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The introduced species fishery of Lake Naivasha, Kenya: ecological impact vs socio-economic benefits

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Abstract Lake Naivasha is a shallow, freshwater lake in the eastern Rift Valley of Kenya. Its fish community now comprises only introduced species. *Oreochromis spirulus niger* was stocked in 1925 as a forage fish for the largemouth bass, *Micropterus salmoides*, introduced in 1929 for sport fishing. Further introductions of tilapiines followed for commercial exploitation. A gillnet fishery opened in 1959, and the annual species catch composition to 2000 was dominated by *Oreochromis leucostictus*. Following their accidental introduction, carp *Cyprinus carpio* appeared in catches in 2002; by 2010, it comprised >99% of landings by weight. Carp now provides a sustainable fishery in a lake heavily impacted by anthropogenic stressors, including water abstraction and nutrient enrichment. *Oreochromis niloticus* was reintroduced in 2011 to reinvigorate tilapia stocks following the collapse of its stocks in the 1990s and early 2000s, and the African catfish *Clarias gariepinus* is now captured in small but increasing numbers. The current status of the fishery, especially the predominance of carp, presents major management challenges; these are addressed by stakeholder engagement and co-management. The introductions have artificially created a commercial fishery that provides substantial societal benefits in a semi-arid region of a developing country with high poverty levels.

KEYWORDS: introduced species, invasive carp, non-native fish, social and economic benefits, species extirpation.

Introduction

Market-driven demands for non-native fishes are on the increase, resulting in introductions that are rapidly diversifying the species exploited by sport anglers and fishers (Hickley & Chare 2004; Gozlan *et al.* 2010). There is also increased understanding of the ecological and economic problems that these species pose for native

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species, communities and ecosystems (Cucherousset & Olden 2011). Reasons for stocking fish are many and varied, but generally fall within the four main categories of mitigation, restoration, enhancement and the creation of new fisheries (Cowx 1994). The creation of new fisheries that drives the introduction of non-native species is usually an attempt to increase productivity by filling a perceived gap in the resident fish community or to change the principal target species to one that is more valuable in terms of food or local economy (Hickley & Chare 2004).

It is known that introductions of non-native fish can detrimentally affect the recipient populations, communities and ecosystem (Cucherousset & Olden 2011). It is also increasingly recognised that introductions of non-native species can result in considerable economic benefits (Gozlan 2008). On many occasions, these perceived economic benefits have provided powerful arguments for such stocking, irrespective of the risks. Moreover, these risks are not always assessed prior to the introduction or are not predicted accurately. This is because impacts of species are rarely uniform across their introduced range and vary according to, for example, the characteristics of the receiving ecosystem (Gozlan *et al.* 2010). There are numerous case studies that provide strong examples of where introduced species have invoked substantial ecological damage but provided considerable social and/or economic benefits through fishery enhancement. For example, the introduction of the peacock bass, *Cichla* sp., into reservoirs in southern Brazil for sport angling has resulted in declines in native species richness (Britton & Orsi 2012). The Nile perch, *Lates niloticus* L., was introduced into Lake Victoria for fishery enhancement but has contributed to substantially reduced haplochromine fish diversity (Goudswaard *et al.* 2008). In addition, the use of non-native crayfish in Europe for improving aquaculture is resulting in the extirpation of native populations (Gherardi *et al.* 2011a).

In such case studies, the introduction of the non-native species has often been a discrete event that enabled its outcome to be assessed directly (e.g. Knapp & Matthews 2000). Understanding the consequences of multiple species, fish introductions can be, however, more complex, particularly in ecosystems that are in flux due to environmental changes. For example, a species' invasion can facilitate the invasion of a subsequently introduced species through invasion meltdown (e.g. Green *et al.* 2011), although it has been argued that evidence for meltdown is often weak, ignoring other factors involved, such as habitat disturbance (Simberloff 2006). Nevertheless, case studies on the consequences of successive introductions of non-native fishes provide temporally integrated impact assessments that contribute to understanding of how economic benefits might offset ecological consequences.

