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Conservation of Freshwater Crayfish in Australia

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Abstract.—**Recent conservation assessments rank the world's freshwater crayfish in the five most endangered animal groups, and the Australian fauna as the most endangered of all the world's crayfish. In this paper, we introduce the 135 described species of freshwater crayfish in Australia, and provide an overview of this fauna and their current IUCN Red List conservation status. The Australian crayfish fauna is almost entirely endemic, and displays enormous variation in biology, distribution and ecology. Some Australian species are the world's fastest growing, most highly fecund and widely distributed crayfishes, and are tolerant of extreme variation in environmental conditions. Conversely, Australia is also home to many crayfish that are remarkably slow growing, late maturing and poorly fecund. Many species have highly restricted distributions and require specific environmental conditions that restrict them to particular areas and habitat types. These crayfish face a wide range of existing and emerging threats, and we discuss the research imperatives, practical actions, legislative changes and collaboration required to facilitate the recovery of crayfish populations.**

INTRODUCTION

Why Conserve Crayfish?

There are many reasons to care about and conserve freshwater crayfish including cultural, social, aesthetic and economic reasons (Holdich, 2002a; 2002b; Horwitz, 2010); there are also a number of very compelling biological and ecological reasons to conserve these animals.

The ecological roles of freshwater crayfish are reasonably well understood after some decades of study, and they are recognised as having an important and rather unique position in aquatic food webs (Hogger, 1988). Being completely polytrophic crayfish are detritivorous, herbivorous and carnivorous, and thereby act as major processors of organic material as shredders, predators, collectors and grazers (i.e. acting as shredders, Anderson & Sedell, 1979; Huryn & Wallace, 1987; Parkyn *et al*., 1997; Usio & Townsend, 2001). They facilitate the release of energy and nutrients (Momot, 1995), and act as "geomorphic agents" through bioturbation of sediments (Statzner *et al*., 2000; 2003) and pedoturbation of soils (Richardson, 1983; Stone, 1993). These natural activities of freshwater crayfish are examples of "ecosystem engineering" (*sensu* Jones *et al*., 1994).

Crayfish can occur in high abundance (densities of up to 77 m^{-2} have been recorded for *Orconectes limosus* (Rafinesque) in Europe (Nystrom, 2002)), and they can dominate biomass in aquatic ecosystems (Mason, 1975; Huryn & Wallace, 1987; Momot, 1995; Nystrom, 2002). Therefore, given the range of ecological services they provide, crayfish often play major roles in shaping the aquatic habitats in which they occur. They are therefore recognised as "Keystone Species" (Hart, 1992; Krebs, 1994; Collier *et al*., 1997; Lodge *et al*., 2000; Nature, 2009).

However, the ecosystem services provided by crayfish may only become apparent when a species is removed or eliminated from the habitat. One such example involves the loss of *Astacus astacus* (Linnaeus) from ponds in Sweden by the crayfish plague (*Aphanomyces astaci* Schikora) in 1964. Abrahamsson (1966) reported dramatic changes to the aquatic flora and fauna of the ponds, apparently attributable to the loss of the crayfish. Submerged aquatic macrophyte growth increased to the extent that the surface of the ponds were, on occasions, covered by plant growth. Dramatic increases in abundance of molluscs, leeches and tadpoles were also evident (Abrahamsson, 1966). Similar ecological responses to mass mortalities of crayfish have been subsequently noted by other workers in Sweden (Unestam, 1973) and Ireland (Matthews & Reynolds, 1992).

Similarly, when freshwater crayfish are introduced outside of their native ranges (and natural controlling mechanisms), many (and often severe) unanticipated consequences may become evident. Introductions of *Orconectes rusticus* (Girard), *Pacifastacus leniusculus* (Dana), and *Procambarus clarkii* (Girard) outside of their native ranges have led to reproductive failure of large freshwater fish species (due to crayfish consuming fish eggs), reduced abundance of aquatic macrophytes, and in the case of *P. clarkii*, ecological and economic damage to rice fields in California, Spain and Japan (Lodge *et al*., 1985; Hogger, 1988; Huner, 1988).

