Potential threats posed by a translocated crayfish: the case of *Cherax destructor* in coastal drainages of New South Wales, Australia

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Abstract.—The yabby, *Cherax destructor*, is endemic to inland waterways of south-eastern Australia. However, as a result of aquaculture feral populations have become established outside its natural range, within and outside of Australia. In recent years, numerous translocated populations have been recorded from coastal drainages in New South Wales, where a sizeable diversity of endemic coastal crayfishes occur. Translocated yabbies represent a potential threat to indigenous fauna in the waterways of eastern New South Wales, and in this paper we outline the habitats and biota that may be at risk. We discuss several key concerns regarding this translocated crayfish, including: the probable pathways of introduction; its propensity to spread; potential competition and predation threats; pathogen concerns; and potential impacts at the habitat and ecosystem level.

INTRODUCTION

The yabby, *Cherax destructor*, is the most widely distributed freshwater crayfish in Australia, with a natural range that extends across several inland catchments west of the Great Dividing Range (Sokol, 1988). However, it has been translocated to other parts of the continent including Western Australia, Tasmania and, more recently, coastal catchments in New South Wales (NSW) (Austin, 1985; Elvey *et al.*, 1996; Horwitz, 1990; Horwitz & Knott, 1995; Coughran *et al.*, 2009). Since the initial report of translocated populations of *C. destructor* in eastern NSW (Coughran *et al.*, 2009), several additional populations have been recorded (McCormack & Daly, unpublished data). The sudden occurrence of this translocated crayfish species in

virtually all coastal drainage systems in NSW is of great concern to the protection and management of the indigenous fauna of these waterways. In this paper we outline the severity of the potential threat involved.

The aquatic ecosystems of NSW are most conspicuously defined by the Great Dividing Range, which divides the State's waterways into inland and coastal draining systems. Inland waterways are characterized by a low diversity of relatively widespread aquatic species, while the coastal drainages support a much richer diversity of species with comparatively small distributions. This difference is highlighted by the crayfish fauna of the state. Apart from a handful of species that occur in the upper headwaters along the Great Dividing Range, the major inland waterways are dominated by two species: the widespread yabby (*Cherax destructor*) and the River Murray Crayfish (*Euastacus armatus*). In contrast, the coastal waterways of NSW support more than 40 species from five genera (Table 1).

Probable pathways.

The probable pathways of translocated *Cherax destructor* in eastern drainages (i.e. aquarium release, use of bait yabbies in fishing, deliberate stocking as a food resource, etc) are all still present. Regrettably, the Australian Crayfish Project surveys have recorded further translocated populations of this species since the paper by Coughran *et al.* (2009) was published, and it has now been recorded in additional coastal drainages of NSW (an update listing the site details of these additional translocated populations will be published in due course; McCormack, pers. comm.).

Table 1. The coastal drainages of New South Wales support more than 40 species of freshwater crayfish, most of which are endemic to coastal drainages. These crayfish are listed as 'restricted' if their estimated distribution is <10,000km², and as 'highly restricted' if their estimated distribution is <1,000km². Current IUCN Red List conservation classifications are provided where available