The freshwater fishery of Lake Naivasha, Kenya, was created by introductions of non-native fish species that commenced from the 1920s, with the most recent introduction occurring in 2011. Whilst 10 non-native fishes have been introduced in total, this includes two fishes for mosquito control. Also some of the fishes were released on a number of occasions (Gherardi *et al.* 2011b). The lake's commercial fishery opened in 1959 following introductions of tilapiine species, and the lake's fish community has since been managed in relation to this fishery, particularly how catches might be enhanced through management interventions. Consequently, this study provides an overview of the history and context of the fish introductions into Lake Naivasha through examining the: (1) history of the lake's fishery in relation to non-native fish; (2) purpose and history of the lake's introduced fishes in a fishery context; (3) relationship between the introduced fishes with environmental changes; (4) recent introductions; and (5) socio-economic drivers and benefits. The study used a combination of literature review, and the analysis of new data provided by the Fisheries Department of the Kenya Government. Outputs are discussed in relation to how this case study on multiple fish introductions contributes to extant knowledge on the ecology and management of non-native fishes.

Lake Naivasha, its fish community and fishery

Lake Naivasha is approximately 160 km^2, is 190 km south of the equator at an elevation of 1890 m asl and has a nominal mean depth of 3.35 m and a maximum of 7 m (Hickley *et al.* 2002). A map of the lake and its environs is available in Oyugi *et al.* (2014). It is bordered by *Cyperus papyrus* L. swamp that intercepts particles from eroded topsoil. Riparian ownership of Lake Naivasha is private, and the pressures on the lake's ecosystem and fishery are considerable. The lake is subject to major fluctuations in water level, and habitats are degraded as a consequence of riparian activity. There has been significant reduction in the total area of *C. papyrus* over the last 40 years as a consequence of both water level fluctuation and some reclamation of newly exposed shore to increased areas of cultivation (Boar 2006). In addition, Lake Naivasha has experienced an almost extirpation of its submerged macrophytes which, at best, are in a state of flux. Some eutrophication has been recorded (Kitaka *et al.* 2002) and is likely to have contributed to macrophyte disappearance. Also, submerged plants are heavily grazed by crayfish when commercial trapping and predation are not sufficient to control their density (Hickley & Harper 2002).

The most significant riparian activity on Lake Naivasha is the large-scale production of flowers for the European market, and at least 50% of the perimeter of the lake is under irrigated agriculture of some description. As the labour-intensive flower industry developed, so did the need for housing, water and latrines (Enniskillen 2002). The lake resources are also of critical importance to geothermal electricity generation, tourism, wildlife and conservation (Harper *et al.* 1990).

Resulting from a probable history of occasional drying out, Lake Naivasha had only one species of fish present when first studied (*c.* 1900). This was the indigenous, possibly endemic, *Aplocheilichthys* species 'Naivasha', previously referred to as *A. antinorii* (Vinc.) (Seegers *et al.* 2003). It was last recorded in 1962 (Elder *et al.* 1971). Prior to the introduction of carp, *Cyprinus carpio* L., in 1999 (Hickley *et al.* 2004b), the only fish species in the lake during recent times were *Oreochromis leucostictus* (Trewavas), *Tilapia zillii* (Gervais) (synonym: *Coptodon zillii*), largemouth bass *Micropterus salmoides* (Lacepède), *Barbus paludinosus* Peters and *Poecilia reticulata* Peters. Also present is the Louisiana red swamp crayfish *Procambarus clarkii* (Girard). Between 1987 and 2000, and prior to carp introduction, *O. leucosticus* dominated the fishery catches (72%), with *M. salmoides* (19%) and *T. zillii* (9%) relatively minor components (Figs 1 and 2).

Considerable temporal fluctuations in fish landings have been evident in the fishery, with three phases of development: an initial 'boom and bust' [1963–1977; mean (95% confidence intervals) annual catch 488 (269–706) t], a period of stability [1978–1987; 387 (257–517) t] and then a poorly performing fishery [1987–2001; 155 (74–236) t] (Fig. 1; Hickley *et al.* 2002). The maximum recorded total catch was 1150 t yr^{-1} in 1970, a contrast to the 21 t yr^{-1} in 1997. Subsequent management interventions included a fishing ban throughout 2001, with the fishery re-opened with only 43 licensed boats, just over one-third of the previous fleet. Annual closure periods have since been imposed, from 1 June to 1 October in 2003 and then June to August inclusive thereafter.

Purpose and history of Lake Naivasha's fish introductions

Since 1925, various fish introductions have been made, some successful and some not (Muchiri & Hickley 1991; Gherardi *et al.* 2011b). *Oreochromis spirulus niger* (Günther), introduced from the Athi River in 1925, was released to provide a forage fish ready for the American largemouth bass *Micropterus salmoides*, destined to be introduced later at the suggestion of US President T. Roosevelt for sport fishing (Robbins & MacCrimmon 1974). *Tilapia zillii* was released in 1956 to establish a population for commercial exploitation. This consignment also contained some *O. leucostictus* and both species established. See Table 1 for a summary of these and subsequent introductions.

