Status and ecosystem interactions of the invasive Louisianan red swamp crayfish Procambarus clarkii *in East Africa*

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INTRODUCTION

There are no indigenous crayfish in continental Africa although there are indigenous crayfish on the island of Madagascar (Hobbs 1988). However, various non-indigenous North American and Australian crayfish have been introduced to continental Africa since the 1970s, notably the Louisianan red swamp crayfish *Procambarus clarkii* (Girard). This is a relatively large, prolific, aggressive, burrowing crayfish (Hobbs *et al.* 1989 quoted in Holdich 1999) and it is well documented as an invasive species worldwide (Holdich 1999). Concern about the impact of exotic crayfish on aquatic ecosystems in South Africa (Mikkola 1996) is mirrored for fresh waters in East Africa where *P. clarkii* has established itself and is spreading (Howard and Matindi 2003).

The status of *P. clarkii* in Kenya and the Lake Victoria catchment was determined by reference to the literature, Nairobi Museum Records, and personal communications from scientists and riparian owners. The actual or probable impacts of *P. clarkii* in Kenya and the Lake Victoria catchment were

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ascertained from the literature, including field studies by the authors (Foster and Harper 2006a, b).

UGANDA

Water bodies in Uganda are illustrated in Fig. 1. *Procambarus clarkii* was introduced to Uganda in East Africa in the 1960s. In 1966, *P. clarkii* was cultured at Fisheries Resources Research Institute/National Agricultural Research Organisation's

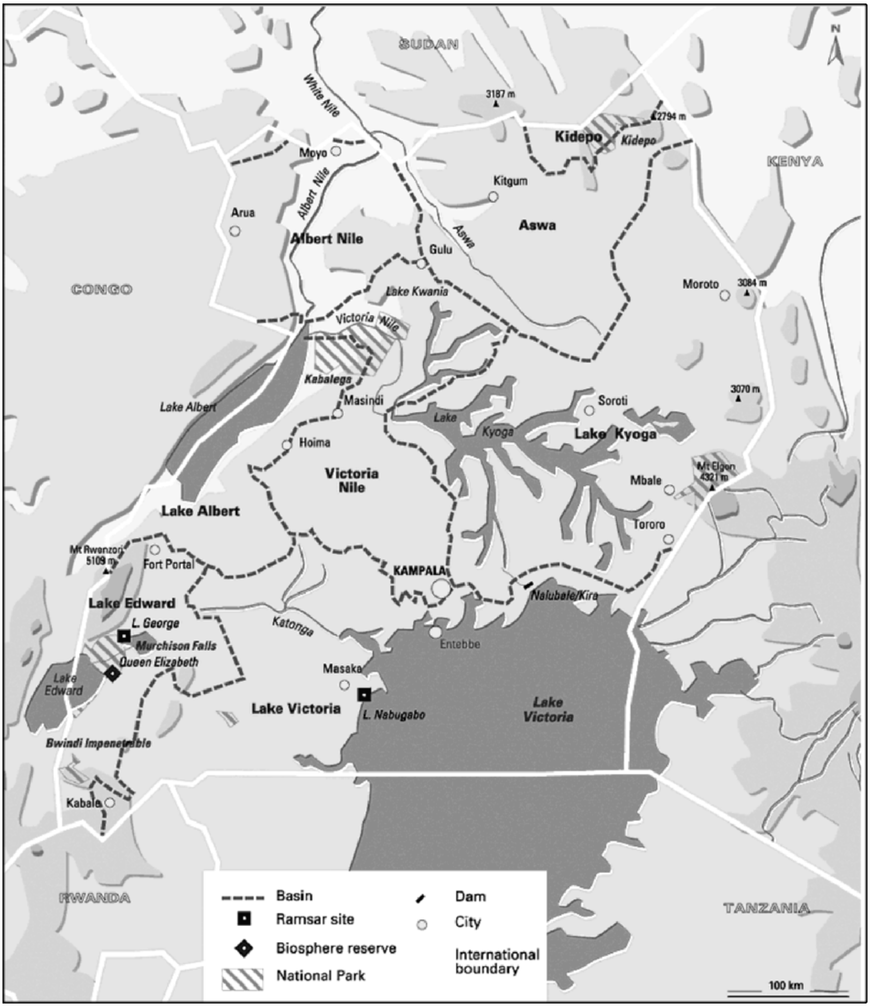

Fig. 1 Map of Uganda. (from www.unesco.org/water/wwap/wwdr2/case_studies/img/uganda_big.gif)

ponds at Kajjansi near Entebbe and Lake Victoria (Lowery and Mendes 1977) where it is still present (W. Daniels 2006, personal communication).

