromis* spp. in Mozambique, South Africa, Zambia and Zimbabwe (Canonico *et al.*, 2005; Weyl, 2008; Zengeya *et al.*, 2011; Firmat *et al.*, 2013). *Oreochromis niloticus* introductions have resulted in extensive hybridization and introgression with native *Oreochromis mossambicus* (Peters 1852) in the Limpopo River system, South Africa (D'Amato *et al.*, 2007; Firmat *et al.*, 2013), and have almost replaced the native *Oreochromis mortimeri* (Trewavas 1966) in Lake Kariba, Zimbabwe (Tweddle, 2010) and *O. andersonii* and *Oreochromis macrochir* (Boulenger 1912) in the Kafue River, Zambia (Deines *et al.*, 2014). There is a paucity of data concerning the impacts of *L. miodon* where they were introduced. In Lake Kariba, Marshall (1991) showed the disappearance of *Chaoborus* sp. larvae post *L. miodon* introduction with subsequent reduced biomass and diversity in zooplankton communities.

NON-NATIVE FISH LEGISLATION: FROM FACILITATING INTRODUCTIONS TO MITIGATING EFFECTS

Legislation related to fish stock enhancements and policy on non-native and invasive fishes varies markedly across southern Africa. In Zimbabwe, pre-independence (*i.e.* pre-1967) fisheries regulations were intended to develop fisheries through enhancement by stocking non-native angling species (Malasha, 2003) and there was a concerted effort to enhance fisheries in small water bodies during the 1990s (Marshall & Maes, 1994). The country has no official stance on the use of non-native fishes for stock enhancements but early legislation actively supported the introduction of non-native fishes and fisheries regulations were largely designed to develop and maintain recreational fisheries (Malasha, 2003). Both the focus on non-native fish introductions and the development of infrastructure and legislation in Zimbabwe were a direct result of close collaboration with South African fisheries authorities (Malasha, 2003) but South Africa subsequently developed legislation intended to mitigate against the results of these introductions. South Africa is therefore an excellent example of the progression of legislation from facilitating the enhancement of fisheries during the colonial era, to ever-decreasing government support for fisheries enhancement and ultimately legislation intended to mitigate effects by controlling further spread.

The situation in Zambia and Botswana mirrors that in Zimbabwe. Although legislation to regulate the introduction and movement of fish exists, it is rarely enforced. Indeed, there is flagrant disregard of regulations to create angling opportunities in reservoirs in Botswana (Cowx, 2012) and wide concerns over the spread of *O. niloticus* as a result of aquaculture development (Cowx & Kalonga, 2013).

In South Africa, the introduction of non-native fishes was actively encouraged by legislation passed in 1867 (Act No. 10 of 1867; Skelton & Davies, 1986), the purpose of which was 'for encouraging the introduction into waters of this Colony of fishes not native to such waters'. Government subsequently constructed the Jonkershoek Hatchery in 1893, where salmonids and many other non-native species were initially grown out, bred and distributed (Weyl *et al.*, 2014). Both *S. trutta* and *O. mykiss* were distributed from this hatchery either directly or with the help of societies such as the CPS whose purpose was, and still is, 'extending and encouraging the culture and protection of salmonids and other desirable freshwater fish in the Cape'. Similar societies were established in other provinces and salmonid-related activities were fully supported by government which, between 1947 and 1974, passed several pieces of legislation to ensure establishment and develop fisheries (McCafferty *et al.*, 2012). This facilitated the rapid spread of non-native species illustrated in Fig. 1.

