Scoping the knowledge requirements for Murray crayfish (*Euastacus armatus*)

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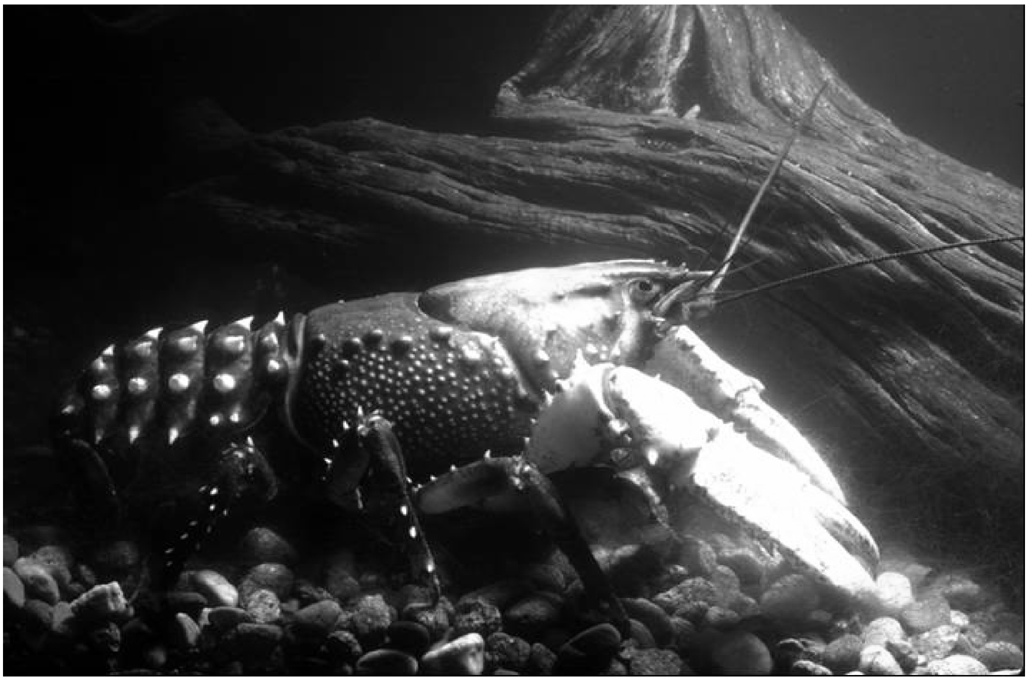

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NSW DEPARTMENT OF
PRIMARY INDUSTRIES

MACQUARIE UNIVERSITY ~ SYDNEY

MURRAY-DARLING BASIN COMMISSION

Territory and Municipal Services
ACT GOVERNMENT

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NON-TECHNICAL SUMMARY

MDBC Project No. 05/1066 Scoping the knowledge requirements for Murray crayfish.

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OBJECTIVES:
Refer to Appendix 1 for a copy of the project brief.
(1) To review and synthesize existing knowledge on the ecology and management of Murray crayfish.
(2) Investigate the scope of various unpublished data sets.
(3) Document traditional knowledge of Murray crayfish.
(4) To identify ecological knowledge gaps and to prioritise areas for future investigations.

NON TECHNICAL SUMMARY:
Murray crayfish (*Euastacus armatus*) is the basis of a popular recreational fishery in many areas of the southern Murray-Darling Basin and is considered an iconic species within the Murray-Darling Basin. However, Murray crayfish is also listed as a threatened species across much of its range. The perception of rural communities and recreational fishers is that Murray crayfish populations have declined in distribution and abundance over the last 50 – 60 years. Because little of the research undertaken on the status, biology or potential threatening processes of this species has been published, it is difficult to validate the reported declines and develop successful management strategies. This report reviews and assimilates all available knowledge on Murray crayfish (both published and accessible unpublished material), identifies key knowledge gaps and makes recommendations relevant to sustainable management of the species.

Biology

Data are available on nomenclature, morphology, systematics, distribution, population genetics, habitat requirements, environmental tolerances, movement and migration, daily and yearly activity patterns, diseases and parasites, breeding biology, sex ratio, growth, age and mortality, and the population size structure and abundance of several populations.

Murray crayfish is the largest of 43 species of spiny freshwater crayfish in the *Euastacus* genus, and the second largest freshwater crayfish in the world. It is more closely related to the Yarra spiny crayfish and Glenelg spiny crayfish that live in coastal Victorian rivers, than the four other *Euastacus* species found in the Murray-Darling Basin, or the *Euastacus* species in coastal NSW. The natural distribution encompassed around 12,500 km of waterways within the Murrumbidgee, Murray, Mitta Mitta, Kiewa, Ovens and Goulburn River catchments, with the distribution ranging from near Murray Bridge in South Australia, upstream to over 700 m altitude. Crayfish captured in the Macquarie and Lachlan catchments are likely to have been translocated, but this has not been confirmed, and natural populations may exist in the uplands of these two catchments. Genetic analyses suggest limited genetic diversity between populations across their range.

Murray crayfish occupy a wide range of habitat types ranging from small upland streams to large lowland rivers. The average size of individuals increases with the amount of habitat available. Clay banks, deep holes, woody debris and boulders are considered important habitat characteristics as they provide shelter. Flowing water is also an important habitat parameter. Murray crayfish are tolerant of temperatures up to 27^{o}C and moderate salinities (under 16 parts per thousand), but are intolerant of low dissolved oxygen concentrations. In general, freshwater crayfish are particularly sensitive to pollutants and pesticides.

Murray crayfish have low dispersal abilities, do not migrate and occupy small home ranges. They do not have any pronounced daily activity patterns and can be active at any time of the day or night. However, they are much more active during the cooler months between May and October.

Mating occurs during a brief period in early to mid May each year. Fecundity is related to size and ranges from about 200 for small females to over 1,200 in larger individuals. The female attaches the eggs to the underside of her abdomen and broods them for over four months. After hatching, juveniles remain with their mother for an additional month before dispersing. Under captive conditions, mortality during this period is around 65% and declines to 30 – 40% up until 1.5 years of age. In the wild, mortality of individuals larger than 40 mm OCL (occipital carapace length) is estimated to be 50% per year.

Like all crustaceans, Murray crayfish grow sequentially through a series of moults. The frequency of moulting is size dependent, with up to 10 moults in the first year and only a single annual moult in late April – early May for individuals over 60 mm OCL. The increase in size at each moult varies among individuals and is most affected by size, the presence of injuries and population density. Data collected by O'Connor (unpublished) suggest that Murray crayfish in lowland rivers are 6 mm OCL at dispersal, 20 mm OCL at one year of age, 50 – 60 mm OCL at 5 years of age. Most females reach sexual maturity 6 to 10 years of age when 70 – 100 mm OCL and most males are physiologically mature at over 50 mm OCL at four years of age (O'Connor, unpublished). It may take over 25 years to reach their maximum size of around 150 – 170 mm OCL.

In the 1800s and early 1900s, Murray crayfish were very abundant. However, recreational fishermen, commercial fisherman and researchers noted that their distribution, abundance and average size began to decline during the 1950s. These declines continued through until the 1980s when fishing regulations and total fishing closures were introduced. Murray crayfish are now considered very rare or locally extinct in the Murray River downstream of Mildura and are reportedly very rare in several lowland river reaches. They are listed as threatened in South

Australia, the ACT, and Victoria and are a part of the Lower Murray endangered ecological community in NSW.

Management

Threatening processes

Threatening processes postulated to have caused of these declines include; river regulation, pesticides and agrochemicals, commercial and recreational overfishing and to a lesser extent, thermal pollution and obstructed fish passage. The construction of weirs and subsequent river regulation and seasonal flow reversal, and the widespread use of agro-chemicals in the 1940s and 1950s are likely to be the two primary threatening processes responsible for the decline of the range and abundance of Murray crayfish. Commercial and recreational over-fishing also contributed to the decline in abundance and average size. Habitat degradation, thermal pollution, obstructed fish passage and predation by introduced fish also pose moderate threats to the sustainability of the population.

Current recreational fishery

A recreational fisher logbook survey undertaken in NSW in the early 1980s indicated that harvesting was concentrated between Albury and Tocumwal and Echuca and Tooleybuc on the Murray River, and from Wagga Wagga to Darlington Point on the Murrumbidgee River. Catch per unit effort was greatest between Barmah and Nyah on the Murray River and between Wagga Wagga and Darlington Point on the Murrumbidgee River. The catch was not evenly distributed amongst recreational fishers, with 66% of the catch taken by only 25% of the fishermen. Most fishermen (66%) viewed crayfishing primarily as a source of relaxation and enjoyment, while 21% viewed it as a food fishery and only 9% viewed it as a sport. A second recreational fisher survey in 1998 suggested that the current recreational fishing regulations were not widely understood by recreational fishers.

Currently, the four key recreational fishing regulations for Murray crayfish, the restricted fishing season, the minimum size limit, the bag limit and the protection of berried and brooding females, are consistent between NSW and Victoria. However a number of other regulations regarding the harvest of Murray crayfish are not. A higher possession limit in NSW may put slightly greater stress on stocks in that state. And an unusual definition of ‘in carcass form’ under the Victorian recreational fishing regulations legalises the removal of ‘one or more’ legs and claws from crayfish prior to release.

A total of 1,084 km of stream within the range of Murray crayfish are closed to crayfishing in NSW, and 16 km are closed to crayfishing in Victoria. Murray crayfish are totally protected in 678 km of streams within their natural range in South Australia and 163 km of streams within the ACT. This equates to around 16% of their natural distribution.

Both abundance and size appear to be increasing in some areas as a result of current recreational fishing regulations and closures. However, by effectively protecting all sexually mature females from harvest, the current regulations put substantial fishing pressure on male crayfish. The implications of a biased sex ratio on the sustainability of the population are yet to be determined.

Current conservation status

Murray crayfish is listed as a threatened species across much of their range. It is protected in South Australia, listed as vulnerable in the ACT and threatened in Victoria. In NSW, Murray crayfish occur in the ‘Lower Murray River Endangered Ecological Community’ and, as such, are nominally granted the status of a threatened species across a large proportion of their range. Nationally, the conservation status of Murray crayfish is indeterminate, due to the lack of knowledge regarding the species at the time of assessment. Murray crayfish are listed internationally as ‘data deficient’ by the IUCN.

In the ACT a specific action plan was developed for Murray crayfish and then a subsequent multi-species recovery plan has incorporated Murray crayfish recovery actions. Despite being protected by law in South Australia, threatened in Victoria, and listed as a component of an endangered ecological community across much of its range in NSW, these states have not yet developed recovery or action plans for Murray crayfish.

Traditional ecological knowledge

A series of consultations with representatives from Aboriginal communities throughout the Murray and Murrumbidgee catchments and a literature search were undertaken to summarise traditional knowledge and uses of the Murray crayfish by Aboriginal people. Despite limited evidence of Aboriginal utilisation of *Euastacus* species in archaeological deposits, Murray crayfish were clearly important to Aboriginal societies. Although no spiritual totemic relationships were identified, Murray crayfish were harvested for food and were sufficiently important that they were given specific names in a number of Aboriginal languages. Traditional knowledge obtained from this study supports current scientific data that Murray crayfish are restricted to flowing river reaches and absent from still waters and billabongs, that they are most active during winter and less active during summer, and that Murray crayfish are good bio-indicators of poor water quality. Aboriginal communities consulted had a significant interest in the conservation of natural resources, including iconic species such as Murray crayfish. Incorporation of traditional ecological knowledge into conventional research programs will both improve management practices and maintain Aboriginal connections with the environment.

Knowledge gaps and research needs

Information on the current status or Murray crayfish throughout their entire range remains the most significant knowledge gap for the species. Other knowledge gaps that may assist with appropriate management of the species include:

- The habitats and biology of juvenile crayfish < 40 mm OCL.
- The endemicity of populations in the Lachlan and Macquarie catchments.
- The impact of river regulation on burrowing behaviour.

Management recommendations

We support previous calls for a Murray crayfish re-introduction program in the lower Murray River. If pesticide use was a cause of past decline, current regulations regarding pesticide use mean that this threatening process will be much reduced. Therefore, potential exists to trial the re-establishment of Murray crayfish in flowing reaches of the lower Murray River. However, given that river regulation may also have been a primary threatening process, only reaches within the lower Murray region that retain reasonable flow velocities should be prioritised for reintroduction trials. These may include Mullaroo Creek, Chowilla Creek, sections of the Edwards and Wakool Rivers and the reach of the Murray River immediately downstream of Lock 7. Subsequent monitoring of reintroduced populations would provide an opportunity to assess the criteria for population establishment and determine the timeframes required for populations to reach self-sustaining levels.

Custodians of the large amount of unpublished quantitative information are encouraged to publish their data as soon as possible. This will inform future reviews of the management arrangements for this species.

KEYWORDS:
Murray crayfish, *Euastacus armatus*, conservation, management.

1. INTRODUCTION

The Murray crayfish (*Euastacus armatus*) is a large freshwater species that is the basis of a popular recreational fishery in many areas the southern Murray-Darling Basin and is considered an iconic freshwater species (Sanger and King 2002). Despite the social importance of Murray crayfish, little information has been formally published. The majority of data are only available as unpublished departmental manuscripts, theses, secondary references to unpublished data, or in items published outside of peer-reviewed scientific journals. Consequently, the information that is available about Murray crayfish is difficult to access.

The perception of rural communities and recreational fishers is that Murray crayfish populations have declined in distribution and abundance over the last 50 – 60 years (Pollard *et al.* 1980; Walker 1982; Barker 1990; Geddes 1990; Horwitz 1990a; Geddes *et al.* 1993; Horwitz 1995). However, the lack of scientific data regarding its status, biology and the impacts of potential threatening processes, limits the ability to validate the reported declines and develop successful management strategies. This report will review and assimilate all available information on Murray crayfish (both published and accessible unpublished material), and identify key knowledge gaps relevant to sustainable management of the species.

Many of the often quoted statements regarding Murray crayfish are second or third hand accounts of unpublished data-sets. In this review, we have tried to use the primary source of the data whenever possible.

2. METHODS

2.1. Published literature

The following electronic literature databases were searched using the keywords 'Murray crayfish', 'Murray cray', '*Euastacus armatus*', '*E. armatus*': Biological Sciences, GeoBase, ASFA, Endanger, CSIRO Journals, OVID, Current Contents databases, AgBiotechnet, Kinetica, Informit, Streamline, Fish and Fisheries Worldwide and CAB Abstracts (1973 – 2005).

Only three published papers provided primary, peer-reviewed data on the ecology of Murray crayfish: Morgan (1986), Geddes *et al.* (1993), McKinnon (1995). A further seven peer-reviewed studies present primary information on morphology, taxonomy and evolutionary genetics: Ache and Sandeman (1980), Sandeman and Wilkens (1982), Sandeman and Wilkens (1983), Lawler and Crandall (1998), Crandall *et al.* (1999), Versteegen and Lawler (1996) and Shull *et al.* (2005). Additionally, seven published peer-reviewed items; Clark (1936), Hale (1927), Walker (1982), Geddes (1990), Lintermans (1993), Horwitz (1994a) and Maloney (1997), discuss Murray crayfish, but do not provide any primary data. Finally, there are several field guides (Healy and Yaldwyn 1970; Williams 1980; Williams 1983; Merrick 1993; Jones and Morgan 1994; Hawking and Smith 1997; Gooderham and Tsyrlin 2002; Lintermans and Osborne 2002), general articles about freshwater crayfish (Francois 1960) and government websites and advisory materials that refer to Murray crayfish, but none provide any primary data on the species.

2.2. Unpublished reports and datasets[1]

Population studies of Murray crayfish were undertaken by Johnson and Barlow in 1974 and 1980, O'Connor from 1981 to 1985, Hume and Morison from 1984 to 1988 (summarised by Morison 1988), Lintermans and Rutzou (1991) between 1988 and 1989, Lintermans (2000) in 1998, Barker (1992) in 1990, Burston *et al.* (1999), Sloan (pers comm) and McMonigle (pers comm) from 1993 to present, Gehrke (1992) in 1992, Closs and Driver (pers comm) in 1994 – 1995, Raadik, O'Connor and Mahoney (2001) in 1997 – 1999 and McCarthy (2005) in 2004. Only Lintermans and Rutzou (1991), Barker (1992), Raadik *et al.* (2001) and McCarthy (2005) released reports on their studies.

Johnson and Barlow (NSW State Fisheries –Narrandera Fisheries Centre) collected samples of Murray crayfish in the Murrumbidgee River at Narrandera in 1974 and again in 1980. In 1980, samples were also collected from Yanco Creek. Sampling was undertaken during the day between May and October. Murray crayfish were collected in 1 m diameter baited hoop nets with mesh ranging from 20 mm to 80 mm. The type of bait used was not specified. Nets were removed after between 15 minutes and one hour. Data collected included weight, size (OCL (occipital carapace length – measured from the rear of the eye socket to the end of the carapace) and total length), sex and reproductive status. The findings were reported in a manuscript that was submitted for publication in three scientific journals between 1983 and 1984. The manuscript was not accepted. For the purposes of this review, we refer to this manuscript as Johnson and Barlow (1982).

Between 1981 and 1985, O'Connor (NSW Department of Agriculture – Narrandera Fisheries Centre) conducted a very extensive study of Murray crayfish populations at six sites within a 50

[1] Numerous text citations to unpublished reports or other works are unavoidable throughout this report. In order to eliminate the 'unpublished' descriptor in each citation, only the year of completion of the source document is given, although the 'unpublished' status of the work concerned is clearly stated in the reference listings.

km reach of the Murrumbidgee River between Berembed and Gogeldrie Weirs, and single sites in Bundidgery Creek at Narrandera, the Murray River three kilometres downstream of Corowa and in Khancoban Pondage in the upper Murray catchment. Two of the sites on the Murrumbidgee River and the site on Bundidgery Creek were sampled on a fortnightly basis between October 1981 and December 1984. Samples were collected using 22 hoop nets baited with carp. Nets were set during daylight hours and were hauled four times at 30 – 45 minute intervals. All individuals were retained in individual moistened hessian bags until the completion of sampling on that day, when all were released. Data recorded included size (OCL), sex, maturity and moult stage. Crayfish were tagged with floy streamer tags under the abdomen and were also marked with tail punches. Temperature and turbidity were recorded during sampling. Three of the Murrumbidgee River sites were used for gear efficiency studies in 1982 and 1984. The remaining Murrumbidgee River site was sampled every 4 to 6 weeks in 1982 and 1983 and irregularly thereafter, with a sub-sample of 15 to 30 specimens sacrificed for dissection at each collection. The site at Corowa was sampled in October 1983 and May 1984. Khancoban Pondage was sampled intermittently between 1982 and 1986 by scuba divers, who collected crayfish by hand and recorded the number of individuals observed within 30 minutes. Data were analysed and discussed by O'Connor as an internal document, and as draft Ph.D. thesis chapters that were never submitted. For the purposes of this review, we refer to this internal document and draft thesis (combined) as O'Connor (1986).

Hume and Morison (Victorian Department of Conservation, Forests and Lands: Kaiela Fisheries Research Station) undertook surveys of Murray crayfish in Lake Nagambie, Wodonga Creek and the Ovens River in August each year between 1984 and 1988. Sites were sampled during the day using hoop nets baited with carp, sheep heads or ox heart. The number of nets, their size, mesh and set times were not specified in the draft report (Morison 1988). However, Sloan (Fisheries Victoria: pers. comm.) advised that 20 hoop nets hauled hourly for eight hauls were used. Data collected included size (OCL), sex and reproductive status. Individuals were tail-marked to enable identification of recaptures. A mark-recapture program to assess growth rates and population size was discontinued due to insufficient recapture rates. Data were summarised as an internal document prepared by Morison that was never published. For the purposes of this review, we refer to this document as Morison (1988).

Lintermans and Rutzou (ACT Parks and Conservation Service) sampled 12 sites along the Murrumbidgee River in the Australian Capital Territory in October/November 1988. Two of these sites were re-sampled in August 1989 as well as a single additional site. Murray crayfish were sampled using a set of 20 x 55 cm diameter hoop nets baited with golden perch fillets, carp or kangaroo meat. Nets were set between 10:30 am and 16:00 pm, being retrieved and reset every 45 – 60 minutes. Two baited 30 m long gillnets (75 mm mesh) set overnight, were trialled at one site as an alternative sampling technique. Some specimens were also collected by hand. Further, riverbanks and water rat/bird feeding sites were searched for exoskeletal remains. Murray crayfish captured were sexed, measured (OCL and claw length) and tagged. Water temperature was recorded at each site. An ACT Parks and Conservation Service research report presents the results of this sampling (Lintermans and Rutzou 1991).

Between May and November 1990, Barker (Victorian Department of Conservation and Environment) undertook sampling of Murray crayfish at Lake Nagambie, Wodonga Creek and the Ovens River (but only specified that the Wodonga Creek site was the same as that used by Hume and Morison (1988), as well as an additional site in Waranga Lake. Sites were sampled during the day using 20 baited 'regulation size' hoop nets pulled at regular intervals over a number of days. Data collected included size (OCL), weight, sex and reproductive status. Individuals were tail-marked to enable identification of recaptures. A Victorian Inland Fisheries Management Branch – Fisheries Management Report, Barker (1992), presents the results of this sampling.

In 1992, Gehrke (NSW Fisheries – Narrandera Fisheries Centre) undertook a further study in the Murrumbidgee River at Narrandera. Two sites sampled by O'Connor (named Bassett's and Whitby's) were re-sampled using 5 hauls (1 hour soak time during daylight) of 22 x 600 mm diameter, 13 mm mesh hoop nets baited with carp, over 5 sampling sessions in May and June 1992. Abundance, size (OCL) and sex were recorded, and individuals were tail-marked to enable identification of recaptures. All individuals were retained in individual moistened hessian bags until the completion of sampling on that day, when all were released. Data were summarised by Gehrke (1992) as an internal NSW Fisheries document that was never distributed.

From 1993, Sloan (Victorian Department of Primary Industries, Wodonga: pers. comm.), McMonigle (Victorian Department of Primary Industries, Wangaratta: pers. comm.) and Burston *et al.* (1999) (La Trobe University) continued sampling the Ovens River site established by Hume and Morison on an intermittent basis following re-opening of the Victorian fishery in 1991. An additional site was also sampled on the Ovens River during this period. The two Ovens River sites represent examples of hard and easy access for recreational fishers. Samples were collected using five net lifts of 20 hoop nets. Data collected up until 1999 were presented as a conference poster by Burston *et al.* (1999). Data collected between 2000 and 2006 are not currently available.

In 1994 and 1995, Closs and Driver (La Trobe University) conducted a two-year study of fish and Murray crayfish in Stoney Creek, north-eastern Victoria. They collected samples using two-pass backpack electrofishing over five sampling periods. Abundance, size (OCL) and sex of Murray crayfish were recorded (pers. comm.) but no outputs have been published.

Between 1997 and 1999 Raadik, O'Connor and Mahoney (Victorian Department of Natural Resources and Environment) collected data on fish and crayfish from throughout Victoria. One hundred and twenty-two sites were sampled within the Upper Murray, Kiewa, Ovens and Goulburn-Broken catchments. At each site ~ 100 m of stream was sampled using single–pass backpack or bank-mounted electrofishing. Abundance, size (OCL) and weight of crayfish were recorded. Water quality and physical parameters of the sampling sites were also presented. Although not a targeted Murray crayfish survey, this study presents useful primary data on Murray crayfish. An Arthur Rylah Institute Technical Report (Raadik *et al.* 2001) summarises and presents the data collected.

In 1998 Lintermans (Environment ACT) re-sampled 10 of the sites on the Murrumbidgee River originally sampled in 1988/89. Twenty 55cm diameter hoop nets, baited with kangaroo meat were used. Nets were set between 09:45 – 10:30 am and had a soak time of approximately five hours, being retrieved and reset every 45 – 60 minutes. Data recorded were size (OCL), sex and reproductive stage of females. Water temperature was recorded at each site. Data were summarised by Lintermans (2000) as an internal document, but never distributed.

Between June and November 2004, McCarthy (CSIRO Murray-Darling Freshwater Research Centre, Lower Basin Laboratory and Mildura) sampled 13 sites within a 700 km reach of the Murray River between Nyah and the South Australian border (including Mullaroo Creek) as well as a single site in the Murrumbidgee River at Narrandera. Samples were collected using 40 Munyana mud crab traps (60mm mesh) (Figure 1) set overnight (16:00 pm – 8:00 am). Each site consisted of 4 river bends (< 90^{o}), each bend stratified into the following zones: inside bends (upstream), inside bends (downstream), outside bends, straights and pelagic, with eight traps set in each zone. Traps were baited with ox heart and liver. At the Narrandera site, 10 x 760 mm (60 mm mesh) hoop nets were set at 16:00 pm and retrieved after 1 hour for comparison with the Munyana trap data. Depth, distance from bank and flow were recorded for each trap and water quality was recorded over the whole site. The abundance, size (OCL), weight, sex and abnormalities of Murray crayfish were recorded. A Murray-Darling Freshwater Research Centre technical report (McCarthy 2005) presents the results of this sampling.

Figure 1. Munyana mud crab traps used to sample Murray crayfish as described by McCarthy (2005). Photo: Bernard McCarthy.

Between August and October 2005, Edney (Latrobe University) undertook a survey of Murray crayfish populations at two sites in the Murray River near Albury. Samples were collected using hoop nets baited with liver. Abundance, size (OCL), sex and the presence of berried females were recorded from the catch (pers. comm.), but no outputs have been published.

2.3. Unpublished student theses

The following sources were searched for primary data sources on Murray crayfish:

1) Library catalogues of academic institutions. These databases included all theses for Masters or Ph.D. degrees. Honours theses were not usually listed.
    - (i) All ten NSW Universities.
    - (ii) The Australian and National Museums.
    - (iii) Two Queensland Universities (University of Queensland and Griffith University).
    - (iv) Two Australian Capital Territory Universities (Australian National University and the University of Canberra).
    - (v) The University of Adelaide.
    - (vi) Three Victorian Universities (La Trobe University, Monash University and Deakin University).
2) Australian Digital Thesis (ADT) database. Holdings vary widely between departments within an institution and between institutions, but are largely restricted to the last 5 to 8 years.
3) Honours thesis holdings of individual University departments. Some departments have very extensive lists, while others only list the titles for the last few years.
4) Linnean Society of NSW indexes for Volumes 1 to 120 (1885 – 2000).
5) Australian Society of Fish Biology (ASFB) thesis database.
6) Australian Society for Limnology (ASL) thesis lists and abstracts.
7) Recent issues of the *Queensland Naturalist*.
8) Recent issues of the *Victorian Naturalist*.
9) The complete index of *Freshwater Crayfish*.

Searches of library catalogues (1) and ADT databases (2) did not yield anything relating specifically to *E. armatus*. Nor was any new material identified from searches (4) to (7). Nine potentially relevant items from departmental searches (3) were identified: Kaires (1979), Kaires (1980), Barley (1983), Atkins (1984), Bezzobs (1988), Asmus (1999), Goode (1999), Ryan (2005) and Baumgartner (2005). Of the nine identified theses, one is only available as an abstract, three include some relevant information or comment (but *E. armatus* is not the main topic), and three relate to reactions to hypoxia. Geddes (1990) and Geddes *et al.* (1993) would have been aware of these theses and would have cited or discussed them if they revealed anything inconsistent or unusual. Only Asmus (1999) and Ryan (2005) provide relevant primary data. The only category of academic material not accessed by the activities summarised above would be older (i.e., pre-1970) honours studies. At least two pre-1970 theses potentially had information on Murray crayfish: Francois (1962) and Kane (1964).

Asmus (Charles Sturt University) surveyed Murray crayfish in the Murrumbidgee River with the objective of assessing the impact of recreational fishing. Twelve sites were sampled twice each year in 1997 and 1998. Sites were spread amongst three reaches of the Murrumbidgee River between Gundagai and Whitton, a distance of 311 river kilometres. The middle reach corresponded to a ~70 km reach of the river closed to Murray crayfish fishing for a period of nine years, and re-opened < 12 months prior to the study. Two sites in each reach were selected for ease of fishing access and two sites per reach were selected to represent difficult access. Sampling was undertaken in June/July and November. Sampling gear used were 20 x 800mm diameter hoop nets with 15 mm mesh baited with carp. Nets were set between 7:00 am and 8:00 am and retrieved after 1 hour, then twice more over a four hour period. All sampled individuals were retained in bags until the completion of sampling and then released at the place of capture. Data recorded was weight, size (OCL), sex and maturity (females only). Individuals were marked using a tail-punch to enable identification of recaptures. In addition, Asmus (1999) undertook angler surveys to quantify knowledge of New South Wales fishing regulations (as they existed in November 1998). All 12 sites were sampled again in summer 2003 and winter 2004. However data collected from the 2003 and 2004 surveys have not been analysed and are not available.

Ryan (University of Canberra) surveyed Murray crayfish in the upper Murrumbidgee River and used radio-telemetry to assess movement, home range size and habitat use. Six sites in the upper Murrumbidgee River (in the Australian Capital Territory) were sampled between January and August 2005. Sampling gear used were six to eight 500mm diameter hoop nets baited with chicken liver. Each net was set for 15 minutes before being checked and replaced. Nets were re-checked and removed after 30 minutes. Data recorded included weight, size (OCL) and sex. Individuals were marked using a tail-punch to enable identification of recaptures. Diel behaviour, movement and home range size were assessed using radio-telemetry to locate the position of seventeen individual Murray crayfish at hourly intervals over 25 hour periods. Each replicate 25 hour assessment was up to 21 days apart. Radio-tracking was undertaken between April and September 2005. Results of this study were summarised in Ryan (2005).

In late 2006, Alves (Macquarie University) began a Master of Philosophy project on the biology of Murray crayfish. The aims of Alves's research are to develop sampling techniques suitable for collection of juvenile Murray crayfish, study the occurrence of cannibalism and the potential for parental care, and study burrowing behaviour and the potential impacts of river regulation on burrow dependant behaviours.

It must be emphasised that unpublished data reports and honours theses in most cases contain preliminary data that have not been subjected to editorial or referee scrutiny. However, these sources contain relevant data that provide useful biological information about Murray crayfish. In our opinion, although most of the draft reports and manuscripts are un-publishable in their current state, none of the data presented are considered to be flawed or unworthy of publication.

3. BIOLOGY

3.1. Nomenclature

Common name: Murray crayfish

Other common names: Murray cray, Murray River crayfish, Murray spiny crayfish, River Murray freshwater crayfish, spiny lobster, Murray lobster.