As the fishery was underperforming, it was proposed in 2002 that additional species could be introduced (Hickley *et al.* 2002). Based on prospective feeding guilds and the actual food web, Muchiri *et al.* (1994) identified four niches in terms of food and space with respect to the potential for stocking additional species of fish. The most convincing case was that for a benthic-feeding species, as oligochaete and chironomid larval resources were under-utilised. Thus, a *Mormyrus* species

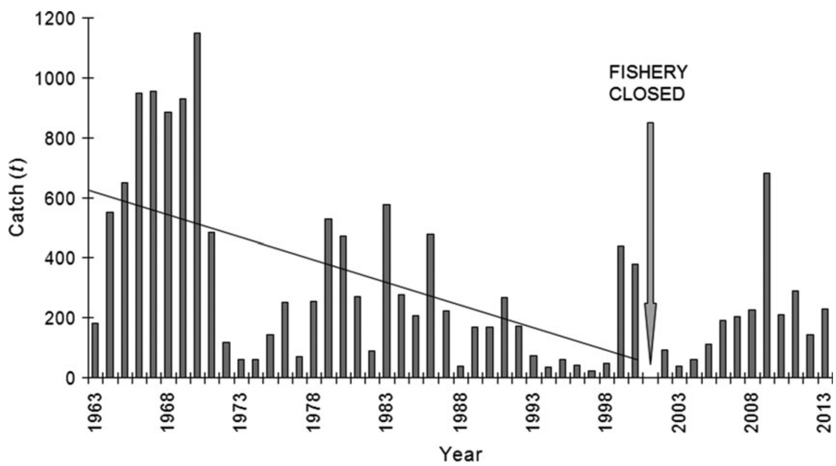

Figure 1. Total annual fish catch (t) for the Lake Naivasha gillnet fishery from 1963 to 2013 inclusive with trend line fitted for the pre-closure period. The arrow indicates 2001 when the year of closure was imposed.

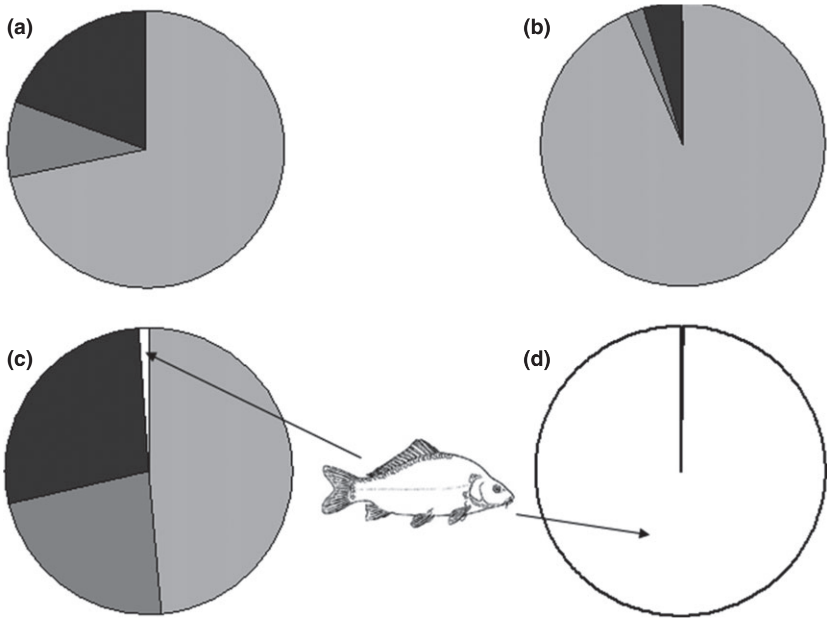

Figure 2. Average composition by weight (%) of the catch from the Lake Naivasha gillnet fishery (a) overall, 1987–2000; (b) 3 years before closure of the fishery, 1998–2000; (c) the year after re-opening of the fishery, 2002; (d) 2010. ▢ *Oreochromis leucostictus,* ▢ *Tilapia zillii,* ■ *Micropterus salmoides,* ☐ *Cyprinus carpio.*

Table 1. Summary of introductions and changes to the fish community of Lake Naivasha (Gherardi *et al.* 2011b; Aloo *et al.* 2013). Bold text indicates the species is still present in the lake.

