Introduction of redclaw crayfish *Cherax quadricarinatus* (von Martens) to Lake Kununurra, Ord River, Western Australia: prospects for a 'yabby' in the Kimberley

R G Doupé[1,3], D L Morgan[2], H S Gill[2] & A J Rowland[2]

[1] Fish Health Unit, Division of Veterinary and Biomedical Sciences, Murdoch University, Murdoch, WA 6150.
[2] Centre for Fish and Fisheries Research, Division of Science and Engineering, Murdoch University, Murdoch, WA 6150.
[3] Correspondence to Rob Doupé: R.Doupe@murdoch.edu.au

Abstract

The recent introduction of redclaw crayfish for aquaculture to the Ord River region of Western Australia has been followed by the detection of a 'wild' population in Lake Kununurra. A gut survey of the lake's fish fauna was used to estimate the degree of assimilation of redclaw crayfish into the lake's food chain, however very few crayfish were found in only two catfish species (Ariidae). These results leave us uncertain of whether this low detection rate is due to either low numbers of redclaw crayfish in the lake, or that alternative food resources in the lake means that predation of redclaw crayfish is either due to opportunism or is of dietary insignificance. A further possibility is that the survey was undertaken at a time too soon to allow redclaw establishment and assimilation into the lake ecosystem. Whichever, translocating non-endemic freshwater crayfish into novel environments inevitably raises the possibilities of competitive interactions between the introduced and endemic species, food web alterations via predation and grazing pressure, the addition of symbionts, habitat alterations, and disease introductions. An account of how the introduction of a non-endemic crayfish causes all or some of these problems is yet to be adequately described in Australia, however there is an urgent need for such an assessment and the opportunity is now available at Lake Kununurra.

Keywords: redclaw crayfish; *Cherax quadricarinatus*; introduced species; translocation

Introduction

The redclaw crayfish *Cherax quadricarinatus* (von Martens) is a physically robust species that grows relatively quickly in a wide range of environments (Jones & Ruscoe 2001). Redclaw crayfish typically breed annually during the spring/summer months, although recurrent spawning has been observed in at least some females (King 1993; Barki *et al.* 1997). Females are moderately fecund (King 1993; Austin 1998) and incubate their eggs until hatching of highly developed juveniles (Jones *et al.* 2000).

In Australia, the pre-European distribution of redclaw crayfish is thought to be confined to the ephemeral catchments of far northern Queensland and the northern and eastern parts of the Northern Territory (Riek 1969; Curtis & Jones 1995), however the significant aquaculture potential of this species (see Jones *et al.* 2000) has resulted in them being widely translocated within Australia and overseas (Horwitz 1990; Curtis & Jones 1995). There are no known native freshwater crayfishes in the Kimberley region of Western Australia's far north (Riek 1967,1969; Jasinska *et al.* 1993) and redclaw crayfish is classified as a restricted fish species for importation into Western Australia (Anon 1997). In 1998, the Western Australian Department of Fisheries (WADF) introduced a small population of the selectively improved 'Walkamin' strain of redclaw crayfish (see Jones *et al.* 2000) to a quarantine station near the northeast Kimberley town of Kununurra, to determine its suitability for aquaculture in the Ord River Irrigation Area (ORIA). Following a quarantine period of about 12 months, the Walkamin stock were certified as 'disease-free' by WADF personnel and redclaw crayfish aquaculture licences were issued to a few farms in the ORIA. In 2000, 'wild' redclaw crayfish were first found in Lake Kununurra (R. Doupé unpub data; D. Harvey, WADF, pers comm), a Ramsar listed irrigation water supply reservoir on the Ord River (Fig 1). Initial speculation was that the animals had escaped from aquacultures in the ORIA, but a comparative investigation of the genotypes of Lake Kununurra redclaw and a range of redclaw genotypes from elsewhere by Greenway & Mather (2000), indicated that these animals were not of the 'Walkamin' strain, but were more closely related to Northern Territory redclaw crayfish populations; the exact population has never been identified. Who translocated redclaw crayfish to Lake Kununurra is unknown, however in the time since their detection, officers of the Australian Quarantine and Inspection Service have occasionally confiscated redclaw crayfish from recreational fishermen attempting to bring these animals from the adjacent Northern Territory into the Kimberley for use as fish bait (T. Thorne, WADF, pers comm).