The species is established in Lake Bunyonyi in SW Uganda where it is exploited for the local restaurant trade. Lake Bunyonyi has no indigenous fish species but was stocked over the years with numerous local and foreign species. Lake Bunyonyi is a deep volcanic barrier lake which flows into the Ruhumba river which, in turn, flows into the Ruhumba swamps (but not to Lake Victoria) (Foster 2005). Water from Lake Bunyonyi flows through rock formations, not as an overflow. *Procambarus clarkii* may be quite widespread but under recorded in Uganda and may even have colonized the periphery of Lake Victoria in Uganda (W. Daniels 2006, personal communication).

Furthermore, anecdotal records suggest that *P. clarkii* may be established in the River Kagera which enters Lake Victoria on the Uganda–Tanzania border. The river originates in up country Rwanda and Burundi close to the Ruzizi River which flows into Lake Tanganyika (G. Howard 2005, personal communication). This presents a possible colonization route for *P. clarkii* into Lake Tanganyika in the long term.

KENYA

Water bodies in Kenya are illustrated in Fig. 2. *Procambarus clarkii* was introduced from Uganda to various parts of Kenya including the eastern basin of Lake Naivasha between 1966 and 1970 to enhance the commercial fisheries in the lakes and dams (Parker 1974, Lowery and Mendes 1977, Mikkola 1996). A commercial fishery was opened for *P. clarkii* in Lake Naivasha in 1975 (Mikkola 1996) and by 1977 the species was prevalent throughout the lake (Oluoch 1990). The status of *P. clarkii* in Lake Naivasha has been reviewed by Oluoch (1990), Harper *et al.* (2002), and Foster and Harper (2006a). The status of *P. clarkii* in the Rivers Gilgil, Malewa, and Karati flowing into Lake Naivasha from 1999 to 2003 is discussed by Foster and Harper (2006b).

Lake Naivasha (0°45′S, 36°20′E) is located in the Eastern Rift Valley at 1,890 m above sea level, approximately 100 km north-west of Nairobi. The lake is freshwater with two main rivers, the Gilgil and the Malewa draining into the northern perimeter of the lake in addition to the minor ephemeral River Karati; the lake has a subterranean inflow and outflow (Ase 1987). The recent biological history of the lake is reviewed by Harper *et al.* (1990).

The Naivasha Basin is bounded by the Aberdare Mountains to the east and the Mau Escarpment to the west. About 90% of the discharge into Lake Naivasha derives from the Malewa River (1,730 km^2 catchment), which receives its water from the Kinangop Plateau and the Aberdares. Much of the remaining inflow is from the River Gilgil (420 km^2 catchment) which drains the Bahati Highlands to the north of the Elmenteita–Nakuru basin, although a significant proportion of the Gilgil's water is abstracted for irrigation (Barnard

Fig. 2 Map of Kenya. (from www.unesco.org/water/wwap/wwdr2/case_studies/img/kenya_big.gif)

and Biggs 1988). A map of Lake Naivasha is illustrated in Foster and Harper (2006a), while a map of the rivers flowing into the lake is illustrated in Barnard and Biggs (1988).

Although *P. clarkii* had colonized the entire area of Lake Naivasha by 1977 (Oluoch 1990), it was only recorded from the lower reaches of the Rivers Gilgil and Malewa flowing into Lake Naivasha since 1999 (Foster and Harper 2006b). There is also anecdotal evidence that the crayfish has been introduced to ponds in the Malewa catchment to control leeches which feed on livestock and horses (S. Higgins 2003, personal communication). In October 2005, *P. clarkii* and guppies were recorded at the Njunu Springs at an altitude of about 2,300 m at Lake Ol Bolossat near Nyahururu in the Aberdare Mountains (www.nature-kenya.org 2006). Lake Ol Bolossat and its adjacent swamps (in the headwaters of the Ewaso Narok which joins the Ewaso Ng'iro North River) have no indigenous fish species.