The Freshwater Crayfish of Australia

Australia is second only to North America in species richness, with more than 135 crayfish species from 10 genera (Table 1). This includes at least five of the world's largest species (in the genera *Astacopsis*, *Euastacus* and *Cherax*), one of the world's smallest (*Tenuibranchiurus glypticus* Riek), and some of the most productive aquaculture candidates (i.e. *Cherax tenuimanus* (Smith), *Cherax quadricarinatus* (von Martens) and *Cherax destructor* Clark) (Riek, 1951; Morgan, 1986; 1988; 1997; Momot, 1995; Holdich, 2002a). Some species (notably *C.*

Table 1. Summary of the Australian Freshwater Crayfish Fauna (Data: In part IUCN)

Genus	Number of Species	Distribution	Percent In IUCN Red List Threatened Categories*	Comments
Astacopsis	3	Tasmania	30%	Includes the largest species in the world (A. gouldi)
Cherax	24	All States on mainland Australia	23%**	Includes some very large and ecologically aggressive species that have been widely translocated
Engaeus	35	Victoria and Tasmania	29%	An unusual group of small, obligate burrowing crayfish
Engaewa	5	Western Australia	60%	An unusual group of small, obligate burrowing crayfish
Euastacus	50	Southeastern mainland	80%	Australia's largest genus, includes the second largest species in the world (E. armatus). The world's most endangered genus of crayfish (Dewhurst, 2010 personal communication)
Geocharax	2	Victoria and Tasmania	50%	A poorly understood group
Gramastacus	1	Southeastern mainland	0%	A poorly understood group
Ombrastacoides	11	Tasmania	27%	All are burrowing species, some have highly restricted distributions
Spinastacoides	3	Tasmania	0%	All are burrowing species with widespread distributions
Tenuibranchiurus	1	Central–eastern mainland	100%	Australia's smallest freshwater crayfish

*The IUCN Red List Threatened Categories include: Critically Endangered, Endangered and Vulnerable.
**Only 13 of the 24 Cherax species were included in the 2010 Red List Assessment. Three of the 13 species assessed were in Threatened Categories

quadricarinatus and *C. destructor*) have proven to be ecologically aggressive and capable of displacing other species when translocated outside their native ranges (Coughran & Leckie, 2007; Coughran *et al.*, 2009; Coughran & Furse, 2010; Furse & Coughran, 2011c; Leland *et al.*, 2012).

The Australian fauna also contains some of the most conspicuous and charismatic species, some feature striking colouration including vivid blues and reds, and fluorescent orange (e.g. *Euastacus sulcatus* Riek, *Euastacus fleckeri* (Watson) and *Euastacus australasiensis* (H. Milne–Edwards)) (Merrick, 1993; Jones & Morgan, 2002; Coughran, 2006; Furse & Coughran, 2011a).

Conservation Assessments: The IUCN and the Invertebrates

The invertebrates have typically been an overlooked group of animals. The publication of the IUCN Invertebrate Red Data Book by Wells *et al*. (1983) brought the imperilled status (and threats) of many invertebrate species and their conservation needs to the world's attention. At that time, five species of freshwater crayfish were included on the Red List. Four species were listed as Vulnerable: *A. astacus* (Europe), *Astacopsis gouldi* Clark (Australia), *Orconectes shoupi* Hobbs and *Pacifastacus fortis* (Faxon) (both USA), and one species as Rare: *Austropotamobius pallipes* Lereboullet (Europe) (Wells *et al.*, 1983).

In 2010, 528 species were included in the first global assessment of the freshwater crayfish versus IUCN Red List Criteria (Table 2). From this we conclude that the world's freshwater crayfish are a highly threatened group of animals (25% of all species are in IUCN threat categories, or extinct) and have been overlooked in the past (22% of species were so poorly understood (i.e. Data Deficient (DD)) that conservation assessments were not possible. Many of these DD species are known to be impacted by numerous threats, and are of considerable conversation concern (e.g. *Euastacus armatus* von Martens, see Coughran & Furse, 2010), and yet a lack of data does not allow conservation assessments.

It was encouraging that 53% of species were Near Threatened or not yet of any immediate conservation concern, however this is not indicative of an improving conservation situation, rather an initial baseline evaluation. Many of these species will require on–going monitoring or further assessment in the future.