There are significant risks associated with the movement of aquatic species by human agency. For example, translocating freshwater crayfish into novel environments raises the possibilities of competitive interactions between the introduced and endemic species (including epibiotic species associated with the crayfish themselves), food web perturbations, habitat alterations, and disease introductions (Horwitz 1990; Holdich 1999; Lodge *et al.* 2000). There may be an increased likelihood that translocated redclaw crayfish could escape and contribute to these types of ecological impacts because their propensity to climb and move out of the water means that they are very difficult to contain (Jones *et al.* 2000). How many redclaw crayfish are now in Lake Kununurra or adjacent waterways is also unknown, but given the potential ecological problems associated with the translocation of freshwater crayfish (and aquatic species generally, see also Doupé & Lymbery 2000; Morgan & Gill 2001; Morgan *et al.* 2002), this introduction should not be ignored. Indeed, Lake Kununurra and the greater Ord River system has been, and continues to be, subjected to a variety of proposed species introductions (*e.g.* Doupé & Bird 1999; Doupé & Pettit 2002; Doupé *et al.* 2005) and escapement from aquacultures (Doupé & Lymbery 1999).

Relatively high fecundity, mobility to invade new habitats, and the ability to compete for available resources, are prominent ecological attributes commonly shared by successful invaders (Elton 1958; Fox & Adamson 1986). Nevertheless, the single-most significant factor affecting their eventual distribution in the new environment concerns the level of ensuing predation of them by resident species (Krebs 1985), and from that end, food webs can form a useful starting point for the theoretical analysis of community organisation (Cohen 1978; Pimm 1982). In this paper, we present the results of a preliminary survey intended to investigate the extent to which redclaw crayfish have thus far been assimilated into the Lake Kununurra ecosystem using a gut survey of the resident fish community. We use those findings to provide a baseline for future research on redclaw crayfish distributions, and to discuss the potential impacts of introducing redclaw crayfish to the waterways of the Kimberley region.

Materials and Methods

The irrigation water supply reservoir of Lake Kununurra (128°46'E 15°57'S) is a very large, linear wetland approximately 55 km long and with a full supply surface area of about 100 million m^2. During daylight hours in December 2002, we surveyed the fish fauna of Lake Kununurra by sampling 12 recognisably different habitats in the lake proper and associated lagoons, and six sites in a major side-creek that connects Lake Kununurra to Lake Argyle (*i.e.* Spillway Creek; see Fig 1). Fishing gear comprised monofilament gill nets (50, 100, 125, 150 and 200 mm stretched mesh width), seine nets (5 and 15 m nets of 3 mm woven mesh width), and rod and line. On capture, all fish were identified and counted.

We also collected 38 lesser salmon (or blue) catfish *Arius graeffei* Kner & Steindachner from one site in Lake Argyle and 56 lesser salmon catfish and 20 barramundi *Lates calcarifer* (Bloch) from three sites in the lower Ord River (approximate locations are given in Fig 1), and whole guts were checked only for the presence of redclaw crayfish remains.

For fishes taken from Lake Kununurra, between 6 and 60 individuals of each species were retained for dietary analyses. The whole stomach was removed for dietary examination, and diets were analysed using the frequency of occurrence (Hynes 1950) and points (Ball 1961) methods; the frequency of occurrence method represents the incidence with which a particular prey type is consumed by a species, whereas the points method gives the relative contribution of each prey type to the total volume of the stomach contents.