Species	Coastal Endemic	Distribution Range	Conservation Status (IUCN)
<i>Cherax cuspidatus</i>	yes	not restricted	Least Concern
<i>Cherax leckii</i>	yes	highly restricted	Critically Endangered
<i>Cherax setosus</i>	yes	restricted	n/a
<i>Engaeus cymus</i>	no	not restricted	Least Concern
<i>Engaeus orientalis</i>	no	restricted	Least Concern
<i>Euastacus australasiensis</i>	yes	not restricted	Least Concern
<i>Euastacus bidawalus</i>	yes	restricted	Endangered
<i>Euastacus brachythorax</i>	yes	restricted	Endangered
<i>Euastacus clarkae</i>	yes	highly restricted	Critically Endangered
<i>Euastacus claytoni</i>	no	restricted	Endangered
<i>Euastacus crassus</i>	no	restricted	Endangered
<i>Euastacus dalagarbe</i>	yes	highly restricted	Critically Endangered
<i>Euastacus dangadi</i>	yes	restricted	Least Concern
<i>Euastacus dharawalus</i>	yes	highly restricted	Critically Endangered
<i>Euastacus gamilaroi</i>	no	highly restricted	Critically Endangered
<i>Euastacus girumalayn</i>	yes	highly restricted	Critically Endangered
<i>Euastacus gumar</i>	yes	highly restricted	Endangered
<i>Euastacus guruhgi</i>	yes	highly restricted	Critically Endangered
<i>Euastacus guwinus</i>	yes	highly restricted	Critically Endangered
<i>Euastacus hirsutus</i>	yes	restricted	Endangered
<i>Euastacus jagabar</i>	yes	highly restricted	Critically Endangered
<i>Euastacus maccai</i>	no	restricted	Endangered
<i>Euastacus mirangudjin</i>	yes	highly restricted	Critically Endangered
<i>Euastacus morgani</i>	yes	highly restricted	n/a
<i>Euastacus neohirsutus</i>	yes	restricted	Least Concern
<i>Euastacus pilosus</i>	yes	highly restricted	Endangered
<i>Euastacus polysetosus</i>	yes	highly restricted	Endangered
<i>Euastacus reductus</i>	yes	restricted	Least Concern
<i>Euastacus rieki</i>	no	restricted	Endangered
<i>Euastacus simplex</i>	yes	not restricted	Vulnerable
<i>Euastacus spinichelatus</i>	yes	highly restricted	Endangered
<i>Euastacus spinifer</i>	no	not restricted	Least Concern
<i>Euastacus sulcatus</i>	no	restricted	Vulnerable
<i>Euastacus suttoni</i>	no	not restricted	Vulnerable
<i>Euastacus valentulus</i>	yes	not restricted	Least Concern
<i>Euastacus yanga</i>	yes	not restricted	Least Concern
<i>Euastacus</i> sp. 1	yes	highly restricted	n/a
<i>Gramastacus</i> sp. 1	yes	highly restricted	n/a
<i>Gramastacus</i> sp. 2	yes	highly restricted	n/a
<i>Tenuibranchiurus</i> sp. 1	yes	highly restricted	n/a
<i>Tenuibranchiurus</i> sp. 2	yes	highly restricted	n/a

The threat of further introductions of this species in NSW is real, and in the absence of education programs or mechanisms to reduce the various introduction pathways, it is most likely that the species will continue to become established in waterways throughout all coastal drainages.

Propensity to spread.

Cherax destructor has a high propensity to spread and colonize new sites. The species is known to leave the water and travel overland considerable distances, and in some cases *en masse*, to colonize new habitats (Olszewski, 1980; Barnham & Barker, 2009). It is environmentally tolerant and able to withstand extreme physicochemical conditions (Beatty *et al.* 2005), enabling it to occupy temporary habitats. Moreover, it is highly fecund and capable of continual spawning when conditions are suitable, advantageous traits for the rapid colonization of new areas (Beatty *et al.*, 2005). The species can persist in a variety of water bodies, including temporary puddles, and may impact on a wide range of lentic and lotic species in coastal NSW. For example, in the Newcastle region¹ it has recently been found in forestry dams, creeks, drains and, at one site, in a vehicle rut (McCormack & Coughran, 2011).

Competition threats and species displacement.

Because of their superior biological attributes, translocated *C. destructor* have the potential to rapidly out-compete endemic crayfish species (Coughran *et al.*, 2009). The population at Fitzroy Falls, for example, appears to be rapidly displacing an endemic crayfish, *Euastacus dharawalus*, which is now considered Critically Endangered (IUCN, 2011, Coughran and Furse, 2010; Furse & Coughran, 2011a, b, c). The Australian Crayfish Project has been undertaking targeted surveys for *E.*

dharawalus in recent years. When the situation at Fitzroy Falls was first brought to attention, a proposal was developed for continued and more specific population research on this species. However, relevant stakeholder agencies did not fund the initiative, on the basis that the issue was not of sufficiently high priority (McCormack, pers. comm.). The situation at Fitzroy Falls has the potential to cause the extinction of the iconic native crayfish that is only known from that site, and similar situations could be occurring elsewhere in coastal NSW.

The potential threat is not simply a matter of resource competition. Overseas studies have found inter-specific interactions can influence species replacements in crayfishes through a complex range of processes, involving factors such as reproductive interference, aggressive dominance, differential susceptibility to predation, habitat availability and quality, disturbance, health status, growth, and spatial and temporal access to food and shelter resources (Rabeni, 1985; Capelli & Munjal, 1982; Butler & Stein, 1985; Lodge *et al.*, 1986; Söderbäck, 1991; Mather & Stein, 1993; Garvey *et al.*, 1994; Hill & Lodge, 1994).

Predation threats.