Traditional names (see section 5.4.1): Parindjak, Thangambuluwa, Mungola, Yinga, Thipil, Thip-Thip, Tanggambalangga, Karta, Popa, Papa, Ponggongalo, Ngathang, Lip-lip-wil, Tjipel, Wuluma, Ringwong, Mowak, Yukalto, Thapul, Ukodku, Pootaronko, Koongola, Meauki, Kawthawi.

Scientific name: *Euastacus armatus* (Clark 1941)
Family: Parastacidae
Order: Decapoda
Class: Malacostraca
Subphylum: Crustacea
Phylum: Arthropoda

Synonyms: *Astacus armatus* (von Martens, 1866), *Astacus serratus* (McCoy 1867), *Astacoides serratus* (McCoy 1878), *Astacopsis armatus* (Huxley 1880), *Astacopsis serratus* (Haswell 1882), *Astacopsis spinifer* (Spence-Bate 1888), *Astacopsis spinifera (*Faxon 1898), *Euastacus serratus* (Clark 1936), *Euastacus elongatus* (Clarke 1941).

Etymology: *Eu* (Latin: true or good) – *astacus* (Latin: a kind of crab, derived from the Greek word astakos) and *armatus* (Latin: armed, or furnished with weapons).

3.2. Identification

3.2.1. Type specimen

The type specimen for the species was collected in the Murray River and is held at the Zoologisches Museum, Berlin, Germany.

3.2.2. Diagnosis

Keys are available in Clark (1941), Williams (1980), Riek (1969), Merrick (1993), Morgan (1986) and Morgan (1997).

Chelipeds are held so that the dactylus closes horizontally to propodus. Cervical and branchiocardiac grooves are fused. Telson is completely or partially divided by a transverse suture. Genital papillae of male are simple and calcified. The male cuticle partition is absent. There are two (rarely three) spines on the mesal margin of the carpus and one to nine spines on telson. Marginal antennal scale spines are present. The postorbital ridge is well developed, ending anteriorly with a sharp spine. Branchiostegite has a lateral zone of enlarged tubercles with a dorsal marginal row of spines. Thorax length is <50% of the cephalon length. Abdominal somites bear large sharp spines that are usually curved towards the anterior. Sternal keel is not obviously raised.

3.2.3. General description

Murray crayfish is the largest species in the genus *Euastacus*, and is the second largest freshwater crayfish in the world (the Tasmanian giant freshwater crayfish *Astacopsis gouldi* is the largest). The largest specimen recorded in any of the primary references presented in this report was a 174 mm (OCL) female collected in the Ovens River in 1985 (Morison 1988). The estimated weight of this individual (using the length-weight relationship of Johnson and Barlow (see section 3.10.3) (R^2 = 0.982) is 2.5 kg. Maximum sizes of 3 kg in weight (Geddes 1990) and 50 cm in total length (Horwitz 1990a) have been reported but are not supported by primary citable data. To provide a measure of scale, Figure 2 shows a large (155 mm OCL) individual captured in the Murray River near Barmah in 2006 (an average size (~ 90 mm OCL) individual is shown for comparison).

Figure 2. Two Murray crayfish captured from the Murray River near Barmah in 2006. The individual on the left was ~ 90 mm OCL, whilst the individual on the right was ~ 155 mm OCL. Photo: Matthew Jones.

The colour of the carapace and abdominal segments generally ranges from blue to brown, with most individuals being khaki green. The colour of the cephalon is generally paler than the carapace (Figures 2 and 3). The spines, maxillipeds, chela (claws) and ventral surfaces of the pereiopods (walking legs) are generally white or cream. The dorsal surfaces of the pereiopods are brown/blue. Robust sharp spines are present on each abdominal segment and on the chelae, with smaller spines on the cephalothorax and pereiopods.

Hatchlings are of a larval form up until the third moult. Subsequently, the morphology of juveniles is generally similar to adults, although colouration can vary, with the chelae of juveniles less than about one year old being mottled green and yellow instead of the characteristic white of larger individuals (Morgan 1986).

Adult Murray crayfish are clearly distinguishable from other Murray-Darling *Euastacus* species by their large size, white or creamy coloured chelae and sharp white spines on the abdominal segments, cephalothorax and chelae. Juvenile Murray crayfish can be differentiated from the thick crayfish or alpine spiny cray (*Euastacus crassus*) (and possibly *E. rieki*) in upland and highland streams of the Murray and Murrumbidgee catchments by having two rather than three spines on the mesal margin of the carpus, large and sharp rather than blunt or absent abdominal spines, medium to long rather than short rostral carinae and different colouration (Morgan 1997). Murray crayfish can be differentiated from the Central highlands spiny crayfish (*E. woiwuru*) in slopes, upland and highland streams of the Ovens and Goulburn catchments by not having a male cuticle partition near the genital papillae (Morgan 1997).

Morgan (1986) observed that Murray crayfish morphology was unusually consistent across the entire species range. However, Morgan (1986) also stated that individuals from Kandos in the Macquarie catchment (the 'potential' northern limit of the species range) had more numerous spines on the telson surface, a more elongate rostrum and a more abrupt posterior margin of the 1st keel process than individuals from elsewhere across the species range. This suggests that at least some morphological variation exists. Further, Clark (1941) proposed that individuals within the Goulburn catchment and adjacent reaches of the Murray River (near Echuca) were a separate species (*Euastacus elongatus*) based on much longer 2nd antennae, more elongate and slender great chelae, less spinous telson and uropods, the structure and size of the abdominal spines and smaller and less numerous spines on the perieopods. However, *E. elongatus* was subsequently discarded as a synonym of *E. armatus* by Riek (1969) and Morgan (1986).

3.3. Relationships with other species

The phylogeny and taxonomy of Australian freshwater crayfishes has been the focus of much published research within Australia (e.g., Crandall *et al.* 1999; Horwitz and Adams 2000; Hansen *et al.* 2001; Hughes and Hillyer 2003; Munasinghe *et al.* 2004; Nguyen *et al.* 2004; Ponniah and Hughes 2004). The Murray crayfish is one of 43 currently recognised species in the genus *Euastacus* (Coughran 2002). The genus is endemic to Australia, with the majority of species present in coastal drainages of the east and south-eastern Australian mainland (Crandall *et al.* 1999). Five *Euastacus* species are found in the Murray-Darling Basin; *E. armatus, E. rieki, E. crassus, E. woiwuru and E. suttoni*.

Sutton's crayfish (*Euastacus suttoni*) is found in the New England Tableland area of northern New South Wales (Merrick 1993).

Euastacus rieki and Murray crayfish are both present in the Murrumbidgee and Murray catchments, but *E. rieki* is restricted to alpine areas above the upper altitude limit of Murray crayfish (Lintermans 2002). The distributions of thick crayfish and Murray crayfish overlap in the upland and highland areas of the Murrumbidgee and Murray catchments, however the two species have not been found in sympatry (Barker and Turnbridge 1990; Raadik *et al.* 2001; Lintermans 2002). Similarly, the distributions of central highlands spiny crayfish and Murray crayfish overlap in the slopes, uplands and highlands of the Goulburn and Ovens catchments (Barker and Turnbridge 1990; Raadik *et al.* 2001), however the two species have not been found in sympatry. Murray crayfish is the only *Euastacus* species that occurs in the lowlands of the Murray-Darling Basin.

Murray crayfish are genetically more similar to the Yarra spiny crayfish (*Euastacus yarraensis*) and Glenelg spiny crayfish (*Euastacus bispinosus*) that exist in coastal Victorian rivers, than they are to *E. rieki* or Sutton's crayfish from the Murray-Darling Basin, or species from coastal New South Wales (Crandall *et al.*1999). Morphologically, they are most similar to the Yarra spiny crayfish (Morgan 1986).

Figure 3. Adult Murray crayfish (*Euastacus armatus*) from the Murrumbidgee River at Narrandera. Photo: Dean Gilligan.

3.4. Distribution

3.4.1. Historical distribution

Murray crayfish have the most widespread distribution of any *Euastacus* species (Merrick 1993). The natural distribution of Murray crayfish encompasses around 12,500 km of waterways (Figure 4). Historically, they were present within the main channel and tributaries of the Murray, Murrumbidgee, Mitta Mitta, Kiewa, Ovens and Goulburn rivers, existing from the upper reaches (from over 700 m: Morgan 1986; Raadik *et al.* 2001), downstream to at least Murray Bridge in South Australia (Geddes *et al.* 1993). Murray crayfish are not considered to occur naturally in the Lachlan, lower Darling, Campaspe, Loddon, Avoca or Wimmera rivers (Cadwallader 1977; Morgan 1986; Geddes 1990).

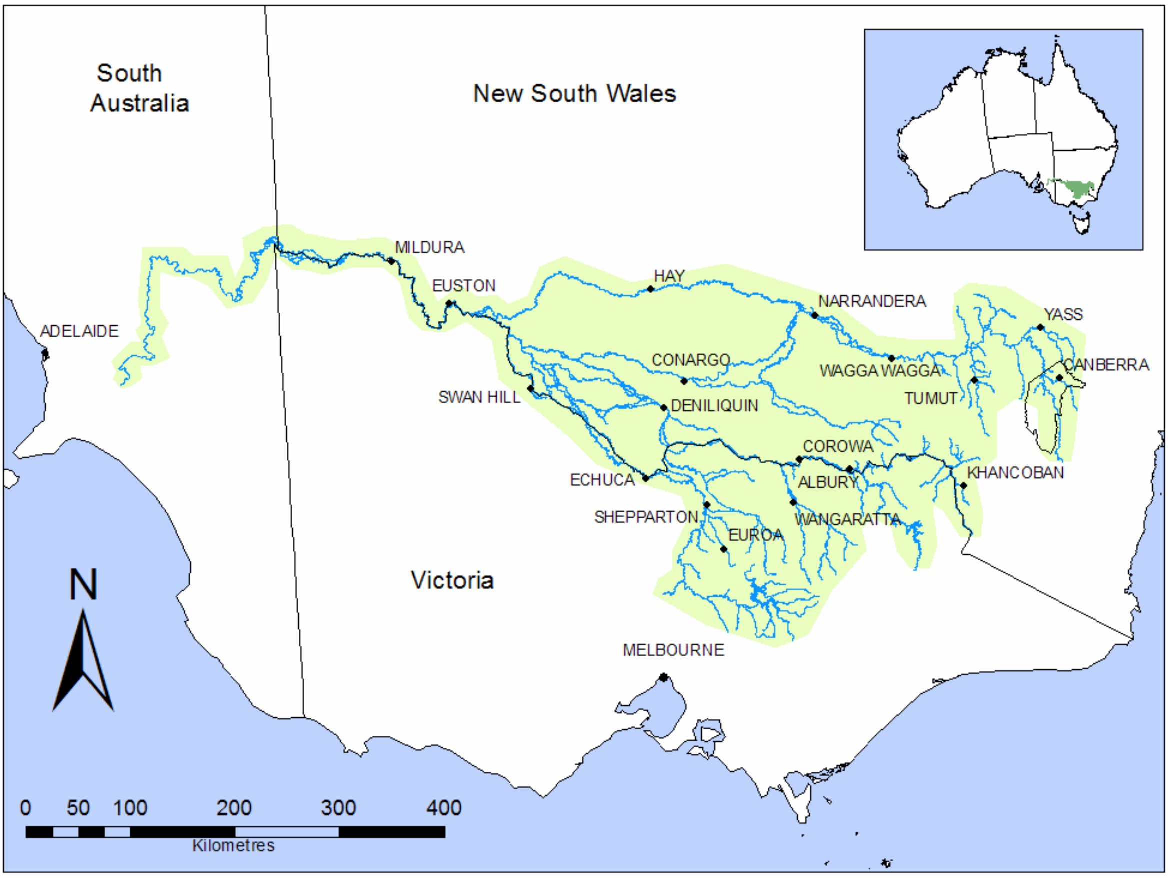

Figure 4. The likely natural distribution of Murray crayfish.

Riek (1969), Healy and Yaldwyn (1970), Morgan (1986), Merrick (1993) and Morgan (1997) stated that the distribution extended to the upper reaches of the Darling River system. This statement was based on the collection of three Murray crayfish (2 males and 1 female) by Dr. R.D. Gauthier, from the upper Macquarie River catchment near Kandos, circa 1967 (Morgan 1986) (Figure 5). These specimens were lodged at the Australian Museum. Others have also reported the continued existence of Murray crayfish in the Kandos area, with the species reported from Carwell Creek in 1999/2000 (800 m altitude, UTM zone 55H, easting 771900, northing 6347200) (Peter Gallagher, pers comm) and in and above Dunn's Swamp on the Cudgegong River in the last few years (650 m altitude, UTM zone 56H, easting 238500, northing 6362400) (Karl Schaerf and Phil

McCarthy, pers comm) (Figure 5). Further, in another part of the upper Macquarie catchment, large spiny crayfish have been reported from the Winburndale River (UTM zone 56H, easting 759000, northing 6303000) (Phil McCarthy, pers comm) (Figure 5). However, New South Wales State Fisheries annual reports document the translocation of Murray crayfish to areas in the Macquarie catchment in 1921, 1923 and 1925 (O'Connor, 1986, see Table 1). Therefore, the populations in the upper Macquarie catchment could be a result of translocation, and therefore the Macquarie and Darling catchments may be outside the species natural range.

However, two Murray crayfish, one male (105 mm OCL) and one female (95 mm OCL), were captured opportunistically in Bolong Creek (Lachlan catchment: UTM zone 55H, easting 740707, northing 6214578) during an electrofishing operation in April 2006 (NSW DPI, unpublished data) (Figure 6). Further, Murray crayfish have also been observed in the nearby Abercrombie National Park (UTM zone 55H, easting 746000, northing 6224000) (Phil McCarthy, pers comm). These are the only known records of Murray crayfish in the Lachlan catchment. Although these populations may have also arisen through non-certified translocations, in the absence of genetic analysis, we cannot rule out the possibility that these, and those Murray crayfish from the upper Macquarie River, may represent natural populations in the upper areas of these two catchments. This possibility is supported further by the fact that despite Morgan's (1986) statement that Murray crayfish were unusually morphologically invariable across their range, at least three morphological characteristics were unique to the three individuals captured in the Macquarie by Dr. Gauthier (Morgan 1986).

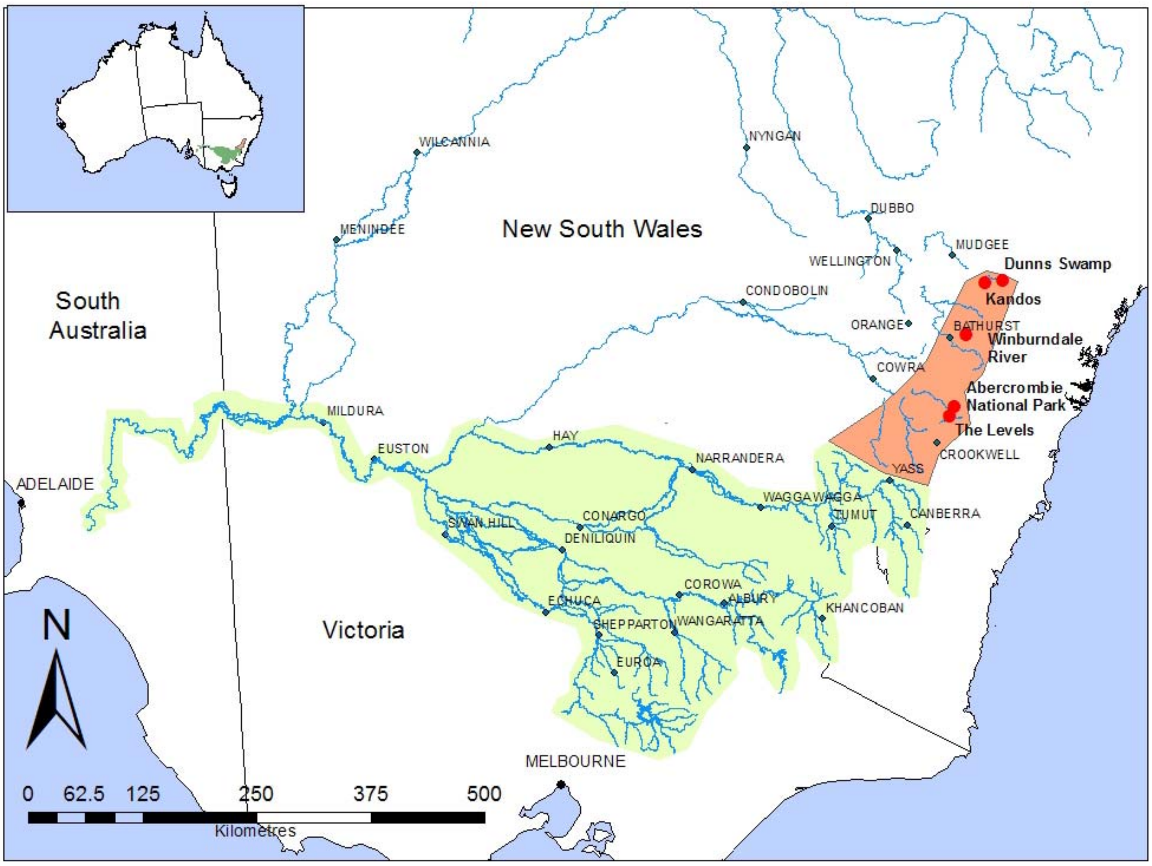

Figure 5. The potential extension to the natural range of Murray crayfish (orange shaded area) if the populations in the upper Macquarie and Lachlan catchments are remnant rather than translocated populations.

Figure 6. Murray crayfish captured from Bolong Creek (Lachlan catchment) in 2006. Phot: Dean Hartwell.

3.4.2. Current distribution

Although commercial catches of Murray crayfish were reported in the Murray River in South Australia up until the 1960s (Geddes 1990; Geddes *et al.* 1993), Murray crayfish are now considered rare or absent from the Murray River downstream of Mildura (Walker 1982; Glover 1987; Geddes *et al.* 1993; McCarthy 2005). This 1,076 km reach (including the main channel plus anabranches) represents the most significant reduction in the distribution of Murray crayfish, of around 8% of the species natural range. However, there has been no recent targeted sampling for Murray crayfish in the South Australian reaches of the Murray River to confirm their continued absence. In the New South Wales reaches of the Murray River, McCarthy (2005) reported a lack of Murray crayfish downstream of Mildura and greater abundances upstream of the Wakool River junction.

Recreational fishers reported declines in the distribution of Murray crayfish in the lower Murrumbidgee River following construction of Maude and Redbank Weirs and the Coleambally Irrigation system, and also reported declines in the Edwards, Wakool and Niemur Rivers (O’Connor, 1986). Also presumably based on recreational fisher reports, Pollard *et al.* (1980) and Geddes (1990) stated that Murray crayfish had vanished from considerable stretches of the Murrumbidgee and Murray Rivers since 1940. However, no primary data exist to substantiate these claims.

In 1988–89, Lintermans and Rutzou (1991) found evidence of Murray crayfish at ten of the thirteen sites sampled (77%) in the main channel of the Murrumbidgee River within the Australian Capital Territory. Murray crayfish have also been reported in the lower reaches of the Cotter River (Morgan 1986; Lintermans and Rutzou 1991), and Paddy's River (Lintermans 2002).

Murray crayfish remain present in Victorian tributaries of the upper Murray and in the Kiewa, Ovens and Goulburn catchments (Raadik *et al.* 2001). They are most widespread below altitudes of 300 m, with the proportion of sites at which they are found declining with altitude (Figure 7).

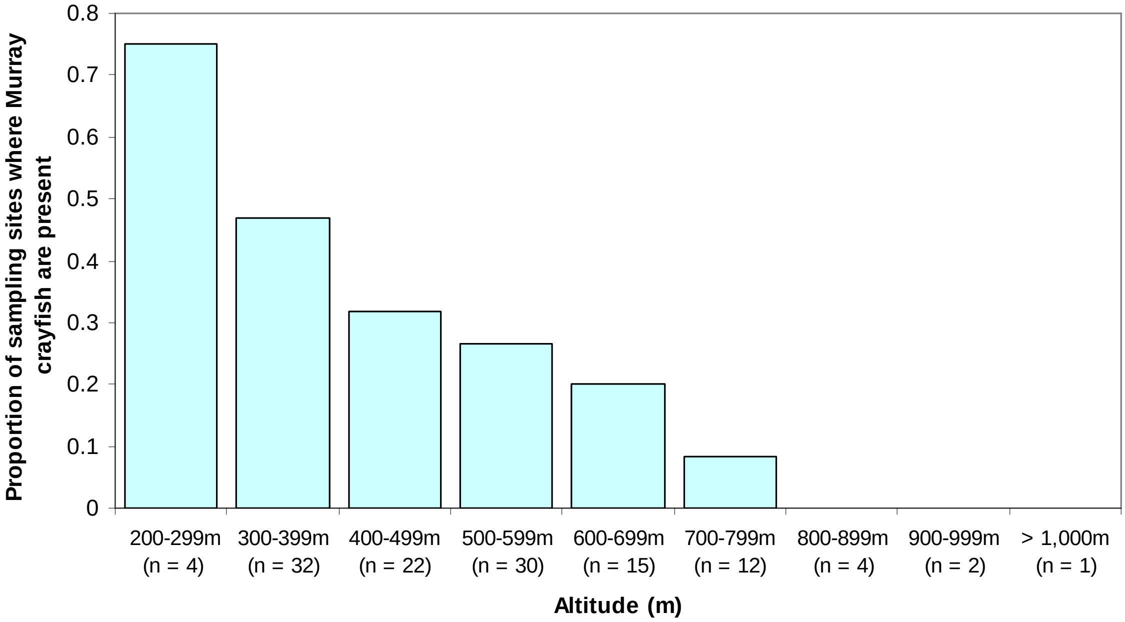

Figure 7. The proportion of Victorian sites sampled by Raadik *et al.* (2001) where Murray crayfish were present, presented at 100 m altitude intervals.

Despite the documented translocations of Murray crayfish at numerous locations in New South Wales (Table 1), and reports of recruitment in at least one of these populations (young Murray crayfish were collected at Dundee, near Inverell in 1922 – O'Connor (1986)). Only the population in the Kandos area is known to have persisted. However, no widespread sampling has been undertaken to confirm this. Although no translocations were referred to in NSW State Fisheries annual reports subsequent to 1926, O'Connor (1986) stated that translocations continued up until at least the 1980s and Lintermans (2000) reports that illegal translocations are still occurring in urban lakes and ponds in the Australian Capital Territory. Therefore, it is possible that Murray crayfish are now present in other waterways outside of their natural range. However, a lack of systematic surveys for freshwater crayfishes in Australia precludes all but inadvertent detection of Murray crayfish during sampling for other purposes, as was the case for those individuals recently discovered in the Lachlan catchment (Figure 6).

Table 1. Documented translocations of Murray crayfish reported in NSW State Fisheries Annual reports in the early 1900s (as reported by O'Connor, 1986).

Year	Release Location	Catchment	Number translocated
1914	Inverell region	Border Rivers	161
1920	Lake Burrinjuck	Murrumbidgee	400
1921	Lake Burrinjuck	Murrumbidgee	300
1921	Unknown	Macquarie	25
1921	Unknown	Gwydir	25
1923	Lake Burrinjuck	Murrumbidgee	303
1923	Unknown	Macquarie	25
1925	Lake Burrinjuck	Murrumbidgee	250
1925	Wambool	Macquarie	25
1925	Bathurst	Macquarie	25
1926	Lake Burrinjuck	Murrumbidgee	280

3.5. Population genetics

Two studies have assessed the population genetics of Murray crayfish. The first was an allozyme study by Geddes *et al.* (1993) analysing 40 loci from samples from the Murrumbidgee (Narrandera), Murray (Albury) and Ovens (Beechworth) catchments. The second was a mitochondrial DNA sequence comparison (COII/COIII genes) of samples from the Goulburn (Seymour), King, Ovens, Murray (Albury), Upper Murray (Koetong, Hinces and Tumbarumba Creeks) and Murrumbidgee (Blowering Dam) catchments (Versteegen and Lawler, 1996). Geddes *et al.* (1993) indicated that crayfish in the Murray and Murrumbidgee rivers were almost genetically identical, and there were only minor differences in the Ovens catchment. Similarly, Versteegen and Lawler (1996) demonstrated that mitochondrial haplotypes were linked in populations separated by long river distances, such as the upper Murray and Goulburn, upper Murray (Koetong Creek) and Ovens, and the Murrumbidgee and King. These unexpected findings are counter to those from studies of the Australian yabby (*Cherax destructor*), where significant population genetic differences exist between catchments (Hughes and Hillyer 2003).

The non-significant differences in allozyme data observed by Geddes *et al.* (1993) could be attributed to lack of statistical power due to small sample size. However, the mitochondrial DNA data of Versteegen and Lawler (1996) are independent of sample size, yet still suggest no significant variation.

Low levels of genetic differentiation across a widespread population are indicative of substantial gene flow between populations (needs a reference). Gene flow can arise naturally through widespread dispersal or artificially through translocation. Available data suggest that dispersal rates of adult Murray crayfish are very low (O'Connor, 1986: See section 3.8). Therefore, adult dispersal is unlikely to have lead to the observed level of gene flow between catchments. However, larval or juvenile dispersal, which has never been quantified, may facilitate the widespread gene flow in Murray crayfish.

Translocation of freshwater crayfish between river catchments has been shown to reduce genetic variation in Hairy marron (*Cherax tenuimanus*) (Nguyen *et al.*, 2002). Despite the translocation of Murray crayfish into many waterways outside their natural range (Table 1), the only reported translocations within areas of their natural range (those that would result in gene flow between populations) were into Lake Burrinjuck (Table 1), lakes within the Australian Capital Territory (Lintermans 2002) and the Yass River (Lintermans 2002), all within the Murrumbidgee catchment.

However O'Connor (1986) stated that subsequent translocations "continued unabated" up until the 1980s, with translocations from the middle reaches of the Murray and Murrumbidgee Rivers into the Edwards and Wakool Rivers, and lower reaches of the Murray and Murrumbidgee. Murray crayfish are still being translocated within their historic range in the upper Murrumbidgee, with individuals regularly recorded in suburban areas of the Australian Capital Territory. Therefore, translocation is potentially a more parsimonious explanation than natural dispersal, and more likely to be responsible for the observed genetic population structure. However, counter to this hypothesis is that populations in New South Wales and Victoria were genetically similar, yet authorised translocations between New South Wales and Victorian waterways are unlikely to have occurred. Therefore, the potential for translocation to result in the observed genetic similarities is still poor.

3.6. Anatomy and sense perception

Ache and Sandeman (1980) studied the innervation of the antennules, their chemo-sensory role and the relationship with feeding behaviours. Sandeman and Wilkens (1982) studied the audible 'hiss' produced by *Euastacus* crayfishes. This sound is produced by stridulation of bristles on the abdominal tergites when individuals adopt the aggressive/defensive posture characteristics of crayfishes. The hissing behaviour is hypothesised to be either a predator deterrent or for aggressive interactions between individual crayfish. However, little evidence to support either hypothesis is available. Lastly, Sandeman and Wilkens (1983) studied the innervation and musculature of the antennae. The antennae act as waterborne vibration-sensitive organs, as effectors in defence and in tactile communications between individuals (Sandeman and Wilkens 1983).

3.7. Habitat

3.7.1. Meso-habitat and micro-habitat

Limited knowledge exists of the micro-habitat preferences of Murray crayfish. However, given its widespread distribution, its existence in both large and small streams, ranging from pasture-lands to sclerophyll forests (Morgan 1986; Horwitz 1990a), and particularly its broad altitudinal range, it appears that Murray crayfish are tolerant of a variety of in-stream habitats.

The Royal Commission into the prospects of Fisheries in New South Wales (1880) noted that Murray crayfish were "found chiefly near clay banks" and "in deep water". These statements are supported by observations of O'Connor (1986). Murray crayfish build and use burrows within the riverbank for shelter (Horwitz and Richardson 1986), often beneath rocks or logs (Morgan 1986). The burrows are rarely more than one metre long and may have up to six entrances (Johnson and Barlow 1982). At higher altitudes, where geomorphology of riverbanks may not be conducive to burrowing, Murray crayfish will shelter in rock crevices, snags or other structure (ACT Government 1999). During scuba diver observations at Khancoban Pondage, approximately 90 % of Murray crayfish were observed sheltered among snags along banks (O'Connor, 1986).

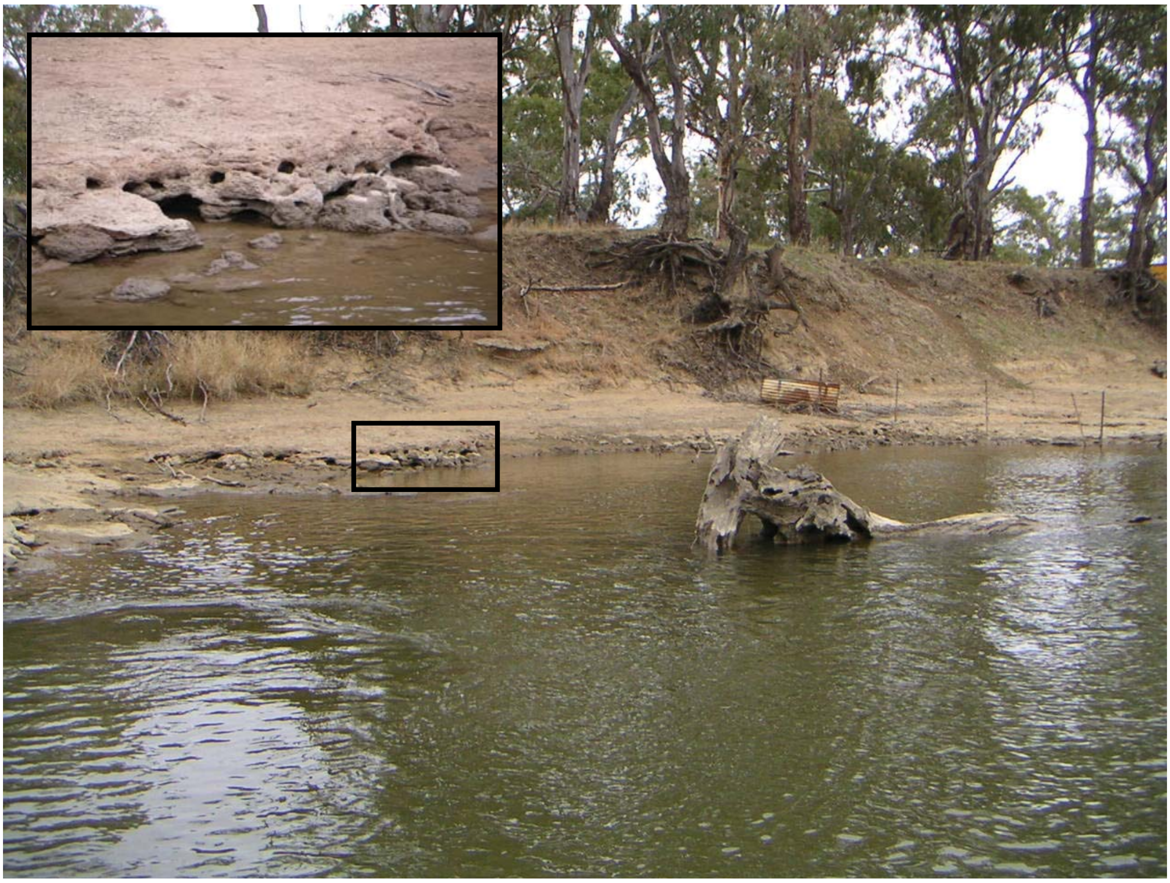

Figure 8. Murray crayfish burrows in a clay bank exposed by low flows in the Murrumbidgee River near Narrandera. Photo: Dean Gilligan.