When evaluated at lower levels (e.g. regional or taxonomic levels such as genera) the 2010 Red List reveals some concerning indications, in particular highlighting species/groups of crayfish at serious risk of extinction. For instance, the Australian *Euastacus* are the most threatened of all crayfish with ~80% (40 of 50 species) Critically Endangered or Endangered. The sole Endangered species of *Tenuibranchiurus* is facing a number threats that could conceivably lead to the rapid extirpation of either of its two small, isolated populations via a "local disaster" (Merrick, 1995), such as an oil or chemical spill (Coughran *et al.*, 2008).

Threats to Australian Freshwater Crayfish

One of the many important contributions of the original IUCN Invertebrate Red Data Book (Wells *et al.*, 1983) was the identification and evaluation of the key threats to invertebrates. Four key threats

Table 2. Summary of 2010 IUCN Red List Assessment of the Freshwater Crayfish (after IUCN, 2011)

IUCN Category	Number of Species (by year of assessment) 1996	2009	2010	Type of Category
Extinct			4	Threatened (or Extinct)
Critically Endangered		1	45	
Endangered	1		61	
Vulnerable	1	1	30	
Near Threatened			34	Non–Threatened
Least Concern		28	243	Non–Threatened
Data Deficient	2	11	111	Not Assessable
Total	4	41	528	

were identified: 1) Habitat Destruction, 2) Pollution, 3) Exotic Species, and 4) Human Exploitation. This suite of common threats are well known, well understood and impact much of the world's biota. However, the 2010 Red List highlighted some important considerations regarding freshwater crayfish, particularly restricted range species and those exploited by humans.

The most recent Red List assessment highlighted the precarious situation of many species with highly restricted ranges and/or occupying single localities. In many cases, these restricted species occur in close proximity to urban development, agricultural encroachment or other anthropogenic pressures (e.g. highway construction, forestry). These species face a considerably elevated risk of extinction from destruction of habitat.

The primary burrowing crayfish ('primary burrowers', Horwitz & Richardson, 1986) in the genus *Engaewa* (from Western Australia) are a good example of species that appear to be almost completely reliant on their extensive and deep burrow networks. Although these obligate burrowers (Horwitz & Adams, 2000) spend much of their time underground, and are to some degree isolated from the common suite of threats faced by non–burrowing species, they are still of considerable conservation concern. *Engaewa pseudoreducta* Horwitz and Adams is classified as Critically Endangered due to a highly restricted and fragmented distribution and a reliance on subterranean (or subsurface) water and their habitat associations with particular soils types (Horwitz & Adams, 2000; Burnham, 2010). The species is absent/extirpated from its type locality and the remaining populations are apparently threatened by water extraction/agriculture and compaction of soil (Burnham, 2010).

Similarly, pollution is a very serious threat to restricted range species. The habitat of many endangered species is downstream from roadways, residential and commercial areas, and areas of substantial development/population growth. In these cases, a single pesticide, oil or "accidental" spill of chemicals (i.e. a road tanker accident) could eliminate an entire species. The Critically Endangered *Euastacus maidae* Riek is one such species occupying a single stream, located in a valley downstream from a small township. The stream and township are located in a mountainous region prone to very high levels of episodic rainfalls, leaving the species particularly vulnerable to accidental pollution, including via a major landslide and siltation event.

Exotic species (including other crayfish) are a considerable threat to restricted range freshwater crayfish. The loss of widespread and/or formerly common native crayfish species due to exotic species (including other crayfish) has been documented in various places (Lodge *et al*., 1985; 1994; Leland *et al*., 2012), and in the Australian context, mobile species such as foxes, pigs, goats, cats and cane toads are very serious threats to the rare and isolated populations of native species. We consider the single population of *Euastacus dharawalus* Morgan to be at serious risk of extinction in the near term due to competition pressure from the more aggressive *C. destructor* (Coughran *et al*., 2009; Coughran & Furse, 2010; Coughran & Daly, 2012).