Species	Date and success of fish release
Aplocheilichthys spec. 'Naivasha'	Possibly endemic. Probably extinct; last reported in 1962. Previously listed as *A. antinorii* (Vinciguerra)
Oreochromis spirulus niger (Gunther)	Introduced in 1925. Disappeared by 1971
Micropterus salmoides (Lacepède)	Introduced in 1929, re-introduced in 1951. **Present today**
Tilapia zillii (Gervais)	Introduced in 1956. **Present today**
Oreochromis leucostictus (Trewevas)	Introduced unintentionally in 1956 with *T. zillii*. **Present today**
O. leucostictus × *O. s. niger* hybrid	Abundant in the early 1960s but due to back crossing with *O. leucostictus* disappeared by 1972
Oreochromis niloticus L.	Introduced in 1967. Disappeared by 1971. Re-introduced in 2011. **Present today**
Gambusia sp. and *Poecilia* sp.	Introduced but dates unknown. Absent since 1977
Poecilia reticulata Peters	Introduced; date unknown. Recorded since 1982 but not seen in recent years
Oncorhyncus mykiss (Walbaum)	Introduced into the River Malewa, dates unknown. Caught in the lake on rare occasions
Barbus paludinosus Peters	Invaded from inflowing rivers (introduced into rivers?). Recorded since 1982. **Present today**
Cyprinus carpio L.	Introduced by escape from a fish farm on the inflow river. First recorded in 2001. **Present today**
Clarias gariepinus (Burchell)	Appeared in catches during 2012. **Present today**

was proposed as it was considered essential that, if the concept of further introductions became acceptable, only African fish should be potential candidate species. *Cyprinus carpio*, however, became the next resident fish.

In March 2001, during fishery closure, a fish eagle *Haliaeetus vocifer* (Gaudin) caught and landed a large carp approximately 680 mm in length (S. Higgins, personal communication), followed by 37 carp approximately 220 mm long and 0.4 kg in weight taken by the gillnet fishers in March 2002 after re-opening of the fishery. By the end of 2002, 1055 carp had been caught, with their average weight increasing to 2.25 kg (Hickley *et al.* 2004b). Its introduction was accidental, with fish escaping from an impoundment high in the River Malewa catchment, the lake's main inflow, and into which carp fingerlings had previously been stocked. Evidence of the establishment of a sustainable population was provided in August 2003 when survey gillnets (5–50 mm mesh size) captured juveniles (85–140 mm) (Britton *et al.* 2007) and during 2004, there was a marked increase in the contribution of carp to fishery commercial catches, culminating in 2009 when they comprised 99.7% of the total catch by weight (Fig. 3). Although the mean weight of landed carp was

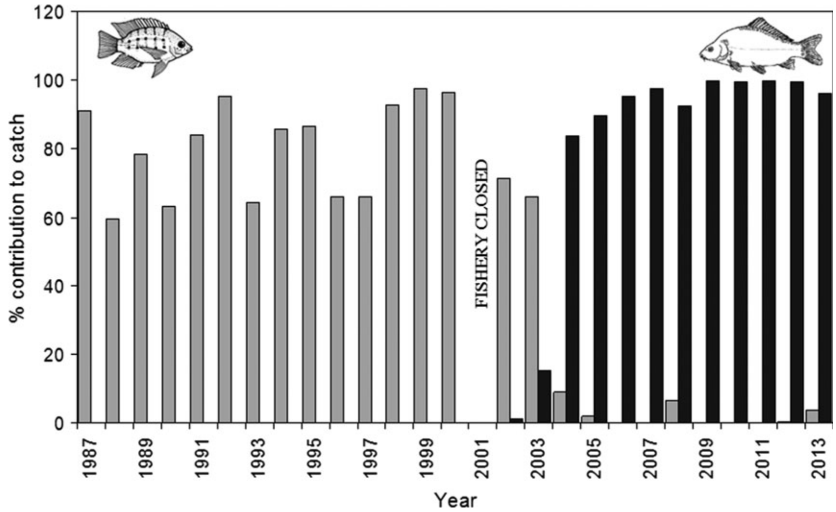

Figure 3. Annual percentage contribution by weight of *Oreochromis leucostictus, Tilapia zillii* and *O. niloticus* combined (grey bars) and *Cyprinus carpio* (black bars) to the commercial gillnet catches of Lake Naivasha showing the change from a tilapiine fishery to a carp fishery.

approximately 1.5 kg, some individual fish exceeded 8 kg. Its sustainability in the lake in the face of heavy fishing pressure is facilitated by its life history traits of rapid growth and high fecundity (Oyugi *et al.* 2011a).