Flow also appears to be an important habitat parameter for Murray crayfish. In a recent study within the Murray River between Nyah and the New South Wales – South Australian border, Murray crayfish were present in five of the six flowing riverine reaches sampled (83%), and in none of the six weir-pool sites (McCarthy 2005). This supports the hypothesis of Walker (2001), who attributed the disappearance of Murray crayfish from the lower Murray River to the construction of weirs and subsequent river regulation. This has transformed the lower Murray River into a continuous series of weir-pools, where hydrology, hydraulics, sedimentation rates and bio-film composition are all altered from the natural riverine state (Walker and Thoms 1993; McCarthy *et al.* 2004). Local flow velocity variation within riverine reaches also appears to be important, as all Murray crayfish sampled by McCarthy (2005) in the lower Murray River downstream of the Wakool River junction, were captured on outside bends where flow velocities were highest.

Although Murray crayfish do persist in large dams and impoundments in the upper Murray and Murrumbidgee catchments, they are reported to have a preference for submerged river channels within these lentic environments (O'Connor, 1986). In the upper reaches of the Murrumbidgee, recent radio-telemetry assessments of Murray crayfish indicated that home ranges encompassed both bank and midstream habitats and that most home ranges existed in the middle or upstream reaches of pools (Ryan 2005).

Scuba diver observation at Khancoban (O'Connor, 1986) and observations in small order streams (Morgan 1986) identified social hierarchies within Murray crayfish populations, with larger individuals restricting the localised distribution of juveniles. At Khancoban, juveniles 6 – 40 mm OCL were only found under rocks and were not found in open areas where adults were sampled (O'Connor, 1986). In smaller order tributary streams, Morgan (1986) reported that adults inhabit deeper holes and smaller crayfish are found under rocks in shallow areas. Merrick (1998) also reported possible size segregation, related to habitat in the Sydney spiny crayfish (*Euastacus spinifer*), with juveniles using littoral shallows to a larger extent than adults.

3.7.2. Environmental tolerances

Geddes *et al.* (1993) provide the only published assessment of environmental tolerances of Murray crayfish. Murray crayfish have long-term tolerances to temperatures as high as 27°C, dissolved oxygen as low as 3 mg l^{-1} and salinities less than 16 parts per thousand (Geddes *et al.* 1993). Geddes *et al.* (1993) recorded LD_{50}s (the point at which 50% of a sample dies due to treatment) for dissolved oxygen and temperature of 2.2 mg l^{-1} and 30°C respectively. Thirty-three percent mortality was observed at a salinity of 16 parts per thousand (Geddes *et al.* 1993).

In cage experiments in the lower Murray River, 100% of crayfish survived from July through to November, but only 63% survived the summer period from November through to the following June (excluding crayfish which were stolen or retrieved) (Geddes *et al.* 1993). Two of the three crayfish that died were within the Lock 3 weir pool, where the flow was 0.02 m s^{-1} as opposed to 0.31 and 0.38 m s^{-1} at the two sites where crayfish survived (Geddes *et al.*, 1993).

Intolerance of low dissolved oxygen concentrations was supported by observations of Murray crayfish leaving the water (crawling onto river banks or snags) when dissolved oxygen concentrations fell to 1.8 mg/L^{-1} during a black water event in the Barmah-Millewa Forest (McKinnon 1995).

Crustaceans are among the aquatic organisms most sensitive to pollutants and pesticides, with crayfishes being particularly sensitive (Carson 1962; France and Collins 1993; Davies *et al.* 1994; ANZECC and ARMCANZ 2000; Radcliffe 2002). However, no data are available on the tolerance or lethal thresholds for agricultural chemicals and pesticides on Murray crayfish (or any other species of *Euastacus*). However, Horwitz (1994b) considered the discharge of nutrients and application of pesticides to possibly contribute to the reduced population densities of the Tasmanian giant freshwater crayfish in northern Tasmania.

3.8. Diet

No known dietary studies of Murray crayfish have been conducted. In general, freshwater crayfish are highly opportunistic feeders (Suter and Richardson 1977). Morgan (1986), Merrick (1993) and McCarthy (2005) suggest that adult Murray crayfish are detritivorous, consuming rotting wood and leaf litter. As fish or other animal meat is most often used to bait nets and traps when targeting Murray crayfish, it can be presumed that dead animal carcases are also consumed when available.

Although no studies provide specific data for Murray crayfish, they are likely to be polytrophic (occupying multiple trophic levels by acting as both invertebrate predators and as detritivores). This is regularly reported for other freshwater crayfish species (Lodge *et al.* 1994; Hiller and Lodge 1995; Turvey and Merrick 1997c; Nyström 2001; Parkyn *et al.* 2001).

Cannibalism within high-density crayfish populations has been reported, resulting in density-dependent effects on population size and structure (Turvey and Merrick 1997b; Nyström 2001). Cannibalism in crayfish is most apparent when food availability is scarce (Nyström 2001). No primary data demonstrating cannibalism in Murray crayfish is published.

3.9. Movement, migration and diel activity

O'Connor (1986) individually tagged 4,170 Murray crayfish over a 3-year period in the Murrumbidgee River. Of 188 recaptures, only 25 individual movements greater than 1 km were recorded. These 'long-range' movements ranged from 1 km to 14 km, with an average (± SE) of 3.5 ± 0.61 km (O'Connor, 1986). Most of the remaining 163 recaptured individuals were collected within a few metres of their tagging location (O'Connor, 1986). These data suggest that adult Murray crayfish have very low dispersal abilities and occupy small home ranges.

In the upper Murrumbidgee, Ryan (2005) documented average home range size of 1,800 – 2,000 m^2, but the average core activity area was only 370 m^2. However, there was substantial variability in the home range size of individual crayfish. Daily movements ranged within areas of between 0 – 938 m^2 (mean 160 m^2) and over distances of 0 – 220 m (mean 82 m). Home ranges often overlapped with other individuals.

Although freshwater crayfish species are generally primarily nocturnal (Morrissy 1970; Turvey 1980; Vanninni and Cannicci 1995) or crepuscular (Barbaresi and Gherardi 2001) and there are anecdotal reports of increased nocturnal activity in Murray crayfish (Lawler, pers. comm.). However, Murray crayfish in the upper Murrumbidgee River exhibited no diel differences in activity (Ryan 2005). This was similar to the Tasmanian giant freshwater crayfish, where activity was also unrelated to diel period (Webb and Richardson 2004). In the study of Ryan (2005), some Murray crayfish individuals were inactive for entire 25 hour sampling periods.

Murray crayfish are most active in the cooler part of the year from May to October when water temperature is 8 – 20°C (O'Connor, 1986). However, Asmus (1999) found no significant difference in any population parameters when comparing data collected in June/July with that collected in November. Ryan (2005) also found no evidence for changes in activity patterns between autumn and winter, however her study was conducted entirely within the May to October period of peak activity identified by O'Connor, so no differences would have been expected.

O'Connor (1986) observed that immigration/emigration was negligible for crayfish larger than 90 mm OCL, but progressively more important in 80 – 89 mm and 70 – 79 mm size classes. However, Ryan (2005) did not observe a relationship between activity and size during this peak immigration/emigration period despite her study animals ranging in size from 47 –110 mm (Ryan 2005).

O'Connor (1986) reported that a number of 'foraging movements' were detected in the lower Murrumbidgee, where recreational fishers recorded the capture of tagged individuals up to 1 km from the tagging site. Following release, these individuals were subsequently recaptured at the original tagging site (O'Connor, 1986).

Ryan (2005) observed that males move greater distances over a 24 hour period than females (males averaged 89 m versus females 17 m), whilst O'Connor (1986) found no evidence of different movement patterns between the sexes.

The movement/migration patterns of juveniles (< 40 mm OCL) are unknown. However, the segregation of small and large crayfish into smaller order tributary streams and large lowland waterways respectively (see section 3.11.7) is suggestive of a population-wide migrations. This could result from juvenile crayfish undertaking upstream migrations into tributary streams, with subsequent downstream migrations into larger waterways at larger sizes.

3.10. Diseases and Parasites

None of the major field studies of Murray crayfish (Johnson and Barlow 1982; O'Connor 1986; Morison 1988; Barker 1992; Gehrke 1992; Asmus 1999; McCarthy 2005; Ryan 2005) have reported the presence of ectoparasites or disease. However, Morgan (1986) identified a Murray crayfish specimen from the Murrumbidgee River that was affected by a sponge infection of the thorax. Further, one of the authors (John Merrick) has observed Murray crayfish suffering from a *Saprolegnia* fungal infection.

Australian freshwater crayfish, including Murray crayfish, are hosts to ectosymbiotic turbellarian worms of the temnocephalan family (Sewell and Cannon 1998), which live either externally or within the branchial chambers (Merrick 1993). At least six species of temnocephalans are known to rely on Murray crayfish as hosts (Sewell *et al.* 2006). A parasitic mite *Astasocroton* was reported by Haswell (1922).

The epidemiology of the crayfish plague disease (Söderhäll and Cerenius 1999) endemic to North America, and decimating populations of native crayfish in Europe (Söderhäll and Cerenius 1999) has been assessed in three species of *Euastacus*, but not in Murray crayfish (Unestam 1975). Unestam (1975) suggested that all species of *Euastacus* are likely to be highly susceptible. Crayfish plague disease is not present in Australia, and therefore imports of any crayfish from the Northern Hemisphere should be prevented in order to ensure that crayfish plague disease does not invade.

3.11. Population Biology

3.11.1. Reproduction and recruitment

3.11.1.1. Mating season

Mating activity of Murray crayfish in the Murrumbidgee River at Narrandera takes place in a brief period in early to mid May, at temperatures of 12 – 15^{o}C, and by late May virtually all sexually mature females have mated (are carrying eggs) (O'Connor, 1986). However, a specific temperature or photoperiod cue is unlikely to be the stimulus for mating across the species range, as mating in Khancoban Pondage occurred at temperatures of 6 – 7 ^{o}C in June (O'Connor, 1986). O'Connor (1986) hypothesised that mating is most likely to be cued by a rapid decline in water temperature.

Reproductive condition of males (as identified by fortnightly calculation of the gonado-somatic index and histological examination of the testes and vas deferens) peaked in the period between April and May (O'Connor, 1986). The observation that some males bore spermatophores into July lead him to hypothesise that either not all males mated, or that males were capable of repetitive mating within the breeding season.

3.11.1.2. Fecundity

Using data from 17 female Murray crayfish sampled from the Murrumbidgee River (with between 300 and 1,495 eggs), Johnson and Barlow (1982) produced the following linear length – fecundity equation (R^2 = 0.848, p <0.001):

Fecundity = 25.9 x OCL (mm) – 1810

O'Connor (1986) also measured fecundity of a sample of 26 female Murray crayfish (between 74 and 120 mm OCL) from the Murrumbidgee River and produced a curvilinear length-fecundity equation (R^2 = 0.88):

$$ln\ (\text{Fecundity}) = -13.355 + 4.339\ [ln\ (\text{OCL(mm)})]$$

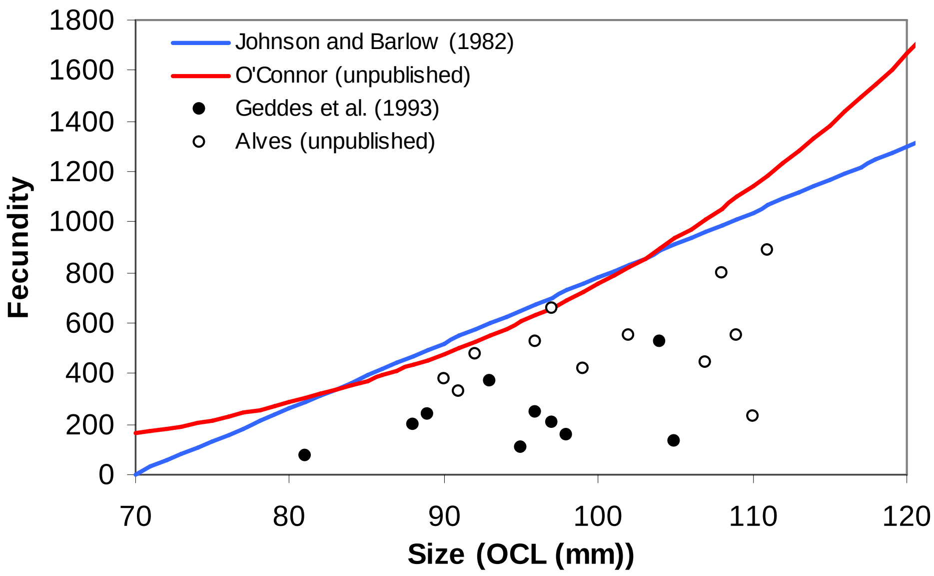

Figure 9. Modelled fecundity and the number of stage 3 juveniles produced by Murray crayfish based on female size. Blue line – model developed by Johnson and Barlow (1982) (n = 17), red line – model developed by O'Connor (n = 26), black dots – number of stage 3 juveniles produced by females of various sizes under captive conditions from Geddes *et al.* (1993), white dots – number of stage 3 juveniles produced by females of various sizes under captive conditions from (Alves, unpublished data).

This fecundity is similar to that reported for other large *Euastacus* species, where fecundities of between 1,000 and 1,200 in Gippsland spiny crayfish (*Euastacus kershawi*) (Clark 1937), 268 and 779 in Sydney spiny crayfish (Turvey and Merrick 1997a) and 63 and 812 in Glenelg spiny crayfish (*Euastacus bispinosus*) (Honan and Mitchell 1995c) have been recorded. In the later two species, fecundity also increased with size (Honan and Mitcell 1995c; Turvey and Merrick 1997a).

3.11.1.3. Incubation and development

Following fertilisation, eggs are attached to the pleopods (swimmerets) under the abdomen of the females (Figure 10), with those females carrying eggs referred to as 'berried'. In the Murrumbidgee River, eggs hatch in late September to early October after an incubation of ~ 20 weeks (140 days) (O'Connor, 1986). This is consistent with the Glenelg spiny crayfish, where incubation also takes around 140 days (Honan and Mitchell 1995c) and the Sydney spiny crayfish, where incubation takes 112–140 days (Merrick 1998).

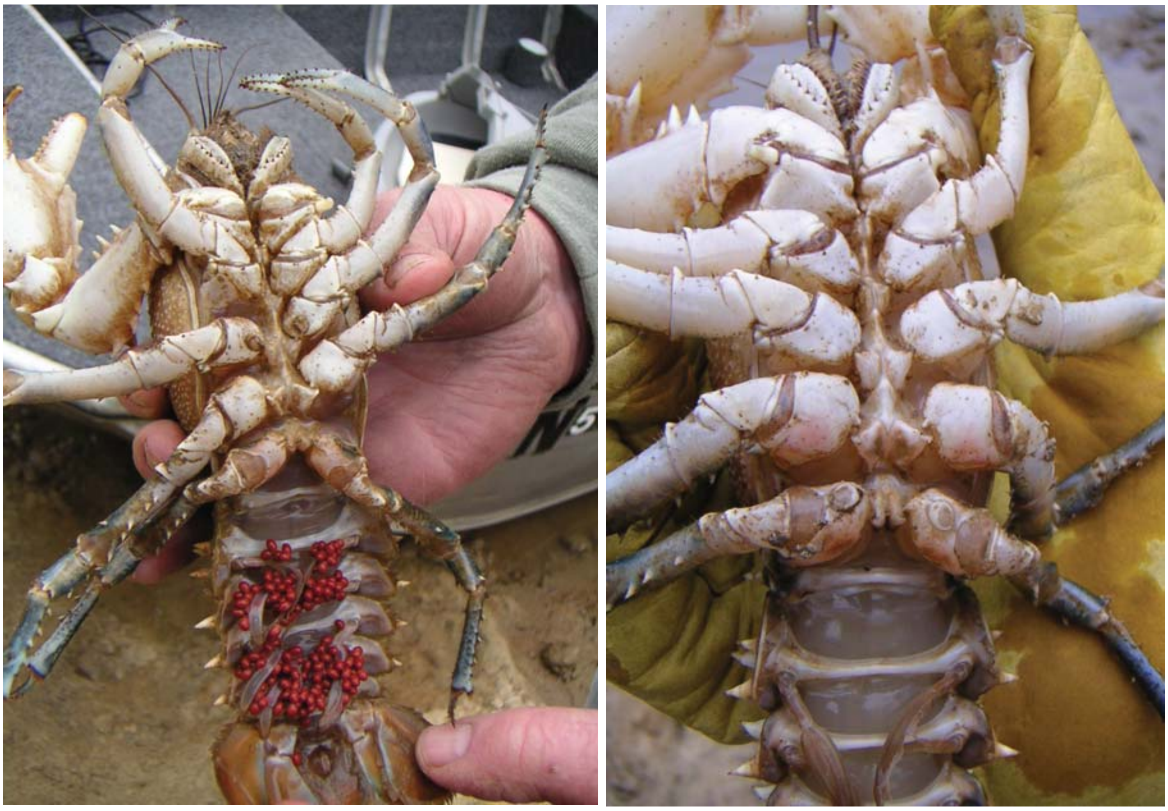

Figure 10. Ventral view of a berried female (left) and male (right) Murray crayfish. Females have gonopores located on the base of the 3rd (middle) pair of pereiopods and males have genital papillae located on the base of the 5th (last) pair of pereiopods. Eggs are attached to the pleopods (swimmerets) under the abdomen of females (right). Photo: Dean Gilligan.

Data from Khancoban pondage differ from those collected in the Murrumbidgee in that only 40.6% of mature females were berried (O'Connor, 1986). Further, the pleopod egg counts of females in Khancoban pondage were lower than those in the Murrumbidgee River in 19.5% of females. This suggests that either fertilisation was less effective, or that egg mortality is greater in Khancoban Pondage (O'Connor, 1986). These data suggest that perhaps Khancoban pondage provides only marginal quality habitat for Murray crayfish reproduction.

Like other species of *Euastacus* studied (Clark 1937; Turvey and Merrick 1997a; Honan 1998), stage 1 (Figure 11) and stage 2 (Figure 12) Murray crayfish juveniles remain attached to the mothers pleopods by the fourth and fifth pairs of pereiopods until they have proceeded through two moults (O'Connor 1986; Geddes *et al.* 1993), each at fortnightly intervals (Geddes *et al*. 1993). Stage 3 juveniles (Figure 13) then become independent at ~ 6.0 mm OCL (O'Connor, 1986; Geddes *et al.* 1993). However, embryonic development times are highly temperature dependent (O'Connor, 1986). O'Connor (1986) reported that development took approximately two months longer in Khancoban pondage (temperature 1 – 14^{o}C) than in the Murrumbidgee (temperature 6 – 20 ^{o}C). Further, in heated aquaria trials, development took only two months at 20^{o}C, four months at 14^{o}C and five months at ambient temperature (6 – 20 ^{o}C) (O'Connor 1986).

Figure 11. Stage 1 Murray crayfish larva. Photo: Vanessa Carracher.

Figure 12. Stage 2 Murray crayfish larva. Photo: Vanessa Carracher.

Figure 13. Stage 3 Murray crayfish juveniles. Photo: Vanessa Carracher.

Figure 14. Four month old Murray crayfish juveniles. Photo: Matthew McCready.

3.11.1.4. Recruitment

No studies have examined the factors affecting recruitment success in wild Murray crayfish populations. However, under captive conditions, Geddes *et al.* (1993) recorded the number of stage 3 juveniles produced by each of 11 wild-caught berried female Murray crayfish (Figure 9). Geddes *et al.* (1993) estimated that mortality to stage 3 was around ~ 50%, but never actually counted the eggs. The number of stage 3 juveniles produced was 35% ± 0.05 % and 36% ± 0.05% of the fecundity predicted by the Barlow and Johnson and O'Connor models respectively. Therefore, we suggest that mortality from the egg until independence is around 65% under captive conditions. Clark (1937) also referred to high mortalities of stage 1 and stage 2 juveniles in Gippsland spiny crayfish. Geddes *et al.* (1993) reported that post-stage 3 mortalities under captive conditions were 31 – 41 % up until 1.5 years of age.

In the wild, survival of young Sydney spiny crayfish is suggested to be strongly influenced by predatory fish (Turvey and Merrick 1997b). However, Hogger (1988) suggested that the carrying capacity of habitat was more important in controlling population sizes of crayfish than the level of predation. For instance, variation in riparian land use surrounding shallow streams is believed to influence recruitment of New Zealand crayfish (*Paranephrops planifrons*) (Parkyn *et al.* 2002).

3.11.2. Age and growth

Like all crustaceans, Murray crayfish grow sequentially through a series of moults. They do not retain any permanent hard or bony structures capable of providing estimates of age (such as otoliths in fish). Therefore, there is no means to determine the number of moults through which an individual has passed at any one point in time, or its total age.

O'Connor (1986) used fortnightly sampling data from the Murrumbidgee and data from 815 recaptured tagged individuals in the Murrumbidgee River, the Murray River at Corowa and Khancoban pondage, as well as a sample of 78 pond-reared and seven wild 0+ Murray crayfish (collected either by hand or in the stomachs of fish from the Murrumbidgee) to develop moult frequency and moult increment models for Murray crayfish. The moult frequency is the period of time between moulting events. The moult increment is the change in body size at any one moulting event. When combined, the moult frequency and moult increment data allow for the development of a size at age model for crustaceans (Honan and Mitchell 1995b; Turvey and Merrick 1997d, e).

3.11.2.1. Moult frequency

In Murray crayfish, the frequency of moulting is size dependent, but relatively invariable for individuals of the same size and between sexes (O'Connor, 1986). Murray crayfish become independent of their mother at an average size of 6.0 mm OCL (O'Connor, 1986; Geddes *et al.* 1993). Data from pond-reared and wild caught 0+ crayfish suggest an average size of 21.3 mm OCL at one year of age (O'Connor, 1986). Given that the growth factor (the growth increment expressed as a percentage of pre-moult size) is assumed to be constant (at 13.20%) in Murray crayfish between 6 – 75 mm OCL (see section 3.10.2.2), growth from 6.0 mm to 21.3 mm in the first year of life was estimated to require a series of 10 moults. This is consistent with observations in the Glenelg Spiny crayfish where juveniles moulted 11 – 12 times in their first year to also reach a size of ~ 20 mm (Honan and Mitchell 1995b).

No data exist for Murray crayfish in the size range of 20 – 35 mm. However, both Sydney spiny crayfish (Turvey and Merrick1997d) and Glenelg spiny crayfish (Honan and Mitchell 1995b) between 20 – 35 mm OCL moult on average three times per annum. Given the general similarities of these two species with Murray crayfish, O'Connor (1986) assumed an equivalent moult frequency for Murray crayfish of similar size.

From 35 – 60 mm OCL, O'Connor (1986) recorded an average of two moults per annum. The first in late November – early December and the second in late April – early May. Similarly, Honan and Mitchell (1995b) and Turvey and Merrick (1997d) observed biennial moults for sub-adult Glenelg spiny crayfish (~ 50 mm) and Sydney spiny crayfish (~55 mm) respectively.

Once above 60 mm OCL, moulting in the Murrumbidgee River is highly synchronised for the entire population, occurring annually in late April – early May (O'Connor, 1986). Similarly, Geddes *et al.* (1993) observed all five of their caged Murray crayfish in the Lower Murray River moulting between 6 April and 8 May and Lintermans (unpublished) (n = 10) has recorded captive adult Murray crayfish from the upper Murrumbidgee moulting in mid-February (n = 1) and April (n = 9). Therefore, this moult period appears consistent throughout the species range.

Turvey and Merrick (1997d) observed a similar moult frequency pattern in Sydney spiny crayfish. In contrast, although adult Glenelg spiny crayfish also moult only once per year, this species has an extended moulting season between late spring and late autumn (Honan and Mitchell 1995b).

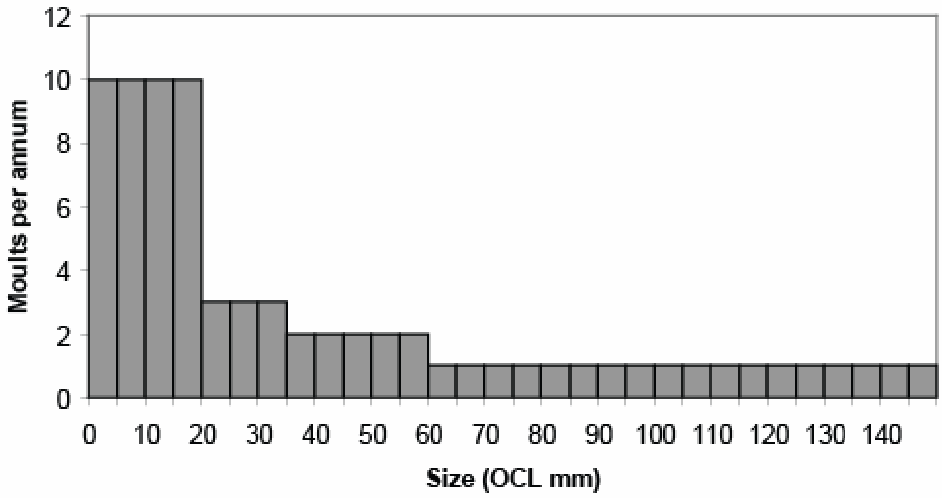

Figure 15. The relationship between moult frequency (number of moults per annum) and size in Murray crayfish as reported by O'Connor (1986).

3.11.2.2. Moult increment

In contrast to moult frequency, moult increment is much more variable between individuals and can be affected by size, sex, injuries, year, temperature, diet, food availability and location (O'Connor, 1986; Turvey and Merrick 1997b). Multiple regression analyses undertaken by O'Connor (1986) found that moult increment was most significantly and consistently affected by size and the presence of injuries (O'Connor, 1986) but the model only explained 33 – 46 % of variance in moult increment. A second example of variability in growth found that under captive conditions, growth and survivorship of juvenile Murray crayfish at low (10 individuals per m^2) and high (50 individuals per m^2) densities was density-dependent, suggesting that competition for food or space occurs at these densities under captive conditions (Geddes *et al.* 1993), presumably arising through declines in the growth increment of individuals in the high density population.

In general, moult increment did not differ consistently between sexes in Murray crayfish (O'Connor, 1986). The only significant sex related difference observed by O'Connor (1986) was that small (<75 mm OCL) females grew faster than small males at one of three Murrumbidgee sites. There were no significant differences between sexually mature male and female Murray crayfish. This is in contrast to most reports of sexual differences in growth of other large freshwater crayfish species, where mature females divert energy to egg production as opposed to growth and therefore grow more slowly than mature males. However, the growth rates of immature crayfish do not differ (Woodland 1967; Morrissy 1975; Reynolds 1980; McKoy 1985; Lowery 1988; Sokol 1988; Turvey and Merrick 1997e).

In addition to variability in growth increment between individuals, O'Connor (1986) reported that consecutive growth increments between moults in the same individual were also variable with few data suggesting that individual crayfish can be either consistently fast or slow growing and the mean growth increment over consecutive moults tending towards the population mean (O'Connor 1986).

After eliminating injured individuals from the data-set, and ignoring those variables that were not found to be significantly related to moult increment (sex, year and location), O'Connor (1986) tested three alternative moult increment at size models (see Figure 16). He concluded that the three models provided relatively consistent results within the size range sampled, although they diverged substantially towards the tails of the distribution where data were scarce (Figure 16). He suggested that the two-phase models (A and C) best reflect patterns in the raw data, but neither model was better than the other. This suggested that it did not matter which moult increment model was used to develop the 'size at age' relationship, and also that given their general consistency, confidence could be placed in the validity of the age estimates obtained. The mean growth factor across the size range actually sampled, ranged from 12.43 – 14.08% in different locations (O'Connor 1986). This is slightly higher than in Sydney spiny crayfish which was 11% (Turvey 1980).

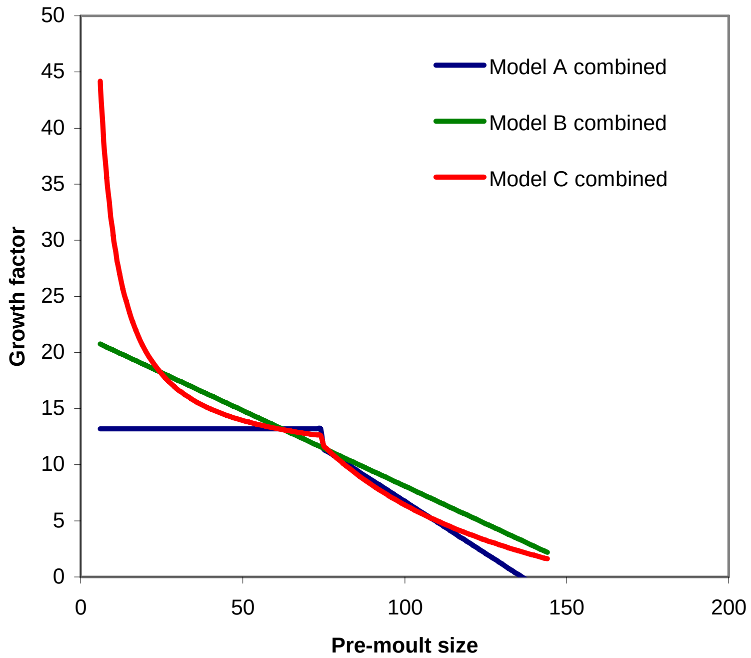

Figure 16. The relationship between moult increment (expressed as growth factor – the moult increment expressed as a proportion of pre-moult size) and pre-moult size for the three models tested by O'Connor (1986). Model A was a two-phase model that produced a separate linear regression for those individuals less than and greater than 75 mm OCL. Model B was a single-phase model producing a single linear regression over the entire size range. Model C was equivalent to model A, but used actual moult increment data rather than growth factor.