Results

Of the 19 fish species collected from Lake Kununurra (see Gill *et al.* 2005), the guts of the freshwater longtom *Strongylura krefftii* (Günther), black catfish *Neosilurus ater* (Perugia), and Macleay's glassfish *Ambassis macleayi* (Castelnau) were empty, and because only three northern trout gudgeon *Mogurnda mogurnda* and a solitary sleepy cod *Oxyeleotris lineolatus* (Steindachner) were collected, dietary data for these species were not recorded. Morgan *et al.* (2004) provide a detailed description and discussion of the component diets of all species.

Claw remnants of redclaw crayfish were found in both the lesser salmon catfish and silver cobbler *A. midgleyi* Kailola & Pierce taken from Lake Kununurra. The frequency of occurrence of redclaw crayfish in the guts of each species was 3.57% and 8% respectively, and this low rate was reflected in a correspondingly small contribution of redclaw crayfish to the total stomach volume of each (2.84% and 7.97% respectively). We also found remains of another decapod, the endemic freshwater prawn or cherabin *Macrobrachium* sp., in the guts of lesser salmon catfish, silver cobbler, barramundi, and Jenkins' grunter or black bream *Hephaestus jenkinsi* (Whitley). Cherabin frequently occurred in the guts of lesser salmon catfish (32.14%) and barramundi (29.79%), and to a lesser extent in Jenkins' grunter (14.81%) and silver cobbler (12%), but contributed significantly less to the total gut content of lesser salmon catfish (7.15%) and Jenkins' grunter (1.10%) than for either silver cobbler (10.95%) or barramundi (26.42%).

No redclaw crayfish were found in either lesser salmon catfish or barramundi taken from Lake Argyle or the lower Ord River, however most guts of both species from all sites contained remnants of cherabin and other species of teleost.

Discussion

Considering that redclaw crayfish was found in very low numbers in lesser salmon catfish and silver cobbler, and contributed similarly low levels to the total volume of their guts, do these results mean that, (1) there are few redclaw crayfish in Lake Kununurra? (2) Predation of redclaw crayfish by these catfishes is a relatively opportunistic event? And/or (3), that the time of sampling (*i.e.* late 2002) was too soon post-discovery to establish the extent to which redclaw have been assimilated into the lake ecosystem? We are also unsure of the significance of redclaw crayfish to the diets of lesser salmon catfish or silver cobbler, or indeed other fish species of the lake; we expect that barramundi would also predate