Many Australian crayfish are slow growing, late maturing, long lived (some live for more than 30 years) and/or are exceptionally rare (reviewed in Furse & Coughran, 2011a). These species are particularly vulnerable to over–exploitation by humans, for recreational consumption, aquarium use or general specimen collection. In the case of species like *A. gouldi*, over–fishing is one of the main reasons this species is now Endangered. It is not uncommon to see native crayfish species that cannot be legally taken from the wild in aquarium stores, and there are forums on the internet that feature discussion threads about illegal collection of protected species, in some cases for the express purpose of domestic and international supply. Most of the activities involved in this category are illegal.

Emerging Threats to Australian Freshwater Crayfish – Increased Environmental Temperature and Changes to Climatic and Weather Patterns

Since the initial treatise by Wells *et al*. (1983), a new threat category to freshwater crayfish has become apparent. Increased environmental temperatures and changes to climatic conditions and weather patterns represent serious threats to many species, and in some cases may exacerbate the previously outlined threats.

Restricted range species in isolated pockets of habitat (i.e. montane species, with little or no capacity to retreat to cooler, higher habitat) are at particular risk from increased environmental temperature (Horwitz, 1990; 2010; Furse & Coughran, 2011b). As poikilotherms, the long term survival of cool–adapted crayfish that are unable to acclimate or retreat to cooler habitats is doubtful. Similarly, many species are associated with specific habitat types (especially vegetation types) and it has been established that forest types will "shift" due to changes in temperature and rainfall (e.g. from rainforest to sclerophyllous Hilbert *et al*., 2001; Hughes, 2003). This is a very serious threat to restricted range habitat–specialist species.

Some regions of Australia are predicted to receive less rainfall, resulting in less water in aquatic systems and potentially more severe bushfires. However, other areas are predicted to receive more precipitation (Chiew & McMahon, 2002; Hughes, 2003), which might be problematic for species in those areas. Changes to weather patterns include more frequent and more severe weather events including floods, droughts, cyclones and storms (Hughes, 2003; IPCC, 2007; Specht, 2008). Freshwater crayfish appear to be particularly sensitive to severe flooding events (Meyer *et al*., 2007) and a number of mass emersions and mass mortalities have been documented.

Reports of these events appear to have been increasing in the last few years (McKinnon, 1995; Parkyn & Collier, 2004; Lewis & Morris, 2008; Furse *et al*., 2012). Increased incidence of severe weather events is of particular concern for the highly restricted range species. A single severe weather event, such as a tropical cyclone or severe storm, could seriously impact, or conceivably even eliminate a species (e.g. *Euastacus jagabar* Coughran) (Furse *et al*., 2012).

Steps to Conservation of Australian Freshwater Crayfish

Ultimately, the goal of conservation efforts is to see threatened species restored to a healthy status. In the following sections we will discuss some of the areas that we consider to be important steps for successful conservation of the Australian species: the importance of increased and more specific research, the need to establish adequate formal recognition of threatened crayfish, and practical measures needed to alleviate the aforementioned threats facing these crayfish.

Research Gaps

To adequately protect and manage endangered crayfish, it is vital that several key knowledge gaps are addressed (and funded). The most fundamental of these gaps is that of basic taxonomy–we are still a long way from identifying the species of crayfish that occur in the wild. There are several new species that have been identified during field surveys, yet still await formal description. For example, we are aware of at least 20 taxa from eastern Australia that appear to be new species, from the genera *Cherax* (8), *Engaeus* (3), *Euastacus* (5), *Gramastacus* (2) and *Tenuibranchiurus* (2). Over the past decade many new species have been described, but the preparation of formal descriptions has nonetheless been lagging behind the rate of discovery of these new species, essentially due to the lack of funding for basic taxonomic work. Many of these undescribed species are likely to be threatened, but appropriate conservation assessment and management cannot proceed until they are formally described.

It is also important that within species, important populations are identified so that the species can be adequately conserved. For example, recent studies on *Euastacus diversus* (a rare species originally described from a limited number of specimens from a single, uncertain site, and not seen again in the wild for almost 50 years) has revealed that the species occurs in fragmented, highland habitats comprising morphologically and genetically distinct populations (McCormack, Coughran & Fetzner, unpublished data). For species such as this, it is essential that conservation plans recognize the distinctive populations that occur across the species' overall range, particularly where some of those populations may be facing anthropogenic threats.