The accuracies of the moult increment models were tested against data collected from tagged and recaptured crayfish known to have progressed through either 2 (n = 157) or 3 (n = 17) moults. The models were found to accurately predict the observed growth rates over several moults (O'Connor, 1986). Growth factors of small crayfish in the Murrumbidgee and Murray Rivers were similar (13.20 ± 2.72 and 13.70 ± 2.84 respectively), but the growth rate in Khancoban pondage was approximately a third of these (4.96 ± 1.41) (O'Connor, 1986). Slower growth rates at Khancoban are likely to be a result of the lower mean temperature of that waterway, again suggesting that Khancoban pondage provides marginal habitat for the species.

3.11.2.3. Size at age

O'Connor (1986) estimated the parameters required for von Bertalanffy growth models from three populations of Murray crayfish (Table 2) and used the following formula to create length-at-age models for each population:

$$L_t = L_\infty\,(1 - \{e^{[-K(t-to)]}\})$$

Table 2. von Bertalanffy model parameters for maximum length (L_∞) and growth constants K and to provided by O'Connor (1986) for three wild populations of Murray crayfish from the Murrumbidgee River (Narrandera), the Murray River (Corowa) and Khancoban pondage.

Parameter	Murrumbidgee	Murray	Khancoban	Mean
L_∞	159.5	192.8	157.9	170.0667
K	0.0904	0.0843	0.1052	0.0933
to	-0.4242	-0.3752	-0.3682	-0.3892

Given the sizes of the largest individuals collected at three sites in the Murrumbidgee (sites 2 = 124 mm, 5 = 142 mm and 7 = 147 mm), O'Connor (1986) suggested that the maximum age of Murray crayfish was 20 – 25 years based on these 'size at age' growth curves (Figure 17). However, the largest Murray crayfish ever recorded, 174 mm OCL in the Ovens River (Morison 1988), is larger than the assumed maximum lengths (L_∞) for all but the Murray River growth model. The estimated age of this individual using the Murray model was 28 years.

3.11.3. Length-weight relationships

A number of length-weight equations have been calculated for Murray crayfish. Johnson and Barlow (1982) provide the following equation (R^2 = 0.982, n = 371):
Weight (g) = 5.5 * (10^{-4} x OCL (mm) $^{2.97}$)

McCarthy (2005) gives this equation (R^2= 0.9642, n = 340):
Weight (g) = 0.0014 * OCL (mm) $^{2.7702}$

Ryan (2005) gives the equation (R^2 = 0.9766, n = 28):
Weight (g) = 0.0963 * OCL $(mm)^2$ – 5.4993 * OCL (mm) +100.74

The model of Johnson and Barlow (1982) has the greatest coefficient of determination at
R^2 = 0.982 and is also based on the largest sample size.

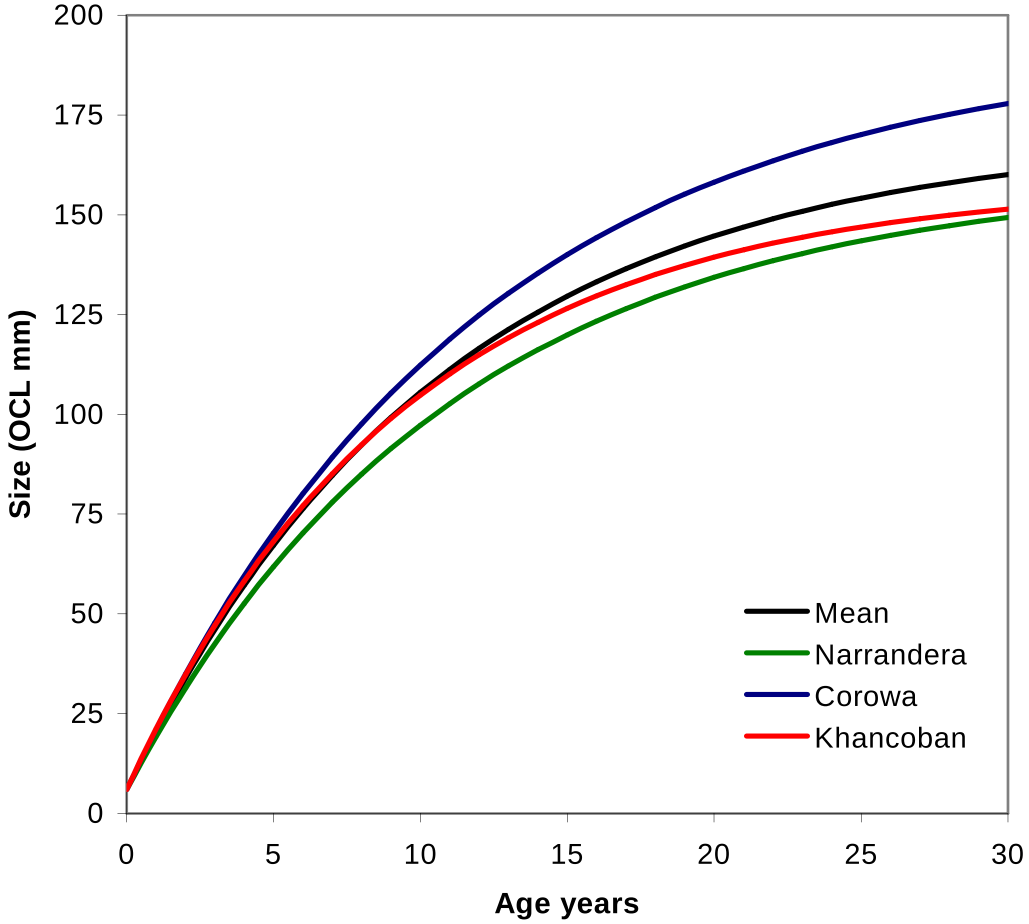

Figure 17. Size at age models developed for Murray crayfish using von Bertalanffy parameters collected by O'Connor (1986) from Murray crayfish populations from the Murrumbidgee River (Narrandera), the Murray River (Corowa) and Khancoban pondage (Table 2).

3.11.4. OCL – claw (propodus) length relationships

Lintermans and Rutzou (1991) also observed that the length of the claws (propodus) of Murray crayfish are strongly correlated to OCL (R^2 = 0.986, n =10, p <0.00 01).

OCL = 7.324 + 0.925 x propodus length

Lintermans and Rutzou (1991) used this model to estimate the size (OCL) of individuals from exoskeleton remains left by predators such as water rats. However, a limitation of using claw length as a proxy for OCL is that when claws are lost and then regrow, the OCL-claw length relationship would not apply.

3.11.5. Maturity

Most authors have assigned females to a sexual maturity stage using the criteria of Turvey and Merrick (1997a) (see Figure 18 for photographs):

- Stage 1 (immature) – calcified gonopore plates with no encircling setae.
- Stage 2 (immature but will mature at next moult) – partially or completely calcified gonopore plates partly encircled by short sparse setae.
- Stage 3 (mature) – uncalcified gonopore plates and gonopores completely encircled by dense, long and matted setae.

Size at first maturity (stage 3) of female Murray crayfish ranges from a minimum of 40 mm (Morgan 1986) to a maximum of 105 mm (O'Connor, 1986). However, mature individuals in the 40 – 80 mm size range were only collected from smaller streams (the Cotter and Howqua Rivers) (Morgan 1986) and from colder areas (Khancoban pondage) (O'Connor, 1986). Morgan (1986) reported that no mature females smaller than 80 mm were found in larger waterways. The smallest mature female collected from a larger waterway was a 71 mm female collected from the Murrumbidgee River by O'Connor (1986). The smallest mature female observed by McCarthy (2005) in the Murray River was 84 mm OCL and the largest immature female was 102 mm OCL. Sizes within this same range were observed by O'Connor in the Murrumbidgee River. The smallest mature female in the upper Murrumbidgee River, in the Australian Capital Territory, was 63.5 mm OCL and the largest immature female was 88.0 mm OCL (Lintermans 2000; Lintermans, unpublished data). In north-east Victoria, Barker (1992) observed that the smallest berried female at Lake Nagambie was 79 mm and at Waranga Lake was 86 mm. Morison (1988) observed that the smallest berried female at Wodonga Creek was 84 mm and at the Ovens River was 74mm OCL.

Mean size at first maturity was estimated by O'Connor (1986) as the size at which 50% of females were berried, which was 87 mm in the Murrumbidgee River at Narrandera. Based on the data of Johnson and Barlow, the mean size of sexual maturity of Murray crayfish in the Murrumbidgee in 1974 was larger, at 91 mm (O'Connor, 1986). Morison (1988) also estimated that 50% of all females reached sexual maturity at 91 mm OCL in Victorian streams. In the Murrumbidgee River, O'Connor reported that virtually all females were mature at 95 mm (O'Connor, 1986). However, in North-East Victoria, Morison (1988) observed that 15% of females were still immature at 100 mm OCL.

Data on the proportion of females that were sexually mature at 10 mm size increments were provided by Johnson and Barlow (1982), Morison (1988), Gehrke (1992) and McCarthy (2005) (Figure 19). Further, Johnson and Barlow (1982) provided a logistic equation for the proportion of berried females of a given size (OCL):

$$\% \text{ berried females} = 100 / (1 + e^{[31.8 - 0.35 * OCL]})$$

The average of these data (Figure 19) suggests that the majority of females reach sexual maturity at sizes between 70 mm and 100 mm OCL, and that the size at which 50% of females reach sexual maturity is between 80 mm and 90 mm.

As an alternative means of defining maturity, Johnson and Barlow (1982) suggested that a distinct divergence in the total length to OCL ratio of females, which exists above and below 75 mm OCL, coincides with the onset of sexual maturity. This divergence in the total length: OCL ratio is possibly due to the development of a proportionally longer abdomen in mature females, a morphological change that confers greater egg-bearing capabilities (a larger abdomen can carry more eggs).

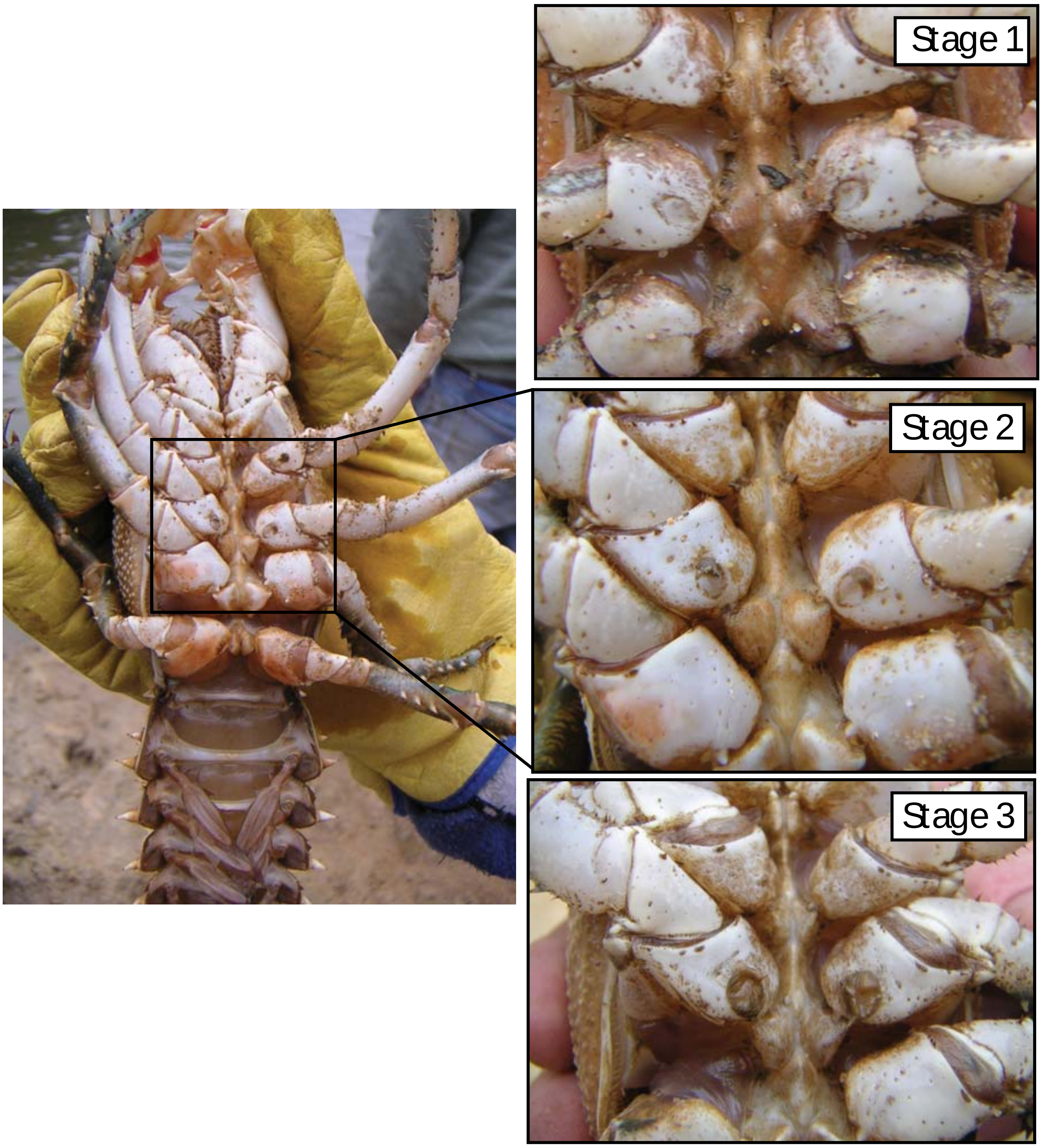

Figure 18. The appearance of the gonopores of immature, maturing and sexual mature female Murray crayfish following the maturity criteria of Turvey and Merrick (1997a). Photos: Dean Gilligan.

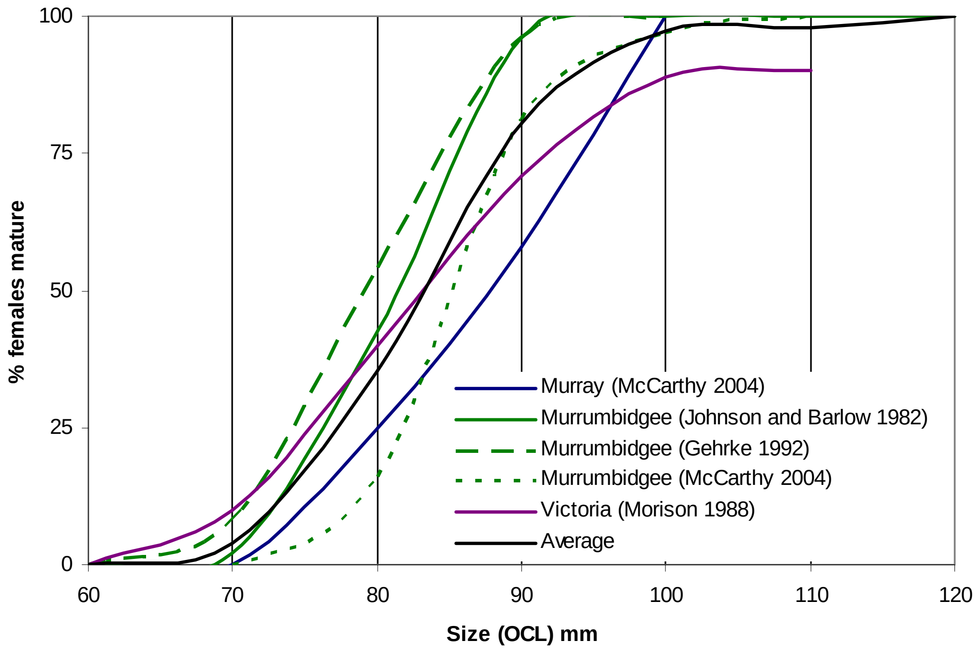

Figure 19. The percentage of females that are sexually mature plotted against size (OCL mm).

Turvey and Merrick (1997a) also describe a means of externally categorising the maturity of males using the degree of inflation of the genital papillae. However, this strategy has not been tested on or applied to Murray crayfish. O'Connor (1986) assessed maturity in male Murray crayfish, doing so by histological examination of the testes and vas deferens, calculation of gonado-somatic indices and observation of the size and colour of vas deferens. The majority of males larger than 54 mm OCL were observed to be physiologically mature (O'Connor, 1986). However, it is unknown if males of 54 mm OCL would be capable of mating, given potential aggressive female interactions during courting behaviour. As a result, despite physiological maturity, males of this size may not be functionally mature (O'Connor, 1986).

Based on the estimated sizes at maturity, and the size at age models presented above, the age at which 50% of females are sexually mature is eight years (87 – 91 OCL mm), and virtually all females are sexually mature at 10 years (95 –102 mm). The minimum and maximum size range of sexual maturity, from 64 – 105 mm corresponds to ages of six to ten years old. Morgan (1986) reported a sexually mature female at 40 mm OCL. However, small mature females were only detected in small upland streams. As the size at age models produced by O'Connor (1986) are based on data collected from large river populations, it is not be appropriate to extrapolate the age of the 40 mm OCL female reported by Morgan (1986). For males, the age at which the majority are physiologically mature is four years (54 mm) (O'Connor, 1986).

There is no evidence to suggest that old females become reproductively senescent (O'Connor 1986).

3.11.6. Mortality

Based on data provided in Geddes *et al.* (1993), Alves (unpublished) and fecundity at size models presented in section 3.10.1.2), mortality from the egg until independence is in the order of 63 ± 18% and 33 ± 22 % respectively under captive conditions. Mortality then declines to 31 – 41 % up until 1.5 years of age in captivity (Geddes *et al.* 1993).

For wild populations under fishing pressure, O’Connor (1986) presented recapture data of tagged individuals from two sites in the Murrumbidgee near Narrandera. At one site (site 2), the proportion of recaptured crayfish declined from 38% in 1981 to 29% in 1982 and 15% in 1983. At a second site (site 5), the proportion decreased from 48% in 1981 to 29% in 1982 and 8% in1983. These data correspond to average (± SE) annual mortality rates of 46 ± 0.10% for adult Murray crayfish. The relative proportion of small (<80 mm) and large (>80 mm) Murray crayfish recaptured in each year was similar, suggesting that mortality was not size dependent at sizes between 40mm and 130 mm (O’Connor, 1986).

3.11.7. Population structure

Sampling techniques used for most of the studies presented, principally hoop nets, with one exception failed to capture small (<40 mm OCL) individuals. The only study reporting the capture small crayfish (< 40 mm OCL) using hoop nets in a large lowland river was Asmus (1999) who recorded approximately 1% of his captures in this size class. In contrast, smaller individuals were regularly collected by Raadik *et al.* (2001) and Closs and Driver (unpublished), both of which used electrofishing in smaller order streams. Therefore, the inability to collect small Murray crayfish in large waterways could be inferred to result from the inefficiency of mesh drop nets for smaller size classes. However, Turvey (1980) and Morrissy (1975) using similar methods in studies of Sydney spiny crayfish and marron had catches dominated by 20 – 35 mm crayfish. Further, McCarthy (2005) used an alternative gear type, Munyana mud crab nets, but also failed to sample small Murray crayfish, with the smallest individuals captured being 60 – 70 mm OCL. Therefore, the lack of small Murray crayfish in the data is not easily explained by inefficiencies of drop nets as a sampling tool for Murray crayfish surveys, as suggested by O’Connor (1986) and McCarthy (2005).

Density-dependent factors such as aggressive social interactions could potentially result in the observed lack of small Murray crayfish from the data-sets, with juveniles and smaller individuals excluded from accessing nets and traps by larger individuals (Turvey and Merrick 1997b; Nyström 2001; O’Connor, 1986). However, even if this hypothesis were true, juveniles and smaller crayfish would still be sampled readily in traps where adults are not captured. Alternative explanations for the absence of small crayfish samples from Murray crayfish studies undertaken in large lowland rivers are that juveniles may have a specific diet that is not catered for by the typical meat/fish baits used in the previous studies, or juveniles may remain permanently within burrows (or other juvenile habitat) until they reach a size of ~ 40 mm OCL. Lastly, it is possible that perhaps juvenile and adult Murray crayfish occupy different habitat types with the juvenile habitats not sampled effectively in most of the studies to date. For example, both Raadik *et al.* (2001) and Closs and Driver (unpublished), who sampled in smaller order streams, sampled predominantly small individuals. This data is suggestive of natural segregation of juveniles and adults into smaller and larger order waterways respectively. Therefore, the absence of smaller size classes in the studies presented, is a result of the fact that almost all of the Murray crayfish studies undertaken to date have been restricted to larger waterways.

3.11.7.1. Temporal patterns in population structure

Between 1974 and 1980, Johnson and Barlow (1982) observed a considerable reduction in the modal size of Murray crayfish populations in the Murrumbidgee River at Narrandera, declining from 80 – 90 mm in 1974 to 60 – 70 mm OCL in 1980 (Figure 20), which they hypothesised to be due to increased mortality through recreational fishing pressure. Between 1981 and 1984, O’Connor (1986) observed a consistent population size structure in the Murrumbidgee River each year, with the same modal peak between 60 – 70 mm OCL, and a low proportion (7.8% ± 0.7%) of the population larger than 90 mm OCL (Figure 20). About ten years later, data collected by Gehrke (1992) suggests that the modal size class had increased slightly to 70 – 80 mm OCL but the proportion of the population larger than 90 mm OCL was still low at 10% (Figure 20). However by 2004, data reported in McCarthy (2005) indicates that the modal size of Murray crayfish at Narrandera had increased to 90 – 100 mm OCL and that 70.0% of individuals within the population were larger than 90 mm OCL (Figure 20). This change in the size frequency distribution of the population is likely to be a response of the changes in the legal size limit in New South Wales, from the absence of a minimum size limit before 1987, when a minimum size limit of 80 mm OCL was introduced, to 90 mm OCL in 1998 following an increase in the minimum size.

In contrast to the reasonably stable size-frequency distribution in the Murrumbidgee River between 1980 and 1992, the size-frequency distributions of the Murray crayfish populations sampled in Victorian streams (Morison, 1988; Barker 1992) varied annually (Figures 21 – 23). The modal size class fluctuated between 70 – 80 mm and 80 – 90 mm OCL in Lake Nagambie and Wodonga Creek, and fluctuated between 40 – 50 mm and 90 – 100 mm in the Ovens River. The proportion of the population greater than 90 mm OCL between 1984 and 1990 fluctuated annually from 19%, 45%, 47%, 42%, 20% and 32% at Lake Nagambie, from 28%, 47%, 40%, 32% and back to 26% in Wodonga Creek, and from 23%, 87%, 17%, 10%, 11% and 21% in the Ovens River. At least some of the variance can be explained by the generally smaller sample sizes of the Victorian studies. However, the Victorian Murray crayfish fishery had been totally closed since 1983. An increasing modal size class and increasing proportion of larger individuals would have been expected if fishing pressure was responsible for the declining sizes prior to the closure. This was not observed. However, this hypothesis assumed that no poaching was occurring.

Although length-frequency data from the 1993 study and ongoing surveys in the Ovens River are not available, Burston *et al.* (1999) suggested that the size (OCL) of Murray crayfish in the Ovens River was decreasing, due to the removal of large (> 90 mm) individuals from the population, particularly large males, since reopening of the fishery in Victoria in 1990. However, this interpretation appears to be influenced by the significantly greater average size and greater proportion of large individuals in the sample collected in 1985. Omission of the data collected in 1985 provides a very different picture of temporal changes in the Ovens River population, with very little difference between the mean size and proportion of large individuals in the population before and after re-opening of the fishery in 1991.

3.11.7.2. Spatial patterns in population structure

Comparison of the size-frequency distributions among the regions sampled is difficult given that individual projects span a period of 30 years from 1974 through until 2004. Over this period of time, fishery regulations had changed numerous times within each jurisdiction and varied between jurisdictions. Consequently, most samples were collected during periods of distinctly different fishing pressure and any spatial differences are confounded by temporal ones. However, some data were collected from two or more sites within a single jurisdiction (and hence have the same fishing regulations) and within the same year.

O'Connor (1986) presented data from both the Murrumbidgee River at Narrandera and from Khancoban Pondage collected in 1982 (Figure 24). Morison (1988) presented data collected from the Lake Nagambie, Wodonga Creek and the Ovens River in each of the years between 1984 and 1988 (Figure 25). Asmus (1999) compared aspects of the population structure along a 311 km reach of the Murrumbidgee River between Gundagai and Whitton in 1997–98. And McCarthy (2005) presented data collected from both the Murray River and Murrumbidgee River collected in 2004 (Figure 26).

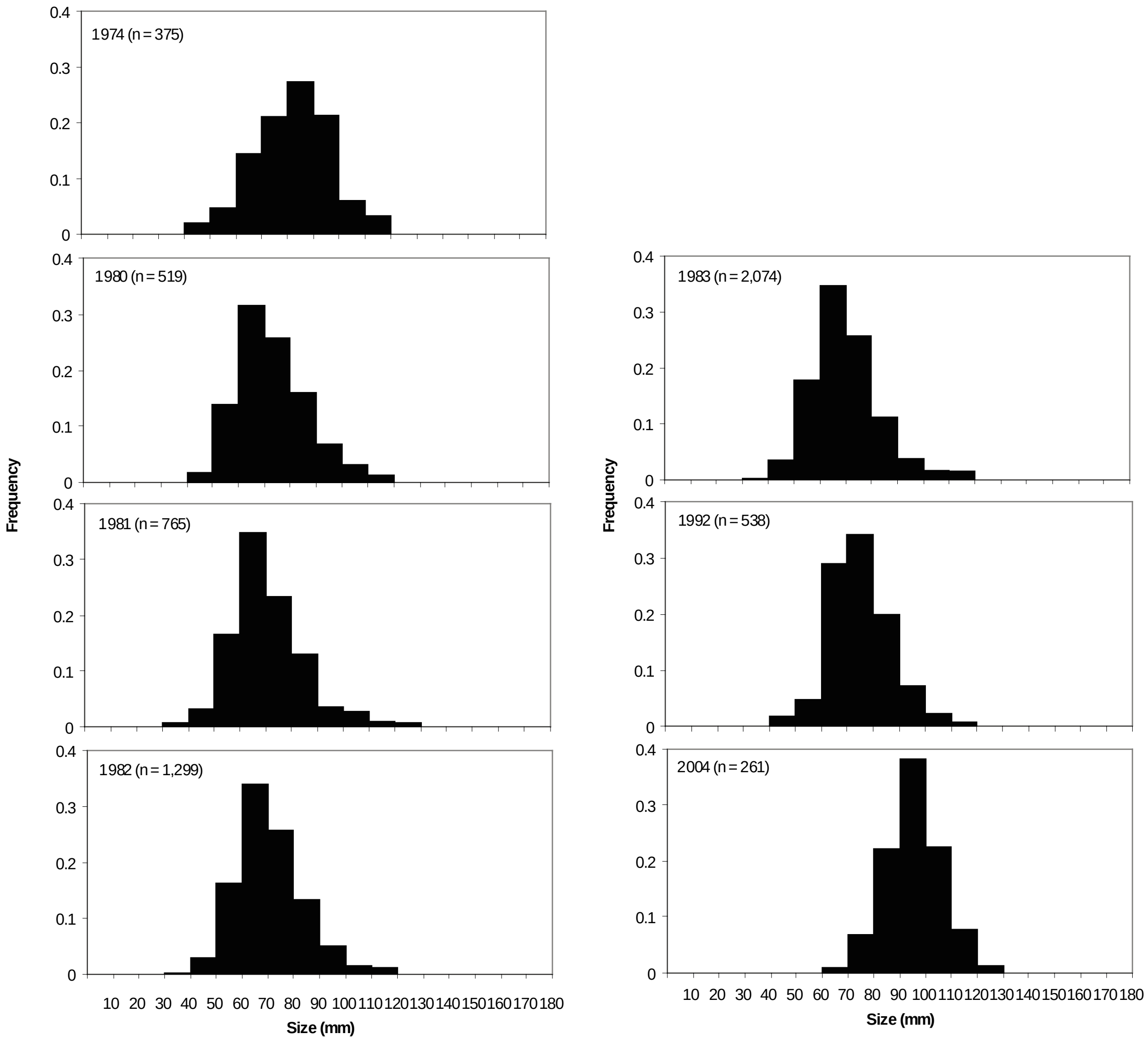

Figure 20. Temporal changes in the length-frequency distribution of the Murray crayfish population in the Murrumbidgee River at Narrandera between 1974 and 2004. Data sourced from Johnson and Barlow (1982), O'Connor (1986), Gehrke (1992) and McCarthy (2005).