Relationships of non-native fish with environmental change

The Lake Naivasha catchment has undergone considerable changes in the last 40 years, including substantial shifts in land-use patterns, especially the extent of large-scale horticulture that abstracts lake water for irrigation, and concomitant increases in human population size. The net effect for the water level of the lake is that it has increasingly becoming disconnected with the amount of rainfall received in the catchment. Models suggest levels were approximately 3–4 m lower during the 1990s and 2000s than they would have been naturally (Becht & Harper 2002; Oyugi *et al.* 2011b). There is also nutrient enrichment of the lake, with elevated phosphorous levels arising from agricultural activities in the catchment (Kitaka *et al.* 2002), and the loss of macrophytes following crayfish introduction (Smart *et al.* 2002).

The fish community changed in the 2000s. Alongside the establishment and population expansion of carp that subsequently dominated fishery catches, annual multi-mesh survey gill surveys (5–50 mm mesh size) completed between 1984 and 2008 revealed substantial population expansion of *B. paludinosus* from 2003. Large abundances of this cyprinid fish became present in most lake habitats at sizes between 50 and 140 mm, invoking a considerable change in *M. salmoides* diet (Britton *et al.* 2010a). Between 1987 and 1991, bass diet was strongly size-structured; with fish <260 mm mainly insectivorous and fish >260 mm feeding mainly on invasive crayfish, with *B. paludinosus* rarely taken (Hickley *et al.* 1994; Hickley *et al.* 2002). Since 2003, however, a combination of stomach contents analysis and stable isotope analysis suggested there had been a strong functional shift to their feeding on small (<100 mm) *B. paludinosus*, including by *M. salmoides* of 120–260 mm that were previously insectivorous (Britton *et al.* 2010a). In fish >260 mm, *P. clarkii* remained an important dietary component. Nevertheless, its population abundance has remained depressed due to the lake's eutrophic and turbid conditions, despite their relatively fast growth (Britton *et al.* 2010b). Thus, the lake is currently dominated by cyprinid species, numerically by *B. paludinosus* and biomass by *C. carpio* (Britton *et al.* 2010a; Aloo *et al.* 2013).

The changing lake level also has had a considerable influence on the fishery of the introduced tilapiines, O. *leucostictus* and *T. zillii*. Fishery data collected between 1975 and 1987 revealed their total catch was a direct function of fishing effort (Oyugi *et al.* 2011b). Since then, the influence of fishing effort on catch has diminished, with catches now significantly correlated with lake level; periods of higher lake levels produce higher catches (Hickley *et al.* 2002a,b; Oyugi *et al.* 2011b). Consequently, management of the tilapiine fishes through application of fishery models based on catch and effort may no longer be applicable (Oyugi *et al.* 2011b). The generally low lake levels that occurred throughout the 2000s, particularly in 2009, meant their catches remained depressed and their fisheries virtually non-existent (Figs 1 and 2). This is important, as tilapiines remain the preferred fishes for consumption for many local people.

Recent introductions

The decline in the tilapiine fishery (Figs 1 and 2) through environmental degradation led to the most recent formal species introduction into the lake. In line with the Kenyan Government's Economic Stimulus Programme, *Oreochromis niloticus* was reintroduced (Kagundu 2011). The species was introduced unsuccessfully in 1987 (Table 1; Gherardi *et al.* 2011a,b). As a micro-herbivore (Hickley & Bailey 1987), the changing lake conditions to a nutrient enriched and turbid lake might now present a more favourable environment in which this species can establish. The reintroduction programme was launched 10 February 2011 with the initial release of 30 000 fingerlings, with 300 000 released by June 2011. Should the species establish then the success of the reintroduction in invigorating, the tilapiine fishery will depend on adherence to the co-management regulatory measures currently in force. Initial indications suggest some success, with the appearance of these stocked fish in commercial landings during 2013. In addition, the African catfish, *Clarias gariepinus* (Burchell), has appeared in catches since October 2012 (Table 2). This was believed to originate from fish produced in aquaculture ponds in the Malewa catchment that flooded, similar to the scenario that previously resulted in carp introduction.

Social and economic benefits

In a survey of local opinion on the importance of Lake Naivasha (Hickley *et al.* 2004a), the top three reasons for its value were fishing 20%, drinking water 19% and irrigation 13%. In addition to the direct value of the fishery, it also provides non-fish benefits including food security, employment, community development, education, recreation, conservation and tourism.