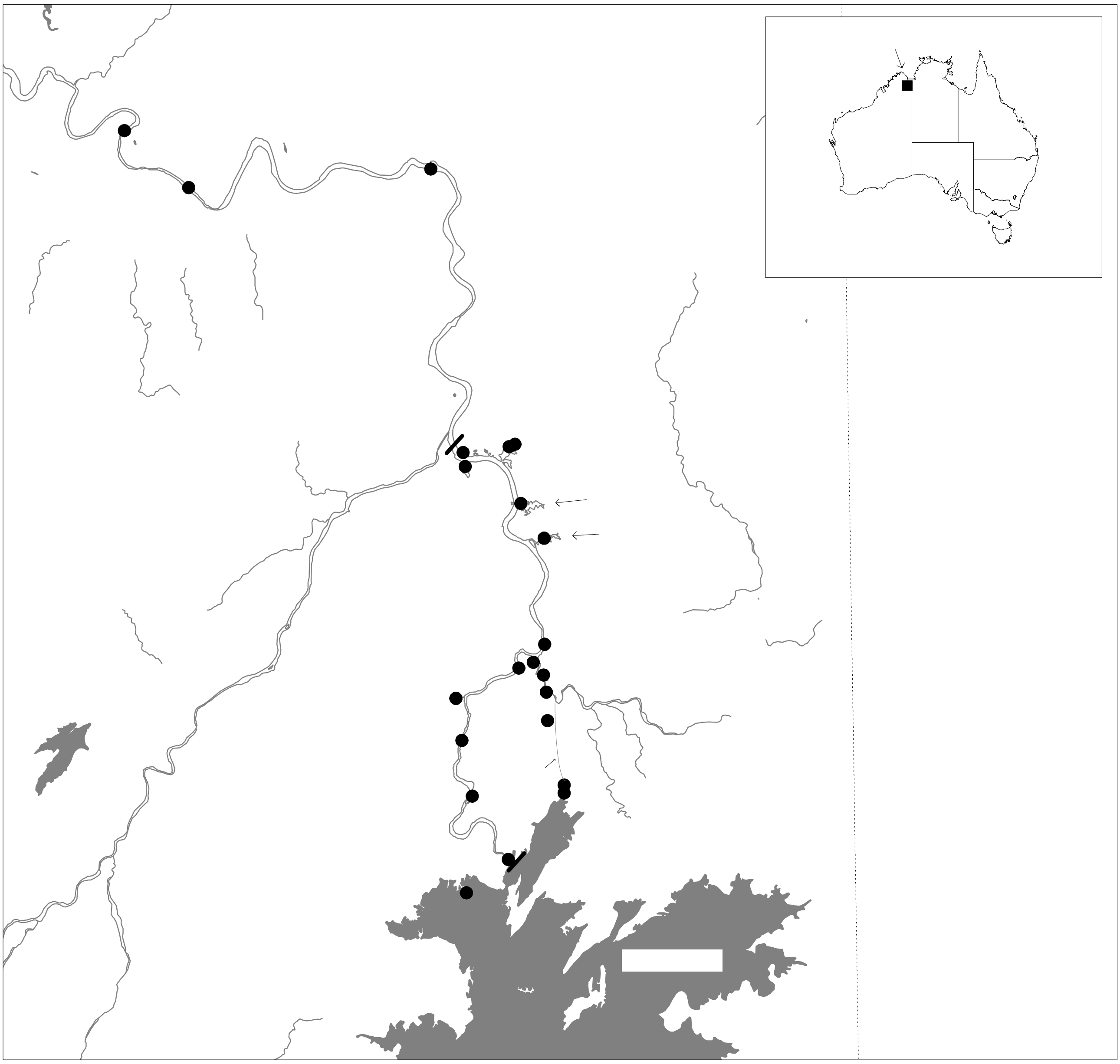

Figure 1. Lake Kununurra in the Ord River system and positions of study sites (●).

on redclaw crayfish, although we only caught four individuals because very few barramundi are found in Lake Kununurra as a consequence of damming (Doupé & Bird 1999).

Lesser salmon catfish and silver cobbler were collected at nine sites in Lake Kununurra and six sites in Lake Argyle, and redclaw crayfish were detected only in samples taken from these two species in the lagoons of Emu Creek and Four Mile Creek (see Fig 1). No evidence of redclaw was found in gut examinations of 94 lesser salmon catfish and 20 barramundi sampled outside of Lake Kununurra; we are therefore uncertain of the distribution of redclaw crayfish in either Lake Kununurra or the greater Ord River system, however we are aware of redclaw crayfish being caught at the lower end of Lake Kununurra (A. Storey, UWA, pers comm.; R.Doupé unpub data).

What are the likely impacts of introducing a crayfish to a water body where the resident community has (presumably) evolved in their absence (*sensu* Horwitz 1990; Jasinska *et al.* 1993; Horwitz & Knott 1995; Lynas *et al.* 2004)? Lamentably we are presently unable to answer this question for Lake Kununurra, however we have a number of concerns. For example, in southwestern Australia, introduced *Cherax* have shown aggressive and predatory behaviour toward congenerics (see Austin & Ryan 2002; Molony *et al.* 2002) and aquatic vertebrates (Bradsell *et al.* 2002), and Fernendez & Rosen (1996) documented similar antagonistic behaviour toward aquatic reptiles by introduced virile crayfish *Orconectes virilis* (Hagen). Jones & Ruscoe (2001) have described redclaw crayfish as "gregarious" in a crowded monoculture, but what might we anticipate when Lake Kununurra suddenly has an extra decapod? In North