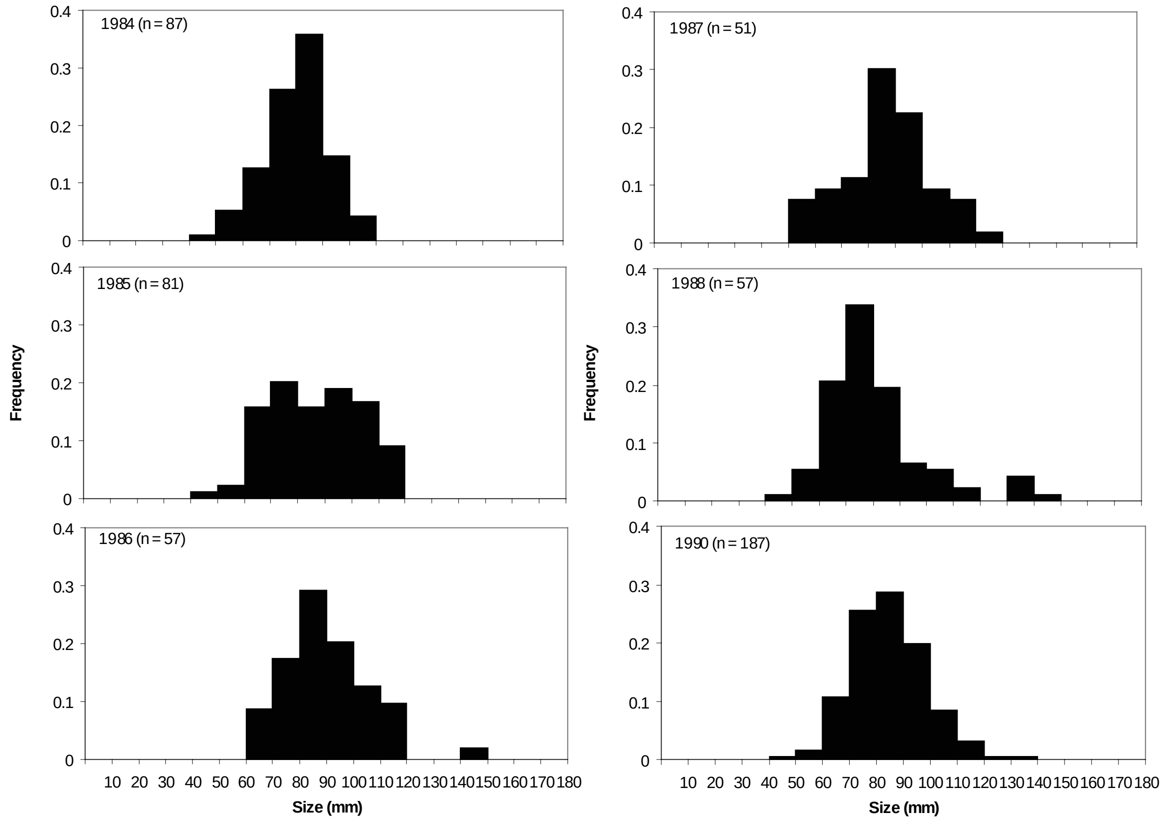

Figure 21. Temporal changes in the length-frequency distribution of the Murray crayfish population in the Goulburn River at Nagambie between 1984 and 1990. Data sourced from figures presented in Morison (1988) and Barker (1992).

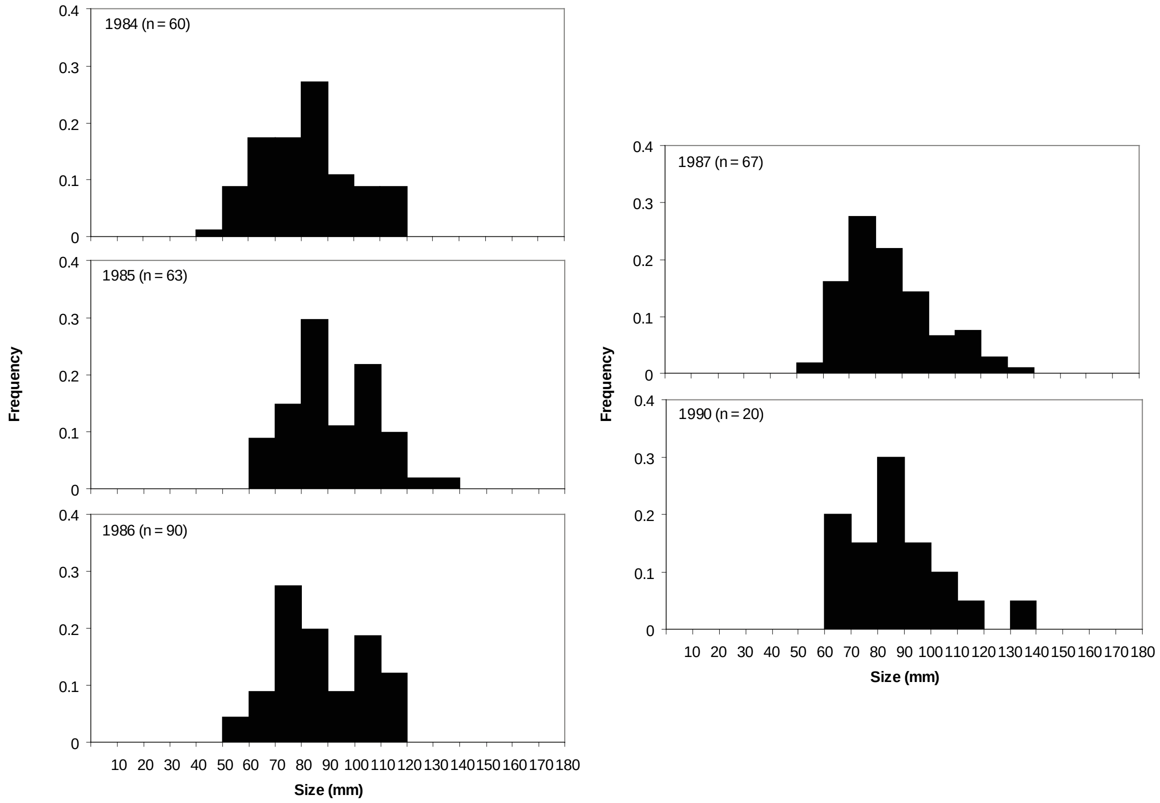

Figure 22. Temporal changes in the length-frequency distribution of the Murray crayfish population in Wodonga Creek between 1984 and 1990. Data sourced from figures presented in Morison (1988) and Barker (1992).

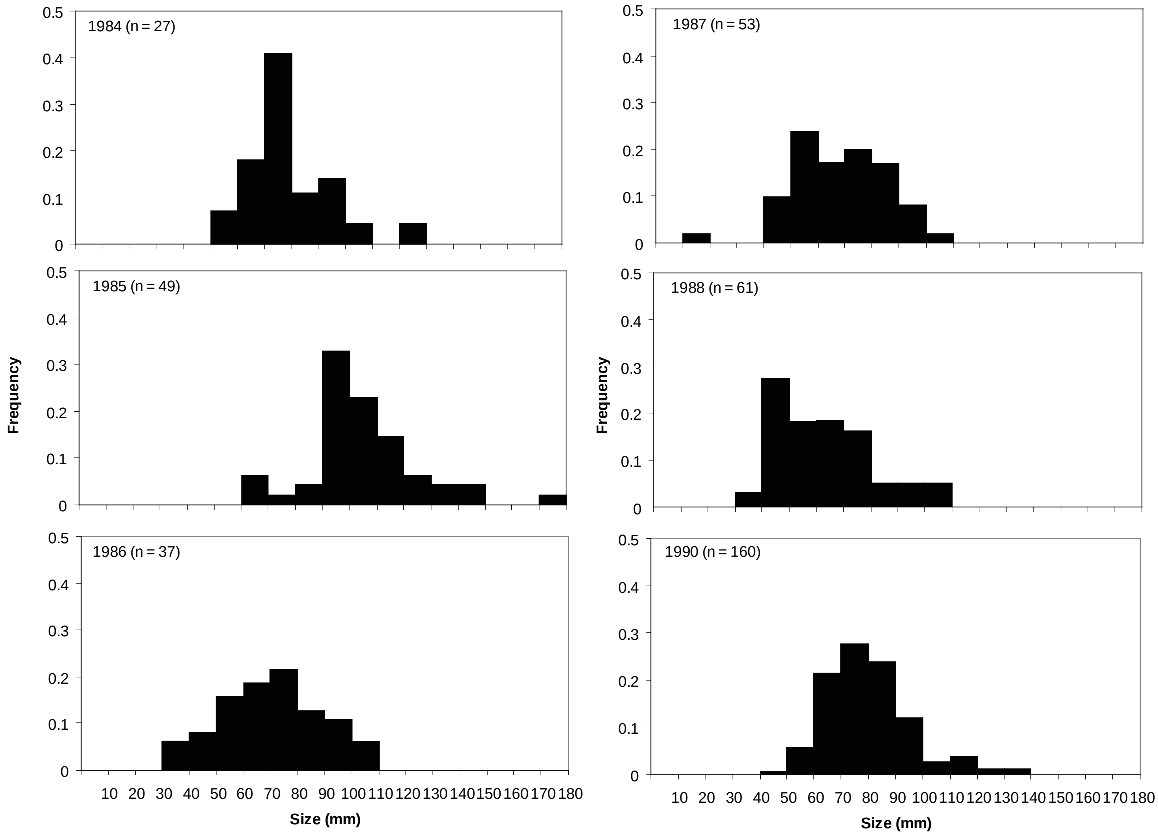

Figure 23. Temporal changes in the length-frequency distribution of the Murray crayfish population in the Ovens River near Wangaratta between 1984 and 1990. Data sourced from figures presented in Morison (1988) and Barker (1992).

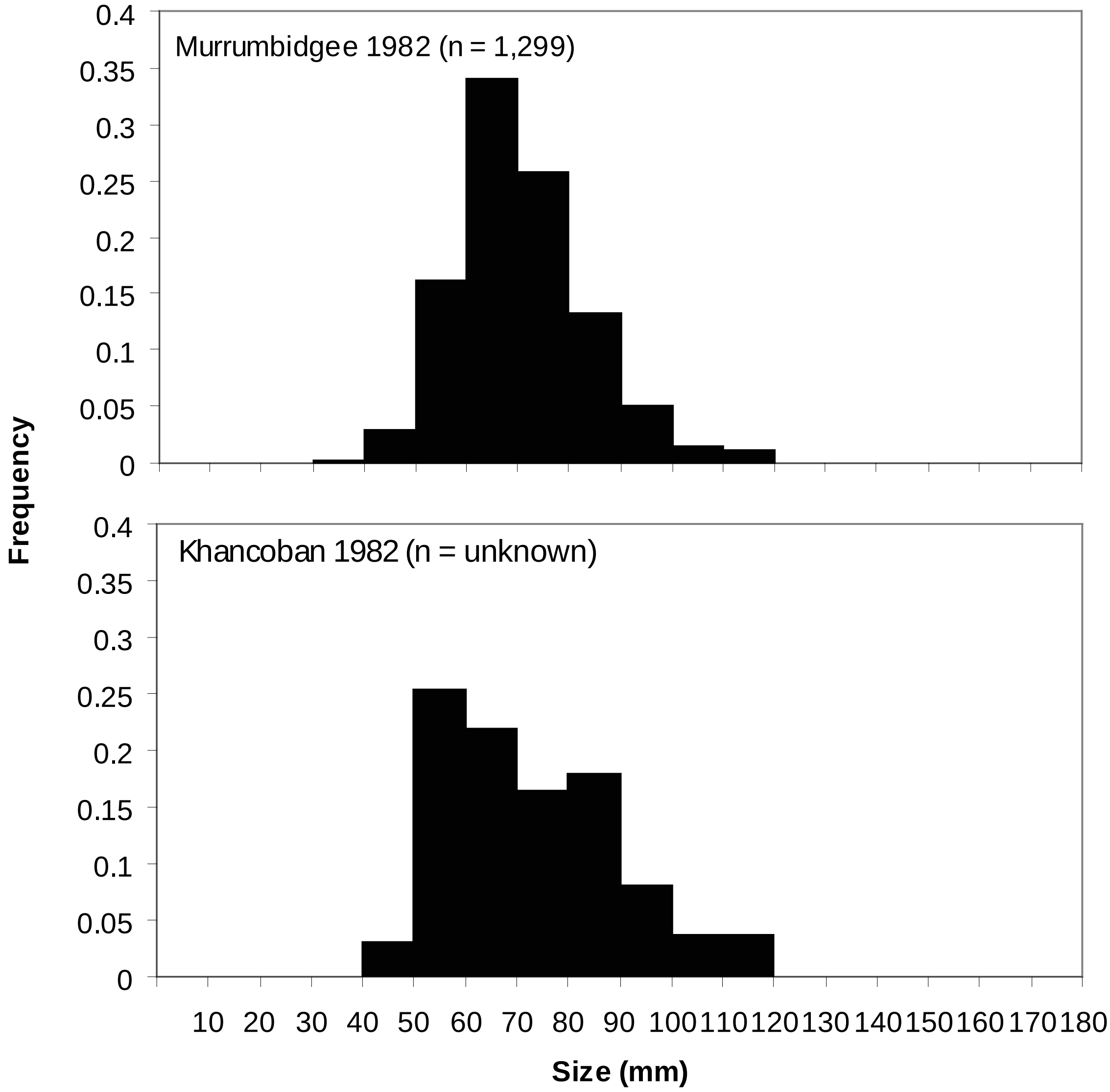

Figure 24. Length frequency distributions of Murray crayfish populations sampled from the Murrumbidgee River at Narrandera and from Khancoban Pondage in 1982 (from O'Connor, 1986).

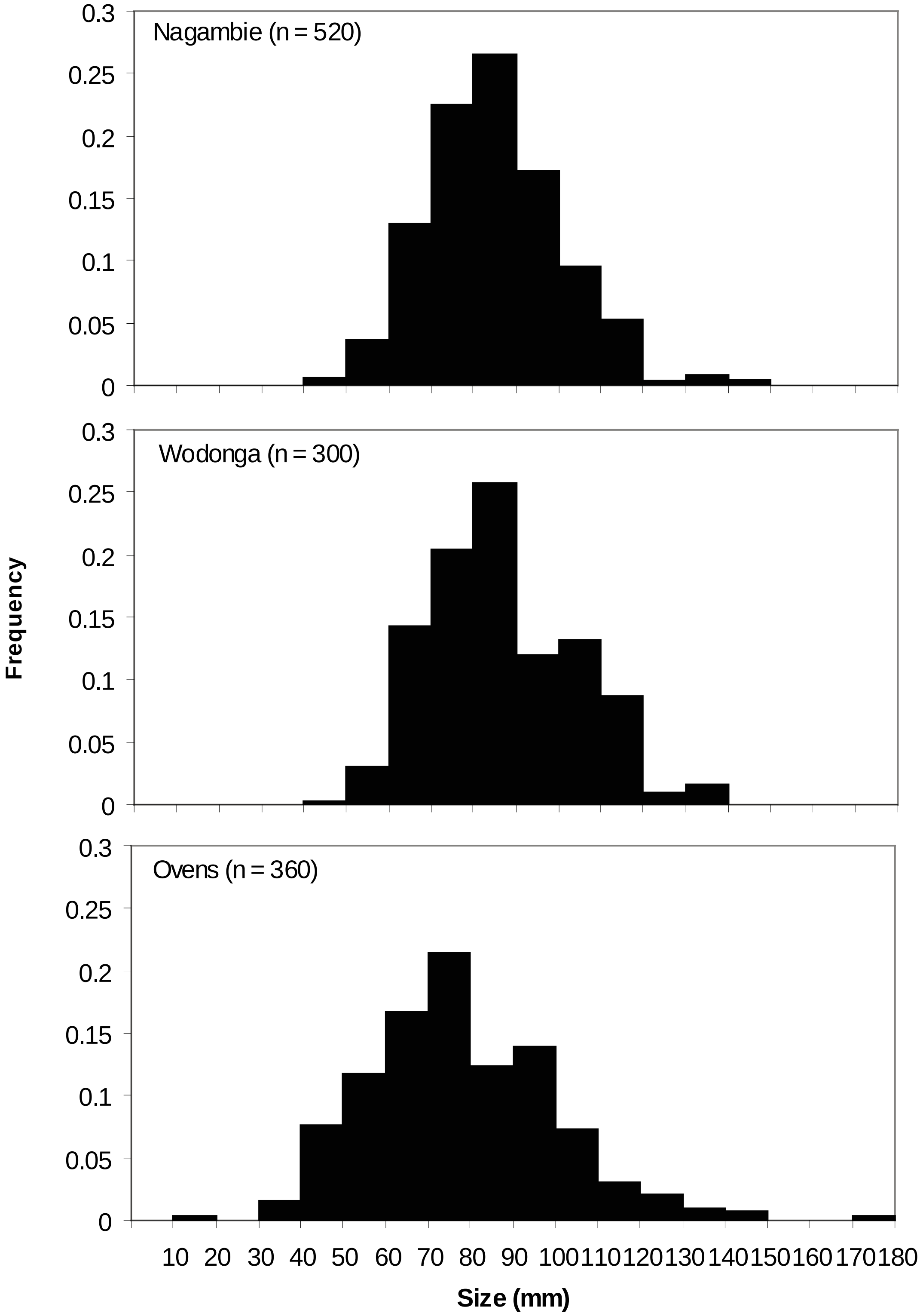

Figure 25. Length frequency distributions of Murray crayfish populations sampled from the Goulburn River (Nagambie), Ovens River and Wodonga Creek between 1984 and 1990. Data sourced from Morison (1988) and Barker (1992).

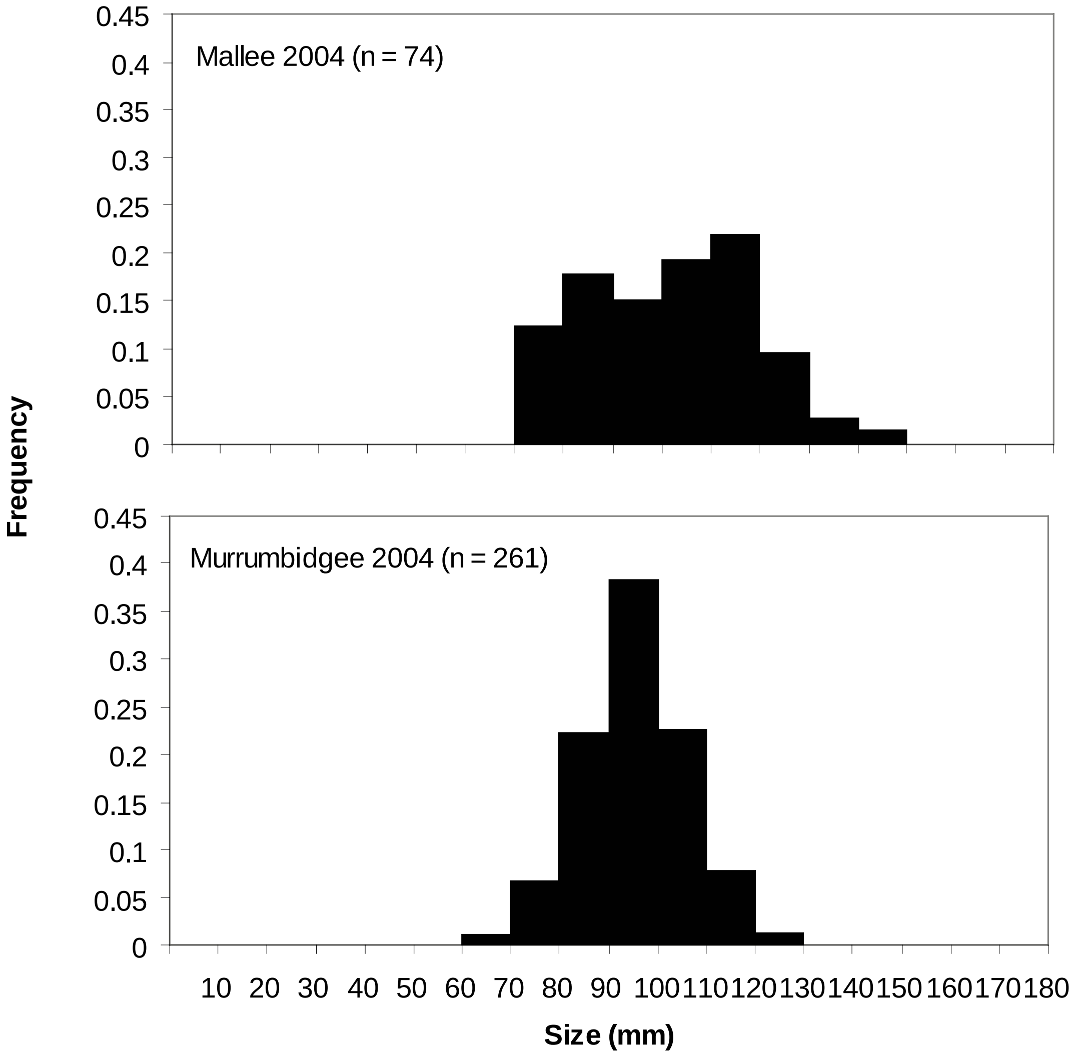

Figure 26. Length frequency distributions of Murray crayfish populations sampled from the Murrumbidgee and Murray Rivers in 2004. Data sourced from McCarthy (2005).

In 1982, the Murray crayfish population at Narrandera had a modal size class of 60 – 70 mm, while the population in Khancoban pondage had a smaller modal size class of 50 – 60 mm (Figure 24). Further, the size frequency distribution at Khancoban was slightly more platykurtic than at Narrandera and skewed towards smaller size classes (Figure 24). However, the proportion of large individuals in the population was only 8% in the Murrumbidgee, but 15% at Khancoban. Both populations had a similar total size range (Figure 24).

The annual variability of the length-frequency distributions of the Victorian populations in Lake Nagambie, Wodonga Creek and the Ovens River was as great as the variability between populations (Figure 25). No population had a size range, modal size class or proportion of large individuals in the population (> 90 mm OCL) that was consistently greater or smaller than any other population across the six years of sampling by Morison (1988) and Barker (1992).

In the Murrumbidgee River in 1997–1998, total abundance, mean size and weight of immature, berried and mature females, and the proportion of immature females in the population all increased in a downstream direction (Asmus 1999). In contrast, no significant trends in sex ratio, size (all individuals), weight (all individuals), proportion of under-sized males, or size and weight of males or females (combined maturity stages) were observed. The only variable to decrease in a downstream direction was the proportion of mature females in the population (Asmus 1999). In 2004, the Murray crayfish population in Murray River was slightly larger than that in the Murrumbidgee River, with a modal size class of 110 – 120 mm and size range of 80 –150 mm, whilst the Murrumbidgee population had a modal size class of 90 – 100 mm and a size range of 70 – 130 mm (Figure 26). Both populations had the same proportion of large individual in the population, with 70% of individuals greater than 90 mm OCL.

3.11.8. Sex ratios

Sex ratio is a particularly relevant parameter in the management of Murray crayfish as the current fishery regulations in New South Wales and Victoria place substantially greater pressure on males than females. As berried females are totally protected, and most females above the minimum size limit are berried for most of the fishing season (1 May – 31 August), a vast majority of the Murray crayfish currently harvested by the recreational fishery are males. As fishing pressure is expected to alter sex ratios of the population, the only means to determine the natural sex ratio is by sampling either a population that has not been fished for several decades, or to estimate the sex ratio from that portion of the population below the legal size limit.

Morison (1988) and Barker (1992) collected sex ratio data each year throughout the crayfishing closure in Victoria. The average sex ratio across this period was 1:1 (49 % females) in the Ovens River, 1:1.3 (56% females) at Lake Nagambie and 1:1.2 (55% females) at Wodonga Creek. The data did not suggest a gradual equalisation of the sex ratio over time as the closure continued at any location. Therefore, in the absence of fishing pressure (these data are conservative given that the closure had only recently been introduced – from 1 to 7 years prior to sampling) the natural sex ratio of Murray crayfish populations ranges from equal to being slightly female dominated.

Gehrke (1992) provided data from two sites on the Murrumbidgee River collected in 1992, suggesting that the population of Murray crayfish below the legal size limit (80mm OCL at the time of sampling) consisted of 52.8% females. This was not significantly different from a 1:1 sex ratio (Gehrke, 1992). Therefore, in the absence of any fishing pressure, a 1:1 sex ratio could be assumed for juveniles. However, the sex ratio of the same population above the legal size limit was 1:1.7 (male:female) (63% females) and statistically significantly different from the 1:1 ratio (Gehrke, 1992).

Johnson and Barlow (1982), O'Connor (1986), Gehrke (1992) and Asmus (1999) observed population-wide sex ratios of between 1:1 and 1:1.4 (between 51% and 59% female) from the same Murrumbidgee River population between 1974 and 1998. Each of these estimates was obtained before the restricted fishing season was introduced, and either before or whilst the minimum legal size limit was only 80 mm. Therefore, all females were available to the fishery during the period of the year when they were not carrying eggs (October – May), as were those females that were not yet sexually mature at 80 mm (> 50% of females) after 1987. As a result, these estimates of modest fishing induced sex ratio bias are not representative of those that exist under the current regulations of a restricted fishing season and a minimum size limit of 90 mm OCL. McCarthy (2005) provides data collected from the Murrumbidgee River two years after the introduction of the revised regulations, at which time the sex ratio was 0.32:1 (79% females). At the same time, the sex ratio in the Murray River population was 0.45:1 (69% females) (McCarthy 2005). Similarly, Edney (unpublished) recorded a sex ratio of 0.61:1 (62% females, n = 50) in the Murray River near Albury in 2005. The current fishing regulations appear to be substantially biased in favour of harvesting male crayfish.

In contrast to all the examples of female dominated populations given above, in the upper Murrumbidgee River, Lintermans and Rutzou (1991) observed a slight (although not significantly different) bias towards males with only 44% of the population being female. This proportion rose to 57.9% in 1998 (Lintermans 2000). By 2005 the proportion of females had declined again to only 36% of the Murray crayfish population (Ryan 2005). However, in all three of these upper Murrumbidgee studies, sample sizes were low.

In other large crayfish species, Morey (1988) observed a similar relationship to that of Murray crayfish in the Australian Capital Territory, with females comprising 45% of the population in waters closed to recreational fishing. Similarly, Horwitz (1991) observed a 1:1 sex ratio for an unfished population of Tasmanian giant freshwater crayfish. Lastly, Turvey and Merrick (1997b) observed a similar relationship to Gehrke (1992) in the Sydney spiny crayfish, with a 1:1 sex ratio among individuals < 30 mm, but a female dominated sex ratio above 30 mm. However, given that the population within the Loddon River (Nepean catchment) is within a catchment with restricted public access, it can be assumed that recreational fishing pressure is negligible. Therefore, it is possible that males may naturally suffer higher natural mortalities than females.

3.12. Role within ecosystems

No studies have examined the ecological role of Murray crayfish in riverine ecosystems. However, as large omnivorous invertebrate predators, leaf shredders and detritivores (Turvey and Merrick 1997c; Usio and Towsend 2000; Nyström 2001; Parkyn *et al.* 2001), crayfish species have the potential to induce changes in the habitat of lower order trophic groups, such as aquatic snails (Turner *et al.* 1999) and other benthic invertebrates (Usio and Townsend 2000) as well as impacts on higher trophic orders within river ecosystems. Given that crayfishes are the largest invertebrates in river systems, their high biomass may dominate a number of ecosystems processes (Horwitz 1995).

At high densities, habitat modification and benthic foraging by crayfish could limit the growth, distribution and abundance of aquatic macrophytes, which would have flow-on effects in aquatic ecosystems. Further, the consumption of eggs of fish species that attach their eggs to a substrate can limit recruitment of fish populations. This could reduce predation pressure on zooplankton, which, in turn, limit densities of phytoplankton (Dorn and Wojdak 2004). However, no data exist which would indicate at what density Murray crayfish populations would begin affecting these 'top-down' ecosystem processes, or whether limiting density-dependent processes within Murray crayfish population would allow populations to reach these densities.

As an available prey item, Murray crayfish are also part of 'bottom-up' ecosystem processes, supporting populations of predatory fish, reptiles, birds and mammals (Nyström 2001). Diet studies of large predatory fish in the Murrumbidgee River at Yanco, New South Wales, indicate that Murray crayfish were identified in 21% of Murray cod (*Maccullochella peelii*) stomachs, 11% of trout cod (*Maccullochella macquariensis*) stomachs and 12% of golden perch (*Macquaria ambigua*) stomachs (Baumgartner 2005). This suggests that Murray crayfish are potentially a very important prey item for these fish species.

As Murray crayfish are the host for a range of ectosymbiotic and parasitic organisms, including six species of temnocephalan, as well as worms and other microcrustaceans, they play a role in supporting these lower order organisms. However the number, names and ecological roles of these dependent organisms are unknown. Crayfish burrows may also provide habitat for a number of other species, with the faunal assemblages of crayfish burrows given a specific descriptive term; pholeteros (Lake 1977).

3.13. Abundance

In the 1800s, during his explorations of the lower Murray River in South Australia, Eyre (1845) observed that Aborigines could spear 10 to 16, two to four pound (~ 1 – 1.5 kg) Murray crayfish (~ 130 – 160 mm OCL based on the length-weight relationship of Johnson and Barlow (1982)) from a bark canoe in an hour or two. And in 1880, the Royal Commission into the Prospects of Fisheries in New South Wales reported that Murray crayfish were "very numerous" in the Murrumbidgee River.

Broughton (1966) reported that workers constructing weirs on the lower Murray River between 1922 and 1935, regularly harvested Murray crayfish, which were said to "swarm" in the river. In 1949/50, Langtry (in Cadwallader 1977) observed that the numbers of Murray crayfish were increasing dramatically throughout the whole Murray system (referring to the New South Wales portion and inclusive of the Murrumbidgee River), and that a catch of 60 crayfish per 'regulation sized' cray-pot was not unusual. In the 1940s and 1950s in South Australia, commercial fishermen considered that catches were good, consisting of crayfish ranging in size from 0.5 kg (~105 mm OCL) to 2.5 kg (~175 mm OCL), with most about 1 kg (~ 130 mm OCL) (Geddes *et al.* 1993).

During the 1950s, Murray crayfish populations reportedly began to decline (O'Connor 1986; Walker 1982; Geddes 1990; Geddes *et al.* 1993). In the 1960 – 80s anglers continued to report declining catches in the middle reaches of the Murray and Murrumbidgee Rivers, with anglers catching fewer and smaller crayfish each year (Pollard *et al.* 1980; Johnson and Barlow, 1982; O'Connor 1986; Barker 1990; Geddes 1990; Sanger and King 2002).

In the 1980s, O'Connor recorded catch-per-unit-effort (CPUE) data at fortnightly intervals throughout the course of his study and determined that CPUE showed marked seasonal variation described by a quadratic regression model on temperature ($R^2 = 0.49$):

$$\text{CPUE (catch per net lift)} = [-97.37 + 17.82(T) - 0.56\,(T)^2]/88$$

where T represents temperature in degrees Celsius. Based on this model, the CPUE observed in the Murrumbidgee River by O'Connor (1986) between 1981 and 1985 would have been a maximum of 0.50 per net lift at temperatures of 15 – 17 ^{o}C. The range of temperatures observed by O'Connor during the May – November period (the sampling period within which most of the other studies sampled) was a minimum of 8^{o}C and a maximum of 21 ^{o}C, corresponding to minimum estimated CPUE of 0.11 and 0.34 crayfish per net lift respectively. Logbook data collected from the Murray and Murrumbidgee Rivers by recreational anglers between 1982 and 1984 report average CPUE of 0.32 per net lift in the Murray River and 0.30 per net lift in the Murrumbidgee (O'Connor, 1986). However, CPUE varied among reaches in each of these rivers (Figure 27). The minimum and maximum average CPUE in the Murray River was 0.09 and 0.53 in the Euston to Mildura and the Yarrawonga to Barmah reaches respectively (Figure 27). The minimum and maximum CPUE in the Murrumbidgee River was 0.10 and 0.51 in the Darlington Point to Hay and the Wagga Wagga to Narrandera reaches respectively (Figure 27). Between 1984 and 1988, Morison (1988) observed considerable differences in CPUE among three Victorian waterways. Within Lake Nagambie, mean CPUE was 0.43 individuals per net lift, whereas Wodonga Creek and the Ovens River had mean CPUEs of 0.51 and 0.74, respectively, with a maximum of 1.9 individuals per net lift recorded at Wodonga Creek in 1986.