Since 1974, *P. clarkii* has been recorded from the Athi/Galana river system which flows into the Indian Ocean in Kenya (Lowery and Mendes 1977, Nairobi Museum records) and was common in the Karen Pools in the suburbs of Nairobi in 1973 (Nairobi Museum Records). It is established in the Nairobi River (K. M. Mavuti, Nairobi University, 2003, personal communication) and in the Ewaso Ng'iro river system flowing off Mount Kenya to the swamps of the arid zones of northern Kenya (Lowery and Mendes 1977). *Procambarus clarkii* has been introduced into various farm dams and into various ditches, streams, and rivers draining these dams across Kenya (Lowery and Mendes 1977). The species is also present in some small high altitude tropical man-made reservoirs in the Kenyan Eastern Rift Valley (Mwaura *et al*. 2002), including Gathanje reservoir which has a fairly reliable fishery for it (Mwaura 2006).

Prior to 1977, *P. clarkii* was introduced into the catchment area of the Nzoia River draining to Lake Victoria from north-west Kenya (Lowery and Mendes 1977). In 1991, the species was recorded in abundance at Eldoret on the Eldoret river system by Mr M. D. MacDonald (Nairobi Museum records) who noted:

> This exotic was abundant in the rivers. While looking for amphibians there I saw one hundred or so. Earlier whilst looking for *Charmaeles ellioti* some boys passed by and asked me if I'd like to see some scorpions from the river. I told them scorpions didn't live in the river. It was only later that I realised that they had been referring to the crayfish.

The River Eldoret also flows into Lake Victoria from north-west Kenya.

BIOLOGICAL CONTROL OF SCHISTOSOMIASIS AND ANOPHELINE MOSQUITOES BY CRAYFISH

Procambarus clarkii has been deliberately introduced to certain aquatic locations in Kenya to combat the debilitating parasitic disease schistosomiasis by eating the parasite's snail vector (Mkoji *et al*. 1992); it may, in any event, inadvertently control schistosomiasis if it colonizes a schistosomiasis infected water body. Under certain environmental conditions, *P. clarkii* exerts a significant impact on the transmission of human schistosomiasis at locations in Kenya (Mkoji *et al*. 1999a).

Laboratory studies have indicated that *P. clarkii* has the ability to consume the aquatic life stages of the malaria-carrying anopheline mosquitoes and may therefore cause decreases in pathogen-transmitting mosquito populations in areas of Kenya where it has become established (Mkoji *et al.* 1999b). Thus there may be an incentive to introduce *P. clarkii* to those areas of Africa where schistosomiasis is endemic (such as the Sudan) in order to attempt to combat the debilitating parasitic disease in the human population. However, Lodge *et al.* (2005) noted that *P. clarkii* reduced populations of slow moving benthic invertebrates including snails, chironomid larvae, and oligochaetes in laboratory mesocosms and that water lilies disappeared from a pond that *P. clarkii* were introduced to. They state that, given the large impacts of freshwater crayfish on indigenous aquatic invertebrate and macrophyte communities, promotion of *P. clarkii* as a biological control agent should not proceed without additional assessment of the risks posed to indigenous African biota including fish. They conclude that, if freshwater crayfish colonized the large natural lakes of East Africa, globally important freshwater biodiversity resources might be at risk.

ECOLOGICAL IMPACTS OF *PROCAMBARUS CLARKII*

The ecological, economic, and social effects of the impacts of invasive species on waters and wetlands can be dramatic. Two classic examples of this are the well documented colonization of Lake Victoria by the exotic floating weed water hyacinth *Eichhornia crassipes* (Mart.) Solms (Howard and Matindi 2003) and the deliberately introduced Nile perch *Lates niloticus* Linnaeus.