America, the introduction of rusty crayfish *Orconectes rusticus* (Girard), presumably for recreational fishing (Horwitz 1990), is believed to be responsible for the decline of two endemic conspecifics, *O. propinquus* (Girard) and *O. virilis* (Hagen)(Lodge *et al.* 1985). Moreover, competitive displacement can occur even between endemic conspecifics if the range of one expands; in southwestern Australia, the spread of smooth marron *C. tenuimanus* (Smith) has resulted in a rapid decline in the population size and distribution of the highly restricted hairy marron *C. cainii* Austin (Austin & Ryan 2002). The redclaw crayfish mostly feeds on detritus and zooplankton (Loya-Javellana *et al.* 1993), and is able to survive and persist in a wide range of habitats (Jones *et al.* 2000), but what effect will it have on its new environment? The extensive burrowing behaviour of the introduced 'yabby' *C. destructor* (or *C. albidus*)(Clark) alters aquatic habitat (Austin 1985) and is thought to contribute to the displacement of native crayfish species such as smooth marron (Lynas *et al.* 2004).

Identifiable remnants of redclaw crayfish taken from fish guts were sent to P. Mather of the Queensland University of Technology for microsatellite gene screening, however DNA extraction (see Baker *et al.* 2000) was unsuccessful and we were unable to determine the genetic origins of those samples. It is important, nevertheless, that we understand how these animals are entering Lake Kununurra and if they are dispersing throughout the Ord River system, because freshwater crayfish harbour a wide variety of symbiotic or parasitic organisms, including bacteria, fungi and parasitic worms (see descriptions in Herbert 1987; Horwitz 1990; Gelder 1999). Following, if these animals are being translocated from wild populations, then what other invertebrates are also being introduced? Alternately, if these animals are escapees from aquacultures, 'disease-free' status should not necessarily diminish concerns for the potential introduction of deleterious symbionts, because presumably, such a certification is limited *a priori* in what is a 'disease'? Some recent Australian work has discovered some disturbing associations between cultured redclaw crayfish and the prevalence of infectious diseases. For example, rickettsia-like parasites have been explicitly linked to a variety of infectious diseases in humans and other vertebrates (Romero & Jimenez 2002), and these organisms have been found in a number of redclaw crayfish aquacultures in Queensland where the crayfish is thought to act as an intermediate host (Edgerton & Prior 1999). At another Queensland redclaw crayfish farm, viral infections characteristic of the Parvoviridae have caused mass mortalities and have again raised concerns for the potential spread of diseases by redclaw crayfish (Bowater *et al.* 2002).

We are unaware of any documented accounts in Australia of where the introduction of a non-endemic tropical crayfish has caused either the displacement or elimination of native freshwater species or changes in aquatic communities. However, the nature of crayfish and particularly their associations with a wide variety of organisms, suggests that there are justifiable reasons to be concerned with any translocation of them, regulated or not. The opportunity to understand better the potential impacts of a redclaw crayfish introduction now presents itself at Lake Kununurra.

Acknowledgements: Financial assistance was provided by the Lake Kununurra Fish Stock Enhancement Committee and administered by Ord Land and Water Inc. We are grateful for the oral histories and unpublished data provided by C Astbury, D Harvey, A Storey and T Thorne, and N Baker and P Mather attempted the genotyping of redclaw samples. S Beatty and P Horwitz kindly commented on the draft manuscript.

References

Anon 1997 The Aquaculture of Non-Endemic Species in Western Australia, Redclaw crayfish. Fisheries Management Paper No. 100, Department of Fisheries, Perth.

Austin C M 1985 Introduction of the yabbie, *Cherax destructor* (Decapoda: Parastacidae) into Southwestern Australia. Western Australian Naturalist 16:78–82.

Austin C M 1998 A comparison of clutch and brood size in the Redclaw, *Cherax quadricarinatus* (von Martens) and the yabby, *C. destructor* Clark (Decapoda: Parastacidae). Aquaculture 167:135–145.

Austin C M & Ryan S G 2002 Allozyme evidence for a new species of freshwater crayfish of the genus *Cherax* Erichson (Decapoda: Parastacidae) from the south-west of Western Australia. *Invertebrate Systematics* **16**:357–367.