In contrast, in 1988/89, Lintermans and Rutzou (1991) recorded CPUE ranging from only 0.01 to 0.13 per lift, which suggest that the populations within the upper Murrumbidgee River had been subjected to considerable fishing pressure. There were no fishing regulations for Murray crayfish in the Australian Capital Territory at that time, with no size limits, bag limits, closed season or ban on taking berried females. Alternatively, because the populations within the upper Murrumbidgee River are approaching the upper known altitudinal limit for Murray crayfish (~700 m asl), the low abundances observed by Lintermans and Rutzou (1991) may reflect populations in marginal habitats. The closure of the fishery in the Australian Capital Territory in 1991 did result in notable increases in abundance of Murray crayfish (Lintermans 2000), suggesting that fishing pressure may have been the major reason for low abundances.

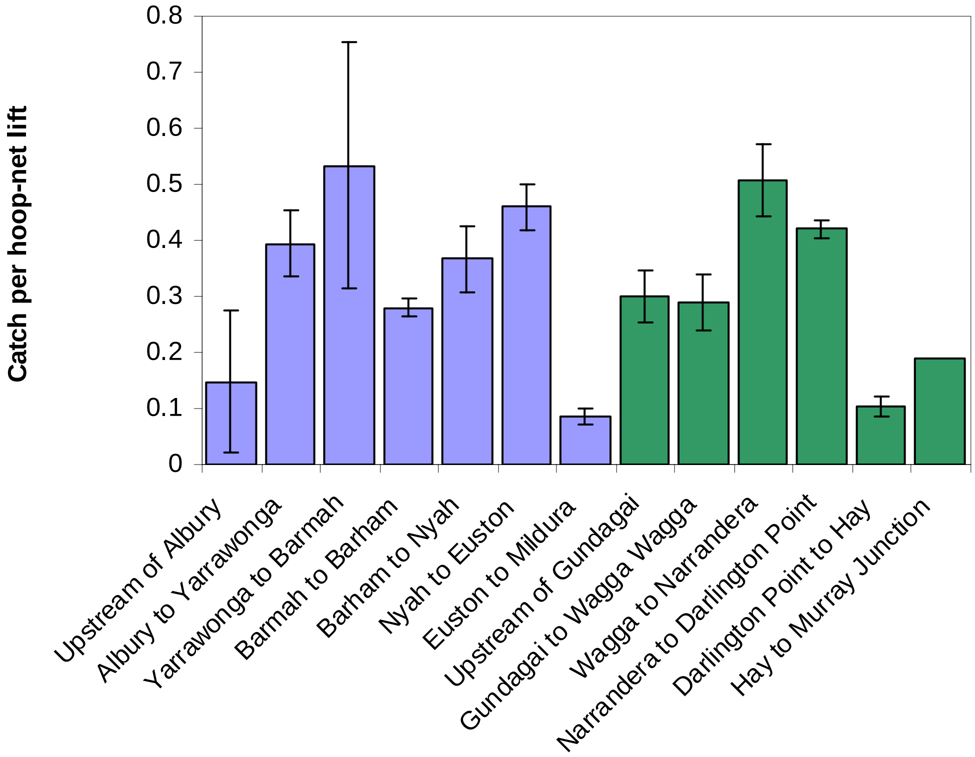

Figure 27. The average catch per unit effort data from reaches of the Murray and Murrumbidgee Rivers reported in the log books of recreational fishermen in New South Wales between 1982 and 1984. Blue: reaches on the Murray River. Green: reaches on the Murrumbidgee River. Data sourced from logbook surveys undertaken by O'Connor (1986).

In the 1990s, Barker (1992) reported CPUEs of 0.59 per net lift (0.4 per hour) at Nagambie, 0.146 (0.135 per hour) at Waranga and 1.33 (0.46 per hour) in the Ovens River, but only 0.044 (0.04 per hour) in Wodonga Creek. In 1992, Gehrke (1992) reported a CPUE of 0.69 ± 0.09 and 0.30 ± 0.10 per net lift at two sites on the Murrumbidgee at Narrandera. Finally, between 1993 and 1999, Burston *et al.* (1999) reported that the CPUE in the Ovens River remained around 0.5 per net lift between 1993 and 1998, but increased to over 1.0 per net lift in 1999.

In the most recent study, McCarthy (2005) reported CPUE of populations in the Murray and Murrumbidgee rivers. But in contrast to all previous studies, McCarthy (2005) used Munyana mud crab traps rather than hoop nets as the primary sampling tool. In the Murrumbidgee River (Narrandera), both Munyana nets and hoop nets were used, and the catch rate of hoop nets was found to be 1.78 times greater than that of Munyana traps. The CPUE for hoop nets in the Murrumbidgee was 0.73 Murray crayfish per net hour. However, this is not an unbiased comparison as the hoop nets were deliberately set in micro-habitats likely to maximise catches, whilst the Munyana traps were set according to the strategy described by McCarthy (2005) (Asmus, pers comm.).

In the upper Murrumbidgee in 2005, Ryan reported an average CPUE of 0.04 crayfish per net hour. In the lower Murray River, where McCarthy (2005) did not use hoop nets, the catch rate was 0.008 Murray crayfish per net hour for Munyana traps. In the upper Murray River in 2005, Edney (unpublished) reported an average CPUE of 0.258 crayfish per net lift.

Comparison of CPUE among regions and through time is generally inappropriate given that most reports were of catch-per-net-lift. Given that a single net lift could be carried out within anything from 15 minutes to over an hour, the level of fishing effort used for each net lift is not a suitably standardised level of sampling effort for comparisons among studies. Further, even those studies that reported the more appropriate CPUE figure of catch-per-net-hour cannot be compared as the dimensions, mesh sizes and baits used in the hoop nets varied across most studies. Therefore, the CPUE data presented only give a general indication and should not be used for direct comparisons of population sizes across studies.

4. MURRAY CRAYFISH MANAGEMENT

4.1. Fisheries

4.1.1. Commercial fishing

Commercial fisheries for Murray crayfish formerly existed in South Australia and New South Wales, but not in Victoria or the Australian Capital Territory. However, there is a restricted trade in Victoria related to spiny crayfish as aquarium specimens.

McCoy (1867) reported that following the arrival of the railway at Echuca in 1865 and in the Riverina in the late 1870s, Murray crayfish were sent to markets in Melbourne and Sydney in "great numbers". However, by 1942, the Murray crayfish was considered to have little economic value (uncited source: O'Connor 1986).

In South Australia, Geddes *et al.* (1993) referred to discussions with 20 long-term commercial fishermen, who suggested that catches were 'good' in the 1940s and began to decline in the 1950s. The last good catches were taken between the mid 1950s and 1965 (Geddes *et al.*, 1993). Following this, Murray crayfish were no longer targeted by the commercial fishery in South Australia (Geddes *et al.* 1993).

No commercial fishery data are available before 1948 in the New South Wales section of the Murray River, or 1955 in the Murrumbidgee River, when the New South Wales government introduced monthly catch reporting by commercial fishers. Unfortunately, no fishing effort data were recorded prior to 1977. Therefore, the commercial fishery dataset is unable to provide an assessment of trends in catch-per-unit-effort through time, as fishing effort was not constant in each year. Despite this limitation, the annual commercial harvests are plotted for the Murray and Murrumbidgee River fisheries (Figures 28 and 29). The Murray fishery peaked at over 15 tonnes in 1955 and reached this level again in 1975 (Figure 28). The Murrumbidgee fishery was an order of magnitude smaller and peaked at only ~ 1.2 tonnes in 1974 (Figure 29). By 1982, professional fishermen in New South Wales rarely marketed Murray crayfish. Any that were caught, were sold to restaurants, hotels or individuals, or were consumed by the fishermen themselves (O'Connor 1986). The New South Wales commercial harvest of Murray crayfish ended in 1987.

4.1.2. Aquaculture

Given their slow growth rates, aggression, very high water quality requirements and low meat yield, Murray crayfish are considered unsuitable for production under aquaculture (Barker 1990; Horwitz 1990a; Merrick and Lambert 1991).

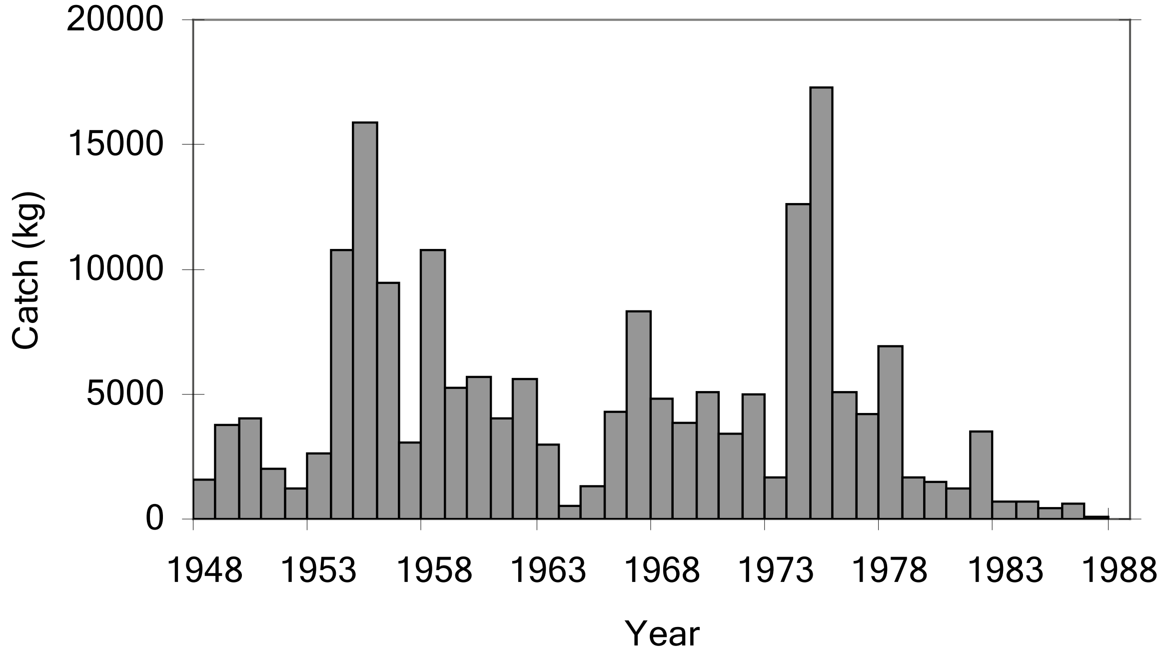

Figure 28. New South Wales inland commercial catch trends for Murray crayfish from the Murray River and major tributaries (NSW DPI Comcatch database, unpublished). These data do not reflect catch-per-unit-effort and cannot be used to infer trends.

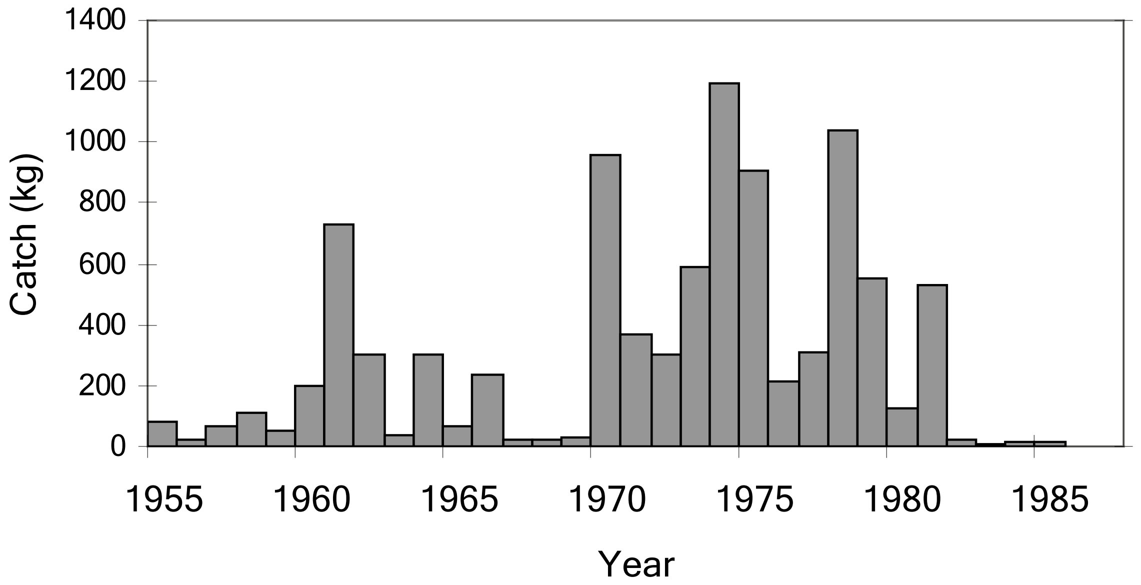

Figure 29. Commercial harvest of Murray crayfish for the Murrumbidgee River (NSW DPI Comcatch database, unpublished). These data do not reflect catch-per-unit-effort and cannot be used to infer trends.

4.1.3. *Recreational fishing*

The Murray crayfish fishery is totally closed in both South Australia and in the Australian Capital Territory. However, a popular recreational fishery for Murray crayfish currently exists in New South Wales and Victoria. In New South Wales, Murray crayfish are one of the four most prominent recreationally fished species in the lower Murray and Murrumbidgee (Sanger and King 2002).

Figure 30. Recreational fishing for Murray crayfish is a popular winter fishing activity in New South Wales and Victoria. Photo: Dean Gilligan.

4.1.3.1. *Current fishery regulations*

The four key recreational fishing regulations for Murray crayfish, the restricted fishing season, the minimum size limit, the bag limit and the protection of berried and brooding females, are consistent between New South Wales and Victoria (Table 3). However a number of other regulations regarding the harvest of Murray crayfish are not (Table 4). The higher possession limit in New South Wales (Table 4) would put slightly greater stress on stocks in New South Wales.

The higher permissible number of nets in Lake Dartmouth and Lake Eildon (Table 4) would have negligible effect on the fishery in those lakes, given that a bag limit and possession limit of five crayfish is in place. The use of 10, rather than five hoop nets would simply mean that the daily bag limit could be captured more quickly in these waters.

Table 3. Crayfishing regulations that are consistent across New South Wales (Tilbrook 2006) and Victoria (http://www.dpi.vic.gov.au/dpi/nrenfaq.nsf).

	Regulation
Closed season	A four-month fishing season exists for the taking of Murray crayfish, from the 1st of May until the 31st August each year.
Size limit	The minimum size limit is 90 mm OCL.
Berried females	All 'berried' females and females carrying young must be returned to the water immediately, regardless of size.
Daily bag limit	The daily bag limit is 5 crayfish per person per day, of which only one individual can be larger than 120 mm OCL.

Differences in the permissible dimensions of hoop nets do have the capacity to affect their efficiency (Table 4). O'Connor (1986) demonstrated catch efficiency differences due to mesh size and hoop diameter, but not mesh drop or the use of bait holders. The permitted mesh size in New South Wales is that which O'Connor (1986) found to be most efficient at capturing Murray crayfish. However, the total catch was increased because of the increased catch of smaller crayfish. Given, the presence of a minimum size limit, the regulation on mesh size in New South Wales may be a redundant regulation for Murray crayfish. O'Connor (1986) found that a hoop diameter of 0.7 m was the most efficient, with hoop diameters of 0.6 m, 0.9 m and 1.2 m catching 62%, 30% and 22% fewer Murray crayfish than the 0.7 m diameter hoop net. As a consequence, despite the differences, the maximum hoop diameter regulations in New South Wales and Victoria are also redundant for Murray crayfish, given that the most efficient hoop size is permitted in both states. Given that O'Connor (1986) found that hoop net depth (drop) was not significantly related to catch, this regulation may also be redundant in both states.

The fact that hand collection is permissible in Victoria, but not in New South Wales (Table 4), is likely to be redundant due to the likelihood that generally very few crayfish would be collected by hand in either state anyway. However, hand collection would be easy where Murray crayfish have been observed emerging from the rivers during black-water events, such as occurred at the Barmah-Millewa Forest in 1992 – 1993 (McKinnon 1995) and other unpublished accounts of similar events near Echuca (Lawler, pers. comm.) and Swan Hill (Tilbrook, pers. comm.) in 2000. As has occurred during these blackwater events in the past, temporary total closures should be enforced in these instances, in order to protect Murray crayfish vulnerable to hand collection.

Differences in the number of lines permitted to capture Murray crayfish (Table 4), and the regulation prohibiting the use of hooks on baited crayfish lines in Victoria, are probably unlikely to impact on Murray crayfish significantly.

Finally, differences between the regulations prohibiting the mutilation of Murray crayfish in New South Wales and Victoria are important (Table 4). Regulations prohibiting mutilation are enforced for two reasons. The first is the prohibition of removing and discarding the cephalothorax of captured crayfish, which is the body part used to measure OCL. If the cephalothorax is discarded, fisheries inspectors cannot gauge compliance with the minimum size limit. As a result, fishermen who remove the cephalothorax may be attempting to illegally retain undersize crayfish. The second is the prohibition of removing claws and/or legs from live crayfish. This regulation is enforced to ensure that fishers do not deliberately remove claws from berried females prior to release, as claws are essential for defence and are important for feeding and potentially also for the moulting process. The prohibition on removing the cephalothorax is consistent between both states.

However, the prohibition on removing claws and legs is not. In New South Wales, the fishing regulations specifically state that it is illegal to remove the claws of crayfish on or adjacent to waters. However, in Victoria the regulation states that crayfish should be landed "in carcass form". The Victorian recreational fishing regulations define carcass as: "The body of a crayfish which is not cut in any way other than to remove one or more legs or claws, or is not mutilated in any way other than the absence of one or more legs or claws". Therefore, this regulation specifically legalises the removal of 'one or more' legs and claws from crayfish prior to release. We suggest that the wording of this definition is an inaccurate portrayal of the intent of the regulation and recommend that the Victorian government review the wording on its definition of carcass within its regulations.

Table 4. Crayfishing regulations that are inconsistent between New South Wales (Tilbrook 2006) and Victoria (http://www.dpi.vic.gov.au/dpi/nrenfaq.nsf).

	New South Wales regulation	Victoria regulation
Possession limit	Possession limit is 10	Possession limit of 5
Number of hoop nets per licensed fisherman	A maximum of five labelled hoop nets in all waters.	A maximum of five labelled hoop nets in all waters except Lake Eildon and Lake Dartmouth. In these two waterbodies 10 hoop nets are permitted.
Dimensions of hoop nets	Hoop nets must not exceed a maximum diameter of 1.25 m, maximum drop of 1 m and minimum mesh size of 13 mm.	Hoop nets must not exceed a maximum diameter of 0.77 m and maximum drop of 0.5 m. There are no mesh size limitation in Victoria.
Collection by hand	Collection by hand not recognised in the fishery regulations.	Can also be collected by hand
Lines	A single attended line, or up to four set lines are permitted. Hooks are allowed.	Limit of 10 bait lines. Hooks are not allowed.
Mutilation	It is illegal to remove the claws, head and/or tail in, on or adjacent to waters.	Must land them in carcass form (see text below).

A number of streams within New South Wales and Victoria are totally closed to recreational fishing for Murray crayfish (Figure 31). In New South Wales, the closures are a combination of reaches closed to all forms of recreational fishing and reaches specifically intended to protect Murray crayfish populations. These include a number of reaches immediately upstream and downstream of weirs, a number of lowland river reaches and in notified trout waters in upland areas (NSW DPI 2006). In Victoria, the three existing closures are reaches closed to all forms of recreational fishing. Although they are not specifically intended to protect Murray crayfish, they do so by default.

In total, 1,084 km of stream within the range of Murray crayfish are closed to crayfishing in New South Wales, and 16 km are closed to crayfishing in Victoria (Figure 31). Given that Murray crayfish are totally protected in the 678 km of stream within their natural range in South Australia and the 163 km of stream within their natural range in the Australian Capital Territory, a total of 1,941 km of waterways are closed to recreational fishing for Murray crayfish across their natural range (Figure 31). This equates to around 16% of their natural distribution.

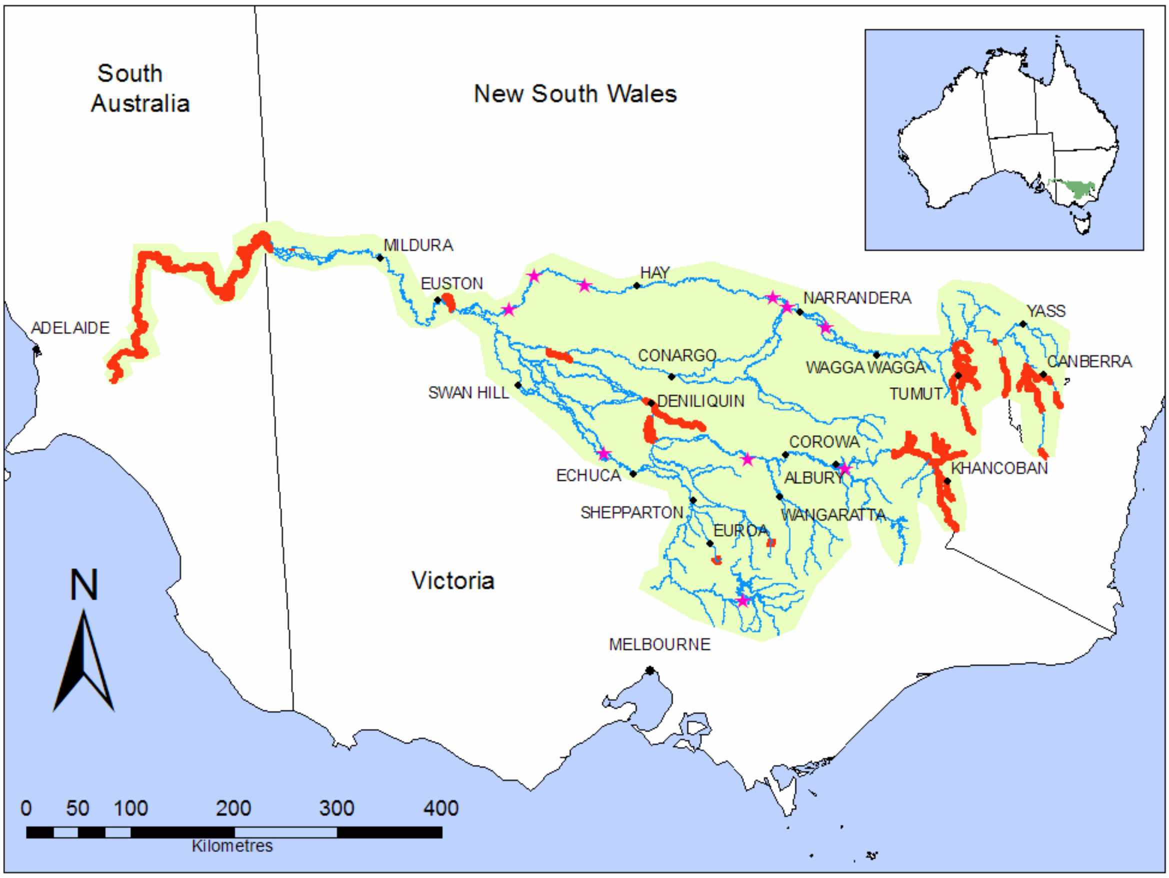

Figure 31. Waterways closed to recreational fishing for Murray crayfish. Reaches marked in red represent closed waters. Pink stars overlay smaller closed waters of several hundred metres that are too small to show-up on a distribution wide map. Refer to state fishing regulations in each jurisdiction for details (Tilbrook 2006; http://www.dpi.vic.gov.au/dpi/nrenfaq.nsf).

4.1.3.2. Recreational fisher surveys

Although now dated due to substantial changes in the fishing regulations since the data were collected between 1982 and 1984, a recreational fisher logbook survey undertaken by O'Connor (1986) provides the most comprehensive information about the recreational fishery for Murray crayfish in New South Wales.

O'Connor distributed logbooks and questionnaires to recreational fishers between 1982 and 1984 in order to collect and analyse data on the timing, locations, methods, effort, catch, size composition and harvest of Murray crayfish by recreational fishers at that time. At the time of the logbook surveys, the only limitation on the recreational fishery was the release of berried females. Of the 510 logbooks distributed, 227 (45%) were returned. The logbooks documented the dates and locations fished, aspects of the techniques used, effort and catch and the proportion of the catch that was released. The questionnaires sought information on motivation, fishery economics and attitudes towards various potential regulation options.

One quarter of fishermen fished only once or twice per year, one quarter fished three to four times, one quarter fished five to seven times and one quarter fished more than seven times per year. The average fishing party was 2.48 anglers, but ranged from one to 16 (O'Connor, 1986). Most fishing was undertaken from a boat, with up to several kilometres of river fished on each trip. Most (74%) crayfishing was undertaken on weekends. The majority (79%) of fishermen only used hoop nets, 6% only used traps (predominantly in the Murray River between Barham and Robinvale) and most of the remainder used both. Only a very small number of people used gill nets, drum nets and fishing lines (Hoop nets and fishing lines are now the only permissible fishing gears allowed in NSW and Victoria). A variety of baits were used, but none were found to be more successful than any other.

Most fishing effort was between Albury and Tocumwal and Echuca and Tooleybuc on the Murray River, and from Wagga Wagga to Darlington Point on the Murrumbidgee River (O'Connor, 1986) (Figure 32). Most fishing effort (72%) occurred in May and June, with 18% in July and August and only 10% between September and April (O'Connor, 1986). This level of fishing effort was not influenced by a closed season, which did not exist at that time. A total catch of 28,165 Murray crayfish was recorded. Most of the catch (78%) was taken in May and June, with fewer (15%) in July and August and only 7% from September through until April. These figures correspond to the levels of fishing effort during these months. Average catch per unit effort was 0.36 crayfish per hoop net lift in the Murray River and slightly higher at 0.42 crayfish per hoop-net lift in the Murrumbidgee River. Catch per unit effort was greatest between Barmah and Nyah on the Murray River and between Wagga Wagga and Darlington Point on the Murrumbidgee River (Figure 27). The catch was not evenly distributed amongst recreational fishers, with 66% of the catch taken by only 25% of the fishermen.

Most (91%) crayfish smaller than 65 mm OCL were released, while only 42% of the non-berried crayfish < 80 mm OCL, and only 3% of non-berried females > 80 mm OCL were released. Most fishermen (66%) viewed crayfishing as primarily a source of relaxation and enjoyment, while 21% viewed it as a food fishery and only 9% viewed it as a sport (O'Connor, 1986).

Asmus (1999) undertook a survey of recreational fishers to collect data on recreational fisher behaviour and the level of understanding of recreational fishing regulations in New South Wales. Of 129 anglers interviewed, 94.9 % were aware of the regulation to return berried females and 67.8 % were aware of the legal number of hoop nets allowed to be used. However, less than 50 % were aware of the minimum legal size limit, the daily bag limit, the total possession limit and the presence of waters closed to recreational fishing. Of those respondents who answered an incorrect legal limit, 65.2 % thought the legal limit was less than 90 mm. The findings of Asmus (1999) suggest that fishing regulations for Murray crayfish were not adequately publicised.

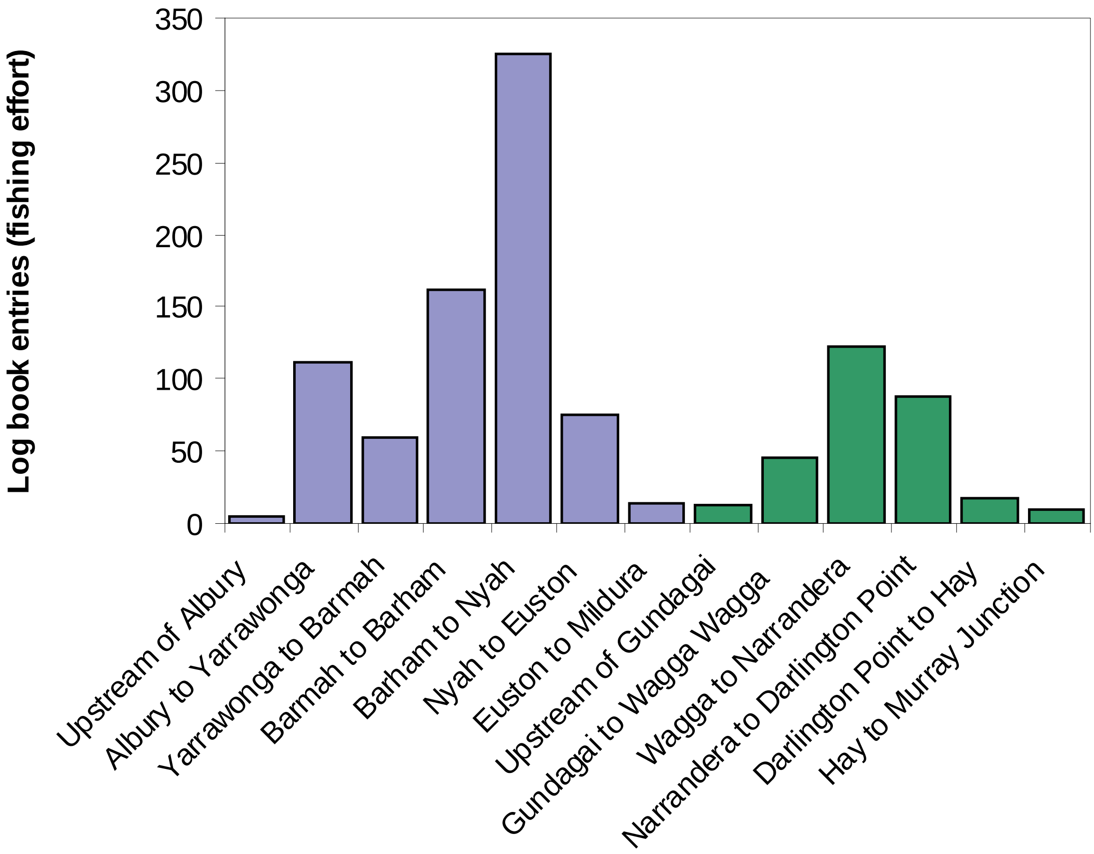

Figure 32. The distribution of recreational fishing effort for Murray crayfish in New South Wales between 1982 and 1984. Blue: reaches on the Murray River. Green: reaches on the Murrumbidgee River. Data sourced from logbook surveys undertaken by O'Connor (1986).