Some non-indigenous crayfish can profoundly impact aquatic ecosystems (Hobbs *et al.* 1989, Holdich 1999, Lodge and Hill 1994, Chapter 28) and can affect the dynamics and biodiversity of the invaded community (Gherardi and Holdich 1999); such impacts may be negative and ecologically disastrous in the long term. These effects may include displacement of indigenous crab (Foster and Harper 2006b) and crayfish species. There may also be transfer of disease; consumption of fish eggs, large quantities of aquatic macroinvertebrates and macrophytes; damage to production in rice fields by eating rice shoots and burrowing into the banks; displacement of amphibians and possible physical damage to irrigation structures and banks of rivers and lakes by burrowing crayfish species (Holdich 1999). The Kenyan rice growing agricultural sector may be impacted by the spread of *P. clarkii* and its burrowing behaviour may also cause adverse impacts within the country.

There is an inverse relationship between *P. clarkii* abundance and the distribution and abundance of floating leaved and submerged aquatic plants in Lake Naivasha (Harper *et al.* 2002) as well as a ‘special’ relationship between water hyacinth *E. crassipes* and *P. clarkii* (Foster and Harper 2006a). *Procambarus clarkii* has been observed at densities in excess of $500\,m^{-2}$ (juveniles and adults) in floating water hyacinth mats on Lake Naivasha (Harper *et al.* 2002). It is likely that these water hyacinth mats, which normally fringe the papyrus reeds at the edge of the lake, play an important role in *P. clarkii* recruitment and population dynamics. Water hyacinth mats were abundant in the littoral zone in 1999 as were *P. clarkii*. In 2001 and 2002, the water hyacinth mats were extensively damaged by an non-indigenous coleopteran, *Cyrtobagus eichhorniae* (Warner), which had been introduced as a biological control agent for *E. crassipes* in 1995 (Harper and Mavuti 2004). Throughout 2001 and 2002, adult *C. eichhorniae* were found in *E. crassipes*. The destruction and lack of recovery of the water hyacinth mats, coupled with their importance to *P. clarkii* recruitment may explain a *P. clarkii* population crash which occurred concurrently in Lake Naivasha (Foster and Harper 2006a).

The related dynamics of *P. clarkii*, floating leaved, and submerged aquatic plants (notably the invasive *E. crassipes* which is abundant about the periphery of Lake Victoria) may follow similar patterns to those observed in Lake Naivasha if *P. clarkii* establishes itself in Lake Victoria or other East African lakes.

Periodic fluctuations in *P. clarkii* populations in Lake Naivasha may also be related to periodic droughts which decimate key littoral habitat along the lake shore (Foster and Harper 2006a) and floods which induce breeding in *P. clarkii*. The droughts and floods are related to the 'El Niño' event and afflict the East African highlands on a regular basis (Vincent *et al.* 1979, Hay *et al.* 2002).

The indigenous freshwater crab *Potamonautes loveni* (Colosi) was recorded in the Rivers Gilgil and Malewa flowing into Lake Naivasha in the 1980s (Barnard and Biggs 1988). In field studies from 1999 to 2003, *P. loveni* was only recorded in these rivers in the absence of the invasive *P. clarkii* (Foster and Harper 2006b). It may be that *P. clarkii* is eliminating *P. loveni* through some mechanism when contact occurs. The possible impact of the non-indigenous crayfish *P. clarkii* on indigenous freshwater crabs has worrying implications for freshwaters in the rest of Kenya and in the Lake Victoria catchment where *P. clarkii* has been introduced and where there were or are populations of indigenous freshwater crabs, some of the species of which are still "new to science".