Baker N, Byrne K, Moore S & Mather P 2000 Characterisation of microsatellite loci in the redclaw crayfish, *Cherax quadricarinatus*. Molecular Ecology 9:494.

Ball J N 1961 On the brown trout of Llyn Tegid. Proceedings of the Zoological Society of London 137:599–622.

Barki A, Levi T, Hulata G & Karplus I 1997 Annual cycle of spawning and moulting in the redclaw crayfish, *Cherax quadricarinatus*, under laboratory conditions. Aquaculture 157:239–249.

Bowater RO, Wingfield M, Fisk A, Condon K M L, Reid A, Prior H & Kulpa E C 2002 A parvo-like virus in cultured redclaw crayfish *Cherax quadricarinatus* from Queensland, Australia. Diseases of Aquatic Organisms 50:79–86.

Bradsell P, Prince J, Kuchling G & Knott B 2002 Aggressive interactions between freshwater turtle, *Chelodina oblonga*, hatchlings and freshwater crayfish, *Cherax* spp.: implications for the conservation of the critically endangered western swamp turtle, *Pseudemydura umbrina*. Wildlife Research 29:295–301.

Cohen J E 1978 Food Webs and Niche Space. Princeton University Press, New Jersey.

Curtis M C & Jones C M 1995 Overview of redclaw crayfish, *Cherax quadricarinatus*, farming practices in northern Australia. Freshwater Crayfish 10:447–455.

Doupé R G & Bird C 1999 Opportunities for enhancing the recreational fishery of Lake Kununurra using barramundi *Lates calcarifer*: a review. Proceedings of the Royal Society of Queensland 108:41–48.

Doupé R G & Lymbery A J 1999 Escape of cultured barramundi (*Lates calcarifer* Bloch) into impoundments of the Ord River system, Western Australia. Journal of the Royal Society of Western Australia 82:131–136.

Doupé R G & Lymbery A J 2000 Managing translocations of aquatic species. Aquaculture Research 31:151–156.

Doupé R G & Pettit N E 2002 Ecological perspectives on regulation and water allocation for the Ord River, Western Australia. River Research and Applications 18:307–320.

Doupé R G, Morgan D L & Gill H S 2005 Prospects for a restorative fishery enhancement of Lake Kununurra: a high-level tropical impoundment on the Ord River, Western Australia. Pacific Conservation Biology 11: in press.

Edgerton B F & Prior H C 1999 Description of a hepatopancreatic rickettsia-like organism in the redclaw crayfish *Cherax quadricarinatus*. Diseases of Aquatic Organisms 36:77–80.

Elton C 1958 The Ecology of Invasions by Animals and Plants. Methuen, London.

Fernendez P J & Rosen P C 1996 Effects of the introduced crayfish *Orconectes virilis* on native aquatic herpetofauna in Arizona. Final Report to Arizona Game and Fish Department, Arizona.

Fox M D & Adamson D 1986 The ecology of invasions. In: A Natural Legacy (eds H F Recher, D Lunney & I Dunn). Pergamon Press, Sydney, 235–255.

Gelder S R 1999 Zoogeography of branchiobdellidans (Annelida) and temnocephalidans (Platyhelminthes) ectosymbiotic on freshwater crustaceans, and their reactions to one another *in vitro*. Hydrobiologia 406:21–31.

Gill H S, Morgan D L, Doupé R G & Rowland A J 2005 The fishes of Lake Kununurra, a

highly regulated section of the Ord River in northern Western Australia. Records of the Western Australian Museum: in press.

Greenway S & Mather P 2000 Report on genotyping of Western Australian crayfish samples. Unpublished Report to Fisheries Western Australia, Kununurra.

Herbert B 1987 Notes on the diseases and epibionts of *Cherax quadricarinatus* and *C. tenuimanus* (Decapoda: Parastacidae). Aquaculture 64:165–173.