4.2. Threatening processes

Several threatening processes have been proposed as the cause of the declining distribution, abundance and average size of Murray crayfish populations throughout the 1900s. Although no single theory adequately explains the declines observed throughout the entire range of Murray crayfish, particular threatening processes are likely to have been principally responsible for population declines in different areas of the species range. Further, some threatening processes which may have resulted in declines in the past are no longer impacting on Murray crayfish populations. Other threatening processes continue to impact on populations, either resulting in continuing declines, or limiting the recovery of Murray crayfish populations that declined historically. However, given the general lack of monitoring programs for the species, particularly within reaches where declines have been reported as being most significant, there are few data on either ongoing decline or recovery in any region.

4.2.1. River regulation

Walker (1982) and Walker (2001) attributed the disappearance of Murray crayfish from the South Australian lower Murray River to the construction of weirs and subsequent river regulation in the 1920s and 30s, which transformed the lower Murray River into a continuous series of weir-pools, where hydrology, hydraulics, sedimentation rates and bio-film composition are all altered from the natural riverine state (Walker and Thoms 1993; McCarthy *et al.* 2004). Data collected by McCarthy (2005) demonstrating the avoidance of weir pool environments by Murray crayfish in the Mallee region of the Murray River, support the proposal that river regulation is an important threatening process in the lower Murray by creating low flow environments that are unsuitable for Murray crayfish. Further, sedimentation may impact upon crayfish by filling deep holes within the river channel, smothering snags or other cover within the channel, or smothering clay banks required for burrowing. Walker (1982) reported that sedimentation in the lower Murray River was severe in the years following weir construction in the lower Murray. Sedimentation was exacerbated during the 1956 floods when a huge silt burden was deposited, and completely filled parts of the channel (Walker 1982). This silt burden has remained in the river in the absence or reduced frequency of flushing flows. Like the lower Murray, anglers in the lower Murrumbidgee report that Murray crayfish declined following the construction of Maude and Redbank Weirs (O'Connor, 1986).

River regulation may also act as a threatening process through seasonal flow reversal, where flows during the May – August active period (see section 3.8) are considerably lower than natural flows. Further, reduced river levels during winter expose burrows and burrowing sites. If brooding females use burrows during autumn–winter, limited or reduced access to burrows may limit localised recruitment of Murray crayfish.

Although river regulation provides a reasonable explanation for the local extinction and reduced abundance of Murray crayfish in heavily regulated reaches, it does not provide an adequate explanation for declines in unregulated or minimally regulated reaches. Further, river regulation does not provide an adequate explanation for the decline in average size reported throughout the remainder of the species range.

4.2.2. Pesticides and pollution

Walker (1982), O'Connor (1986), Geddes (1990), Horwitz (1990a) and Geddes *et al.* (1993) referred to threats posed by pesticides and pollution. O'Connor (1986) noted that the areas of major decline in crayfish numbers were downstream of major irrigation systems, where synthetic organochlorine pesticides such as DDT were applied liberally in the late 1940s and 1950s (Radcliffe 2002). Run-off from irrigation is one of the most important contributors to the transport of pesticides into waterways and their subsequent accumulation in sediments and aquatic organisms (Nowell *et al.* 1999). Spray-drift also results in the input of pesticides to waterways (Raupach and Briggs 1998). Given the sensitivity of crayfish to pesticides and pollution (Geddes 1990; France and Collins 1993; Davies *et al.* 1994; ANZECC and ARMCANZ 2000) (section 3.6.2), their persistency in aquatic sediments (Radcliffe 2002) and ecosystems, and the bio-accumulative and bio-magnifying nature of the toxins (Radcliffe 2002), it is highly likely that this may have been a critical factor in the decline of not only Murray crayfish, but the entire aquatic ecosystem in the 1950s. For example, the reported declines of Murray crayfish in the Edwards and Wakool Rivers coincide with the construction of the Coleambally Irrigation scheme in 1960, which drains agricultural run-off into the Edwards River via Billabong Creek (O'Connor, 1986). Further, O'Connor (1986) cites L.F. Reynolds as stating that fishermen suggested that spraying of locust plagues in South Australia in the early 1950s left residues in the soil that entered the river during the 1956 flood, and that the demise of crayfish could be associated with this single input of pesticides. Pesticide monitoring in waterways in the north-west of New South Wales indicates that the impacts of pesticide residues and agricultural pollution increase in a downstream direction (Muschal and Warne 2001). Therefore, it would be expected that Murray crayfish populations in the Lower Murray River would be most affected by pesticide use in irrigation schemes upstream.

The spatial and temporal patterns in the disappearance of Murray crayfish from the lower Murray and Edwards, Wakool and Niemur Rivers are more closely associated with the advent and proliferation of use of pesticides than any other threatening process. However, the most persistent of the organo-chlorine family of pesticides, such as DDT, were banned from use in Australia in 1987 (Radcliffe 2002) and the environment has now had time to purge accumulated residues in aquatic sediments. As a consequence, the threat posed by some of this particular group of chemicals has been removed. However, crayfish are sensitive to numerous pesticides and agro-chemicals that remain in use. Further, the quantities of those pesticides used, continue to increase (Radcliffe 2002), albeit under reasonably comprehensive regulations governing their use in areas adjacent to waterways.

Collapse of mine tailings dumps at Captains Flat in the upper Murrumbidgee catchment in 1938 and 1943 released large quantities of heavy metals into the Molonglo River (ACT Government 1999). Fifty years later, fish are still absent up to 15 km downstream of the mine. Therefore, in some locations pollution originating from mining sites is as significant a threat as are agro-chemicals, but only at very localised places. Pesticide use is much more widespread.

4.2.3. Overfishing

O'Connor (1986), Geddes (1990), Horwitz (1990a), Lintermans and Rutzou (1991), Geddes *et al.* (1993), Horwitz (1995), the ACT Government (1999), van Praagh (2003) and McCarthy (2005) suggested that overfishing was also a primary cause of decline of Murray crayfish. O'Connor (1986) associated the extensive declines of Murray crayfish in the middle reaches of the Murray River and the Murrumbidgee River with the advent of the caravan, aluminium trailer boat and freezer in the 1950s and 1960s. The implications of these inventions were that fishermen could travel further, travel more regularly and harvest greater numbers of crayfish than had previously been possible. Fishing inspectors working within the range of Murray crayfish during this period recall the extremely large catches that were regularly taken by local and travelling recreational fishers during this period, and that individuals of all sizes were harvested indiscriminately (Peter Angel, pers. comm.: Narrandera Fisheries Centre).

Commercial fisheries for Murray crayfish only ever existed in New South Wales and South Australia. Therefore, commercial fishing never impacted on populations of Murray crayfish in Victoria or the Australian Capital Territory. Commercial fisheries for Murray crayfish closed in New South Wales and South Australia in 1987. Therefore, whether commercial fisheries contributed as a serious threatening process or not, they no longer impact on Murray crayfish populations.

Recreational fisheries existed throughout the range of Murray crayfish. Most jurisdictions had limited or no recreational fishing regulations for Murray crayfish up until the 1980s. Several studies have attempted to assess the impact of recreational fishing on Murray crayfish populations, by either documenting the response to total fishing closures (Morison 1988; Barker 1990; Lintermans 2000), or by comparing the characteristics of crayfish populations in areas with easy versus difficult access for recreational fishers (Lintermans and Rutzou 1991; Asmus 1999; McMonigle unpublished; Edney, unpublished).

Only three studies have documented the response of Murray crayfish populations to total fishing closures. There was little evidence that the abundance, average size or sex ratio of Murray crayfish populations had changed over the seven year total closure of the Victorian fishery (Morison 1988; Barker 1992; Lintermans 2000). As a result, the Victorian monitoring program provides little evidence that recreational fishing was responsible for the observed declines and small average size. However, in the upper Murrumbidgee Lintermans (2000) reported a significant increase in abundance of Murray crayfish at three of four sites sampled in the Australian Capital Territory following the closure of the recreational fishery for Murray crayfish in 1991 (Table 5), suggesting that recreational fishing in the Australian Capital Territory was placing pressure on the Murray crayfish population. This is further supported by an observation that fishing pressure by only 1 – 2 recreational fishers decimated a local Murray crayfish population in the Murrumbidgee River at Allens Creek, over a period of less than twelve months (Lintermans and Rutzou 1991).

Illegal harvest of Murray crayfish has also contributed to population declines. There are anecdotal reports of widespread illegal fishing that involved substantial quantities of crayfish, (eg. wheat bags full and box trailer loads from the Tumut River system, Lintermans pers. comm.) and berried females being sold for $5.00 each in hotels in the Canberra region in the 1990s.

Table 5. Number of Murray crayfish captured between 1979 and 1998 at four sites in the upper Murrumbidgee River in the Australian Capital Territory. Numbers in brackets indicate the number of sampling trips in each period. Data sourced from Lintermans (2000). No sampling was conducted between 1989 and 1993.

Sampling period	Angle Crossing	Kambah Pool	Casuarina Sands	Retallack's Hole
1979 – 1984	0 (3)	0 (3)	0 (3)	0 (7)
1985 – 1988	0 (1)	8 (3)	0 (2)	0 (2)
1994 – 1998	46 (3)	8 (3)	14 (4)	26 (4)

Similar comparisons for other large crayfish species also detected evidence of the impacts of recreational fishing pressure. Morey (1988) and Morey (1998) observed differences in the sex ratios of the Gippsland freshwater crayfish in waters closed and open to recreational fishing in the Latrobe River systems, south-eastern Victoria. In closed waters, females comprised 45% of the population, whereas in waters open to recreational fishing, females comprised 59%. This suggests that recreational fishing was having an impact on the sex ratio of that population. Further, populations in closed waters were markedly larger than those in waters where recreational harvests are allowed (Morey 1988). However, despite sex ratio and size differences, there were no differences in abundance between recreationally fished and closed waters (closed for 5 years) (Morey 1988). Similarly, Horwitz (1991) observed a skewed sex ratio (0.5 males:1 female), lower abundances and smaller average size at sites where Tasmanian giant freshwater crayfish were fished, whereas the population sex ratio was close to 1:1 at unfished sites.

Studies comparing Murray crayfish populations at sites that are easy and difficult to access have also provided mixed results. In the Australian Capital Territory, Lintermans and Rutzou (1991) caught few crayfish (13% of total captures) at easily accessible sites, suggesting that angler accessibility had a significant impact on Murray crayfish abundance. Similarly, Edney (unpublished) recorded a CPUE of only 0.06 crayfish per net lift at an easily accessible reach versus a CPUE of 0.405 crayfish per net lift at a more inaccessible reach. In contrast, Asmus (1999) found no significant differences between sites with easy versus limited recreational fisher access for any of the variables assessed. However, although sex ratios did not differ significantly between easy and limited access sites, the difference was only just non-significant ($p = 0.056$), with a lower proportion of male Murray crayfish in reaches with 'easy' access for fisherman. Asmus (1999) also identified a marginally non-significant relationship ($p = 0.082$) between recreational fishing pressure and the proportion of immature (stage 1: see section 3.10.5) females in the population, with near mature (stage 2) and mature (stage 3) females less frequent in reaches with easier fishing access. This study was undertaken prior to the introduction on the Murray crayfish fishing closure between September and April. Therefore, the observed relationship would be expected in areas with higher fishing pressure, given that a greater proportion of the larger maturing and mature females would be harvested during the periods of the year when they are not 'berried'. Under the current limited fishing season, from 1 May to 31 August, most mature females will be berried for almost the entire fishing season and therefore protected from recreational harvest.

Despite the lack of a response in average size of the Victorian populations following the recreational fishing closure in that state, the widely reported decline in the average size of individuals since the 1960s (Pollard *et al.* 1980; Johnson and Barlow, 1982; O'Connor 1986; Barker 1990; Geddes 1990; Geddes *et al.* 1993; Sanger and King 2002) is most likely to be a result of recreational fishing pressure. Most other threatening processes, such as river regulation, pesticides and agro-chemicals would be expected to either impact upon all size classes equally, or impact upon smaller size classes rather than larger ones. The reported declining average size of Murray crayfish can only be explained by increased mortality of large individuals, which is most likely an indication of fishing pressure. Data presented in section 3.10.7.1 (Figure 20) provide support for this argument. The introduction of an 80 mm OCL minimum size limit in New South Wales in 1987 resulted in the median size class of the Murray crayfish population increasing from 60 – 70 mm to 70 – 80 mm OCL (Gehrke 1992 and Figure 20). The subsequent increase of the minimum size limit to 90 mm in 1998 resulted in a further increase in the median size to 90 – 100 mm OCL (McCarthy 2005 and Figure 20).

Similarly, despite the lack of a response in the sex ratio of the Victorian populations to the recreational fishing closure, and the non-significant results reported by Asmus (1999), sex ratio data from the Murrumbidgee River at Narrandera provide evidence of fishing induced sex ratio bias. Gehrke (1992) provided data demonstrating that the sex ratio of Murray crayfish below the legal minimum size limit (80mm OCL at the time of sampling) was not significantly different from a 1:1 sex ratio (Gehrke, 1992). However, the sex ratio of the same population above the legal size limit was 1:1.7 (male:female) (63% females) and statistically significantly different to the 1:1 ratio (Gehrke, 1992). Sex ratios reported from the same population between 1974 and 1998 ranged from 1:1 and 1:1.4 (between 51% and 59% female) (Johnson and Barlow, 1982; O'Connor, 1986; Gehrke, 1992; Asmus, 1999). Each of these estimates was obtained before the restricted fishing season was introduced, and either before or whilst the minimum legal size limit was only 80 mm. Therefore, all females were available to the fishery during the period of the year when they were not carrying eggs (September – May), as were those females that were not yet sexually mature at 80mm (> 50% of females) after 1987. As a result, these estimates of modest fishing induced sex ratio bias are not representative of those that exist under the current regulations of a restricted fishing season and a minimum size limit of 90 mm OCL. However, McCarthy (2005) provided data collected from the Murrumbidgee River two years after the introduction of the revised (and current) regulations in New South Wales, at which time the sex ratio was 0.32:1 (79% females). At the same time, the sex ratio in the Murray River population was 0.45:1 (69% females) (McCarthy 2005). Therefore, the current fishing regulations appear to be substantially biased in favour of harvesting male crayfish.

Although the Victorian study (Morison 1988) and Asmus (1999) failed to provide convincing evidence that recreational fishing pressure impacted upon populations of Murray crayfish, data from the Murrumbidgee River in both the Australian Capital Territory and at Narrandera indicate that recreational fishing has detectable impacts on the abundance, average size and the sex ratio of the population. Both abundance and size appear to be improving as a result of current recreational fishing regulations. However, by effectively protecting all sexually mature females from harvest, the current regulations put substantial fishing pressure on male crayfish. The implications of a biased sex ratio on the sustainability of the population are yet to be determined. As long as sufficient densities of reproductively active males remain in the population to inseminate the larger population of mature females, the fishery should remain viable. Further, Lintermans (2000) and the data from Narrandera cited above suggest that in some cases, recovery of Murray crayfish populations following implementation of appropriate fishing regulations can be reasonably rapid.

The lack of a similarly rapid response to the fishery closure in Victoria may have been due to undetected illegal poaching confounding the monitoring program (Morey 1998).

No studies have examined the influence of handling stress on the survival, growth or recruitment in Murray crayfish. The common yabby (*Cherax destructor*) is known to have reduced growth rates when subjected to regular handling stress, even more so than reduced food availability (Farrell and Leonard 2000). In areas of significant fishing pressure, individual Murray crayfish protected under fishery regulations (berried females and small individuals) may suffer reduced growth rates due to frequent handling as a result of recreational fishing. Further, air exposure of eggs (on berried females) and the potential for stress related 'mis-mothering' may also lead to handling losses within the population (Horwitz 1990a).

4.2.4. Habitat degradation

Like most other components of aquatic ecosystems, Murray crayfish are threatened by habitat degradation of riverine habitats. Specific examples that are likely to have impacts upon Murray crayfish are the infilling of formerly deep holes and smothering of substrates through sedimentation (Walker 1982; ACT Government 1999), the removal of snags (ACT Government 1999) and the clearing of riparian zones (ACT Government 1999; van Praagh 2003).

4.2.5. Translocation of crayfish

Translocation of non-native crayfish into Australian waters is a potentially major threatening process for all species of crayfishes and aquatic ecosystems in Australia (Holdich 1988; Horwitz 1990a, 1990b, 1995). Several crayfish diseases present overseas, such as the crayfish plague disease (Söderhäll and Cerenius 1999), pose a specific threat. The threat posed by translocation of exotic crayfish species (and their diseases) into Australia is reduced by a ban on importation of crayfish, but ongoing vigilance is essential.

The translocation of Australian crayfishes into waterways in which they are not native also has potential to impact on native species as has occurred with translocated populations of yabby, smooth marron (*Cherax cainii*) and redclaw (*Cherax quadricarinatus*) (Horwitz 1990b; Merrick 1995; ACT Government 1999; Austin and Ryan 2002; Nguyen *et al.* 2002; Miller 2005; Morgan and Beatty 2005; Anon. 2006). For example, numbers of the endemic Hairy marron in the Margaret River dropped dramatically (up to 80% reduction) following the introduction of the Smooth marron in the 1980s (Anon. 2006; Miller 2005). The reduction in Hairy Marron numbers and distribution is thought to be related to competition from the Smooth marron.

The translocation of species outside of their natural range is listed as a key threatening process under the Fisheries Management Act 1994 in New South Wales.

4.2.6. Thermal pollution

Thermal pollution by the release of cold water downstream of Burrinjuck, Blowering, Hume, Dartmouth, and Eildon Dams significantly alters the natural thermal regimes for hundreds of kilometres downstream (Phillips 2001). As mating, development and activity of Murray crayfish are influenced by temperature (O'Connor, 1986), thermal pollution may detrimentally impact on Murray crayfish populations by increasing development times and altering the reproductive season. The influence of reduced summer water temperatures on the growth, survival and recruitment of Murray crayfish remains unknown.

4.2.7. Introduced fish species

The impacts of competition with and predation by introduced trout (*Salmo trutta* and *Oncorhynchus mykiss*), redfin (*Perca fluviatilis*) and carp (*Cyprinus carpio*) are unknown. However, it is highly likely that these species impact upon juvenile and immature Murray crayfish (Merrick 1995; ACT Government 1999).

4.2.8. Fish passage

Given the observations of minimal movement of radio-tracked (Ryan 2005) and tagged (O'Connor, 1986) Murray crayfish, fish passage may not be a particularly important requirement for Murray crayfish populations. However, questions remain regarding the segregation of large and small individuals into larger waterways and tributaries, and this may alter our perception of the requirements for upstream and downstream migrations during early life stages. Over longer time-scales, movement within river systems is important for the purposes of gene flow, dispersal and colonisation. Although Murray crayfish are capable of movement on land, and therefore can walk around weirs, fish passage through fishways should be facilitated where possible.

Knowledge of fishway use by non-finfish organisms is poor (Meehan 2003). The current fishway program underway in the Murray River, the Murray-Darling Basin Commission's 'Lake Hume to the Sea' program, acknowledges the importance of migration of macro-invertebrates and has incorporated new fishway design concepts, such as roughened surfaces and embedded rock-work (Barrett and Mallen-Cooper, 2006), that may aid the upstream migration of Murray crayfish. However, all but three of the fishways scheduled for construction under this program are downstream of Mildura, where Murray crayfish are currently locally extinct. Further, we are not aware of data recording the passage of Murray crayfish through fishways in those reaches of the Murray River were Murray crayfish are still present (Euston, Torrumbarry and Yarrawonga Weirs), or anywhere else within their range.

4.3. Conservation Status

Due to the variability in abundance among different regions within its range, the conservation status of Murray crayfish is not consistent across states. For example, although they are presumed locally extinct in South Australia (Glover 1987; Geddes *et al.* 1993), they are not uncommon in New South Wales, and are not currently considered to warrant threatened status in that state.

In South Australia, Murray crayfish are protected under the *Fisheries Act 1982*. They are listed as vulnerable in the Australian Capital Territory under Section 21 of the *Nature Conservation Act 1980* (Protected Invertebrate – schedule 1 of the *Nature Conservation Act 1980*, Gazette No. S85, 28 Aug 1991). The species is listed as threatened in Victoria under the *Flora & Fauna Guarantee Act 1988*. In New South Wales, Murray crayfish are not listed under any threatened species legislation, but they are part of the 'Lower Murray River Endangered Ecological Community', listed under the *NSW Fisheries Management Act 1994*, which includes the Murray River and its New South Wales tributaries between Hume Weir and the South Australian border, and the entire Murrumbidgee catchment downstream of Blowering and Burrinjuck Dams (NSW Fisheries 2002). As a consequence, Murray crayfish are nominally granted the status of a threatened species across a large proportion of their range in New South Wales. However, recreational crayfishing is permitted within the Endangered Ecological Community boundaries, and the threatened status is more aligned to protecting the species from habitat disturbance.

Nationally, Horwitz (1990) defined the conservation status of Murray crayfish as 'indeterminate', due to the lack of knowledge regarding the species at that time. Similarly, Murray crayfish were listed as internationally ‘indeterminate’ following a review of their status in 1994 by the IUCN (Groombridge 1994). Horwitz (1995) subsequently suggested the national conservation status be raised to threatened. Following re-assessment in 1996 (Crandall 1996), the IUCN listed Murray crayfish as vulnerable (VU A1ade) on the *IUCN Red List of Threatened Species*. However, a review of the IUCN categorisation for the species using the *Ramas Red-List* software program (Akçakaya and Ferson 1999) resulted in a listing category of ‘data deficient’ (Clarke and Spier 2003).

4.4. Recovery Actions

In the Australian Capital Territory a specific action plan was developed for Murray crayfish (ACT Government 1999). Further, a new multi-species recovery plan for the Australian Capital Territory has incorporated Murray crayfish recovery actions (ACT Government 2006). In Victoria, an action statement has been developed for both Murray crayfish and Glenelg spiny crayfish (van Praagh 2003).

Despite being protected by law in South Australia and listed as a component of an endangered ecological community across much of its range in New South Wales, these states have not yet developed recovery or action plans for Murray crayfish. However, New South Wales has declared several key threatening processes to aquatic ecosystems that are relevant to the conservation of Murray crayfish.

The Murray-Darling Basin Commission’s Native Fish Strategy (NFS) does not generally include crustaceans under its charter, concentrating on the finfish species of the Basin (MDBC 2004). However, in 2005 the Commission’s Fish Management & Science Committee, the advisory committee for the implementation of the NFS, recognised the special status of Murray crayfish in the Basin, and agreed to include the species as part of the fish community covered by the NFS. This resulted in the current report, as a scoping study to summarise current knowledge and identify knowledge gaps and research and management needs. The inclusion of Murray crayfish within the scope of the NFS will facilitate improved coordination of management and knowledge generation across jurisdictions within the Basin.

5. TRADITIONAL ECOLOGICAL KNOWLEDGE, HISTORICAL USE AND CULTURAL SIGNIFICANCE.

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5.1. Abstract

Traditional Ecological Knowledge (TEK) enhances conventional natural resource research methods as it can provide a long-term record of environmental change from specific locations. This report summarises the key findings of a series of consultations with representatives from Aboriginal communities throughout the Murray and Murrumbidgee catchments of south-eastern Australia. The objective was a summary of TEK and traditional uses of the Murray crayfish (*Euastacus armatus*). Murray crayfish did not have a significant spiritual role within the Aboriginal culture of the tribal groups consulted, although were traditionally harvested by hand for food, particularly during winter. Information obtained from this study supports current scientific opinion that Murray crayfish are restricted to flowing river reaches and are absent from still waters and billabongs, that they are most active during winter and less active during summer, and that Murray crayfish are good bio-indicators of poor water quality. Aboriginal communities consulted had a significant interest in the conservation of natural resources, including iconic species such as Murray crayfish. Incorporation of TEK into conventional research programs will both improve management practices and maintain Aboriginal connections with the environment.

5.2. Introduction

As part of a larger knowledge review of the biology and fishery of Murray crayfish (*Euastacus armatus*), this paper provides an overview of traditional ecological knowledge (TEK) of this large species of spiny crayfish, endemic to the Murray-Darling Basin. The overview was prepared following a series of consultations with Aboriginal communities throughout the Murray and Murrumbidgee river catchments in southern New South Wales, Australia.

TEK of indigenous cultures is accrued over an extensive period of time through a spatial, emotional and spiritual connection with a specific local environment (Klubnikin *et al*. 2000) or species (Huntington 2000). The use and incorporation of TEK is becoming an increasingly important tool in the conservation and management of natural resources (Berkes *et al.* 2000; Drew 2005). A key benefit of the use of TEK in biological studies is that it is based on a record of observations from specific locations over a long time period (Kimmerer 2000), and is particularly useful for gathering data of long-term patterns in the abundance, distribution and population trends of key species (Drew 2005). Three significant advantages of the integration of TEK into management and research programs are: the provision of location-specific knowledge, increased knowledge of environmental linkages, and local capacity building and power sharing (Drew 2005). In regions where the fauna and flora are not well described, or the ecosystem processes well understood, indigenous cultures may have an accrued knowledge of the species and interactions not recorded in the scientific literature (Drew 2005).

Indigenous Australians are believed to have utilised freshwater crayfishes as a food source throughout Australia (Horwitz and Knott 1995). Kohen and Merrick (1998) examined archaeological remains from Aboriginal sites in NSW for evidence of utilisation of *Euastacus* species, but identified few sites with concentrations of *Euastacus* remains. The sites examined were primarily along coastal NSW outside of the known range of Murray crayfish and consequently, the findings of Kohen and Merrick (1998) may not necessarily reflect the utilisation of Murray crayfish in the Murray-Darling Basin. However, the conclusions drawn are applicable to archaeological assessments for Murray crayfish. That is, limited remains of crayfish in archaeological deposits could be attributed to inadequate sampling and sorting of archaeological collections, poor preservation of *Euastacus* remains, destruction or dispersal by scavengers, or very low utilisation by Aboriginals (Kohen and Merrick 1998). However, in South Australia, remains of Murray crayfish have been identified from an archaeological site along the Murray River at Devon Downs (Smith 1982).

Aboriginal people hold a strong and significant interest in river environments and the processes that occur within them, due to their strong cultural connection with rivers. Yet Australian Aboriginals have been poorly represented in water resource decision-making processes (Jackson *et al*. 2005). Integration of TEK in management and conservation decisions would assist Aboriginal people in maintaining connections to significant landscapes and allow them to express their interest in the ecology of their traditional lands.

5.3. Methods

A number of alternative approaches exist to gather TEK (see Huntington 2000). In this study, a series of semi-directive interviews (Huntington 2000) with representatives from Aboriginal communities across the Murray and Murrumbidgee catchments were held in September 2005. Semi-directive interviews are aimed to be informal discussions about a particular topic, in this case, Murray crayfish, where participants are invited to share as much information as they are willing. Consultations were held with between 1 and 9 representatives from Local Aboriginal Land Councils (LALCs), Aboriginal Nations within the region, or individuals recommended by either the Murray or Murrumbidgee Catchment Management Authorities (Table 6). Not all geographic regions within the Murray or Murrumbidgee catchments were represented in this study, either due to a lack of interest by particular groups in the project or representatives acknowledging they had no TEK of Murray crayfish for that region.

Community consultations were held in Albury, Balranald, Barmah, Deniliquin, Echuca and Narrandera (Table 6). Topics of interest to this study that were covered during interviews included: the role of Murray crayfish in Aboriginal culture, roles of Murray crayfish in Aboriginal diet and society, and historical patterns in the abundance and habitat use of Murray crayfish. It should be noted that none of the Aboriginal community representatives acknowledged that they also continued to speak their traditional language.

Table 6. Names and locations of Aboriginal community groups contacted during this study, availability of TEK about Murray crayfish and the number of community participants (in brackets) present at each consultation meeting.

Group	Location	Attempted contact No response	Contact made – No interest or TEK	Contact made - Provided TEK
Albury LALC	Albury			* (2)
Barkinji Elders Council	Dareton	*		
Birrapa Birrapa	Barham	*		
Birrapa Birrapa	Kerang	*		
Cummeragunja LALC	Moama			* (1)
Deniliquin LALC	Deniliquin			* (9)
Hay LALC	Hay	*		
Lower Murray Darling CMA – Aboriginal liaison	Buronga		*	
Moama LALC	Moama	*		
Mungabareena Aboriginal Corporation	Albury	*		
Muthi Muthi	Balranald			* (1)
Narrandera LALC	Narrandera			* (4)
Ngunawal	Yass		*	
Tumut Brungle LALC	Tumut	*		
Wamba Wamba LALC	Swan Hill	*		
Wiradjuri	Wagga Wagga		*	
Yarkuwa Indigenous Knowledge Centre	Deniliquin	*		
Yorta Yorta	Barmah			* (2)

LALC = Local Aboriginal Land Council, CMA = Catchment Management Authority.

5.4. Results and Discussion

5.4.1. Traditional name

According to Thieberger and McGregor (1994), Murray crayfish were traditionally named *lip lip wil* by the Wemba Wemba tribe, occupying the Murray River between Swan Hill and Barham, the lower reaches of the Loddon and Avoca catchments and sections of the Edwards and Wakool Rivers (Horton 1994). *Lip lip wil* is interpreted as 'spike-spike-having' (Theiberger and McGregor 1994) and clearly refers to Murray crayfish as opposed to the yabby.

In accounts of his scientific expeditions around the upper Murrumbidgee catchment in the 1830s, George Bennett documented the traditional name of *Mungola* used by the Ngunnawal tribe (Scott 2005).

Blake (2005) documented the traditional names for 'yabby' for many of the Aboriginal languages throughout the Murray crayfish's range (Table 7). Although many of these refer to the yabby (*Cherax destructor*) others may refer to Murray crayfish. Traditional names likely to describe Murray crayfish were *thangambuluwa* (Ngarigo) and the relatively similar *tanggambalangga*

(Jaitmatang) in the highlands of the Murray and Murrumbidgee catchments respectively. In the Murray Riverina and lower Murray River, several Aboriginal languages had names phonetically similar to *lip lip wil*, including; *tjipel* (Wadi Wadi), *thipil* or *thip thip* (Madi Madi) and *thapul* (Meru) which are likely to describe Murray crayfish. The 'yabby' names of the Waveroo, Yorta Yorta and Latje Latje languages were quite different to these and to each other (Table 7).