The African clawless otter, *Aonyx capensis* (Davis), occurs in Kenya and in the Lake Victoria catchment and will feed on both non-indigenous crayfish and indigenous freshwater crabs. *Procambarus clarkii* has been observed in abundance in the spraints of the African clawless otter at Lake Naivasha (J. Foster 1999, personal observation). Interactions between the African clawless otter, crayfish, and freshwater crabs in the Ewaso Ng'iro river system, Kenya have been studied by Ogada (2006). Crayfish have supplanted the indigenous freshwater crabs in the Ewaso Ng'iro river system. The crayfish are the primary food source of the African clawless otter, but this resource varies seasonally due to the increased exposure of crayfish to other predators such as baboons, genets, herons, and monitor lizards. A stable prey for the African clawless otters (freshwater crabs) has been replaced by an unstable prey (crayfish). This is leading to seasonal variation in otter behaviour and a predicted local extinction of otters. A similar situation is likely to exist in respect of the marsh mongoose, *Atilax paludinosus* (Cuvier). Low ambient water temperature may be a limiting factor on the spread of *P. clarkii* in the high altitude mountainous areas of East Africa.

Procambarus clarkii may have other impacts on river and lake ecology in East Africa, including likely undocumented impacts on aquatic invertebrates. It is exposed to a range of predator types such as aquatic invertebrates, predatory fish, amphibians, reptiles, birds, and mammals, and will interact with them (Foster and Slater 1995). *Procambarus clarkii* is an important component of the diet of American largemouth bass, *Micropterus salmoides* (Lacepède), in Lake Naivasha and it is also fed upon by cormorants, fish eagles, wading birds such as ibises, and mammals such as the marsh mongoose (Harper *et al.* 2002). Crayfish can have effects on food webs by direct and indirect trophic effects (Nyström 2002).

IMPACT ON COMMERCIAL FISHERIES

Procambarus clarkii detrimentally affected established commercial finfish fisheries in Lake Naivasha by attacking fish caught in commercial nets and damaging the nets by entangling their bodies in the mesh of the nets (Lowery and Mendes 1977). This scenario may be repeated in respect of the substantial commercial finfish fisheries of Lake Victoria, if or when *P. clarkii* becomes established there. It has been demonstrated that *P. clarkii* may out-compete tilapia for food, at least under experimental conditions (Brummett and Alon 1994) and significant potentially adverse impacts may occur in the two lakes.

Procambarus clarkii can form the basis of substantial new commercial fisheries in its own right, as has been the case at Lake Naivasha since 1975, and may become the case at Lake Victoria. Catches of several hundred tonnes per annum of *P. clarkii* were exported live, mainly to Europe (predominantly Sweden and Germany) until 1981 when catches peaked at 500 tonnes or about 19 million adult crayfish. Then, the European Union imposed a temporary ban on the import of live crayfish from Kenya due to fears concerning an outbreak of 'cholera' in East Africa (Foster *et al.* 2001).

This led to a collapse of the Lake Naivasha commercial crayfish fishery and bankruptcy for some of the businesses involved. The internal Kenyan market for crayfish is small and mainly limited to tourist outlets in the Naivasha and Nairobi areas and some local consumption in the Naivasha area. Since 1981 catches have been well below observed potential maximum sustainable yields, averaging about 20–60 tonnes per annum or about 0.75–2.25 million adult crayfish per annum (Foster *et al.* 2001).

Despite this, efforts to establish commercial crayfish fisheries in Kenya have been hampered by the fact that many Kenyans do not eat crayfish, nor do they have economic or technical means to catch or export them properly (Mikkola 1996).

CONCLUSIONS

Procambarus clarkii is now abundant in freshwater bodies across Kenya and also occurs in Uganda. It has impacted the aquatic ecology of those waters and it may eliminate indigenous African freshwater crabs when it comes into competition with them. It supports a variable commercial fishery on Lake Naivasha but does not seem to be exploited elsewhere in Kenya. It has been used, with some success, as a biological control agent for the parasitic disease, schistosomiasis, in Kenya.

The crayfish has been recorded from the Nzoia and Eldoret rivers draining to Lake Victoria from north-west Kenya (Lowery and Mendes 1977, Nairobi Museum records) and it may already have escaped into Lake Victoria from ponds at Kajjansi, Uganda (W. Daniels 2006, personal communication) The colonization routes for *P. clarkii* into Lake Victoria clearly exist. Lake Victoria may be subject to ecological perturbations and changes to its fisheries associated with colonization by *P. clarkii* in the foreseeable future. The pattern and effects of colonization of Lake Victoria by *P. clarkii* may be similar to that observed in Lake Naivasha since 1970.

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