Holdich D M 1999 The negative effects of established crayfish introductions. In: Crustacean Issues 11 Crayfish in Europe as Alien Species. How to Make the Best of a Bad Situation? (eds F Gherhardi & D M Holditch). A A Balkema, Rotterdam, 31–46.

Horwitz P 1990 The translocation of freshwater crayfish in Australia: potential impact, the need for control and global relevance. Biological Conservation 54:291–305.

Horwitz P & Knott B 1995 The distribution and spread of the yabby *Cherax destructor* complex in Australia: speculations, hypotheses and the need for research. Freshwater Crayfish 10:81–91.

Hynes H B N 1950 The food of sticklebacks with a review of the methods used in studies of the food of fishes. Journal of Animal Ecology 19:36–58.

Jasinska E J, Knott B & Poulter N 1993 Spread of the introduced yabby, *Cherax* sp (Crustacea: Decapoda: Parastacidae), beyond the natural range of freshwater crayfishes in Western Australia. Journal of the Royal Society of Western Australia 76:67–69.

Jones C M & Ruscoe I M 2001 Assessment of five shelter types in the production of redclaw crayfish *Cherax quadricarinatus* (Decapoda: Parastacidae) under earthen pond conditions. Journal of the World Aquaculture Society 32:41–52.

Jones C M, McPhee C P & Ruscoe I M 2000 A review of genetic improvement in growth rate in redclaw crayfish *Cherax quadricarinatus* (von Martens)(Decapoda: Parastacidae). Aquaculture Research 31:61–67.

King C 1993 Potential fecundity of redclaw crayfish, *Cherax quadricarinatus* von Martens, in culture. Aquaculture 114:237–241.

Krebs C 1985 Ecology. Harper & Row, New York.

Lodge D M, Beckel A L & Magnuson J J 1985 Lake-bottom tyrant. Natural History 94:33–37.

Lodge DM, Taylor C A, Holdich D M & Skurdal J 2000 Nonindigenous crayfishes threaten North American biodiversity. Fisheries 25:7–20.

Loya-Javellana G N, Fielder D R & Thorne M J 1993 Food choice by free-living stages of the tropical freshwater crayfish, *Cherax quadricarinatus* (Parastacidae: Decapoda). Aquaculture 118:299–308.

Lynas J, Lindhjem P, Storey A & Knott B 2003 Is the yabby, *Cherax destructor* (Parastacidae) in Western Australia an ecological threat? Freshwater Crayfish 14: in press.

Molony B, Morrissy N M & Bird C 2002 The West Australian recreational marron fishery (*Cherax tenuimanus* (Smith)): history and future challenges. Freshwater Crayfish 13:207–220.

Morgan D L & Gill H S 2001 The green swordtail *Xiphophorus helleri* Heckel (Poeciliidae): another aquarium fish established in the wild in Western Australia. Records of the Western Australian Museum 20:349–352.

Morgan D L, Hambleton S J, Gill H S & Beatty S J 2002 Distribution, biology and likely impacts of the introduced redfin perch (*Perca fluviatilis*)(Percidae) in Western Australia. Marine and Freshwater Research 53:1211–1221.

Morgan D L, Rowland A J, Gill H S & Doupé R G 2004 Implications of introducing a large piscivore (*Lates calcarifer*) into a regulated northern Australian river (Lake Kununurra, Western Australia). Lakes and Reservoirs: Research and Management 9:181–193.

Pimm S L 1982 Food Webs. Chapman & Hall, London.

Riek E F 1967 The freshwater crayfish of Western Australia (Decapoda: Parastacidae). Australian Journal of Zoology 15:103–121.

Riek E F 1969 The Australian freshwater crayfish (Crustacea: Decapoda: Parastacidae), with descriptions of new species. Australian Journal of Zoology 17:855–918.

Romero X & Jimenez R 2002 Histopathological survey of diseases and pathogens present in redclaw crayfish, *Cherax quadricarinatus* (von Martens), cultured in Ecuador. Journal of Fish Diseases 25:653–667.