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The importance of investigating invasive freshwater crayfish

Crayfish are globally invasive species, causing environmental and socioeconomic impacts in the areas they invade (Lodge *et al*, 2012). They are of particular concern to the invasion sciences due to their interactions on many trophic levels, as well as being the largest and longest-lived invertebrates in freshwater systems (Gherardi, 2007). Crayfish are also a costly invasive freshwater species, with a global cost of US$ 120.5 million (2000-2020) (Kouba *et al*, 2021). Their invasion into non-native environments is largely driven by human activity (Madzivanzira *et al*, 2021; Gherardi, 2007), such as escaping from farms and being introduced to ecosystems as a pest control (Gherardi, 2007). As a result, crayfish are a major threat to freshwater ecosystems, which are already threatened by climate change and anthropogenic activity (Kouba *et al,* 2021), causing declines in biodiversity and habitat degradation. This review aims to discuss the impact of invasive freshwater crayfish on habitats and the communities around them, and thus the importance of prevention and management methods.

Invasive species are the largest threat to biodiversity (Riccardi and MacIsaac, 2011; Blackburn *et al*, 2019). A generalist diet allows the invaders to occupy a dietary niche or overlap a native species niche (Jackson *et al*, 2016). This leads to interspecific competition not only with the native crayfish, but also with other species in the ecosystem. A survey conducted in Kenyan rivers found that the native crab species began to decrease in size when in a mixed population with invasive red swamp crayfish (*Procambarus clarkii*), becoming the primary food source of the African clawless otter, due to the crayfish being able to consume more than the native species (Jackson *et al*, 2016). Another key part of the omnivorous crayfish diet is foliage, and they exhibit shredding behaviour (Madzivanzira *et al*, 2022; Kouba *et al,* 2021). Invasive crayfish species have a higher rate of shredding (Jackson *et al,* 2016), which has two impacts; firstly, it disrupts nutrient cycling by speeding up the degradation process (Jackson et al, 2016; Madzivanzira *et al,* 2020), and secondly it directly or indirectly competes with other species, such as birds and fish in the ecosystem (Madzivanzira *et al,* 2020). Invaders may also introduce new diseases and/or parasites to the native species, such as microsporidia infections (Dunn *et al,* 2008). Furthermore, freshwater crayfish structurally engineer their habitats via burrowing (Kouba et al, 2021; Jackson *et al,* 2016). In Italy, *P. clarkii* has caused damage to 30% of irrigation canals, which causes an increased flood risk, and changes the composition of sediment (Kouba *et al,* 2021).

The socioeconomic costs of invasion are complex, and often lack data, such as in Africa, Asia and Oceana (Kouba *et al,* 2021). In Kenya, disruption to the ecosystem has caused a decline in native birds (Madzivanzira *et al,* 2020), whose economy partly relies on ornithological tourism. There are also negative consequences for fishing communities in Africa. It was found that catch yield was reduced after the introduction of invasive species, compiled with the presence of partially eaten fish within the catch, which are not sellable (Madzivanzira *et al,* 2022), ultimately leading to a decrease in

fisherman income. China produces the most crayfish globally (estimated 100 million tonnes per year) (FAO, 2020), making crayfish farming economically important. However, crayfish farming requires the flooding of land that could otherwise be used for crops, creating a food security issue within the country (Kouba *et al,* 2021). The loss of land and habitat caused by the invasion or farming of crayfish ultimately leads to the loss of culturally significant sites and tradition (Kouba *et al,* 2021).

A major threat that the North American Signal crayfish (*Pacifastacus Leniusculus)* poses to all European crayfish species is crayfish plague. Signal crayfish are resistant to *Aphanomyces astaci* (the causative agent of crayfish plague) but carry it into new ecosystems (Dunn *et al,* 2008; Kouba *et al,* 2021). The infectious agent is considered one of the 100 worst invasive species (Kouba *et al*, 2021). This has caused extinction events in some parts of the UK (Dunn *et al,* 2008). The only native crayfish species in the UK is the White Claw (*Austropotamobius pallipes*) and is threatened by the invasion of P. *leniusculus* , which escaped from aquaculture farms (Dunn *et al*, 2008). *P. leniusculus* has been introduced to over 40 countries on four continents (Kouba et al, 2021). Surveys conducted from 2002 to 2005 at the river Wharfe (Northern England) found that *P. leniusculus* moved greater distances than the native White clawed crayfish (*Austropotamobius pallipes)* (Bubb *et al*, 2006), which would supposedly aid in their ability to disperse at a fast rate. The native *A. pallipes* was found to move more frequently, and to change refuge sites more frequently (Bubb *et al,* 2006), which may be due to competitive exclusion from refuges (Dunn *et al*, 2008). As a result of competitive exclusion, the native species recorded in mixed populations are smaller than the invaders compared to single species populations (Dunn *et al,* 2008), suggesting the invaders have a higher consumption rate. It is therefore suggested that the invader is successful due to its more aggressive nature, allowing it to outcompete the native species via a variety of displacement mechanisms (Jackson *et al,* 2016; Dunn *et al*, 2009; Bubb *et al,* 2006). By the end of the survey at River Wharfe, there were no native populations (Bubb *et al*, 2006).

Prevention and management strategies are not currently successful anywhere in the world. It is thought that a lack of incentive and funding may hinder the potential for policy making (Christie *et al,* 2019), which can be illustrated by China benefitting financially from crayfish farming despite the risk of flooding, and use of land (Ho, 2020). Public perceptions may be key to combatting the lack of policy around invasive species (Höbart et al, 2020), by educating the public on the threat that these taxa pose to their livelihoods and the environment. Education on invasive species is also key for policy makers to make informed decisions on methods to combat the spread of these species (Gherardi *et al*, 2011). However, in countries where crayfish are viewed as a cheap food source, interest in reporting invasion may be limited. There is also a lack of widespread policy due to the complexity of the issue posed by eradicating invasive species, including the effects of non-selective biocides on the whole ecosystem (Chadwick *et al*, 2021). For example, crayfish are only one type of invasive freshwater taxa, as well as the fact that these species diffuse rapidly, which often counteracts eradication methods, such as mechanical removal (Gherardi *et al*, 2011). It is suggested that contingency plans may be valuable for prompt detection of invasion incidences and subsequent prevention of spread on regional and national levels (Gherardi *et al,* 2011). A potential solution for

the economic losses caused by invaders are misdirection traps, which have been found to save fishers an average of US$ 3.57 per day (Madzivanzira *et al,* 2023).

Freshwater crayfish are a global issue that negatively affects biodiversity, habitat structure, and the livelihoods of communities living close to freshwater systems. Through education, the public and policymakers can be better informed on the threat that these invasive species pose. Thus, a more robust and central mechanism of prevention can be established to protect the ecosystem, and the socioeconomic standing of those affected by invasive species.

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