Food security, employment and income generation

Small-scale and inland fisheries are significant contributors to rural food security and income generation, providing benefit to the poorest households in the rural sector (FAO 2012). There are three facets of food security: availability, access and use. Lake Naivasha, being adjacent to Naivasha town, enables compliance with these food security criteria, and the fish provide a valuable source of protein for local residents.

Up to 50 boats are licensed to fish each year and, generally, each has a crew of three fishers. In addition, however, there are traders, fisheries officers and research workers for whom the fishery is of direct importance. Overall, the fishing industry generates employment for more than 1000 Kenyans (Kundu *et al.* 2010), excluding those that participate in illegal fishing in the absence of legitimate work.

For fishers, whilst income figures are necessarily related to the amount of fish landed, in comparative terms they can be considered as good. Total value of fish landed was KSh 12 712 241 ($147 132) in 2010 and KSh 15 446 922 in 2012 ($178 784), giving an annual average value per fisher of KSh 84 760 ($981) and KSh 102 960 ($1192) for 2010 and 2012, respectively. Although the income from catches will not be equal for all fishers, these figures are comparable to the legal minimum wages for semi-skilled and skilled agricultural industry employees of KSh 66 498–105 086 ($770–1216) yr^{-1} (Mywage 2013). Although these figures must also be offset against the purchase and running costs of boats, sails or outboard engines and gillnets, they suggest all fishers are capable of keeping themselves and family above the poverty line, defined as expenditure necessary to meet minimum nutritional requirements and basic non-food needs (approximately KSh 18 750 [rural]–35 000 [urban] ($217–405) yr^{-1}).

Community development

Since the country's independence, Kenyan fisheries administration has been controlled by central government. As with any top-down approach to the management of resources, there was little or no provision for involving fisheries stakeholders in the decision-making process (Lwenya & Abila 2003). In the late 1990s, the Lake Naivasha fishery appeared to be on the point of collapse. It was being threatened by uncontrolled and excessive fishing, the use of illegal methods and gears, and disturbance of the fish breeding grounds in the shallow lakeshore areas.

Table 2. The biomass (kg) of species landed by the commercial fishers during 2011, 2012 and 2013 with 50 boats operating

Year	*Micropterus salmoides*	*Tilapia zillii*	*Oreochromis leucostictus*	*Oreochromis niloticus*	*Cyprinus carpio*	*Clarias gariepinus*
2011	159	4	17	0	287 897	0
2012	178	189	138	145	142 533	139
2013	562	1	2382	5905	220 373	11

The FAO Code of Conduct for Responsible Fisheries (1995) states that users of living and aquatic resources should conserve aquatic ecosystems and that the right to fish carries with it the obligation to do so in a responsible manner so as to ensure effective conservation and management of the living aquatic resources. Any fisheries sector needs to recognise such responsibilities. In keeping with this, the management regime for Lake Naivasha ought to provide quality fishing experiences within limits set by ecology, economics and society. It would need to adopt long-term conservation and sustainability measures, using the ecosystem approach as its guiding philosophy. Most important is the identification of all parties with a legitimate interest and engage them in the management process. Thus, the Kenyan government recognised that better management of fisheries resources required full engagement with fishers and other stakeholders, with the benefits of a strong fisheries community recognised and co-management approaches implemented (Kundu *et al.* 2010). A dual approach to engaging the stakeholder community was used. Firstly, in terms of overall lake welfare, a management plan was developed by the riparian owners. Secondly, in terms of specific action to benefit the fishery, the Kenyan Government facilitated the introduction of strategies based on the principles of co-management.

The management plan for Lake Naivasha was written by the Lake Naivasha Riparian Association (LNRA), an association of about 150 owners of riparian land. The Plan (LNRA 1999) was endorsed by the President of Kenya in August 1997. The Association's Management Implementation Committee has members from Kenya Wildlife Service, the Kenya Electricity Generating Company, the World Conservation Union, the Municipal Council of Naivasha, Government Ministries and the horticultural, tourism, livestock and fishing industries. Using international standards, Kenyan law and scientific studies of Lake Naivasha, the LNRA has made recommendations about how the lake's resources should be used, the aim being to prevent the lake and its foreshore from being 'damaged, polluted or wasted'. All categories of users were encouraged to write their own Codes of Conduct for their industry according to the Plan's guidelines, and these Codes are included in the Plan. Codes of Conduct and LNRA recommendations are followed voluntarily. The Plan targets everyone: residents, farmers, growers, hotel and curio shop owners, casual workers, people watering their animals, tourists, scientists, fishers and the purchasers of fish. Specifically, for the protection of the fishery, when open, the regulations and recommendations adopt a traditional approach (Gulland 1971) including gear specification, size limits and closed areas. The fisheries components of the plan were embraced during development of the fishery rules within the co-management process that ran alongside implementation of the plan.