During this period, salmonids enjoyed special protection despite increasing recognition that some non-native species were problematic. For example, in 1947, the Cape Province enacted legislation prohibiting the sale and transportation of *C. carpio* while enacting measures to protect other game fishes including salmonids (Cape Province, Inland Fisheries Ordinance, No. 12 of 1947) and the Transvaal Nature Conservation Ordinance (No. 19 of 1974) continued stipulated protective measures for salmonids (closed seasons, bag and size limits) despite prohibiting the transport of other non-native fishes (McCafferty *et al.*, 2012). By the 1980s, however, evidence of the effect of non-native species including salmonids could no longer be ignored and in 1986 the proposed removal of protective rights assigned to salmonids was discussed by nature conservation authorities (Skelton & Davies, 1986) and eventually resulted in a cessation of government support to non-native fisheries and the closure of government hatcheries by the mid-1990s (McCafferty *et al.*, 2012). This was reflected in the National Environmental Management: Biodiversity Act (Act No. 10 of 2004) (NEM: BA), which recognized invasive species as a threat to biodiversity and included legislation intended to prevent their unauthorized introduction and spread.

In recognition of the social, recreational and economic importance of angling species, the proposed NEM: BA regulations for non-native fishes published in 2009 included lists that prohibit the import, possession, movement and release of >100 listed fish taxa, and proposed managing non-native sport fishes by activity and area. To do this, a complex system of maps was developed in consultation with angling organizations, conservationists and government, with demarcated areas where stocking of non-native fishes would be allowed, prohibited or where a risk assessment was needed (van Rensburg *et al.*, 2011). Unfortunately, the maps were considered too complex and legally indefensible to be used in national legislation and were excluded from the revised regulations published in 2013 (NEM: BA Alien and Invasive Species Regulations 2013). These new regulations simply listed non-native species as either prohibited or as invasive species requiring an invasive-species management programme for which government departments were obligated to develop monitoring, control and eradication plans. Under these regulations, private land owners were also obliged to report the presence of listed invasive species and take steps to manage, eradicate or prevent them from spreading. As a result of public comment, these new regulations were again amended in 2014 to include provisions for enhancing non-native fisheries in areas that are not of conservation concern while attempting to regulate non-native fish introductions into new environments.

WHERE DO THE CONFLICTS COME FROM?

Conflicts arise from the risks posed by introducing or moving non-native species into novel environments. For this reason, legislation is put in place to control introduction and spread. Some recreational anglers believe that human needs should be put above all others and that due to their large perceived benefits to society their introduction and spread should continue unhindered (Cox, 2013).

SOUTH AFRICAN CONFLICT FISHERIES

In South Africa, the response of angling organizations to emerging non-native species regulations depended on which species anglers were targeting. Centrarchid and *C. carpio* anglers, for example, saw little threat to their sport from emerging legislation because 'their' species were well established in major reservoirs and require no further stocking. As a result, SAFBAF and SABAA have not formally challenged the NEM: BA regulations, although they initially contributed towards the debate for some water bodies. By contrast, salmonid fisheries in many areas depend on regular stocking and salmonid angling organizations saw this change in government attitude regarding salmonids (and other non-native species) as a direct threat to their sport and have been actively involved in legislative debates.

In response to the 1986 colloquium on salmonids, anglers formed the FOSAF to promote the sport of fly-fishing and provide fly-fishers with a platform for negotiation with higher authorities (www.fosaf.co.za/history.php). In addition, salmonid fishing became increasingly privatized because fisheries enhancements were now dependent on the purchase of fishes from private producers and stocking of public waters became a regulated activity.

Continued stocking resulted in heavy criticism from conservationists, including references to anglers as 'eco-terrorists' and calls to review legislation to halt the spread of salmonids and rehabilitating invaded areas through the eradication of salmonids (Cambray, 2003). These views were reflected in the NEM: BA, legislation, which was fiercely contested through public and political lobbying by FOSAF (and other angling organizations) who are concerned about the consequences of this new legislation on the stocking of salmonids (McCafferty *et al.*, 2012). This included opposition to the 2009 NEM: BA regulations; opposition to a project intending to remove non-native fishes from four rivers to allow for the recovery of native fish populations (Marr *et al.*, 2012; Weyl *et al.*, 2014); challenging 2013 and 2014 revisions of the NEM: BA regulations as unconstitutional and challenging the status of salmonids as invasive species. The salmonid lobby is gaining momentum, and in 2013 interested parties including legal practitioners, university academics, recreational anglers, including FOSAF, salmonid hatcheries and the tourism industry, discussed the formation of a new action group to lobby against the alien and invasive species regulations, which they perceive as restrictive.