Blake (2005) identified the name *lip lip wil* as belonging to the Wimmera language (Wergaia) as opposed to the Wemba Wemba. However, given that the Murray crayfish is unlikely to have existed in the Wimmera catchment, and the fact that the interpretation of *lip lip wil* clearly characterises Murray crayfish rather than the yabby, we would conclude that it is most likely to be a Wemba Wemba name.

None of the Aboriginal communities consulted during this study knew of their traditional names, which may be due to widespread adoption of the non-Aboriginal Australian name for Murray crayfish and/ or the loss of traditional language.

Table 7. Traditional Aboriginal names for yabbies, crayfish and Murray crayfish exist for a number of Aboriginal languages across the range of Murray crayfish, as reported by Bennett (1834: cited by Scott, 2005), Fraser (1892), Theiberger & McGregor (1994), Blake (2005) and Jim Ingram (pers. comm). The language names specified by Blake (2005) were re-assigned to tribes identified by Horton (1994) using a combination of information from Tindale (1974), Clark (1996) and Blake (2005) and various internet sources.

Tribe	Traditional names*
Ngarigo	*Parindjak* (crayfish), *Thangambuluwa* (lobster)
Ngunawal	*Mungola*
Wiradjuri	*Yinga* (crayfish), *Dhagamang*?
Nari Nari	Unknown
Madi Madi	*Thipil* or *Thip-thip*
Jaitmatang	*Tanggambalangga*
Waveroo	*Karta*
Taungurong	Unknown
Ngurraiillam	Unknown but probably similar to Taungurong (Clark 1996)
Yorta Yorta	*Popa*, *Papa* or *Ponggongalo*
Baraba Baraba	Unknown but shared 93% of vocabulary with Wemba Wemba (Clark 1996)
Wemba Wemba	*Ngathang* or *Lip-lip-wil* (crayfish)
Wadi Wadi	*Yapi* (*Yapitj*) or *Tjipel* (*Tjipoli*)
Dadi Dadi	Unknown
Kureinji	Unknown
Latje Latje	*Wuluma*, *Ringwong* or *Mowak* (crayfish)
Meru	*Yukalto* (crayfish), *Thapul* (lobster), *Ukodku* (yabby) or *Koongola* (yabby)
Barkindji	Unknown
Ngarrindjeri	*Meauki* (crayfish), Kawthawi

* All the names reported by Blake (2005) were pooled as 'yabby' with additional detail entered in parentheses. Although many of these would refer to the yabby (*Cherax destructor*), others (particularly those referring to 'lobster') probably refer to Murray crayfish.

5.4.2. Cultural and social significance of Murray crayfish

Murray crayfish did not have a significant cultural value or totemic role within any of the Aboriginal communities interviewed. However, they were (and continue to be) utilised by Aboriginals as a food resource. A seasonal pattern in resource use between Murray crayfish and yabbies exists, with Murray crayfish harvested during the cooler months and yabbies collected during summer as each species becomes active during these periods.

Across all geographic regions surveyed, a significant sense of sustainable fishery management for Murray crayfish appears to be a strong part of traditional Aboriginal culture. Historical harvests were geographically patchy, with a cyclic pattern of harvest over a number of different sites and river reaches, ensuring that localised populations were not placed under sustained fishing pressure. In this way, populations were able to continually regenerate. Further, to maintain sustainability, berried females were consistently returned to the water. Harvests were traditionally limited to feed only the family group, and as no methods for preservation were used, harvests were limited to what could be consumed soon after capture.

In the Lower Murray, Murray crayfish were harvested by hand from the shallows during low river flows, when water was clear, or by diving, which was often done by women (Eyre 1845). In the upper Murrumbidgee, Bennett also reported that Aboriginal people harvested them by hand when the river was low (Scott 2005). However, Bennett also stated that they were hunted by torchlight in the evening or at night, as they were difficult to get during the day, and that they were often collected from under large stones (Scott 2005). Eyre (1845) also reports witnessing Aboriginals capturing Murray crayfish by spearing, which was occasionally a very efficient method of harvest. Alternatively, animal remains wrapped in reeds and placed in shallow water or on sand bars were used as a lure, with the crayfish then collected by hand. Harvests of Murray crayfish were discussed as being considerably more productive during years with high flows and floods. This pattern corresponds to significant commercial harvests of Murray crayfish in the Murray River in 1953–1954 and 1973–1975, periods of significant high river flows (Asmus 1999). No known methods for trapping or cultivation of Murray crayfish were identified, despite being suggested to have occurred with yabbies (Horwitz and Knott 1995).

5.4.3. Ecological considerations

Murray crayfish were historically common in most of the areas where consultations were held, although they were considered rare in the Balranald region of the Murrumbidgee River. The Aboriginal representative interviewed at Balranald considered that weirs now present in the lower Murrumbidgee River may have contributed to the lack of Murray crayfish in this reach, or prevented any recolonisation from the Murray River (Danny Kelly, pers. comm.).

Murray crayfish were not considered to exist in still or standing waters such as billabongs, and only occurred in the flowing reaches of the main river channels. The species was not known to have any particular affinity to specific habitat types within river channels, although mature females are considered to benefit from improved access to riverbanks during high flows and floods while brooding.

Aboriginal people perceive Murray crayfish to be key indicators of river health. Observations of Murray crayfish leaving their habitat were considered a sign of poor health of the riverine environment. This is verified by modern observations of Murray crayfish leaving the water (climbing upon exposed snags and river banks) during and following ‘black water’ events, when water chemistry changes due to the leaching of carbon compounds from leaf litter from inundated floodplains (McKinnon 1995). During these events, dissolved oxygen concentrations are known to decline to as low as 1.8 mg L^{-1} (15% saturation) (McKinnon 1995). Geddes *et al.* (1993) observations that dissolved oxygen concentrations below 2.2 mg/L^{-1} were lethal or sub-lethal for Murray crayfish explain this behaviour. McKinnon (1995) reported that dying Murray crayfish were occasionally removed for human consumption after they leave the water; however no Aboriginal communities interviewed suggested they harvested Murray crayfish during these periods, as they were considered to be unhealthy or contaminated.

The Aboriginal community representatives interviewed perceive benthic crustaceans such as Murray crayfish and yabbies as 'river cleaners'. If populations of these key species are depleted, then it is believed that the natural nutrient cycling process and breakdown of detritus will not occur at the rates needed to maintain healthy riverine ecosystems.

The Aboriginal communities consulted unanimously suggest that the current sustained recreational harvesting of Murray crayfish, primarily by non-Aboriginal people, was unsustainable and has contributed to a recent decline of Murray crayfish. Interviewees continue to regularly witness localised illegal overfishing of Murray crayfish, with recreational fishers travelling significant distances and harvesting significant numbers of crayfish.

5.5. Conclusions

Our consultations with Aboriginal communities in NSW suggest that there were no known significant patterns in the abundance of Murray crayfish over time apart from a possible decline in abundance in the Lower Murrumbidgee River following construction of weirs and flow regulation in that part of the river.

Despite limited evidence of Aboriginal utilisation of *Euastacus* species in archaeological deposits (Smith 1982; Kohen and Merrick 1998) this study suggests that Murray crayfish were clearly important to Aboriginal societies. Although no spiritual totemic relationships were identified, Murray crayfish were harvested for food and were sufficiently important that they were given specific names in a number of Aboriginal languages. TEK obtained from this study supports current scientific opinion that Murray crayfish are restricted to flowing river reaches and absent from still waters and billabongs, that they are most active during winter and less active during summer, and that Murray crayfish are good bio-indicators of poor water quality. Further, a limited scientific understanding of the role of Murray crayfish in riverine ecosystems may be guided by the perception of Aboriginal people that Murray crayfish and other benthic crustaceans play an important detritivorous role.

Our interviews have heard that Aboriginal people, who have a considerable connection to natural resources, feel unrepresented when making management decisions for the successful conservation of native species. Methods to improve the participation of Aboriginal communities in resource management have recently been suggested and include 'two-way' approaches to scientific research, whereby field based research would allow traditional owners to demonstrate knowledge and maintain attachment to significant landscapes and habitats (Jackson *et al.* 2005) by developing a long-term collaborative relationship with natural resource management agencies (Drew 2005). We recommend such an approach.

6. KNOWLEDGE GAPS AND POTENTIAL MANAGEMENT ACTIONS

6.1. Knowledge gaps and research needs

6.1.1. Current status of Murray crayfish throughout the range

Information on the current status of Murray crayfish throughout their entire range remains the most significant knowledge gap for the species. A comprehensive set of representative monitoring sites should be established throughout all areas of the species range. A standardised sampling protocol should be established and adhered to. This protocol would ensure that all collaborating partners use the same sampling technique, the same bait type, record data in a consistent manner (catch-per-net-hour) and sample at the same time of year.

Most previous studies have used hoop nets of various sizes as the principal sampling technique. However, McCarthy (2005) used Munyana traps and Raadik *et al.* (2001) and Closs and Driver (unpublished) used backpack or bank-mounted electrofishing. Munyana nets have a benefit over hoop nets as escapement from Munyana traps is only 5% over a period of 5.9 hours, they are less labour intensive more than a single site can be samples in a day (McCarthy 2005). There are no differences in length, weight or length-frequency distribution of the catch (McCarthy 2005). However, CPUE of Munyana nets for Murray crayfish is considerably lower (0.408 individuals per hour) than hoop nets (0.725 individuals per hour). The use of gill nets also warrants consideration for presence/absence detection where Murray crayfish abundance is very low. Lintermans and Rutzou (1991) caught two crayfish in gill nets but none in 48 hoop net lifts and Lintermans (2000) sampled numerous crayfish in gill nets as bycatch during sampling for a finfish monitoring program. However, gill nets pose risks to air breathing vertebrates, can be difficult to set in flowing waters and are only effective where the net contacts the substrate. Electrofishing is very effective in small wadeable streams (Raadik *et al.* 2001), but is totally ineffective for sampling Murray crayfish in large lowland rivers.

We recommend hoop nets of 700 mm diameter and with a mesh size of 13 mm as the primary sampling tool, supplemented with both Munyana traps and gill nets at a sub-sample of sites. No studies have assessed the effectiveness of a range of bait types, but the recreational logbook data of O’Connor (1986) suggest that bait type is not particularly important. However, to maintain consistency of sampling, we would recommend a standardised, effective and easily obtainable bait (carp or ox liver may be the most suitable potential candidate baits). The catch should be recorded as catch-per-net-hour in order to standardise effort, with each net relocated after each haul. A total of 100 hoop net hauls should be undertaken at each site. All sampling should be completed in May–June. Data recorded from each net set are date, position (latitude and longitude), flow, depth, distance from bank, time set, time retrieved and habitat characteristics. The catch data recorded should include number of crayfish, size (OCL), sex, and the maturity stage of females and whether females are berried. Sampling sites should be selected randomly and at a sufficient density to achieve adequate spatial coverage. This sampling strategy should be repeated on a three to five yearly rotation in order to monitor changes in status through time.

6.1.2. Habitats and biology of juvenile crayfish < 40 mm OCL

The only data available for small Murray crayfish was collected from small tributary streams (Raadik *et al.* 2001; Closs and Driver, unpublished). Given that few previous studies have adequately sampled juvenile Murray crayfish, their biology, habitat requirements, dispersal behaviour and survivorship remain poorly understood. This knowledge would be of considerable use in improving our understanding and management of Murray crayfish populations as a whole. However, assessment of these issues is dependent on the development of sampling techniques for juveniles in both large and small waterways. We recommend that strategies to sample small juvenile Murray crayfish effectively be developed as a research priority. One of the aims of the study of Edney (Latrobe University), which began in August 2005, was the development of methods to sample juvenile Murray crayfish. However, the results of this research are not yet available. Similarly, Alves (Macquarie University) aims to develop methods to sample juvenile Murray crayfish as part of her Master of Philosophy project, beginning in 2006. We recommend integrating methods developed to target juvenile Murray crayfish into the monitoring program suggested above as soon as possible.

Additionally, in light of the disjunct distribution of adults and juveniles recorded by Raadik *et al.* 2001 and Closs and Driver (unpublished), we recommend study of migration and movement behaviour of juvenile crayfish and berried females; especially movement between large major river channels where the adult population resides, and smaller order tributary streams. If juvenile migration occurs, resulting in population size segregation, there will be associated fish passage implications as well as implications for management of the smaller order tributary streams that may be important for recruitment into the fishable adult population.

6.1.3. Impact of river regulation on habitat availability

Over a majority of their range, Murray crayfish use burrows for shelter. In upland areas and tributaries, rocks, boulders and snags are used for shelter. No previous studies have assessed the seasonal use of burrows or use of burrows during different life history stages. If brooding females use burrows during autumn–winter, reduced river flows during this period, as a consequence of river regulation, may limit access to burrows or burrow sites within riverbanks. Limited or reduced access to burrows may limit localised recruitment of Murray crayfish. Therefore, information is required on the importance of burrows to individuals and recruitment, the characteristics of burrowing sites, the position and depth of burrows within the river channel, and the impact of river regulation on them.

6.1.4. Endemicity of populations in the Lachlan and Macquarie catchments

Doubts regarding the endemicity of Murray crayfish collected from the Macquarie and Lachlan catchments warrant further study. If Murray crayfish are native to the Macquarie and Lachlan catchments, they represent an important and neglected extension of the species range. However, if the populations observed in these catchments arose via translocation, then they do not warrant any special conservation actions. Although previous genetic assessments have not identified any major population sub-structure across much of the species range, modern nuclear genetic markers such as microsatellites may provide a more sensitive means of defining population sub-structure, and as a consequence, may provide a tool for assessing the origin of the populations in question. However, genetic analyses are dependent on the provision of samples from across the species range. Therefore, we suggest that a leg segment or tail punch be retained from 20 – 30 individuals collected from each population during sampling for the suggested monitoring program.

6.1.5. Previously identified research priorities

The following list of issues considered to be important research needs for Murray crayfish have been proposed previously:

1. The effects of habitat modification on Murray crayfish populations (ACT Government 1999; Clark and Spiers 2003; van Praagh 2003).

2. The effects of pesticides on aquatic ecosystems (as studies indicate that crustaceans are sensitive to heavy metals) (Clark and Spiers 2003).

3. The effects of eutrophication and salinity (Horwitz 1990a; Clark and Spiers 2003; van Praagh 2003).

4. Spatial variability in biology and ecology of Murray crayfish e.g., size at first breeding (ACT Government 1999; Clark and Spiers 2003; van Praagh 2003).

5. The effects of introduced species (ACT Government 1999; Clark and Spiers 2003; van Praagh 2003).

6. Seasonal use of microhabitats by Murray crayfish (ACT Government 1999; Clark and Spiers 2003; van Praagh 2003).

7. The effect of land use practices and sedimentation (ACT Government 1999; Clark and Spiers 2003).

8. Quantifying the population size of Murray crayfish (Barker 1990; Horwitz 1990a; Sanger and King 2002; Clark and Spiers 2003; van Praagh 2003).

9. Possibility for reintroduction into sites in South Australia at sites downstream from weirs, as sites above them appear to be unsuitable for Murray crayfish (Geddes *et al*. 1993; Clark and Spiers 2003).

10. Surveys across the entire species range (Barker 1990; Clark and Spiers 2003; van Praagh 2003).

11. Develop a population model for Murray crayfish to assist in determining sustainable levels of recreational fishing (van Praagh 2003).

Research needs 6, 8 and 10 were discussed in section 6.1.1, 6.1.2 and 6.1.3 are strongly supported. Research needs 1, 2, 3 5 and 7 are general issues for many aquatic species, and are being, or need to be addressed by state and territory fisheries agencies and the Murray-Darling Basin Commission in the context of the *Native Fish Strategy*. The need for information identified under research need 4 has been at least partly addressed by the data presented in this report (with the exception of several issues identified below). Research need 9 is more a management action than a knowledge gap, and is addressed below. The relative priorities of each of these research needs are summarised in Table 8.

6.2. Management recommendations

6.2.1. Reintroduction programs

Geddes *et al.* (1993) provided data suggesting that a reintroduction program into the South Australian reaches of the Murray River was feasible. Threats posed by commercial fishing no longer exist (Geddes *et al.* 1993; McCarthy 2005). Further, if pesticide use in the 1950s was a primary cause of decline, current regulations regarding pesticide use mean that this threatening process has been and will continue to be much reduced. The fact that Geddes *et al.* (1993) found that caged animals survived in the lower Murray for at least five months, suggests that pesticide residues may longer threaten crayfish in the reaches studied. However, given that river regulation may also have been a primary threatening process, only reaches within the lower Murray region that retain reasonable flow velocities should be prioritised for reintroduction trials. McCarthy (2005) identified Mullaroo Creek and the reach of the Murray River immediately downstream of Lock 7 as potentially viable reintroduction sites, as these reaches have higher than average flows for the region. Chowilla Creek warrants consideration on the same basis. Flows within Mullaroo Creek and Chowilla Creek have both increased as a result of river regulation in the Murray and the reach of the Murray River downstream of Lock 7 has increased river flows as a result of outflows from Lake Victoria (McCarthy 2005). Subsequent monitoring of reintroduced populations would provide an opportunity to assess the criteria for population establishment and determine the timeframes required for populations to reach self-sustaining levels.

Under its action plan for Murray crayfish, the ACT Government (1999) identified the possibility of reintroducing Murray crayfish to the Cotter River upstream of Cotter Dam. Recent field work has resulted in captures of Murray crayfish from this location (Lintermans, unpublished data) and so reintroduction is no longer required in this location.

6.2.2. Reviewing the appropriateness of fishery regulations

Considering that all *Euastacus* species are characterised by slow growth, and have long reproductive lives (Honan and Mitchell 1995c), allowing only half of the female population to have the opportunity to reproduce once before being exposed to recreational harvest, as is the case under the current minimum size limit of 90 mm OCL, limits the reproductive output of the population. Increasing the minimum size limit to 100 mm OCL, would ensure that almost 100% of females would have reached sexual maturity. A 100 mm size limit was also recommended by Morison (1988) and Sanger and King (2002). An increase in the minimum size limit would not only increase the reproductive output of the population, and therefore the population growth rate and sustainability of the fishery, but would also increase the average size of individuals within the population. This would provide a more satisfying fishery for recreational fishers. High minimum size limits combined with a moderate-high harvest rate is considered superior to all other strategies in terms of post harvest abundance, size structure, yields and endpoints of harvest rates for territorial stream fishes (Nordwall *et al.* 2000).

Female Murray crayfish carry eggs underneath their tail from May to October each year (O'Connor, 1986). At present, the fishing season for Murray crayfish opens on 1 May and continues until 31 August. As not all mature females have spawned by the time the recreational fishery opens, a proportion of mature females are susceptible to harvest before they have had an opportunity to spawn. This is particularly important given the high level of fishing effort early in the crayfishing season (Rich and Johnstone 1988; Barker 1990). Delaying the opening of the crayfishing season until at least 15 May would allow all mature females to mate and develop eggs prior to the fishery opening. This would increase the reproductive output of the population, and therefore the population growth rate and sustainability of the fishery (Skurdal *et al.* 1997).

At present, fishing regulations in both New South Wales and Victoria limit the harvest of crayfish larger then 120 mm OCL to only one per fisherman. However, given that the average percentage of individuals larger than 120 mm OCL only comprise in the order of 0.4% of individuals within populations (averaged across all studies where length-frequency data are available), introducing a 'slot limit', with a maximum size limit of around 150 mm OCL (the size of the individual pictured in Figure 2) could also be considered in order to ensure the persistence of very large individuals in the population. Currently, individuals of this size only comprise an average of 0.08% of the population, or one individual in every 1,250. Slot limits are known to maintain population size at relatively high harvest rates (Nordwall *et al.* 2000) and could improve recreational harvests in reaches subject to considerable fishing pressure (Asmus 1999). Preserving larger individuals of a harvested fishery is seen as being more sustainable, both on the population and ecological scales, as larger individuals within a population produce more larvae (section 3.11.1.2). Further, an increase in the frequency of capture of very large individuals would enhance the enjoyment and sporting aspects of recreational fishing for the species.

Introduction of fishing regulation amendments can result in short-term reductions in the retainable catch. Temporary closures in some areas may facilitate adoption of the amended regulations by allowing the Murray crayfish population to grow in order to service the new fishing regime. This is particularly relevant in populations at the periphery of the fishery.

Inconsistencies between New South Wales and Victoria in the regulations outlined in Table 4 (e.g., possession limits, mutilation, gear specifications etc) should be reviewed and where possible harmonised. Where individual jurisdictions are considering changing their regulations, liaison with other jurisdictions would be recommended in order to ensure consistency.

6.2.3. Previously identified management recommendations

The following list of management recommendations have been proposed previously:

1. A monitoring program needs to be set up in each State and Territory (Barker 1990; ACT Government 1999; Sanger and King 2002; Clark and Spiers 2003; van Praagh 2003).

2. Legislation needs to be drafted so as to strengthen control over trade of crayfish between states and all States and Territories need to have similar regulations and fines for the protection of fisheries (Barker 1990; Horwitz 1990a; ACT Government 1999; Sanger and King 2002; Clark and Spiers 2003).

3. A national system or policy to control trade in introduced crayfish needs to be adopted by all of the appropriate States and Territories to reduce the spread of crayfish diseases (Clark and Spiers 2003).

4. Better management is also required into the allocation of water from the Murray and other rivers for irrigators and environmental flows, as reasonable flows are essential for breeding (Maloney 1997; Clark and Spiers 2003).

5. An education program is required to inform the public of the plight of Murray crayfish and the ways in which they can be protected (Barker 1990; ACT Government 1999; Clark and Spiers 2003; van Praagh 2003).

6. Future management of Murray crayfish habitats needs to include:
   i) Fencing of riverbanks so as to reduce bank erosion and allow natural revegetation.

ii) Balanced water harvesting so as to allow adequate environmental water flows.
iii) Better management at the state level of catchments.
iv) Employment of more fisheries inspectors may be useful in some areas where there has been greater pressure.
v) Rehabilitation of many sites altered by siltation, erosion and habitat modification.

(Maloney 1997; Clark and Spiers 2003; van Praagh 2003).

A means to implement recommendation 1 is addressed in section 6.1.1, which we support strongly. Trading aspects referred to in recommendation 2 are required in order to limit the threat posed by translocation of indigenous species outside their natural ranges and consistency in recreational fishing regulations are discussed in section 4.1.2.1. We support recommendation 3 based on the potential threat posed by crayfish plague disease and other pathogens referred to in section 3.9. Recommendation 4 is also supported, but no data are available on the specific flow requirements for the species other than they prefer areas of high flow velocity over lower flow positions within river channels, and are not found in still water or weir pool environments (McCarthy 2005). Therefore, it is premature to make any recommendations on appropriate management of environmental flows for the benefit of Murray crayfish. Given the results of Asmus (1999), which indicated a limited awareness of recreational fishing regulations for Murray crayfish, we support the development of more effective education and advisory materials as per recommendation 5. Further, an effective education program would be a prerequisite for any future revisions to recreational fishing regulations. Lastly, we support the habitat rehabilitation and enhanced enforcement suggested under recommendation 6 as a general means to improve the condition of aquatic ecosystems that in turn improve the status of Murray crayfish populations.

6.2.4. New management recommendations arising from this review

- We recommend that the national conservation status of Murray crayfish be reviewed in light of the information assembled in this report.

- Develop a long-term collaborative relationship with Aboriginal stakeholders in relation to conservation and management of Murray crayfish.

- We recommend that the Murray-Darling Basin Commission establishes and resources a Murray crayfish working group similar to that formed for Murray cod to ensure that this equally iconic species is managed effectively within the basin. Membership could include management agencies, researchers, anglers, conservation groups and indigenous representatives.

Table 8. Summary of priority knowledge gaps and management recommendations.

Priority	Research Need	Priority	Management Recommendation
High	Current status of Murray crayfish across their range	High	Establish an ongoing monitoring program for Murray crayfish
High	Habitats and biology of juvenile crayfish (< 40 mm OCL)	High	Review of the appropriateness of current fishery regulations.
High	The effects of habitat modification on Murray crayfish populations	High	Promote inter-state consistency of fishery regulations (where the fishery is still legal)
High	The effects of pesticides on aquatic ecosystems	High	Undertake community education program
High	Seasonal use of microhabitats by Murray crayfish	High	Review of national and international conservation status
High	The effect of land use practices and sedimentation	Moderate	Reintroduce Murray crayfish at appropriate sites in the lower Murray River and monitor success
Moderate	Impacts of river regulation on habitat availability	Moderate	Legislation strengthened to control inter-state trade of crayfishes
Moderate	Spatial variability in biology and ecology of Murray crayfish	Moderate	National policy on trade in introduced crayfish
Moderate	The effects of introduced species	Moderate	Effective environmental flow management for Murray crayfish
Moderate	Develop a population model for Murray crayfish to assist in determining sustainable levels of recreational fishing	Moderate	Habitat protection/rehabilitation
Low	Endemicity of Lachlan and Macquarie populations	Moderate	Increase enforcement capacity/activity for Murray crayfish
Low	The effects of eutrophication and salinity	Moderate	Develop a collaborative relationship with Aboriginal stakeholders regarding conservation and management f Murray crayfish
		Low	Establishment of a Murray crayfish working group by the MDBC

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APPENDIX 1

1. Priority Area addressed by project: Native Fish Strategy Driving Action 5: Protecting threatened native fish species

Project Description

2. Project Title:(maximum 20 words)
Scoping the knowledge requirements for Murray Crayfish

3. Region: lowland Basin | *4. Catchment*

5. Explain how proposal addresses an issue or performance area outlined in the Natural Resources Knowledge Plan

This project addresses Goals 1 & 2 of the ICM Policy (2001):

1. Healthy Rivers – providing water for the environment, consumption and recreation
2. Healthy ecosystems and catchments – maintaining or enhancing the integrity of soils, surface water and groundwater, flora and fauna.

Knowledge investment addressing the Healthy rivers *ICM goal focused on* Riverine ecosystem health *was identified as a priority knowledge need in the* ***MDBC Natural Resources Knowledge Plan 2004–05 to 2006–07.***

Knowledge requirements for Riverine ecosystem health *are:Knowledge to support the developme within floodplain, wetland, riparian, in-stream and estuarine ecosystems*

Background
Murray Crayfish are the second largest freshwater crayfish in the world, reaching weights of 3 kg and estimated to live for up to 50 years. Murray Crayfish have undergone significant declines and are classified as a threatened species in the ACT and SA, and are listed as Vulnerable under the 2004 IUCN redlist. Horwitz (1990, 1995) reviewed their national conservation status and classified them as indeterminate, meaning they were rare, vulnerable or endangered, but there was insufficient information to determine which. Murray Crayfish have been relatively neglected by funding bodies because of their 'indeterminate' national status, and lack of vertebrate status. They are an icon freshwater species of the Murray-Darling Basin, and support popular fisheries in NSW and Victoria. They are now functionally extinct in SA, and are absent from the Murray River below Mildura. Because of the lack of research attention directed at the species, or because previous studies have been largely unreported, relatively little is known of the species ecology or the reasons for decline. Some information is available in unpublished reports or theses, but this information is difficult to access and has not been synthesised to provide a species overview. If the species is to be recovered, then a review of existing knowledge is required before knowledge gaps and potential future research directions can be identified.

Horwitz, P. 1990. *The conservation status of Australian freshwater crustacea*. Australian National Parks and Wildlife Service, Report Series 14. Canberra.

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6. *Project objectives:*
   - To review and synthesize existing knowledge on the ecology and management of Murray Crayfish
   - To identify existing ecological knowledge gaps and to prioritise areas for future investigations

7 *Anticipated Products of the Project:*
   - A scoping report summarising existing knowledge and identifying priorities for future studies.

8. *Anticipated Outcomes of the Project:*
   - Identification of knowledge gaps in Murray Crayfish ecology and management
   - Priorities for research to address these knowledge gaps
   - Improved management options for maintaining or recovering Murray Crayfish populations.

9. *Why should the Commission, rather than another initiative, fund this work?*

Murray Crayfish only occur in the Murray-Darling Basin, and are an icon species. Because of their national 'indeterminate' conservation status, Murray Crayfish are not eligible for national threatened species funding. There are no other funding programs that focus on non-threatened or non-recreational fish species within the Basin.

10. *What involvement will other interested organisations have in this project?*

Jurisdictional fisheries agencies, Catchment Management Authorities, Forestry agencies, recreational anglers etc all have an interest in sustainably managing or utilising components of aquatic resources and would likely be involved in research projects emanating from the scoping study. In the scoping study itself, all relevant agencies or organisations thought likely to hold information on Murray Crayfish will be contacted and encouraged to share data, or collaborate with report preparation. A small steering committee to oversee the scoping study will be established.

11. *What links will be established with other related initiatives such as the National Land and Water Audit?*

During the scoping study, links will be established with other research providers or data custodians in the Basin such as Barmah-Millewa Forum, Living Murray, fisheries agencies and CRC Freshwater Ecology. Any research projects emanating from the scoping study would be expected to develop links with programs such as NHT2, NAP, State fisheries programs, FRDC etc.

12. *How will end-users of the products and outcomes of this project be involved in and structured into the project?*

The end user of the scoping study are the MDBC Fish Management and Science Committee, and through them, the state fisheries agencies. A small steering committee to oversee the project will be established encompassing FMSC membership.

13. *How will the products and outcomes of the project be transferred to end-users, and how will adoption of the outcomes be promoted?*

All projects developed under the SI&E program must state how they will ensure that information developed will be transferred and taken-up by resources managers and the community. The project will utilise the Commission's Communication Strategy (see our web site www.mdbc.gov.au) and use it to develop a project Communication Plan. Part of the plan will be to develop a 2 page information flyer on the project (two in projects which span more than one year – one at the beginning and one at the end of the project). In addition, the project should address the need for future SI&E projects that address the need for further transfer and adoption activities.

It is expected that communication activities could include presentations and scientific and regional seminars and workshops, information sheets, and briefings to key end-users.

14. How will the project be established (eg. open call, commissioning, public tender)? If commissioned, who will be approached?

Given the specialist nature of this project, it will be established through selective tender. Potential providers include:

- Arthur Rylah Institute
- NSW Department of Primary Industries
- Murray-Darling Freshwater Research Centre
- Individuals with experience in Murray Crayfish ecology (John Merrick, Mark Lintermans)

Anticipated Project duration: Commencement Date __1/03/05__________ Completion Date _30/06/05_________

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