In line with the principles underlying devolution and co-management (Pomeroy 2004), the Lake Naivasha stakeholder community network comprises the necessary members of government, the resource users and other interested stakeholders. Government departments responsible for fisheries include, police, water, environment, provincial administration and municipal councils. The fishing community is represented by fishers, merchants, boat builders and gear stockists. Other interested stakeholders include the LNRA members, Kenya Marine and Fisheries Research Institute (KMFRI) and Kenya Wildlife Service (KWS).

Adequate funding is always a difficult issue for new co-management initiatives. However, in response to this development of a fisheries co-management community, community members contributed funds via the LNRA to supplement the cost. Over 30 stakeholders, including individuals, flower farms and tourist hotels, contributed donations ranging from KSh 1500 to 1.4 million ($18–16 200). This community funding supported: training workshops for fishers, traders, police and judiciary officials; lake patrols and research activities; repairing patrol boats and purchasing outboard engines and mobile phones.

Compliance with agreed co-management actions is an indicator of success. For example, the Lake Naivasha fishers are using the legal large mesh size gillnets. Such compliance demonstrates a sense of ownership of the rules that the fishers helped to develop. This resulted in enhanced trust and cooperation between fishers, government officials and land owners. The associated substantial financial contributions from stakeholders improved surveillance. Also, the security of the patrol teams improved as a consequence of raised community awareness. Beach Management Units (BMUs) and welfare groups were formed, and a suite of favourable banking packages was made available to fishers. Community participation in making rules for the fishery increased the effectiveness of implementation and the sense of ownership of the same rules. Co-management at Lake Naivasha occurred as a result of problem recognition in resource management related to resource deterioration (Kundu *et al.* 2010). Although such problems as illegal seine netting in shallow water remain a challenge, co-management continues to evolve and adjust, and appears to have matured over time.

Education

Education of stakeholders is an important component of good fisheries management (FAO 1995). Public education campaigns were conducted during 2001 to increase the general understanding of sustainable use of the Lake Naivasha fishery. These campaigns involved public assembly meetings that created linkages and awareness across fishers, community and government officials. In addition, training workshops were held for fishers, traders, police and the judiciary. Such community education creates a sense of appreciation towards responsible fishing. Training for those involved in the Beach Management Units continues to enhance the understanding of the dynamics of fisheries resources management and exploitation. Community engagement, education and training remain important priorities for the future (Harper *et al.* 2011).

Recreation

Micropterus salmoides was introduced for recreational sport fishing and angling activity continues to the present day. Angling in industrialised societies constitutes an important and highly valued leisure activity (Hickley 2009). Most anglers are visitors from Nairobi rather than international tourists but associated with direct angling expenditure will be indirect and induced financial flows in the local economy. Recreational fishing has been described as the ritual pursuit of pleasure and comprises two principal components; a fishing factor which includes the number and size of fish caught, and a recreational factor which includes non-catch elements such as personal satisfaction. Aspects contributing to satisfaction are senses of freedom, excitement, relaxation and enjoyment of the natural setting. The Lake Naivasha fishery facilitates these recreational benefits (albeit non-fishing enjoyment of Lake Naivasha by ordinary residents is compromised by private ownership with only four small public access sites).

Conservation

Lake Naivasha became a Wetland of International Importance under the Ramsar Convention in April 1995 (Ramsar 2014). In determining whether a wetland is of sufficient international importance to become a Ramsar site, water birds and their habitat are a key consideration. Over 350 species of bird use the habitats of Lake Naivasha and many birds are directly dependent upon the fishery. For example, up to 165 resident, African fish eagles *Haliaeetus vocifer* (Daudin) have been known to predate the fish community (Harper *et al.* 2002). Similarly reliant upon the fishery are the breeding populations of the great cormorant, *Phalacrocorax carbo,* and the long-tailed cormorant, *P. africanus,* comprising several thousand birds (Childress *et al.* 2002). Other piscivorous birds that visit the lake regularly to forage (as observed by the authors) include two species of pelican and four species of heron.