This is unfortunate because the NEM: BA regulations point towards a mutually beneficial strategy, conserving native biodiversity in key areas while allowing for fisheries development in others. It is unlikely that the conflict will be resolved soon but what should be recognized is that current legislation threatens few established salmonid areas and only potentially limits the introduction of salmonids into new rivers. It should, however, be noted that the lack of acceptance of the proposed legislation by salmonid lobby groups creates potential for non conformity and illegal stockings. It is essential that agreement between the Department of Environmental Affairs and the anti-NEM: BA lobby groups is reached to facilitate compliance, enhancing the chances of a successful management strategy.

CONFLICTS OUTSIDE OF SOUTH AFRICA

Similar conflicts also arise in other southern African countries for both development of recreational and subsistence/artisanal fisheries, but the greatest threat appears from the aquaculture sector and the proliferation of *O. niloticus* in cage and pond culture (Davis & Britz, 2011; Cowx, 2012; Cowx & Kalonga, 2013), and the issues arising from their escape and possible transmission of diseases. There is, however, also demand from angling groups to enhance fishing opportunities such as the unregulated introduction of *H. vittatus* into Lestibogo Dam in Botswana (Cowx, 2012). These types of activities are causes for concern because local demands for food security, either directly through fishery and aquaculture enhancement or indirectly through employment and demands to expand recreational opportunities, tend to override legislation to protect ecosystems and endemic biodiversity. Much of the pressure to expand comes from economic development driven by sources external to the region or country and risk assessments are rarely carried out.

FINDING SOLUTIONS FOR PRESENT AND FUTURE CONFLICTS

The recurring pattern in stock enhancement conflicts to date has been a lack of consistent policies that could regulate the balance between potential economic gain and potential environmental loss. There is therefore a need for alignment between non-native species management policies and inland fisheries policies. Moving forward, there are two contrasting issues that require solutions: solving current conflicts associated with existing fisheries based on non-native species and regulating future stock enhancements based on these or new species.

For progress to be made in addressing current conflicts, there needs to be improved dialogue between regulators, conservationists and fishery users, so that policies for established non-native fisheries are supported by all. For example, the initial lack of information exchange between conservationists and stakeholders around the eradication of *M. dolomieu* from a South African mountain stream resulted in objections to the project by bass anglers, despite the targeted *M. dolomieu* population having little fishery value (Marr *et al.*, 2012). Subsequent increases in stakeholder engagement resulted in the bass angling fraternity fully supporting the eradication (Weyl *et al.*, 2014). The lack of trust between regulators and stakeholders remains evident in the on-going debate over the proposed NEM: BA alien species regulations (Cox, 2013) and can only be addressed through further consultation.

Across southern Africa, there is a more urgent need to address the demand for creating new fisheries based on non-native species, which represent a major risk to biodiversity (Tweddle, 2010), but are nonetheless important for food security and economic growth (Cowx, 1999). This threat is not unique to the region, as developed countries such as England and Wales have also witnessed a rapid increase in demand for a variety of exotic big-game-type fishes to be introduced (Hickley & Chare, 2004). The lack of adequate regulatory frameworks in developing countries nonetheless makes the southern African situation more problematic. Here, there is a need to develop regional policies and best practices for stock enhancements, which should adopt a risk assessment approach (Cowx, 1999).

Such risk assessments should include assessment of known and potential consequences for the region, the likelihood of spread following introduction and the potential damage that the species might cause if it establishes elsewhere, as well as identification of the economic, environmental and social effects of the introduction (Gozlan *et al.*, 2010). The risk assessment protocol should examine both the economic benefit and the environmental risk of introducing a non-native species to a fishery, with the do-nothing alternative being favoured if there is insufficient information to confidently predict the negative result (Cowx, 1999).