The premeditated stalking and hunting for live prey, including frogs, tadpoles and fish, is a known feeding behaviour of yabbies generally (Bradsell *et al.*, 2002; Hawking *et al.*, 2009; Merrick, 1993), but specific studies are required to document this in coastal habitats of NSW where translocated populations of *C. destructor* occur. Of the more than 40 indigenous freshwater fish species in coastal NSW (Allen *et al.*, 2003), only four are listed as threatened:

- Eastern Freshwater Cod *Maccullochella ikei* is a large species (growing to > 65 cm) that displays parental guarding of egg masses (Allen *et al.*, 2003; New South Wales Fisheries, 2004), and is unlikely to be susceptible to predation by *C. destructor*.

- Oxleyan Pigmy Perch *Nannoperca oxleyana* is a small species (< 7 cm) that inhabits lowland creek and wallum habitats in northeastern NSW (Allen *et al.*, 2003). At present, *C. destructor* is not known to

¹It is worth noting that there is an endemic crayfish, *C. setosus*, restricted to this coastal area that could be threatened by reproductive interference from the translocated *C. destructor* (McCormack & Coughran, 2011). Studies have shown that when crossed, the two species produce sterile, all male offspring (Lawrence *et al.*, 1998, 2000).

Table 2. Species of amphibian listed as threatened under the TSC Act (1995) and risk of impact from predation of tadpoles and or eggs by *C. destructor*. Superscripts relate to listings under the TSC Act (1995): 1 indicates species listed as critically endangered, 2 indicates species listed as endangered, 3 indicates species listed as vulnerable

Species	Common Name	Risk Assessment	Rationale
<i>Litoria castanea</i> ¹	Yellow-spotted Tree Frog	Low	Historically sympatric with natural distribution of <i>C. destructor</i>
<i>Litoria piperita</i> ¹	Peppered Tree Frog	Moderate	High altitude species
<i>Litoria spenceri</i> ¹	Spotted Frog	Moderate	Historically sympatric with natural distribution of <i>C. destructor</i>
<i>Pseudophryne corroboree</i> ¹	Southern Corroboree Frog	Low	Breeds in alpine bogs
<i>Pseudophryne pengilleyi</i> ¹	Southern Corroboree Frog	Low	Breeds in alpine bogs
<i>Litoria aurea</i> ²	Green and Golden Bell Frog	Low of range.	Historically sympatric with <i>C. destructor</i> in a portion of range.
<i>Litoria booroolongensis</i> ²	Booroolong Frog	Low	Historically sympatric with <i>C. destructor</i> in a portion of range.
<i>Litoria verreauxii alpina</i> ²	Alpine Tree Frog	Moderate	Historically sympatric with natural distribution of <i>C. destructor</i>
<i>Mixophyes balbus</i> ²	Stuttering Frog	High	Breeds on creeks suitable for <i>C. destructor</i>
<i>Mixophyes fleayii</i> ²	Fleay's Barred Frog	High	Breeds on creeks suitable for <i>C. destructor</i>
<i>Mixophyes iteratus</i> ²	Giant Barred Frog	High	Breeds on creeks suitable for <i>C. destructor</i>
<i>Neobatrachus pictus</i> ²	Painted Burrowing Frog	Low	Sympatric with natural distribution of <i>C. destructor</i>
<i>Philoria kundagurum</i> ²	Mountain Frog	Low	Eggs and tadpoles develop in nest cavity
<i>Philoria loveridgei</i> ²	Loveridge's Frog	Low	Eggs and tadpoles develop in nest cavity
<i>Philoria pughii</i> ²	Pugh's Frog	Low	Eggs and tadpoles develop in nest cavity
<i>Philoria richmondensis</i> ²	Richmond Range Frog	Low	Eggs and tadpoles develop in nest cavity
<i>Assa darlingtoni</i> ³	Pouched frog	N/A	Tadpoles develop within skin fold on the back of the frog
<i>Crinia sloanei</i> ³	Sloane's Froglet	Low	Historically sympatric with natural distribution of <i>C. destructor</i>
<i>Crinia tinnula</i> ³	Wallum Frog	Moderate	Tadpoles develop in wallum swamps and are benthic
<i>Litoria brevipalmata</i> ³	Green-thighed Frog	Low	Breeds in ephemeral ponds, eggs laid as sheet on water surface, tadpoles develop rapidly
<i>Litoria daviesae</i> ³		Moderate	Eggs laid in streams attached to sticks, susceptible to predation by <i>C. destructor</i>
<i>Litoria littlejohni</i> ³	Littlejohn's Tree Frog	High	Eggs laid in streams attached to sticks, susceptible to predation by <i>C. destructor</i>
<i>Litoria olongburensis</i> ³	Olongburra Frog	Moderate	Tadpoles develop in wallum swamps but are active in midwater
<i>Litoria subglandulosa</i> ³	Glandular Frog	Moderate	Eggs laid in streams attached to sticks, susceptible to predation by <i>C. destructor</i>
<i>Philoria sphagnicolus</i> ³	Sphagnum Frog	Low	Eggs and tadpoles develop in nest cavity
<i>Pseudophryne australis</i> ³	Red-crowned Toadlet	Low	Eggs develop in nest cavity and live in shall pools

