



Invasive crayfish threaten Okavango Delta

No indigenous freshwater crayfish exist in continental Africa, but several North American and Australian species have been introduced since the 1970s. The invasive Australian red-claw crayfish (*Cherax quadricarinatus*) is now spreading rapidly in southern Africa, especially in Zambia. Introductions have resulted from their use in aquaculture, so that the species was first reported in the middle Zambezi system in the Kafue River in 2001, and later in Lake Kariba in 2008 (Figure 1). The Zambezi River basin is the fourth largest river basin in Africa and contains 11 Ramsar wetlands of international importance, as well as the UNESCO World Heritage Sites of Lake Malawi and Victoria Falls. It is also periodically connected to the Okavango Delta, another World Heritage Site. Crayfish have now spread through much of the middle Zambezi, where the river ecosystem has unfortunately been transformed by flood regulation associated with dam construction for hydroelectric power generation, and where a number of alien vertebrates – for instance, Nile tilapia (*Oreochromis niloticus*) and Lake Tanganyika sardine (*Limnothrissa miodon*) – are now present (Tweddle 2010). However, the flows of the upper Zambezi and the Okavango Delta are unregulated and their associated habitats are in pristine condition, with no invasive aquatic animals reported in the Delta, one of the largest intact wetlands in the world. In the upper Zambezi, the only record of an alien animal is for Nile tilapia in off-channel aquaculture ponds (Alonso and Nordin 2003; Tweddle 2010).

Until recently, Victoria Falls prevented the spread of crayfish from Lake Kariba into the upper Zambezi, but in November 2014 a new population was reported spreading on the Barotseland floodplains after their introduction near Mongu (Figure 1). The extent of this population is currently unknown, but there is now an extremely high risk



Figure 1. Presence of the invasive crayfish *Cherax quadricarinatus* in Zambia and its potential spread from Mongu to the Okavango Delta World Heritage site. Black circles indicate crayfish presence until 2009, and red circles represent crayfish expansion between 2010 and 2015.

of it spreading to the Okavango Delta via the seasonal Selinda Spillway, which connects the Okavango to the Linyanti and Chobe rivers, and ultimately to the upper Zambezi River.

While very little work has focused on the ecological impacts of red-claw crayfish invasions, freshwater crayfish are high-impact invaders that can act as keystone ecosystem engineers, disrupting the trophic chain at multiple levels (Twardochleb *et al.* 2013). The potential impact of crayfish invasions

includes the destruction of aquatic macrophytes, disruption of macroinvertebrate communities, competition with native invertebrates, predation on fish and amphibian eggs, and disturbance of fish breeding habitats, resulting in overall alterations to ecosystem functioning (eg Rodríguez *et al.* 2005), along with damage to artisanal fisheries. This is of particular importance in the Zambezi River basin where fisheries – an important source of livelihoods – are

already under severe pressure from overfishing (Tweddle *et al.* 2015).

Although the consequences of this invasion are difficult to predict, there is already evidence of its disruptive effects. On the Kafue Flats, artisanal fishermen have reported substantial damage to fish caught in gill nets, as well as to the nets themselves, by scavenging crayfish (Phiri 2009; Tyser 2010). Crayfish caught in nets are generally discarded, as local superstitions seem to inhibit the eating of crayfish/shellfish and there is no local market for them. In both Zambia and South Africa, populations of *C quadricarinatus* have been responsible for the introduction of an undesirable non-native temnocephalan ectoparasite that might be harmful to native decapods (du Preez and Smit 2013; RJD personal obs). Furthermore, although some predatory fish species in the Kafue region have incorporated crayfish into their diets, positive impacts linked to the availability of a new prey species are likely to be limited, as crayfish have relatively low energy content in comparison to fish prey (Elvira *et al.* 1996). It is also doubtful that fish predation will deplete crayfish populations, because only small-sized crayfish seem to be vulnerable to this (Tyser and Douthwaite 2014). As such, research to identify the extent of this invasion – as well as the impacts on native biota linked to the role of *C quadricarinatus* as a predator, competitor, habitat disruptor, and parasite carrier – is urgently required.

Given the rapid spread of this species, it is important to develop proactive management and control/eradication measures to prevent further spread and mitigate invasion-related impacts. Crayfish control can be attempted through mechanical (trapping and electrofishing), physical (draining water bodies or creating barriers), chemical (use of biocides), or biological (microbial insecticides and introduction of fish predators) techniques (Freeman *et al.* 2010). However, since complete eradication is not realistic for established and abundant crayfish populations

(Gherardi 2007), in order to stop or hinder crayfish invading the Okavango Delta, immediate action is needed to determine whether eradication at Mongu is still feasible, or if measures to reduce crayfish abundance through a combination of intensive trapping and chemical control between two physical barriers on the Selinda Spillway should be implemented. In addition, legislation restricting the movement of the species and education of local people on the dangers of promoting the spread of this alien invader are necessary. While these are not definitive solutions, and will be difficult and costly to implement, failure to control the spread of this crayfish will most likely have enormous adverse consequences for the ecological structure and functioning of the Okavango Delta ecosystem.

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Pedagogy for the pedosphere

The United Nations designated 2015 as the International Year of Soils (IYOS), which reminded us of the irreplaceable value of the pedosphere – the Earth's complex, dynamic layer of soil – for supporting human well-being. During the year, a series of high-profile articles emphasized the research, policy, and governance dimensions of soils (Amundson *et al.* 2015; Nielsen *et al.* 2015; Oldfield *et al.* 2015; Wall and Six 2015; others listed at www.nature.com/soils). Although essential, advancing these aspects alone will be insuffi-