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APPENDIX

Presence or absence (x = presence) of the most important groups of non-native fishes (CC, *Cyprinus carpio*; C, centrarchids; S, salmonids; ON, *Oreochromis niloticus*; LM, *Limnothrissa miodon*) used for fisheries enhancements in southern Africa (Bots, Botswana; Les, Lesotho; Moz, Mozambique; Nam, Namibia; SA, South Africa; Swa, Swaziland; Zam, Zambia; Zim, Zimbabwe)

Impoundment	Country	Latitude (° S)	Altitude (m.a.s.l.)	Surface area (km^2)	CC	C	S	ON	LM
Letsibogo	Bots	21	853	18		x			
Shashe	Bots	21	975	32					
Ntimbale	Bots	20	1103	15					
Dikgatlhong	Bots	21	871	15					
Katse	Les	29	2053	35			x		
Chicamba	Moz	19	630	160	x	x		x	
Cahorra Bassa	Moz	15	314	2739				x	x
Von Bach	Nam	22	1348	4·9	x	x			
Hardap	Nam	24	1136	25	x	x			
Sinqemeni	SA	33	100	0·09	x				
Ndlambe	SA	33	100	0·16	x				
Mnyameni	SA	32	900	0·18			x		
Lotlamoreng	SA	25	1246	0·35	x				
Mankazana	SA	33	67	0·35		x			
Dimbaza	SA	32	350	0·46	x	x			
Cata	SA	32	775	0·86			x		
Sandile	SA	32	590	1·5		x	x		
Nnywane	SA	25	1143	1·7		x			
Lindleyspoort	SA	25	1117	1·8	x				
Binfield	SA	32	665	1·8	x	x	x		
Laing	SA	32	330	2·0	x				
Katriver	SA	32	795	2·1	x	x			
Koster	SA	25	1267	2·6	x				
Bospoort	SA	25	1076	3·8	x				
Ngotwane	SA	25	1115	4·0					
Madikwe	SA	25	1068	4·3					
Taung	SA	27	1158	4·7	x				
Molatedi	SA	24	961	7·6	x				
Wriggleswade	SA	32	721	10	x	x			
Vaalkop	SA	25	981	11	x				
Lubisi	SA	31	1020	11	x	x			
Clanwilliam	SA	32	180	11	x	x			
Tzaneen	SA	23	724	12	x	x			

Appendix Continued

Impoundment	Country	Latitude (° S)	Altitude (m.a.s.l.)	Surface area (km^2)	CC	C	S	ON	LM
Grassridge	SA	31	1058	14	x	x			
Xonxa	SA	31	935	1	x	x			
Voelvlei	SA	33	76	15	x				
Roodekopjes	SA	25	1016	16	x	x			
Hartbeestpoort	SA	25	1164	19	x	x			
Quaggaskloof	SA	33	210	20	x	x			
Mohale	SA	29	2106	22					
Umtata	SA	31	680	25	x	x			
Darlington	SA	33	239	35	x				
Theewaterskloof	SA	34	308	51	x	x			
Sterkfontein	SA	28	1700	70		x	x		
Pongolapoort	SA	27	144	133	x				
Vanderkloof	SA	29	1175	133	x		x		
Gariep	SA	30	1260	374	x	x	x		
Mnjoli	Swa	26	297	15					
Itezhi-tezhi	Zam	15	1056	390					x
Kariba	Zim/Zam	16	485	5400				x	x
Malilangwe	Zim	21	366	2·0		x			
Chivero	Zim	17	1368	26	x	x		x	
Osborne	Zim	18	1160	26		x			
Mutirikwe	Zim	20	1051	90		x			
Mayfair	Zim	20	1136	15		x		x	
Inyankuni	Zim	20	1086	15		x		x	
Troutbeck	Zim	18	2020	1·0			x		
Lough Corrib	Zim	18	2226	1·0			x		
Mare Dam	Zim	18	1964	1·0			x		
Gulliver	Zim	18	1963	1·0			x		
Purdon	Zim	18	1929	1·0			x		
Rhodes	Zim	18	1730	1·0			x		
Udu	Zim	18	1666	1·0			x		
Lake Alexander	Zim	18	1529	1·0	x	x	x		
Smallbridge	Zim	18	1549	1·0		x			
Van Buuren	Zim	19	653	1·0		x		x	