occur in *N. oxleyana* habitat, but this small fish would likely be susceptible to predation impacts should *C. destructor* become established within its range in the future.

- **Macquarie Perch** *Macquaria australasica* is a medium species (~45 cm) with eggs that settle amongst the stones and gravel of the stream bed (Primary Industries Fishing and Aquaculture 2012); these eggs are considered to be susceptible by predation by *C. destructor*, which is known to occur within its range.

- **Purple Spotted Gudgeon** *Mogurnda adspersa* has experienced substantial declines in both its inland and coastal populations of NSW (West 2008). Although males guard the eggs, the small size of this fish (12 cm) would likely render both the eggs and the fish susceptible to predation impacts should *C. destructor* become established within the distribution of its coastal populations in future.

There are several coastal species of frog at potential risk from predation by *C. destructor*. The TSC Act 1995 (New South Wales Government, 2012) lists 29 frog species that are either critically endangered (5 spp.), endangered (12 spp) or vulnerable (12 spp.) to extinction (as at 8th July 2011). Of these species, two critically endangered, four endangered and five threatened species are considered at risk from impacts of *C. destructor* (Table 2). Four of these are considered at high risk of being impacted by *C. destructor*, as they breed in creeks (lotic) and lay their eggs in a single or several masses, hence making them more susceptible to being eaten than species that lay their eggs as dispersed, single units. Apart from *Mixophyes fasciolatus*, all other species of Barred frog, *Mixophyes* spp., in NSW are obligate stream breeders, whereas the Heath Frog is a species complex with populations in the Illawarra region of NSW mainly breeding in streams. These threatened species are considered to be most at risk from *C. destructor* because of their reproductive biology (lay eggs on clumps or masses) and the fact that they occur at relatively low altitude in habitat considered suitable for *C. destructor*.

Cherax destructor also impacts on

species of frog that lay their eggs in still water. In general, ponds and dams that support large populations of *C. destructor* appear devoid of tadpoles (G. Daly pers. obs.). Species of frog that lay their eggs in masses, as opposed to those that lay single eggs, are considered at most risk of mortality associated with predation of eggs by *C. destructor*. Species that utilise ephemeral ponds and have a relatively short aquatic life phase are considered to have a lower risk than those that occur in more permanent habitats and/or have a longer aquatic life phase. Species that lay their eggs in the far upper reaches of creeks (seepages) such as members of the genus *Pseudophryne* and *Philoria* are also considered to have a low risk of predation by *C. destructor*, as these habitats are not favourable to yabbies. Species that occur in restricted habitats such as montane forests (e.g. *Litoria piperita*, *L. spenceri*, *L. daviesae*, and *L. subglandulosa*) are considered to have a moderate risk of impact, as *Cherax destructor* prefers warm temperatures and is less likely to proliferate in cold water in shaded environments (Withnall, 2000; Capinha & Anastácio, 2011).

There is concern that *C. destructor* will also cause significant impacts on those species of frog that are currently not listed under the Threatened Species Section (1995) Act, and may cause additional species to be listed under that act. The greatest risk is considered to be for those species endemic to lowland habitats, lay eggs in masses and have a relatively slow aquatic phase. Species such as the Blue Mountains Tree Frog *Litoria citropa*, Haswell's Froglet *Paracrinia haswelli* and species within the *Litoria phyllochroa* complex may be at risk.

Predation impacts from translocated *C. destructor* are also relevant to aquatic invertebrates. The invertebrate fauna of coastal NSW is not as well known as other groups, but four species of dragonfly are currently listed as 'endangered' under State conservation legislation: Giant Dragonfly *Petalura gigantea*, Coastal Petaltail *Petalura litorea*, Adam's Emerald Dragonfly *Archaeophya adamsi*, and the Sydney Hawk Dragonfly *Austrocordulia leonardi*.