The ecology of many species is still poorly understood (or unknown), and basic information is needed on distribution and habitat associations. In Australia, most crayfish are very restricted in distribution, and can be classed as "short range endemics" (Harvey, 2002) – species with a very narrow or confined distribution. However, precise distribution data and estimates of extent of occurrence are lacking for many species. Information on environmental tolerances are largely unknown, and specific studies are required to clarify relevant thresholds for parameters such as temperature, water/moisture availability and pollutants (e.g. soil/sediments, nutrients and pesticides). Biological information is also lacking for most crayfish species. Information on growth rates, longevity, size/age at maturity, fecundity, mating and breeding season, diet and general behaviour is required for all but a handful of species in Australia.

Legislation

To protect and manage endangered species, it is essential that their threatened situation is formally recognized. That may seem obvious, but it is not currently the case for most of the endangered Australian crayfish species. There are different forms of recognition, from the global IUCN list down to local government or catchment management plans. The most important form of recognition is through government legislation, and in Australia this occurs at the National and State government levels. The on–ground actions and recovery planning, and even research and funding, all filter down from formal, legislative recognition; essentially, without this legislative recognition there is no framework in place for the protection and recovery of a species.

Unfortunately, Australia is well behind in this area, and there are striking differences between the various State and Territory governments. For example, Victoria is notably organized, with legislation that already recognizes many of its threatened species, as well as an official "advisory list" of species known or suspected to be threatened but which have not yet been formally assessed for inclusion on the list. Other states (e.g. NSW) have yet to include any threatened crayfish under relevant conservation legislation[1]. Importantly, until this gap is addressed at the Federal and State government levels, there is simply no mechanism for Local governments to enforce any actual protection measures to local settings.

Action

Many of the species that have been identified as threatened require specific intervention through practical, on–ground works to alleviate the threats facing them. Examples of practical actions required range from habitat restoration works to managing exotic pests. Appropriate activities need to be identified by experienced biologists and managers, but in many cases the works will be best achieved by a coordinated initiative between various stakeholders, with inputs from management agencies, researchers, community groups and individuals. However, crayfish are simply not on the radar of current ecological networks, and it is therefore important that the profile of these species (and their plight) is raised with the landholder, catchment management, government and Non–government organization networks that already exist.

It is also important that regulations about fishing activities are enforced, so that species at threat from exploitation and illegal fishing are adequately protected. For example, many *Euastacus* are illegally targeted in growing numbers, and there appears to be a need for greater enforcement of fishing bans and restrictions. We concede that this is a difficult

[1]: At the time of writing, the authors have just been advised that a nomination has been submitted to list *Euastacus dharawalus* Morgan as "Critically Endangered" under the (NSW) Fisheries Management Act, 1994.

challenge, particularly with limited resources, but with prioritisation of species and target areas it is likely that further improvement is possible in this area.

Recovery and Monitoring

When a threatened species is adequately understood, its status is recognised, and the threats are identified and being managed, there may yet be an additional need to actively encourage the recovery of the species. For example, education programs that increase public awareness and appreciation would be beneficial for most species. But for some very precarious species special intervention, through initiatives such as captive breeding programs, are going to be important. This will also necessitate research into the feasibility of restocking programs where the species has become extinct or near extinct in the wild, or the wild population is otherwise deemed unviable. It is also important that coordinated and planned monitoring programs are established for many species, so that the recovery can be tracked and additional intervention needs identified.

Collaboration

Clearly, the current conservation status of the world's freshwater crayfish indicates that this fauna is at crisis point. There is an alarmingly high proportion of threatened species, and a broad range of inter–related threats involved. Managing this situation will require considerable efforts to build collaboration between the various stakeholders involved, from Local, State and Federal Government agencies through to researchers, landholders, conservation field workers and funding bodies. Furthermore, although the Australian fauna provides a particularly dire example of the conservation crisis, many of the problems and potential recovery steps will be loosely applicable to threatened crayfish in other regions of the world. To that end, we also consider that increased global collaboration will be invaluable in helping abate the crisis, gaining a better understanding of the threats involved, and recovering crayfish populations most effectively.

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