Tourism

Kenya is an important tourist destination (Kenya Ministry of Tourism 2013) receiving 1.5 million holiday visitors annually, worth KSh 73.7 billion ($853 million) to revenue earnings. Whilst Lake Naivasha accounts for a very small proportion of the total tourism industry in Kenya, it has a high profile due its proximity to Nairobi. The basin is bounded by the famous Aberdare National Park in the north and has the Hell's Gate National Park nearby which has 87 000 visitors yr^{-1} (cf. Maasai Mara 157 900 yr^{-1}). Also, there are several private nature sanctuaries bordering the lake. There are approximately 4000 accommodation beds at Lake Naivasha that cater across a range of markets from international political and business delegations to truck drivers carrying freight to Uganda. Anecdotal estimates are that about 5% of all international tourists visiting Kenya (1.8 million in 2007) pass through Naivasha. The total value of the tourism sector in Naivasha in 2010 was estimated at KSh 600 million ($6.95 million) albeit only 5% of the horticulture industry (Pegram 2011).

The bird life of Lake Naivasha, especially the fish eagles that are dependent upon the fishery, plays a major part in attracting tourists and generating employment with the hotel trade, guided tours and boat charters.

Discussion

The drivers of the multiple fish introductions into Lake Naivasha were principally fishery creation and then enhancement, with the major introduced species still supporting the fishery today, albeit with substantial changes in species' proportions in the last decade. Given the extent of the environmental changes around the lake, including land-use and large-scale abstraction, it can be argued that in comparison, the introduced fishes have caused relatively minor ecological changes. Moreover, the recent shift in the fish community to cyprinid species is more likely to be a response to the environmental changes than due to invasion meltdown processes.

Without the release of the non-native fishes, the lake would have not had its viable bass and tilapiine fishery from 1963 to 2003, and the current dominance of carp is providing a sustainable fishery in the face of environmental degradation. It could thus be argued that these multiple introductions constitute an economic and social success. It could also be argued, however, that the species used have often been inappropriate, given that they include *C. carpio*, a species on the list of the World's 100 worst invaders (Lowe *et al.* 2000), and *O. niloticus* is a highly invasive fish in many countries (Gozlan 2008). Indeed, detrimental ecological impacts arising from *C. carpio* invasions have been recorded widely and include habitat disruption through macrophyte loss via their destructive foraging activities shifting lakes towards eutrophic states (e.g. Koehn 2004; Vilizzi 2012). These specific impacts attributable to carp have yet to be recorded in Naivasha, most likely due to the lake's already degraded state resulting from the anthropogenic stressors outlined. Moreover, it is the traits that make these species so invasive in their introduced range that has also enabled their establishment in Naivasha, and ensured populations have remained sustainable despite heavy exploitation and the degraded state of the lake.

The original ecological and conservation value of the native fish fauna of Lake Naivasha is difficult to determine today, given it comprised only the now extinct lampeye *Aplocheilichthys* spec. 'Naivasha'. Whilst it is speculative whether the bass sport fishery, and the subsequent commercial tilapiine fishery, would have been created if the present day approach to biodiversity had been in place in 1925, it can be considered unlikely that the economic and social benefits provided by these species would also have been delivered by the lampeye alone. Nevertheless, whilst these multiple introductions appear to paint a positive picture regarding economic and social gain, this case study also supports the view that, in dealing with non-native fish introductions, great care should be exercised. Several international protocols exist to facilitate this and they should be applied rigorously (Turner 1988; FAO 1995, 1996). If introductions are being considered, the critical questions to be answered are whether or not the action could invoke undesirable ecological consequences, will provide social and economic benefits and can be justified. It should be remembered that the release of a non-native fish species into a waterbody is effectively irreversible and, accordingly, the following guiding principles (after Hickley & Chare 2004) should be adhered to by fishery stakeholders:

- Demands for new sport fishing or commercial target species should be taken into account, but new introductions should only be considered where there is a demonstrable social, economic, recreational or research benefit;
- Fish introductions should not in any circumstances be allowed to jeopardise the well-being of naturally established ecosystems;
- There should be no detriment to the fisheries (stock, habitat, performance) of the recipient water, or to the viability of the species involved in transfer and introduction.

Notwithstanding this guidance, how could any perceived need to conserve the unique Naivasha lampeye have been balanced against demands for fishery development? The non-fish benefits of the Lake Naivasha fishery, especially those of food security, employment and community development could provide substantive argument in favour of an artificially created fishery dependent upon introduced species. Moreover, given the driving force of birds in the allocation of Ramsar status to wetlands, would this have been possible for Lake Naivasha had the introduced fish species not supported the development of an extensive piscivorous bird community? It could be argued, therefore, that fish conservation suffered but wetland conservation has gained. It is hoped, however, that with modern day guidance on sustainable development and responsible fisheries management that any contemporary stocking regime would be less destructive at the outset.

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