In general, dragonfly nymphs are likely to be susceptible to predation by yabbies, although there is perhaps more chance of exposure for species that utilise surface water habitats (*A. adamsi* and *A. leonardi*) than those that utilise bogs and swamps (*Petalura* spp.) (Department of Environment and Conservation, 2005a,b; Department of Primary Industries, 2005a,b). However, translocated yabbies could colonize swamp habitats, and observations of *C. destructor* within the vicinity of recorded sites for any of these threatened dragonfly species should be reported immediately.

One important consideration for the potential for damage by *C. destructor* on coastal ecosystems lies in the fact that the indigenous fauna may simply lack crucial recognition cues for this invading species. Furthermore, *C. destructor* also displays a generally high level of aggressive behaviour compared to many coastal crayfishes (J. Coughran pers. obs.). Gherardi *et al.* (2002) also found that invasive *C. destructor* in Western Australia make faster and more appropriate use of alarm odours than the indigenous *C. tenuimanus*.

Because *C. destructor* is a very robust animal with broad environmental tolerances it is capable of colonizing many aquatic habitats. The predation risk to endemic coastal fauna could therefore be wide reaching. In Western Australia, Bradsell *et al.* (2002) considered the introduced *C. destructor* more likely to present a threat to the critically endangered western swamp turtle, *Pseudemydura umbrina*, than three native species of *Cherax*. The turtle has a very restricted distribution and laboratory experiments indicated that *C. destructor* displayed higher aggression to turtle hatchlings than the indigenous *C. quinquecarinatus*. *Cherax destructor* is more a habitat generalist than all five *Cherax* endemic to Western Australia, and was considered more likely to successfully colonize the turtle habitat (Bradsell *et al.*, 2002). This is comparable to the current situation in eastern NSW, where most native coastal crayfishes have specific habitat requirements and, consequently, restricted distributions (Merrick, 1993).

Potential pathogen threats.

Cherax destructor is known to carry a range of pathogens and parasites, including the microsporidian protozoan *Thelohania* sp., the fungus *Saprolegnia* sp. and the bacterium *Pseudomonas* sp. (Merrick, 1993). Currently there are no observations of transmission to endemic species in the coastal environments where *C. destructor* has been translocated, although the information base on existing pathogens and parasites of endemic coastal species is poor or absent.

Potential impacts at the habitat and ecosystem level.

Translocated *C. destructor* may cause significant habitat destruction that may adversely affect native flora and fauna in coastal catchments of NSW. In southern Australia where it has become established, it has destroyed macrophytes and caused siltation, and has thus been recognized as a threat to the native fish Dwarf Galaxias, *Galaxiella pusilla* (Threatened Species Section, 2006). Elsewhere in the world, translocated crayfish compete with fish for food, modify fish habitat by reducing shelter, spawning and nursery areas, and limit nutrient and food availability (Momot, 1995). For example, the invading *Orconectes rusticus* has not only significantly reduced macrophytes, but in so doing, may have significantly reduced fish populations (Capelli, 1982). The potential for adverse habitat impacts from *C. destructor* in coastal NSW should also be recognized, and could result from rapid population growth and/or different behaviour of *C. destructor* in the receiving environment. For example, *C. quadricarinatus* display no burrowing ability in their natural environment, but when they became established in some overseas areas they were found to construct large U-shaped burrows that compromised stream integrity (Todd & D'Andrea, 2003). The occurrence of *C. destructor* in all coastal catchments of NSW, and in essentially all habitat types, increases the potential for these impacts.

General Remarks.

Elsewhere in Australia where it has been introduced (e.g. Western Australia

and Tasmania, where it has been listed as noxious), *C. destructor* has continued to expand its distribution and colonise new areas (Lynas *et al.*, 2004; Beatty *et al.*, 2005; Threatened Species Section, 2006). The situation appears to be the same in coastal NSW, where new populations are increasingly being recorded. The potential problems posed by this species require not just recognition, but co-ordinated research, management and education efforts (Coughran & Furse, 2012), and it is imperative that this is initiated as soon as possible to minimize the potential for damage.

The coastal catchments of NSW have a relatively high biodiversity, with many species of indigenous crayfish and frog having restricted distributions. Until 2004, no translocated populations of crayfish were known from coastal NSW, but within a short timeframe numerous populations of *C. destructor* and another species, the Redclaw *C. quadricarinatus*, have become widely reported (Coughran & Leckie, 2007; Coughran *et al.*, 2009; Leland *et al.*, 2012). Taking action on this issue would therefore appear to be of imminent importance.

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